AMSAT Fox-1 Systems Engineering Documentation

By Jerry Buxton, N0JY
Fox-1 Systems Engineer
n0jy@amsat.org

The AMSAT Fox program introduced a new engineering process for AMSAT in which engineering documentation is provided at each stage of development. We are archiving all of this documentation on an on-line, backed-up, version control server. When the satellite has been completed, we will have an archive of traceable documentation. This can serve as the basis for planning and executing future satellite programs and can be updated to apply the lessons learned of what went well and what did not.

AMSAT is a truly unique organization in that we are a non-profit corporation that manufactures satellites using a geographically distributed, all-volunteer engineering staff. There are no common or established guidelines to cover our situation. As such, the Fox program engineering practices are themselves a work in progress. The practices used are drawn from industry sources, especially NASA[1] and IEEE.

AMSAT has adopted a common industry scheme known as *numbered* requirements. Each individual requirement has a unique number assigned to it. The number allows a very precise reference to a specific requirement and this enhances the overall traceability of the specifications. Design documents use these references to show which module or subsystem is responsible and how they are meeting each of the requirements. The requirements are tracked throughout the documents using requirements tracking software, from the ConOps down to the test results, in order to verify that all requirements are properly implemented.

Due to US State Department ITAR[2] restrictions, our document server is only available to project members who have been vetted to meet the requirements for a "US-person." AMSAT, as an educational organization, would like to publicly release the majority of our design documentation to serve as a learning tool to anyone interested in satellite development. However, this must be done in a specific way to meet the ITAR requirements. The information must first be released via an openly available publication.

We would also like to be able to discuss our satellite projects with our own members, some of whom are not "US-persons" per ITAR. These AMSAT Space Symposium proceedings provide a convenient mechanism for the needed publication in order to make this information public domain and allow us to communicate with our members.

While the Concept of Operations (ConOps) and System Requirements Specification were published in the *Proceedings of the AMSAT-NA 29th Space Symposium and AMSAT-NA Annual Meeting*, the System Requirements Specification has undergone changes and will be reproduced in these Space Symposium proceedings.

In addition these proceedings will also present new engineering documents including the System Design Specification, Experiment Payload Requirements, IHU to RF System Interface Control Document, IHU to PSU Interface Control Document, IHU to Battery Interface Control Document, IHU to Attitude Determination Experiment Interface Control Document, and IHU Software Architecture Specification. An introduction to each of these documents follows.

The System Requirements Specification is a document that provides the top level technical specifications derived from the ConOps. This document describes what the system should do. The inputs, outputs, functions, mass, volume, environment and other external characteristics are included and specified in the system requirements. The level of detail for each requirement is specifically chosen to provide a clear definition of what the systems will do without too much specific detail or declaring how it will be done. This allows the engineers latitude in designing the best approach to satisfying the requirement.

The Avionics System Design Specification is a document that does provide specific details of how the system will be designed. The specifications are based on best design choices determined by the teams. The signals, connections, connectors, volume, and requirements specific to each system are stated in this document so that each system will fit together and function with the other systems.

The Experiment Payload Requirements are a smaller level of system requirements written specifically for the Penn State student designed attitude determination system. While the actual system designed by the students was not constructed before their graduation, the experiment payload system design itself will be incorporated onto the IHU board and this document describes the necessary functions of the system although revised to remove the physical requirements of a separate printed circuit board.

The Interface Control Documents (ICD) for the IHU to RF System, IHU to PSU, IHU to Battery, and IHU to Attitude Determination Experiment set the requirements for connections and communication between the IHU and the various systems. Each of the systems sends telemetry measurements and other signals to the IHU. The IHU sends telemetry audio and control signals to the RF System. The ICD allows the systems teams to work independently, knowing that their systems will interface successfully.

The IHU Software Architecture Specification provides the design specifications needed for the software design and operation of the Internal Housekeeping Unit.

The engineering documents published in these proceedings are what was available at time needed for inclusion and are intended to be interesting and informative. They may have changed since publication. AMSAT intends to continue to make the majority of the final technical documents, exclusive of satellite control information, available in future publications.

Some other documents are included in these proceedings because they contain additional information about Fox-1 that may be of interest to our members.

Also included here are Antenna Details showing the EZNEC 5.0+ models of the 2 meter and 70 centimeter antennas used on the satellite. Thank you to David Ping, WB6DP.

The IHU Software Components is included to show a breakdown of the software systems that were developed and written for the STMicroelectronics STM32L151 ultra-low-power 32-bit MCU, used for the IHU. Thank you to Bill Reed NX5R.

The Fox-1 Downlink Power Amplifier is a presentation of the findings during the prototype testing of the 2 meter PA that will be used for RF downlink. Thank you to Marc Franco, N2UO.

Receiving FOX-1 Satellite on 2 meters is a link budget for the 2 meter downlink based on the 400 mW (minimum) output of the Fox-1 power amplifier. Thank you to Tony Monteiro, AA2TX.

The Fox-1 Experimental Payload document is an IEEE presentation of their experiment given by the Penn State students. Thank you to Mike Corona, Brandon Marvenko, and Edward Pizzella.

---

[1] NASA Systems Engineering Handbook, NASA/SP-2007-6105 Rev1

[2] International Traffic in Arms Regulations, see: http://www.pmddtc.state.gov/regulations_laws/itar_official.html

Date: September 4, 2012
Version: Version 1.12

AMSAT *Fox-1*

System Requirements Specification

1 Introduction

This document specifies the system level technical requirements for the AMSAT *Fox-1* satellite project. This 1 Unit CubeSat is a part of the AMSAT Fox program and includes a subset of the technical capabilities envisioned for the overall program.

Fox-1 is specifically intended as a replacement for the failing AMSAT *Echo* (i.e. AO-51) satellite. *Echo* has been the most widely used amateur satellite due to its ability to provide basic radio communications with very simple ground station equipment. Its FM repeater provides very wide geographical coverage allowing amateur radio operators to communicate over substantial distances using just a handheld transceiver (i.e. a *walkie-talkie*) and a small handheld antenna. This so called "*EasySat*" mode is extremely valuable in providing an introduction to satellite communications and is often used for demonstrations given at schools, to scouting organizations and at amateur radio publicity events. *Fox-1* will not duplicate all of the features and modes of Echo but its primary mission is to provide an FM Transponder in order to allow continued access to this *EasySat* mode of communications.

In addition to its mission as a communications satellite, *Fox-1* will host an experiment payload. The satellite will reserve mass and volume for the experiment and will provide DC power and a communications facility. The experiment is expected to be provided by students at Penn State University – Erie through an AMSAT sponsored senior design project.

1.1 Document History

DATE	VERSION	SUMMARY
October 5, 2011	1.0	From Draft E
October 8, 2011	1.01	Fix typos in sections 1.2 and 3.5
October 9, 2011	1.02	Add Requirements Tracking
October 23, 2011	1.03	Additional Requirements Tracking
February 21, 2012	1.04	Update Section 3 and Formatting changes
April 18, 2012	1.05	Correction in Section 4
April 22, 2012	1.06	Correct link in Section 1.4 item 2
April 29, 2012	1.1	Revised 3.12.3, 3.12.7, 3.12.8, 3.13.3, 3.13.4, figure 1 to remove RESET and add IHU OFF and IHU ON commands
August 2, 2012	1.11	Added hidden text for requirements tracking to be shown in System Design Specification
September 4, 2012	1.12	Added the previously missing “Table 6” label

1.2 Document Scope

The purpose of this document is to specify the technical requirements of the satellite at the system (i.e. "black box") level. It is intended to be used by the hardware, software and mechanical designers to develop the architecture/high-level design specifications. It is also intended to be used for test planning and development.

1.3 Document Format

This document provides the requirements in numbered format. Each requirement is assigned a unique number. Additional information such as comments or examples that are provided for guidance or clarity is *italicized* to distinguish them from requirements.

1.4 References

1. AMSAT *Fox-1,* Concept of Operations, Version 1.0, September 19, 2011
2. CubeSat Design Specification Rev. 12. by The CubeSat Program Cal Poly SLO available from: http://www.cubesat.org/images/developers/cds_rev12.pdf
3. Launch Services Program, Program Level Poly Picosatellite Orbital Deployer (PPOD) and CubeSat Requirements Document LSP-REQ-317.01 Revision Basic (from NASA)
4. ITU Radio Regulations, Edition of 2008. available from http://www.itu.int/publ/R-REG-RR-2008/en

2 General Requirements

2.1 CubeSat Requirements

2.1.1 The satellite shall meet the requirements specified in the CubeSat Design Specification Rev. 12.

2.1.2 The satellite shall meet the requirements specified in the NASA LSP-REQ-317.01 Revision Basic.

2.1.3 The satellite shall meet the requirements for a 1 unit (single) CubeSat.

2.1.4 The satellite shall provide mass for an experiment payload up to 100 g.

2.1.5 The satellite shall provide volume for an experiment payload up to 95 x 95 x 15.7 mm.

2.2 Environmental Requirements

2.2.1 The satellite avionics shall be designed for -40C to +70C operating temperature.

2.2.2 The satellite shall be designed to operate in a 650 km, sun-synchronous, circular orbit.

2.2.3 The satellite shall be designed to tolerate the radiation environment in orbit.

2.3 Reliability Requirements

2.3.1 The satellite shall be designed for a minimum 5-year, on-orbit lifetime.

2.4 RF Frequency Requirements

2.4.1 All RF transmitters shall meet or exceed the requirements specified in the ITU Radio Regulations, Technical Characteristics, Volume 3, article 3.

2.4.2 All satellite uplinks shall be in the 70 cm band of the amateur satellite service.

2.4.3 All satellite downlinks shall be in the 2 meter band within the amateur satellite service.

2.4.4 All satellite transmitter and receiver frequencies shall deviate by no more than 5 parts-per-million from the specified values including initial accuracy and temperature variation.

2.4.5 All satellite frequencies shall be coordinated with the IARU.

Note that the band plan with the actual coordinated frequencies will be specified in a separate document.

3 Functional Requirements

3.1 Antenna System

3.1.1 The satellite shall include a deployable antenna system.

3.2 Attitude Control

3.2.1 The satellite shall incorporate passive magnetic stabilization to align the deployed antennas with the magnetic field of the earth.

3.3 Access Ports

3.3.1 The satellite shall include a "Remove Before Flight" pin as per the CubeSat Design Specification.

3.3.2 The satellite shall include an umbilical port as per the CubeSat Design Specification.

3.4 Pre-launch Features

3.4.1 The satellite battery and photovoltaic panels shall be electronically disconnected from the avionics when the "Remove Before Flight" pin is inserted, regardless of the state of the deployment switch(es).

3.4.2 The satellite shall provide the means to charge the battery via the umbilical port while integrated with the P-POD.

3.4.3 The satellite shall provide the means to run diagnostic tests via the umbilical port while integrated with the P-POD.

3.5 Power

3.5.1 The satellite shall produce electrical power from sunlight.

3.5.2 The satellite shall produce electrical power while in sunlight regardless of orientation and while tumbling or spinning.

3.5.3 The satellite shall produce sufficient average electrical power to operate continuously in the orbit of maximum eclipse.

3.5.4 The satellite shall provide sufficient battery capacity to operate continuously in the orbit of maximum eclipse.

3.5.5 If the battery fails, including a short-circuit condition, the satellite shall continue to operate using only the photovoltaic panel power when in sunlight.

3.6 Experiment

3.6.1 The satellite shall provide current limited DC power for an experiment payload.

3.6.2 The satellite shall provide a means to activate and deactivate the experiment payload.

3.6.3 The satellite shall provide a means to telemeter data from the experiment payload.

Note that the experiment payload will be specified in a separate document.

3.7 RF Uplink

3.7.1 The satellite shall include an FM uplink receiver.

3.7.2 The receiver shall have specifications as shown in Table 1.

Table 1

Sensitivity	-120 dBm for 12 dB SINAD (min.)
FM Deviation	5 kHz
Audio Bandwidth	3 kHz
Input Frequency Acceptance	Receiver shall accept signals that are off frequency by ±2.5 kHz (min.)

3.8 RF Downlink

3.8.1 The satellite shall include an FM downlink transmitter.

3.8.2 The transmitter shall have specifications as shown in Table 2.

Table 2

Power Output	400 mW (min.)
FM Deviation	5 kHz
Audio Bandwidth	3 kHz

3.8.3 The transmitter shall provide a means to prevent over modulation.

3.9 FM Transponder

3.9.1 The satellite shall provide an FM transponder via the RF uplink and RF downlink.

3.9.2 The transponder shall detect the presence of a 67 Hz CTCSS tone on the uplink.

3.9.3 The downlink transmitter shall be keyed (*i.e. PTT-on*) for 2 minutes following detection of the 67 Hz CTCSS tone.

3.9.4 The downlink transmitter shall stay on continuously as long as the 67 Hz CTCSS tone is detected at least once every 2 minutes on the uplink.

3.9.5 The 67 Hz CTCSS tone is not required for a received signal to be repeated on the downlink, once the transmitter has been keyed.

3.9.6 If the downlink transmitter has been un-keyed for a period of 5 minutes, the satellite shall send " HI THIS IS AMSAT FOX " in Morse code via a keyed audio tone on the downlink transmitter.

3.9.7 The satellite shall default to Transponder Mode in the event of an IHU processor failure.

3.10 Telemetry Data

3.10.1 The satellite shall collect telemetry data.

3.10.2 The telemetry data shall include measured parameters as shown in Table 3.

Table 3

Parameter Name	Description
CELL V	Voltages of battery cells
PANEL V	Voltages of solar panels
TOTAL I	Total DC current out of power system
PA I	DC current into RF power amp
BATTERY T	Temperature of battery
PANEL T	Temperatures of solar panels
PA T	Temperature of RF power amp
OSC T	Temperature of RF oscillators

3.10.3 The measured parameters shall be sampled at least every 15 seconds.

3.10.4 The minimum and maximum values of each of the measured parameters shall be saved in non-volatile memory.

3.10.5 The telemetry data shall also include calculated parameters as shown in Table 4.

Table 4

Parameter Name	Description
UP TIME	Total seconds since avionics power-up or reset
SPIN	Satellite spin rate and direction

3.10.6 A telemetry frame shall include the current measured values, the saved minimum and maximum values, and the current calculated values.

Note that the telemetry interface will be specified in a separate document.

3.11 Telemetry Transmission

3.11.1 The satellite shall send telemetry using FSK on the RF downlink.

3.11.2 The FSK shall use the frequency spectrum below the audible range.

3.11.3 The telemetry shall be transmitted simultaneously with any transponder communications.

3.11.4 The telemetry transmission shall include telemetry frames.

3.11.5 The telemetry transmission shall include experiment data.

3.12 Command Capability

3.12.1 The satellite shall provide the means to process commands sent via the RF uplink from a ground control station.

3.12.2 The commands received via the RF uplink shall not be repeated on the RF downlink.

3.12.3 The following commands shall be provided, as shown in Table 5.

Table 5

Command	Operation
TEST	Send test message
INHIBIT	Inhibit RF transmission
IHU OFF	Power off IHU
IHU ON	Power on IHU
CLEAR	Clear stored telemetry
TRANSPONDER MODE	Enter Transponder Mode
COMMAND MODE	Enter Command Mode

3.12.4 A TEST command shall cause the satellite to respond by sending " TEST TEST TEST " in Morse code via a keyed audio tone on the RF downlink.

3.12.5 An INHIBIT command shall cause the satellite to cease RF transmissions.

3.12.6 Any command other than INHIBIT shall remove a transmit inhibit condition.

3.12.7 An IHU OFF command shall cause the IHU System to power off.

3.12.8 An IHU ON command shall cause the IHU System to power on.

3.12.9 A CLEAR command shall cause the satellite to clear the saved minimum and maximum telemetry parameter values.

3.12.10 A TRANSPONDER MODE command shall cause the satellite to enter the Transponder Mode.

3.12.11 A COMMAND MODE command shall cause the satellite to enter the Command Mode.

Note that the control interface will be specified in a separate document.

3.13 On-Orbit Operating Modes

3.13.1 The satellite shall provide on-orbit operating modes as shown in Table 6.

Table 6

Name	Description
Startup Mode	Wait 45 minutes and deploy antennas
Transponder Mode	FM transponder and telemetry active
Command Mode	Telemetry active, no FM transponder

3.13.2 The satellite shall transition between modes as shown in Figure 1.

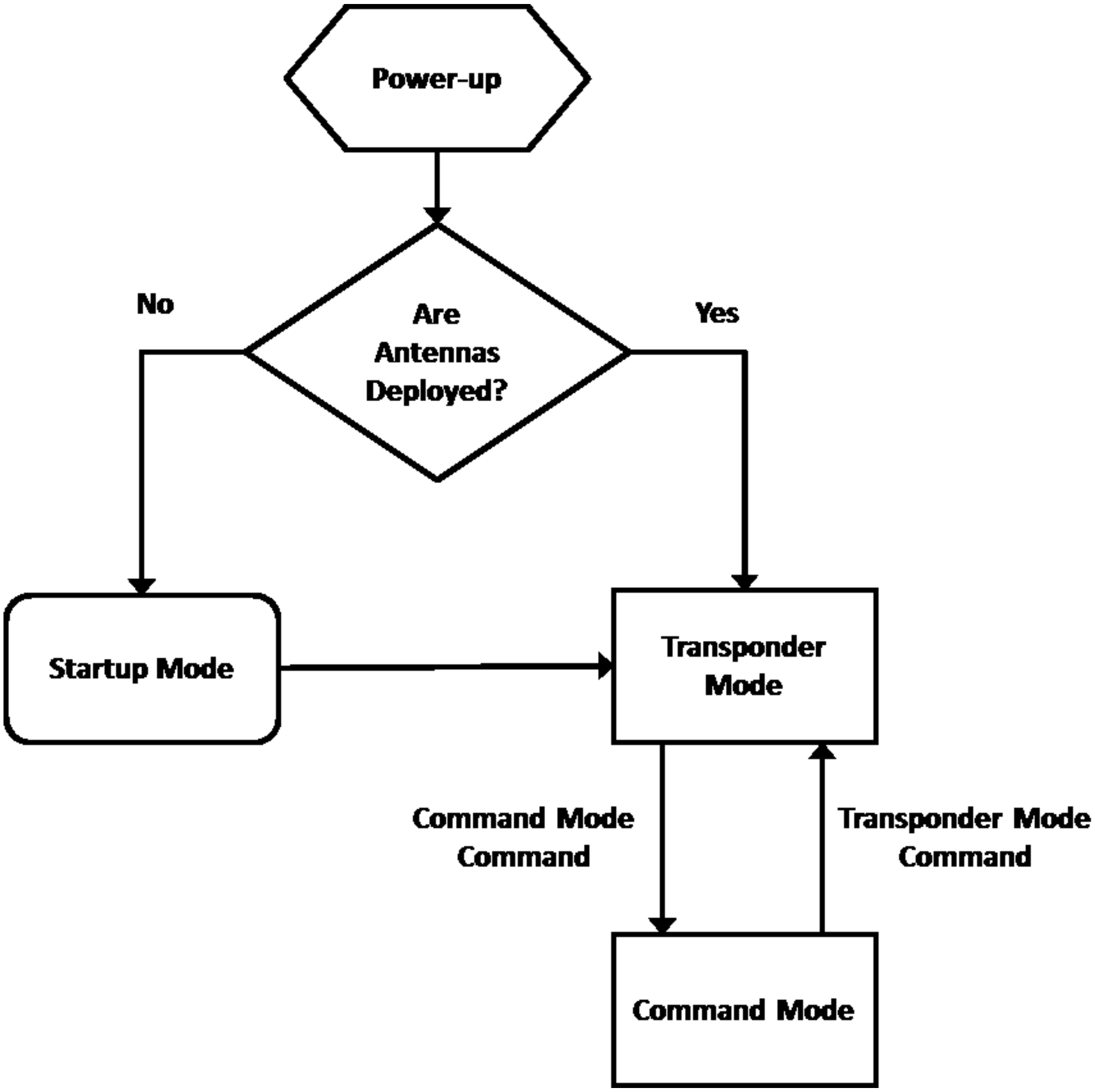


Figure 1. On-Orbit Operating Modes

3.13.3 Upon power-up of the avionics, the satellite shall begin operation from the "Power-up" state as shown in Figure 1.

3.13.4 An IHU ON Command shall cause the satellite to begin operation from the "Power-up " state as shown in Figure 1.

3.13.5 If the antennas have been deployed, the satellite shall enter the Transponder Mode.

3.13.6 If the antennas have not been deployed, the satellite shall enter the Startup Mode.

3.13.7 In Startup Mode, the satellite shall wait 45 minutes, deploy the antennas and then enter Transponder Mode.

3.13.8 In Transponder Mode, the transponder and the telemetry shall be active.

3.13.9 In Command Mode, the telemetry shall be active and the transponder shall not be active. *(i.e. signals that appear on the uplink shall not be repeated on the downlink.)*

3.13.10 If another Command Mode command is not received, the satellite shall automatically enter Transponder Mode 24 hours after having entered Command Mode.

3.13.11 The RF uplink shall be monitored for commands in all modes.

4 External Interface Documents

To fully specify the satellite technical requirements, the following documents must also be provided;

1. IARU Coordinated Frequency Plan
2. Telemetry Interface Specification
3. Control Interface Specification
4. Experiment Payload Specification

5 Summary

The *Fox-1* satellite will be AMSAT's first CubeSat. Its primary mission is to provide an FM Transponder communications capability. The secondary mission is to host a university-provided experiment payload.

Date: September 30, 2012
Version: 3.14

AMSAT *Fox-1*
Avionics System Design Specification

1 Introduction

This document contains the system level design specifications for the AMSAT *Fox-1* satellite avionics systems. It is driven by the System Requirements Specification and other documents provided by the developers of the individual systems that make up the satellite system.

1.1. Document History

DATE	VERSION	SUMMARY
February 21, 2012	1.0	From Draft F
April 9, 2012	1.1	Add signal characteristics, update bus pin connections per System Team input
April 17, 2012	1.2	Add external connector specification in sections 2.6, 2.12 and 2.14 and references in section 6
April 18, 2012	1.21	Add MMCX connectors gender
April 22, 2012	1.3	Minor corrections in signal characteristics, remove +Z antenna deploy and sensor connections
July 10, 2012	2.0	Many revisions from PDR
July 11, 2012	2.01	One RBF pin removed from bus pin assignments, updated 2.1 interconnect diagram, updated 2.1 signal characteristics
July 21, 2012	2.1	Revised bus signals, bus pin assignments Updated RF block diagram
July 22, 2012	2.11	Revision to some RF signal descriptions, change antenna/coax connectors to UMCC type, updated RF block diagram, added driving and load system columns to signal characteristics
September 9, 2012	3.0	Major changes.
September 11, 2012	3.01	Defunct IHU block diagram pending update
September 12, 2012	3.1	Added PCB volume requirements
September 23, 2012	3.11	Change TX PTT to RX PTT, -Z Deploy switches to TX, update figures and tables accordingly
September 26, 2012	3.12	Update bus and pin assignment drawings
September 27, 2012	3.13	Update bus pin assignment drawings
September 30, 2012	3.14	Update RF block diagram to remove ITAR notice

1.2. Document Scope

The purpose of this document is to specify the avionics systems and their connections to each other and to external components for the satellite. It is intended to be used by the hardware, software, and mechanical designers to develop the architecture and interconnections for the satellite avionics systems.

1.3. Document Format

This document provides these elements in a numbered format. The numbered sections specify each major system in the satellite while numbered items for each system specify the external connections required and the number of lines for each connection. Satellite bus and external connections are further described in figures and tables.
Where System Requirements are reproduced their numbers are from the AMSAT *Fox*-1 System Requirements Specification.

1.4. References

1. AMSAT *Fox-1* ConOps
2. AMSAT *Fox-1* System Requirements Specification
3. AMSAT *Fox-1* Bus Signal Connections Diagram
4. AMSAT *Fox-1* Bus Pin Assignment
5. AMSAT *Fox-1* Avionics System Design Specification Spreadsheet
6. AMSAT FOX-ME-112_PCB_ASSY.pdf
7. AMSAT FOX-ME-114_BATTERY_ASSY.pdf

Contents

2 Avionics System Bus Signals, Characteristics, and Connections

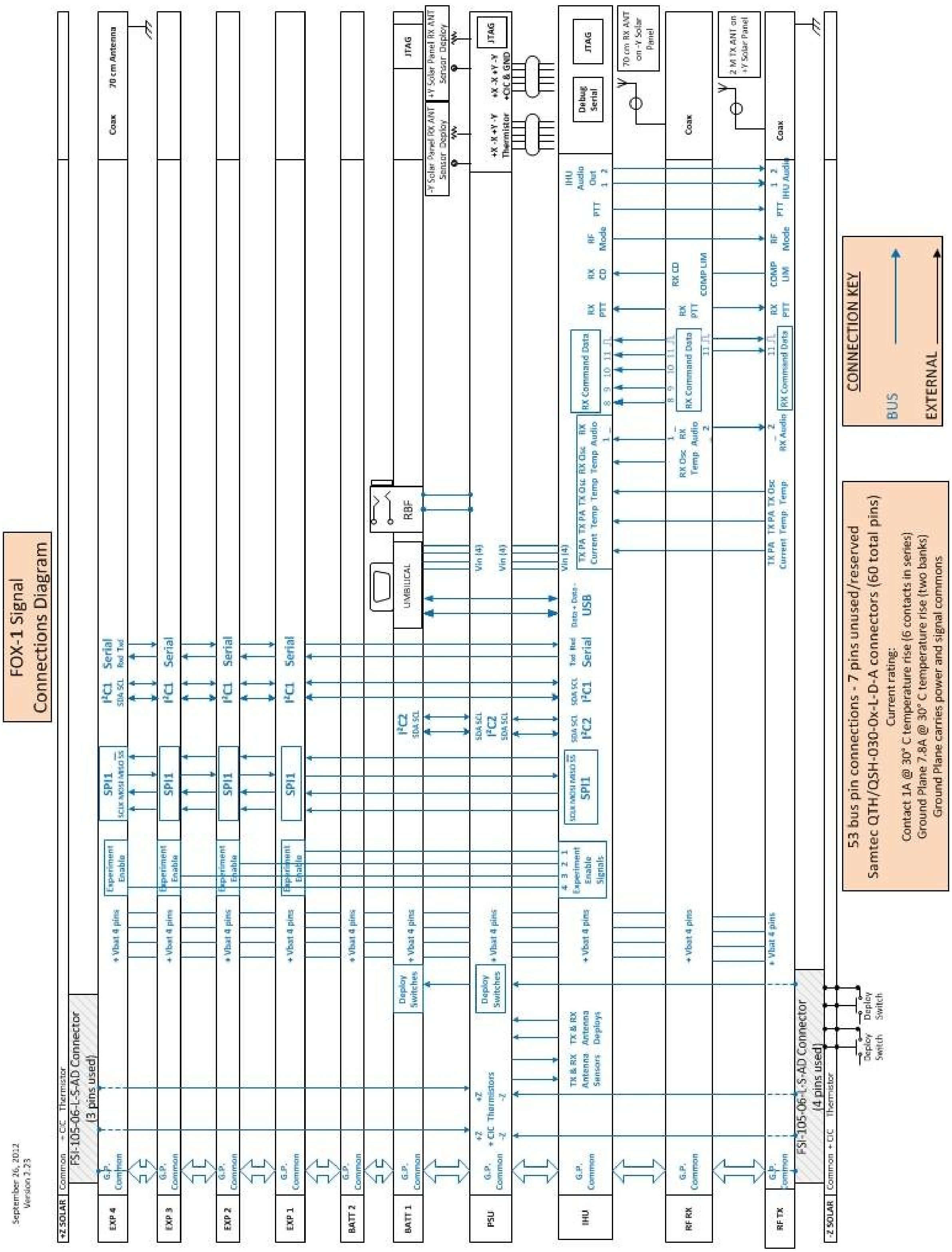


Figure 1: Interconnect Diagram

Table 1: System Bus Signal Characteristics

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Load System	Notes
1	SPI1 NSS	Digital	Note[1]	IHU		EXP 1-4	SPI Standard, IHU Master
2	TX PA Current	Analog	0 - 3.0 V	TX	30 - 60 kΩ	IHU	
3	SPI1 SCK	Digital	Note[1]	IHU		EXP 1-4	SPI Standard, IHU Master
4	TX PA Temperature	Analog	100-2000 mV	TX	30 - 60 kΩ	IHU	Analog Devices TMP36F
5	SPI1 MISO	Digital	Note[1]	IHU		EXP 1-4	SPI Standard, IHU Master
6	TX Osc Temperature	Analog	100-2000 mV	TX	30 - 60 kΩ	IHU	Analog Devices TMP36F
7	SPI1 MOSI	Digital	Note[1]	IHU		EXP 1-4	SPI Standard, IHU Master
8	RX Osc Temperature	Analog	100-2000 mV	RX	30 - 60 kΩ	IHU	Analog Devices TMP36F
9	Serial RXD	Digital	3.0 V	EXP 1-4		IHU	TTL, Async, Mark High
10	*RESERVED*						
11	Serial TXD	Digital	3.0 V	IHU		EXP 1-4	TTL, Async, Mark High
12	IHU Audio 1 Out	Analog	2 V p-p audio	IHU	600 Ω, Unbalanced	TX	For 5 kHz deviation, 10 Hz - 7 kHz bandwidth
13	Experiment Enable 1	Digital		IHU		EXP 1-4	HIGH = Enable EXP 1
14	IHU Audio 2 Out	Analog	N/A	IHU	N/A	TX	*RESERVED FOR FUTURE USE*
15	Experiment Enable 2	Digital		IHU		EXP 2	HIGH = Enable EXP 2
16	RX Command Data 8	Digital		RX		IHU	
17	Experiment Enable 3	Digital		IHU		EXP 3	HIGH = Enable EXP 3
18	RX Command Data 9	Digital		RX		IHU	
19	Experiment Enable 4	Digital		IHU		EXP 4	HIGH = Enable EXP 4
20	RX Command Data 10	Digital		RX		IHU	
21	*RESERVED*						
22	RX Command Data 11	Digital		RX		TX	
23	I^2C1 SCL	Digital	Note[1]	IHU			I^2C Standard, IHU Master
24	RX Command Strobe	Digital		RX	30 - 60 kΩ	IHU	
25	I^2C1 SDA	Digital	Note[1]	IHU			I^2C Standard, IHU Master
26	COMMAND Mode	Digital		IHU		TX	HIGH = Command Mode
27	*RESERVED*						
28	IHU PTT	Digital		IHU		TX	HIGH = TRANSMIT
29	*RESERVED*						
30	RX PTT	Digital		TX	30 - 60 kΩ	IHU	HIGH = HANG TIMER ACTIVE
31	*RESERVED*						
32	RX CD	Digital		RX	30 - 60 kΩ	IHU	
33	*RESERVED*						
34	RX Audio 1	Analog	2 V p-p audio	RX	600 Ω, Unbalanced	IHU	10 Hz - 7 kHz bandwidth
35	*RESERVED*						
36	RX Audio 2	Analog	N/A	RX	N/A	IHU	*RESERVED FOR FUTURE USE*
37	I^2C2 SCL	Digital	Note[1]	IHU		PSU	I^2C Standard, IHU Master
38	Comp Lim	Analog	1.4 VDC	RX	100 kΩ	TX	
39	I^2C2 SDA	Digital	Note[1]	IHU		PSU	I^2C Standard, IHU Master
40	RBF 1	Analog	N/A	RBF	N/A	PSU	N.O. for operation
41	+Z Thermistor	Analog	N/A	EXT	N/A	PSU	NCP21XM472J03RA
42	RBF 2	Analog	N/A	RBF	N/A	PSU	N.O. for operation
43	-Z Thermistor	Analog	N/A	EXT	N/A	PSU	NCP21XM472J03RA
44	TX Antenna Deploy	Analog	TBR	IHU	TBR	PSU	Not designed yet
45	+Z CIC	Analog	0.1 - 3 VDC	EXT	N/A	PSU	
46	TX Antenna Sensor	Digital	N/A	IHU	N.O.	PSU	N.O. when deployed
47	-Z CIC	Analog	0.1 - 3 VDC	EXT	N/A	PSU	
48	RX Antenna Sensor	Digital	N/A	IHU	N.O.	PSU	N.O. when deployed
49	Umbilical USBP	Digital		USB		IHU	USB Standard
50	RX Antenna Deploy	Analog	TBR	IHU	TBR	PSU	Not designed yet
51	Umbilical USBM	Digital		USB		IHU	USB Standard
52	-Z Deploy Switches	Analog	N/A	EXT	N/A	PSU	TBR - (N.O. = OPERATE?)
53	Umbilical Ext 5V Supply	USB	≤ 5.0 VDC	USB		IHU/PSU	Battery Charge Supply, USB Standard
54	Umbilical Ext 5V Supply	USB	≤ 5.0 VDC	USB		IHU/PSU	Battery Charge Supply, USB Standard
55	Umbilical Ext 5V Supply	USB	≤ 5.0 VDC	USB		IHU/PSU	Battery Charge Supply, USB Standard
56	Umbilical Ext 5V Supply	USB	≤ 5.0 VDC	USB		IHU/PSU	Battery Charge Supply, USB Standard
57	Vbatt	Power Bus	3.3 - 4.2 VDC	BATT/PSU		ALL	
58	Vbatt	Power Bus	3.3 - 4.2 VDC	BATT/PSU		ALL	
59	Vbatt	Power Bus	3.3 - 4.2 VDC	BATT/PSU		ALL	
60	Vbatt	Power Bus	3.3 - 4.2 VDC	BATT/PSU		ALL	

Note[1] All SPI and I^2C signals are 3.0 V levels

All Digital signals are CMOS logic levels high impedance load unless otherwise noted

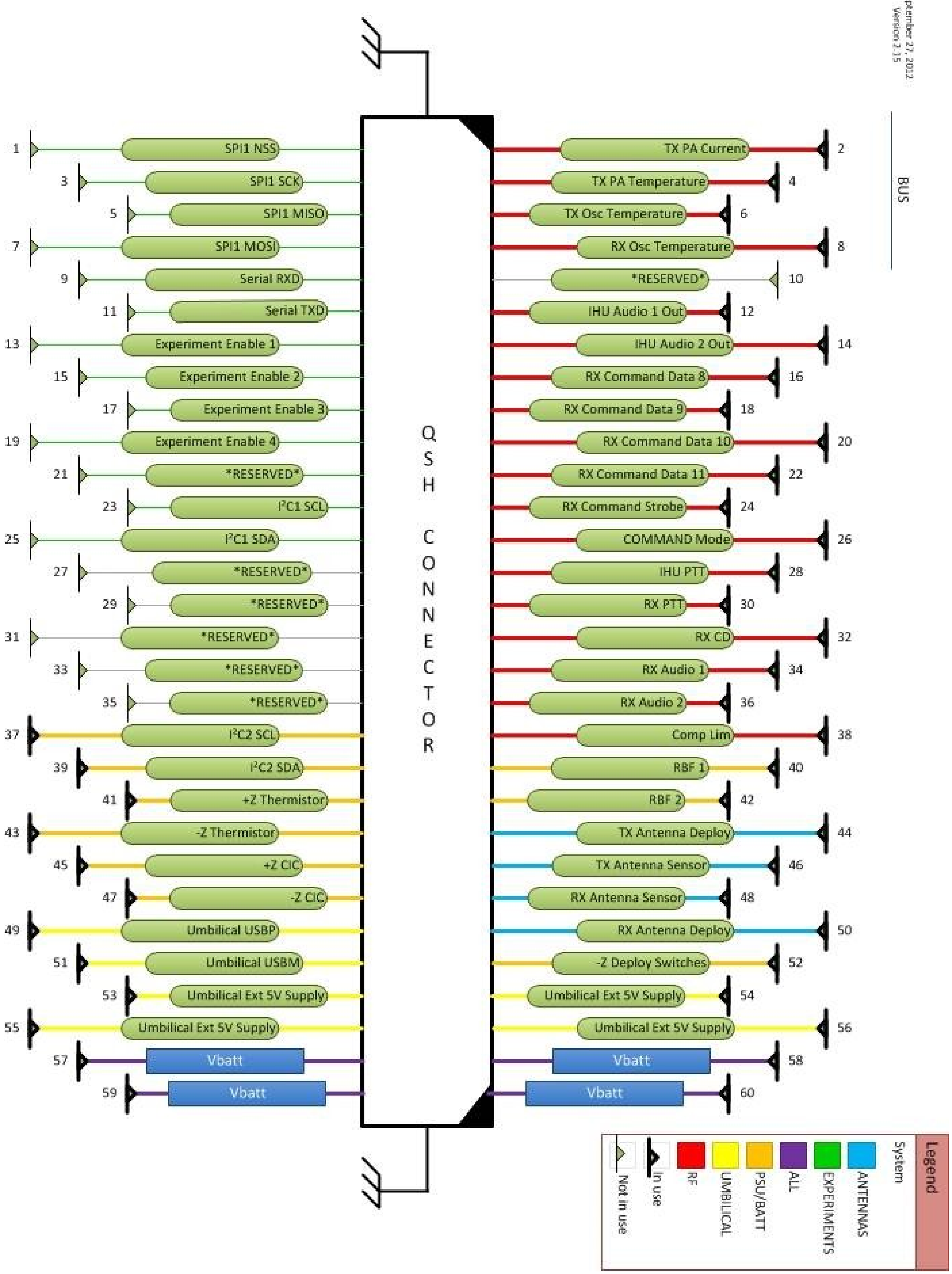


Figure 2: Complete Bus Connection Pin Assignments

3 RF Transmitter System

3.1 System Requirements Applicable to RF Transmitter System

2.2.1 The satellite avionics shall be designed for -40C to +70C operating temperature.

2.2.3 The satellite shall be designed to tolerate the radiation environment in orbit.

2.3.1 The satellite shall be designed for a minimum 5-year, on-orbit lifetime.

2.4.1 All RF transmitters shall meet or exceed the requirements specified in the ITU Radio Regulations, Technical Characteristics, Volume 3, article 3.

2.4.3 All satellite downlinks shall be in the 2 meter band within the amateur satellite service.

2.4.4 All satellite transmitter and receiver frequencies shall deviate by no more than 5 parts-per-million from the specified values including initial accuracy and temperature variation.

2.4.5 All satellite frequencies shall be coordinated with the IARU.

3.8.1 The satellite shall include an FM downlink transmitter.

3.8.2 The transmitter shall have specifications as shown in Table 2.

Power Output	400 mW (min.)
FM Deviation	5 kHz
Audio Bandwidth	3 kHz

3.8.3 The transmitter shall provide a means to prevent over modulation.

3.9.1 The satellite shall provide an FM transponder via the RF uplink and RF downlink.

3.9.2 The transponder shall detect the presence of a 67 Hz CTCSS tone on the uplink.

3.9.3 The downlink transmitter shall be keyed (i.e. PTT-on) for 2 minutes following detection of the 67 Hz CTCSS tone.

3.9.4 The downlink transmitter shall stay on continuously as long as the 67 Hz CTCSS tone is detected at least once every 2 minutes on the uplink.

3.9.5 The 67 Hz CTCSS tone is not required for a received signal to be repeated on the downlink, once the transmitter has been keyed.

3.9.6 If the downlink transmitter has been un-keyed for a period of 5 minutes, the satellite shall send " HI THIS IS AMSAT FOX " in Morse code via a keyed audio tone on the downlink transmitter.

3.9.7 The satellite shall default to Transponder Mode in the event of an IHU processor failure.

3.10.1 The satellite shall collect telemetry data.

3.10.2 The telemetry data shall include measured parameters as shown in Table 3.

Parameter Name	**Description**
CELL V	Voltages of battery cells
PANEL V	Voltages of solar panels
TOTAL I	Total DC current out of power system
PA I	DC current into RF power amp
BATTERY T	Temperature of battery
PANEL T	Temperatures of solar panels
PA T	Temperature of RF power amp
OSC T	Temperature of RF oscillators

3.10.3 The measured parameters shall be sampled at least every 15 seconds.

3.11.1 The satellite shall send telemetry using FSK on the RF downlink.

3.11.2 The FSK shall use the frequency spectrum below the audible range.

3.11.3 The telemetry shall be transmitted simultaneously with any transponder communications.

3.12.1 The satellite shall provide the means to process commands sent via the RF uplink from a ground control station.

3.12.2 The commands received via the RF uplink shall not be repeated on the RF downlink.

3.12.3 The following commands shall be provided, as shown in Table 5.

Command	**Operation**
TEST	Send test message
INHIBIT	Inhibit RF transmission
IHU OFF	Power off IHU
IHU ON	Power on IHU
CLEAR	Clear stored telemetry
TRANSPONDER MODE	Enter Transponder Mode
COMMAND MODE	Enter Command Mode

3.12.4 A TEST command shall cause the satellite to respond by sending " TEST TEST TEST " in Morse code via a keyed audio tone on the RF downlink.

3.12.5 An INHIBIT command shall cause the satellite to cease RF transmissions.

3.12.6 Any command other than INHIBIT shall remove a transmit inhibit condition.

3.12.10 A TRANSPONDER MODE command shall cause the satellite to enter the Transponder Mode.

3.12.11 A COMMAND MODE command shall cause the satellite to enter the Command Mode.

3.13.1 The satellite shall provide on-orbit operating modes as shown in Table 6.

Name	**Description**
Startup Mode	Wait 45 minutes and deploy antennas
Transponder Mode	FM transponder and telemetry active
Command Mode	Telemetry active, no FM transponder

3.13.5 If the antennas have been deployed, the satellite shall enter the Transponder Mode.

3.13.8 In Transponder Mode, the transponder and the telemetry shall be active.

3.13.9 In Command Mode, the telemetry shall be active and the transponder shall not be active. (i.e. signals that appear on the uplink shall not be repeated on the downlink.)

3.2 Volume Requirements Applicable to RF Transmitter System

3.2.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 5 mm from the –Z surface of the PC board.

3.2.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 6.0 mm from the +Z surface of the PC board.

3.3 Interface Control Documents Applicable to RF Transmitter System

AMSAT *Fox-1* IHU to RF System Interface Control Document

3.4 RF Transmitter System PCB Bus Connections

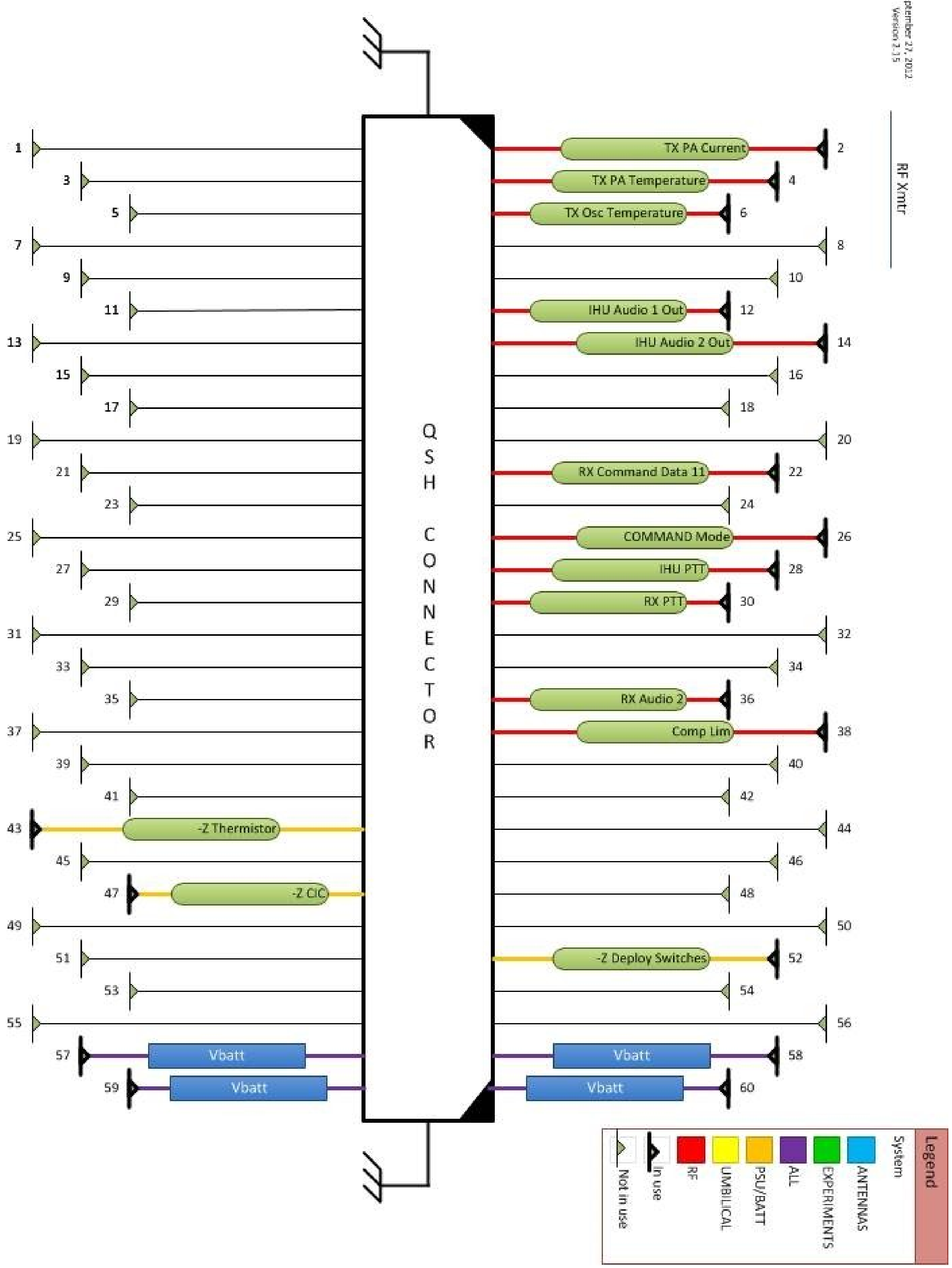


Figure 3: RF Transmitter System Bus Connection Pin Assignments

3.5 RF Transmitter System PCB External Connections

3.5.1 2 meter band RF output, coaxial cable to Transmit Antenna
3.5.2 Spacecraft deployment switches cable(s) TBR
3.5.3 Three connections via Samtec FSI-105-06-L-S-AD connector
  3.5.3.1 1 contact -Z Solar Panel Thermistor
  3.5.3.2 1 contact -Z Solar Panel CIC +
  3.5.3.3 1 contact common or - for above four connections

Table 2: External Connection Signal Characteristics

External Connection	Nomenclature	Type	Voltage/ Power	Source System	Load Z	Bus Pin
Coaxial Cable	2 meter Antenna ≈ 145.9 MHz	RF	0 to +30 dBm	2 meter Antenna	50 Ω unbal.	N/A
Cable **TBR**	Spacecraft Deployment Switches	Analog	N/A	Switch	N/A	52

Table 3: -Z PCB face FSI-105-06-L-S-AD connector mates to pads on –Z Solar Panel

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Load System	Bus Pin
1	-Z Thermistor	Analog	N/A	N/A	N/A	PSU	43
2	-Z Deploy Switches	Analog	N/A	N/A	N/A	PSU	52
3	-Z Solar Panel Common						Ground Plane
4	N/C						
5	-Z CIC (+)	Analog	2.66 VDC nominal	N/A	N/A	PSU	47

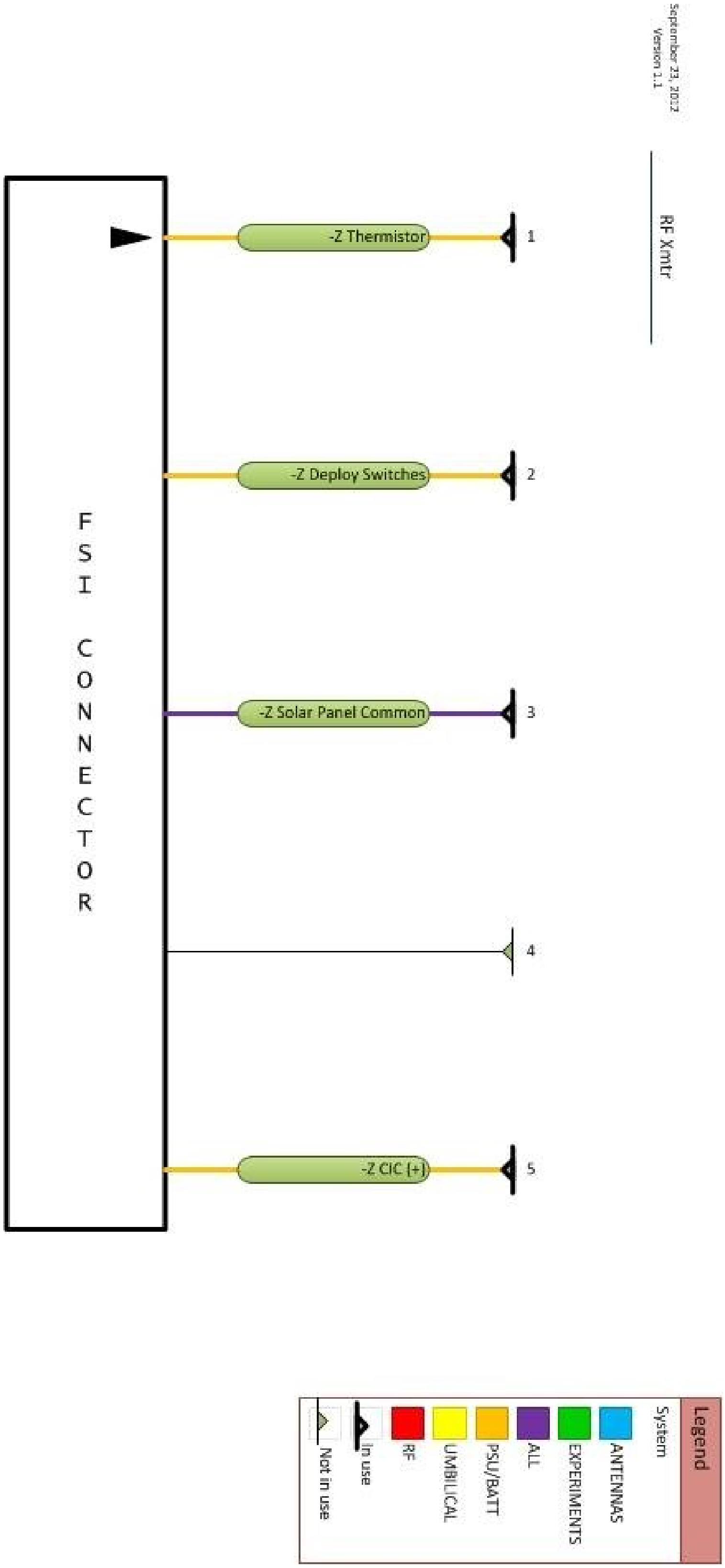


Figure 4: RF Transmitter System FSI-105-06-L-S-AD Connection Pin Assignments

4 RF Receiver System

4.1 System Requirements Applicable to RF Receiver System

2.2.1 The satellite avionics shall be designed for -40C to +70C operating temperature.
2.2.3 The satellite shall be designed to tolerate the radiation environment in orbit.
2.3.1 The satellite shall be designed for a minimum 5-year, on-orbit lifetime.
2.4.2 All satellite uplinks shall be in the 70 cm band of the amateur satellite service.
2.4.5 All satellite frequencies shall be coordinated with the IARU.
3.7.1 The satellite shall include an FM uplink receiver.
3.7.2 The receiver shall have specifications as shown in Table 1.

Sensitivity	-120 dBm for 12 dB SINAD (min.)
FM Deviation	5 kHz
Audio Bandwidth	3 kHz
Input Frequency Acceptance	Receiver shall accept signals that are off frequency by ±2.5 kHz (min.)

3.8.3 The transmitter shall provide a means to prevent over modulation.
3.9.1 The satellite shall provide an FM transponder via the RF uplink and RF downlink.
3.9.2 The transponder shall detect the presence of a 67 Hz CTCSS tone on the uplink.
3.9.4 The downlink transmitter shall stay on continuously as long as the 67 Hz CTCSS tone is detected at least once every 2 minutes on the uplink.
3.9.5 The 67 Hz CTCSS tone is not required for a received signal to be repeated on the downlink, once the transmitter has been keyed.
3.9.7 The satellite shall default to Transponder Mode in the event of an IHU processor failure.
3.10.1 The satellite shall collect telemetry data.
3.10.2 The telemetry data shall include measured parameters as shown in Table 3.

Parameter Name	**Description**
CELL V	Voltages of battery cells
PANEL V	Voltages of solar panels
TOTAL I	Total DC current out of power system
PA I	DC current into RF power amp
BATTERY T	Temperature of battery
PANEL T	Temperatures of solar panels
PA T	Temperature of RF power amp
OSC T	Temperature of RF oscillators

3.10.3 The measured parameters shall be sampled at least every 15 seconds.
3.12.1 The satellite shall provide the means to process commands sent via the RF uplink from a ground control station.
3.12.2 The commands received via the RF uplink shall not be repeated on the RF downlink.

3.12.3 The following commands shall be provided, as shown in Table 5.

Command	**Operation**
TEST	Send test message
INHIBIT	Inhibit RF transmission
IHU OFF	Power off IHU
IHU ON	Power on IHU
CLEAR	Clear stored telemetry
TRANSPONDER MODE	Enter Transponder Mode
COMMAND MODE	Enter Command Mode

3.12.10 A TRANSPONDER MODE command shall cause the satellite to enter the Transponder Mode.

3.12.11 A COMMAND MODE command shall cause the satellite to enter the Command Mode.

3.13.1 The satellite shall provide on-orbit operating modes as shown in Table 6.

3.13.5 If the antennas have been deployed, the satellite shall enter the Transponder Mode.

3.13.8 In Transponder Mode, the transponder and the telemetry shall be active.

3.13.9 In Command Mode, the telemetry shall be active and the transponder shall not be active. (i.e. signals that appear on the uplink shall not be repeated on the downlink.)

3.13.11 The RF uplink shall be monitored for commands in all modes.

4.2 Volume Requirements Applicable to RF Receiver System

4.2.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 1 mm from the –Z surface of the PC board.

4.2.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 6.0 mm from the +Z surface of the PC board.

4.3 Interface Control Documents Applicable to RF Receiver System

AMSAT *Fox-1* IHU to RF System Interface Control Document

4.4 RF Receiver System PCB Bus Connections

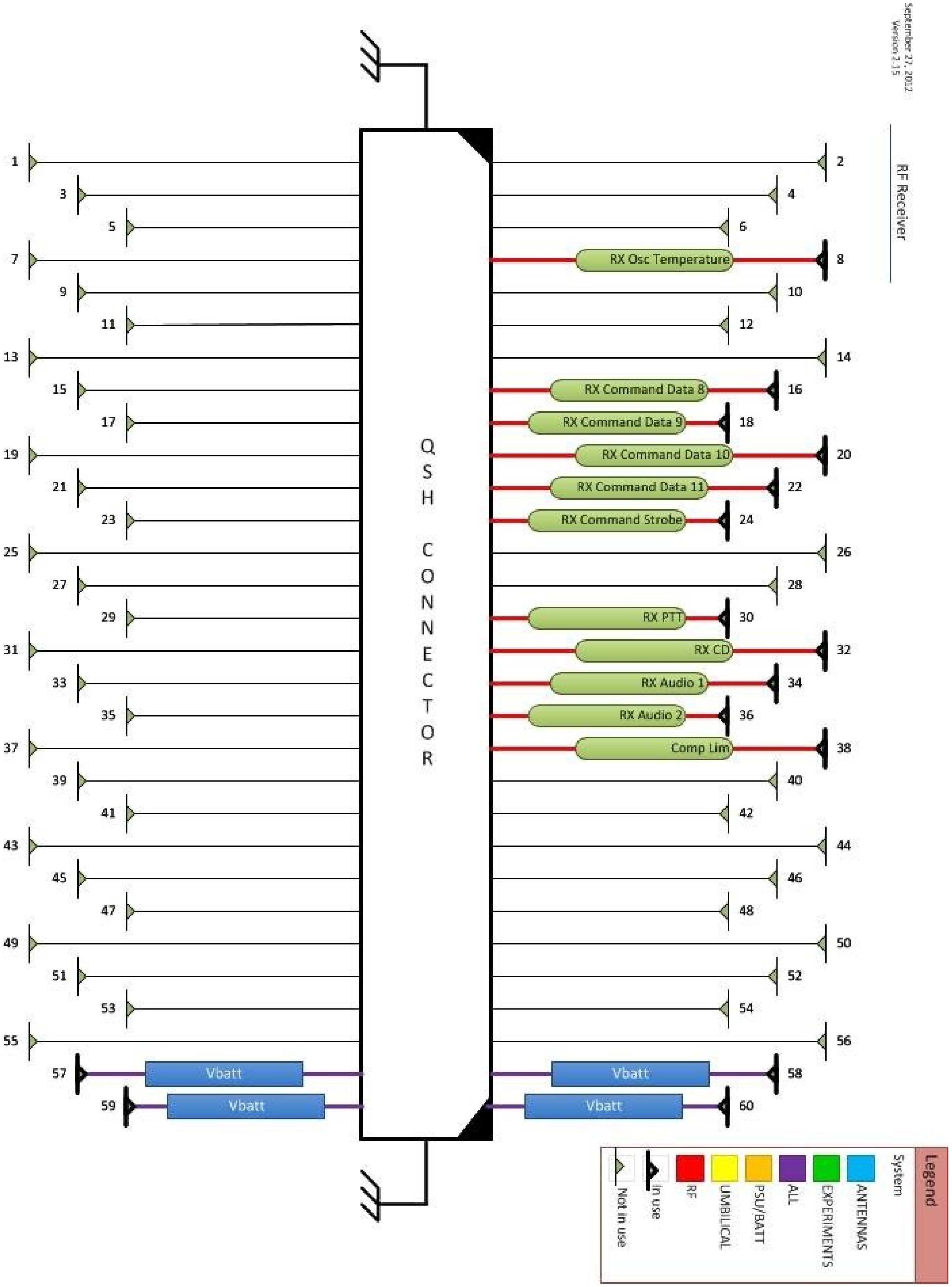


Figure 5: RF Receiver System Bus Connection Pin Assignments

4.5 RF Receiver System PCB External Connections

4.5.1 70cm band RF input, coaxial cable to Receive Antenna

Table 4: RF Receiver System External Connection Signal Characteristics

External Connection	Nomenclature	Type	Voltage/Power	Source System	Load Z	Bus Pin
Coaxial Cable	70 cm RF Input 437 MHz	RF	-60 dBm to -140 dBm	70 cm Antenna	50 Ω unbal.	N/A

5 Internal Housekeeping Unit (IHU) System

5.1 System Requirements Applicable to Internal Housekeeping Unit (IHU) System

2.2.1 The satellite avionics shall be designed for -40C to +70C operating temperature.
2.2.3 The satellite shall be designed to tolerate the radiation environment in orbit.
2.3.1 The satellite shall be designed for a minimum 5-year, on-orbit lifetime.
3.3.2 The satellite shall include an umbilical port as per the CubeSat Design Specification.
3.4.3 The satellite shall provide the means to run diagnostic tests via the umbilical port while integrated with the P-POD.
3.6.2 The satellite shall provide a means to activate and deactivate the experiment payload.
3.6.3 The satellite shall provide a means to telemeter data from the experiment payload.
3.9.6 If the downlink transmitter has been un-keyed for a period of 5 minutes, the satellite shall send " HI THIS IS AMSAT FOX " in Morse code via a keyed audio tone on the downlink transmitter.
3.9.7 The satellite shall default to Transponder Mode in the event of an IHU processor failure.
3.10.1 The satellite shall collect telemetry data.
3.10.2 The telemetry data shall include measured parameters as shown in Table 3.

Parameter Name	**Description**
CELL V	Voltages of battery cells
PANEL V	Voltages of solar panels
TOTAL I	Total DC current out of power system
PA I	DC current into RF power amp
BATTERY T	Temperature of battery
PANEL T	Temperatures of solar panels
PA T	Temperature of RF power amp
OSC T	Temperature of RF oscillators

3.10.3 The measured parameters shall be sampled at least every 15 seconds.
3.10.4 The minimum and maximum values of each of the measured parameters shall be saved in non-volatile memory.
3.10.5 The telemetry data shall also include calculated parameters as shown in Table 4.

Parameter Name	**Description**
UP TIME	Total seconds since avionics power-up or reset
SPIN	Satellite spin rate and direction

3.10.6 A telemetry frame shall include the current measured values, the saved minimum and maximum values, and the current calculated values.
3.11.1 The satellite shall send telemetry using FSK on the RF downlink.
3.11.2 The FSK shall use the frequency spectrum below the audible range.
3.11.3 The telemetry shall be transmitted simultaneously with any transponder communications.
3.11.4 The telemetry transmission shall include telemetry frames.

3.11.5 The telemetry transmission shall include experiment data.

3.12.1 The satellite shall provide the means to process commands sent via the RF uplink from a ground control station.

3.12.3 The following commands shall be provided, as shown in Table 5.

Command	**Operation**
TEST	Send test message
INHIBIT	Inhibit RF transmission
IHU OFF	Power off IHU
IHU ON	Power on IHU
CLEAR	Clear stored telemetry
TRANSPONDER MODE	Enter Transponder Mode
COMMAND MODE	Enter Command Mode

3.12.4 A TEST command shall cause the satellite to respond by sending " TEST TEST TEST " in Morse code via a keyed audio tone on the RF downlink.

3.12.7 An IHU OFF command shall cause the IHU System to power off.

3.12.8 An IHU ON command shall cause the IHU System to power on.

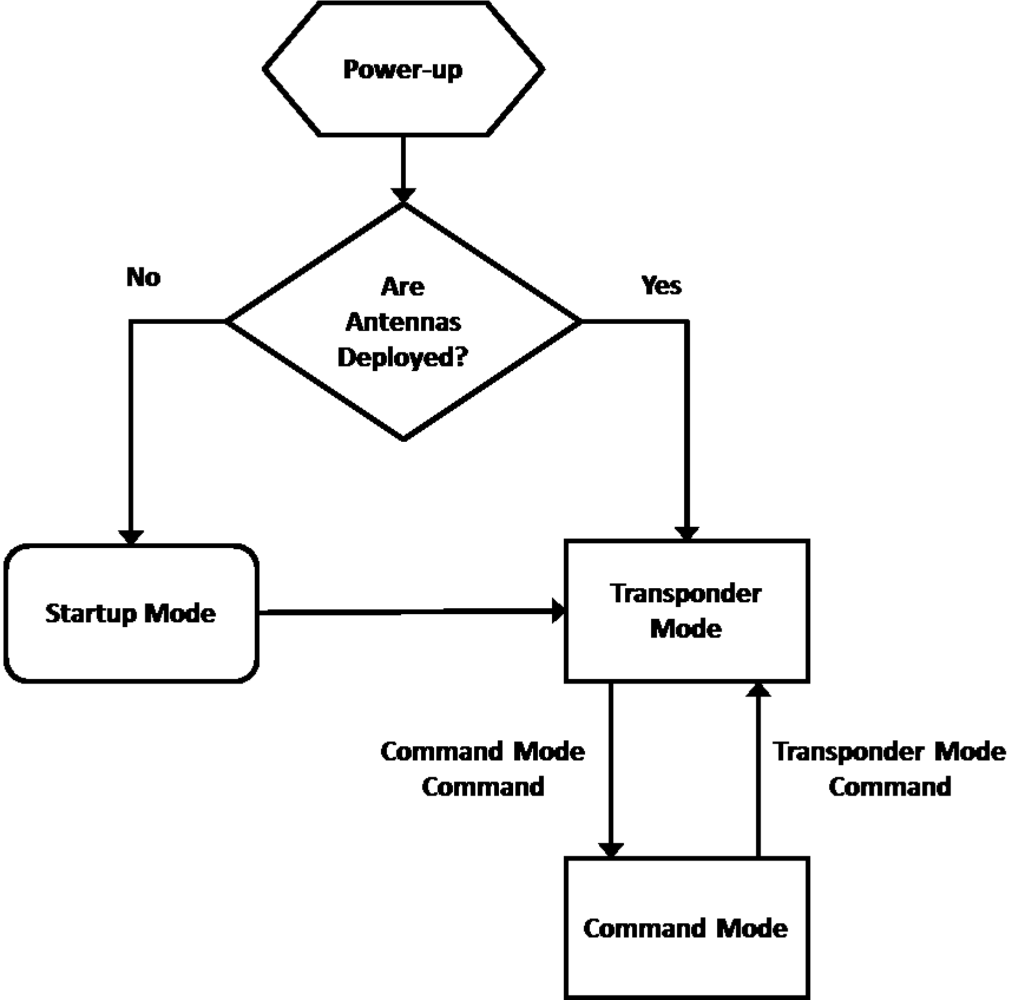
3.12.9 A CLEAR command shall cause the satellite to clear the saved minimum and maximum telemetry parameter values.

3.12.10 A TRANSPONDER MODE command shall cause the satellite to enter the Transponder Mode.

3.13.1 The satellite shall provide on-orbit operating modes as shown in Table 6.

Name	**Description**
Startup Mode	Wait 45 minutes and deploy antennas
Transponder Mode	FM transponder and telemetry active
Command Mode	Telemetry active, no FM transponder

3.13.2 The satellite shall transition between modes as shown in Figure 1.



3.12.11 A COMMAND MODE command shall cause the satellite to enter the Command Mode.

3.13.3 Upon power-up of the avionics, the satellite shall begin operation from the "Power-up" state as shown in Figure 1.

3.13.4 An IHU ON Command shall cause the satellite to begin operation from the "Power-up " state as shown in Figure 1.

3.13.5 If the antennas have been deployed, the satellite shall enter the Transponder Mode.

3.13.6 If the antennas have not been deployed, the satellite shall enter the Startup Mode.

3.13.7 In Startup Mode, the satellite shall wait 45 minutes, deploy the antennas and then enter Transponder Mode.

3.13.8 In Transponder Mode, the transponder and the telemetry shall be active.

3.13.9 In Command Mode, the telemetry shall be active and the transponder shall not be active. (i.e. signals that appear on the uplink shall not be repeated on the downlink.)

3.13.10 If another Command Mode command is not received, the satellite shall automatically enter Transponder Mode 24 hours after having entered Command Mode.

3.13.11 The RF uplink shall be monitored for commands in all modes.

5.2 Volume Requirements Applicable to IHU System

5.2.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 1 mm from the –Z surface of the PC board.

5.2.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 6.0 mm from the +Z surface of the PC board.

5.3 Interface Control Documents Applicable to IHU System

AMSAT *Fox-1* IHU to RF System Interface Control Document
AMSAT *Fox-1* IHU to PSU Interface Control Document
AMSAT *Fox-1* IHU to Attitude Determination Experiment Interface Control Document

5.4 Internal Housekeeping Unit (IHU) System PCB Bus Connections

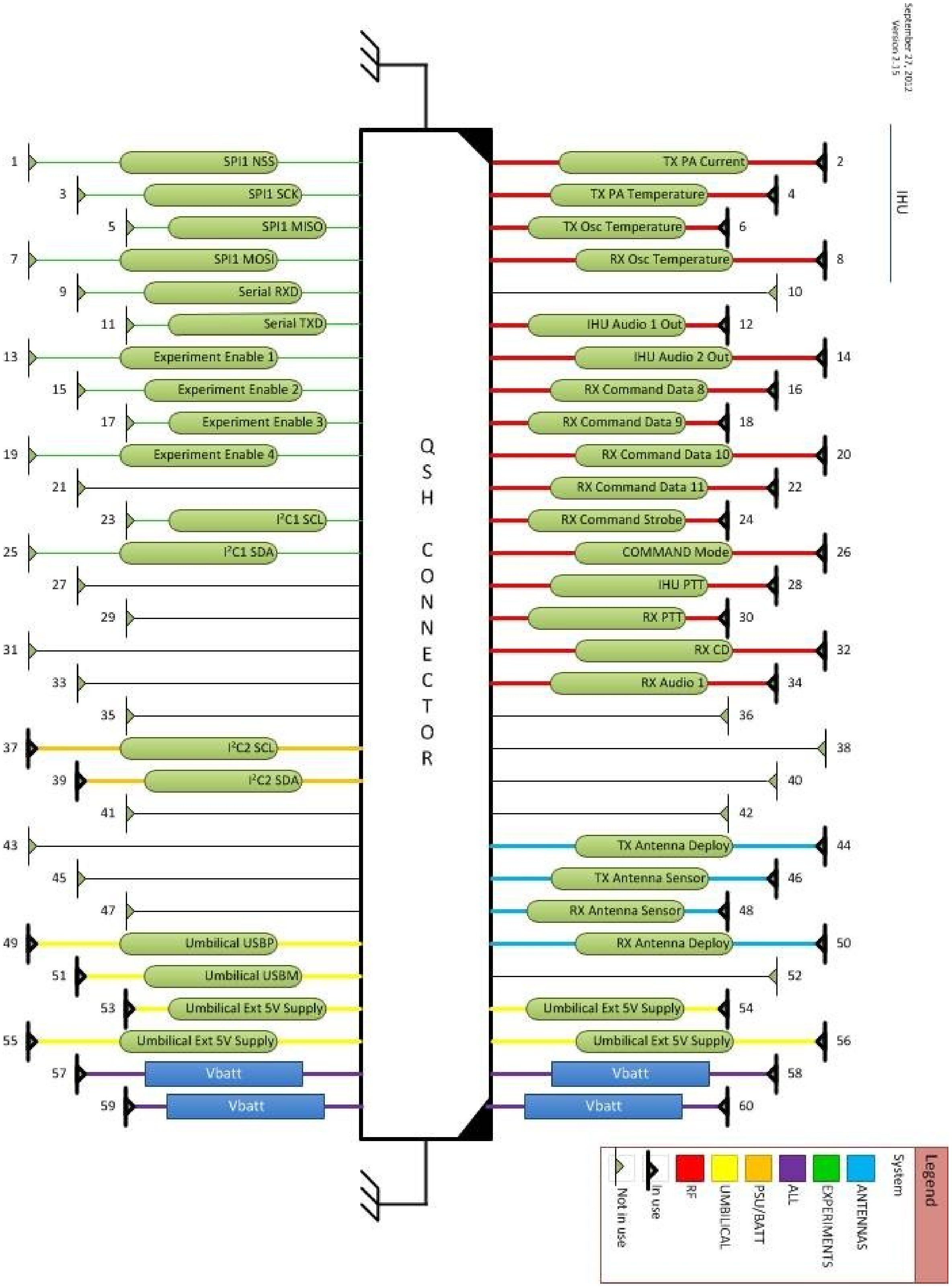


Figure 6: IHU System Bus Connection Pin Assignments

6 Power Supply System (PSU)

6.1 System Requirements Applicable to Power Supply System (PSU)

2.2.1 The satellite avionics shall be designed for -40C to +70C operating temperature.
2.2.3 The satellite shall be designed to tolerate the radiation environment in orbit.
2.3.1 The satellite shall be designed for a minimum 5-year, on-orbit lifetime.
3.3.1 The satellite shall include a "Remove Before Flight" pin as per the CubeSat Design Specification.
3.4.1 The satellite battery and photovoltaic panels shall be electronically disconnected from the avionics when the "Remove Before Flight" pin is inserted, regardless of the state of the deployment switch(es).
3.4.2 The satellite shall provide the means to charge the battery via the umbilical port while integrated with the P-POD.
3.5.1 The satellite shall produce electrical power from sunlight.
3.5.2 The satellite shall produce electrical power while in sunlight regardless of orientation and while tumbling or spinning.
3.5.3 The satellite shall produce sufficient average electrical power to operate continuously in the orbit of maximum eclipse.
3.5.4 The satellite shall provide sufficient battery capacity to operate continuously in the orbit of maximum eclipse.
3.5.5 If the battery fails, including a short-circuit condition, the satellite shall continue to operate using only the photovoltaic panel power when in sunlight.
3.6.1 The satellite shall provide current limited DC power for an experiment payload.
3.10.1 The satellite shall collect telemetry data.
3.10.2 The telemetry data shall include measured parameters as shown in Table 3.

Parameter Name	Description
CELL V	Voltages of battery cells
PANEL V	Voltages of solar panels
TOTAL I	Total DC current out of power system
PA I	DC current into RF power amp
BATTERY T	Temperature of battery
PANEL T	Temperatures of solar panels
PA T	Temperature of RF power amp
OSC T	Temperature of RF oscillators

3.10.3 The measured parameters shall be sampled at least every 15 seconds.
3.10.5 The telemetry data shall also include calculated parameters as shown in Table 4.

Parameter Name	Description
UP TIME	Total seconds since avionics power-up or reset
SPIN	Satellite spin rate and direction

6.2 Volume Requirements Applicable to PSU System

6.2.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 1 mm from the –Z surface of the PC board.

6.2.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 3.0 mm from the +Z surface of the PC board within the area 0 to 4.0 mm from the +Y and +X edges of the board, and 6.0 mm from the +Z surface of the PC board in the rest of the board area.

6.3 Interface Control Documents Applicable to PSU System

AMSAT *Fox-1* IHU to PSU Interface Control Document

6.4 Power Supply System (PSU) PCB Bus Connections

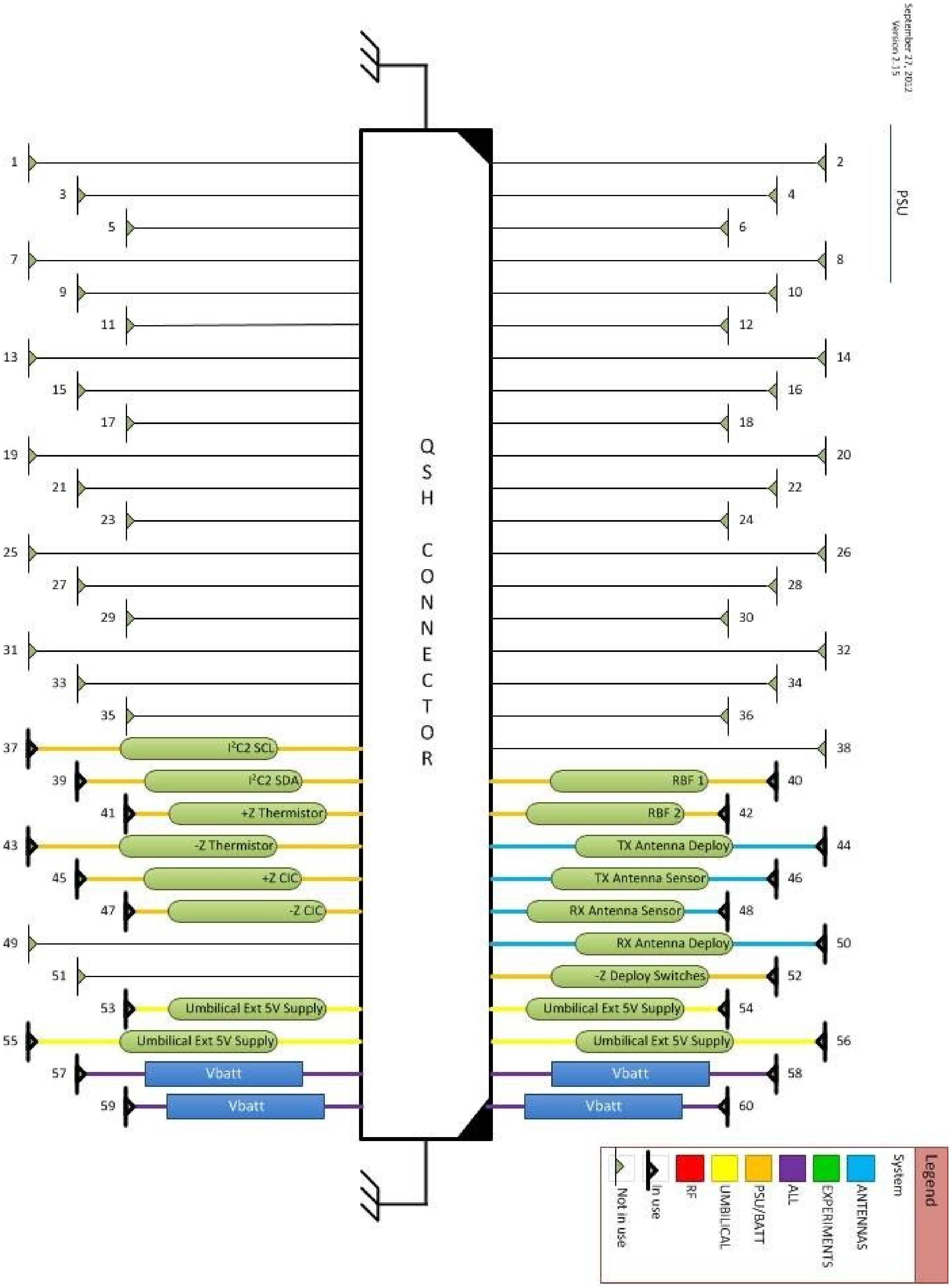


Figure 7: PSU Bus Connection Pin Assignments

6.5 Power Supply System (PSU) PCB External Connections

6.5.1 Three connections to +X Solar Panel using Samtec MEC1-105-02-L-D-NP-A connector
- **6.5.1.1** 1 contact +X Solar Panel Thermistor
- **6.5.1.2** 1 contact +X Solar Panel CIC +
- **6.5.1.3** 1 contact common or - for above two connections

6.5.2 Three connections to -X Solar Panel using Samtec MEC1-105-02-L-D-NP-A connector
- **6.5.2.1** 1 contact -X Solar Panel Thermistor
- **6.5.2.2** 1 contact -X Solar Panel CIC +
- **6.5.2.3** 1 contact common or - for above two connections

6.5.3 Five connections to +Y Solar Panel using Samtec MEC1-105-02-L-D-NP-A connector
- **6.5.3.1** 1 contact +Y Solar Panel Thermistor
- **6.5.3.2** 1 contact +Y Solar Panel CIC +
- **6.5.3.3** 1 contact TX Antenna Deploy
- **6.5.3.4** 1 contact TX Antenna Sensor
- **6.5.3.5** 1 contact common or - for above connections

6.5.4 Five connections to -Y Solar Panel using Samtec MEC1-105-02-L-D-NP-A connector
- **6.5.4.1** 1 contact -Y Solar Panel Thermistor
- **6.5.4.2** 1 contact -Y Solar Panel CIC +
- **6.5.4.3** 1 contact RX Antenna Deploy
- **6.5.4.4** 1 contact RX Antenna Sensor
- **6.5.4.5** 1 contact common or - for above connections

6.5.5 All PCB edges that connect to solar panel MEC1-105-02-L-D-NP-A connectors shall have contact pads on the PCB for all connector pins, whether connected to a trace or not.

Table 5: +X PCB edge mates to MEC1-105-02-L-D-NP-A connector on +X Solar Panel

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Bus Pin
1	N/C					
2	+X Solar Panel Thermistor	Analog	N/A	N/A	N/A	N/A
3	N/C					
4	N/C					
5	N/C					
6	+X Solar Panel Common					Ground Plane
7	N/C					
8	N/C					
9	N/C					
10	+X Solar Panel CIC (+)	Digital	2.66 VDC nominal	N/A	N/A	N/A

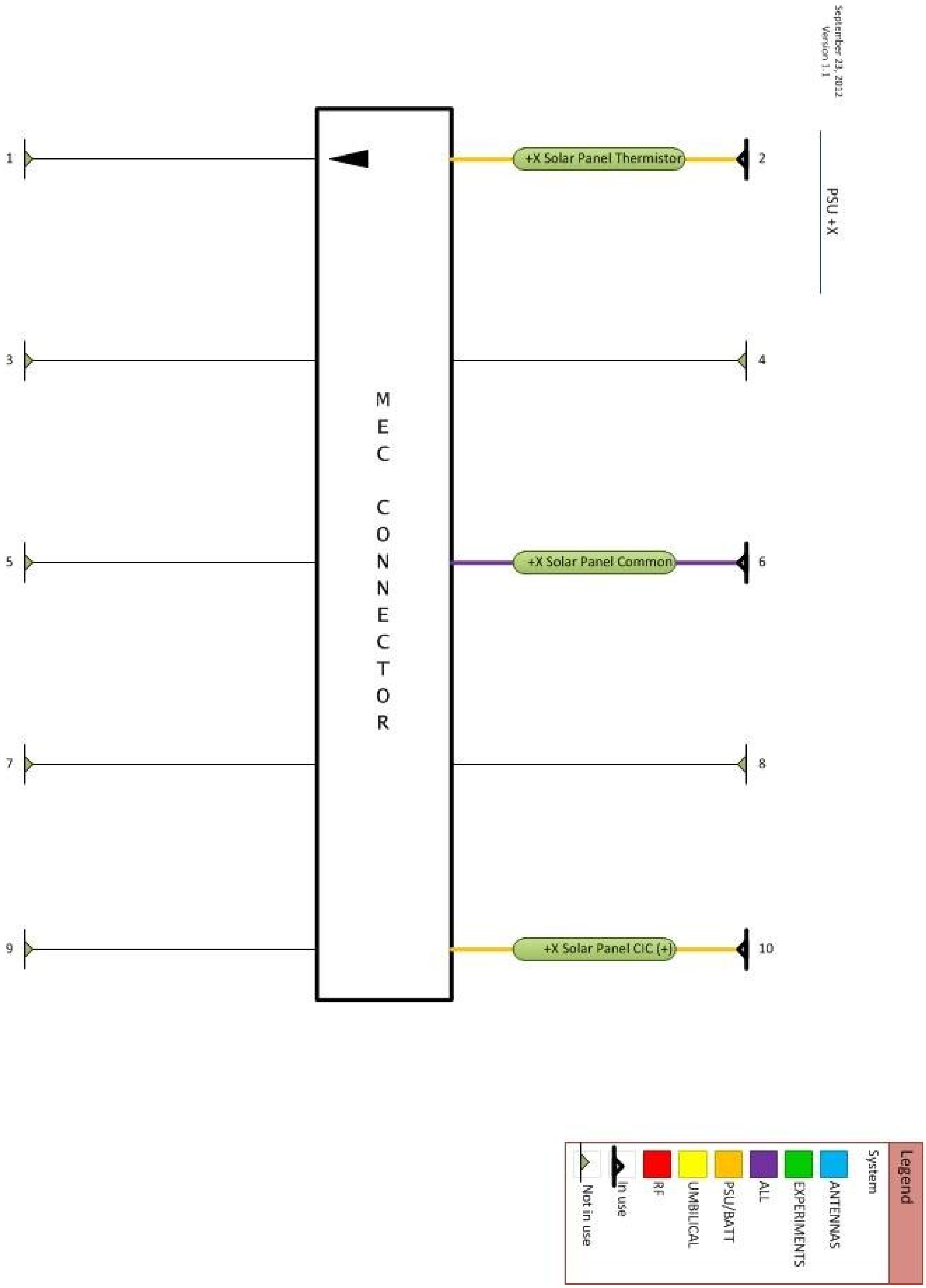


Figure 8: PSU System +X Edge MEC1-105-02-L-D-NP-A Connection Pin Assignments

Table 6: -X PCB edge mates to MEC1-105-02-L-D-NP-A connector on -X Solar Panel

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Bus Pin
1	N/C					
2	-X Solar Panel Thermistor	Analog	N/A	N/A	N/A	N/A
3	N/C					
4	N/C					
5	N/C					
6	-X Solar Panel Common					Ground Plane
7	N/C					
8	N/C					
9	N/C					
10	-X Solar Panel CIC (+)	Digital	2.66 VDC nominal	N/A	N/A	N/A

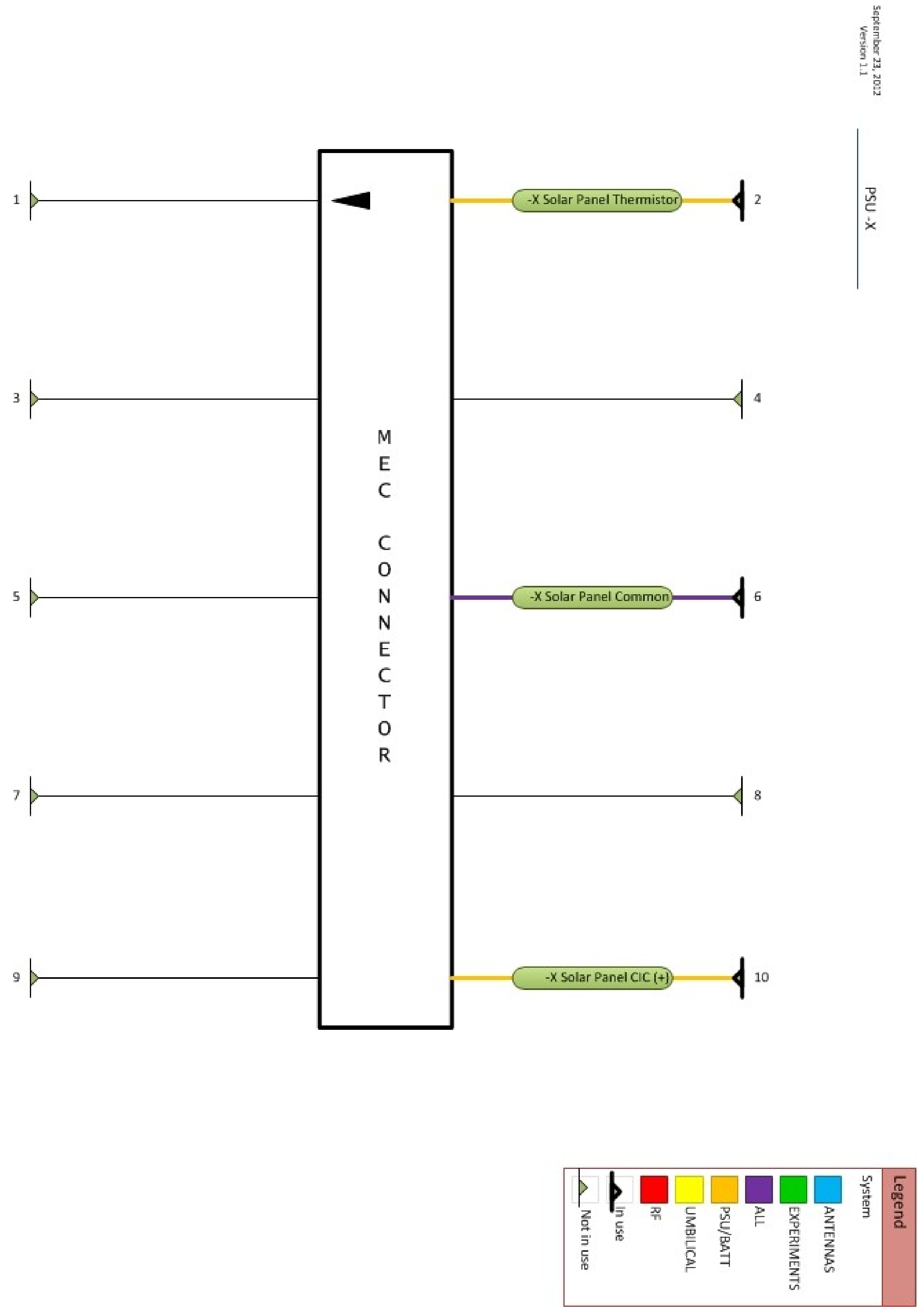


Figure 9: PSU System -X Edge MEC1-105-02-L-D-NP-A Connection Pin Assignments

Table 7: +Y PCB edge mates to MEC1-105-02-L-D-NP-A connector on +Y Solar Panel

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Bus Pin
1	N/C					
2	+Y Solar Panel Thermistor	Analog	N/A	N/A	N/A	N/A
3	N/C					
4	TX Antenna Sensor	Analog	N/A	IHU	N.O.	46
5	N/C					
6	+Y Solar Panel Common					Ground Plane
7	N/C					
8	TX Antenna Deploy	Analog	TBR	TBR	TBR	TBR
9	N/C					
10	+Y Solar Panel CIC (+)	Digital	2.66 VDC nominal	N/A	N/A	N/A

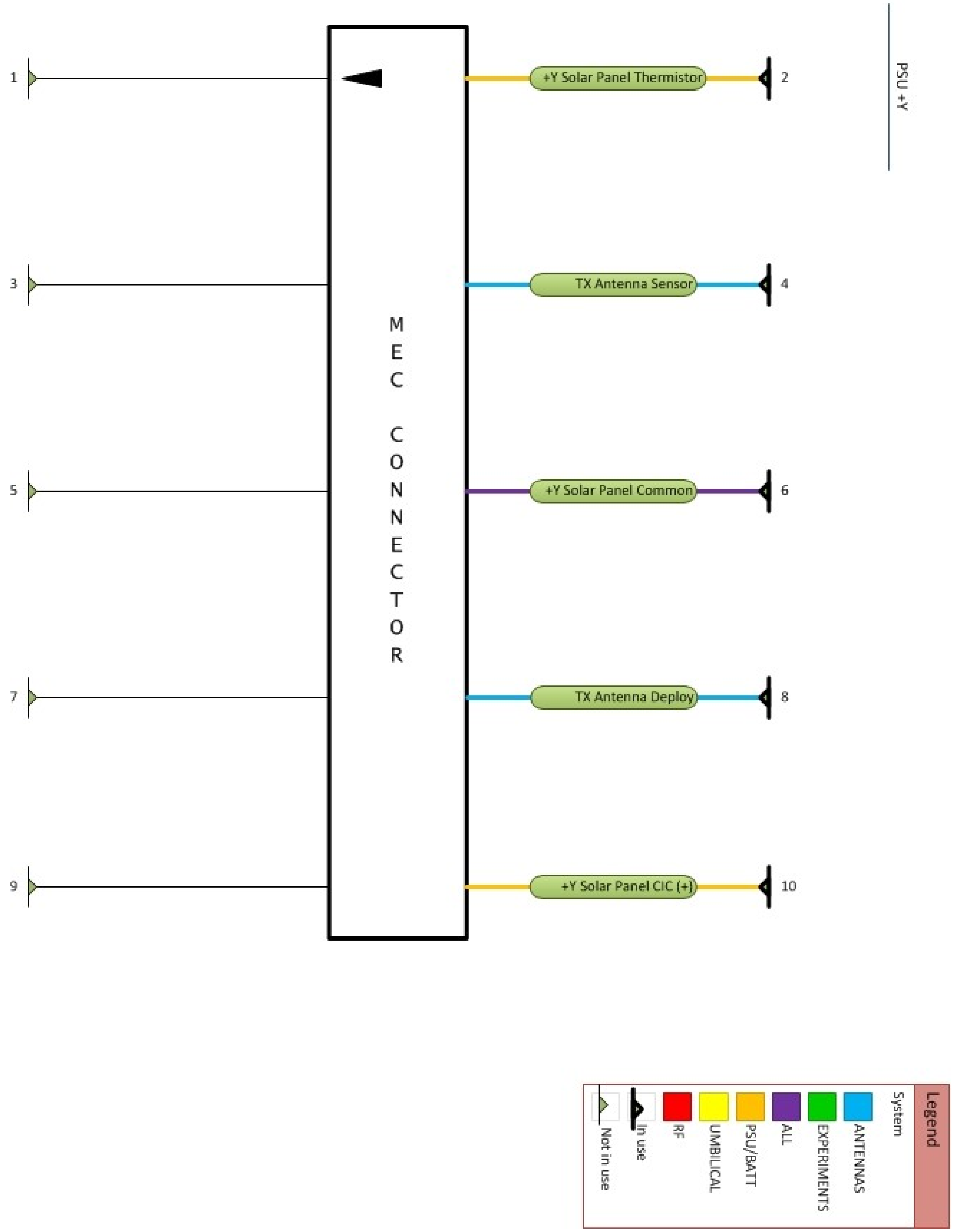


Figure 10: PSU System +Y Edge MEC1-105-02-L-D-NP-A Connection Pin Assignments

Table 8: -Y PCB edge mates to MEC1-105-02-L-D-NP-A connector on -Y Solar Panel

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Bus Pin
1	N/C					
2	-Y Solar Panel Thermistor	Analog	N/A	N/A	N/A	N/A
3	N/C					
4	RX Antenna Sensor	Analog	N/A	IHU	N.O.	48
5	N/C					
6	-Y Solar Panel Common					Ground Plane
7	N/C					
8	RX Antenna Deploy	Analog	TBR	TBR	TBR	TBR
9	N/C					
10	-Y Solar Panel CIC (+)	Digital	2.66 VDC nominal	N/A	N/A	N/A

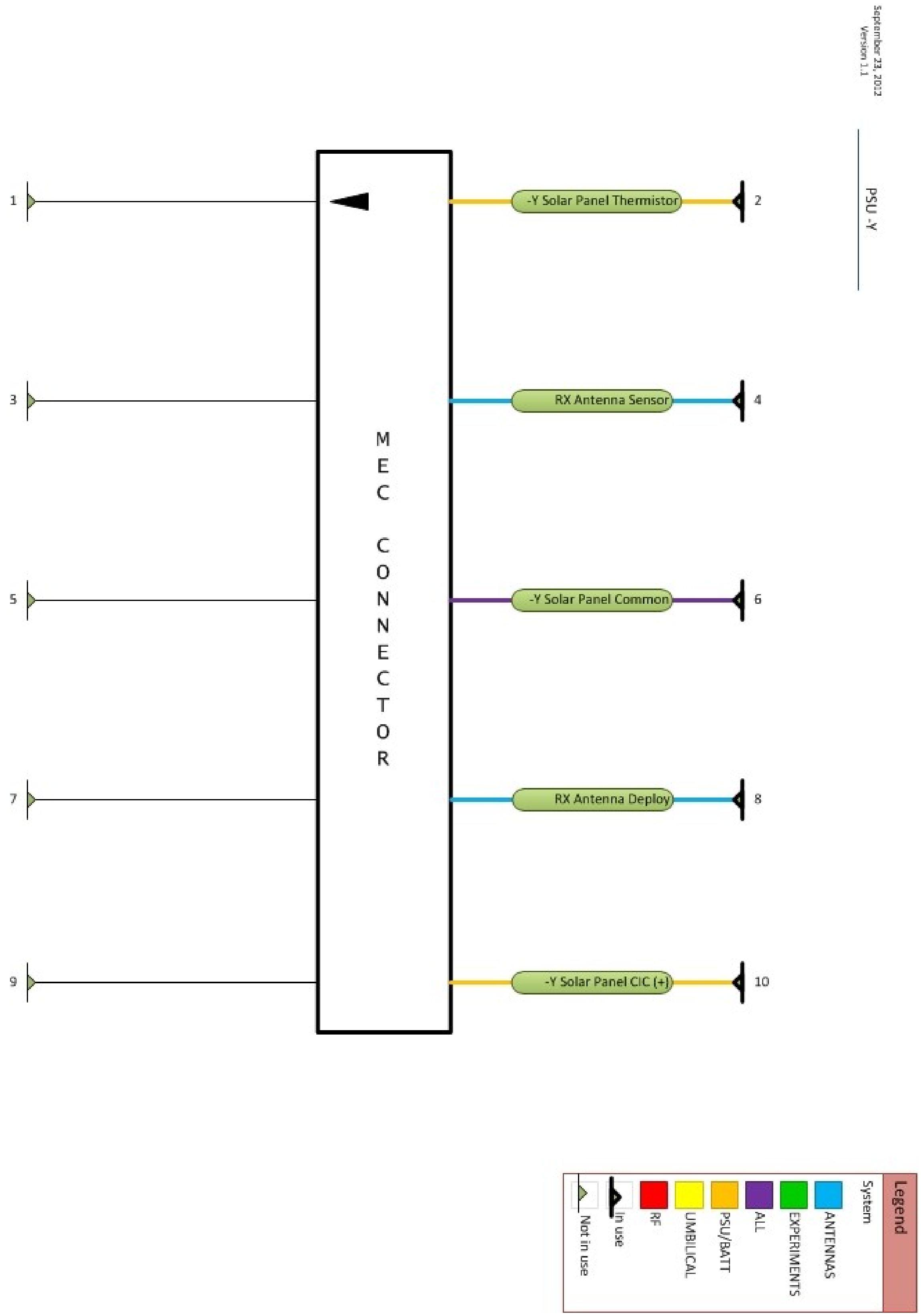


Figure 11: PSU System -Y Edge MEC1-105-02-L-D-NP-A Connection Pin Assignments

7 Battery System

7.1 Volume Requirements Applicable to Battery PCB 1 System

7.1.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 4.0 mm from the -Z surface of the PC board within the area 0 to 4.0 mm from the +Y and +X edges of the board, and 1.0 mm from the -Z surface of the PC board in the rest of the board area.

7.1.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 17.0 mm from the +Z surface of the PC board.

7.2 Battery PCB 1 System Bus Connections

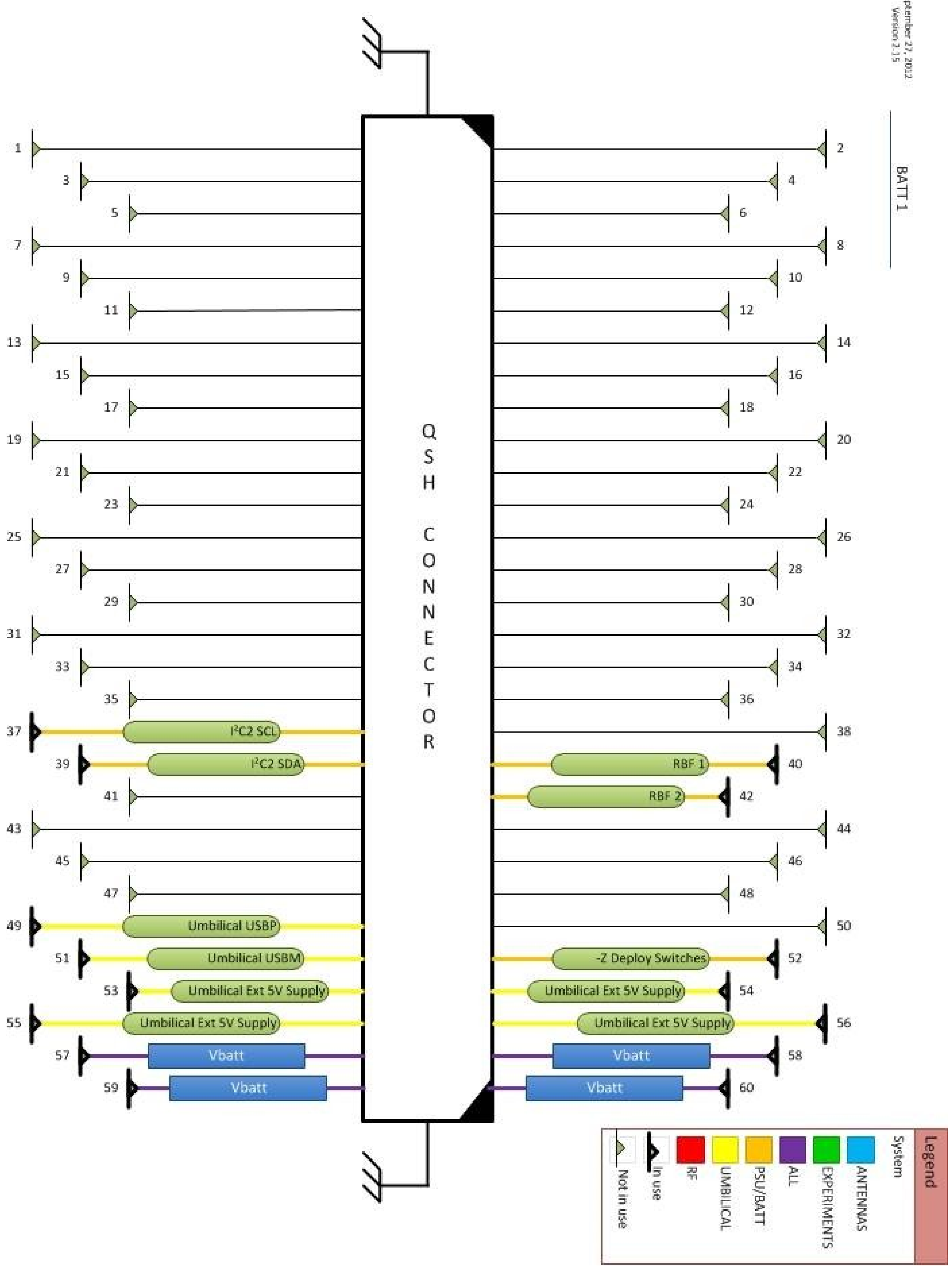


Figure 12: Battery 1 System Bus Connection Pin Assignments

7.3 Battery PCB 1 System External Connections

7.3.1 Umbilical as USB mini type B receptacle
7.3.2 Remove Before Flight as 3.5mm normally open TS jack

Table 9: Battery 1 External Connection Signal Characteristics

External Connection	Nomenclature	Type	Voltage/Power	Source System	Load Z	Bus Pin
USB 1	+5 VDC*	Analog	5 VDC	USB CONNECTOR	N/A	53, 54, 55, 56
USB 2	USB Data - (USBM)	Digital	3.0 V CMOS logic	USB CONNECTOR	N/A	51
USB 3	USB Data + (USBP)	Digital	3.0 V CMOS logic	USB CONNECTOR	N/A	49
USB 4	Ground			USB CONNECTOR	N/A	Ground Plane
RBF 1	RBF 1	Analog	N/A	3.5mm N.O. TS jack	N/A	40
RBF 2	RBF 2	Analog	N/A	3.5mm N.O. TS jack	N/A	42

*When external supply is connected to USB port

7.4 Battery PCB 2 System Bus Connections

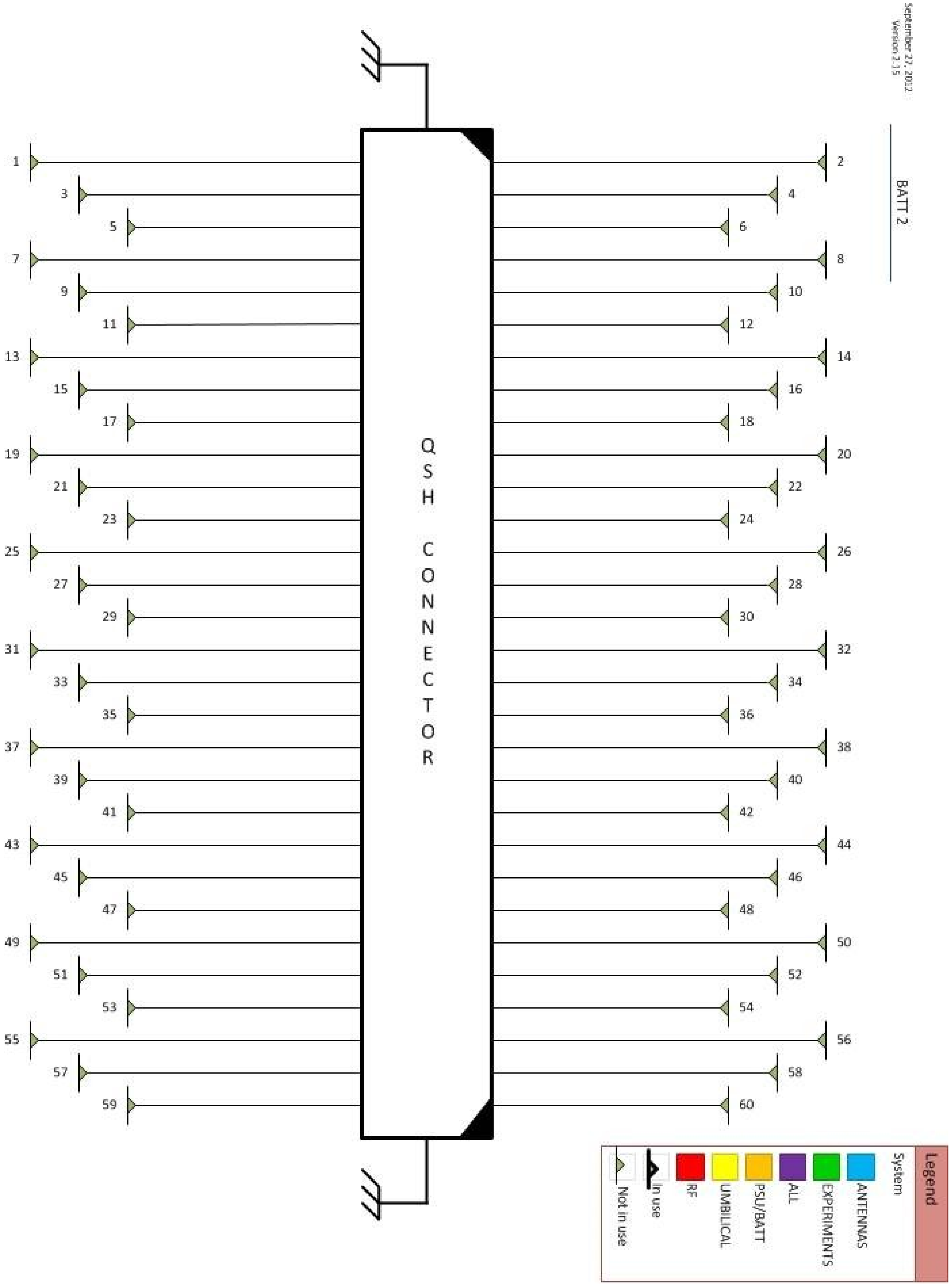


Figure 13: Battery 2 Bus Connection Pin Assignments

8 Experiment Payload Systems 1 through 4

8.1 System Requirements Applicable to Experiment Payload Systems 1-4

2.1.4 The satellite shall provide mass for an experiment payload up to 100 g.

2.1.5 The satellite shall provide volume for an experiment payload up to 95 x 95 x 15.7 mm.

2.2.1 The satellite avionics shall be designed for -40C to +70C operating temperature.

2.2.3 The satellite shall be designed to tolerate the radiation environment in orbit.

2.3.1 The satellite shall be designed for a minimum 5-year, on-orbit lifetime.

3.6.2 The satellite shall provide a means to activate and deactivate the experiment payload.

3.6.3 The satellite shall provide a means to telemeter data from the experiment payload.

8.2 Volume Requirements Applicable to Experiment Payload System 1

8.2.1 No components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall protrude from the –Z surface of the PC board.

8.2.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 6.0 mm from the +Z surface of the PC board.

8.3 Volume Requirements Applicable to Experiment Payload Systems 2 and 3

8.3.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 1 mm from the –Z surface of the PC board.

8.3.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 6.0 mm from the +Z surface of the PC board.

8.4 Volume Requirements Applicable to Experiment System 4

8.4.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 1 mm from the –Z surface of the PC board.

8.4.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 5.0 mm from the +Z surface of the PC board.

8.5 Experiment Payload 1-3 Systems PCB Bus Connections

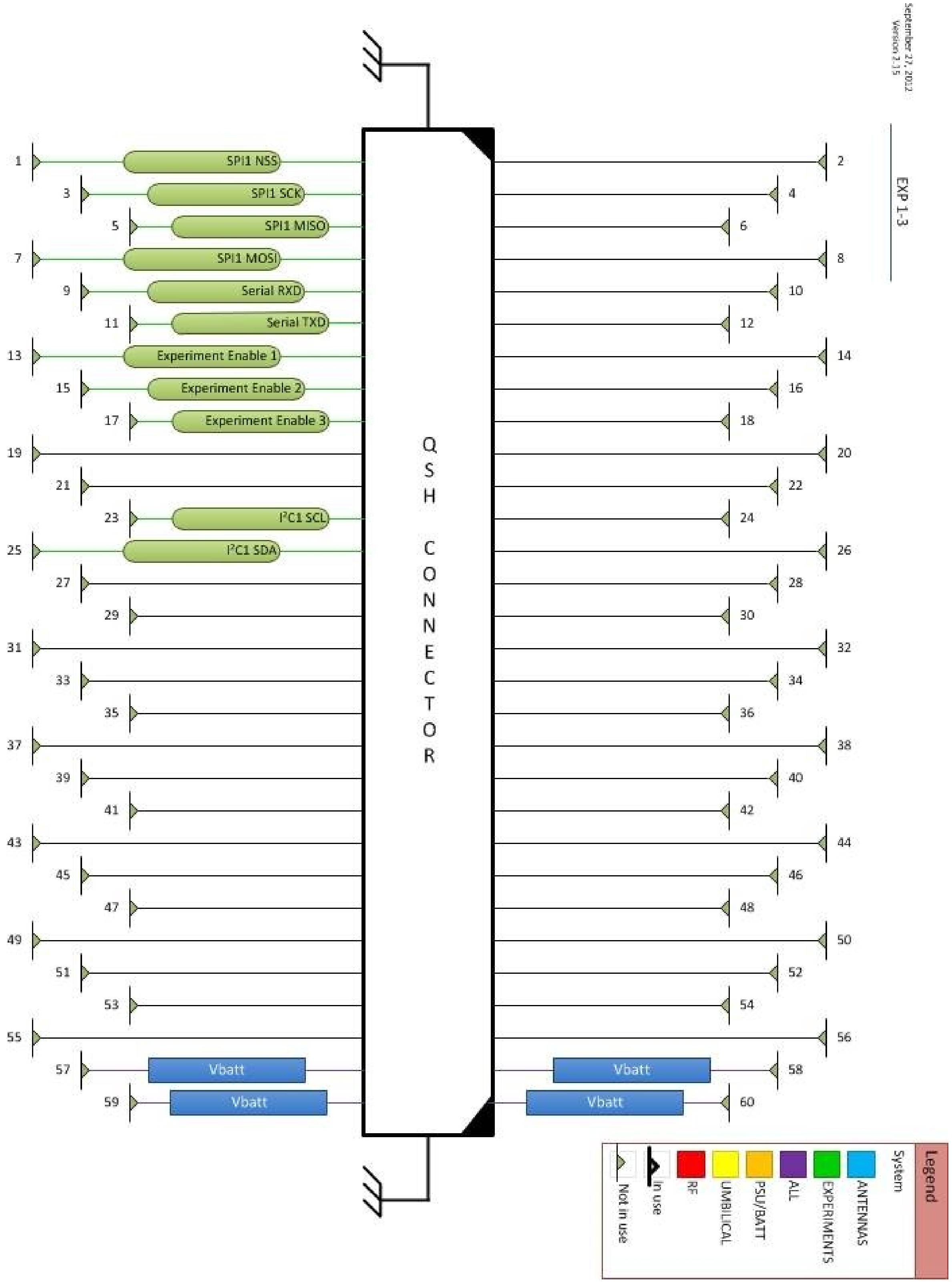


Figure 14: Experiment Payload 1-3 Systems Bus Connection Pin Assignments

8.6 Experiment Payload 4 System PCB Bus Connections

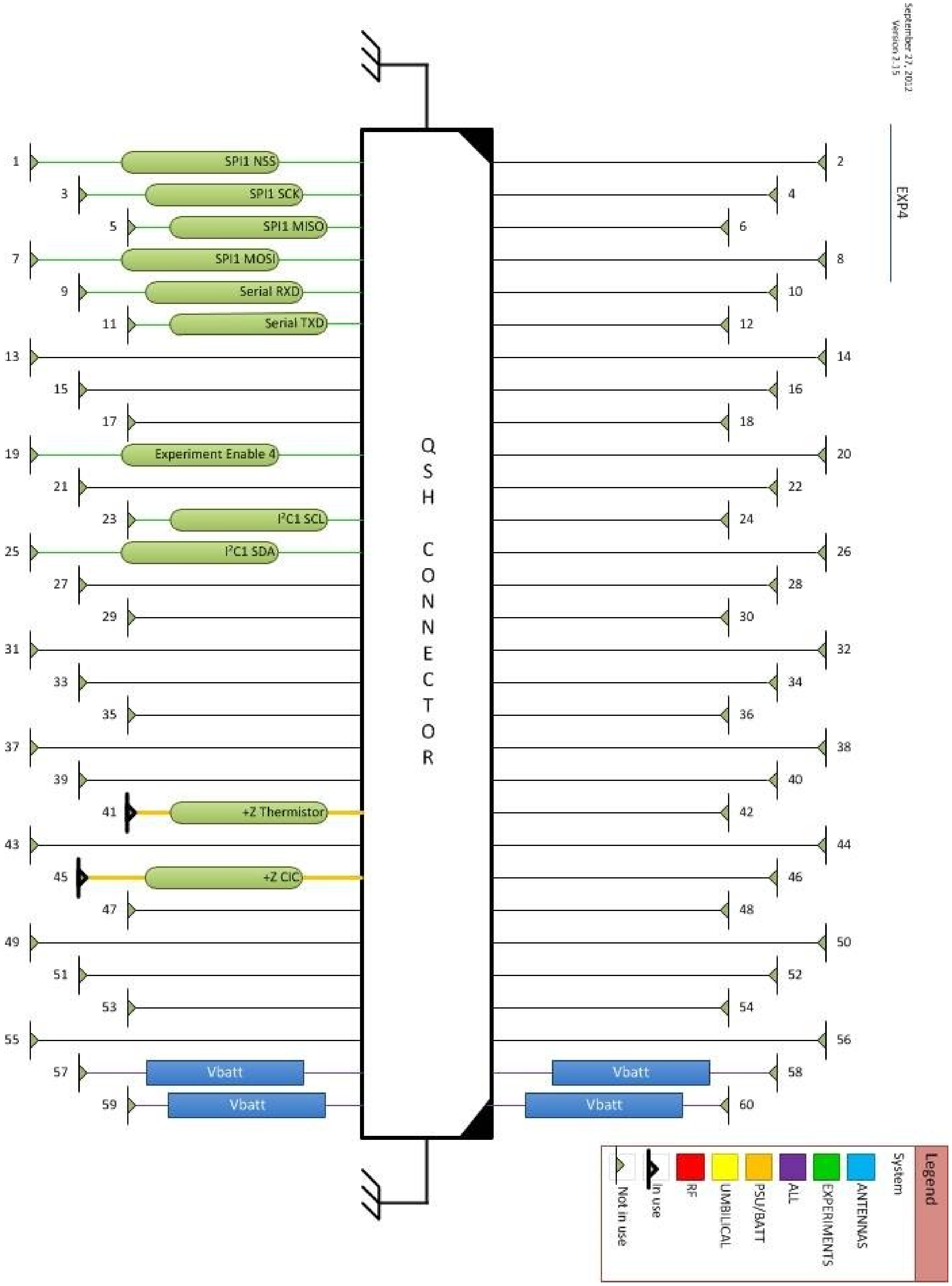


Figure 15: Experiment Payload 4 System Bus Connection Pin Assignments

8.7 Experiment Payload 4 System PCB External Connections

8.7.1 Three connections using Samtec FSI-105-06-L-S-AD connector
- **8.7.1.1** 1 contact +Z Solar Panel Thermistor
- **8.7.1.2** 1 contact +Z Solar Panel CIC +
- **8.7.1.3** 1 contact common or - for above two connections

Table 10: +Z PCB face FSI-105-06-L-S-AD connector mates to pads on +Z Solar Panel

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Load System	Bus Pin
1	+Z Thermistor	Analog	N/A	N/A	N/A	PSU	41
2	N/C						
3	+Z Solar Panel Common						Ground Plane
4	N/C						
5	+Z CIC (+)	Analog	nominal	N/A	N/A	PSU	45

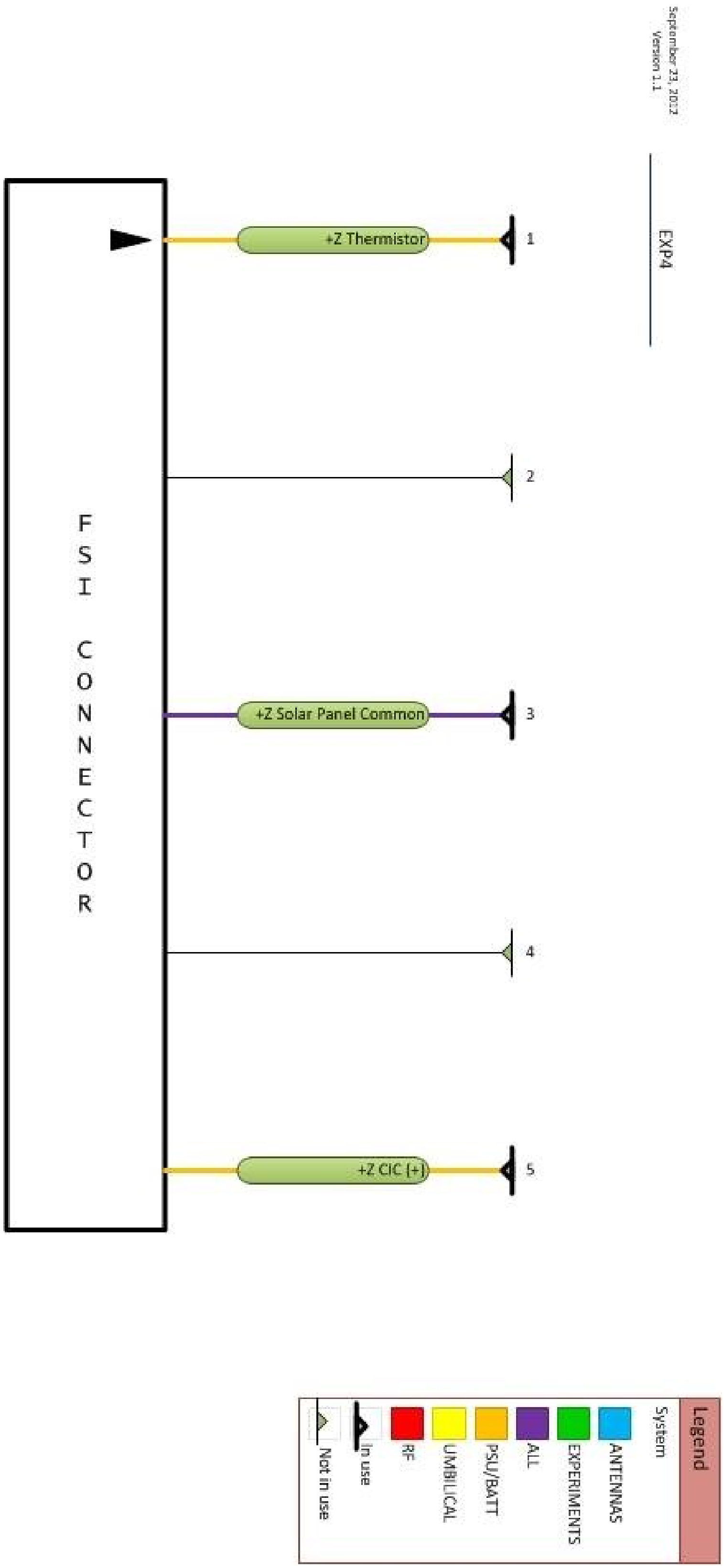
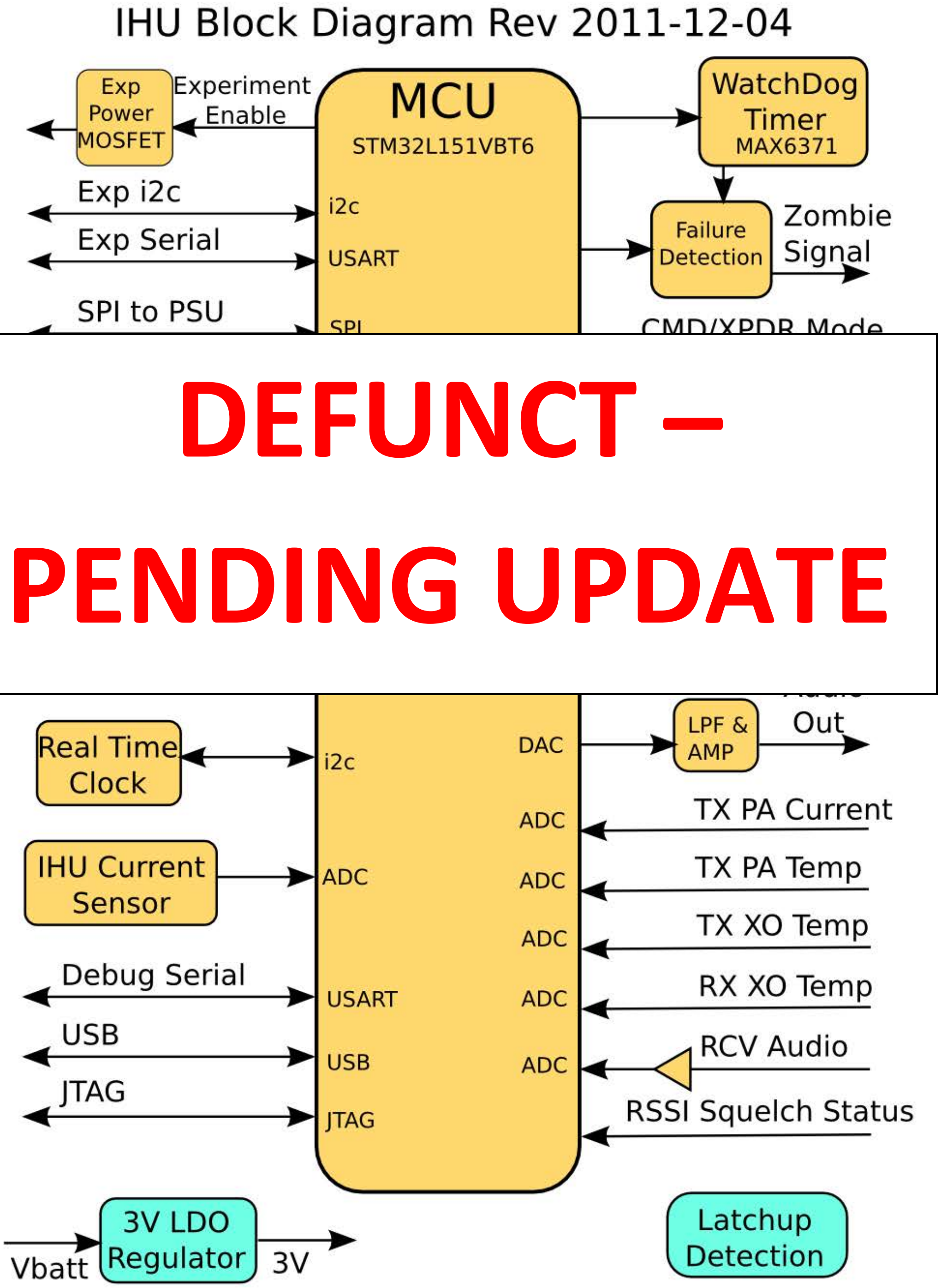


Figure 16: Experiment Payload 4 System FSI-105-06-L-S-AD Connection Pin Assignments

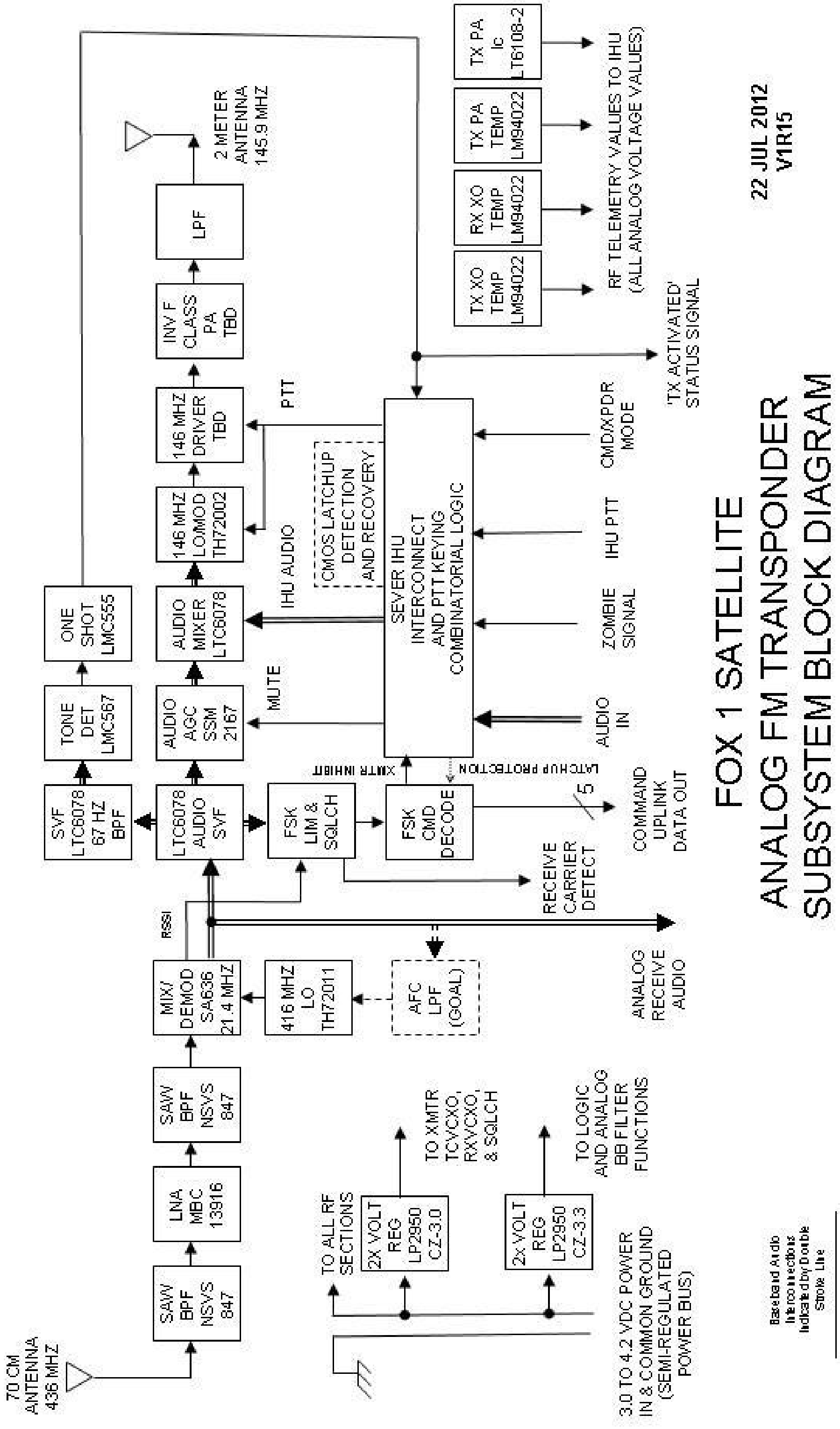
9 System Block Diagrams Reference

9.1 IHU System


IHU Block Diagram Rev 2011-12-04

DEFUNCT – PENDING UPDATE

9.2 RF System

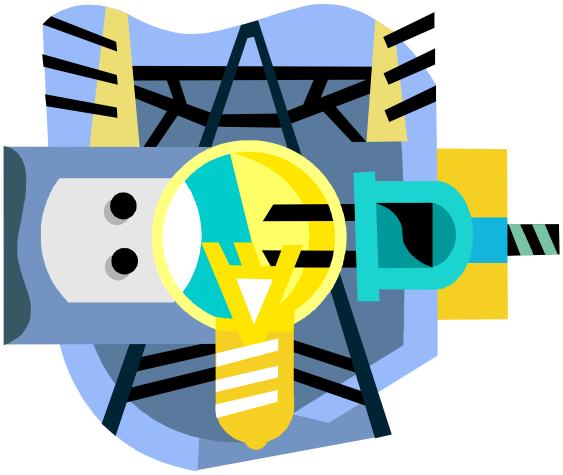


FOX 1 SATELLITE
ANALOG FM TRANSPONDER
SUBSYSTEM BLOCK DIAGRAM

22 JUL 2012
V1R15

Baseband Audio Interconnections Indicated by Double Stroke Line

9.3 PSU System (TBR)



10 System Interconnection References

10.1 Bus Connectors

10.1.1 Samtec QTH-030-02-L-D-A and QSH-030-01-L-D-A connectors
10.1.2 QTH connector shall be mounted on the +Z surface of each circuit board except the Receive Antenna PCB / GPS Payload circuit board
10.1.3 QSH connector shall be mounted on the –Z surface of each circuit board

10.2 Bus Connector Documentation

10.2.1 Samtec QSH
10.2.2 Samtec QTH
10.2.3 Samtec QxH High Speed Characterization Report
10.2.4 Samtec QxH Single Ended Channel Properties

10.3 External Connectors

10.3.1 Samtec MEC1-105-02-L-D-NP-A connector mounted on +X, -X, +Y, -Y Solar Panels
10.3.2 Samtec FSI-105-06-L-S-AD connector mounted on -Z face of RF Transmitter System PCB and +Z face of Experiment Payload 4 System PCB

10.4 External Connector Documentation

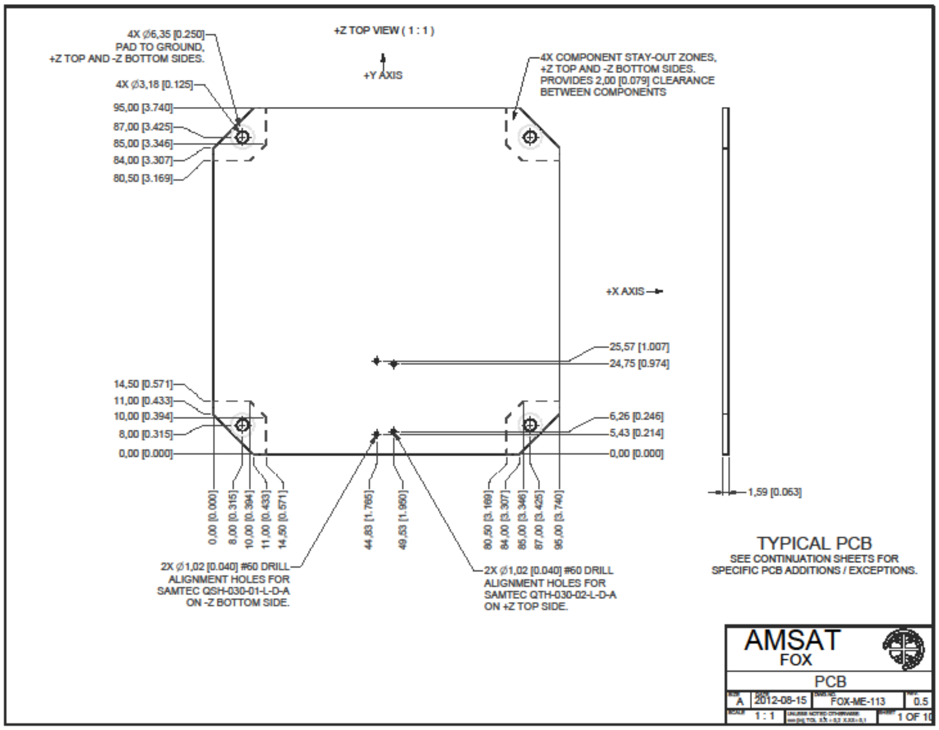
10.4.1 Samtec MEC1
10.4.2 Samtec MEC1 Qualification Testing
10.4.3 Samtec FSI

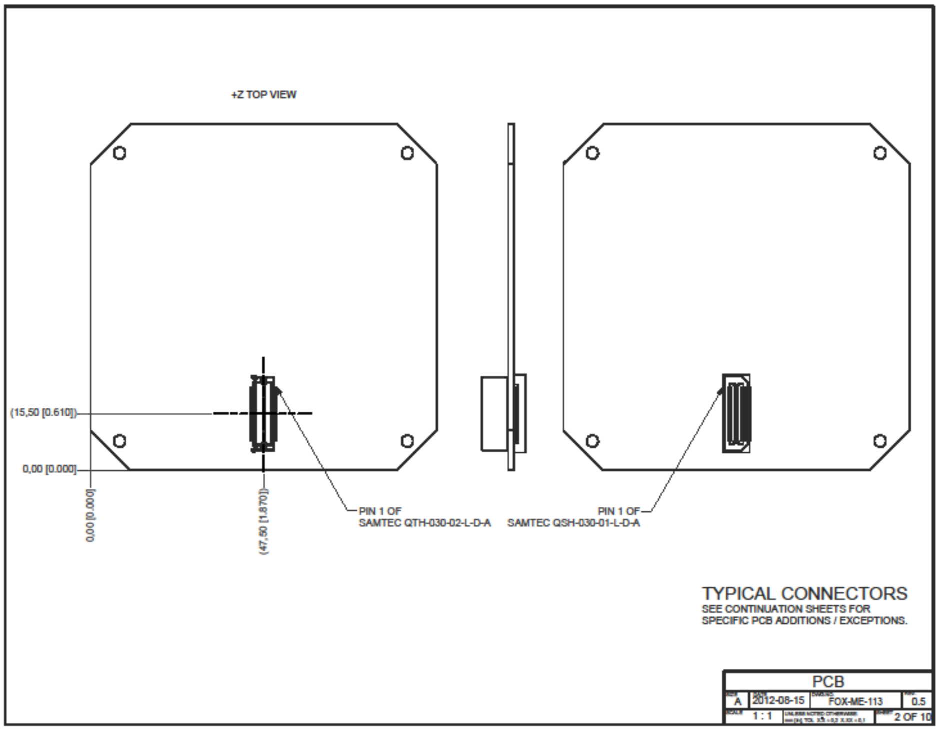
10.5 PCB Connector Layout Documentation

10.5.1 FOX-ME-113_PCB.pdf

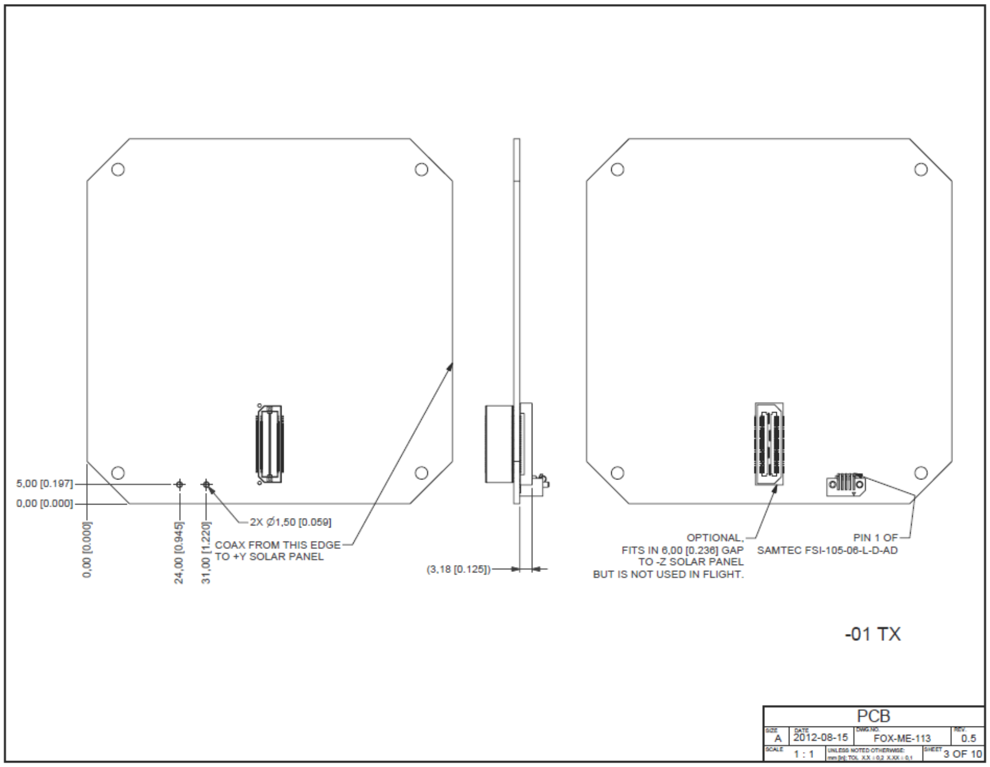
10.6 Systems PCB Connector Layout

10.6.1 Common to All Systems

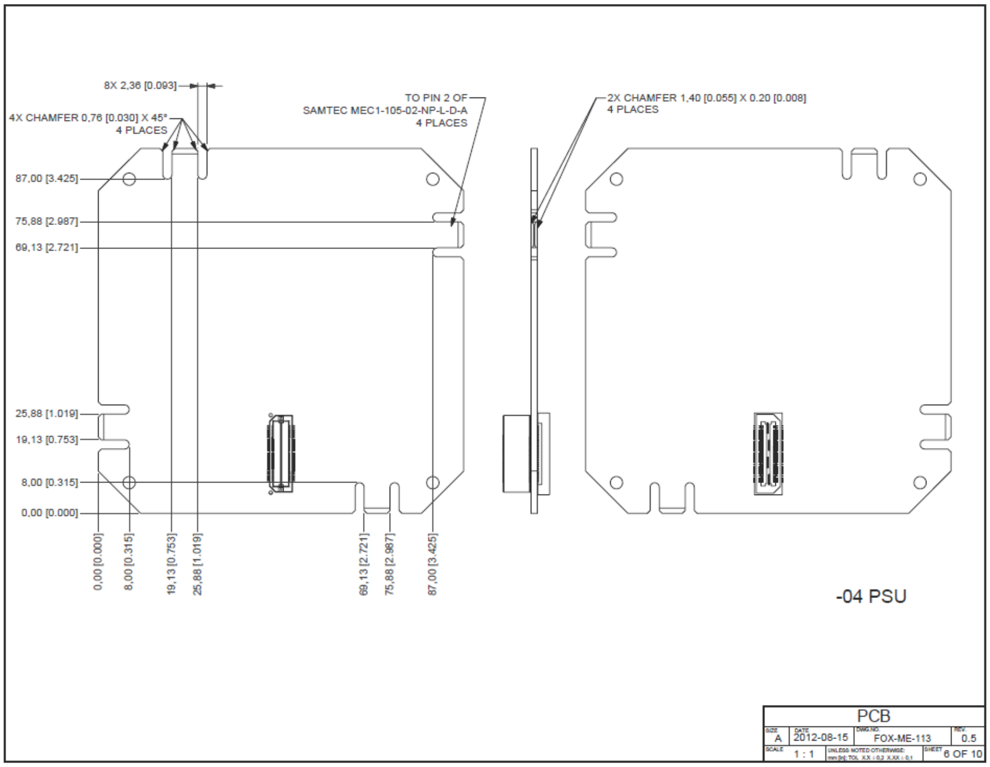




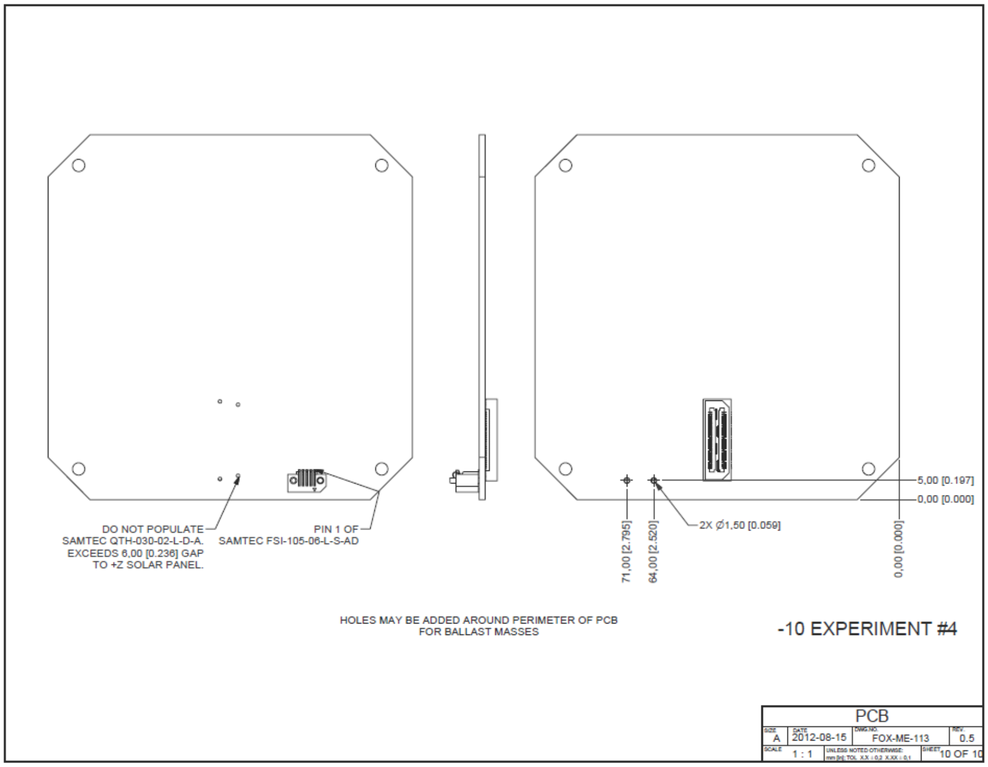
10.6.2 RF Transmitter System



10.6.3 PSU System



10.6.4 Experiment 4 System



Date: June 29, 2012
Version: 2.0

AMSAT *Fox-1*

Attitude Determination Experiment Payload System Requirements Specification

1 Introduction

This document specifies the system level technical requirements for the AMSAT *Fox-1* satellite project attitude determination experiment payload.

The *Fox*-1 satellite is a 1 Unit CubeSat with a primary mission of providing amateur radio communications. In addition to its mission as a communications satellite, *Fox-1* will host an experiment payload. The satellite will reserve mass and volume for the experiment and will provide DC power and a communications facility. The experiment is expected to be provided by students at Penn State University – Erie, through an AMSAT sponsored senior design project.

The goal of the experiment will be to measure the spin rate and direction, about the Z axis of the satellite, and any off Z-axis "wobble".

1.1 Document History

DATE	VERSION	SUMMARY
November 9, 2011	1.0	From Draft F
December 4, 2011	1.01	Fix formatting
December 23, 2011	1.03	Update references to other documents
December 27, 2011	1.04	Update 2.1.13 for QTH/QSH connectors
February 12, 2011	1.10	Change bus to SPI and add power signal Removed references to multiple PCBs and conflicting component placement Adjust PCB stay out zone and other requirements per latest mechanical revisions
June 29, 2012	2.0	Modified extensively due to move of experiment equipment to the IHU card

1.2 Document Scope

The purpose of this document is to specify the technical requirements of the experiment payload at the system (i.e. "black box") level. It is intended to be used to by the hardware, software and mechanical designers to develop the architecture/high-level design specifications. It is also intended to be used for test planning and development.

1.3 Document Format

This document provides the requirements in numbered format. Each requirement is assigned a unique number. Additional information such as comments or examples that are provided for guidance or clarity are *italicized* to distinguish them from requirements.

1.4 References

1. AMSAT *Fox-1,* Concept of Operations, Version 1.03, September 19, 2011
2. AMSAT *Fox-1*, System Requirements Specification, Version 1.1, April 29, 2012
3. AMSAT *Fox-1* IHU to Attitude Determination Experiment Interface Control Document, Version 2.0, June 29, 2012

2 General Requirements

2.1 Physical Requirements

2.1.1 The experiment payload shall be constructed on the satellite IHU system PCB.

2.2 Environmental Requirements

2.2.1 The experiment payload shall be designed for -40C to +70C operating temperature.

3 Functional Requirements

3.1 Experiment Data

3.1.1 The experiment payload shall measure the spin rate and direction about the Z axis of the satellite.

3.1.2 The experiment payload shall measure any deviation (*wobble*) of the Z axis of the satellite caused by the spin of the satellite.

3.1.3 The experiment payload data shall have an accuracy of 1 degree.

3.1.4 The experiment payload shall be able to resolve the rate of spin in the range of 0 to 50 degrees per second. The experiment payload shall be able to resolve the deviation of the Z axis (*wobble*) in the range of 0 to 50 degrees.

3.2 Satellite Interface

3.2.1 The experiment data shall be directly collected by the satellite IHU system.

3.3 Power

3.3.1 The experiment payload shall receive electrical power from the satellite battery and photovoltaic panels.

3.3.2 The electrical power voltage will be nominally DC 3.6 V.

3.3.3 The satellite IHU system will activate and deactivate the experiment payload as necessary.

3.3.4 The electrical power drawn by the experiment payload shall not exceed 200 mW.

3.4 Experiment Data

3.4.1 The IHU system shall process the experiment data for telemetry transmission†.

3.4.2 The IHU system shall sample the experiment data at a rate sufficient to provide telemetry data at least every 15 seconds.

3.4.3 The experiment payload data shall include the following measured and calculated parameters:

Parameter Name	**Description**
SPIN RATE	Rate of spin of the satellite about the Z axis, in degrees per minute
SPIN DIRECTION	Direction of spin of the satellite about the Z axis (+X or –X)
DEVIATION	Deviation (*wobble*) of +Z axis caused by satellite spin
UP TIME	Total seconds since experiment payload power-up or reset

†Note that the telemetry data frame is specified in the AMSAT Fox-1 IHU to Attitude Determination Experiment Interface Control Document.

4 External Interface Documents

To fully specify the experiment payload technical requirements, the following documents must also be provided;

1. AMSAT *Fox-1* IHU to Attitude Determination Experiment Interface Control Document

5 Summary

The *Fox-1* satellite attitude determination experiment payload will provide data on the spin and wobble of the passive-magnetically stabilized satellite. This includes the first known measurements of the wobble about the Z axis of a magnetically stabilized AMSAT satellite.

Date: September 18, 2012
Version: Version 1.91

AMSAT *Fox-1*

IHU to RF System Interface Control Document

1 Introduction

This document specifies the message interface between the Internal Housekeeping Unit (IHU) and the RF System, as required per the AMSAT *Fox-1* System Requirements Specification document.

1.1 Document History

DATE	VERSION	SUMMARY
March 24, 2012	1.0	Initial version
March 24, 2012	1.1	Add 2nd RX Audio Out section 3.4.1
March 26, 2012	1.2	Section 3.2 rename Zombie to IHU Control, rename Audio to Audio 1, Section 3.4 remove RX Audio 2, section 4 removed entirely
March 26, 2012	1.3	Many updates using input from teams
March 30, 2012	1.4	Update 3.4.1.1 to clarify that receive signal CTCSS is responsible for state
March 31, 2012	1.5	3.3.1.3 updated to read no less than 100 mS
April 24, 2012	1.6	Update impedances and voltages to match SDS
June 18, 2012	1.7	Update 3.3.1.5 per PDR change to SRS, remove RESET add IHU OFF and IHU ON commands, signal characteristic updates per PDR, 3.4.1.2 to indicate command station signal strength
September 13, 2012	1.8	Remove IHU CONTROL signal, match signal characteristics to system design specification
September 16, 2012	1.9	Changes to 3.3.1.1 and Table 4 per Tony
September 18, 2012	1.91	Removed Command Table (section 3.3) and re-stated section 3.3 requirements accordingly

1.2 Document Scope

The purpose of this document is to specify the signal types, levels, and direction for connections between the IHU and the RF System as described in the AMSAT *Fox-1* System Requirements Specification.

1.3 References

1. AMSAT *Fox-1* System Requirements Specification
2. AMSAT *Fox-1* System Design Specification
3. AMSAT *Fox-1* IHU Software Architecture Specification

2 General Requirements

2.1 Telemetry

2.1.1 RF System Telemetry values shall be conveyed as analog voltage levels sent from the RF System to the IHU System.

2.1.2 The IHU System shall convert the analog signals to digital representations.

2.1.3 Audio signals for the purpose of conveying telemetry via sub-audible audio frequencies shall be sent from the IHU System to the RF System.

2.2 RF System Control

2.2.1 Control of the RF System shall be accomplished by means of digital signals sent from the IHU System to the RF System.

2.3 Satellite System Command

2.3.1 Command data for the purpose of controlling the satellite shall be processed by the RF System and sent to the IHU System.

2.3.2 Command data shall be conveyed to the IHU via digital signals.

2.4 Operational Components

2.4.1 Demodulated baseband audio signals shall be passed from the RF System to the IHU System for processing.

2.4.2 Baseband audio signals shall be passed from the IHU System to the RF System for transmission.

2.4.3 Operational Status signals shall be conveyed as digital signals sent from the RF System to the IHU System.

2.5 Signal Transmission

2.5.1 Signals shall use the pin assignments shown in the Fox-1 System Design Specification document.

2.5.2 Signal connections shall comply with the impedance and signal type shown in the parameters for each type of signaling.

2.6 Signal Type Definitions and Levels

2.6.1 **Analog**: 0.1 – 3.5 VDC analog voltage.

2.6.2 **Digital**: 3.0 VDC logic levels.

2.6.2.1 Digital signals High State shall be ≥ 2.4 V.

2.6.2.2 Digital signals Low State shall be ≤ 0.4 V.

3 Signal Connection Requirements

3.1 Telemetry

3.1.1 The RF System shall provide raw telemetry values from the RF System components as shown in Table 1.

Table 1

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Load System	Notes
2	TX PA Current	Analog	0 - 3.0 V	TX	30 - 60 kΩ	IHU	
4	TX PA Temperature	Analog	100-2000 mV	TX	30 - 60 kΩ	IHU	Analog Devices TMP36F
6	TX Osc Temperature	Analog	100-2000 mV	TX	30 - 60 kΩ	IHU	Analog Devices TMP36F
8	RX Osc Temperature	Analog	100-2000 mV	RX	30 - 60 kΩ	IHU	Analog Devices TMP36F

3.1.1.1 The values shall be updated at a rate to provide new samples at least every 15 seconds.

3.2 RF System Control

3.2.1 The IHU System shall provide control and audio signals to the RF System as shown in Table 2.

Table 2

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Load System	Notes
12	IHU Audio 1 Out	Analog	2 V p-p audio	IHU	600 Ω, Unbalanced	TX	For 5 kHz deviation, 10 Hz - 7 kHz bandwidth
26	COMMAND Mode	Digital		IHU		TX	HIGH = Command Mode
28	IHU PTT	Digital		IHU		TX	HIGH = TRANSMIT

3.2.1.1 COMMAND Mode signal when High shall inhibit received RF audio retransmission (COMMAND MODE).

3.2.1.2 IHU PTT signal when High shall key the RF transmitter on.

3.3 Satellite System Command

3.3.1 The RF System shall provide ground station command signals to the IHU System as shown in Table 3.

Table 3

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Load System	Notes
16	RX Command Data 8	Digital		RX		IHU	
18	RX Command Data 9	Digital		RX		IHU	
20	RX Command Data 10	Digital		RX		IHU	
22	RX Command Data 11	Digital		RX		TX	
24	RX Command Strobe	Digital		RX	30 - 60 kΩ	IHU	

3.3.1.1 RX Command data shall be read on the rising edge of the RX Command Strobe signal.

3.3.1.2 Upon an RX Command Strobe rising transition the IHU System shall read the signal values RX Command Data 8, RX Command Data 9, and RX Command Data 10.

3.3.1.3 The duration of an RX Command Strobe signal High state shall be no less than 500 mS.

3.3.1.4 RX Command Data 11 shall be the most significant bit, RX Command Data 8 shall be the least significant bit.

Note that the control interface will be specified in a separate document.

3.4 Operational Components

3.4.1 The RF System shall provide operational and audio signals to the IHU System as shown in Table 4.

Table 4

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Load System	Notes
30	RX PTT	Digital		TX	30 - 60 kΩ	IHU	HIGH = HANG TIMER ACTIVE
32	RX CD	Digital		RX	30 - 60 kΩ	IHU	
34	RX Audio 1	Analog	2 V p-p audio	RX	600 Ω, Unbalanced	IHU	10 Hz - 7 kHz bandwidth

3.4.1.1 TX Active signal when High shall indicate that the transponder uplink signal CTCSS hang timer is activating the RF transmitter.

3.4.1.2 RX CD signal when High shall indicate that the RF receiver detects a signal on the uplink.

Date: August 7, 2012
Version: Version 1.03

AMSAT *Fox-1*

IHU to PSU Interface Control Document

1 Introduction

This document specifies the message interface between the Internal Housekeeping Unit (IHU) and the Power Supply (PSU) System, as required per the AMSAT *Fox-1* System Requirements Specification document.

1.1 Document History

DATE	VERSION	SUMMARY
February 21, 2012	1.0	Initial version
February 21, 2012	1.01	Clarify I^{2}C address
March 7, 2012	1.02	2.3.1 updated Vdd to 3.0V
August 7, 2012	1.03	Remove BATT1 data fields and adjust message accordingly

1.2 Document Scope

The purpose of this document is to specify the message format and the I^{2}C bus hardware operation for the communications between the IHU and the PSU as described in the AMSAT *Fox-1* System Requirements Specification.

1.3 References

1. AMSAT *Fox-1,* System Requirements Specification
2. AMSAT *Fox-1*, System Design Specification
3. AMSAT *Fox-1*, IHU Software Architecture Specification

2 General Messaging Requirements

2.1 Link Protocol Requirements

2.1.1 The IHU shall be the I²C Master.

2.1.2 The PSU shall be the I²C Slave.

2.1.2.1 The IHU shall request the PSU to send.

2.1.2.2 The PSU shall send a single telemetry data message.

2.1.3 Each telemetry data message sent by the PSU shall be preceded by a header containing the message version and the software version of the PSU.

2.1.4 Message byte order shall be Little Endian.

2.2 General Message Requirements

2.2.1 Each telemetry data message shall contain a header block, a data block, and a CRC block.

2.2.2 The PSU shall sample data at a rate sufficient to provide telemetry data to the IHU at least every 15 seconds.

2.3 I²C Bus Hardware Interface Requirements

2.3.1 The I²C Vdd shall be 3.0V.

2.3.2 The bus speed shall be Fast (400kbit/s).

2.3.3 The PSU I²C 7 bit address shall be 0x10.

3 Message Content Requirements

3.1 Message Header Block

3.1.1 The message header block shall be constructed as shown in table 1.

Table 1

Field	Size (Bytes)	Type	Value	Description
Message Version	2	Unsigned integer	Variable	Message ICD version
Software Build	2	Unsigned integer	Variable	Software Build version

3.1.1.1 The Message Version shall be an integer representing the IHU to PSU ICD document version number from which the message format is derived, having the decimal point removed (e.g. version 1.03 would be 103 decimal or 0x67).

3.1.1.2 The Software Build shall be an integer representing the software build version number of the PSU system, having the decimal point removed (e.g. version 1.03 would be 103 decimal or 0x67).

3.2 Message Data Block

3.2.1 The message data block shall be constructed as shown in Table 2.

Table 2

Field	Size (Bytes)	Type	Value	Description
DATA	28	Unsigned integers	Variable	Message data

3.2.2 The message data block shall contain the DATA fields as shown in Table 3.

Table 3

Field	Size (Bytes)	Type	Value	Description
TOTAL I	2	Unsigned integer	Variable	Total system DC current raw value
+X PANEL V	2	Unsigned integer	Variable	+X solar panel voltage raw value
-X PANEL V	2	Unsigned integer	Variable	-X solar panel voltage raw value
+Y PANEL V	2	Unsigned integer	Variable	+Y solar panel voltage raw value
-Y PANEL V	2	Unsigned integer	Variable	-Y solar panel voltage raw value
+Z PANEL V	2	Unsigned integer	Variable	+Z solar panel voltage raw value
-Z PANEL V	2	Unsigned integer	Variable	-Z solar panel voltage raw value
+X PANEL T	2	Unsigned integer	Variable	+X solar panel temperature raw value
-X PANEL T	2	Unsigned integer	Variable	-X solar panel temperature raw value
+Y PANEL T	2	Unsigned integer	Variable	+Y solar panel temperature raw value
-Y PANEL T	2	Unsigned integer	Variable	-Y solar panel temperature raw value
+Z PANEL T	2	Unsigned integer	Variable	+Z solar panel temperature raw value
- Z PANEL T	2	Unsigned integer	Variable	-Z solar panel temperature raw value
SPIN	2	Unsigned integer	Variable	Calculated spin rate

3.3 CRC Block

3.3.1 The CRC block shall be constructed as shown in Table 4.

Table 4

Field	Size (Bytes)	Type	Value	Description
CRC	1	CRC	Variable	CRC-8-CCITT

3.3.1.1 The CRC shall be CRC-18-CCITT (0x07).

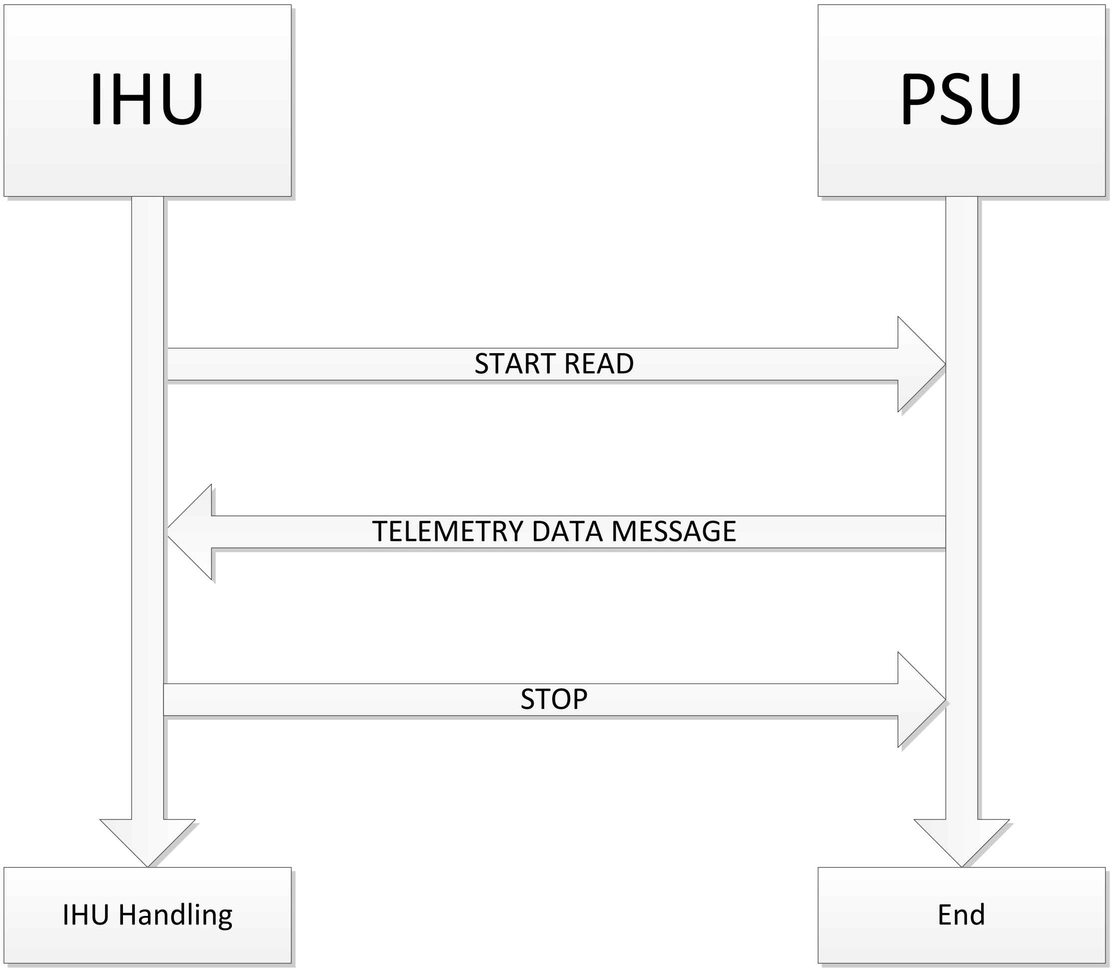
4 Message Integrity

4.1.1 If the CRC fails, the message shall be considered invalid.

4.1.2 If the Message Version does not match the message version in use for the construction of messages on the IHU system, the message shall be considered invalid.

5 Message Flow Diagrams

5.1 READ



Date: August 7, 2012
Version: Version 1.00

AMSAT *Fox-1*

IHU to Battery Interface Control Document

1 Introduction

This document specifies the message interface between the Internal Housekeeping Unit (IHU) and the Battery (BATT1) System, as required per the AMSAT *Fox-1* System Requirements Specification document.

1.1 Document History

DATE	VERSION	SUMMARY
August 7, 2012	1.00	Initial version

1.2 Document Scope

The purpose of this document is to specify the message format and the I²C bus hardware operation for the communications between the IHU and the BATT1 as described in the AMSAT *Fox-1* System Requirements Specification.

1.3 References

1. AMSAT *Fox-1,* System Requirements Specification
2. AMSAT *Fox-1*, System Design Specification
3. AMSAT *Fox-1*, IHU Software Architecture Specification

2 General Messaging Requirements

2.1 Link Protocol Requirements

2.1.1 The IHU shall be the I²C Master.

2.1.2 The BATT1 shall be the I²C Slave.

2.1.2.1 The IHU shall request the BATT1 to send.

2.1.2.2 The BATT1 shall send a single telemetry data message.

2.1.3 Each telemetry data message sent by the BATT1 shall be preceded by a header containing the message version and the software version of the BATT1.

2.1.4 Message byte order shall be Little Endian.

2.2 General Message Requirements

2.2.1 Each telemetry data message shall contain a header block, a data block, and a CRC block.

2.2.2 The BATT1 shall sample data at a rate sufficient to provide telemetry data to the IHU at least every 15 seconds.

2.3 I²C Bus Hardware Interface Requirements

2.3.1 The I²C Vdd shall be 3.0V.

2.3.2 The bus speed shall be Fast (400kbit/s).

2.3.3 The BATT1 I²C 7 bit address shall be 0x1B.

3 Message Content Requirements

3.1 Message Header Block

3.1.1 The message header block shall be constructed as shown in table 1.

Table 1

Field	Size (Bytes)	Type	Value	Description
Message Version	2	Unsigned integer	Variable	Message ICD version
Software Build	2	Unsigned integer	Variable	Software Build version

3.1.1.1 The Message Version shall be an integer representing the IHU to BATT1 ICD document version number from which the message format is derived, having the decimal point removed (e.g. version 1.03 would be 103 decimal or 0x67).

3.1.1.2 The Software Build shall be an integer representing the software build version number of the BATT1 system, having the decimal point removed (e.g. version 1.03 would be 103 decimal or 0x67).

3.2 Message Data Block

3.2.1 The message data block shall be constructed as shown in Table 2.

Table 2

Field	Size (Bytes)	Type	Value	Description
DATA	14	Unsigned integers	Variable	Message data

3.2.2 The message data block shall contain the DATA fields as shown in Table 3.

Table 3

Field	Size (Bytes)	Type	Value	Description
CELL 1 V	2	Unsigned integer	Variable	Battery cell 1 voltage raw value
CELL 2 V	2	Unsigned integer	Variable	Battery cell 2 voltage raw value
CELL 3 V	2	Unsigned integer	Variable	Battery cell 3 voltage raw value
CELL 4 V	2	Unsigned integer	Variable	Battery cell 4 voltage raw value
CELL 5 V	2	Unsigned integer	Variable	Battery cell 5 voltage raw value
CELL 6 V	2	Unsigned integer	Variable	Battery cell 6 voltage raw value
CELL T	2	Unsigned integer	Variable	Battery temperature raw value

3.3 CRC Block

3.3.1 The CRC block shall be constructed as shown in Table 4.

Table 4

Field	Size (Bytes)	Type	Value	Description
CRC	1	CRC	Variable	CRC-8-CCITT

3.3.1.1 The CRC shall be CRC-18-CCITT (0x07).

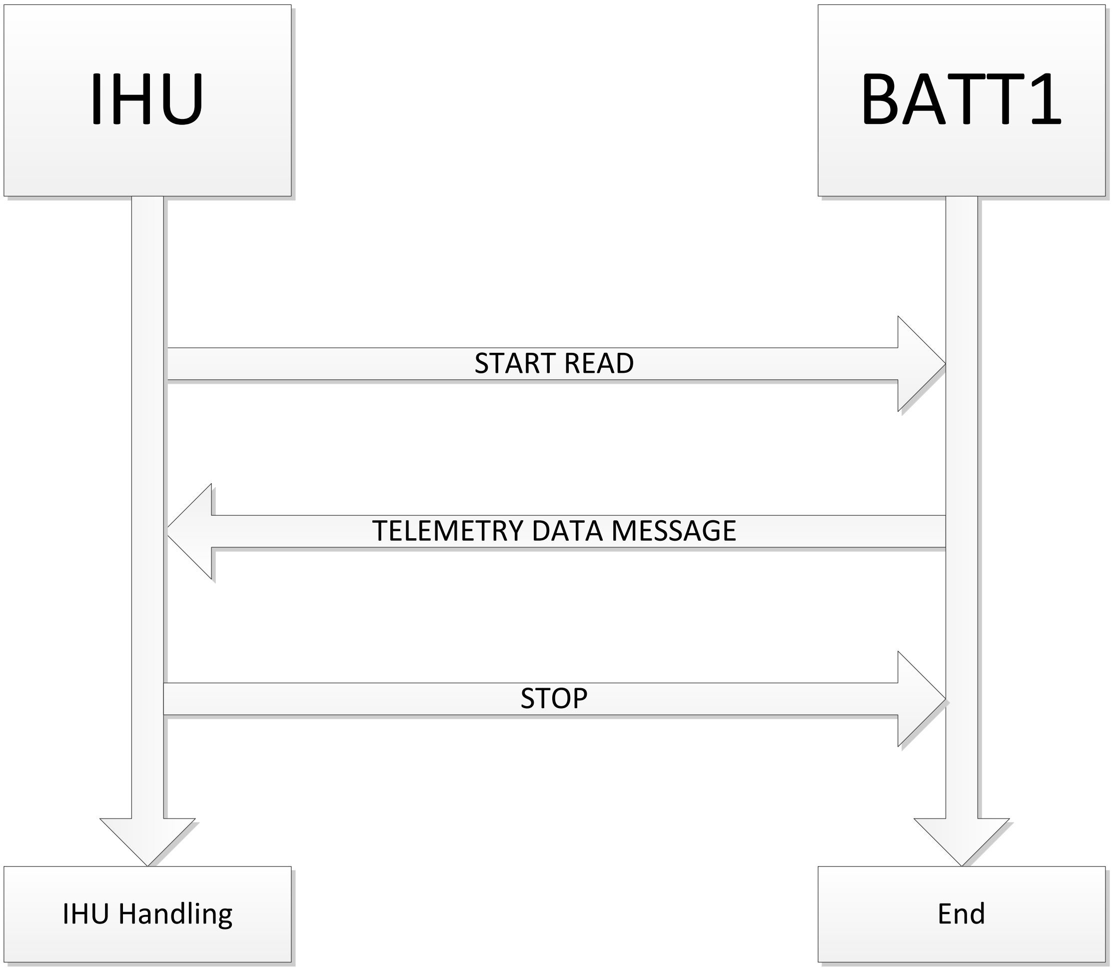
4 Message Integrity

4.1.1 If the CRC fails, the message shall be considered invalid.

4.1.2 If the Message Version does not match the message version in use for the construction of messages on the IHU system, the message shall be considered invalid.

5 Message Flow Diagrams

5.1 READ



Date: June 29, 2012
Version: Version 2.0

AMSAT *Fox-1*

IHU to Attitude Determination Experiment Interface Control Document

1 Introduction

This document specifies the message interface and the power activation interface between the Internal Housekeeping Unit (IHU) system and the Experiment Payload, as required per the AMSAT *Fox-1* Attitude Determination Experiment Payload System Requirements Specification document.

The experiment is expected to be provided by students at Penn State University – Erie through an AMSAT sponsored senior design project.

1.1 Document History

DATE	VERSION	SUMMARY
February 12, 2012	1.0	From Draft and now SPI
February 15, 2012	1.01	Add SPI Bus Hardware Interface Requirements Change to DATA block types and values
February 20, 2012	1.02	Add SPI framing and CRC polynomial
February 20, 2012	1.03	Requirements Tracking Changes
February 21, 2012	1.04	Deviation corrected from 90 to 50 per Experiment System Requirement 3.1.5
February 26, 2012	1.05	Corrected description of SPIN RATE field in Table 6 to read seconds instead of minutes
March 7, 2012	1.06	Change 6.1.1.1 high state signal to ≥2.4V
April 5. 2012	1.07	Add new DATA field MEMS GYRO STATUS
April 9, 2012	1.08	Added requirement 2.2.4
April 11, 2012	1.1	Add bits to MEMS GYRO STATUS
April 24, 2012	1.11	Set logic level Low as ≤0.2V in 6.1.1.2
June 29, 2012	2.0	Modified extensively due to move of experiment equipment to the IHU card

1.2 Document Scope

The purpose of this document is to specify the data format for the communications between the Attitude Determination Experiment and the IHU system, as described in the

AMSAT *Fox-1* Attitude Determination Experiment Payload System Requirements Specification.

1.3 References

1. AMSAT *Fox-1* System Requirements Specification, Version 1.1, April 29, 2012
2. AMSAT *Fox-1* Experiment Payload System Requirements Specification, Version 2.0, June 29, 2012
3. AMSAT *Fox-1* IHU Software Architecture Specification, Draft E, January 19, 2012

2 Telemetry Content Requirements

2.1 Telemetry Data Block

2.1.1 The telemetry data block shall contain the data fields as shown in Table 1.

Table 1

Field	Size (Bytes)	Type	Value	Description
SPIN RATE	2	Signed integer	Variable -50 to +50	Rate of spin of the satellite about the Z axis, in degrees per second. Negative indicates -X spin direction, positive indicates +X spin direction.
DEVIATION	2	Unsigned integer	Variable 0 to +50	Deviation (wobble) of Z axis in degrees.
UP TIME	2	Unsigned integer	Variable 0 to 65535	Total seconds since experiment payload power-up or reset

Date: January 19, 2012
Version: *draft E*

AMSAT *Fox-1*

IHU Software Architecture Specification

1 Introduction

This document specifies the software architecture design for the IHU of the AMSAT Fox-1 satellite.

1.1 Document History

DATE	VERSION	SUMMARY

1.2 Document Notes

Procedures are described in this document using a "C-like" *psuedocode* syntax. This is intended to be a high-level description of the procedures and not compilable code.

1.3 References

1. AMSAT *Fox-1,* Concept of Operations, Version 1.03, OCT 19, 2011
2. AMSAT *Fox-1,* System Requirements Specification, Version 1.03, OCT 23, 2011

2 Interfaces

This section specifies the signals and information elements that interface with the IHU software. This document provides the high-level semantics. An interface specification is expected to be produced for each of these that provides the detailed syntax, bit patterns, timing, levels etc. required to run the interfaces.

2.1 PSU Telemetry

These data elements come from the PSU via an I2C interface

Name	Number of parameters
Battery Cell Volts	6
Solar Panel Volts	6
Solar Panel Temperature	6
Battery Temperature	1
Avionics Current	1
Calculated Spin rate	1

2.2 IHU Telemetry

This is the telemetry information from the IHU card. It comes directly from the STM3 CPU itself.

Name	Type	Description
CPU Temp	A/D	STM3 temperature

2.3 RF Telemetry

These are the telemetry elements from the RF card. They are sensed via analog levels that are sent to the A/D converter channels on the CPU.

Name	Type	Description
PA Current	A/D	Tx Power Amplifier Current
PA Temp	A/D	Tx Power Amp Temperature
Rx Osc Temp	A/D	Rx Oscillator Temperature
Tx Osc Temp	A/D	Tx Oscillator Temperature

2.4 RF Downlink

These are the signals needed to operate the RF downlink. These are via GPIO leads and D/A channels.

Name	**Type**	**Description**
Tx Active	input	TRUE if 2-min CTCSS timer is active
RF Mode	output	Selects command or transponder mode
PTT	output	Turns on transmitter if not already on
Tx Narrow	D/A output	Low-bit-rate PCM samples to transmit
Tx Wide	D/A output	High-bit-rate PCM samples to transmit

2.5 RF Uplink

These are the signals from RF uplink. These are via GPIO leads and an A/D channel on the CPU. There is a hardware command decoder on the RF card and the decoded commands are sent digitally to the IHU card on the GPIO leads. The carrier detect (Rx CD) and received audio samples (Rx Audio) are not used on the initial Fox-1 mission.

Name	**Type**	**Description**
Rx CD	input	ON if Receiver has carrier - NOT USED
Rx Audio	A/D	Receiver audio samples - NOT USED
Rx CMD	input	Received command - 4-bits plus strobe

These are the received command values:

Bit Pattern	**Command**
1xxx	Tx Inhibit - done in HW
0000	Reset - done in HW
0001	Test
0010	Clear stored min/max telemetry values
0011	Transponder Mode
0100	Command Mode
0101	- Reserved -
0110	- Reserved -
0111	- Reserved -

2.6 Antenna System

These are GPIO leads. The antenna system has an active primary deployment mechanism and a passive backup mechanism. The primary is under control of the IHU software. The secondary mechanism uses UV radiation from the sun to deploy the antennas in the event of a failure of the primary mechanism. The backup mechanism may take some time (i.e. several weeks or months) to deploy the antennas should the primary fail. Therefore, the IHU software must always test the deployment status of the antenna system before activating the RF transmitter PTT. This is to prevent inadvertent damage to the RF transmitter if waiting for the secondary mechanism to deploy the antennas.

Since the antenna deployment mechanism has not yet been designed, information about the precise sequencing and operation of these signals is unknown at this time.

Name	**Type**	**Description**
Antenna Deployed	input	TRUE if Antennas are deployed
Deploy Antenna1	output	Turning ON deploys antenna 1
Deploy Antenna2	output	Turning ON deploys antenna 2

2.7 Zombie Detector

The Zombie detector is an external hardware device that checks the cpu for *sanity* and radiation-induced, CMOS latch-up conditions. The IHU software must pulse the Alive (GPIO) lead at least once per second. Failure to do this for any reason will cause the IHU to be power-cycled.

Name	**Type**	**Description**
Alive	output	Pulse resets Zombie timer

2.8 GPS Receiver

Power is controlled via a GPIO lead. Data is via a serial (UART) port: 4800 bps, 8 data bits, no parity bit, one stop bit. Uses National Marine Electronics Recommended Minimum Sentence C format. *The actual availability of the GPS receiver for the Fox-1 mission is currently unknown.*

Name	**Type**	**Description**
GPS Power	output	controls power to GPS receiver
GPS Data	UART	time, longitude, latitude and altitude

2.9 Experiment

This is the interface to the experiment subsystem. Power is controlled via a GPIO lead. Data is via an SPI port.

Name	**Type**	**Description**
Spin Rate	input	satellite spin rate and direction (signed)
Wobble	input	satellite maximum deviation angle from axis
EXP Power	output	controls power to experiment

2.10 Umbilical Port

The umbilical port is functionally a USB port. Unlike a standard USB port, the satellite batteries can be charged directly from the +5 lead on the USB connector. Since battery charging may require in excess of the standard USB current capability, a special power adapter will be used when charging the batteries so the port will appear as a self-powered device. To the USB host, the satellite will look like a COM port and will allow use of the standard host USB COM driver. The intention is that the satellite can be easily used with common terminal emulation programs such as PuTTY.

The Umbilical port is required for system test activities and during launch integration. It is also available for general use in software development. Additional commands can be added as needed. The only limitation is that there must not be any capability from this port to directly activate the transmitter PTT without first testing to insure that the antennas have been deployed as this could accidentally damage the satellite.

The following commands are the minimal set that is required.

2.10.1 Umbilical Port Display Functions

1. Display Telemetry Data
2. Display Experiment Data
3. Display Satellite Mode (command or transponder mode)
4. Display RF Status (Tx active)
5. Display Antenna Status (antennas deployed or not)
6. Display Up Time
7. Display Reset Count
8. Display Software Version
9. Display CPU available

2.10.2 Umbilical Port Control Functions

1. Load the CPU Program (FLASH) Memory
2. Clear Telemetry Min/Max data
3. Clear Reset Count
4. Clear non-volatile memory error count
5. Transponder Mode
6. Command Mode
7. Send Test Message
8. Reset CPU (let Zombie detector fire)
9. Force Antenna Deployment - must be a multi-step command (i.e. always ask "Are you sure?" !!!)

2.11 Non-volatile Memory

Certain satellite data is stored in non-volatile memory so that it will survive through a CPU reset. This data needs to be protected to reduce the bit errors due to space radiation. The protection must be at least double error detecting and single error correcting. The data stored is as follows:

1. Telemetry Min/Max values
2. Experiment Data
3. CPU Reset count
4. Running total of non-volatile memory error count (reported in telemetry)

2.12 Debug Port

This is a serial port available for SW development use. It is not needed or used for the mission. It is expected that a call to a debug "printf()" would direct the output string to the debug port. It is expected this port would use asynchronous ASCII 8 Data bits, no parity, 1 stop bit, 19.2 k bps. As an alternative, the Umbilical port could be enhanced to display software debug messages rather than use a dedicated serial port. This port could be used for a debugger such as GDB if desired.

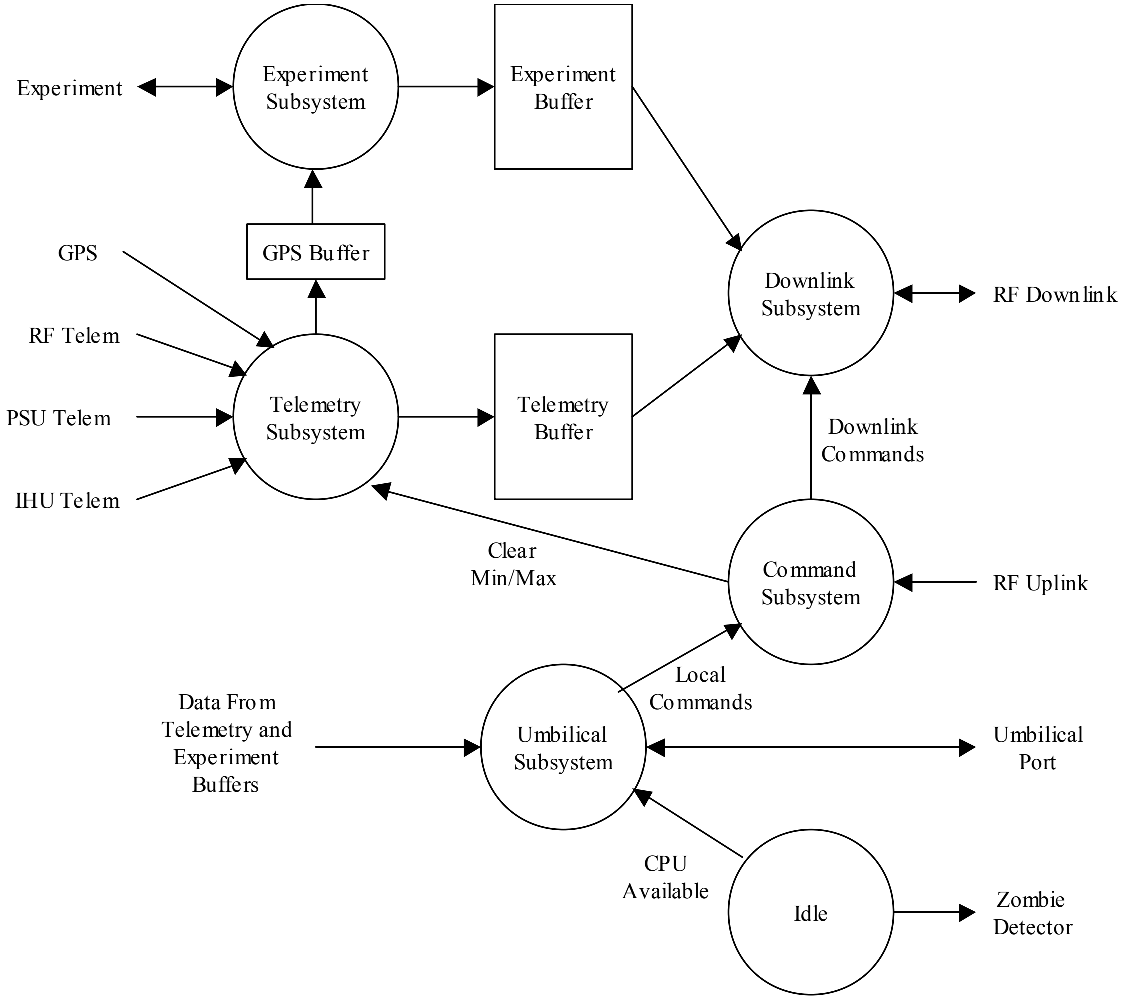
3 IHU Start Up Sequence

This is the sequence of events after a CPU reset.

```
// Run Power On Self Test (POST)
// Max duration must be less than one second or pulse the Zombie detector
// Check the program FLASH and run some kind of CPU test - at the very
// least, test the CPU internal RAM.

calculate checksum on program FLASH;
compare with stored value;
if (no match) {
        halt and let Zombie detector fire;
}

check CPU;
if (CPU failed) {
        halt and let Zombie detector fire;
}

// POST passed. See if we need to deploy the antennas.
if ( (Umbilical Port is NOT active) AND (Antennas are NOT Deployed) ) {
        wait here 45 minutes while pulsing Zombie detector;
        Activate antenna deployment mechanism;
}

increment Reset Count in Non-Volatile Memory;

boot up system;

done;
```

4 Software Architecture

This shows the applications software subsystems and their interfaces after the start up sequence has been executed (i.e. after system boot up.) The required functionality of each subsystem is specified in this section.



4.1 Telemetry Subsystem

This module is responsible for collecting all of the telemetry and GPS information from all of the interfaces, doing the Min/Max telemetry processing and providing the data in the Telemetry Buffer.

4.1.1 Telemetry Buffer Data

```
Telemetry Data = {
        CPU Up Time;
        CPU Reset Count;
        GPS Time;
        GPS Location;
        NV memory error count;
        Current Telemetry Values { PSU, IHU, RF }
        Min/Max Values;
}
```

4.1.2 Telemetry Processing

```
Do this every 15 seconds;

Get all telemetry parameters from interfaces;
Get GPS data and save in GPS buffer;

// Do MinMax processing
Read Min/Max Data from non-volatile memory;
if  (Clear Min/Max command was received) {
        set Min/Max data to current telemetry values;
}
else {
        update Min/Max data using current values;
}
Write new Min/Max data to non-volatile memory;

Get Up Time;
Get Reset Count;
Update data in Telemetry Buffer;
done;
```

4.2 Experiment Subsystem

The Experiment Subsystem is responsible for running the experiment, collecting the data, and updating the Experiment Buffer. The functionality of this subsystem depends directly on the experiment requirements and will likely be different for each the *Fox-1* type satellites.

The initial *Fox-1* satellite mission will fly the Penn State Attitude Determination Experiment. The required operation of this experiment is as follows. Once per day, the experiment is activated. Experiment data is sampled by the IHU every 3 minutes for one complete orbit. The orbit period will be approximately 100 minutes and a total of 34 data samples will be collected. If the experiment successfully runs to completion, the new experiment data is saved in non-volatile memory and the Experiment Buffer is updated with the latest values. In between experiment runs, the Experiment Buffer shall contain the data from the last successful experiment run or all 0's if it has not been run yet.

Note that the above description and following procedure is predicated on the assumption that the power system can provide enough power to run the experiment in both command and transponder mode. Based on current satellite bus and experiment power estimates, this is the case but should the situation change, this procedure may need to be modified.

4.2.1 Experiment Buffer Data

```
// This is the contents of each experiment data record
type Experiment Record = {
        Spin Rate;
        Wobble Angle;
        GPS Location;
};

// This is the data stored in the Experiment Buffer
Experiment Data = {
        CPU Up Time;
        CPU Reset Count;
        GPS Time;
        Experiment Record[34];
}
```

4.2.2 Experiment Processing

```
Do this once at initialization {
        Get saved Experiment Data from non-volatile memory;
        if (data is valid) {
                copy data to Experiment Buffer;
        }
        else {
                clear Experiment Buffer;
        }
}

Do this {
        Wait 24 hours;
        Power up experiment;
        Get CPU Up Time;
        Get CPU Reset Count;
        Get GPS Time from GPS Buffer;
        Save to a local data structure;         // Note: not in non-volatile memory!

        Do this every 3 minutes for 34 times{
                Get data from experiment;
                Get GPS location from GPS Buffer;
                Save in a local experiment record;
        }

        Power OFF experiment;
        Copy saved local experiment data to non-volatile memory;
        Update Experiment Buffer with saved local experiment data;
}

done;
```

4.3 Command Subsystem

This subsystem is responsible for handling demodulation, decoding and execution of commands sent from a ground control station via the RF uplink or from a local user via the Umbilical port. For the initial *Fox-1* mission, only the commands decoded in hardware on the RF card are needed so no additional software demodulation and decoding is necessary. This capability is reserved for use in future missions.

The Command Subsystem is responsible for controlling the satellite mode. Most commands are handled by just sending a message to the appropriate subsystem. However, if the satellite is in Command Mode, it must automatically switch to Transponder mode after 24 hours unless a new Command Mode command has been received.

4.3.1 Command Subsystem Processing

```
Do this continuously {
        Monitor RF Uplink interface and Umbilical Subsystem for a new command;

        if (Clear MinMax command is received) {
                send clear telemetry message to Telemetry Subsystem;
        }
        else {  // for. all other commands
                send corresponding message to Downlink Subsystem;
        }

        if (command was Command Mode) {
                Start or re-start the 24 hour timer;
        }
        if (received command was Transponder Mode) {
                Stop the 24 hour timer;
        }

        if (24 hour timer expires) {
                send transponder mode message to Downlink Subsystem;
        }
}

done;
```

4.4 Downlink Subsystem

This subsystem is responsible for generating all of the downlink signals from the IHU. This includes telemetry and experiment data frames and CW messages.

To create a data frame, the Downlink Process will add framing information such as a satellite identifier, a data type field and frame number. The frame will have forward error correction and interleaving (FEC) added and the resulting bits will be used to generate the modulation waveform. The data format, framing, FEC and modulation details will be specified in the Telemetry Interface document.

The Downlink Subsystem has 2 modes of operation; transponder mode and command mode. These are controlled by messages from the Command Subsystem. The Downlink Subsystem starts up in transponder mode.

In transponder mode, the data frames are sent continuously as long as the RF transmitter is active. Data frames are sent at the low bit rate (~100 bps) to the RF card using the Tx Narrow (narrow band) D/A channel. Telemetry and experiment frames are multiplexed at a 5:1 ratio (i.e. 5 telemetry sent for each experiment frame.) If the RF transmitter is inactive for 5 minutes, a CW Beacon message is sent to the RF card using the Tx Wide (wide band) D/A channel. This continues every 5 minutes as long as the RF transmitter is otherwise inactive.

In command mode, the RF transmitter is power-cycled at a 50% duty cycle to save power. Approximately every 20 seconds, the transmitter is activated and the CW beacon message is transmitted followed by one telemetry frame and one experiment frame. Data frames are sent at the high bit rate (~10k bps.) The CW and data frames are sent to the RF card using the Tx Wide (wide band) D/A channel.

In either mode, if a TEST command is received from the uplink subsystem, the IHU will send the CW Test message and then revert to the prior mode operation.

As noted previously (see section 2.6 Antenna System,) it is essential that the IHU software refrain from activating the RF transmitter if the antennas have not been deployed. The IHU software will be needed for the launch integration activities while the satellite is inside the P-POD. Turning on the RF transmitter inside the P-POD could cause irreparable damage to the satellite. Similarly, should the primary antenna deployment mechanism fail for whatever reason, the satellite must not activate the RF transmitter until the backup (passive) mechanism has deployed the antennas.

4.4.1 Downlink Subsystem Processing

```
At initialization, enter Transponder Mode;
Continuously monitor interface to Uplink Subsystem for a command message;

In Transponder Mode {
    Put RF card in transponder mode;
    While (Tx Active) {
        Send 5 Telemetry frames at low data rate;
        Send 1 Experiment frame at low data rate;
    }
    While (NOT Tx Active) {
        start 5 minute timer;
        if (timer expires before Tx Active) {
            if (Antennas Deployed) {
                Put RF card in Command mode;
                Turn on PTT;
                Send CW beacon message;
                Send 1 Telemetry frame at high data rate;
                Send 1 Experiment frame at high data rate;
                Turn off PTT;
                Put RF card in Transponder mode;
            }
        }
    }
}

In Command Mode {
    Put RF card in command mode;
    Do this every 20 seconds {          // Set time to for 50% RF Tx duty cycle
        if (Antennas Deployed) {
            Turn on PTT;
            Send CW beacon message;
            Send 1 Telemetry frame at high data rate;
            Send 1 Experiment frame at high data rate;
            turn off PTT;
        }
    }
}
```

```
// Downlink Subsystem Processing continued

In either mode {
        if (TEST command is received) {
                save current downlink mode;
                if (Antennas Deployed) {
                        Put RF card in Command mode;
                        Turn on PTT;
                        Send CW TEST message;
                        Turn off PTT;
                        Go back to previous downlink mode;
                }
        }
}
done;
```

4.5 Umbilical Subsystem

This implements a local user interface on the satellite. This is expected to be used for system testing and launch integration activities. The Umbilical Subsystem implements the commands that are specified in the Umbilical Port section of this document (section 2.1 Umbilical Port.) It is also available for software development use. This subsystem is not used in orbit.

4.6 Idle Subsystem

This subsystem handles the Zombie Detector and calculates the average available CPU. It is intended that this Subsystem will run only when no other Subsystem has anything to do. The Zombie detector is intended to detect transient CPU failures due to radiation events that cause a system lockup. The Zombie Detector must not be serviced via an interrupt as this could defeat the lockup protection.

5 System Considerations

5.1 Physical Device Drivers

This software is needed to access and control the IHU hardware.

1. I^2C
2. SPI
3. UART
4. A/D converter channels
5. D/A converter channels
6. GPIO inputs
7. GPIO outputs

5.2 Logical Device Drivers

This is the software needed to support the IHU interfaces. They may make use of one or more underlying hardware drivers and provide the logical interfaces for the applications software.

1. PSU Telemetry
2. IHU Telemetry
3. RF Telemetry
4. RF Downlink
5. RF Uplink
6. Antenna System
7. Zombie Detector
8. GPS Receiver
9. Experiment
10. Umbilical Port
11. Non-volatile (EDAC) Memory
12. Debug Port (i.e. "printf()" facility)

5.3 Operating System

The IHU software will use the free version of the FreeRTOS operating system.

5.3.1 OS Task List and Priorities

5.3.2 Inter-Task Communications

5.4 Performance Requirements

The Downlink Tx Audio D/A converters have hard real-time requirements. DMA should be considered to offload the CPU for these interfaces.

5.5 CPU and Memory Constraints

Max CPU is 32 MHz.
Max RAM is 32K Bytes
Program FLASH is 128K bytes

5.6 Operational Constraints

System is intended to run on orbit but must also be able to run inside the P-Pod to support the launch integration activities. Inside the P-POD, the antennas MUST NOT be deployed automatically and the RF transmitter MUST NOT be activated!

5.7 Modularity and Maintainability

The experiment will likely be changed for each future *Fox-1* type satellite mission. The experiment processing software needs to be modularized so it is easy to change. New experiments may have different up link and downlink requirements.

6 External Interface Specifications

Although not part of this document, detailed specifications are needed for each external interface:

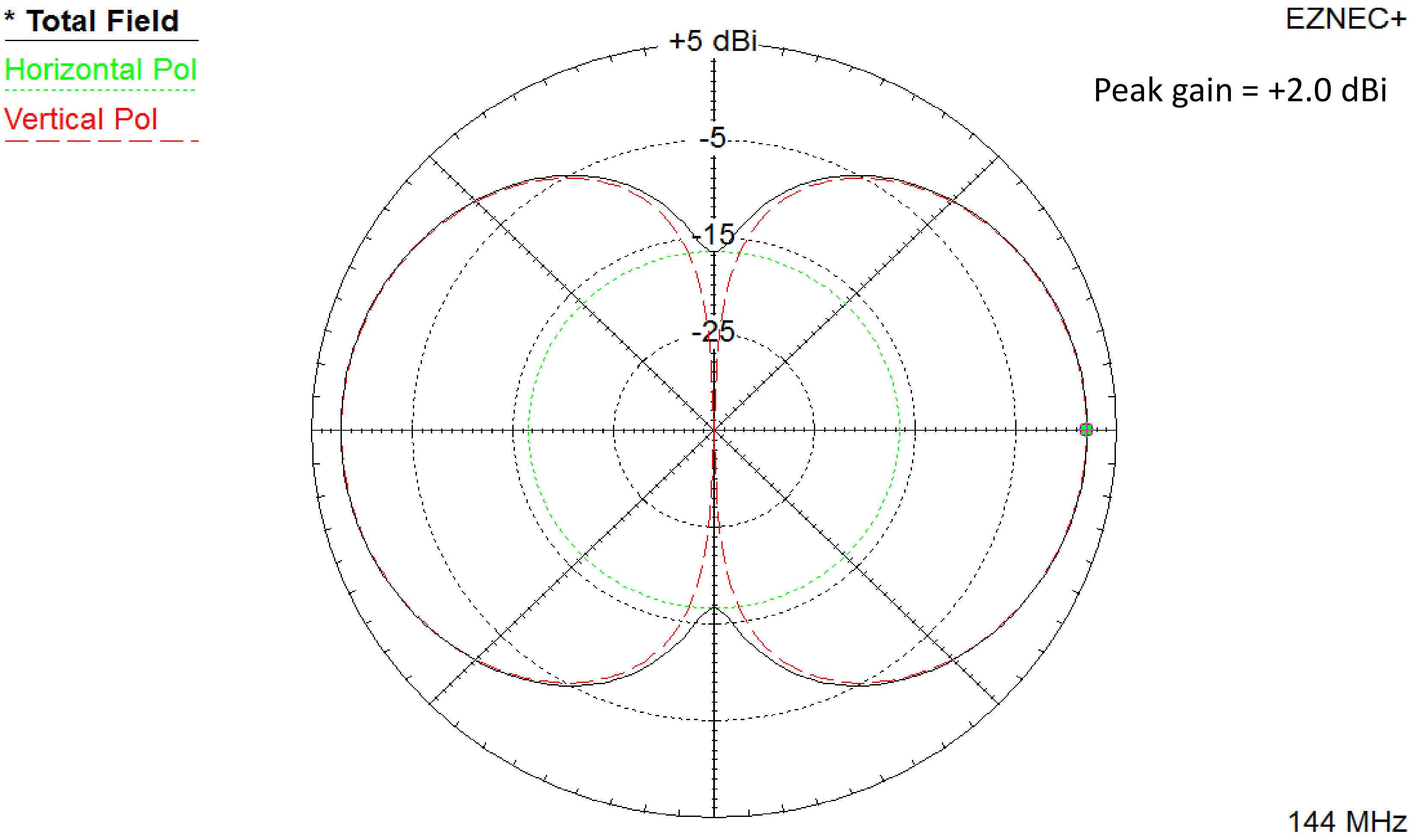
- PSU Interface
- RF System Interfaces
- Experiment Interface
- RF Downlink (Telemetry)
- Command Uplink
- Umbilical Port
- Antenna System
- Zombie Detector

7 Summary

This document specifies the Software Architecture for the AMSAT *Fox-1* satellite. This specification covers the initial mission flying the Penn State Attitude Experiment. Future missions may require changes to this specification in order to support the experiment.

Fox1 Antenna Details 2012-08-05

Aug 5, 2012

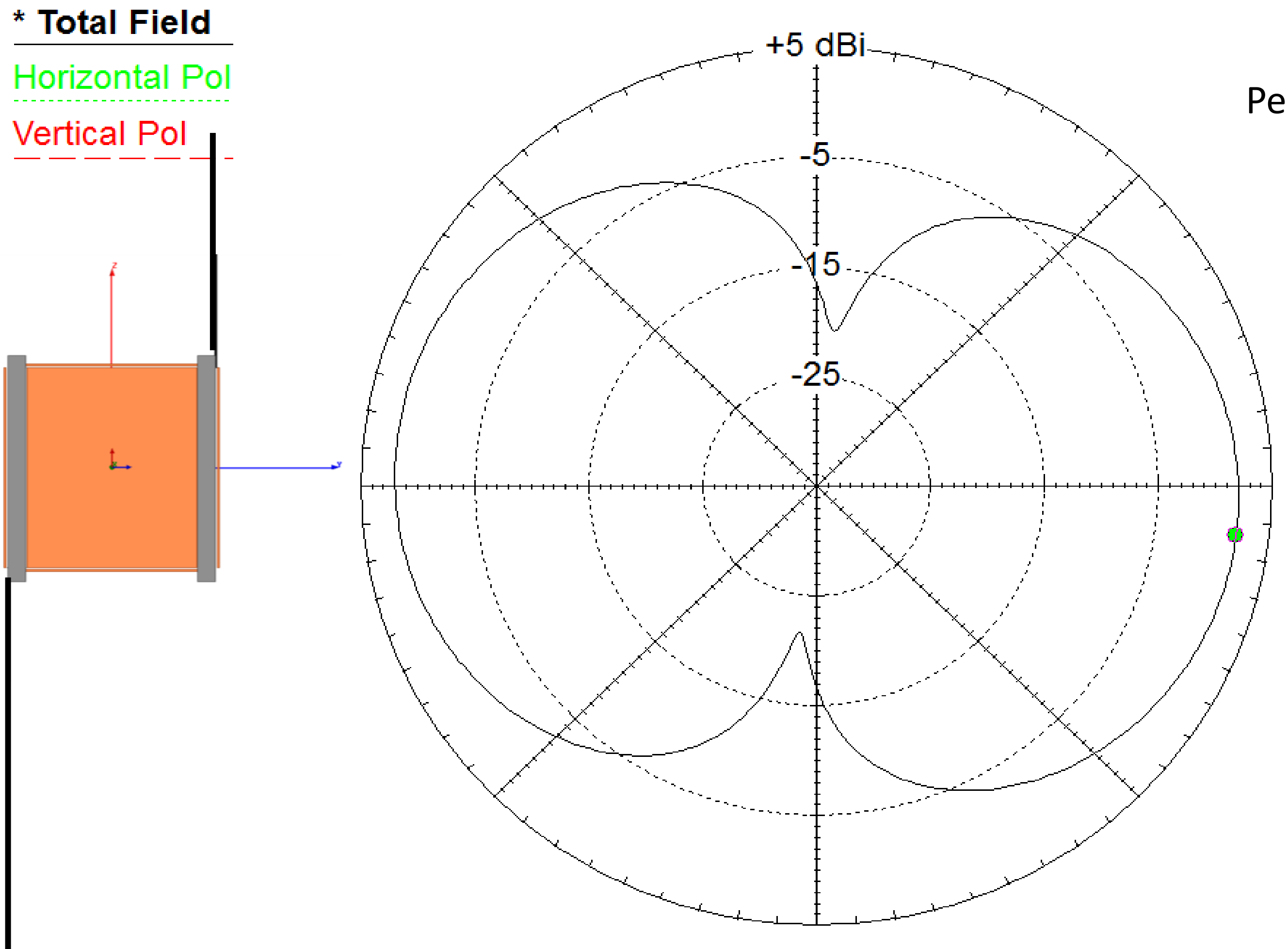


```
Elevation Plot
Azimuth Angle      0.0 deg.
Outer Ring         5.0 dBi

3D Max Gain        2.06 dBi
Slice Max Gain     2.05 dBi @ Elev Angle = 0.0 deg.
Front/Side         18.62 dB
Beamwidth          83.3 deg.; -3dB @ 318.1, 41.4 deg.
Sidelobe Gain      2.05 dBi @ Elev Angle = 180.0 deg.
Front/Sidelobe     0.0 dB
```

2m antenna pattern in XZ plane
(theta cut at phi = 0 deg.)
Vertical Polarization (relative to satellite's XY plane), horizontal, and total polarization.

```
Cursor Elev    0.0 deg.
Gain           2.05 dBi
               0.0 dBmax
               0.0 dBmax3D
```

Aug 5, 2012



EZNEC+

Peak gain = +2.0 dBi

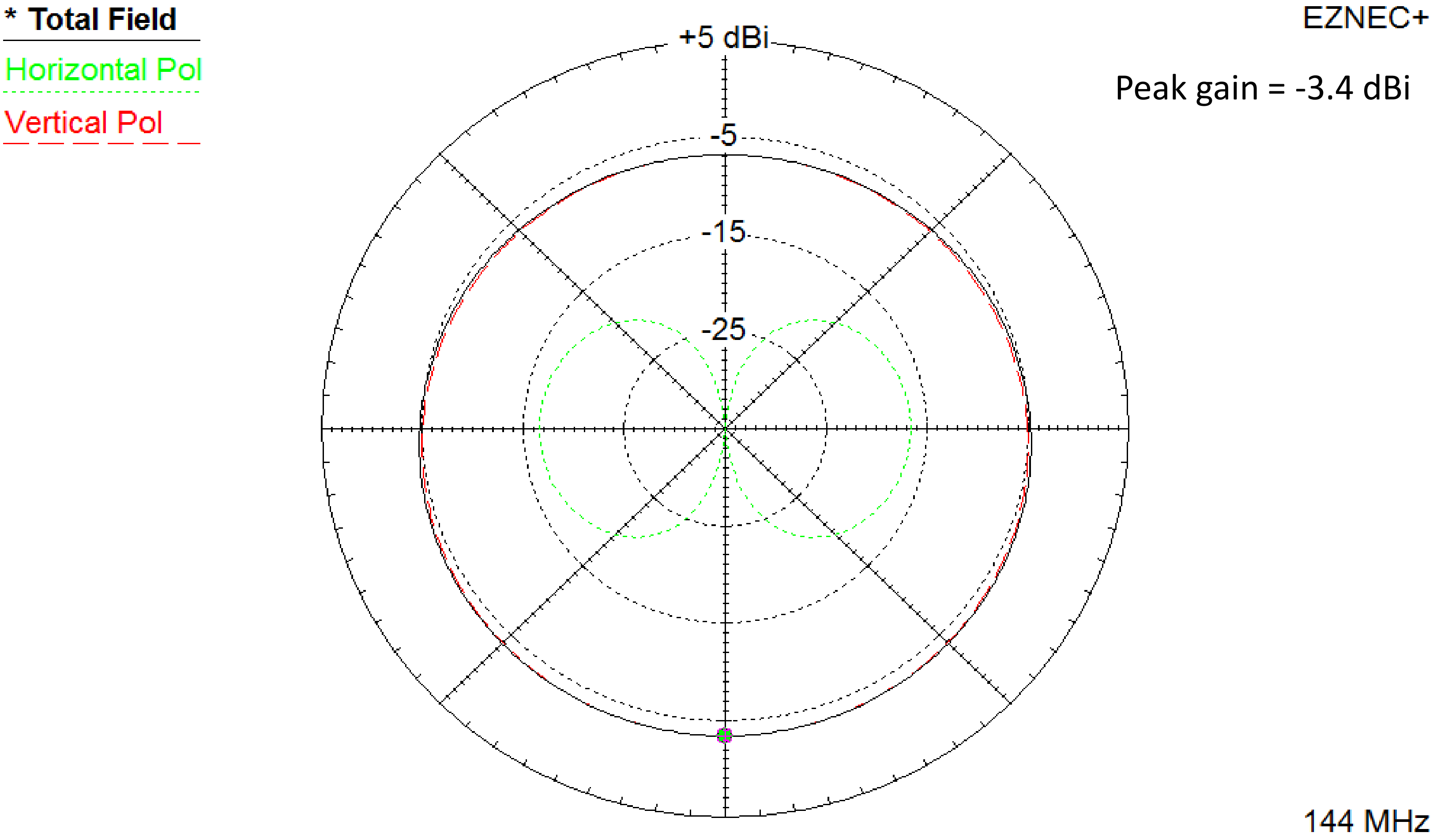
144 MHz

```
Elevation Plot
Azimuth Angle     90.0 deg.
Outer Ring        5.0 dBi

3D Max Gain       2.06 dBi
Slice Max Gain    2.06 dBi @ Elev Angle = 353.0 deg.
Front/Back        0.04 dB
Beamwidth         82.8 deg.; -3dB @ 312.1, 34.9 deg.
Sidelobe Gain     2.02 dBi @ Elev Angle = 174.0 deg.
Front/Sidelobe    0.04 dB
```

```
Cursor Elev    -7.0 deg.
Gain           2.06 dBi
               0.0 dBmax
               0.0 dBmax3D
```

2m antenna pattern in YZ plane
(theta cut at phi = 90 deg.)
Vertical Polarization (relative to satellite’s XY plane)

Aug 5, 2012



Peak gain = -3.4 dBi

Azimuth Plot	
Elevation Angle	60.0 deg.
Outer Ring	5.0 dBi
3D Max Gain	2.0 dBi
Slice Max Gain	-3.38 dBi @ Az Angle = 270.0 deg.
Front/Back	3.43 dB
Beamwidth	292.0 deg.; -3dB @ 124.0, 56.0 deg.
Sidelobe Gain	< -100 dBi
Front/Sidelobe	> 100 dB

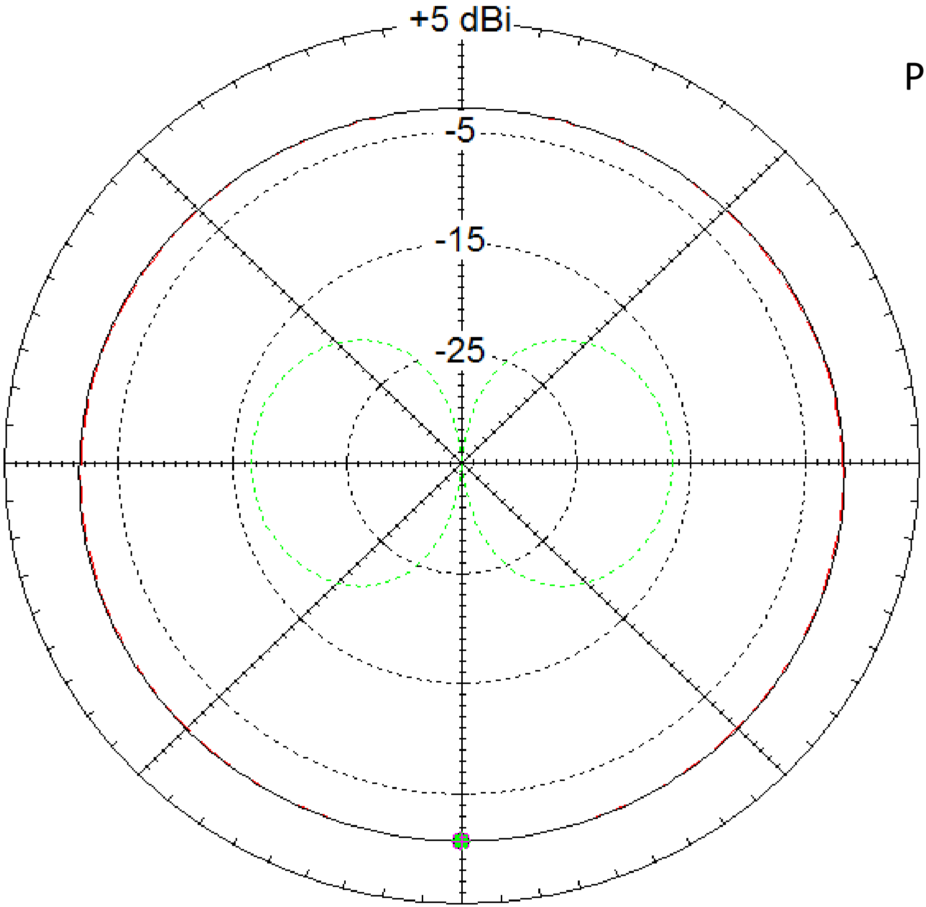
Cursor Az	270.0 deg.
Gain	-3.38 dBi 0.0 dBmax -5.38 dBmax3D

2m antenna pattern
conical (phi) cut at theta = 30 deg. (60 deg. Elevation); Vertical Polarization (relative to satellite's XY plane)

Aug 5, 2012

EZNEC+

Peak gain = -0.7 dBi



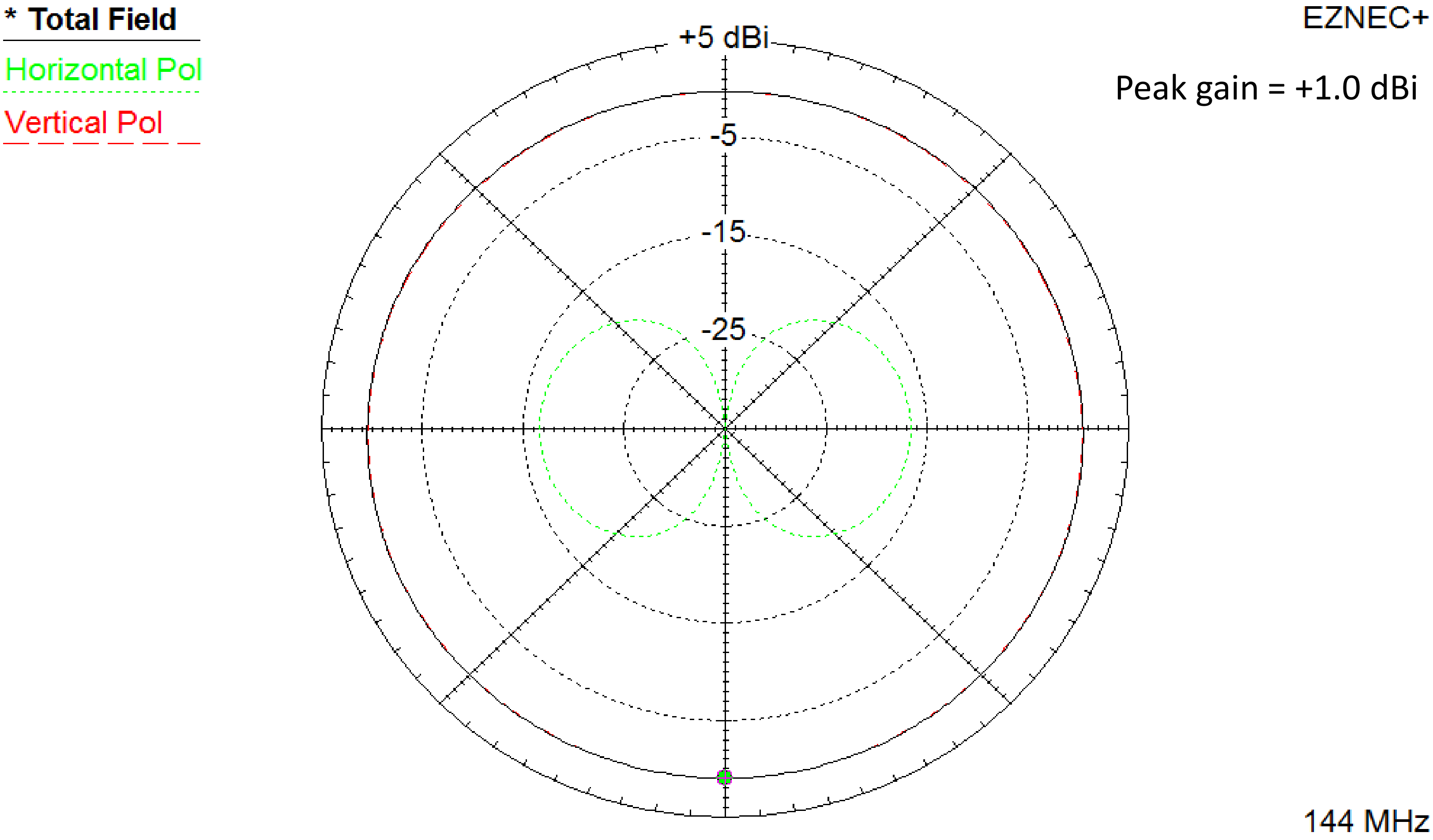
144 MHz

Azimuth Plot	
Elevation Angle	45.0 deg.
Outer Ring	5.0 dBi
3D Max Gain	2.0 dBi
Slice Max Gain	-0.69 dBi @ Az Angle = 270.0 deg.
Front/Back	2.11 dB
Beamwidth	?
Sidelobe Gain	< -100 dBi
Front/Sidelobe	> 100 dB

2m antenna pattern
conical (phi) cut at theta = 45 deg. (45 deg. Elevation); Vertical Polarization (relative to satellite's XY plane)

Cursor Az	270.0 deg.
Gain	-0.69 dBi
	0.0 dBmax
	-2.68 dBmax3D

Aug 5, 2012



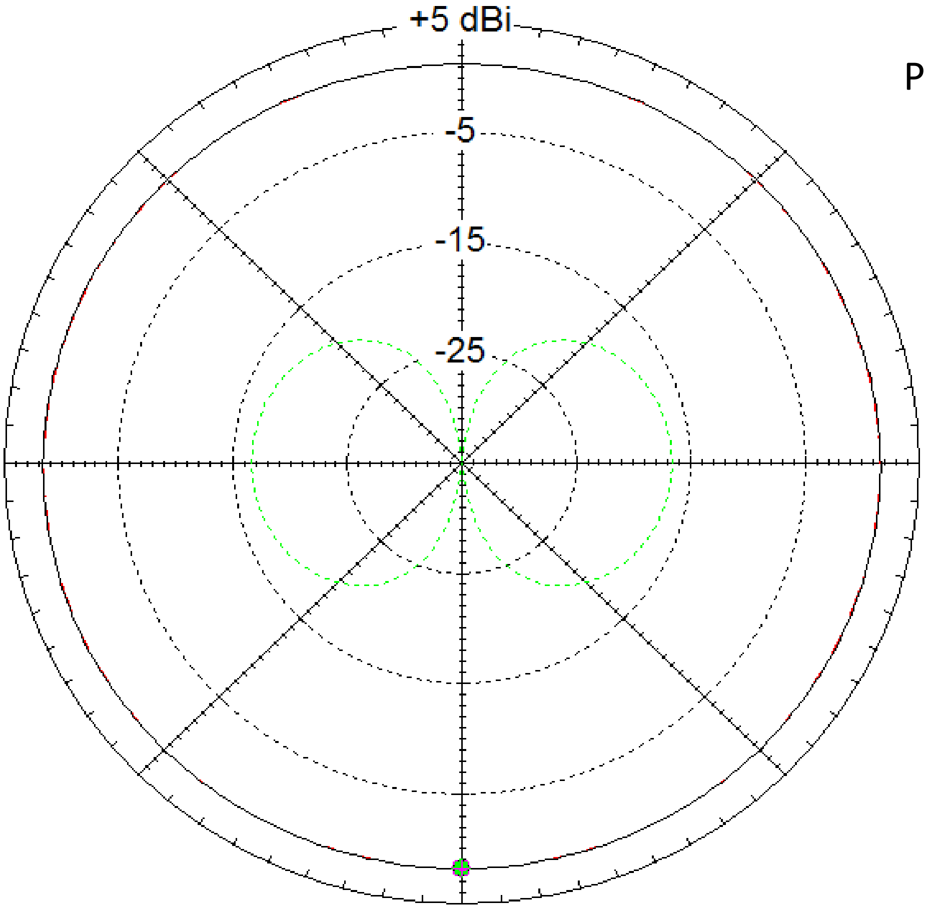
Peak gain = +1.0 dBi

```
Azimuth Plot
Elevation Angle   30.0 deg.
Outer Ring        5.0 dBi

3D Max Gain       2.0 dBi
Slice Max Gain    0.98 dBi @ Az Angle = 270.0 deg.
Front/Back        1.29 dB
Beamwidth         ?
Sidelobe Gain     < -100 dBi
Front/Sidelobe    > 100 dB
```

```
Cursor Az     270.0 deg.
Gain          0.98 dBi
              0.0 dBmax
              -1.02 dBmax3D
```

2m antenna pattern
conical (phi) cut at theta = 60 deg. (30 deg. Elevation); Vertical Polarization is relative to satellite's XY plane.

Aug 5, 2012



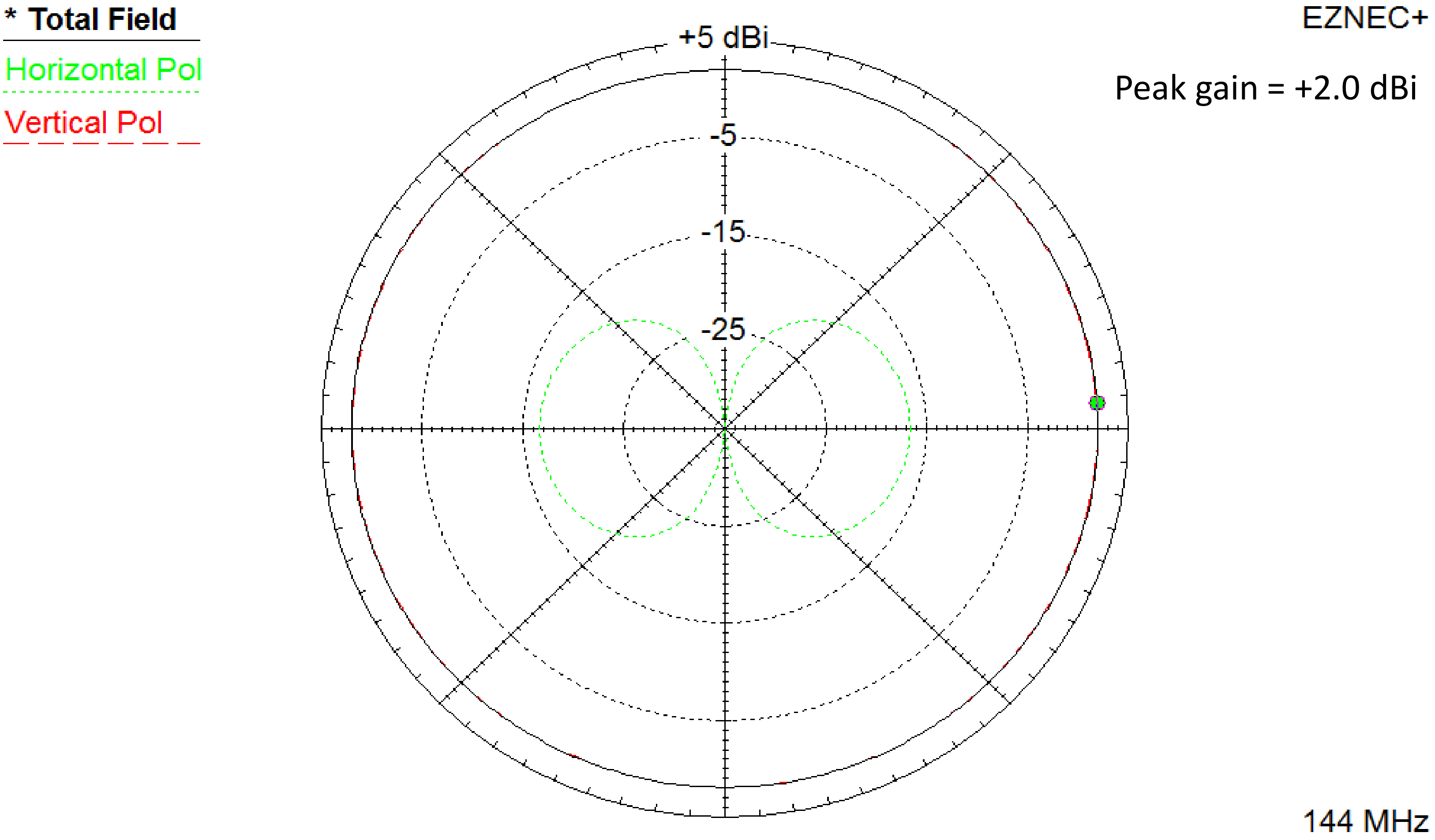
Peak gain = +1.8 dBi

```
Azimuth Plot
Elevation Angle    15.0 deg.
Outer Ring         5.0 dBi

3D Max Gain        2.0 dBi
Slice Max Gain     1.83 dBi @ Az Angle = 270.0 deg.
Front/Back         0.62 dB
Beamwidth          ?
Sidelobe Gain      < -100 dBi
Front/Sidelobe     > 100 dB
```

```
Cursor Az    270.0 deg.
Gain         1.83 dBi
             0.0 dBmax
             -0.17 dBmax3D
```

2m antenna pattern
conical (phi) cut at theta = 75 deg. (15 deg. Elevation); Vertical Polarization is relative to satellite's XY plane.

Aug 5, 2012



Peak gain = +2.0 dBi

```
Azimuth Plot
Elevation Angle   0.0 deg.
Outer Ring        5.0 dBi

3D Max Gain       2.0 dBi
Slice Max Gain    1.99 dBi @ Az Angle = 4.0 deg.
Front/Side        0.07 dB
Beamwidth         ?
Sidelobe Gain     1.99 dBi @ Az Angle = 176.0 deg.
Front/Sidelobe    0.0 dB
```

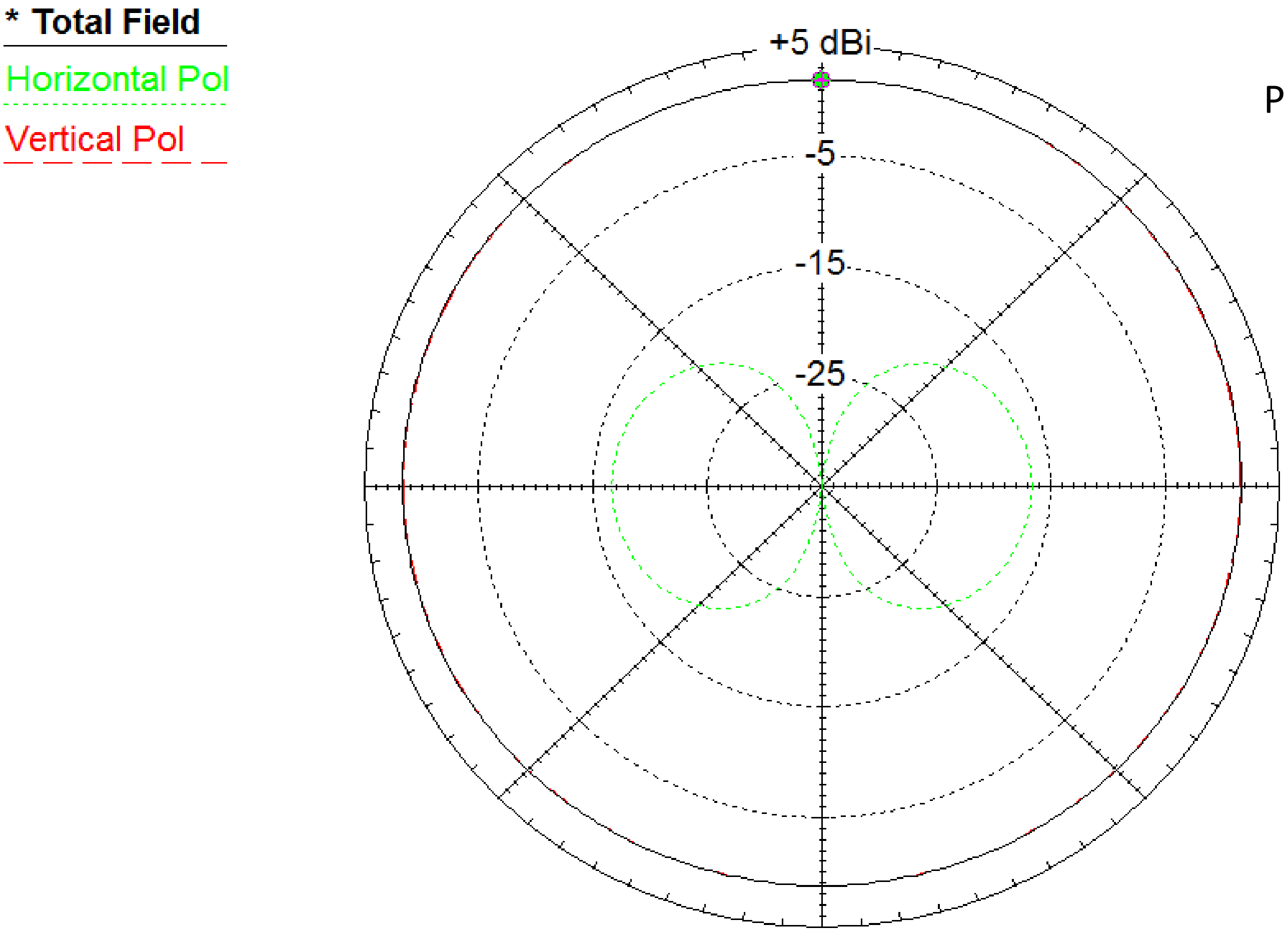
2m antenna pattern
conical (phi) cut at theta = 90 deg. (0 deg. Elevation); Vertical Polarization is relative to satellite’s XY plane.

```
Cursor Az    4.0 deg.
Gain         1.99 dBi
             0.0 dBmax
             0.0 dBmax3D
```

Aug 5, 2012

EZNEC+

Peak gain = +1.9 dBi



144 MHz

```
Azimuth Plot
Elevation Angle   -15.0 deg.
Outer Ring        5.0 dBi

3D Max Gain       2.0 dBi
Slice Max Gain    1.87 dBi @ Az Angle = 90.0 deg.
Front/Back        0.65 dB
Beamwidth         ?
Sidelobe Gain     < -100 dBi
Front/Sidelobe    > 100 dB
```

2m antenna pattern
conical (phi) cut at theta = 105 deg. (-15 deg. Elevation); Vertical Polarization is relative to satellite's XY plane.

```
Cursor Az    90.0 deg.
Gain         1.87 dBi
             0.0 dBmax
             -0.12 dBmax3D
```

Aug 5, 2012

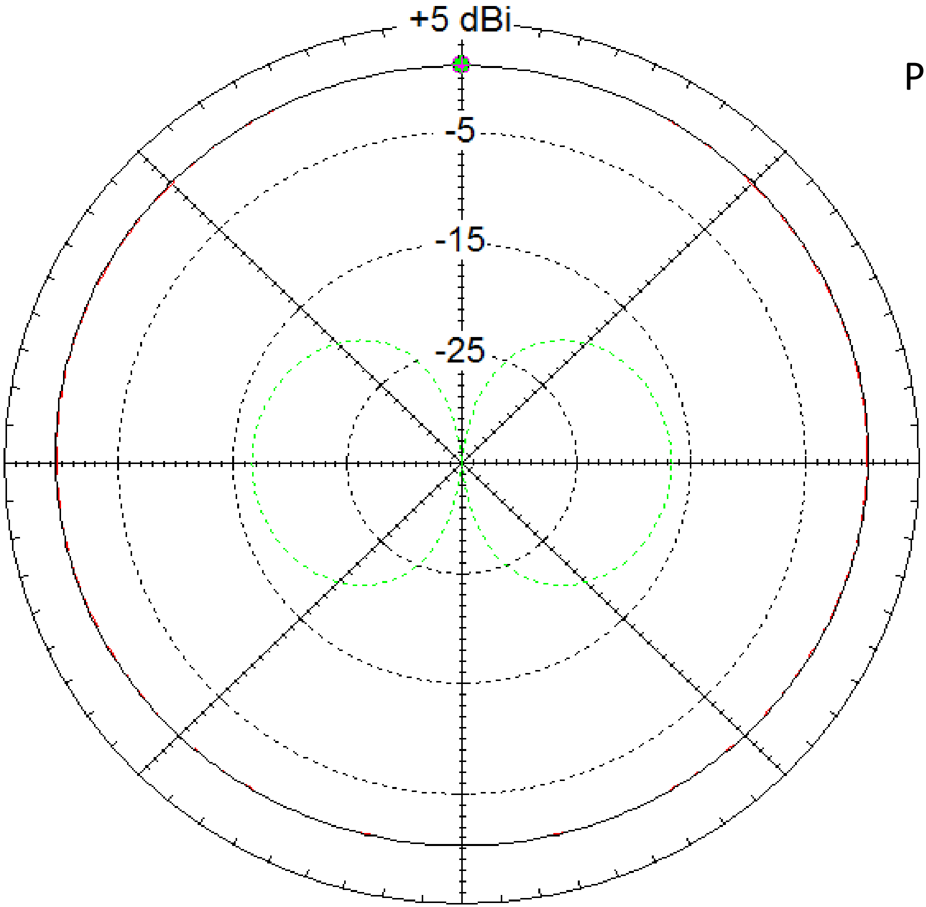
*** Total Field**

Horizontal Pol

Vertical Pol

EZNEC+

Peak gain = +2.0 dBi



144 MHz

```
Azimuth Plot
Elevation Angle   -30.0 deg.
Outer Ring        5.0 dBi

3D Max Gain       2.0 dBi
Slice Max Gain    1.06 dBi @ Az Angle = 90.0 deg.
Front/Back        1.34 dB
Beamwidth         ?
Sidelobe Gain     < -100 dBi
Front/Sidelobe    > 100 dB
```

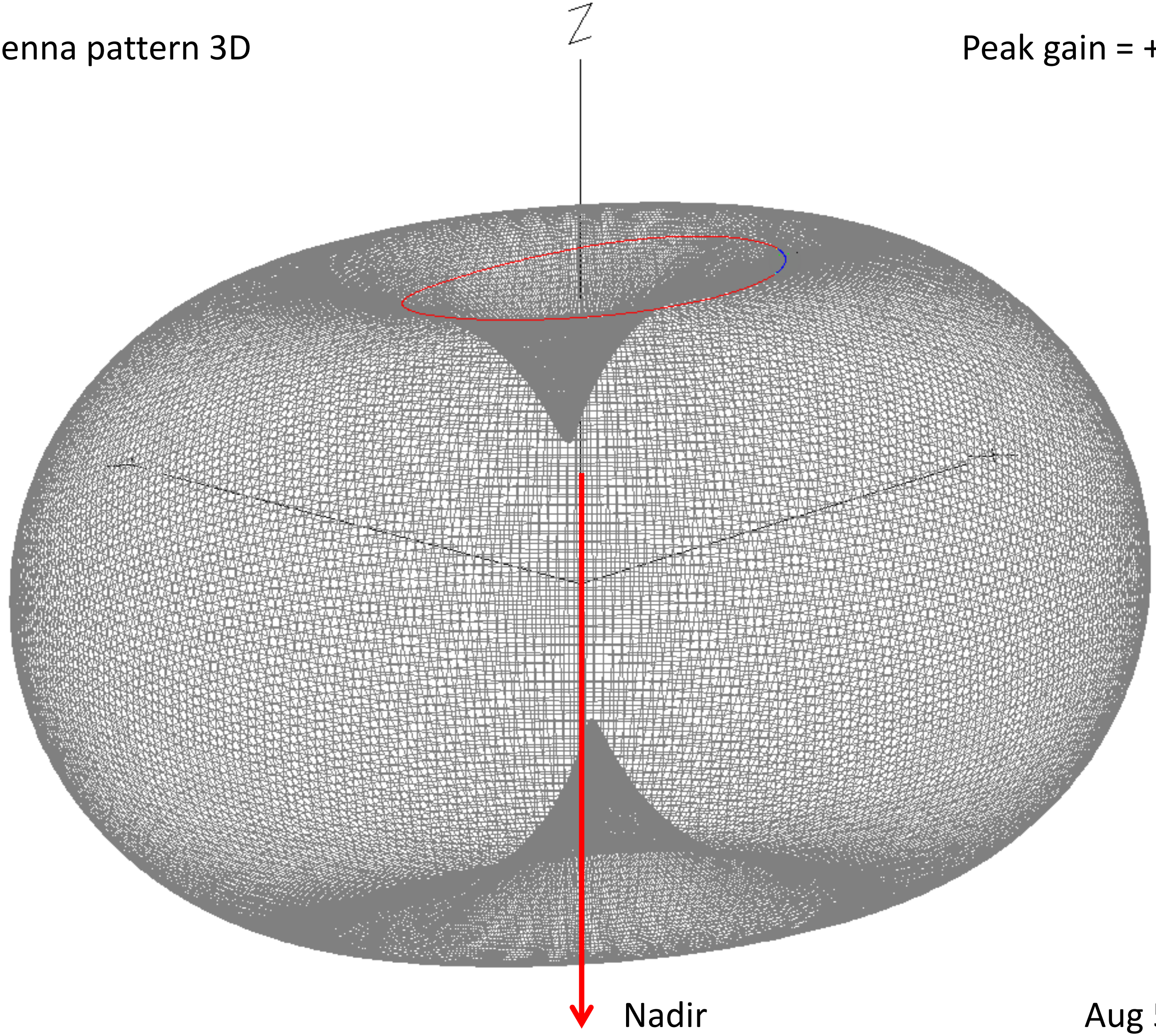
2m antenna pattern
conical (phi) cut at theta = 120 deg. (-30 deg. Elevation); Vertical Polarization is relative to satellite’s XY plane.

```
Cursor Az    90.0 deg.
Gain         1.06 dBi
             0.0 dBmax
             -0.94 dBmax3D
```

Aug 5, 2012

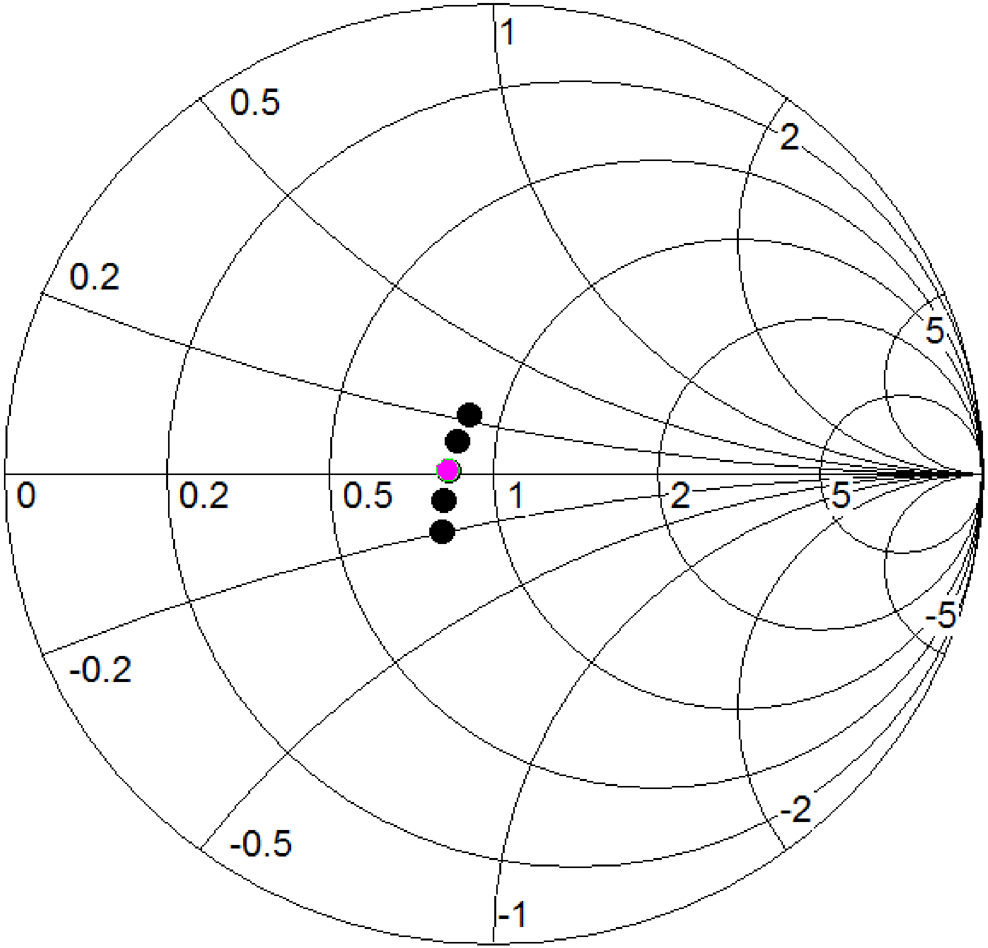
2m antenna pattern 3D

Peak gain = +2.0 dBi



Aug 5, 2012

EZNEC+



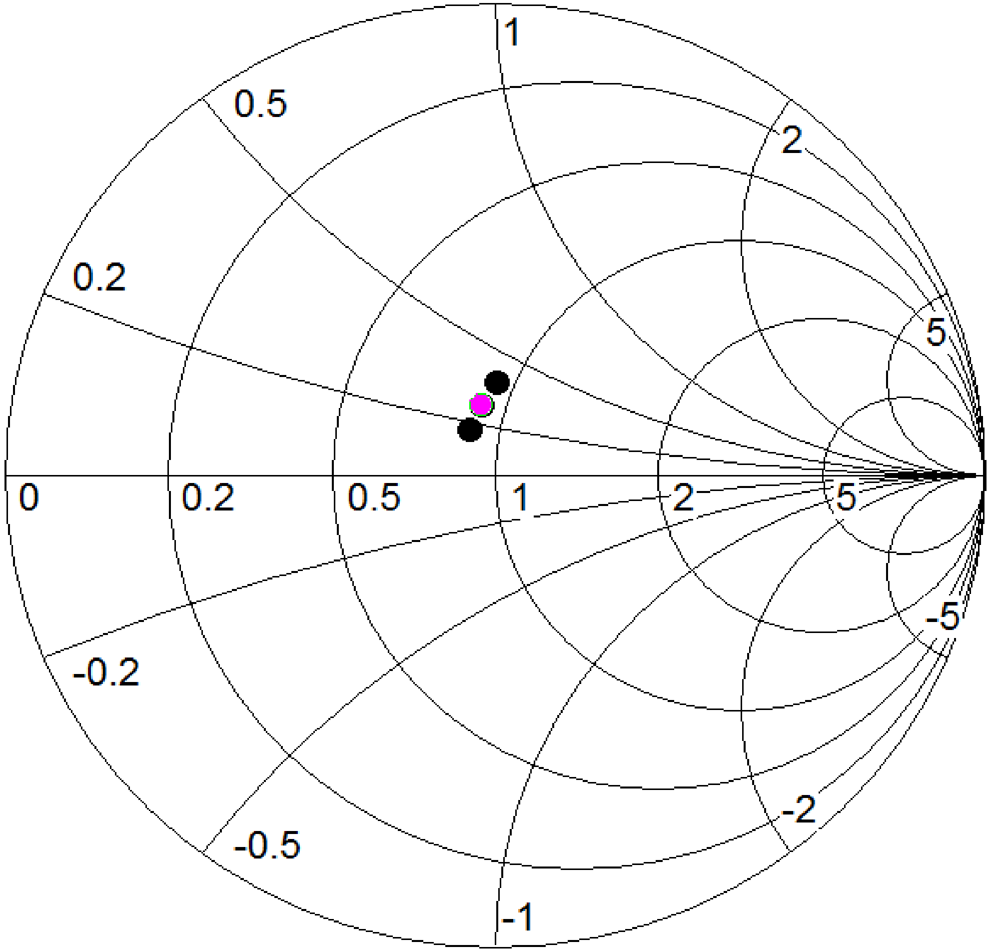
```
Freq        146 MHz
SWR         1.2
Z           41.59 at 0.94 deg.
            = 41.58 + j 0.6829 ohms
Refl Coeff  0.09225 at 174.94 deg.
            = -0.09189 + j 0.008142
Ret Loss    20.7 dB
```

Base impedance of 598 mm 2 m antenna with the 437 MHz antenna floating (at 146 MHz)

```
Source #    1
Z0          50 ohms
```

Aug 5, 2012

EZNEC+



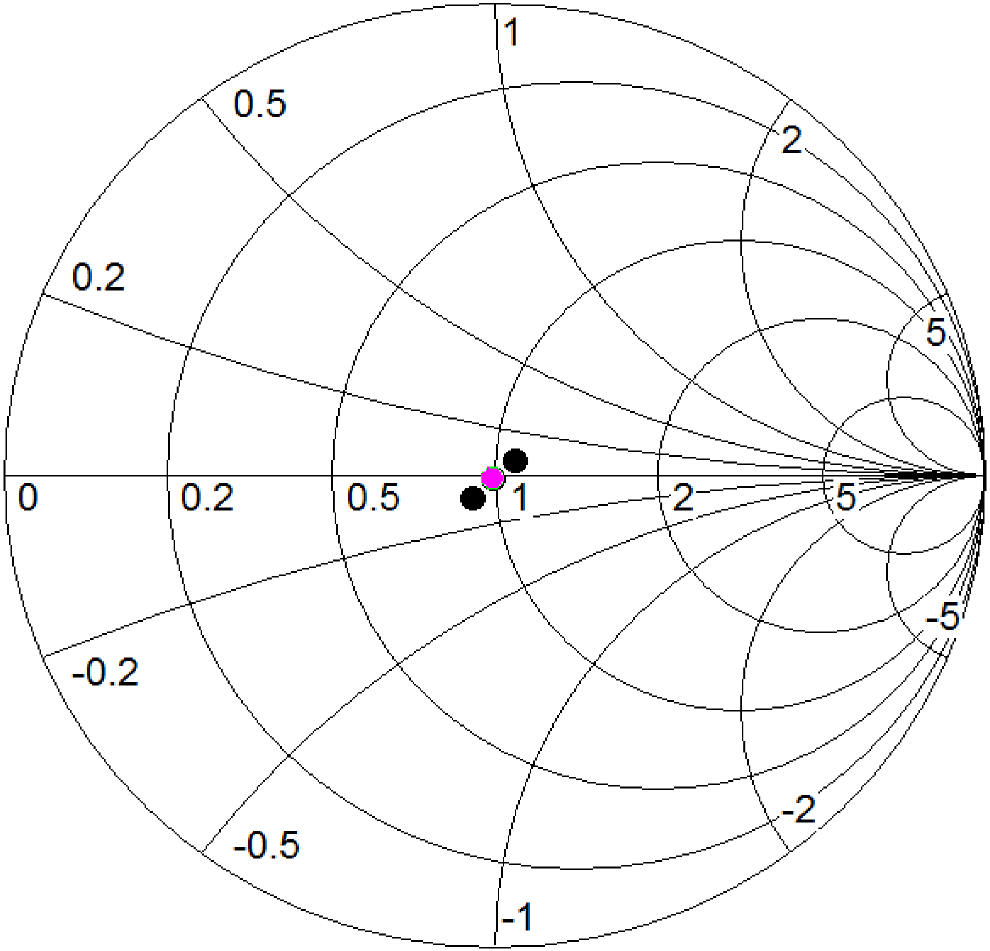
```
Freq       146 MHz
SWR        1.36
Z          47.44 at 16.94 deg.
           = 45.38 + j 13.82 ohms
Refl Coeff 0.1512 at 100.24 deg.
           = -0.02687 + j 0.1488
Ret Loss   16.4 dB
```

Base impedance of 597 mm 2 m antenna with the 437 MHz antenna grounded (at 146 MHz)

```
Source #   1
Z0         50 ohms
```

Aug 5, 2012

EZNEC+



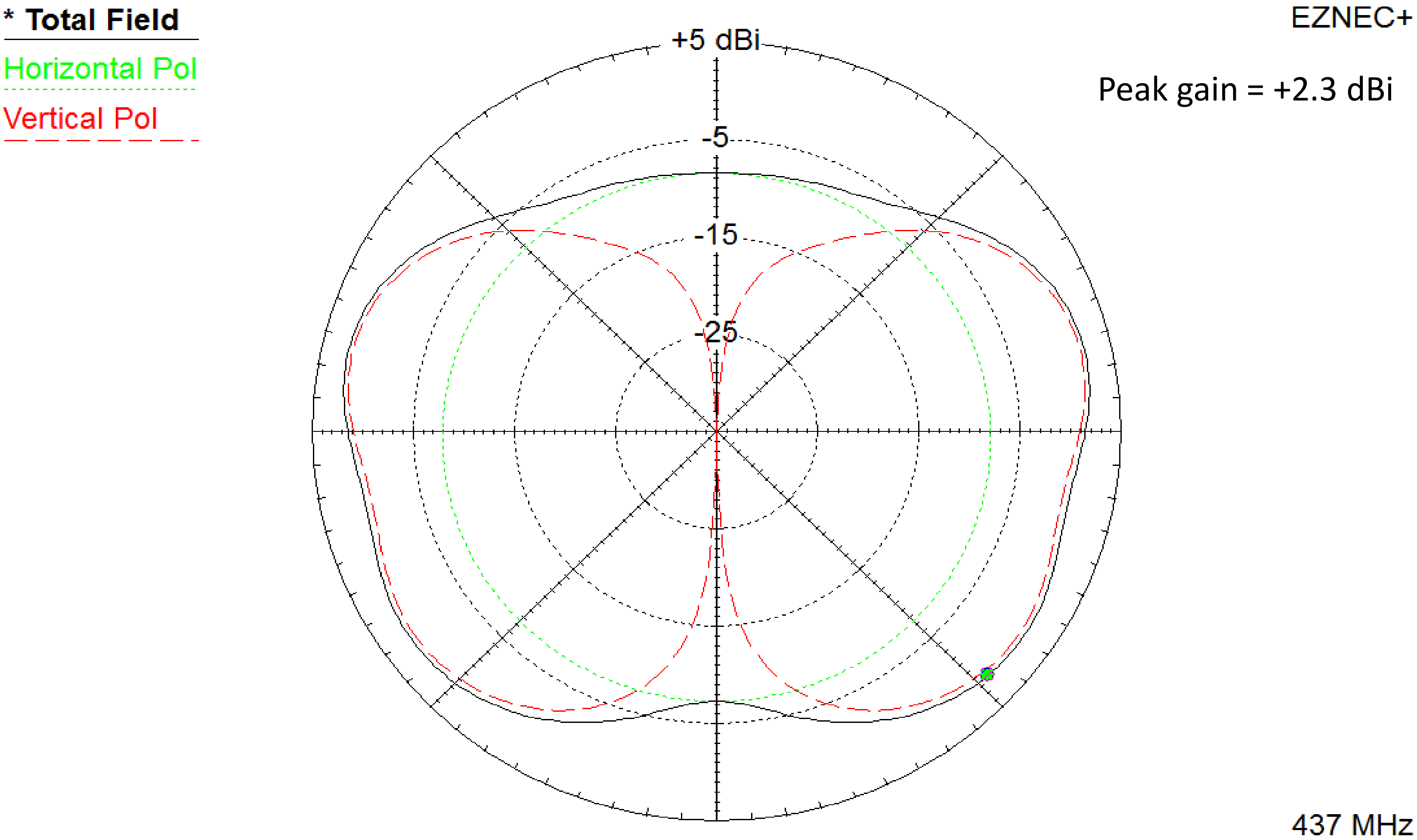
```
Freq        146 MHz
SWR         1.016
Z           49.57 at -0.78 deg.
            = 49.57 - j 0.6734 ohms
Refl Coeff  0.008025 at -122.18 deg.
            = -0.004274 - j 0.006792
Ret Loss    41.9 dB
```

Base impedance of 597 mm 2 m antenna with a 7 pF shunt capacitor at base of antenna.
The 437 MHz antenna is grounded (at 146 MHz).

```
Source #  1
Z0        50 ohms
```

Aug 5, 2012

Slides that follow are for the 437 MHz antenna on the +Z edge of the +Y solar panel.



Peak gain = +2.3 dBi

```
Elevation Plot
Azimuth Angle      0.0 deg.
Outer Ring         5.0 dBi

3D Max Gain        3.33 dBi
Slice Max Gain     2.3 dBi @ Elev Angle = 12.0 deg.
Front/Back         1.82 dB
Beamwidth          93.0 deg.; -3dB @ 300.8, 33.8 deg.
Sidelobe Gain      2.3 dBi @ Elev Angle = 167.0 deg.
Front/Sidelobe     0.0 dB
```

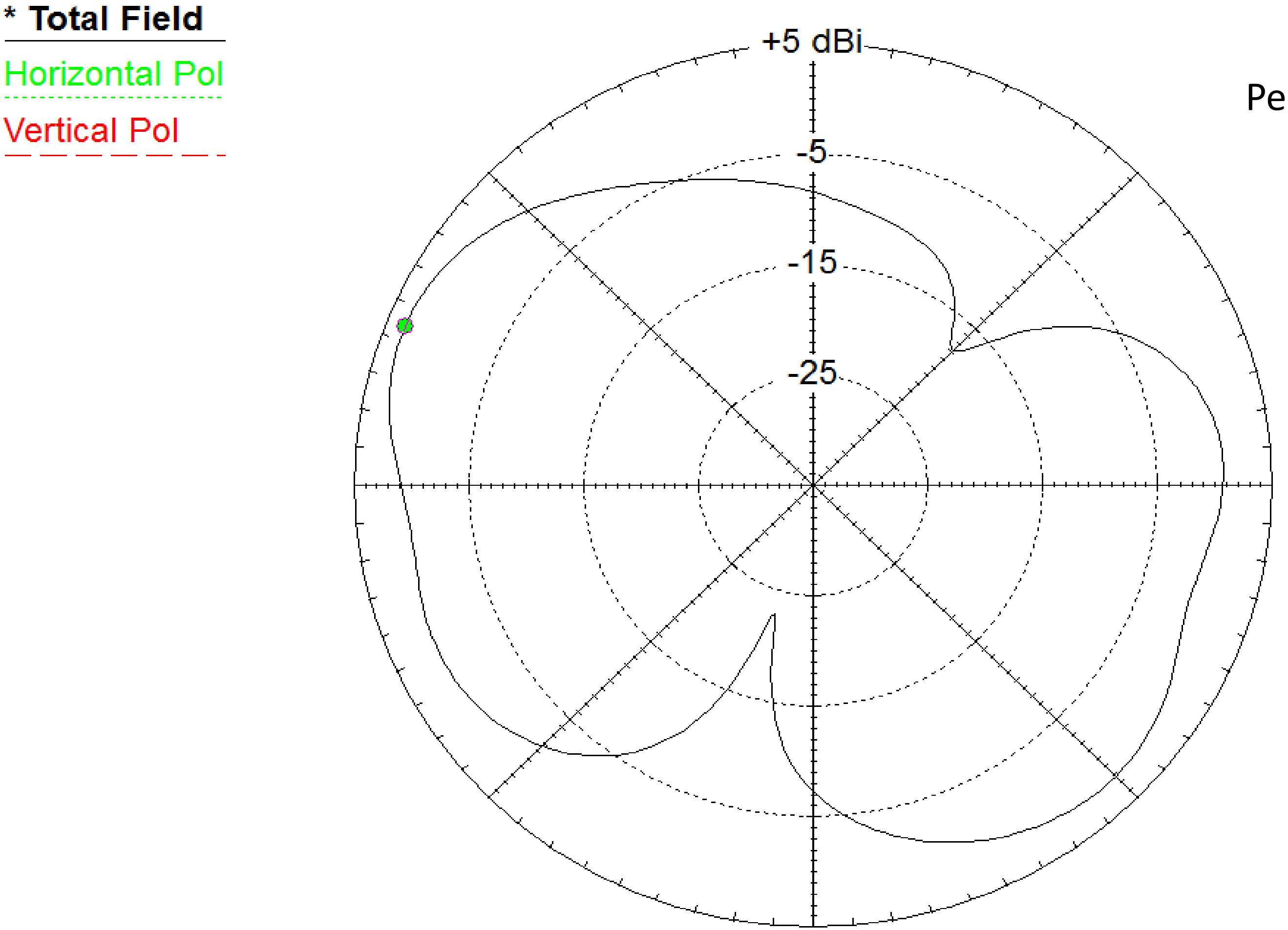
70 cm antenna pattern in XZ plane
(theta cut at phi = 0 deg.)
Vertical Polarization is relative to satellite's XY plane.

```
Cursor Elev    -43.0 deg.
Gain           1.68 dBi
               -0.61 dBmax
               -1.64 dBmax3D
```

Aug 5, 2012

EZNEC+

Peak gain = +3.3 dBi



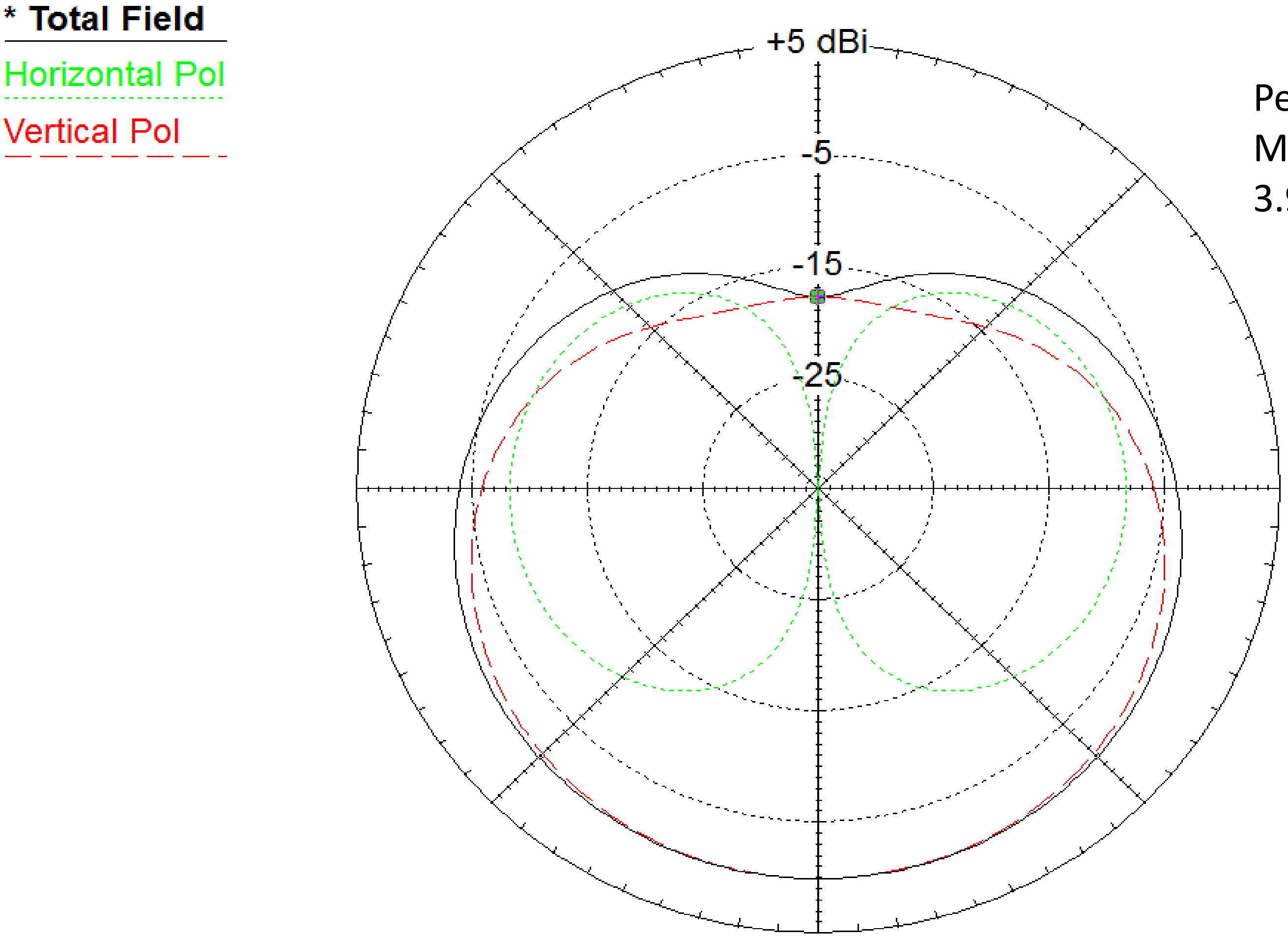
437 MHz

Elevation Plot	
Azimuth Angle	90.0 deg.
Outer Ring	5.0 dBi
3D Max Gain	3.33 dBi
Slice Max Gain	3.33 dBi @ Elev Angle = 158.0 deg.
Front/Back	3.63 dB
Beamwidth	49.8 deg.; -3dB @ 135.9, 185.7 deg.
Sidelobe Gain	2.26 dBi @ Elev Angle = 314.0 deg.
Front/Sidelobe	1.07 dB

70 cm antenna pattern in YZ plane
(theta cut at phi = 90 deg.)
Vertical Polarization is relative to satellite’s XY plane.

Cursor Elev	158.0 deg.
Gain	3.33 dBi
	0.0 dBmax
	0.0 dBmax3D

Aug 5, 2012



EZNEC+

Peak gain = +2.3 dBi
Min. Gain = -1.6 dBi
3.9 dB variation

437 MHz

```
Azimuth Plot       
Elevation Angle    45.0 deg.
Outer Ring         5.0 dBi

3D Max Gain        3.33 dBi
Slice Max Gain     0.11 dBi @ Az Angle = 270.0 deg.
Front/Back         17.88 dB
Beamwidth          156.2 deg.; -3dB @ 191.9, 348.1 deg.
Sidelobe Gain      < -100 dBi
Front/Sidelobe     > 100 dB
```

70 cm antenna pattern
conical (phi) cut at theta = 45 deg. (45 deg. elevation)

```
Cursor Az     90.0 deg.
Gain          -17.77 dBi
              -17.88 dBmax
              -21.1 dBmax3D
```

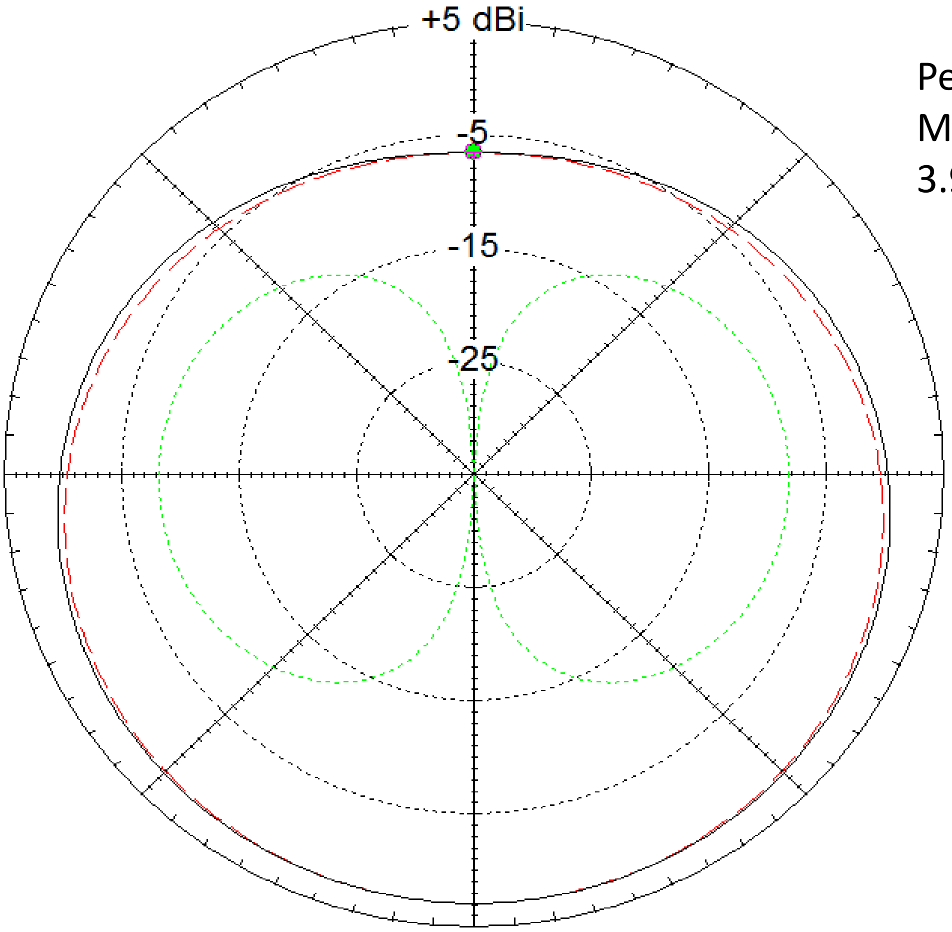
Aug 5, 2012

*** Total Field**

Horizontal Pol

Vertical Pol

EZNEC+



Peak gain = +2.3 dBi
Min. Gain = -1.6 dBi
3.9 dB variation

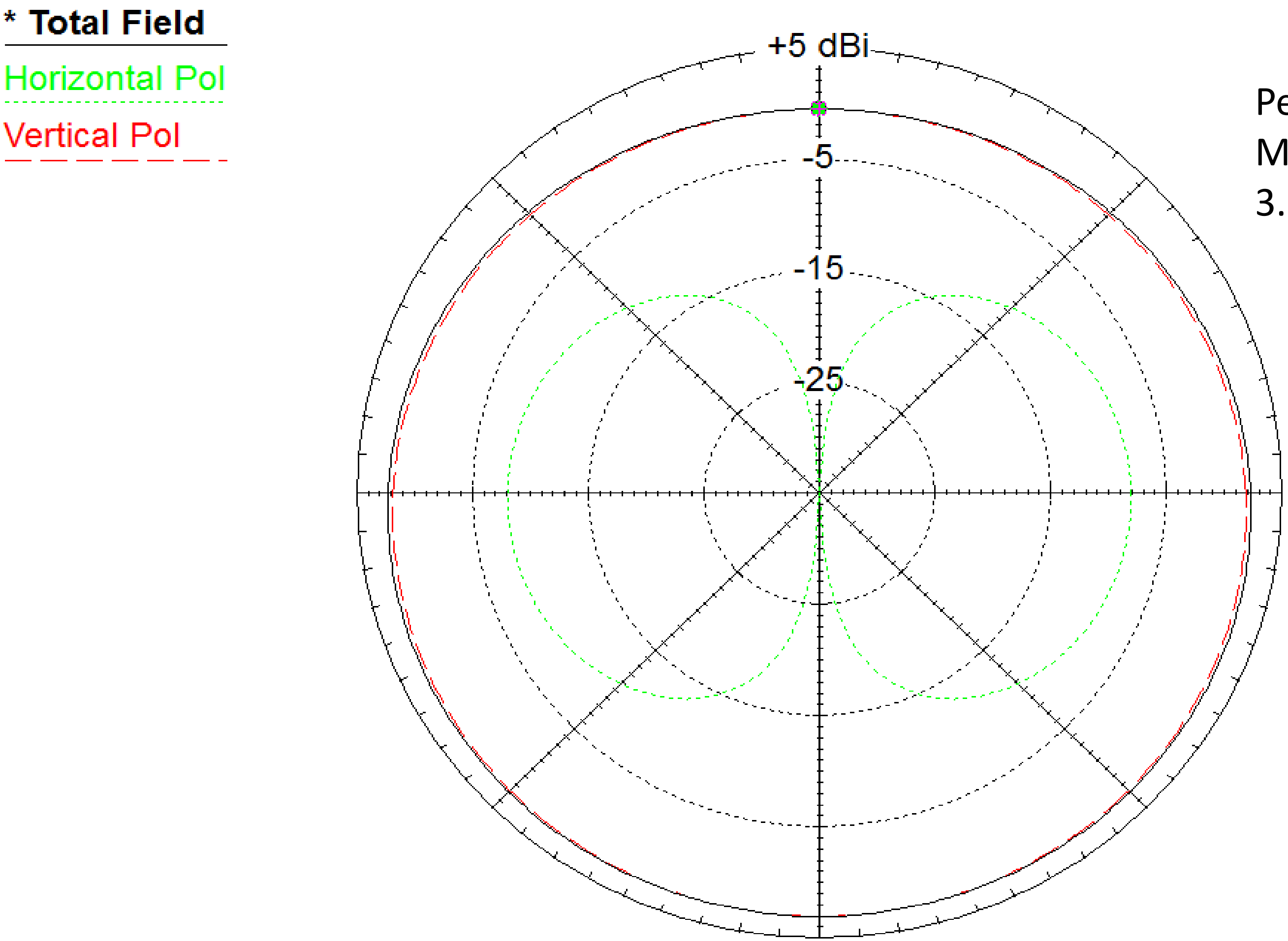
437 MHz

Azimuth Plot	
Elevation Angle	30.0 deg.
Outer Ring	5.0 dBi
3D Max Gain	3.33 dBi
Slice Max Gain	2.88 dBi @ Az Angle = 270.0 deg.
Front/Back	9.47 dB
Beamwidth	190.2 deg.; -3dB @ 174.9, 5.1 deg.
Sidelobe Gain	< -100 dBi
Front/Sidelobe	> 100 dB

70 cm antenna pattern
conical (phi) cut at theta = 60 deg. (30 deg. elevation)

Cursor Az	90.0 deg.
Gain	-6.59 dBi -9.47 dBmax -9.92 dBmax3D

Aug 5, 2012



Peak gain = +2.3 dBi
Min. Gain = -1.6 dBi
3.9 dB variation

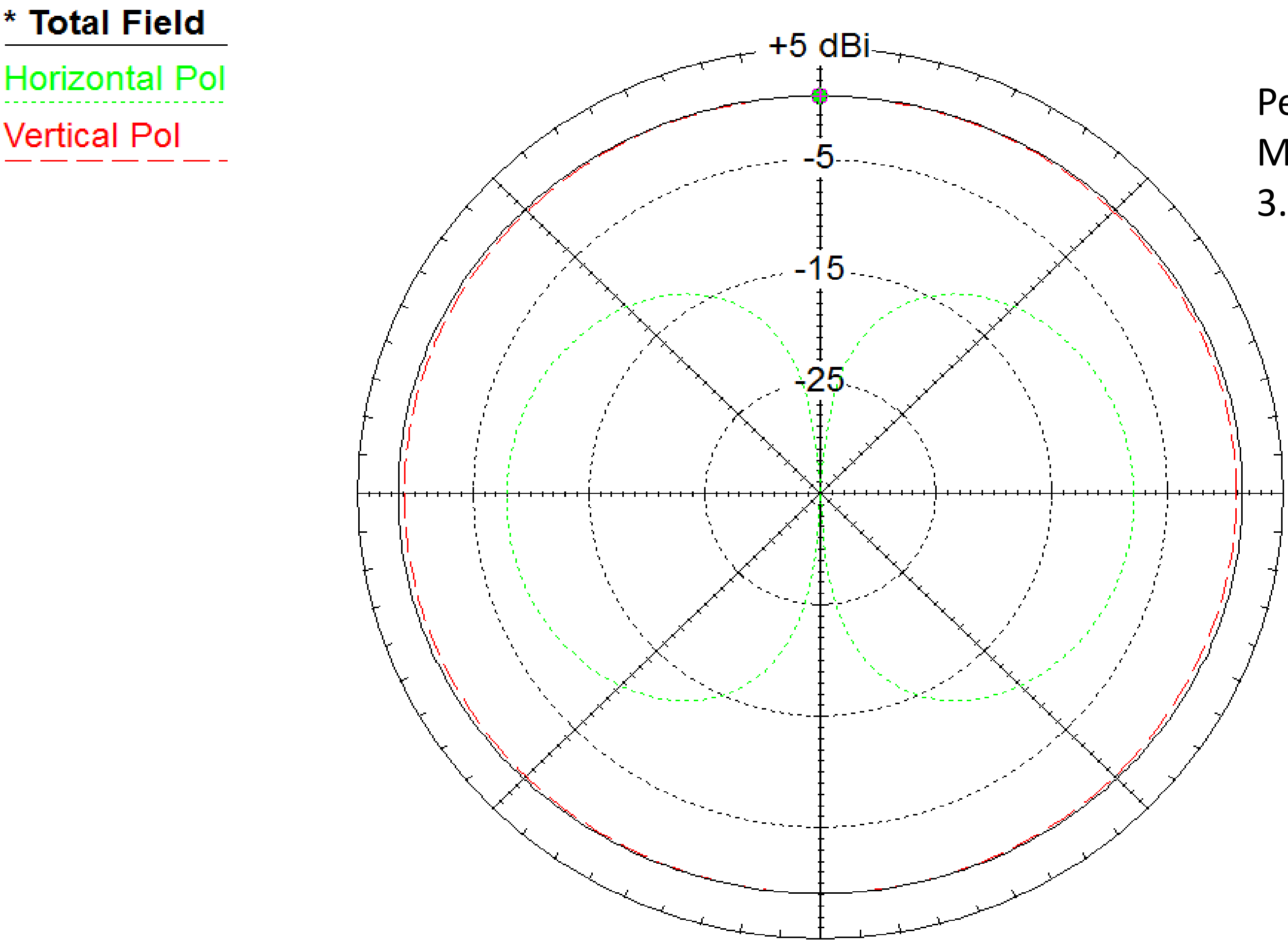
437 MHz

```
Azimuth Plot
Elevation Angle   15.0 deg.
Outer Ring        5.0 dBi

3D Max Gain       3.33 dBi
Slice Max Gain    3.03 dBi @ Az Angle = 270.0 deg.
Front/Back        3.58 dB
Beamwidth         298.6 deg.; -3dB @ 120.7, 59.3 deg.
Sidelobe Gain     < -100 dBi
Front/Sidelobe    > 100 dB
```

70 cm antenna pattern
conical (phi) cut at theta = 75 deg. (15 deg. elevation)

```
Cursor Az    90.0 deg.
Gain         -0.55 dBi
             -3.58 dBmax
             -3.88 dBmax3D
```

Aug 5, 2012



EZNEC+

Peak gain = +2.3 dBi

Min. Gain = -1.6 dBi

3.9 dB variation

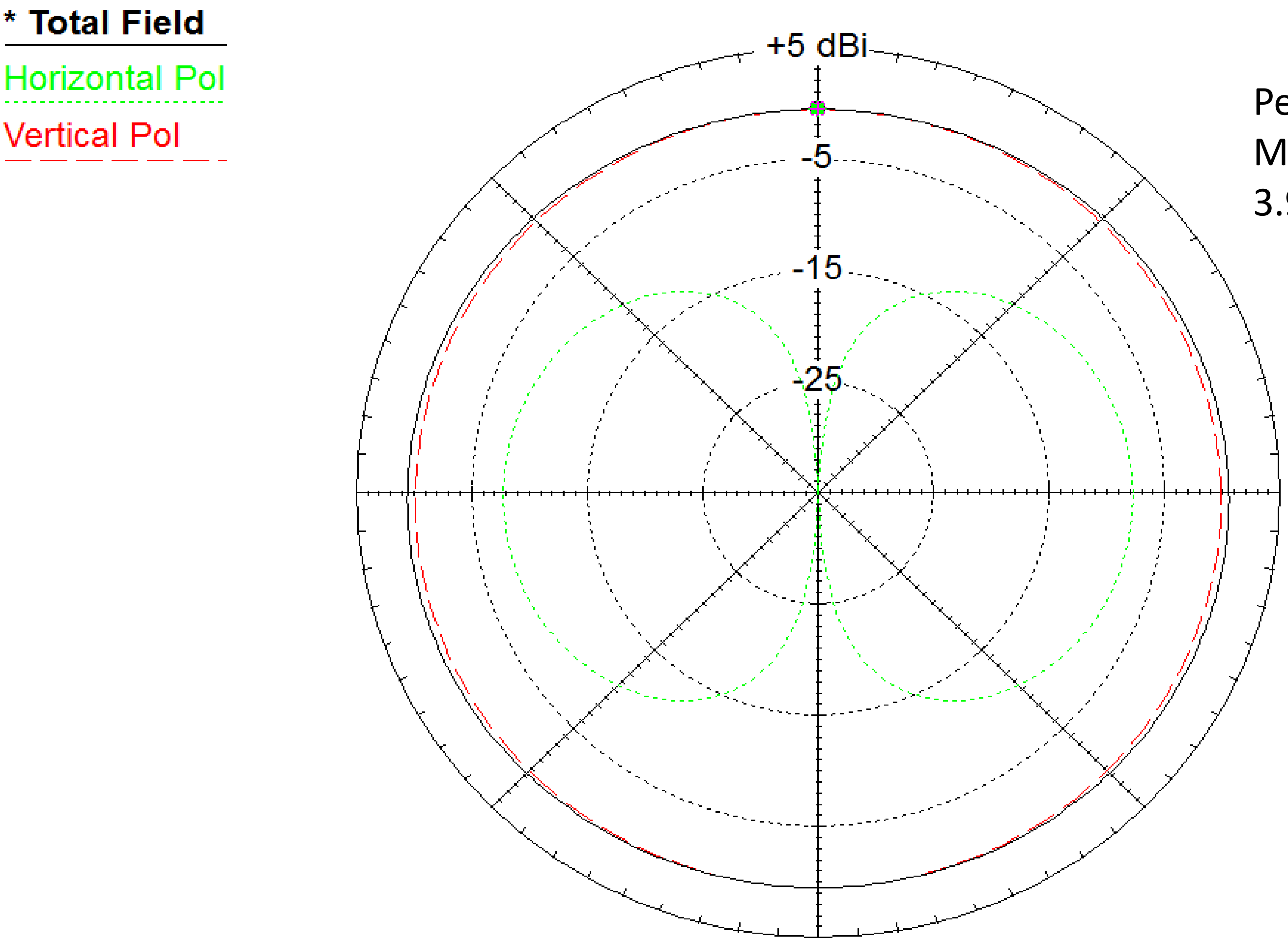
437 MHz

```
Azimuth Plot
Elevation Angle     0.0 deg.
Outer Ring          5.0 dBi

3D Max Gain         3.33 dBi
Slice Max Gain      1.45 dBi @ Az Angle = 186.0 deg.
Front/Back          0.03 dB
Beamwidth           ?
Sidelobe Gain       1.45 dBi @ Az Angle = 354.0 deg.
Front/Sidelobe      0.0 dB
```

70 cm antenna pattern
conical (phi) cut at theta = 90 deg. (0 deg. elevation)

```
Cursor Az     90.0 deg.
Gain          0.67 dBi
              -0.78 dBmax
              -2.66 dBmax3D
```

Aug 5, 2012



EZNEC+

Peak gain = +2.3 dBi
Min. Gain = -1.6 dBi
3.9 dB variation

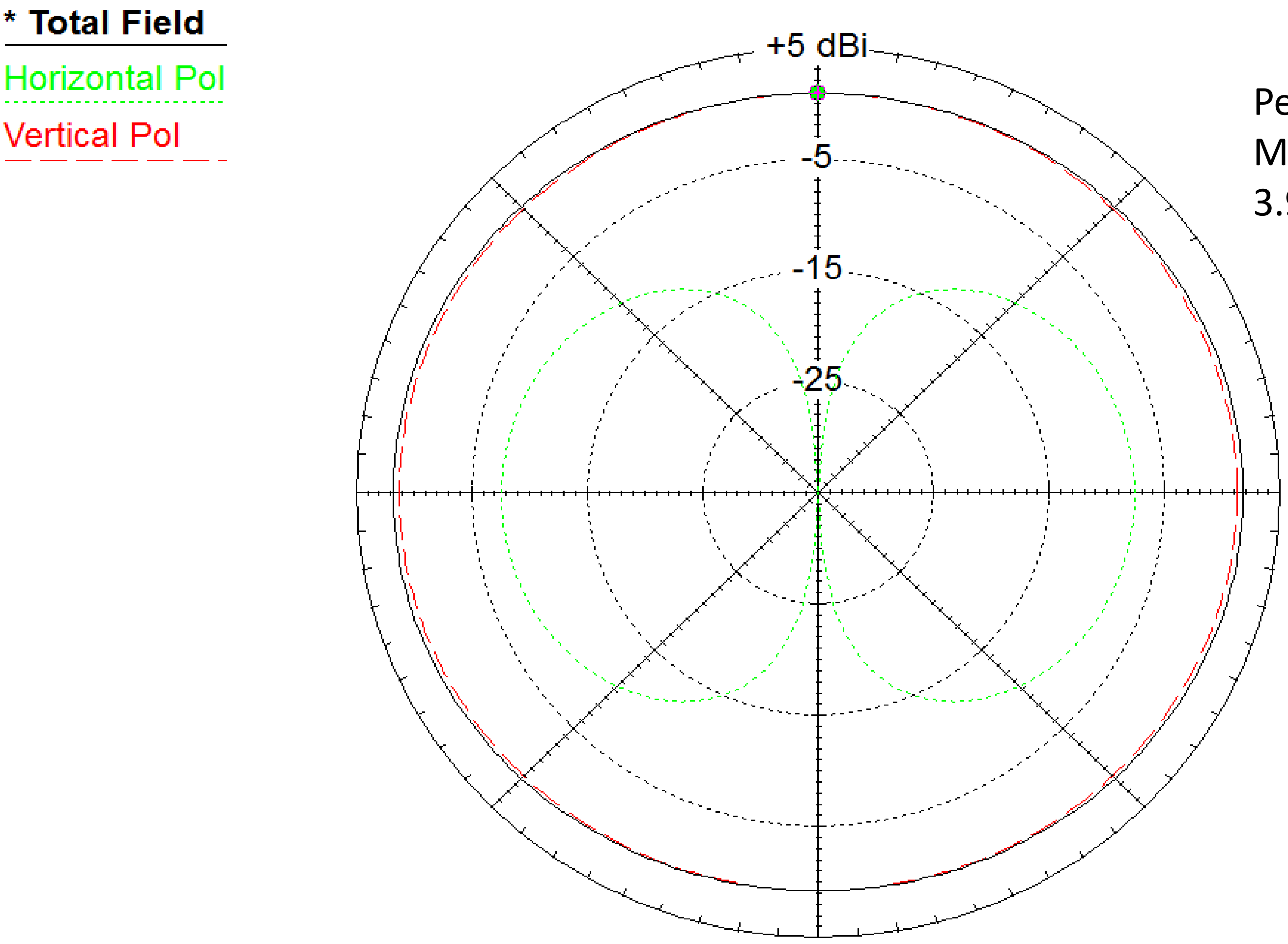
437 MHz

```
Azimuth Plot
Elevation Angle   -15.0 deg.
Outer Ring        5.0 dBi

3D Max Gain       3.33 dBi
Slice Max Gain    0.71 dBi @ Az Angle = 210.0 deg.
Front/Back        0.62 dB
Beamwidth         ?
Sidelobe Gain     0.71 dBi @ Az Angle = 330.0 deg.
Front/Sidelobe    0.0 dB
```

70 cm antenna pattern
conical (phi) cut at theta = 105 deg. (-15 deg. elevation

```
Cursor Az    90.0 deg.
Gain         -0.59 dBi
             -1.3 dBmax
             -3.91 dBmax3D
```

Aug 5, 2012



EZNEC+

Peak gain = +2.3 dBi
Min. Gain = -1.6 dBi
3.9 dB variation

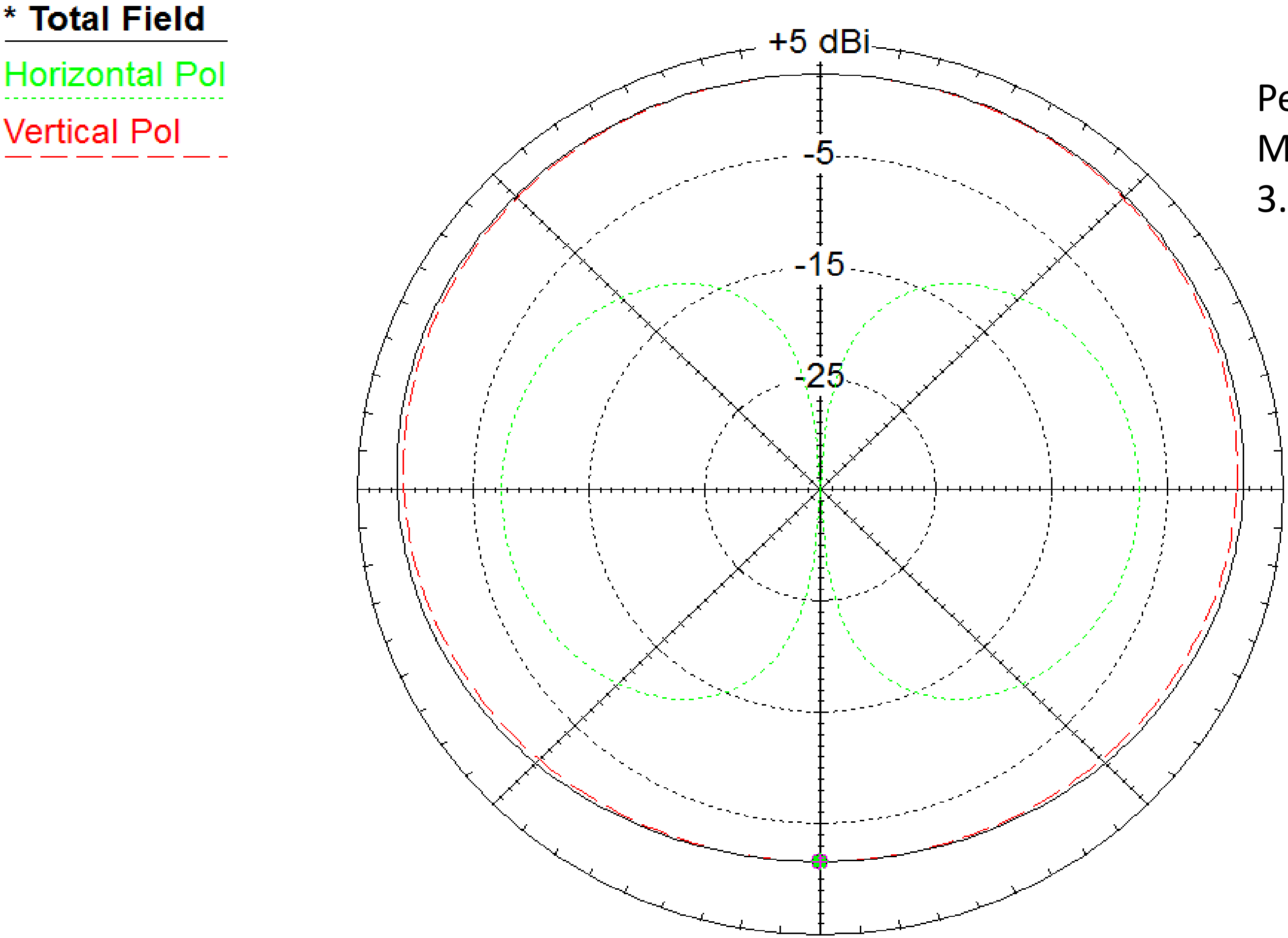
437 MHz

```
Azimuth Plot
Elevation Angle     -30.0 deg.
Outer Ring          5.0 dBi

3D Max Gain         3.33 dBi
Slice Max Gain      1.77 dBi @ Az Angle = 358.0 deg.
Front/Side          0.89 dB
Beamwidth           ?
Sidelobe Gain       1.77 dBi @ Az Angle = 182.0 deg.
Front/Sidelobe      0.0 dB
```

70 cm antenna pattern
conical (phi) cut at theta = 120 deg. (-30 deg. elevation

```
Cursor Az     90.0 deg.
Gain          0.88 dBi
              -0.89 dBmax
              -2.45 dBmax3D
```

Aug 5, 2012



EZNEC+

Peak gain = +2.3 dBi
Min. Gain = -1.6 dBi
3.9 dB variation

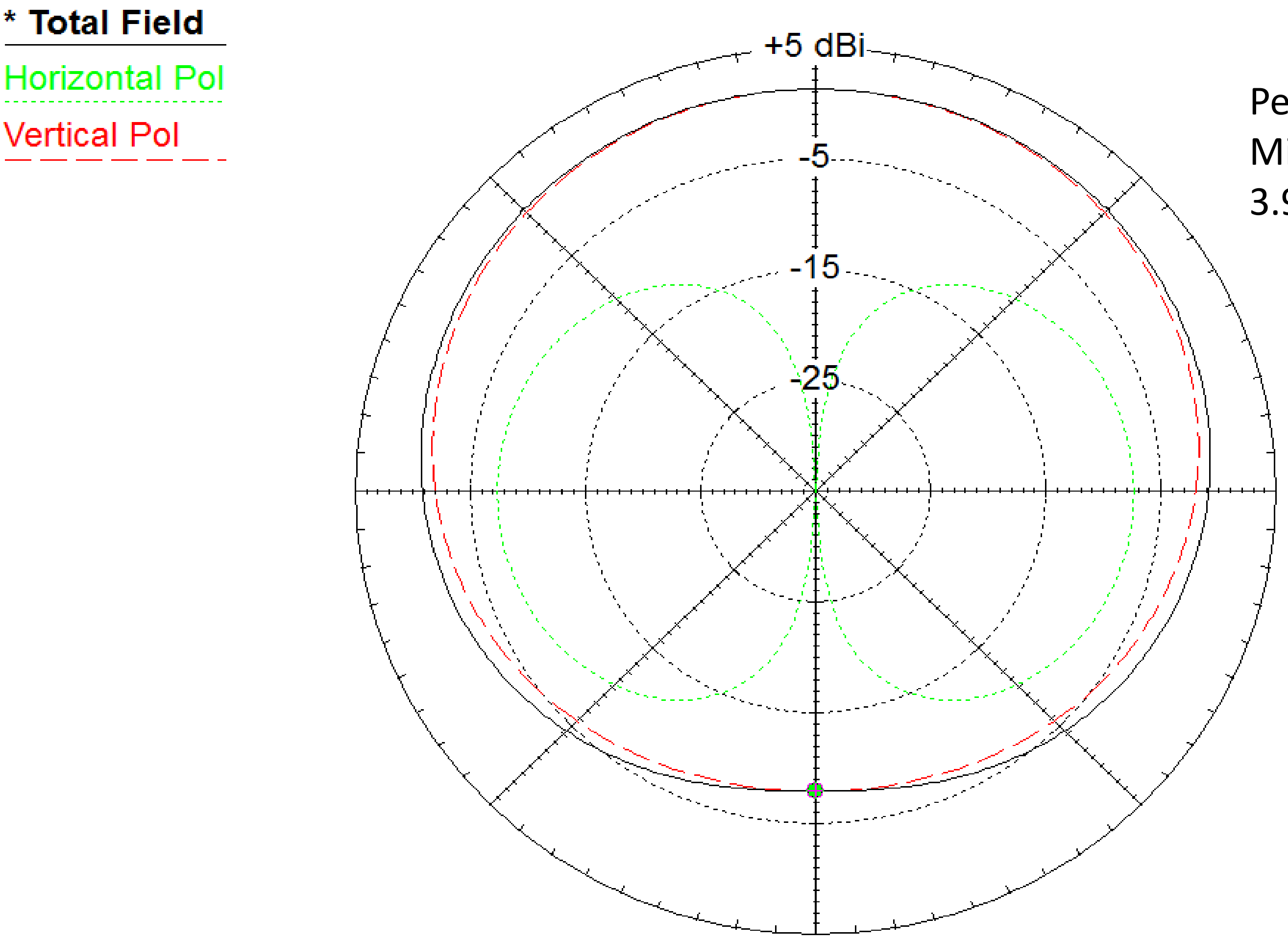
437 MHz

```
Azimuth Plot
Elevation Angle      -45.0 deg.
Outer Ring           5.0 dBi

3D Max Gain          3.33 dBi
Slice Max Gain       2.25 dBi @ Az Angle = 90.0 deg.
Front/Back           3.86 dB
Beamwidth            292.5 deg.; -3dB @ 303.7, 236.2 deg.
Sidelobe Gain        < -100 dBi
Front/Sidelobe       > 100 dB
```

70 cm antenna pattern
conical (phi) cut at theta = 135 deg. (-45 deg. elevation

```
Cursor Az       270.0 deg.
Gain            -1.61 dBi
                -3.86 dBmax
                -4.93 dBmax3D
```

Aug 5, 2012



Peak gain = +2.3 dBi

Min. Gain = -1.6 dBi

3.9 dB variation

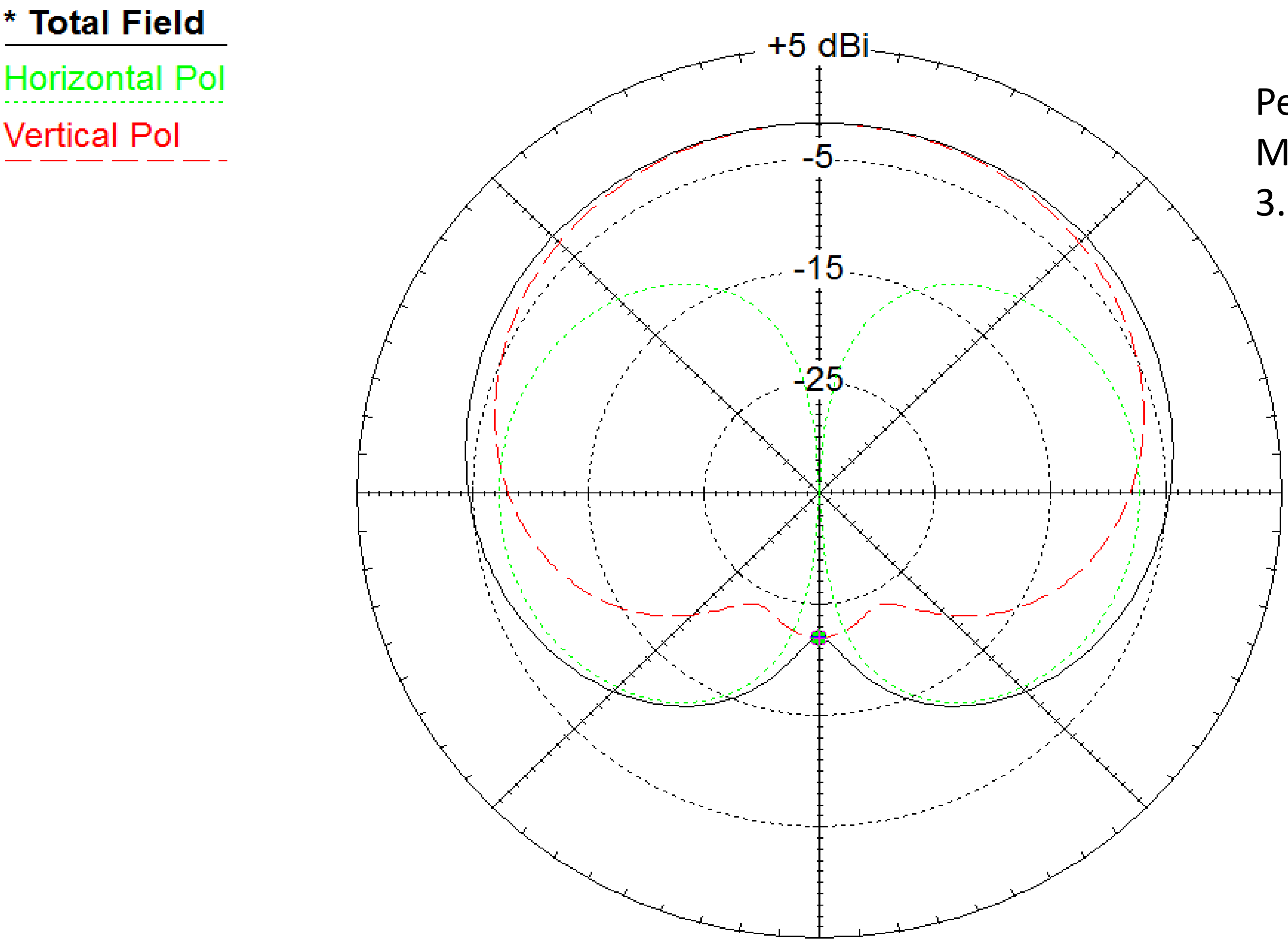
```
Azimuth Plot
Elevation Angle    -60.0 deg.
Outer Ring         5.0 dBi

3D Max Gain        3.33 dBi
Slice Max Gain     1.24 dBi @ Az Angle = 90.0 deg.
Front/Back         9.16 dB
Beamwidth          208.4 deg.; -3dB @ 345.8, 194.2 deg.
Sidelobe Gain      < -100 dBi
Front/Sidelobe     > 100 dB
```

70 cm antenna pattern

conical (phi) cut at theta = 150 deg. (-60 deg. Elevation)

```
Cursor Az    270.0 deg.
Gain         -7.92 dBi
             -9.16 dBmax
             -11.25 dBmax3D
```

Aug 5, 2012



Peak gain = +2.3 dBi

Min. Gain = -1.6 dBi

3.9 dB variation

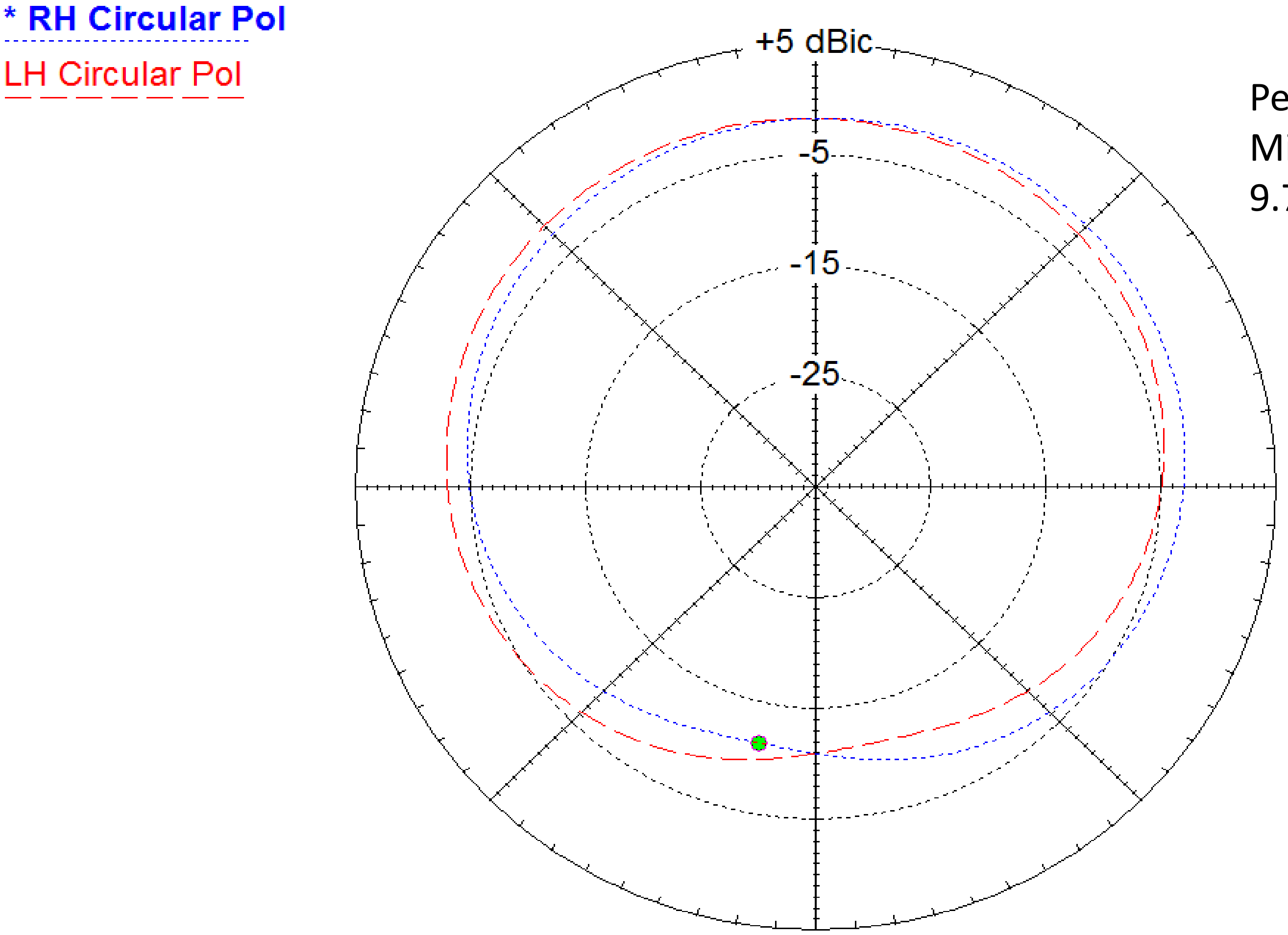
```
Azimuth Plot
Elevation Angle   -75.0 deg.
Outer Ring        5.0 dBi

3D Max Gain       3.33 dBi
Slice Max Gain    -1.82 dBi @ Az Angle = 90.0 deg.
Front/Back        20.18 dB
Beamwidth         183.5 deg.; -3dB @ 358.2, 181.7 deg.
Sidelobe Gain     < -100 dBi
Front/Sidelobe    > 100 dB
```

```
Cursor Az    270.0 deg.
Gain         -22.0 dBi
             -20.18 dBmax
             -25.32 dBmax3D
```

70 cm antenna pattern

conical (phi) cut at theta = 165 deg. (-75 deg. Elevation)

Aug 5, 2012



EZNEC+

Peak gain = -1.7 dBi

Min. Gain = -11.4 dBi

9.7 dB variation

437 MHz

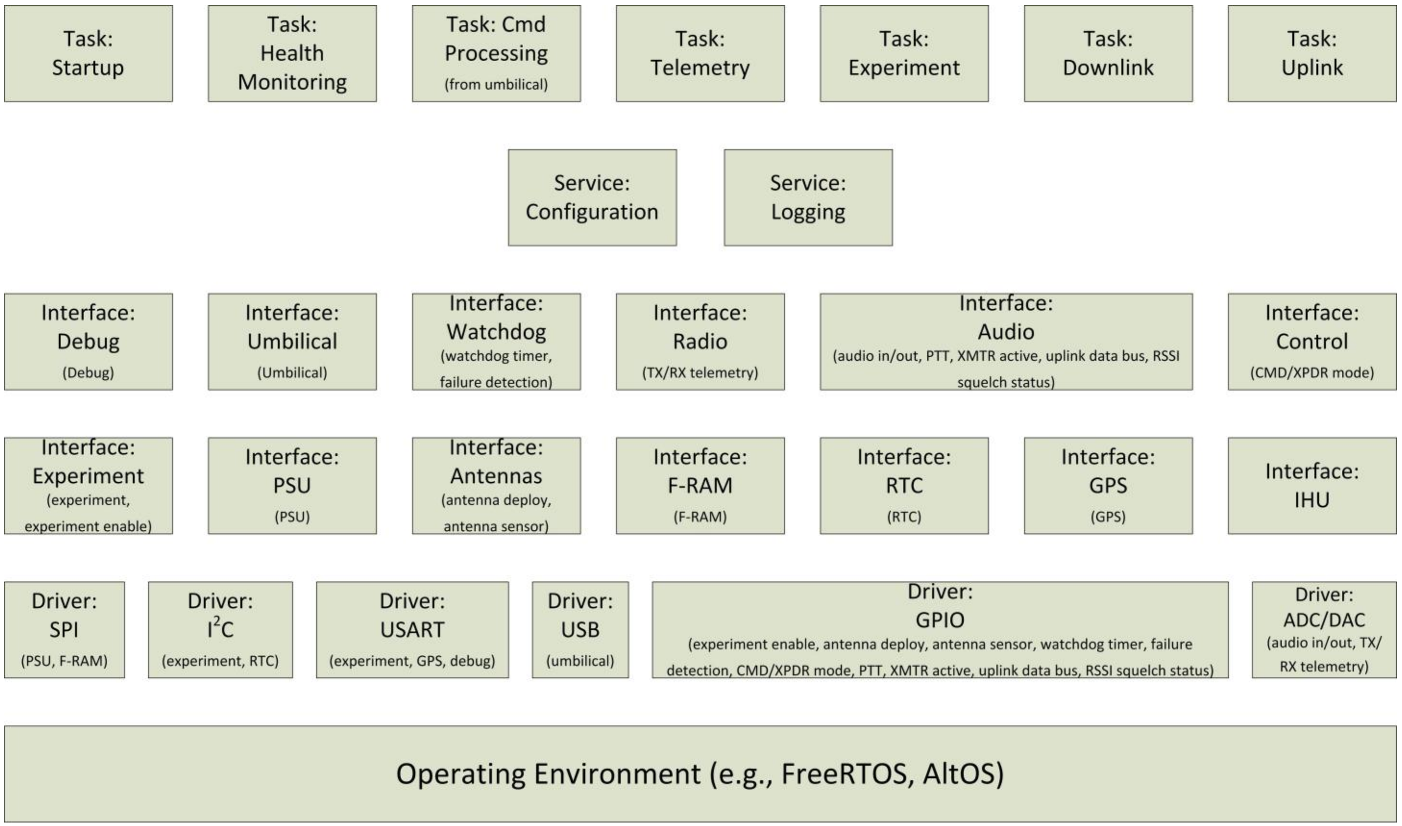
```
Azimuth Plot
Elevation Angle   -60.0 deg.
Outer Ring        5.0 dBic

3D Max Gain       0.32 dBic
Slice Max Gain    -1.63 dBic @ Az Angle = 65.0 deg.
Front/Back        9.24 dB
Beamwidth         201.1 deg.; -3dB @ 333.9, 175.0 deg.
Sidelobe Gain     < -100 dBic
Front/Sidelobe    > 100 dB
```

```
Cursor Az         258.0 deg.
Gain              -11.36 dBic
                  -9.73 dBmax
                  -11.68 dBmax3D
```

70 cm RHCP and LHCP antenna pattern
conical (phi) cut at theta = 150 deg. (-60 deg. Elevation)

FOX1 IHU SOFTWARE COMPONENTS

Version 1.0, April 1, 2012



Fox-1 Downlink Power Amplifier Prototype

Measurement results

Marc Franco, N2UO

August 17, 2012

Power supply voltage sweep

Frequency: 145.9 MHz

Temp.: 25°C

Pin: 12 dBm

Vcc	Current [mA]	Pout [dBm]	Pout [W]	Pdc [W]	Eff [%]
3.2	169	26.32	0.429	0.541	79.2
3.3	174	26.56	0.453	0.574	78.9
3.4	179	26.81	0.480	0.609	78.8
3.5	184	27.05	0.507	0.644	78.7
3.6	190	27.28	0.535	0.684	78.2
3.7	195	27.51	0.564	0.722	78.1
3.8	200	27.7	0.589	0.760	77.5
3.9	206	27.92	0.619	0.803	77.1
4	211	28.13	0.650	0.844	77.0
4.1	215	28.29	0.675	0.882	76.5
4.2	221	28.49	0.706	0.928	76.1

Temperature testing

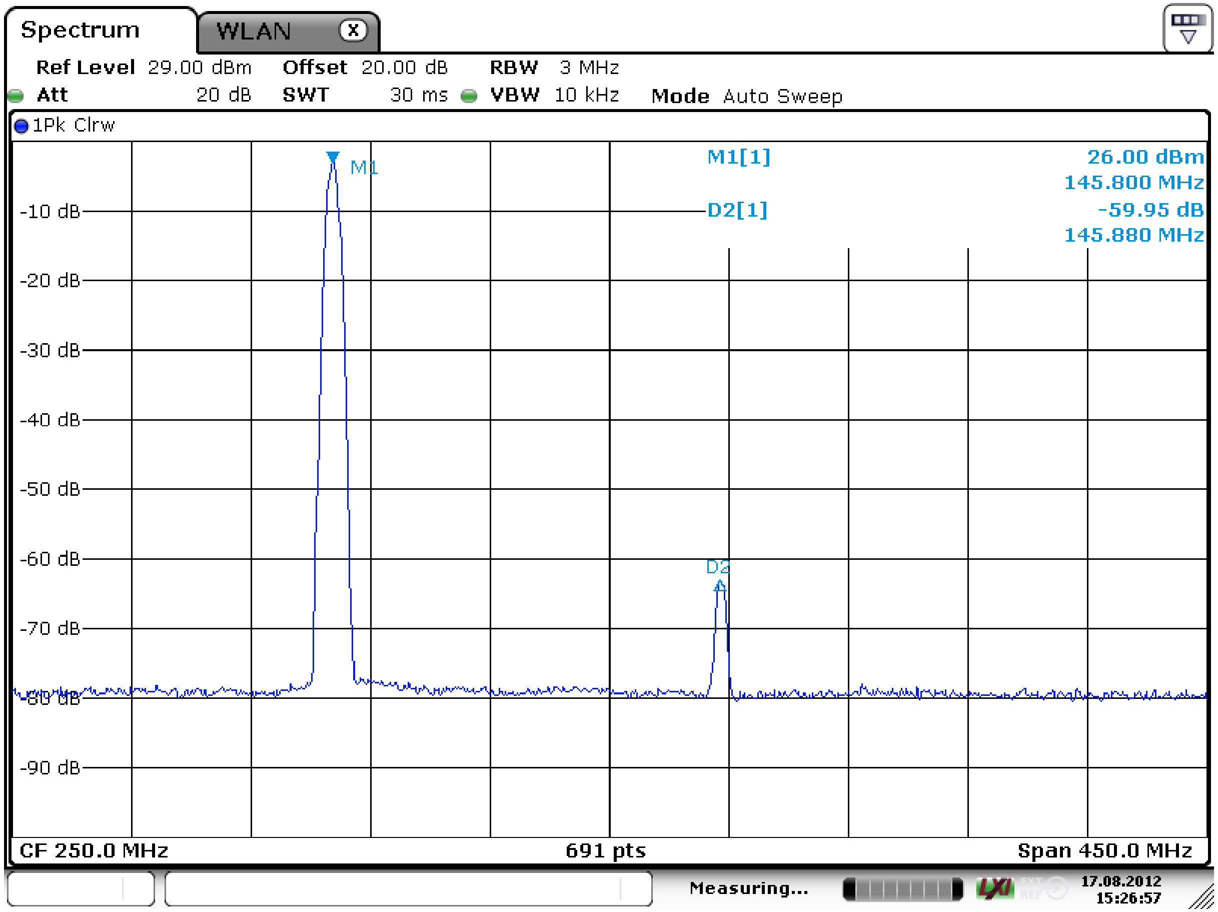
Frequency: 145.9 MHz

Vcc: 3.3 V

Pin: 12 dBm

Temp [°C]	2nd harm. [dBc]	Current [mA]	Pout [dBm]	Pout [W]	Pdc [W]	Eff [%]
-40	-59.4	181	26.92	0.492	0.597	82.4
25	-60.8	174	26.56	0.453	0.574	78.9
85	-60	166	26.19	0.416	0.548	75.9

Output spectrum



Ref Level 29.00 dBm Offset 20.00 dB RBW 3 MHz
Att 20 dB SWT 30 ms VBW 10 kHz Mode Auto Sweep

M1[1] 26.00 dBm
145.800 MHz
D2[1] -59.95 dB
145.880 MHz

CF 250.0 MHz 691 pts Span 450.0 MHz

Measuring... 17.08.2012 15:26:57

Date: 17.AUG.2012 15:26:56

- The third harmonic is guaranteed to be at least -75 dBc (below measurement capability)

Ruggedness and stability

- Test conditions:
  - Vcc: 3.3 to 4.2 V
  - Pin: 12 dBm
  - Load mismatch: short circuit, open circuit, various values in between

- Results:
  - No failure or degradation in performance after tests
  - No oscillations or spurs observed

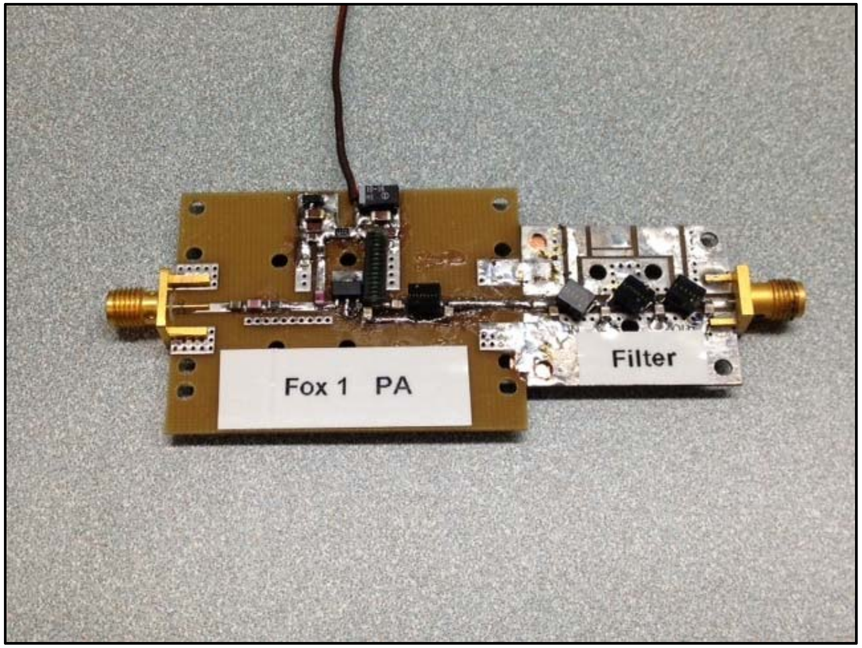
Future work

- Awaiting exciter board to perform interface with the amplifier

- A driver stage may be needed

- After integration is complete, more environmental and performance tests will be performed

- Final PCB layout, schematic and bill of materials will be generated after all the tests are complete



- Hand assembled prototype using existing PC boards

Receiving FOX-1 Satellite on 2 meters

Satellite Transmitter

Power	400.00	**mW**	minimum
Power (dBm0)	26.02	**dBm0**	
Antenna Gain	1.00	**dBi**	
EIRP	27.02	**dBm0**	

Path Loss

Orbit Altitude	650.00	**Km**	
Earth Radius	**6378.00**	**Km**	
Elevation Angle	10.00	**degrees**	= 0.174533 **radians**
Slant Range @ 0º	2951.93	**Km**	
Slant Range @ elevation angle	2045.33	**Km**	10.00 **degrees**
Slant Range @ 90º	650.00	**Km**	
Frequency	145.90	**MHz**	
wavelength	2.06E-03	**Km**	2 meters
Path Loss @ 0º elevation	-145.13	**dB**	
Path Loss @ elevation angle	-141.94	**dB**	10.00 **degrees**
Path Loss @ 90º elevation	-131.98	**dB**	

Ground Station

Antenna Gain	8.00	**dBi**	hand held "Arrow" antenna as measured by Central States VHF society
Rx Signal Level @ 0º elevation	-110.10	**dB**	
Rx Signal Level @ elevation angle	-106.92	**dB**	
Rx Signal Level @ 90º elevation	-96.96	**dB**	

Noise

Antenna Temperature	1000	**K**	
Receiver Noise Figure	6.00	**dB**	Kenwood D7 HT -122 dBm for 12 dB SINAD
Receiver Noise Temperature	864.51	**K**	
Total System Noise Temp	1864.51	**K**	
Receiver Bandwidth	15000.00	**Hz**	
Boltzmanns constant	**1.38E-23**	**J/K**	
Noise Power	3.86E-16	**W**	
Rx Noise Level	-124.13	**dBm0**	

Carrier to Noise Ratio

0º elevation	14.03	**dB**	
@ elevation angle	17.22	**dB**	10.00 **degrees**
90º elevation	27.17	**dB**	
C/N for 12 dB SINAD	4.00	**dB**	Kenwood D7 HT -122 dBm for 12 dB SINAD

Link Margin

0º elevation	10.03	**dB**	
@ elevation angle	13.22	**dB**	10.00 **degrees**
90º elevation	23.17	**dB**	

Fox-1 Experimental Payload

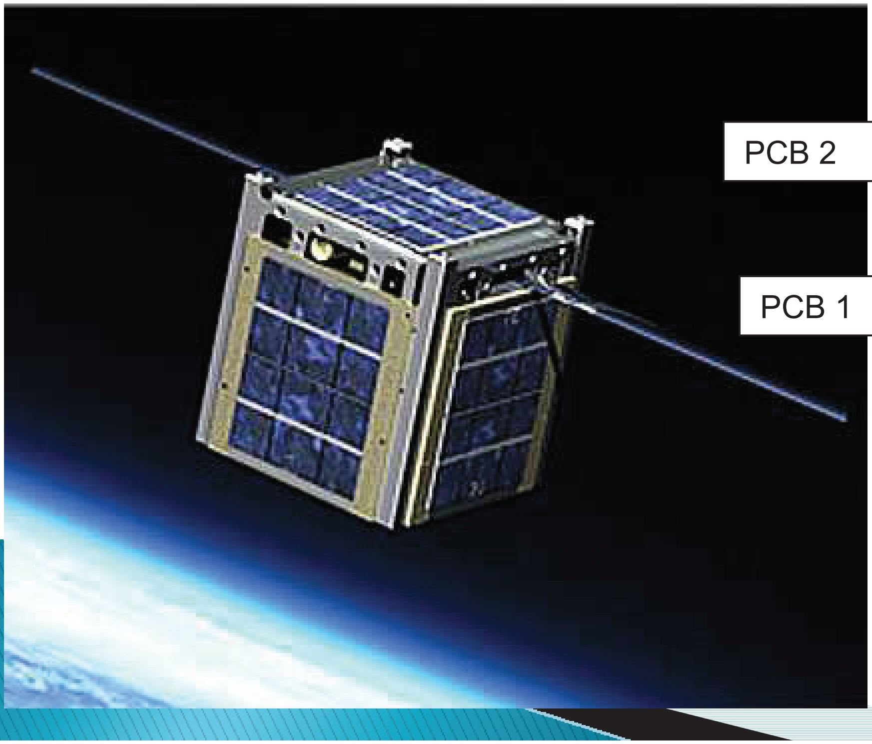
AMSAT

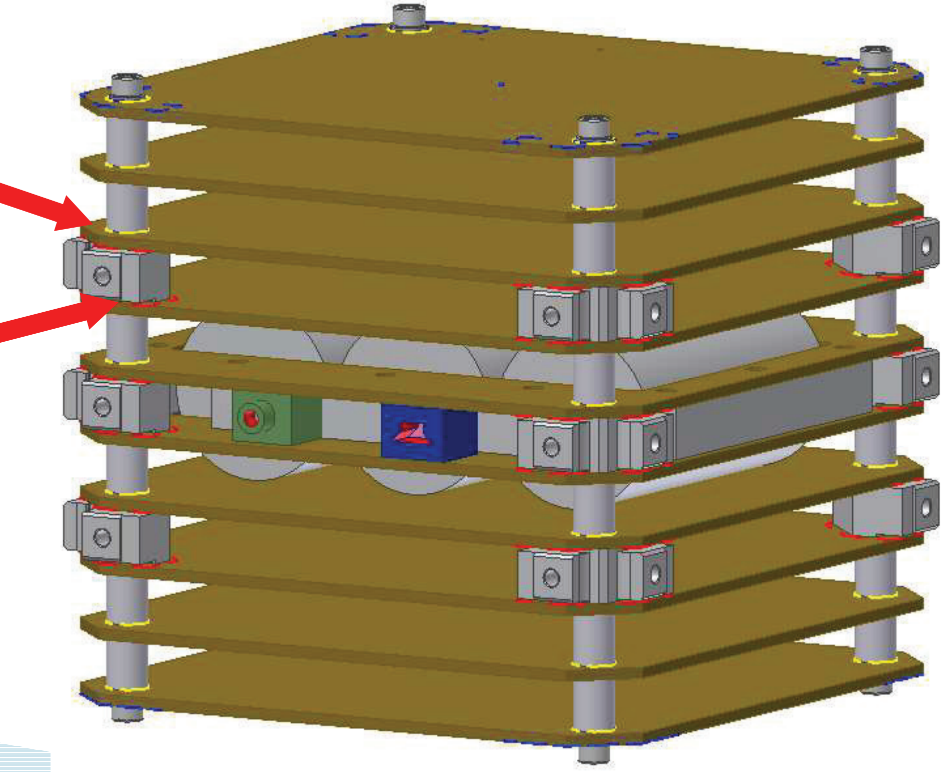
Faculty Advisor: Steven Strom
CoAdvisors: George Walters, Chris Coulston
Industrial Supervisor: Alexander Harvilchuck
Industry Sponsor: IBM

Mike Corona
Brandon Marvenko
Edward Pizzella

Introduction

- What is AMSAT?
- What is the experimental payload?
- NASA accepted
  - Fox Satellite project participating in the ELaNa program





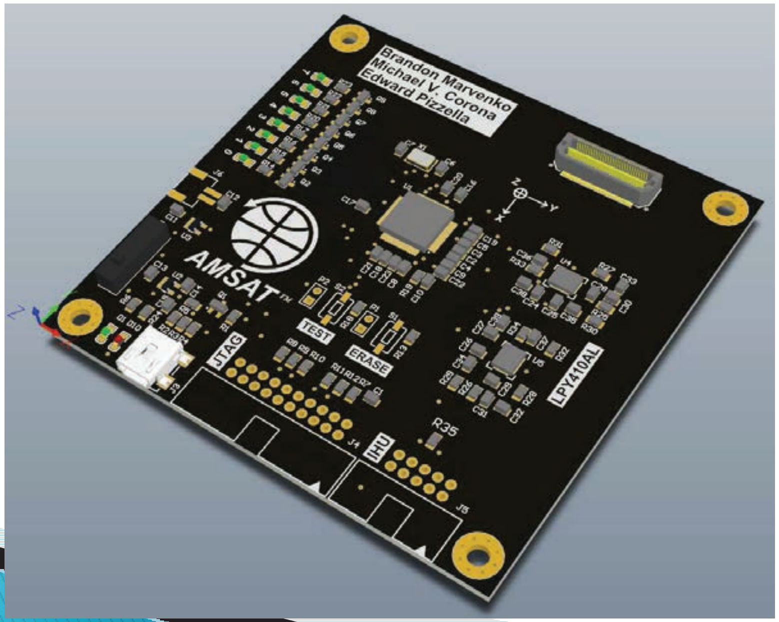
Engineering Requirements

- Receive and interpret commands from the IHU (Internal Housekeeping Unit) via SPI
- Average power consumption will not exceed 200mW
- Measure Spin Rate, Deviation, Up Time
- Respond correctly to IHU commands: Reset and Send
- PCB will conform to the internal dimensions of the 1U CubeSat chassis (10x10x10 cm)
- Withstand the launch and space conditions

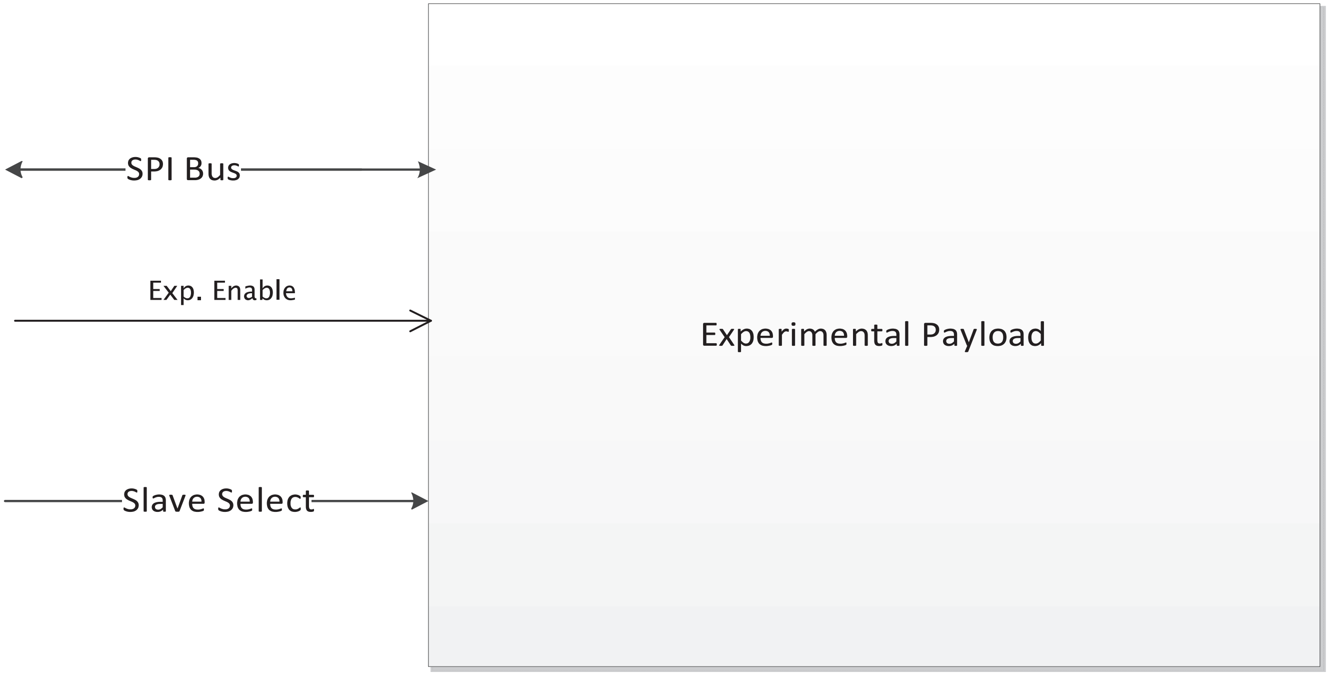
Design (Hardware)

- Completed Prototype
  - AT91SAM7 MCU
  - Various Interface Headers
  - Multiple Power Sources
  - Indicator LEDs
  - Two MEMS Gyros
  - J-TAG Header

- In Progress Flight Board
  - Final PCB
  - Similar to prototype
  - Four MEMS gyros for redundancy
  - Only high speed board-to-board connectors



Design – Level 0



SPI Bus

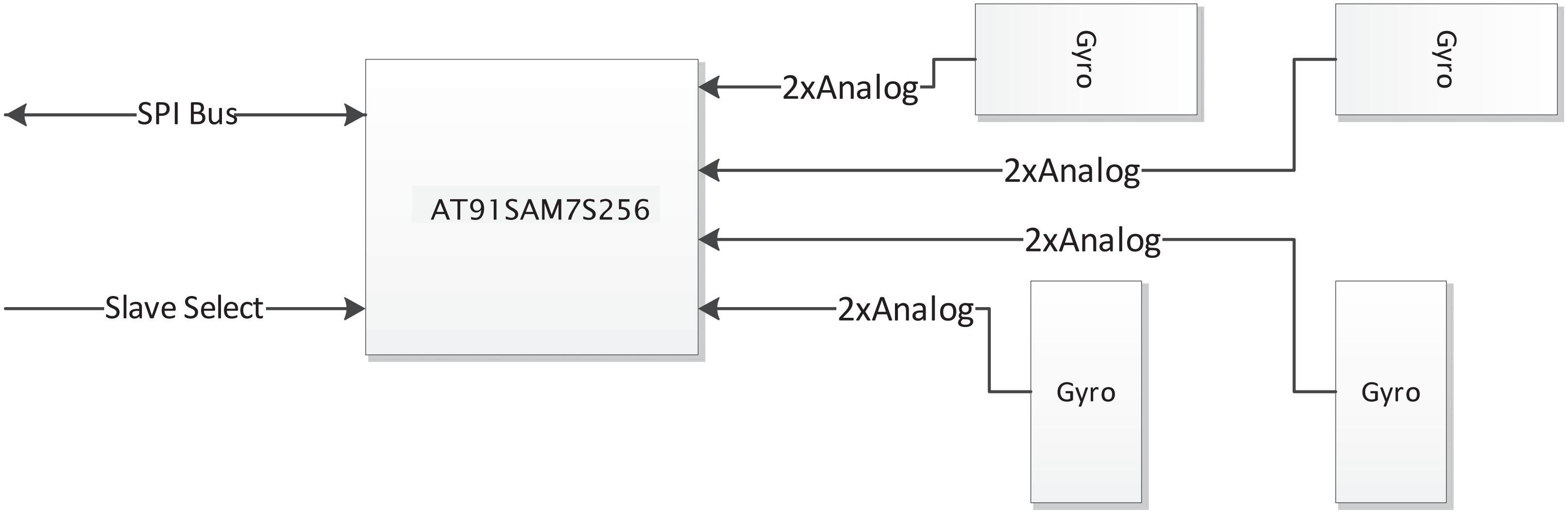
Exp. Enable

Slave Select

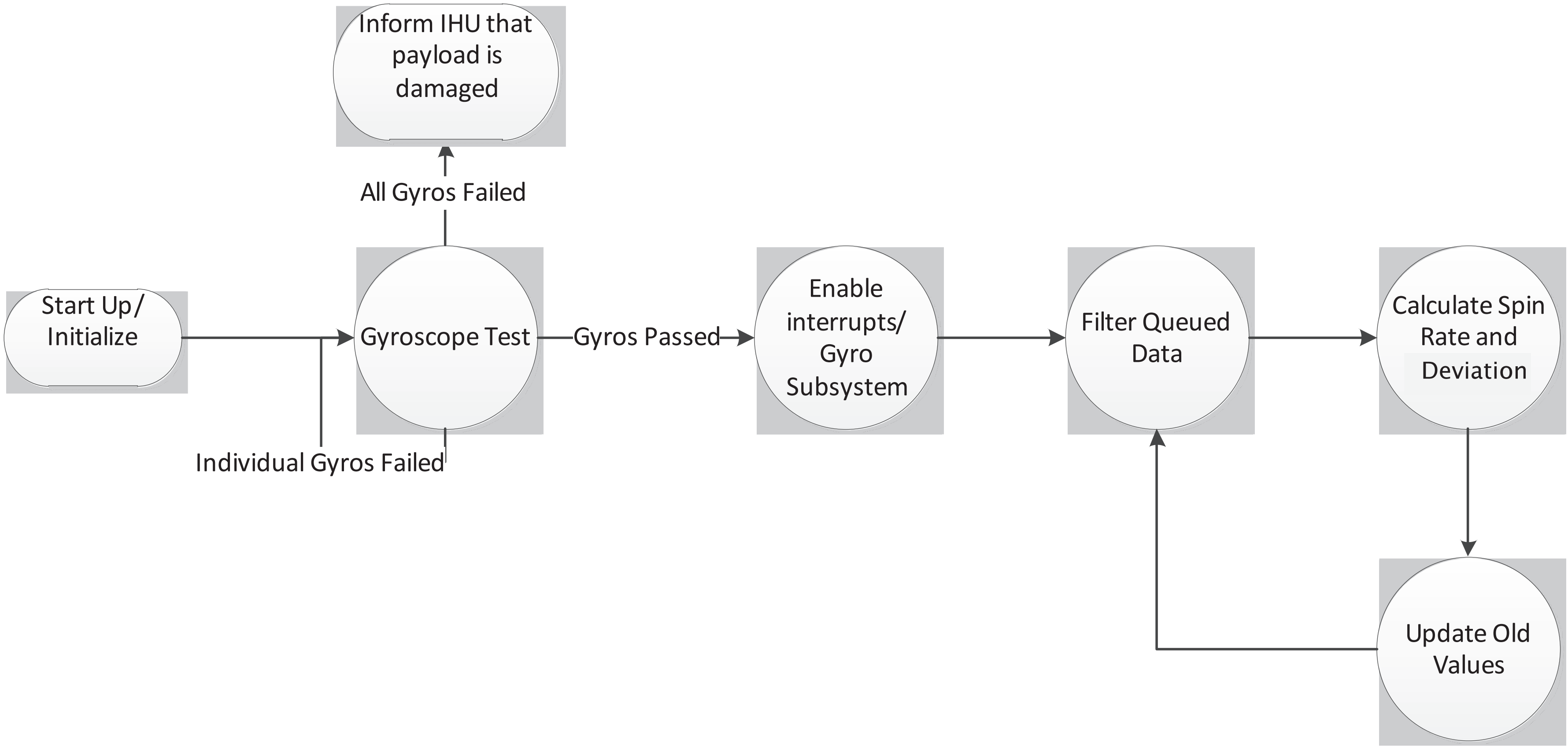
Experimental Payload

Design – Level 1

- ARM Microcontroller: AT91SAM7S256C
- Gyroscope: 2 axis analog output -> ADC

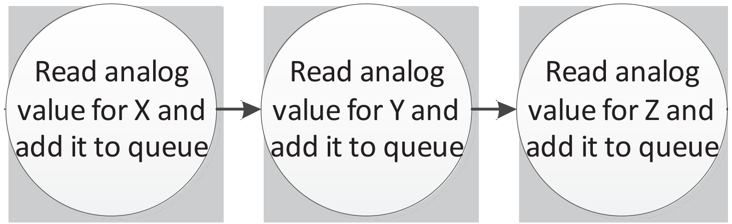


Main FSM

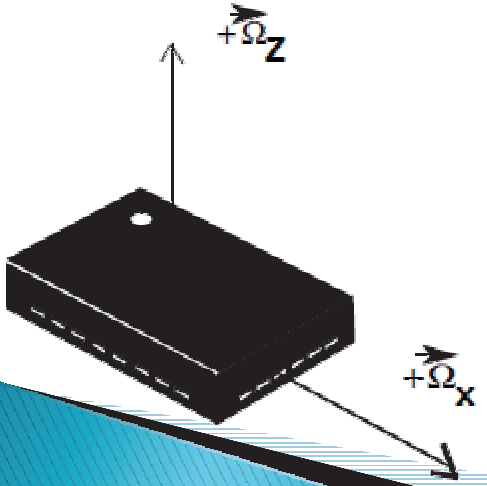

Inform IHU that payload is damaged
All Gyros Failed
Start Up/ Initialize
Gyroscope Test
Gyros Passed
Enable interrupts/ Gyro Subsystem
Filter Queued Data
Calculate Spin Rate and Deviation
Individual Gyros Failed
Update Old Values

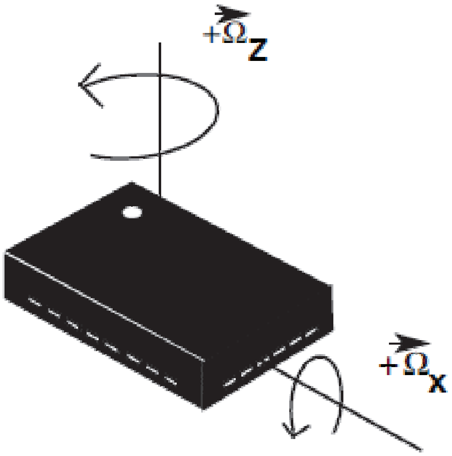
Gyro Subsystem FSM

- LPY410AL
- 2 Gyros in different orientations for all 3 axis
- 10 Hz Sampling rate

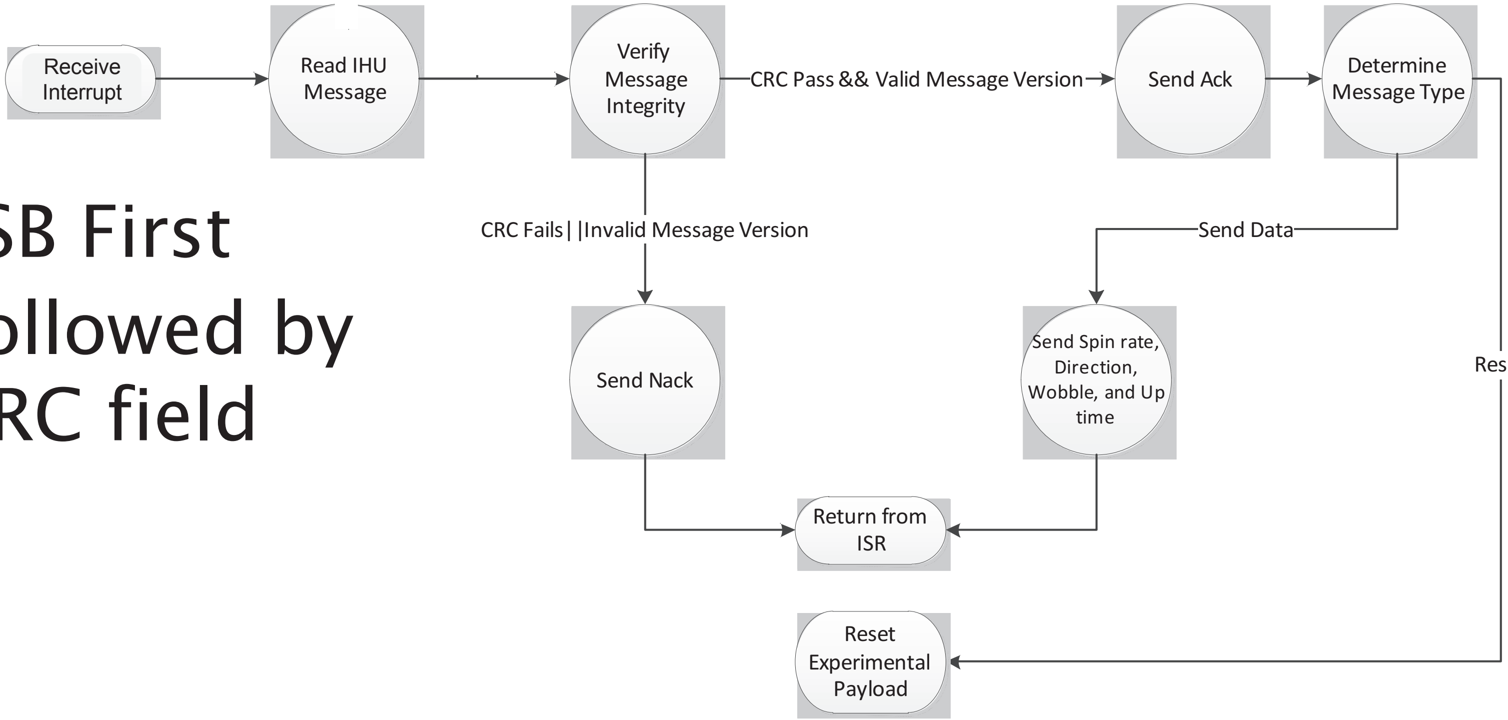


Read analog value for X and add it to queue → Read analog value for Y and add it to queue → Read analog value for Z and add it to queue





Communication ISR FSM



- LSB First
- Followed by CRC field

Field	Size (Bytes)	Type	Value	Description
SPIN RATE	2	Signed integer	Variable –50 to +50	Rate of spin of the satellite about the Z axis, in degrees per second. Negative indicates –X spin direction, positive indicates +X spin direction.
DEVIATION	2	Signed integer	Variable –50 to +50	Deviation (wobble) of +Z axis in degrees.
UP TIME	2	Signed integer	Variable 0–32767	Total seconds since experiment payload power–up or reset [FOX1:XSR:3.4.3]~

IHU to Experimental Payload Interface Control Diagram

IHU to Experimental Payload ICD

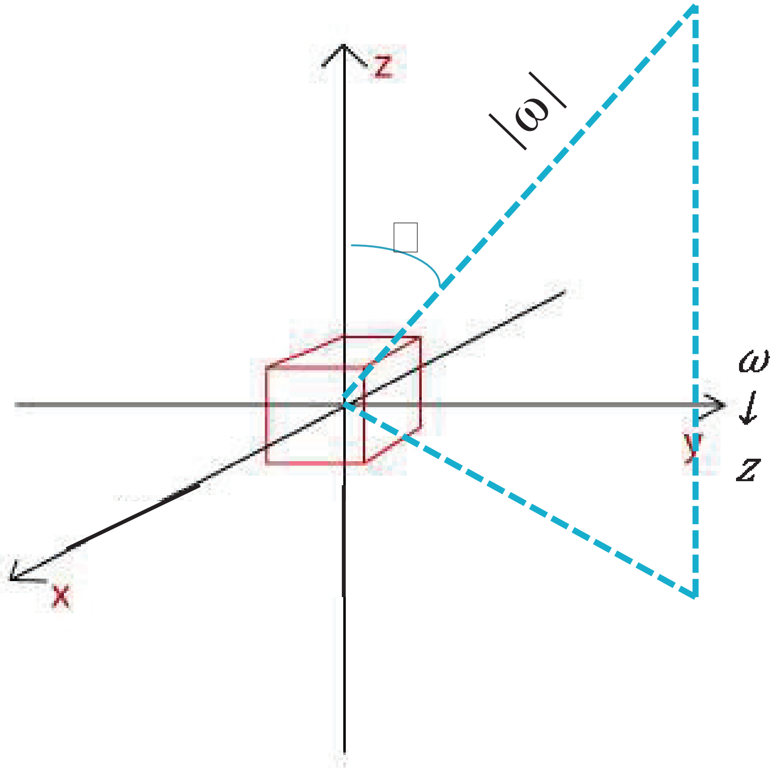
Message Header Block			Message Name Block	Message CRC Block
Start of Message	Message Version	Software Build	Name	CRC
4 Bytes 0xFFFFFFFF	2 Bytes Message ICD Version	2 Bytes Software Build Version	2 Bytes Message name (e.g. 0x0FA0 = "SEND")	2 Byte CRC-16-CCITT

Response

Data Block		
Spin Rate	Deviation	Up Time
2 Bytes Signed	2 Bytes Unsigned	2 Bytes Unsigned

Possible Name Blocks
RESET = 0x9F6
SEND = 0xFA0
DATA = 0xBB8
ACK = 0x7D0
NAK = 0x3E8

Deviation Algorithm

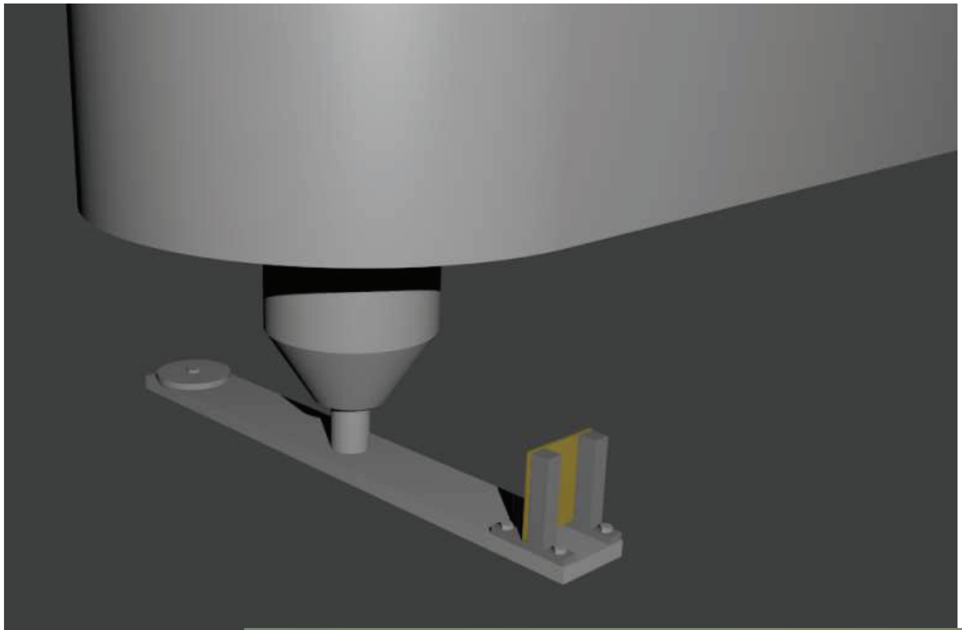


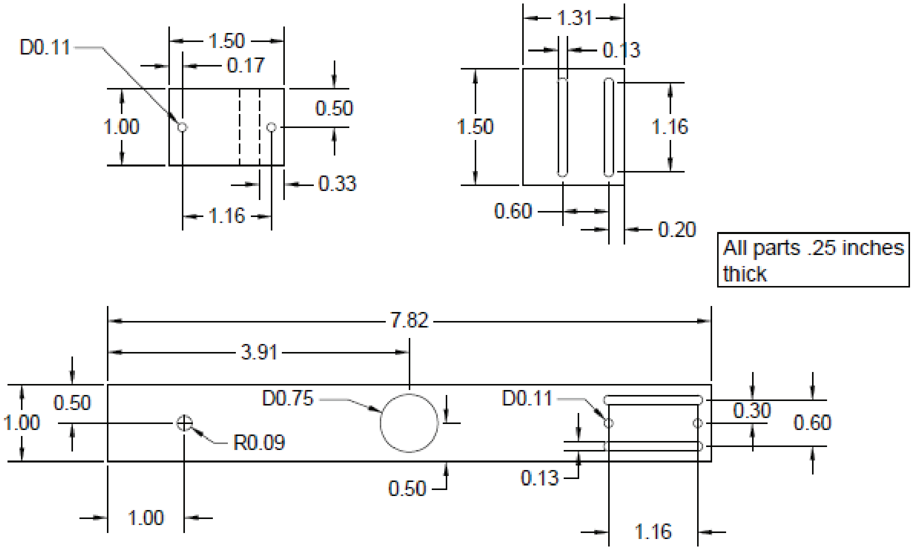
$\cos\theta = \omega\downarrow z \,/|\omega|$

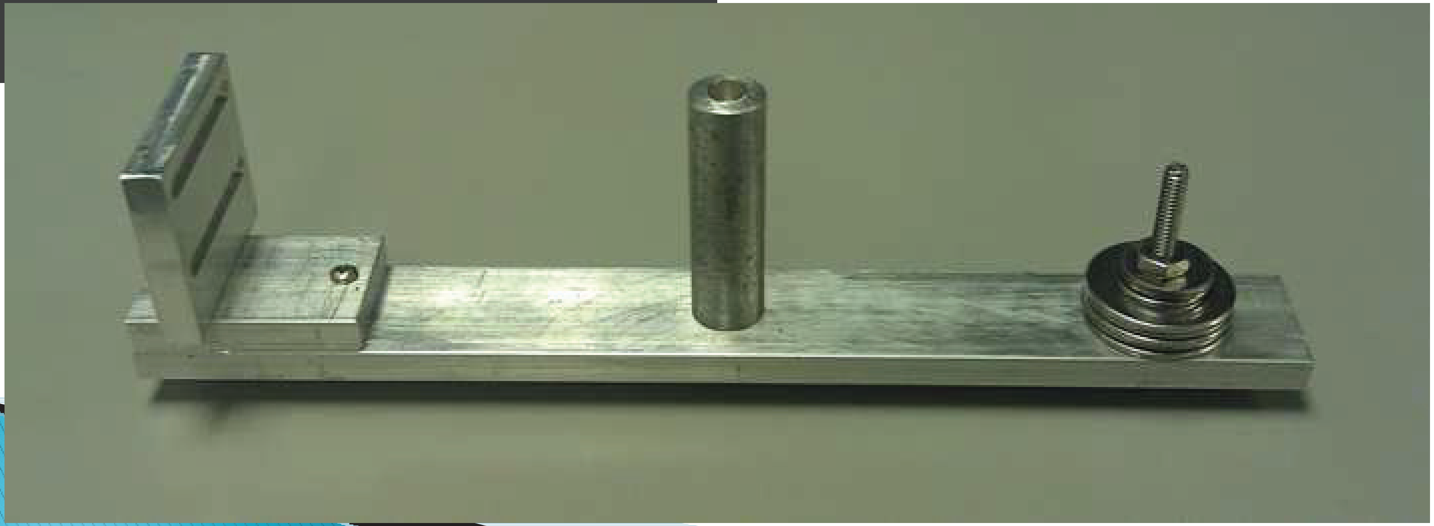
$|\omega| = \sqrt{}\omega\downarrow x + \omega\downarrow y + \omega\downarrow z$

$\theta = \cos\uparrow -1\ (\omega\downarrow z \,/\sqrt{}\omega\downarrow x + \omega\downarrow y + \omega\downarrow z\ \ ){*}1$

Centrifuge Test







Vibrations Test

Test Writer:	Mike Corona		
Test Case Name:	Vibration Unit Test	Test ID#:	Experimental Payload -9.1
Description:	The Experimental Payload must be capable of withstanding the vibration frequencies and amplitudes of launch provided by NASA	Type:	Black Box
Tester Information			
Name of Tester:	Team 1	Date:	
Hardware Ver:	Experimental Payload 1.0	Time:	
Setup:	The Experimental Payload system will be strapped to a shaker.		

Step	Action	Expected Result	Pass	Fail	N/A	Comments
1	Verify all components of the Experimental Payload system are on and working properly.	All Experimental Payload components are functioning.				
2	Place the Experimental Payload system on the shaker.	The Experimental Payload system will maintain the same position on the shaker.				
3	Set up the shaker to test the board at the vibration and amplitude provided by NASA	The system is programmed and ready to be run.				
4	Turn the shaker on and test the system for 5 minutes.	The Experimental Payload remains in the same position on the shaker.				
5	Power off the shaker after 5 minutes and remove the board.	The Experimental Payload is fully intact (no pieces have fallen off) and in the same condition as started.				
6	Communicate with the Experimental Payload and make sure the gyroscope still functions properly.	The Experimental Payload system still functions properly.				
Overall test result:						

AMSAT Fox-1 Systems Engineering Documentation

By Jerry Buxton, N0JY
Fox-1 Systems Engineer
n0jy@amsat.org

The AMSAT Fox program introduced a new engineering process for AMSAT in which engineering documentation is provided at each stage of development. We are archiving all of this documentation on an on-line, backed-up, version control server. When the satellite has been completed, we will have an archive of traceable documentation. This can serve as the basis for planning and executing future satellite programs and can be updated to apply the lessons learned of what went well and what did not.

AMSAT is a truly unique organization in that we are a non-profit corporation that manufactures satellites using a geographically distributed, all-volunteer engineering staff. There are no common or established guidelines to cover our situation. As such, the Fox program engineering practices are themselves an evolving process. The practices used are drawn from industry sources, especially NASA[1] and IEEE.

AMSAT has adopted a common industry scheme known as numbered requirements. Each individual requirement has a unique number assigned to it. The number allows a very precise reference to a specific requirement and this enhances the overall traceability of the specifications. The requirements are tracked throughout the documents using requirements tracking software, from the ConOps down to the test results, in order to verify that all requirements are properly implemented by the various systems that make up the satellite.

Due to US State Department ITAR[2] restrictions, our document server is only available to project members who have been vetted to meet the requirements for a "US-person." AMSAT, as an educational organization, would like to publicly release the majority of our design documentation to serve as a learning tool to anyone interested in satellite development. However, this must be done in a specific way to meet the ITAR requirements. The information must first be released via an openly available publication. We would also like to be able to discuss our satellite projects with our own members, some of whom are not "US-persons" per ITAR. These AMSAT Space Symposium proceedings provide a convenient mechanism for the needed publication in order to make this information public domain and allow us to communicate with our members.

While many of these documents were published in the *Proceedings of the AMSAT-NA 30th Space Symposium and AMSAT-NA Annual Meeting*, most of these documents have undergone changes as the satellite design has progressed and evolved and so they will be reproduced in these 2013 Space Symposium proceedings. In addition, these proceedings also present new engineering documents that have been produced since the last publication.

An introduction to these documents follows.

The ConOps document is the original form describing the expectations of the satellite. It is the governing document from which all development is derived.

The System Requirements Specification is a document that provides the top level technical specifications derived from the ConOps. This document describes what the system should do. The inputs, outputs, functions, mass, volume, environment and other external characteristics are included and specified in the system requirements. The level of detail for each requirement is specifically chosen to provide a clear definition of what the systems will do without too much specific detail or declaring how it will be done. This allows the engineers latitude in designing the best approach to satisfying the requirement.

The Avionics System Design Specification is a document that provides specific details of how the avionics system will be designed. The specifications are based on best design choices determined by the teams. The signals, connections, connectors, volume, and requirements specific to each system are stated in this document so that each system will fit together and function with the other systems.

The Experiment Payload Requirements are requirements written for the Penn State student designed attitude determination system. The actual system designed by the students was not constructed before their graduation. The experiment payload system design is incorporated onto the IHU board.

The Interface Control Documents (ICD) for the IHU to Attitude Determination Experiment, IHU to RF System, IHU to PSU, IHU to Battery, IHU to Experiment 1, and IHU to Experiment 4 set the requirements for connections and communication between the IHU and the various systems. Each of the systems sends telemetry measurements and other signals to the IHU. The IHU sends telemetry audio and control signals to the RF System and controls the experiments. The ICD allows the systems teams to work on their systems knowing that their systems will interface successfully.

The Downlink Specification Document sets the requirements for the downlink protocol and the data to be sent in the slow and high speed downlinks. This allows the satellite and ground station software teams to send the information to the ground and recover the data successfully.

The IHU Software Architecture Specification provides the design specifications needed for the software design and operation of the Internal Housekeeping Unit.

The engineering documents published in these proceedings are what was available at time needed for inclusion and we hope you find them interesting and informative. AMSAT intends to continue to make the majority of the final technical documents, exclusive of satellite control information, available in future publications.

---

[1] NASA Systems Engineering Handbook, NASA/SP-2007-6105 Rev1

[2] International Traffic in Arms Regulations, see: http://www.pmddtc.state.gov/regulations_laws/itar_official.html

Date: October 19, 2011
Version: 1.03

AMSAT *Fox-1* Satellite
Concept of Operations

1 Introduction

The AMSAT *Echo* satellite, also known as AO-51, has been the most widely used amateur satellite due to its ability to provide basic radio communications with very simple ground station equipment. It provides an FM repeater function that has very wide geographical coverage allowing amateur radio operators to communicate over substantial distances using just a handheld transceiver (i.e. a *walkie-talkie*) and a small handheld antenna. This type of satellite operation is often referred to as the *EasySat* mode due to its simplicity. It is extremely valuable in providing an introduction to satellite communications and is often used for demonstrations given at schools, to scouting organizations and at amateur radio publicity events.

After 6 years of service, *Echo* is nearing the end of its life due to battery failure. For the sake of our space education and outreach activities, it is essential that AMSAT quickly provide a replacement for *Echo* that can continue to provide access to the *EasySat* mode. The *Fox-1* satellite is intended as this replacement.

Building on a harsh lesson learned from *Echo* and inspired by the longevity of AO-7[1], the *Fox-1* satellite project will introduce the concept of *designed-in,* partial-failure operation. The satellite will be specifically designed so that when the battery fails, the transponder can continue to operate when the satellite is in sunlight. Similarly, the satellite will be designed so that the FM transponder can operate without relying on ground control or a functioning processor in the IHU. These modes are intended to extend the usable life of the satellite.

In addition to its primary mission as a communications satellite, the *Fox-1* satellite will host an experiment payload. Over the past two academic years, AMSAT has sponsored senior design *capstone* projects to engage university students in a real-world engineering experience. The AMSAT projects have focused on aspects of CubeSat design and construction. Building on this success, one of the AMSAT sponsored student projects for the 2011-2012 academic year at Penn State University will be to provide the experiment payload that will be flown on the *Fox-1* satellite. This experiment is a technology investigation that is of interest to AMSAT.

Our previous spacecraft have often used passive magnetic attitude stabilization. While the results have been satisfactory, we have no actual data on how well this mechanism works. Large spacecraft with much higher power budgets have a substantially larger margin of error with little ill effect. But the error in the stabilization of the antenna system on a CubeSat is far more of a concern since the transmitter power is very limited. Additionally, we have typically had to analyze the telemetry data on the ground to try to ascertain the satellite spin rate about its magnetic axis. The objective of the student experiment is to directly measure the satellite spin rate and direction as well as the "wobble" about the magnetic axis using a 3-axis micro electro-magnetic gyroscope and to provide this information in telemetry to the ground.

AMSAT expects to submit a proposal to the NASA ELaNa[2] program for a low-cost launch of this satellite. Proposals will be due in November of this year. If accepted, the launch would be in the 2013 time frame. While AMSAT believes that this project would nicely address the goals and objectives of the NASA program, there can be no guarantee that the proposal will be accepted. However, AMSAT would still be free to purchase a market-rate launch of this satellite through any of the CubeSat launch integrators such as Cal-Poly.

1.1 Document History

DATE	VERSION	SUMMARY
Sept 20, 2011	1.00	Base Version
October 8, 2011	1.01	Req. 3.3 updated to 45 min. for NASA LSP-REQ-317.01, added ref. to NASA LSP-REQ-317.01 in sec. 5, added document history in 1.1
October 9, 2011	1.02	Added Requirements Tracking
October 19, 2011	1.03	Update information on student experiment

1.2 Program Goals and Objectives

The AMSAT Fox-1 satellite program is intended to:

1. Provide an on-orbit FM transponder to allow wide-area communications between amateur radio operators using simple ground-station equipment.
2. Develop a 1U CubeSat design that can host an experiment payload.
3. Promote closer relationships with universities including student development of satellite components and subsystems.
4. Implement a new engineering process that will improve AMSAT's ability to plan, manage and finance satellite projects.
5. Implement an engineering process that will meet the requirements for submission of proposals to the NASA ELaNa program.
6. Provide required software needed by the AMSAT Operations team to operate the satellite in orbit and to collect and archive telemetry and experiment data.
7. Complete the satellite development in time for a 2H 2013 launch.

1.3 Mission Overview

The primary mission of the satellite is to provide a wide-area, amateur radio communications capability that can be accessed using very simple ground station equipment such as a handheld FM transceiver paired with a small, handheld beam antenna. The satellite communications transponder will employ analog, narrow-band FM like that typically used on the amateur radio VHF and UHF bands. The satellite is expected to support the primary mission for at least 5 years in orbit.

The secondary mission of the satellite is to host an experiment payload. The radio communications capabilities of the satellite will be used to uplink control commands for the experiment as needed and to downlink data collected from the experiment to ground stations.

1.4 Document Scope

The purpose of this Concept of Operations (CONOPS) document is to describe the satellite system and how it will be used. This is not a requirements document but provides operational context that should be helpful in developing and understanding system requirements and interface specifications.

2 System Description

2.1 Spacecraft

The *Fox-1* satellite is expected to have the following features and characteristics:

- 1 Unit CubeSat
- 650 km, sun-synchronous, circular orbit
- FM analog transponder
- 400 mW or greater RF power output
- Uplink on 70 cm band
- Downlink on 2 meter band
- Experiment payload
- Permanent magnetic stabilization
- Deployable antennas (no other deployables)
- Fixed solar panels on all 6 sides for power
- Rechargeable battery to support operation during eclipse
- Simple IHU based on a 16-bit microcontroller
- Proprietary scheme for control uplink
- FSK for sending telemetry and experiment data

This list is preliminary and is subject to change. Please note that this CONOPS is not the controlling document for satellite technical specifications.

2.2 Telemetry and Experiment Data

Telemetry data consists of monitored points that provide a measure of the satellite health. The satellite will autonomously measure these points and transmit them on the downlink.

Experiment data will be collected as per the requirements of the experiment and will be stored and/or transmitted as needed.

The telemetry and experiment data, will be transmitted in the clear allowing any ground station to receive it. The information needed to demodulate and decode the downlink signal will be placed in the public domain. An open-source, software package for decoding the telemetry and experiment data will be made available by AMSAT.

2.3 Satellite Commands

The satellite will accept commands from a control station. These are used to control the mode and operation of the satellite. Commands are intended to be limited to use by authorized stations only. Private codes and/or unpublished information will be required to command the satellite.

2.4 Ground Control Stations

It is expected that control stations will not require any specialized radio equipment but may need to be able to generate higher radiated power levels than typical for users in order to gain control of the satellite. This could be accomplished with a high-gain Yagi antenna and/or a high-power amplifier.

In order to command the satellite, specialized software will likely be required. This software will be provided as part of the satellite development effort.

2.5 Amateur Radio User Stations

This satellite will use radio standards commonly used on the amateur radio VHF and UHF bands and will not require any specialized equipment for normal operation. A handheld, dual-band FM transceiver paired with a small hand-held Yagi antenna should be considered a typical user station. Operation with fixed, omni-directional antennas should also be possible with typical amateur radio base and mobile transceivers.

3 Satellite Operational Modes

3.1 Quiescent Mode

This mode will be used when the satellite is flight ready but has not yet been integrated into the deployer (P-POD.) A "*Remove Before Flight*" pin, inserted into its receptacle on the satellite, will disconnect the battery and prevent any operation of the avionics.

3.2 Deployer (P-POD) Mode

After the satellite is integrated with the deployer, the "*Remove Before Flight*" pin will be pulled but deployment switches on the satellite will prevent power-up of the avionics. In this mode, a test umbilical cable can be connected to a port on the satellite which will allow the avionics to be powered, the battery to be charged and diagnostic tests to be run. Once a CubeSat has been integrated with its deployer and the launch acceptance tests have been run, the only way to know if a satellite is still functional is via these diagnostic tests. Therefore, the diagnostics should be as thorough as possible within the limitations of the deployer environment.

3.3 Startup Mode

When the satellite is released in orbit, the deployment switches on the satellite will be activated allowing the satellite to power up. At this point, the satellite will enter Startup Mode. The satellite will time a 45-minute interval and then deploy the antennas. This delay is required by the CubeSat Design Specification. After deploying the antennas, the satellite will enter Transponder Mode.

3.4 Transponder Mode

In Transponder Mode, signals appearing on the uplink will be repeated on the downlink. Amateur radio user stations can use the satellite for general communications with each other. The satellite will simultaneously send telemetry data on the downlink using the frequency spectrum below the audible range so as not to interfere with transponder communications.

The satellite will also monitor the uplink frequency for a command from a control station. A control station can command the satellite to enter Command Mode**.**

3.5 Command Mode

Command Mode is intended to support experiments that require more satellite resources than can be provided in Transponder Mode. This would include more power and higher downlink data rates.

In Command Mode, signals appearing on the uplink will not be repeated on the downlink. The satellite will use the downlink exclusively to send telemetry and experiment data. It will also monitor the uplink for commands from a control station.

After 24 hours, the satellite will automatically return to Transponder Mode unless another command is received. For multi-day experiments, a control station would need to send a command at least once a day to the satellite to keep it in Command Mode. A control station can also directly command the satellite to enter Transponder Mode**.**

3.6 Transmitter Inhibit

In order to meet FCC requirements, the satellite will accept a control station command to inhibit the transmitter regardless of the operating mode. Once inhibited, the transmitter will not be activated under any conditions but the satellite will continue to monitor the uplink for commands. A control station can send a command to remove the inhibit and re-enable the transmitter.

3.7 Partial Failure Operation

Partial failure tolerance is intended to extend the usable life of the primary mission of the satellite. An experiment may or may not be operable under a partial failure scenario.

3.7.1 Battery Failure

If the battery deteriorates or fails completely including a short circuit, the satellite will continue to operate on its solar panels while in the sun. In eclipse, the satellite may power down. When back in sunlight, the satellite will automatically enter Transponder Mode.

3.7.2 IHU Processor Failure

The satellite will operate in Transponder Mode by default and will not require intervention from a ground control station. If the processor on the IHU fails, there may be limited control of the satellite and limited or no telemetry data available but the transponder will continue to operate.

4 Mission Operations Overview

The AMSAT operations and engineering teams will work together to commission the satellite after launch. Commissioning is expected to last for only a few days to insure the satellite is operating nominally. After commissioning, the satellite will be turned over to the operations team. It is expected that the operations team would then open the satellite for general communications use by any licensed amateur radio station.

When required for experiment operation, an authorized control station can command the satellite to enter Command Mode. This will turn off the repeater function and enable the transmission of the telemetry and experiment data. When this data transfer has been completed, the authorized control station can command the satellite to return to Transponder Mode.

It is expected that the AMSAT operations team will collect and archive all telemetry and experiment data and make it freely available on the Internet.

5 Reference Documents

1. CubeSat Design Specification Rev. 12. by The CubeSat Program Cal Poly SLO available from: http://www.cubesat.org/images/developers
2. ITU Radio Regulations, Edition of 2008. available from http://www.itu.int/publ/R-REG-RR-2008/en
3. Launch Services Program, Program Level Poly Picosatellite Orbital Deployer (PPOD) and CubeSat Requirements Document LSP-REQ-317.01 Revision Basic (from NASA)

---

[1] AMSAT OSCAR 7 (AO-7) was launched in 1974 and failed in orbit in 1981 when its battery short-circuited. In 2002, at least one of the battery cells opened up allowing the satellite to resume operation when the solar panels are illuminated. As of July 2011, after 37 years in space, AO-7 continues to be operational in sunlight.

[2] Information on the NASA Educational Launch of NanoSatellites (ELaNa) program can be found on the NASA web site: http://www.nasa.gov/offices/education/centers/kennedy/technology/elana_feature.html

Date: August 20, 2013
Version: Version 1.4

AMSAT *Fox-1*

System Requirements Specification

1 Introduction

This document specifies the system level technical requirements for the AMSAT *Fox-1* satellite project. This 1 Unit CubeSat is a part of the AMSAT Fox program and includes a subset of the technical capabilities envisioned for the overall program.

Fox-1 is specifically intended as a replacement for the failing AMSAT *Echo* (i.e. AO-51) satellite. *Echo* has been the most widely used amateur satellite due to its ability to provide basic radio communications with very simple ground station equipment. Its FM repeater provides very wide geographical coverage allowing amateur radio operators to communicate over substantial distances using just a handheld transceiver (i.e. a *walkie-talkie*) and a small handheld antenna. This so called "*EasySat*" mode is extremely valuable in providing an introduction to satellite communications and is often used for demonstrations given at schools, to scouting organizations and at amateur radio publicity events. *Fox-1* will not duplicate all of the features and modes of Echo but its primary mission is to provide an FM Transponder in order to allow continued access to this *EasySat* mode of communications.

In addition to its mission as a communications satellite, *Fox-1* will host an experiment payload. The satellite will reserve mass and volume for the experiment and will provide DC power and a communications facility. The experiment is expected to be provided by students at Penn State University – Erie through an AMSAT sponsored senior design project.

1.1 Document History

DATE	VERSION	SUMMARY
October 5, 2011	1.0	From Draft E
October 8, 2011	1.01	Fix typos in sections 1.2 and 3.5
October 9, 2011	1.02	Add Requirements Tracking
October 23, 2011	1.03	Additional Requirements Tracking
February 21, 2012	1.04	Update Section 3 and Formatting changes
April 18, 2012	1.05	Correction in Section 4
April 22, 2012	1.06	Correct link in Section 1.4 item 2
April 29, 2012	1.1	Revised 3.12.3, 3.12.7, 3.12.8, 3.13.3, 3.13.4, figure 1 to remove RESET and add IHU OFF and IHU ON commands
August 2, 2012	1.11	Added hidden text for requirements tracking to be shown in System Design Specification
September 4, 2012	1.12	Added the previously missing “Table 6” label
October 17, 2012	1.2	Changed mode descriptions in 3.13.1 Table 6; changed 3.9.2, 3.9.3, 3.9.4, 3.9.5, 3.9.6, 3.9.7 to reflect IHU involvement; changed COMMAND MODE to DATA MODE
April 25, 2013	1.3	3.10.2 Remove PA Temperature, add TX T as RF Transmitter Temperature, OSC T as referring to TX oscillator no longer measured changed to read RX oscillator only
August 20, 2013	1.4	Requirements 3.5.5, 3.6.1, 3.9.6, 3.10.2, 3.11.1, 3.12.4, 3.12.6, 3.13.7.1, 3.13.7.2, 3.13.8, 3.13.9 modified, removed or added to reflect the evolving satellite design

1.2 Document Scope

The purpose of this document is to specify the technical requirements of the satellite at the system (i.e. "black box") level. It is intended to be used by the hardware, software and mechanical designers to develop the architecture/high-level design specifications. It is also intended to be used for test planning and development.

1.3 Document Format

This document provides the requirements in numbered format. Each requirement is assigned a unique number. Additional information such as comments or examples that are provided for guidance or clarity is *italicized* to distinguish them from requirements.

1.4 References

1. AMSAT *Fox-1*, Concept of Operations, Version 1.0, September 19, 2011
2. CubeSat Design Specification Rev. 12. by The CubeSat Program Cal Poly SLO available from: http://www.cubesat.org/images/developers/cds_rev12.pdf
3. Launch Services Program, Program Level Poly Picosatellite Orbital Deployer (PPOD) and CubeSat Requirements Document LSP-REQ-317.01 Revision Basic (from NASA)
4. ITU Radio Regulations, Edition of 2008. available from http://www.itu.int/publ/R-REG-RR-2008/en

2 General Requirements

2.1 CubeSat Requirements

2.1.1 The satellite shall meet the requirements specified in the CubeSat Design Specification Rev. 12.

2.1.2 The satellite shall meet the requirements specified in the NASA LSP-REQ-317.01 Revision Basic.

2.1.3 The satellite shall meet the requirements for a 1 unit (single) CubeSat.

2.1.4 The satellite shall provide mass for an experiment payload up to 100 g.

2.1.5 The satellite shall provide volume for an experiment payload up to 95 x 95 x 15.7 mm.

2.2 Environmental Requirements

2.2.1 The satellite avionics shall be designed for -40C to +70C operating temperature.

2.2.2 The satellite shall be designed to operate in a 650 km, sun-synchronous, circular orbit.

2.2.3 The satellite shall be designed to tolerate the radiation environment in orbit.

2.3 Reliability Requirements

2.3.1 The satellite shall be designed for a minimum 5-year, on-orbit lifetime.

2.4 RF Frequency Requirements

2.4.1 All RF transmitters shall meet or exceed the requirements specified in the ITU Radio Regulations, Technical Characteristics, Volume 3, article 3.

2.4.2 All satellite uplinks shall be in the 70 cm band of the amateur satellite service.

2.4.3 All satellite downlinks shall be in the 2 meter band within the amateur satellite service.

2.4.4 All satellite transmitter and receiver frequencies shall deviate by no more than 5 parts-per-million from the specified values including initial accuracy and temperature variation.

2.4.5 All satellite frequencies shall be coordinated with the IARU.

Note that the band plan with the actual coordinated frequencies will be specified in a separate document.

3 Functional Requirements

3.1 Antenna System

3.1.1 The satellite shall include a deployable antenna system.

3.2 Attitude Control

3.2.1 The satellite shall incorporate passive magnetic stabilization to align the deployed antennas with the magnetic field of the earth.

3.3 Access Ports

3.3.1 The satellite shall include a "Remove Before Flight" pin as per the CubeSat Design Specification.

3.3.2 The satellite shall include an umbilical port as per the CubeSat Design Specification.

3.4 Pre-launch Features

3.4.1 The satellite battery and photovoltaic panels shall be electronically disconnected from the avionics when the "Remove Before Flight" pin is inserted, regardless of the state of the deployment switch(es).

3.4.2 The satellite shall provide the means to charge the battery via the umbilical port while integrated with the P-POD.

3.4.3 The satellite shall provide the means to run diagnostic tests via the umbilical port while integrated with the P-POD.

3.5 Power

3.5.1 The satellite shall produce electrical power from sunlight.

3.5.2 The satellite shall produce electrical power while in sunlight regardless of orientation and while tumbling or spinning.

3.5.3 The satellite shall produce sufficient average electrical power to operate continuously in the orbit of maximum eclipse.

3.5.4 The satellite shall provide sufficient battery capacity to operate continuously in the orbit of maximum eclipse.

3.6 Experiment

3.6.1 The satellite shall provide DC power for experiment payloads.

3.6.2 The satellite shall provide a means to activate and deactivate the experiment payloads.

3.6.3 The satellite shall provide a means to telemeter data from the experiment payloads.

Note that the experiment payloads will be specified in a separate documents.

3.7 RF Uplink

3.7.1 The satellite shall include an FM uplink receiver.

3.7.2 The receiver shall have specifications as shown in Table 1.

Table 1

Sensitivity	-120 dBm for 12 dB SINAD (min.)
FM Deviation	5 kHz
Audio Bandwidth	3 kHz
Input Frequency Acceptance	Receiver shall accept signals that are off frequency by ±2.5 kHz (min.)

3.8 RF Downlink

3.8.1 The satellite shall include an FM downlink transmitter.

3.8.2 The transmitter shall have specifications as shown in Table 2.

Table 2

Power Output	400 mW (min.)
FM Deviation	5 kHz
Audio Bandwidth	3 kHz

3.8.3 The transmitter shall provide a means to prevent over modulation.

3.9 FM Transponder

3.9.1 The satellite shall provide an FM transponder via the RF uplink and RF downlink.

3.9.2 In Transponder Mode, the IHU shall detect the presence of a 67 Hz CTCSS tone on the uplink.

3.9.3 In Transponder Mode, the downlink transmitter shall be keyed (*i.e. PTT-on*) by the IHU for 2 minutes following detection of the 67 Hz CTCSS tone.

3.9.4 In Transponder Mode, the downlink transmitter shall stay on continuously as long as the 67 Hz CTCSS tone is detected at least once every 2 minutes on the uplink.

3.9.5 In Transponder Mode, the 67 Hz CTCSS tone is not required for a received signal to be repeated on the downlink, once the transmitter has been keyed.

3.9.6 In Transponder Mode, if the downlink transmitter has been un-keyed for a period of 3 minutes, the satellite shall send "HI THIS IS AMSAT FOX" as a voice announcement on the downlink transmitter.

3.9.7 In the event of shutdown or failure of the IHU, the satellite shall default to simple carrier operated repeater operation.

3.10 Telemetry Data

3.10.1 The satellite shall collect telemetry data.

3.10.2 The telemetry data shall include at a minimum, measured parameters as shown in Table 3.

Table 3

Parameter Name	**Description**
CELL V	Voltages of battery cells
PANEL V	Voltages of solar panels
TOTAL I	Total DC current out of power system
PA I	DC current into RF power amp
BATTERY T	Temperature of battery
PANEL T	Temperatures of solar panels
TX T	Temperature of RF transmitter card
RX T	Temperature of RF receiver card

3.10.3 The measured parameters shall be sampled at least every 15 seconds.

3.10.4 The minimum and maximum values of each of the measured parameters shall be saved in non-volatile memory.

3.10.5 The telemetry data shall also include at a minimum, calculated parameters as shown in Table 4.

Table 4

Parameter Name	Description
UP TIME	Total seconds since avionics power-up or reset
SPIN	Satellite spin rate and direction

3.10.6 A telemetry frame shall include the current measured values, the saved minimum and maximum values, and the current calculated values.

Note that the telemetry interface will be specified in a separate document.

3.11 Telemetry Transmission

3.11.1 The satellite shall send slow speed telemetry using FSK on the RF downlink.

3.11.2 The FSK shall use the frequency spectrum below the audible range.

3.11.3 The telemetry shall be transmitted simultaneously with any transponder communications.

3.11.4 The telemetry transmission shall include telemetry frames.

3.11.5 The telemetry transmission shall include experiment data.

3.12 Command Capability

3.12.1 The satellite shall provide the means to process commands sent via the RF uplink from a ground control station.

3.12.2 The commands received via the RF uplink shall not be repeated on the RF downlink.

3.12.3 The following commands shall be provided, as shown in Table 5.

Table 5

Command	Operation
TEST	Send test message
INHIBIT	Inhibit RF transmission
IHU OFF	Power off IHU & PSU
IHU ON	Power on IHU & PSU
CLEAR	Clear stored telemetry
TRANSPONDER MODE	Enter Transponder Mode
DATA MODE	Enter Data Mode

3.12.4 A TEST command shall cause the satellite to respond by sending a voice announcement on the RF downlink.

3.12.5 An INHIBIT command shall cause the satellite to cease RF transmissions.

3.12.6 An IHU OFF command shall cause the IHU and PSU Systems to power off.

3.12.7 An IHU ON command shall cause the IHU and PSU Systems to power on.

3.12.8 A CLEAR command shall cause the satellite to clear the saved minimum and maximum telemetry parameter values.

3.12.9 A TRANSPONDER MODE command shall cause the satellite to enter the Transponder Mode.

3.12.10 A DATA MODE command shall cause the satellite to enter the Data Mode.

Note that the control interface will be specified in a separate document.

3.13 On-Orbit Operating Modes

3.13.1 The satellite shall provide on-orbit operating modes as shown in Table 6.

Table 6

Name	**Description**
Startup Mode	Wait 45 minutes and deploy antennas
Transponder Mode	FM transponder; PTT and low speed telemetry via IHU
Data Mode	FM transmitter; PTT and high speed telemetry via IHU

3.13.2 The satellite shall transition between modes as shown in Figure 1.

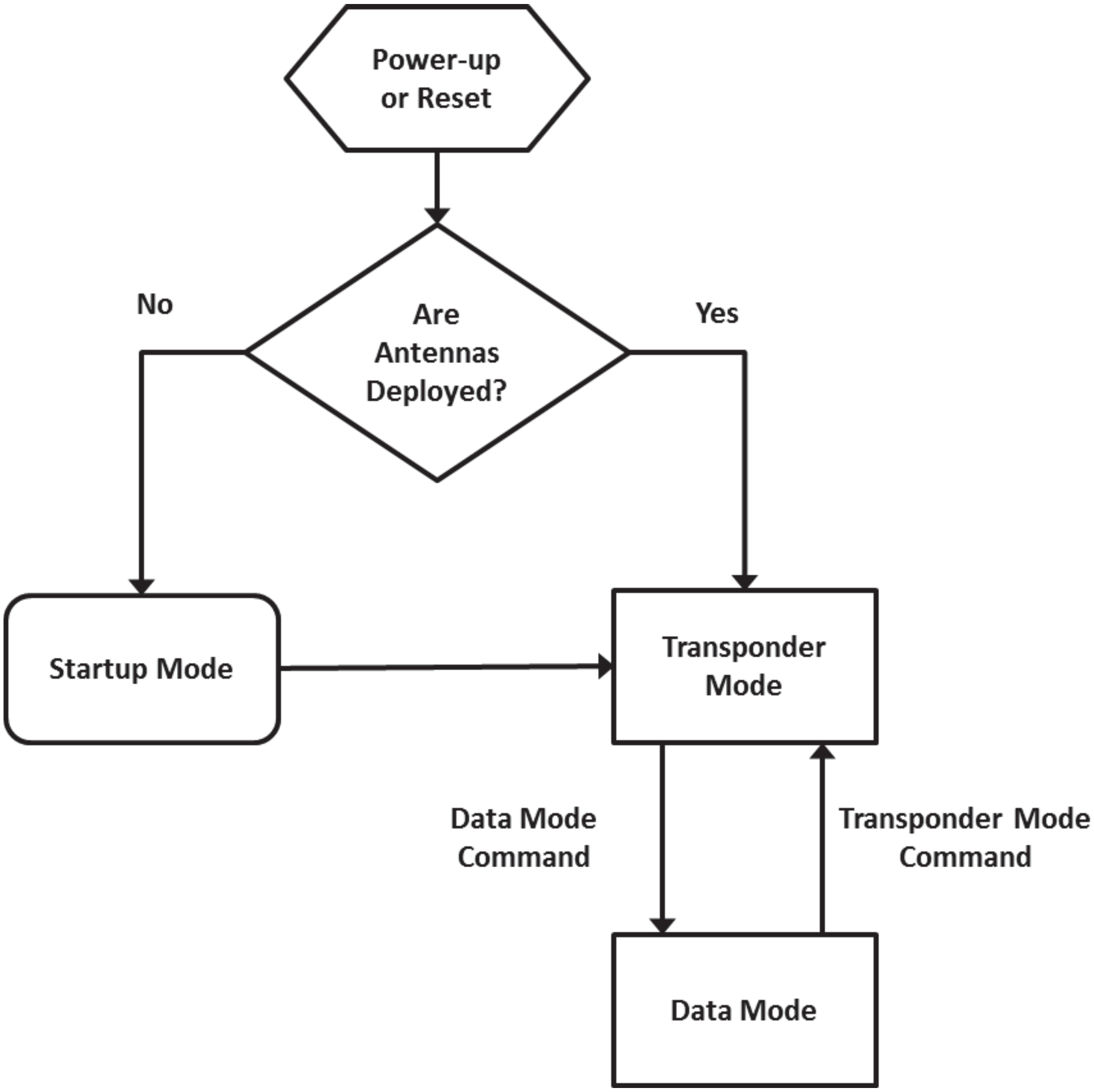


Figure 1. On-Orbit Operating Modes

3.13.3 Upon power-up of the avionics, the satellite shall begin operation from the "Power-up" state as shown in Figure 1.

3.13.4 An IHU ON Command shall cause the satellite to begin operation from the "Power-up" state as shown in Figure 1.

3.13.5 If the antennas have been deployed, the satellite shall enter the Transponder Mode.

3.13.6 If the antennas have not been deployed, the satellite shall enter the Startup Mode.

3.13.7 In Startup Mode, the satellite shall wait 45 minutes, deploy the antennas, and then enter Transponder Mode.

3.13.7.1 During the 45 minute wait the IHU shall flash a red LED.

3.13.7.2 During the 45 minute wait the IHU shall sound a 1 kHz beeping tone.

3.13.8 In Transponder Mode, the transponder and the slow speed telemetry shall be active.

3.13.9 In Data Mode, the high speed telemetry shall be active and the transponder shall not be active. *(i.e. signals that appear on the uplink shall not be repeated on the downlink.)*

3.13.10 If another Data Mode command is not received, the satellite shall automatically enter Transponder Mode 24 hours after having entered Data Mode.

3.13.11 The RF uplink shall be monitored for commands in all modes.

4 External Interface Documents

To fully specify the satellite technical requirements, the following documents must also be provided;

1. IARU Coordinated Frequency Plan
2. Downlink Specification
3. Control Interface Specification
4. Experiment Payload Specifications

5 Summary

The *Fox-1* satellite will be AMSAT's first CubeSat. Its primary mission is to provide an FM Transponder communications capability. The secondary mission is to host a university-provided experiment payload.

Date: October 4, 2013
Version: 3.82

AMSAT *Fox-1*
Avionics System Design Specification

1 Introduction

This document contains the system level design specifications for the AMSAT *Fox-1* satellite avionics systems. It is driven by the System Requirements Specification and other documents provided by the developers of the individual systems that make up the satellite system.

1.1. Document History

DATE	VERSION	SUMMARY
February 21, 2012	1.0	From Draft F
April 9, 2012	1.1	Add signal characteristics, update bus pin connections per System Team input
April 17, 2012	1.2	Add external connector specification in sections 2.6, 2.12 and 2.14 and references in section 6
April 18, 2012	1.21	Add MMCX connectors gender
April 22, 2012	1.3	Minor corrections in signal characteristics, remove +Z antenna deploy and sensor connections
July 10, 2012	2.0	Many revisions from PDR
July 11, 2012	2.01	One RBF pin removed from bus pin assignments, updated 2.1 interconnect diagram, updated 2.1 signal characteristics
July 21, 2012	2.1	Revised bus signals, bus pin assignments Updated RF block diagram
July 22, 2012	2.11	Revision to some RF signal descriptions, change antenna/coax connectors to UMCC type, updated RF block diagram, added driving and load system columns to signal characteristics
September 9, 2012	3.0	Major changes.
September 11, 2012	3.01	Defunct IHU block diagram pending update
September 12, 2012	3.1	Added PCB volume requirements
September 23, 2012	3.11	Change TX PTT to RX PTT, -Z Deploy switches to TX, update figures and tables accordingly
September 26, 2012	3.12	Update bus and pin assignment drawings
September 27, 2012	3.13	Update bus pin assignment drawings
September 30, 2012	3.14	Update RF block diagram to remove ITAR notice
October 17, 2012	3.15	Import changes to requirements from System Requirements
February 17, 2013	3.2	Incorporate system bus signal nomenclature and pin assignment changes
February 28, 2013	3.3	MEC connector changed orientation (flipped) on +X -X +Y -Y panels.

DATE	VERSION	SUMMARY
March 28, 2013	3.4	Add second –Z PPOD deploy switch (pin 54), PPOD deploy switches now on TX system card
March 31, 2013	3.41	Updates to the TX, RX, IHU, and BUS pin diagrams.
March 31, 2013	3.42	Adjusted RESERVED pin colors only
April 21, 2013	3.43	Addition of RX Frequency Control, TX Frequency Control, and Sensor Power signals Pin reassignments: Moved pins 52 and 54 to pins 33 and 35 respectively Moved pins 40 and 42 to pins 29 and 42 respectively Added the above new signals to pins 42, 40, and 38 respectively
April 25, 2013	3.5	Update per System Requirements 3.10.2 changes. Updated bus connection pin assignments, bus interconnect diagram, and system bus signal characteristics account removal of TX OSC Temp and TX PA Temp and addition of TX Temperature
June 26, 2013	3.6	Add requirements for PSU and BATT1 CPU reset from RX Command Data, updated IHU block diagram
July 24, 2013	3.7	Add ALERT signal, SENSOR POWER signal, remove RBF2, rename RBF1 to Solar Safe N, remove RX Command Data connection from BATT1, flip MEC connector orientation on +X, -X, +Y, -Y panels, update ME-113 mechanical drawings
August 26, 2013	3.8	Rename RX OSC TEMP to RX Temperature, add Initial Surge Current Limits for certain systems, move Command Decoder to IHU system (bus pin changes), update some bus nomenclature, update System Requirements for each system per changes to the System Requirements
August 27, 2013	3.81	Correct source and destination for RX Command Strobe in Table 1
September 17, 2013	3.82	Add (move) RSSI to Pin 10, rename Pin 32 as RX CD, add Solar Power A and Solar Power B to pins 55 and 56, update TX Block Diagram, remove RX Command Data connection from PSU, update hyperlinks.

1.2. Document Scope

The purpose of this document is to specify the avionics systems and their connections to each other and to external components for the satellite. It is intended to be used by the hardware, software, and mechanical designers to develop the architecture and interconnections for the satellite avionics systems.

1.3. Document Format

This document provides these elements in a numbered format. The numbered sections specify each major system in the satellite while numbered items for each system specify the external connections required and the number of lines for each connection. Satellite bus and external connections are further described in figures and tables.

Where System Requirements are reproduced their numbers are from the AMSAT *Fox*-1 System Requirements Specification.

1.4. References

1. AMSAT *Fox-1* ConOps
2. AMSAT *Fox-1* System Requirements Specification
3. AMSAT *Fox-1* Bus (Signal Connections Diagram)
4. AMSAT *Fox-1* Bus Pin Assignment
5. AMSAT *Fox-1* Avionics System Design Specification Spreadsheet
6. AMSAT FOX-ME-120_Z_TOPBOTT_SOLAR_PANEL.pdf
7. AMSAT FOX-ME-127_Y_SIDE_SOLAR_PANEL.pdf

Contents

2 Avionics System Bus Signals, Characteristics, and Connections

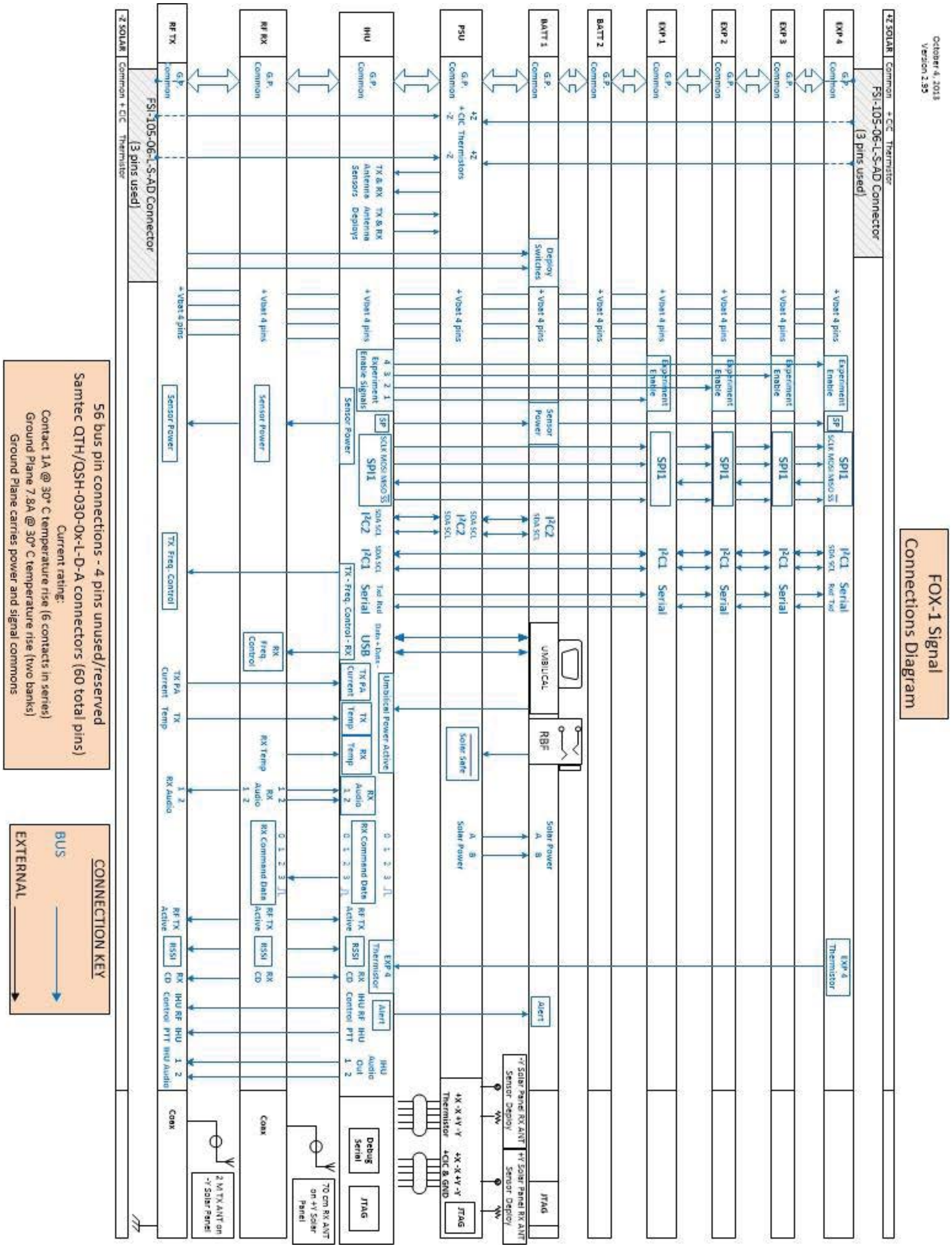


Figure 1: Interconnect Diagram

Table 1: System Bus Signal Characteristics

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Load System	Notes
1	SPI1 NSS	Digital	Note[1]	IHU		EXP 1-4	SPI Standard, IHU Master
2	TX PA Current	Analog	0 - 3.0 V	TX	30 - 60 kΩ	IHU	
3	SPI1 SCK	Digital	Note[1]	IHU		EXP 1-4	SPI Standard, IHU Master
4	TX Temperature	Analog	0 - 3.0 V	TX	30 - 60 kΩ	IHU	Thermistor Circuit
5	SPI1 MISO	Digital	Note[1]	IHU		EXP 1-4	SPI Standard, IHU Master
6	Experiment 4 Thermistor	Analog	N/A	EXP 4	N/A	IHU	Temperature from Experiment 4 position
7	SPI1 MOSI	Digital	Note[1]	IHU		EXP 1-4	SPI Standard, IHU Master
8	RX Temperature	Analog	0 - 3.0 V	RX	30 - 60 kΩ	IHU	Thermistor Circuit
9	Serial RXD	Digital	3.0 V	EXP 1-4		IHU	Async, Mark High
10	RSSI	Analog	0 - 3.0 V	RX	30 - 60 kΩ	IHU	Received Signal Strength Indication
11	Serial TXD	Digital	3.0 V	IHU		EXP 1-4	Async, Mark High
12	IHU Audio 1 Out	Analog	0 - 3 V (audio)	IHU	> 10 kΩ unbal.	TX	For 5 kHz deviation, 10 Hz - 7 kHz bandwidth
13	Experiment Enable 1	Digital		IHU		EXP 1-4	HIGH = Enable EXP 1
14	IHU Audio 2 Out	Analog	0 - 3 V (audio)	IHU	> 10 kΩ unbal.		IHU Audio 2 Out Not Used on Fox-1A
15	Experiment Enable 2	Digital		IHU		EXP 2	HIGH = Enable EXP 2
16	RX Command Data 0	Digital		IHU			(Least Significant Bit) Not Used on Fox-1A
17	Experiment Enable 3	Digital		IHU		EXP 3	HIGH = Enable EXP 3
18	RX Command Data 1	Digital		IHU			Not Used on Fox-1A
19	Experiment Enable 4	Digital		IHU		EXP 4	HIGH = Enable EXP 4
20	RX Command Data 2	Digital		IHU			HIGH = IHU off
21	Not Used						
22	RX Command Data 3	Digital		IHU		TX	(Most Significan Bit) HIGH = Inhibit Transmit
23	I^{2}C1 SCL	Digital	Note[1]	IHU			I^{2}C Standard, IHU Master
24	RX Command Strobe	Digital		IHU			HIGH = Command Data change
25	I^{2}C1 SDA	Digital	Note[1]	IHU			I^{2}C Standard, IHU Master
26	IHU RF Control	Digital		IHU		TX	HIGH = IHU Controls RF LOW = Standalone Analog Transponder
27	Not Used						
28	IHU PTT	Digital		IHU		TX	HIGH = TRANSMIT
29	Solar Safe N	Switch	N/A	BATT	N/A	PSU	N.O. for operation
30	RF TX Active	Digital		TX		IHU	HIGH = RF TX on
31	Alert Signal	Digital		IHU		BATT	
32	RX CD	Digital		RX		TX IHU	HIGH = valid receive signal
33	-Z Deploy Switch 1	Switch	N/A	TX	N/A	PSU/BATT	N.O. when deployed
34	RX Audio 1	Analog	0 - 3 V (audio)	RX	> 10 kΩ unbal.	IHU	10 Hz - 7 kHz bandwidth
35	-Z Deploy Switch 2	Switch	N/A	TX	N/A	PSU/BATT	N.O. when deployed
36	RX Audio 2	Analog	0 - 3 V (audio)		> 10 kΩ unbal.	IHU	RX Audio 2 Not Used on Fox-1A
37	I^{2}C2 SCL	Digital	Note[1]	IHU		PSU/BATT	I^{2}C Standard, IHU Master
38	Sensor Power	Analog	+3 VDC	IHU		TX RX BATT EXP4	Power for analog telemetry sensors
39	I^{2}C2 SDA	Digital	Note[1]	IHU		PSU/BATT	I^{2}C Standard, IHU Master
40	TX Frequency Control	Digital		IHU		TX	Not Used on Fox-1A
41	+Z Thermistor	Analog	N/A	EXP 4	N/A	PSU	
42	RX Frequency Control	Digital		IHU		RX	Not Used on Fox-1A
43	-Z Thermistor	Analog	N/A	TX	N/A	PSU	
44	-Y Antenna Deploy	Analog	Vbatt	IHU	7 Ω resistor	PSU	
45	+Z CIC	Power	N/A	EXP 4	N/A	PSU	
46	-Y Antenna Sensor	Switch	N/A	PSU	N.O.	IHU	N.O. when deployed
47	-Z CIC	Power	N/A	TX	N/A	PSU	
48	+Y Antenna Sensor	Switch	N/A	PSU	N.O.	IHU	N.O. when deployed
49	Umbilical USBP	Digital		BATT		IHU	USB Standard
50	+Y Antenna Deploy	Analog	Vbatt	IHU	7 Ω resistor	PSU	
51	Umbilical USBM	Digital		BATT		IHU	USB Standard
52	Not Used						
53	Umbilical Power Active	Digital		BATT		IHU	HIGH = Running on Umbilical Port Power
54	*RESERVED*						Must not use on v1 IHU Card
55	Solar Power A	Power	Vbatt	PSU		BATT	
56	Solar Power B	Power	Vbatt	PSU		BATT	
57	Vbatt	Power Bus	3.3 - 4.2 VDC	BATT/PSU		ALL	
58	Vbatt	Power Bus	3.3 - 4.2 VDC	BATT/PSU		ALL	
59	Vbatt	Power Bus	3.3 - 4.2 VDC	BATT/PSU		ALL	
60	Vbatt	Power Bus	3.3 - 4.2 VDC	BATT/PSU		ALL	

Version 2.95

Note[1] All SPI and I^{2}C signals are 3.0 V levels

All Digital signals are CMOS logic levels high impedance load unless otherwise noted

Note¹ All SPI and I²C signals are 3.0 V levels

All Digital signals are 3.0 V CMOS logic levels high impedance load unless otherwise noted

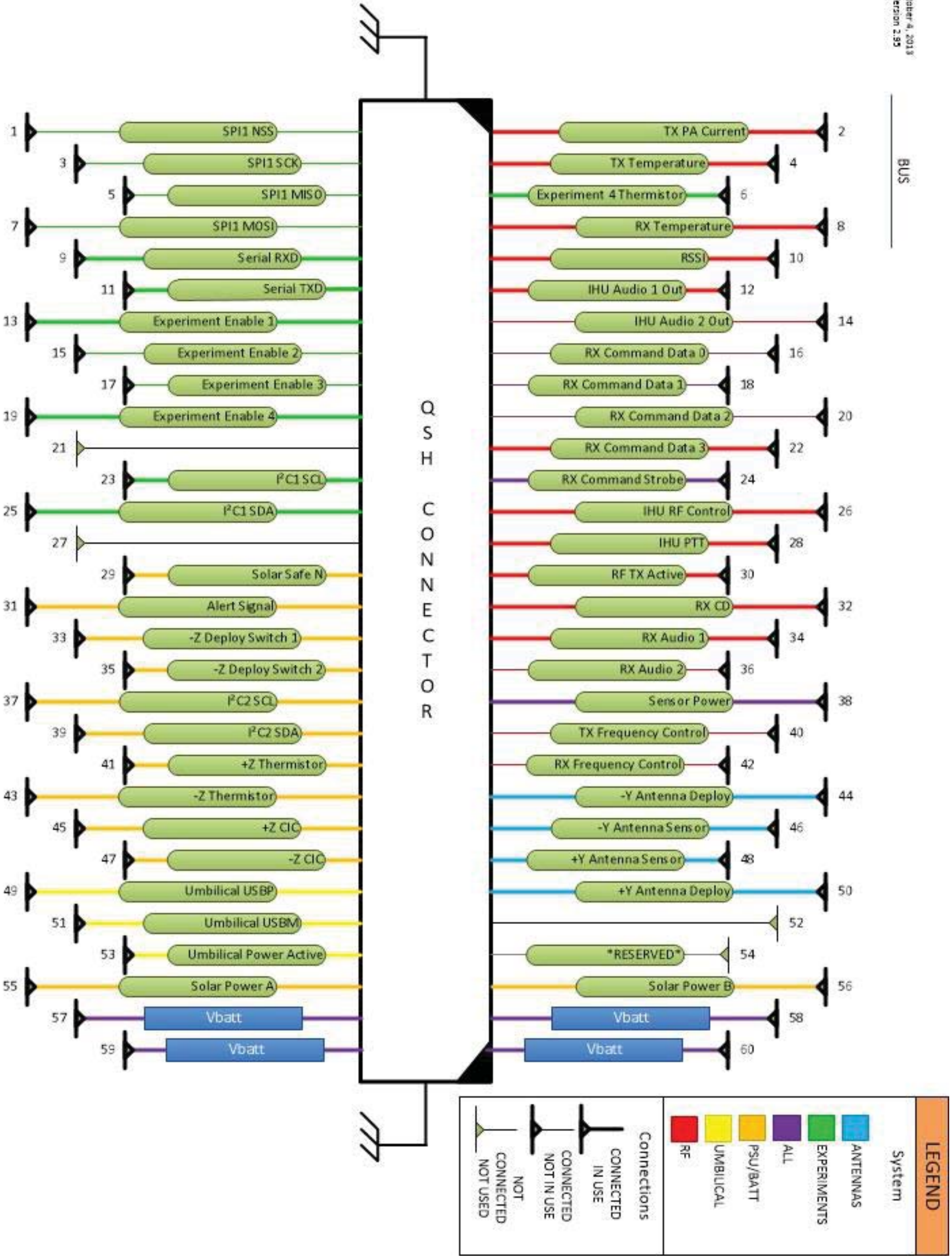


Figure 2: Complete Bus Connection Pin Assignments

3 RF Transmitter System

3.1 System Requirements Applicable to RF Transmitter System

<table>
<tr><td>2.2.1</td><td>The satellite avionics shall be designed for -40C to +70C operating temperature.</td></tr>
<tr><td>2.2.3</td><td>The satellite shall be designed to tolerate the radiation environment in orbit.</td></tr>
<tr><td>2.3.1</td><td>The satellite shall be designed for a minimum 5-year, on-orbit lifetime.</td></tr>
<tr><td>2.4.1</td><td>All RF transmitters shall meet or exceed the requirements specified in the ITU Radio Regulations, Technical Characteristics, Volume 3, article 3.</td></tr>
<tr><td>2.4.3</td><td>All satellite downlinks shall be in the 2 meter band within the amateur satellite service.</td></tr>
<tr><td>2.4.4</td><td>All satellite transmitter and receiver frequencies shall deviate by no more than 5 parts-per-million from the specified values including initial accuracy and temperature variation.</td></tr>
<tr><td>2.4.5</td><td>All satellite frequencies shall be coordinated with the IARU.</td></tr>
<tr><td>3.8.1</td><td>The satellite shall include an FM downlink transmitter.</td></tr>
<tr><td>3.8.2</td><td>The transmitter shall have specifications as shown in Table 2.
<table>
<tr><td>Power Output</td><td>400 mW (min.)</td></tr>
<tr><td>FM Deviation</td><td>5 kHz</td></tr>
<tr><td>Audio Bandwidth</td><td>3 kHz</td></tr>
</table></td></tr>
<tr><td>3.8.3</td><td>The transmitter shall provide a means to prevent over modulation.</td></tr>
<tr><td>3.9.1</td><td>The satellite shall provide an FM transponder via the RF uplink and RF downlink.</td></tr>
<tr><td>3.9.3</td><td>In Transponder Mode, the downlink transmitter shall be keyed (i.e. PTT-on) by the IHU for 2 minutes following detection of the 67 Hz CTCSS tone.</td></tr>
<tr><td>3.9.5</td><td>In Transponder Mode, the 67 Hz CTCSS tone is not required for a received signal to be repeated on the downlink, once the transmitter has been keyed.</td></tr>
<tr><td>3.9.7</td><td>In the event of shutdown or failure of the IHU, the satellite shall default to simple carrier operated repeater operation.</td></tr>
<tr><td>3.10.1</td><td>The satellite shall collect telemetry data.</td></tr>
<tr><td>3.10.2</td><td>The telemetry data shall include at a minimum, measured parameters as shown in Table 3.
<table>
<tr><th>Parameter Name</th><th>Description</th></tr>
<tr><td>CELL V</td><td>Voltages of battery cells</td></tr>
<tr><td>PANEL V</td><td>Voltages of solar panels</td></tr>
<tr><td>TOTAL I</td><td>Total DC current out of power system</td></tr>
<tr><td>PA I</td><td>DC current into RF power amp</td></tr>
<tr><td>BATTERY T</td><td>Temperature of battery</td></tr>
<tr><td>PANEL T</td><td>Temperatures of solar panels</td></tr>
<tr><td>TX T</td><td>Temperature of RF transmitter card</td></tr>
</table></td></tr>
</table>

<table>
<tr><td></td><td><table><tr><td>RX T</td><td>Temperature of RF receiver card</td></tr></table></td></tr>
<tr><td>3.10.3</td><td>The measured parameters shall be sampled at least every 15 seconds.</td></tr>
<tr><td>3.11.1</td><td>The satellite shall send slow speed telemetry using FSK on the RF downlink.</td></tr>
<tr><td>3.11.2</td><td>The FSK shall use the frequency spectrum below the audible range.</td></tr>
<tr><td>3.11.3</td><td>The telemetry shall be transmitted simultaneously with any transponder communications.</td></tr>
<tr><td>3.12.1</td><td>The satellite shall provide the means to process commands sent via the RF uplink from a ground control station.</td></tr>
<tr><td>3.12.2</td><td>The commands received via the RF uplink shall not be repeated on the RF downlink.</td></tr>
<tr><td>3.12.3</td><td>The following commands shall be provided, as shown in Table 5.
<table>
<tr><th>Command</th><th>Operation</th></tr>
<tr><td>TEST</td><td>Send test message</td></tr>
<tr><td>INHIBIT</td><td>Inhibit RF transmission</td></tr>
<tr><td>IHU OFF</td><td>Power off IHU</td></tr>
<tr><td>IHU ON</td><td>Power on IHU</td></tr>
<tr><td>CLEAR</td><td>Clear stored telemetry</td></tr>
<tr><td>TRANSPONDER MODE</td><td>Enter Transponder Mode</td></tr>
<tr><td>DATA MODE</td><td>Enter Data Mode</td></tr>
</table></td></tr>
<tr><td>3.12.4</td><td>A TEST command shall cause the satellite to respond by sending a voice announcement on the RF downlink.</td></tr>
<tr><td>3.12.5</td><td>An INHIBIT command shall cause the satellite to cease RF transmissions.</td></tr>
<tr><td>3.12.9</td><td>A TRANSPONDER MODE command shall cause the satellite to enter the Transponder Mode.</td></tr>
<tr><td>3.12.10</td><td>A DATA MODE command shall cause the satellite to enter the Data Mode.</td></tr>
<tr><td>3.13.1</td><td>The satellite shall provide on-orbit operating modes as shown in Table 6.
<table>
<tr><th>Name</th><th>Description</th></tr>
<tr><td>Startup Mode</td><td>Wait 45 minutes and deploy antennas</td></tr>
<tr><td>Transponder Mode</td><td>FM transponder; PTT and low speed telemetry via IHU</td></tr>
<tr><td>Data Mode</td><td>FM transmitter; PTT and high speed telemetry via IHU</td></tr>
</table></td></tr>
<tr><td>3.13.5</td><td>If the antennas have been deployed, the satellite shall enter the Transponder Mode.</td></tr>
<tr><td>3.13.8</td><td>In Transponder Mode, the transponder and the slow speed telemetry shall be active.</td></tr>
<tr><td>3.13.9</td><td>In Data Mode, the high speed telemetry shall be active and the transponder shall not be active. (i.e. signals that appear on the uplink shall not be repeated on the downlink.)</td></tr>
</table>

3.2 Initial Surge Current Limits

3.2.1 The RF Transmitter design shall limit initial inrush current to 2.5 Amperes.

3.3 Volume Requirements Applicable to RF Transmitter System

3.3.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 5 mm from the –Z surface of the PC board.

3.3.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 6.0 mm from the +Z surface of the PC board.

3.4 Interface Control Documents Applicable to RF Transmitter System

AMSAT *Fox-1* IHU to RF System Interface Control Document

3.5 RF Transmitter System PCB Bus Connections

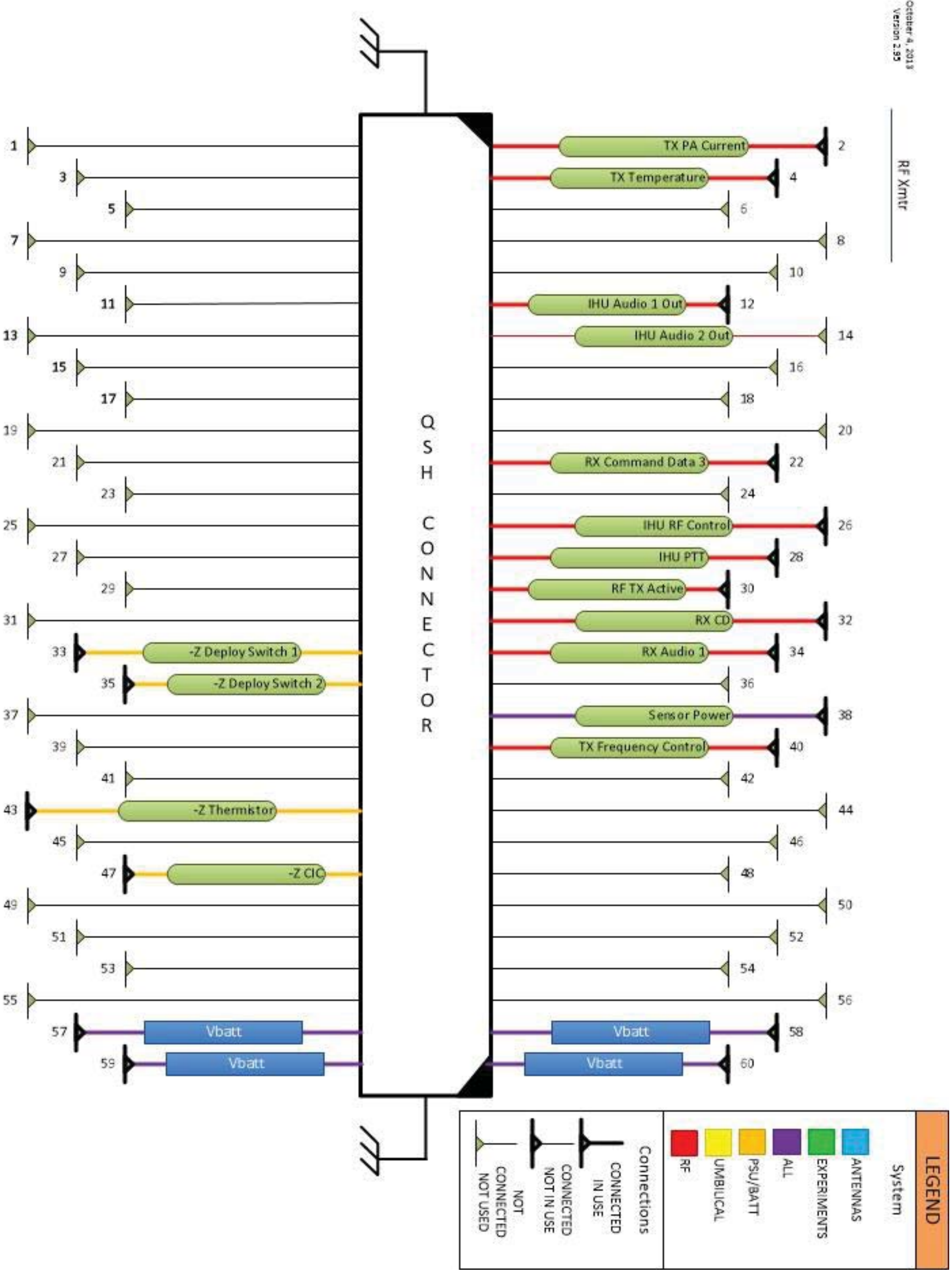


Figure 3: RF Transmitter System Bus Connection Pin Assignments

3.6 RF Transmitter System PCB External Connections

- **3.6.1** 2 meter band RF output, coaxial cable to Transmit Antenna
- **3.6.2** Spacecraft deployment switches cable(s) TBR
- **3.6.3** Three connections via Samtec FSI-105-06-L-S-AD connector
    - **3.6.3.1** 1 contact -Z Solar Panel Thermistor
    - **3.6.3.2** 1 contact -Z Solar Panel CIC +
    - **3.6.3.3** 1 contact common or - for above four connections

Table 2: External Connection Signal Characteristics

External Connection	Nomenclature	Type	Voltage/ Power	Source System	Load Z	Bus Pin
Coaxial Cable	2 meter Antenna ≈ 145.9 MHz	RF	0 to +30 dBm	2 meter Antenna	50 Ω unbal.	N/A

Table 3: -Z PCB face FSI-105-06-L-S-AD connector mates to pads on –Z Solar Panel

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Load System	Bus Pin
1	-Z Thermistor	Analog	N/A	N/A	N/A	PSU	43
2	N/C						
3	-Z Solar Panel Common						Ground Plane
4	N/C						
5	-Z CIC	Power	N/A	N/A	N/A	PSU	47

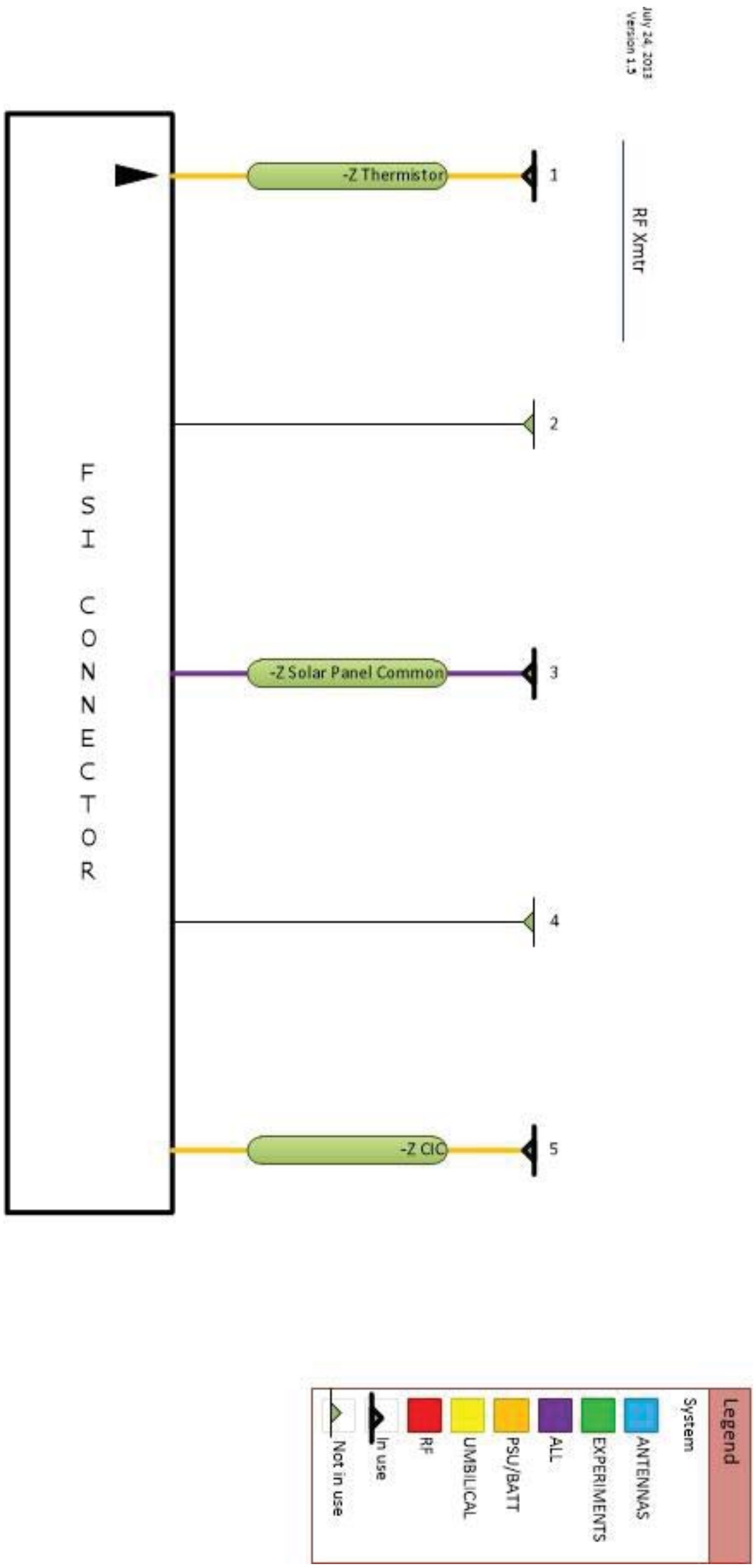


Figure 4: RF Transmitter System FSI-105-06-L-S-AD Connection Pin Assignments

4 RF Receiver System

4.1 System Requirements Applicable to RF Receiver System

<table>
<tr><td>2.2.1</td><td>The satellite avionics shall be designed for -40C to +70C operating temperature.</td></tr>
<tr><td>2.2.3</td><td>The satellite shall be designed to tolerate the radiation environment in orbit.</td></tr>
<tr><td>2.3.1</td><td>The satellite shall be designed for a minimum 5-year, on-orbit lifetime.</td></tr>
<tr><td>2.4.2</td><td>All satellite uplinks shall be in the 70 cm band of the amateur satellite service.</td></tr>
<tr><td>2.4.5</td><td>All satellite frequencies shall be coordinated with the IARU.</td></tr>
<tr><td>3.7.1</td><td>The satellite shall include an FM uplink receiver.</td></tr>
<tr><td>3.7.2</td><td>The receiver shall have specifications as shown in Table 1.
<table>
<tr><td>Sensitivity</td><td>-120 dBm for 12 dB SINAD (min.)</td></tr>
<tr><td>FM Deviation</td><td>5 kHz</td></tr>
<tr><td>Audio Bandwidth</td><td>3 kHz</td></tr>
<tr><td>Input Frequency Acceptance</td><td>Receiver shall accept signals that are off frequency by ±2.5 kHz (min.)</td></tr>
</table></td></tr>
<tr><td>3.8.3</td><td>The transmitter shall provide a means to prevent over modulation.</td></tr>
<tr><td>3.9.1</td><td>The satellite shall provide an FM transponder via the RF uplink and RF downlink.</td></tr>
<tr><td>3.9.7</td><td>In the event of shutdown or failure of the IHU, the satellite shall default to simple carrier operated repeater operation.</td></tr>
<tr><td>3.10.1</td><td>The satellite shall collect telemetry data.</td></tr>
<tr><td>3.10.2</td><td>The telemetry data shall include at a minimum, measured parameters as shown in Table 3.
<table>
<tr><th>Parameter Name</th><th>Description</th></tr>
<tr><td>CELL V</td><td>Voltages of battery cells</td></tr>
<tr><td>PANEL V</td><td>Voltages of solar panels</td></tr>
<tr><td>TOTAL I</td><td>Total DC current out of power system</td></tr>
<tr><td>PA I</td><td>DC current into RF power amp</td></tr>
<tr><td>BATTERY T</td><td>Temperature of battery</td></tr>
<tr><td>PANEL T</td><td>Temperatures of solar panels</td></tr>
<tr><td>TX T</td><td>Temperature of RF transmitter card</td></tr>
<tr><td>RX T</td><td>Temperature of RF receiver card</td></tr>
</table></td></tr>
<tr><td>3.10.3</td><td>The measured parameters shall be sampled at least every 15 seconds.</td></tr>
<tr><td>3.12.2</td><td>The commands received via the RF uplink shall not be repeated on the RF downlink.</td></tr>
<tr><td>3.13.11</td><td>The RF uplink shall be monitored for commands in all modes.</td></tr>
</table>

4.2 Initial Surge Current Limits

4.2.1 The RF Receiver design shall limit initial inrush current to 0.1 Amperes.

4.3 Volume Requirements Applicable to RF Receiver System

4.3.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 1 mm from the –Z surface of the PC board.

4.3.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 6.0 mm from the +Z surface of the PC board.

4.4 Interface Control Documents Applicable to RF Receiver System

AMSAT *Fox-1* IHU to RF System Interface Control Document

4.5 RF Receiver System PCB Bus Connections

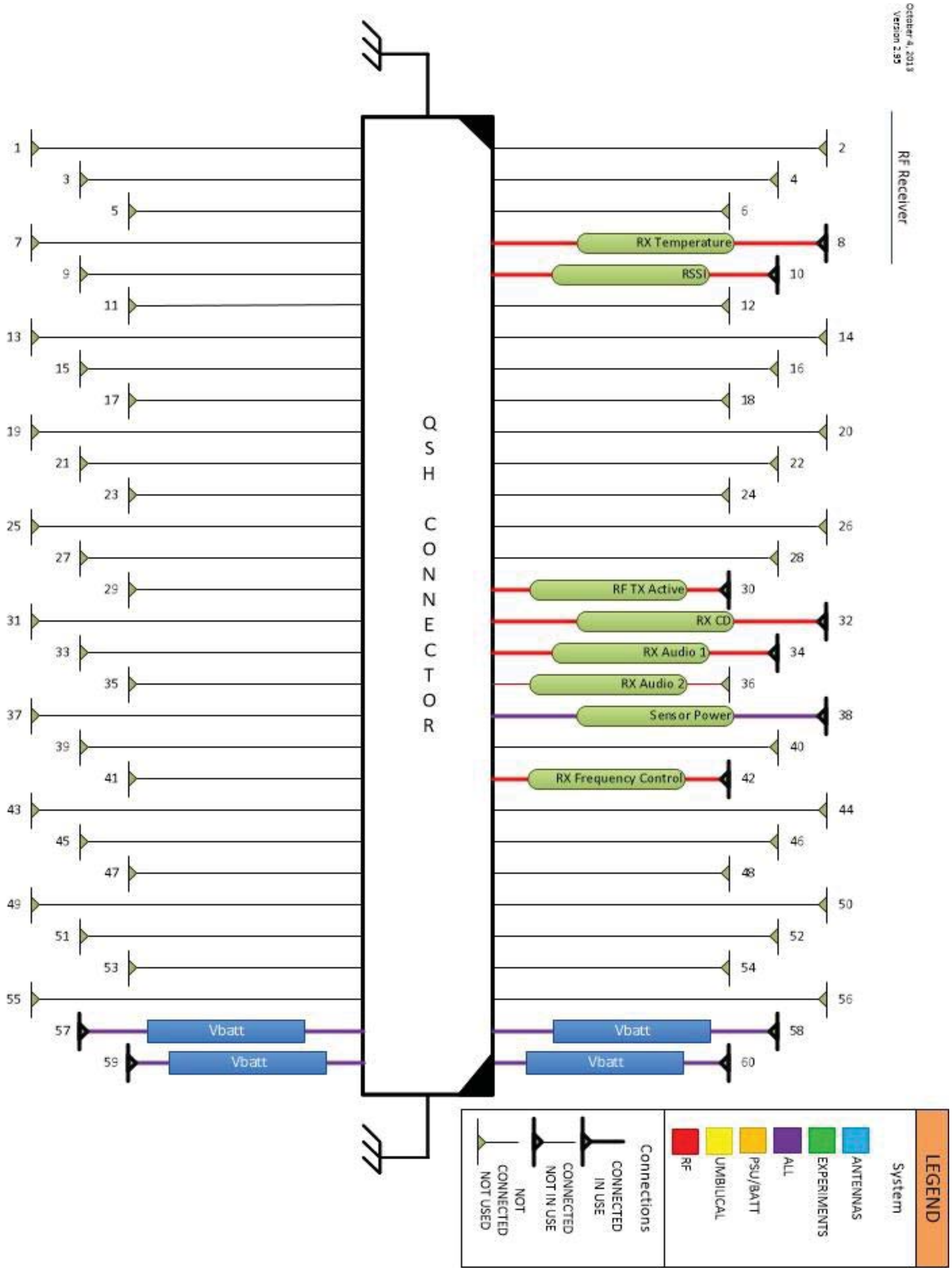


Figure 5: RF Receiver System Bus Connection Pin Assignments

4.6 RF Receiver System PCB External Connections

4.6.1 70cm band RF input, coaxial cable to Receive Antenna

Table 4: RF Receiver System External Connection Signal Characteristics

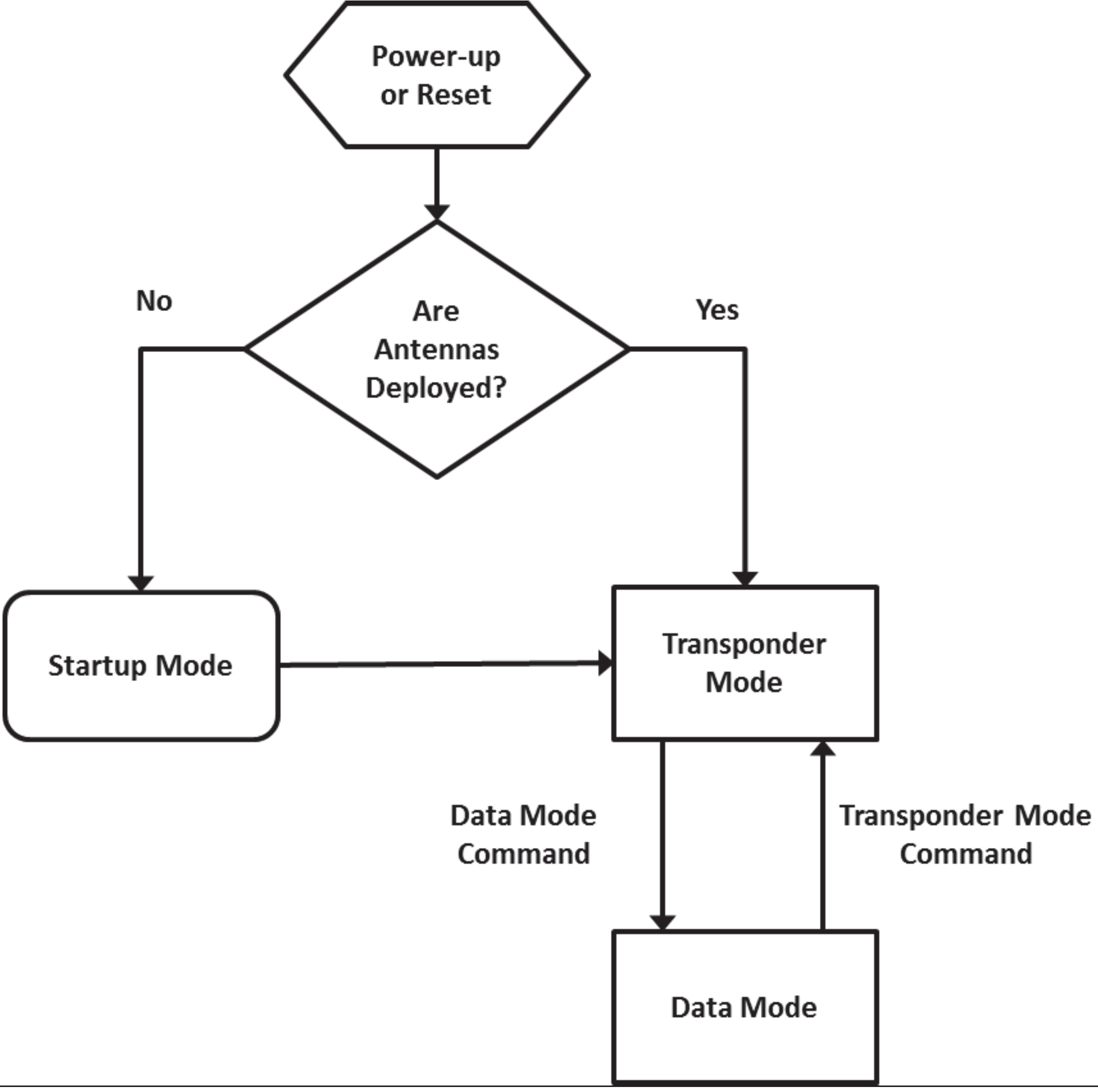
External Connection	Nomenclature	Type	Voltage/ Power	Source System	Load Z	Bus Pin
Coaxial Cable	70 cm RF Input 437 MHz	RF	-60 dBm to -140 dBm	70 cm Antenna	50 Ω unbal.	N/A

5 Internal Housekeeping Unit (IHU) System

5.1 System Requirements Applicable to Internal Housekeeping Unit (IHU) System

<table>
<tr><td>2.2.1</td><td>The satellite avionics shall be designed for -40C to +70C operating temperature.</td></tr>
<tr><td>2.2.3</td><td>The satellite shall be designed to tolerate the radiation environment in orbit.</td></tr>
<tr><td>2.3.1</td><td>The satellite shall be designed for a minimum 5-year, on-orbit lifetime.</td></tr>
<tr><td>3.3.2</td><td>The satellite shall include an umbilical port as per the CubeSat Design Specification.</td></tr>
<tr><td>3.4.3</td><td>The satellite shall provide the means to run diagnostic tests via the umbilical port while integrated with the P-POD.</td></tr>
<tr><td>3.6.2</td><td>The satellite shall provide a means to activate and deactivate the experiment payloads.</td></tr>
<tr><td>3.6.3</td><td>The satellite shall provide a means to telemeter data from the experiment payloads.</td></tr>
<tr><td>3.9.2</td><td>In Transponder Mode, the IHU shall detect the presence of a 67 Hz CTCSS tone on the uplink.</td></tr>
<tr><td>3.9.3</td><td>In Transponder Mode, the downlink transmitter shall be keyed (i.e. PTT-on) by the IHU for 2 minutes following detection of the 67 Hz CTCSS tone.</td></tr>
<tr><td>3.9.4</td><td>In Transponder Mode, the downlink transmitter shall stay on continuously as long as the 67 Hz CTCSS tone is detected at least once every 2 minutes on the uplink.</td></tr>
<tr><td>3.9.5</td><td>In Transponder Mode, the 67 Hz CTCSS tone is not required for a received signal to be repeated on the downlink, once the transmitter has been keyed.</td></tr>
<tr><td>3.9.6</td><td>In Transponder Mode, if the downlink transmitter has been un-keyed for a period of 3 minutes, the satellite shall send "HI THIS IS AMSAT FOX" as a voice announcement on the downlink transmitter.</td></tr>
<tr><td>3.9.7</td><td>In the event of shutdown or failure of the IHU, the satellite shall default to simple carrier operated repeater operation.</td></tr>
<tr><td>3.10.1</td><td>The satellite shall collect telemetry data.</td></tr>
<tr><td>3.10.2</td><td>The telemetry data shall include at a minimum, measured parameters as shown in Table 3.
<table>
<tr><th>Parameter Name</th><th>Description</th></tr>
<tr><td>CELL V</td><td>Voltages of battery cells</td></tr>
<tr><td>PANEL V</td><td>Voltages of solar panels</td></tr>
<tr><td>TOTAL I</td><td>Total DC current out of power system</td></tr>
<tr><td>PA I</td><td>DC current into RF power amp</td></tr>
<tr><td>BATTERY T</td><td>Temperature of battery</td></tr>
<tr><td>PANEL T</td><td>Temperatures of solar panels</td></tr>
<tr><td>TX T</td><td>Temperature of RF transmitter card</td></tr>
<tr><td>RX T</td><td>Temperature of RF receiver card</td></tr>
</table></td></tr>
<tr><td>3.10.3</td><td>The measured parameters shall be sampled at least every 15 seconds.</td></tr>
<tr><td>3.10.4</td><td>The minimum and maximum values of each of the measured parameters shall be saved in non-volatile memory.</td></tr>
</table>

<table>
<tr><td>3.10.5</td><td>The telemetry data shall also include at a minimum, calculated parameters as shown in Table 4.
<table>
<tr><th>Parameter Name</th><th>Description</th></tr>
<tr><td>UP TIME</td><td>Total seconds since avionics power-up or reset</td></tr>
<tr><td>SPIN</td><td>Satellite spin rate and direction</td></tr>
</table></td></tr>
<tr><td>3.10.6</td><td>A telemetry frame shall include the current measured values, the saved minimum and maximum values, and the current calculated values.</td></tr>
<tr><td>3.11.1</td><td>The satellite shall send slow speed telemetry using FSK on the RF downlink.</td></tr>
<tr><td>3.11.2</td><td>The FSK shall use the frequency spectrum below the audible range.</td></tr>
<tr><td>3.11.3</td><td>The telemetry shall be transmitted simultaneously with any transponder communications.</td></tr>
<tr><td>3.11.4</td><td>The telemetry transmission shall include telemetry frames.</td></tr>
<tr><td>3.11.5</td><td>The telemetry transmission shall include experiment data.</td></tr>
<tr><td>3.12.1</td><td>The satellite shall provide the means to process commands sent via the RF uplink from a ground control station.</td></tr>
<tr><td>3.12.3</td><td>The following commands shall be provided, as shown in Table 5.
<table>
<tr><th>Command</th><th>Operation</th></tr>
<tr><td>TEST</td><td>Send test message</td></tr>
<tr><td>INHIBIT</td><td>Inhibit RF transmission</td></tr>
<tr><td>IHU OFF</td><td>Power off IHU</td></tr>
<tr><td>IHU ON</td><td>Power on IHU</td></tr>
<tr><td>CLEAR</td><td>Clear stored telemetry</td></tr>
<tr><td>TRANSPONDER MODE</td><td>Enter Transponder Mode</td></tr>
<tr><td>DATA MODE</td><td>Enter Data Mode</td></tr>
</table></td></tr>
<tr><td>3.12.4</td><td>A TEST command shall cause the satellite to respond by sending a voice announcement on the RF downlink.</td></tr>
<tr><td>3.12.6</td><td>An IHU OFF command shall cause the IHU System to power off.</td></tr>
<tr><td>3.12.7</td><td>An IHU ON command shall cause the IHU System to power on.</td></tr>
<tr><td>3.12.8</td><td>A CLEAR command shall cause the satellite to clear the saved minimum and maximum telemetry parameter values.</td></tr>
<tr><td>3.12.9</td><td>A TRANSPONDER MODE command shall cause the satellite to enter the Transponder Mode.</td></tr>
<tr><td>3.12.10</td><td>A DATA MODE command shall cause the satellite to enter the Data Mode.</td></tr>
<tr><td>3.13.1</td><td>The satellite shall provide on-orbit operating modes as shown in Table 6.
<table>
<tr><th>Name</th><th>Description</th></tr>
<tr><td>Startup Mode</td><td>Wait 45 minutes and deploy antennas</td></tr>
</table></td></tr>
</table>

<table>
<tr><td></td><td><table><tr><td>Transponder Mode</td><td>FM transponder; PTT and low speed telemetry via IHU</td></tr><tr><td>Data Mode</td><td>FM transmitter; PTT and high speed telemetry via IHU</td></tr></table></td></tr>
<tr><td>3.13.2</td><td>The satellite shall transition between modes as shown in Figure 1.</td></tr>
<tr><td>3.13.3</td><td>Upon power-up of the avionics, the satellite shall begin operation from the "Power-up" state as shown in Figure 1.</td></tr>
<tr><td>3.13.4</td><td>An IHU ON Command shall cause the satellite to begin operation from the "Power-up" state as shown in Figure 1.

</td></tr>
<tr><td>3.13.5</td><td>If the antennas have been deployed, the satellite shall enter the Transponder Mode.</td></tr>
<tr><td>3.13.6</td><td>If the antennas have not been deployed, the satellite shall enter the Startup Mode.</td></tr>
<tr><td>3.13.7</td><td>In Startup Mode, the satellite shall wait 45 minutes, deploy the antennas, and then enter Transponder Mode.</td></tr>
<tr><td>3.13.8</td><td>In Transponder Mode, the transponder and the slow speed telemetry shall be active.</td></tr>
<tr><td>3.13.9</td><td>In Data Mode, the high speed telemetry shall be active and the transponder shall not be active. (i.e.</td></tr>
</table>

	signals that appear on the uplink shall not be repeated on the downlink.)
3.13.10	If another Data Mode command is not received, the satellite shall automatically enter Transponder Mode 24 hours after having entered Data Mode.
3.13.11	The RF uplink shall be monitored for commands in all modes.
3.13.7.1	During the 45 minute wait the IHU shall flash a red LED.
3.13.7.2	During the 45 minute wait the IHU shall sound a 1 kHz beeping tone.

5.3 Initial Surge Current Limits

5.3.1 The IHU design shall limit initial inrush current to 0.1 Amperes.

5.4 Volume Requirements Applicable to IHU System

5.4.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 1 mm from the –Z surface of the PC board.

5.4.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 6.0 mm from the +Z surface of the PC board.

5.5 Interface Control Documents Applicable to IHU System

AMSAT *Fox-1* IHU to RF System Interface Control Document
AMSAT *Fox-1* IHU to PSU Interface Control Document
AMSAT *Fox-1* IHU to Battery Interface Control Document
AMSAT *Fox-1* IHU to Attitude Determination Experiment Interface Control Document
AMSAT *Fox-1* IHU to Experiment 1 Interface Control Document
AMSAT *Fox-1* IHU to Experiment 4 Interface Control Document

5.6 Internal Housekeeping Unit (IHU) System PCB Bus Connections

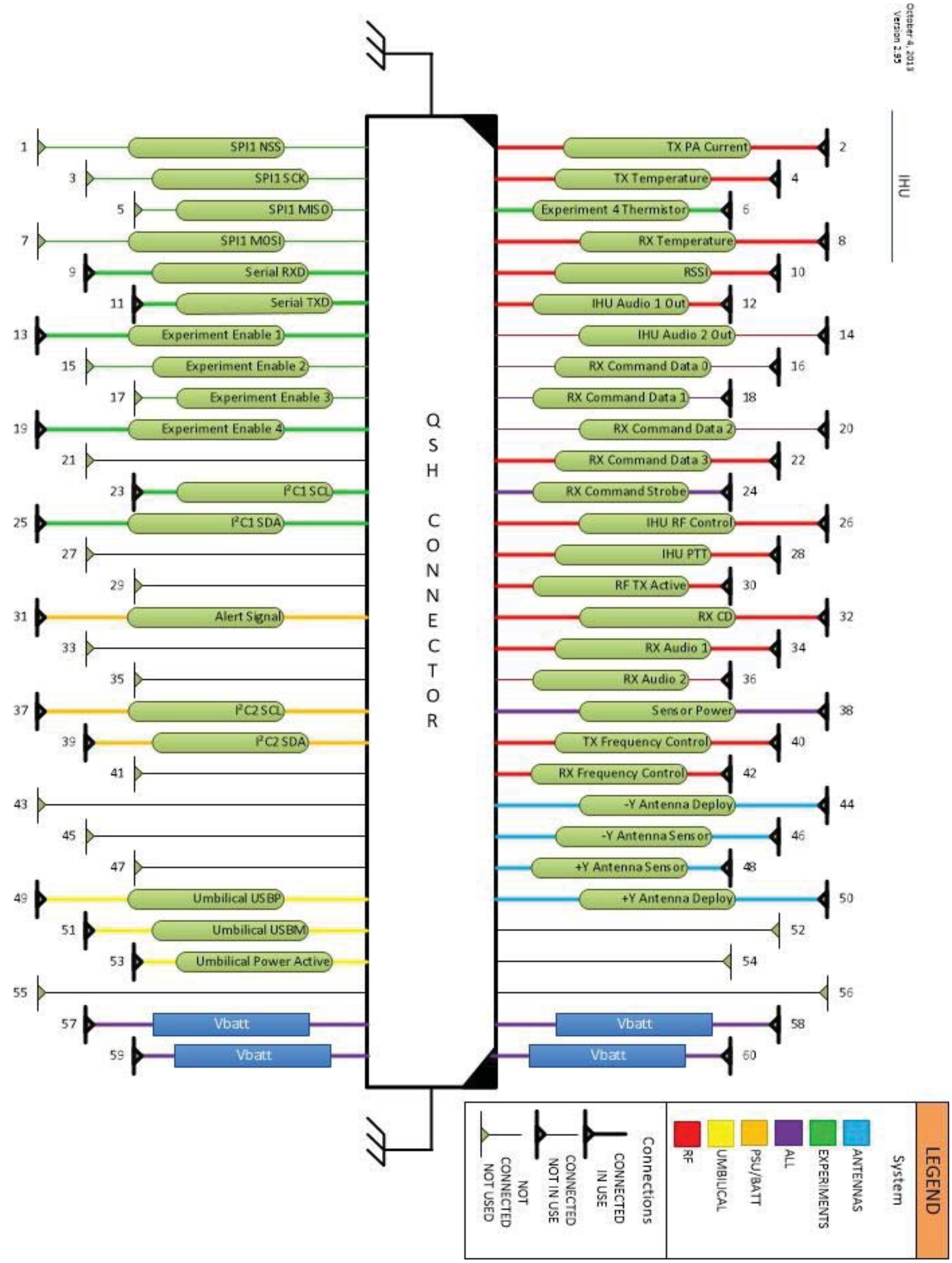


Figure 6: IHU System Bus Connection Pin Assignments

6 Power Supply System (PSU)

6.1 System Requirements Applicable to Power Supply System (PSU)

<table>
<tr><td>2.2.1</td><td>The satellite avionics shall be designed for -40C to +70C operating temperature.</td></tr>
<tr><td>2.2.3</td><td>The satellite shall be designed to tolerate the radiation environment in orbit.</td></tr>
<tr><td>2.3.1</td><td>The satellite shall be designed for a minimum 5-year, on-orbit lifetime.</td></tr>
<tr><td>3.3.1</td><td>The satellite shall include a "Remove Before Flight" pin as per the CubeSat Design Specification.</td></tr>
<tr><td>3.4.1</td><td>The satellite battery and photovoltaic panels shall be electronically disconnected from the avionics when the "Remove Before Flight" pin is inserted, regardless of the state of the deployment switch(es).</td></tr>
<tr><td>3.4.2</td><td>The satellite shall provide the means to charge the battery via the umbilical port while integrated with the P-POD.</td></tr>
<tr><td>3.5.1</td><td>The satellite shall produce electrical power from sunlight.</td></tr>
<tr><td>3.5.2</td><td>The satellite shall produce electrical power while in sunlight regardless of orientation and while tumbling or spinning.</td></tr>
<tr><td>3.5.3</td><td>The satellite shall produce sufficient average electrical power to operate continuously in the orbit of maximum eclipse.</td></tr>
<tr><td>3.5.4</td><td>The satellite shall provide sufficient battery capacity to operate continuously in the orbit of maximum eclipse.</td></tr>
<tr><td>3.6.1</td><td>The satellite shall provide DC power for experiment payloads.</td></tr>
<tr><td>3.10.1</td><td>The satellite shall collect telemetry data.</td></tr>
<tr><td>3.10.2</td><td>The telemetry data shall include at a minimum, measured parameters as shown in Table 3.
<table>
<tr><th>Parameter Name</th><th>Description</th></tr>
<tr><td>CELL V</td><td>Voltages of battery cells</td></tr>
<tr><td>PANEL V</td><td>Voltages of solar panels</td></tr>
<tr><td>TOTAL I</td><td>Total DC current out of power system</td></tr>
<tr><td>PA I</td><td>DC current into RF power amp</td></tr>
<tr><td>BATTERY T</td><td>Temperature of battery</td></tr>
<tr><td>PANEL T</td><td>Temperatures of solar panels</td></tr>
<tr><td>TX T</td><td>Temperature of RF transmitter card</td></tr>
<tr><td>RX T</td><td>Temperature of RF receiver card</td></tr>
</table>
</td></tr>
<tr><td>3.10.3</td><td>The measured parameters shall be sampled at least every 15 seconds.</td></tr>
<tr><td>3.10.5</td><td>The telemetry data shall also include at a minimum, calculated parameters as shown in Table 4.
<table>
<tr><th>Parameter Name</th><th>Description</th></tr>
</table>
</td></tr>
</table>

<table>
<tr><td></td><td><table><tr><td>UP TIME</td><td>Total seconds since avionics power-up or reset</td></tr><tr><td>SPIN</td><td>Satellite spin rate and direction</td></tr></table></td></tr>
<tr><td>3.12.3</td><td>The following commands shall be provided, as shown in Table 5.<table><tr><td>Command</td><td>Operation</td></tr><tr><td>TEST</td><td>Send test message</td></tr><tr><td>INHIBIT</td><td>Inhibit RF transmission</td></tr><tr><td>IHU OFF</td><td>Power off IHU & PSU</td></tr><tr><td>IHU ON</td><td>Power on IHU & PSU</td></tr><tr><td>CLEAR</td><td>Clear stored telemetry</td></tr><tr><td>TRANSPONDER MODE</td><td>Enter Transponder Mode</td></tr><tr><td>DATA MODE</td><td>Enter Data Mode</td></tr></table></td></tr>
<tr><td>3.13.7.1</td><td>During the 45 minute wait the IHU shall flash a red LED.</td></tr>
</table>

6.2 Initial Surge Current Limits

6.2.1 The PSU design shall limit initial inrush current to 0.1 Amperes.

6.3 Volume Requirements Applicable to PSU System

6.3.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 1 mm from the –Z surface of the PC board.

6.3.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 3.0 mm from the +Z surface of the PC board within the area 0 to 4.0 mm from the +Y and +X edges of the board, and 6.0 mm from the +Z surface of the PC board in the rest of the board area.

6.4 Interface Control Documents Applicable to PSU System

AMSAT *Fox-1* IHU to PSU Interface Control Document

6.5 Power Supply System (PSU) PCB Bus Connections

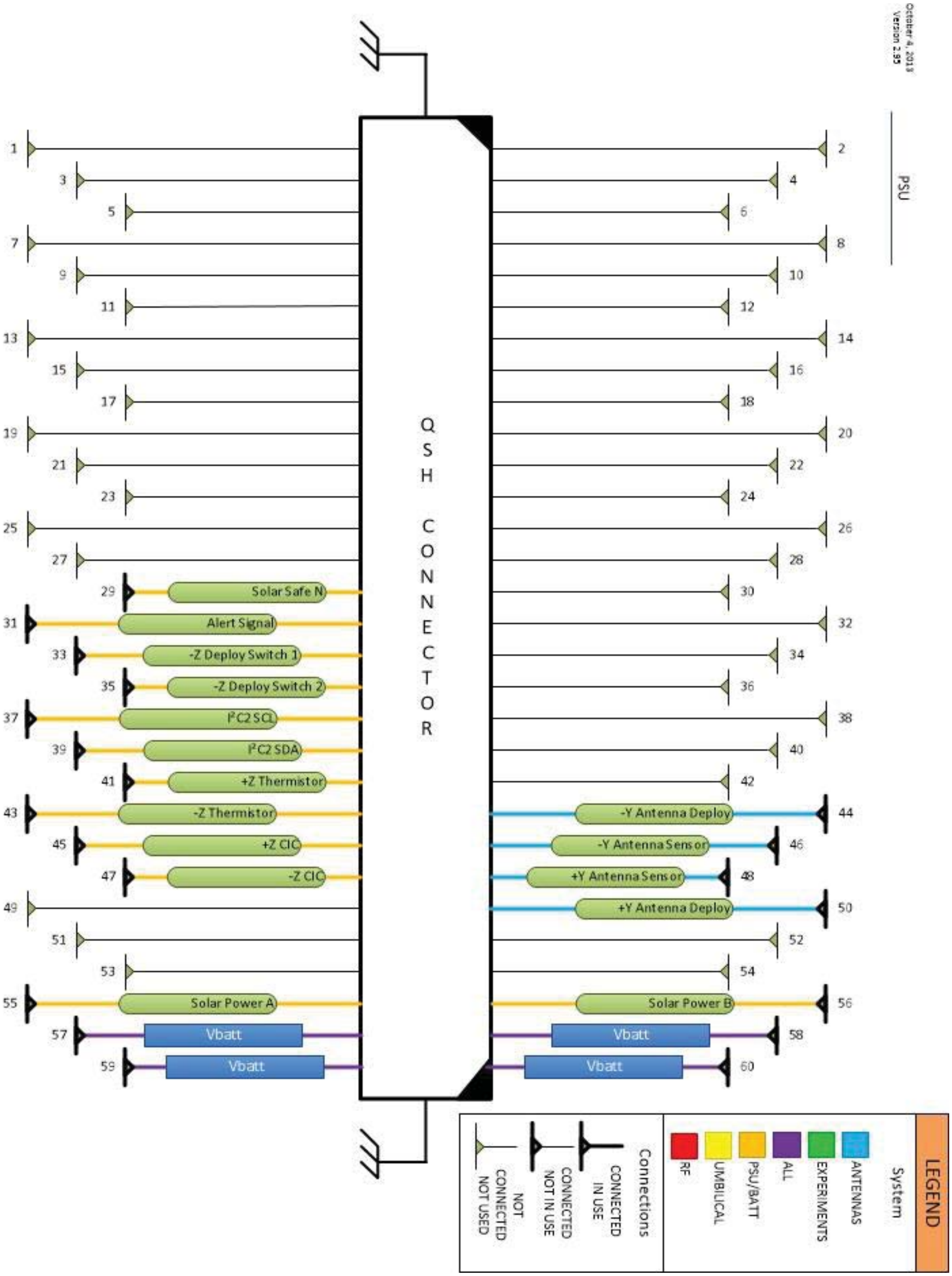


Figure 7: PSU Bus Connection Pin Assignments

6.6 Power Supply System (PSU) PCB External Connections

6.6.1 Three connections to +X Solar Panel using Samtec MEC1-105-02-L-D-NP-A connector
  6.6.1.1 1 contact +X Solar Panel Thermistor
  6.6.1.2 1 contact +X Solar Panel CIC +
  6.6.1.3 1 contact common or - for above two connections

6.6.2 Three connections to -X Solar Panel using Samtec MEC1-105-02-L-D-NP-A connector
  6.6.2.1 1 contact -X Solar Panel Thermistor
  6.6.2.2 1 contact -X Solar Panel CIC +
  6.6.2.3 1 contact common or - for above two connections

6.6.3 Five connections to +Y Solar Panel using Samtec MEC1-105-02-L-D-NP-A connector
  6.6.3.1 1 contact +Y Solar Panel Thermistor
  6.6.3.2 1 contact +Y Solar Panel CIC +
  6.6.3.3 1 contact TX Antenna Deploy
  6.6.3.4 1 contact TX Antenna Sensor
  6.6.3.5 1 contact common or - for above connections

6.6.4 Five connections to -Y Solar Panel using Samtec MEC1-105-02-L-D-NP-A connector
  6.6.4.1 1 contact -Y Solar Panel Thermistor
  6.6.4.2 1 contact -Y Solar Panel CIC +
  6.6.4.3 1 contact RX Antenna Deploy
  6.6.4.4 1 contact RX Antenna Sensor
  6.6.4.5 1 contact common or - for above connections

6.6.5 All PCB edges that connect to solar panel MEC1-105-02-L-D-NP-A connectors shall have contact pads on the PCB for all connector pins, whether connected to a trace or not.

Table 5: +X PCB edge mates to MEC1-105-02-L-D-NP-A connector on +X Solar Panel

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Bus Pin
1	N/C					
2	+X Solar Panel Thermistor	Analog	N/A	N/A	N/A	N/A
3	N/C					
4	N/C					
5	N/C					
6	+X Solar Panel Common					Ground Plane
7	N/C					
8	N/C					
9	N/C					
10	+X Solar Panel CIC (+)	Power	N/A	N/A	N/A	N/A

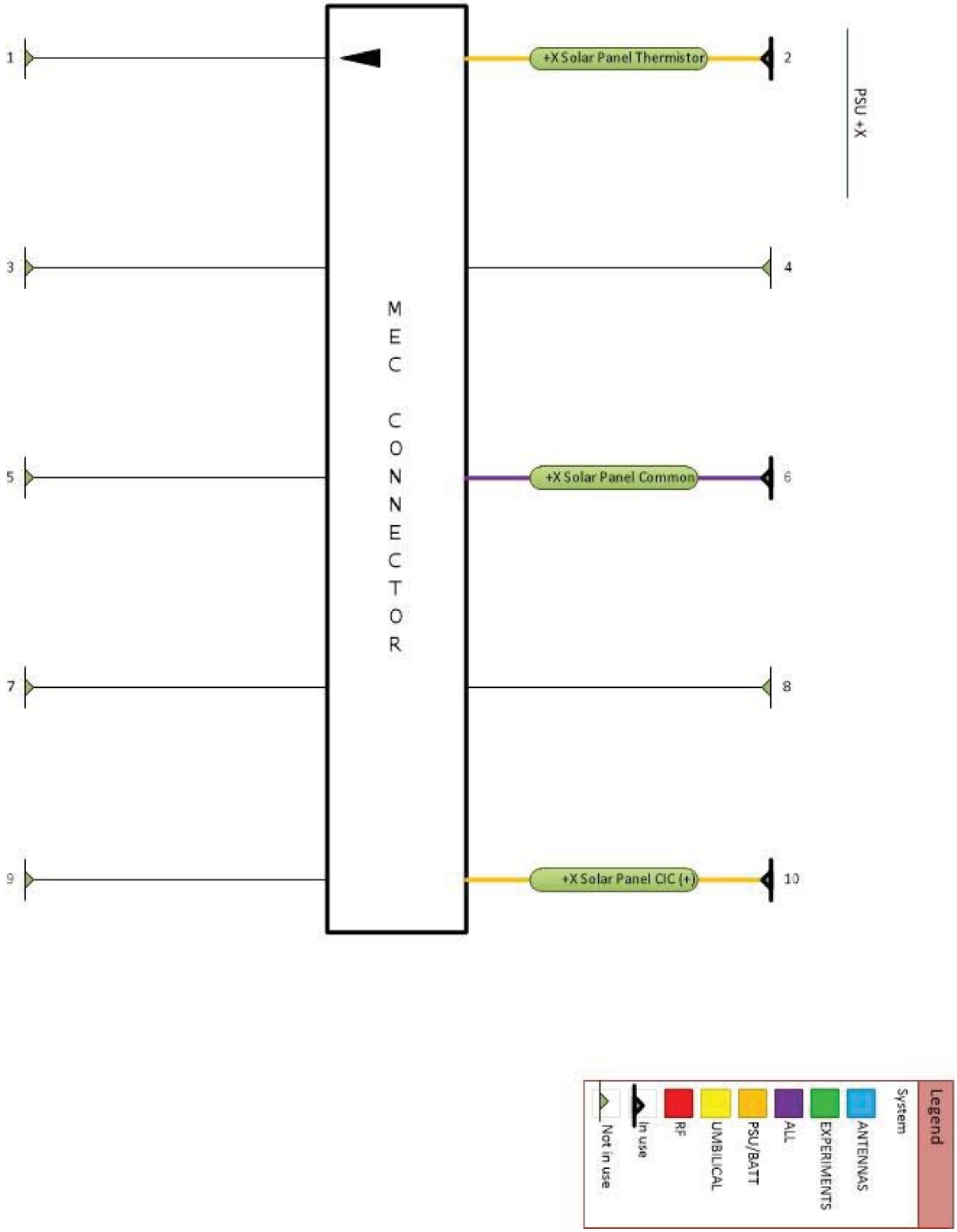


Figure 8: PSU System +X Edge MEC1-105-02-L-D-NP-A Connection Pin Assignments

Table 6: -X PCB edge mates to MEC1-105-02-L-D-NP-A connector on -X Solar Panel

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Bus Pin
1	N/C					
2	-X Solar Panel Thermistor	Analog	N/A	N/A	N/A	N/A
3	N/C					
4	N/C					
5	N/C					
6	-X Solar Panel Common					Ground Plane
7	N/C					
8	N/C					
9	N/C					
10	-X Solar Panel CIC (+)	Power	N/A	N/A	N/A	N/A

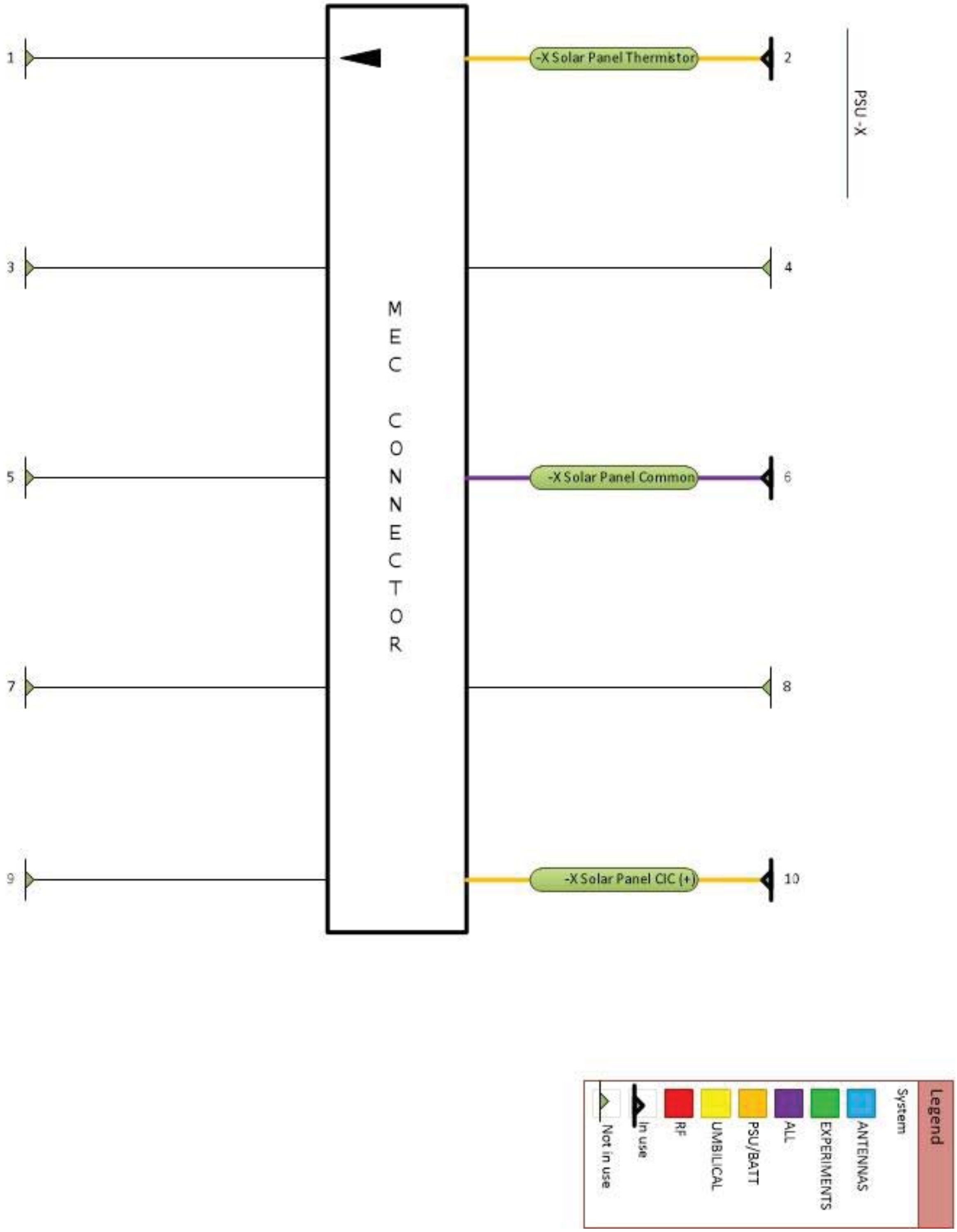


Figure 9: PSU System -X Edge MEC1-105-02-L-D-NP-A Connection Pin Assignments

Table 7: +Y PCB edge mates to MEC1-105-02-L-D-NP-A connector on +Y Solar Panel

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Bus Pin
1	N/C					
2	+Y Solar Panel Thermistor	Analog	N/A	N/A	N/A	N/A
3	N/C					
4	+Y Antenna Sensor	Switch	N/A	PSU	N.O.	48
5	N/C					
6	+Y Solar Panel Common					Ground Plane
7	N/C					
8	+Y Antenna Deploy	Analog	Vbatt	IHU	7 Ω resistor	50
9	N/C					
10	+Y Solar Panel CIC (+)	Power	N/A	N/A	N/A	N/A

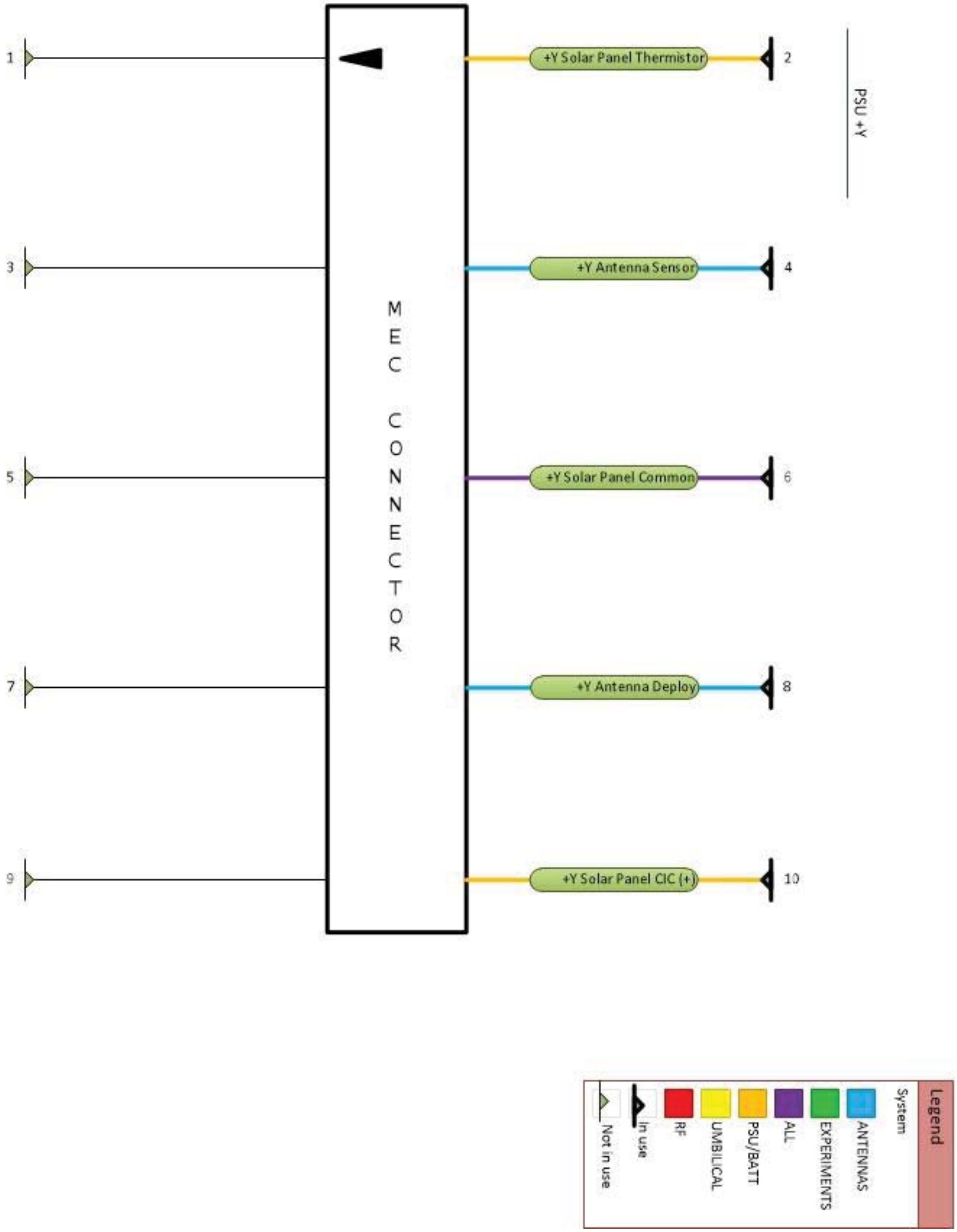


Figure 10: PSU System +Y Edge MEC1-105-02-L-D-NP-A Connection Pin Assignments

Table 8: -Y PCB edge mates to MEC1-105-02-L-D-NP-A connector on -Y Solar Panel

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Bus Pin
1	N/C					
2	-Y Solar Panel Thermistor	Analog	N/A	N/A	N/A	N/A
3	N/C					
4	-Y Antenna Sensor	Switch	N/A	PSU	N.O.	46
5	N/C					
6	-Y Solar Panel Common					Ground Plane
7	N/C					
8	-Y Antenna Deploy	Analog	Vbatt	IHU	7 Ω resistor	44
9	N/C					
10	-Y Solar Panel CIC (+)	Power	N/A	N/A	N/A	N/A

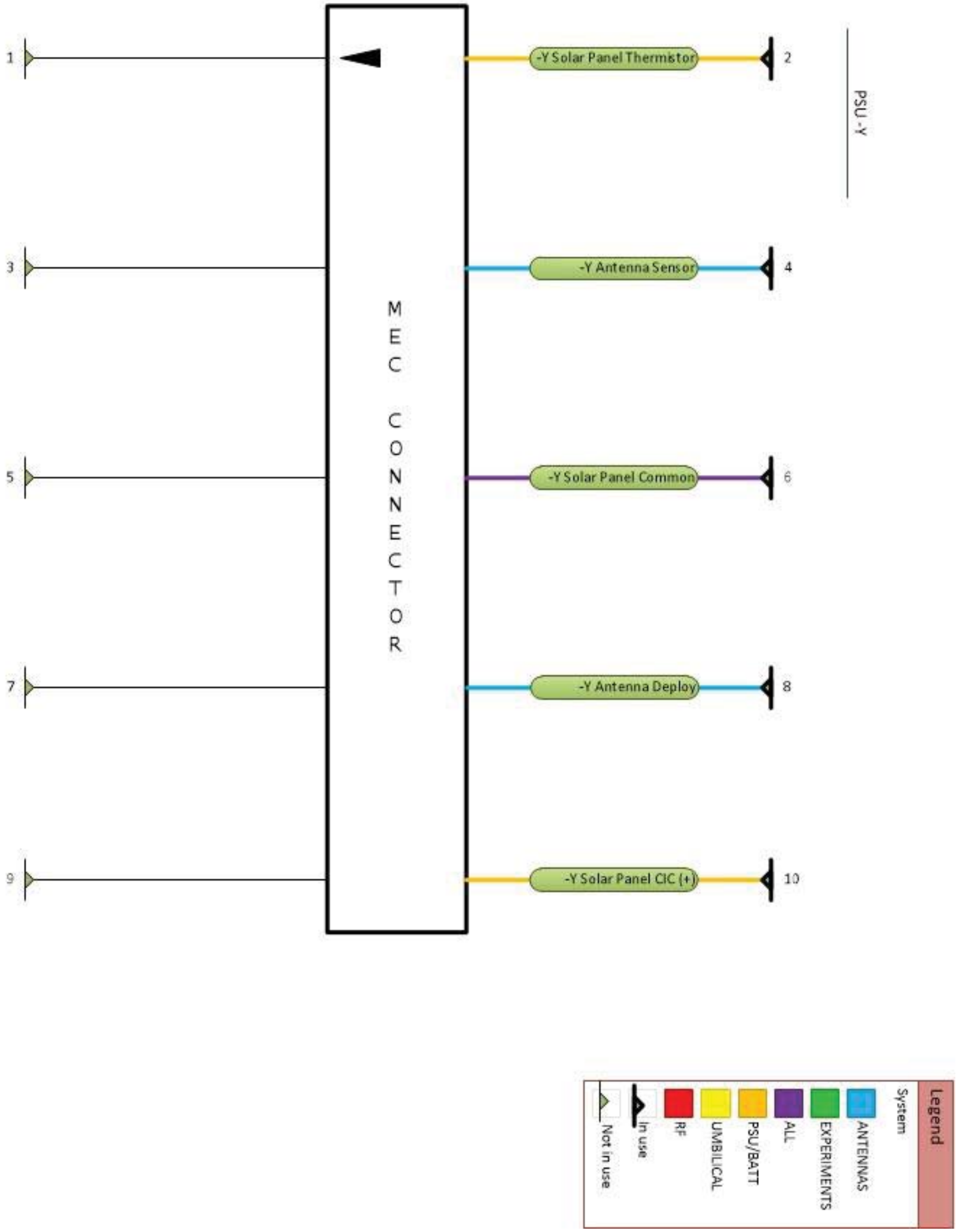


Figure 11: PSU System -Y Edge MEC1-105-02-L-D-NP-A Connection Pin Assignments

7 Battery System

7.1 System Requirements Applicable to Battery PCB 1 System (BATT1)

<table>
<tr><td>2.2.1</td><td>The satellite avionics shall be designed for -40C to +70C operating temperature.</td></tr>
<tr><td>2.2.3</td><td>The satellite shall be designed to tolerate the radiation environment in orbit.</td></tr>
<tr><td>2.3.1</td><td>The satellite shall be designed for a minimum 5-year, on-orbit lifetime.</td></tr>
<tr><td>3.3.1</td><td>The satellite shall include a "Remove Before Flight" pin as per the CubeSat Design Specification.</td></tr>
<tr><td>3.4.1</td><td>The satellite battery and photovoltaic panels shall be electronically disconnected from the avionics when the "Remove Before Flight" pin is inserted, regardless of the state of the deployment switch(es).</td></tr>
<tr><td>3.4.2</td><td>The satellite shall provide the means to charge the battery via the umbilical port while integrated with the P-POD.</td></tr>
<tr><td>3.5.3</td><td>The satellite shall produce sufficient average electrical power to operate continuously in the orbit of maximum eclipse.</td></tr>
<tr><td>3.5.4</td><td>The satellite shall provide sufficient battery capacity to operate continuously in the orbit of maximum eclipse.</td></tr>
<tr><td>3.10.1</td><td>The satellite shall collect telemetry data.</td></tr>
<tr><td>3.10.2</td><td>The telemetry data shall include at a minimum, measured parameters as shown in Table 3.
<table>
<tr><th>Parameter Name</th><th>Description</th></tr>
<tr><td>CELL V</td><td>Voltages of battery cells</td></tr>
<tr><td>PANEL V</td><td>Voltages of solar panels</td></tr>
<tr><td>TOTAL I</td><td>Total DC current out of power system</td></tr>
<tr><td>PA I</td><td>DC current into RF power amp</td></tr>
<tr><td>BATTERY T</td><td>Temperature of battery</td></tr>
<tr><td>PANEL T</td><td>Temperatures of solar panels</td></tr>
<tr><td>TX T</td><td>Temperature of RF transmitter card</td></tr>
<tr><td>RX T</td><td>Temperature of RF receiver card</td></tr>
</table>
</td></tr>
<tr><td>3.10.3</td><td>The measured parameters shall be sampled at least every 15 seconds.</td></tr>
</table>

7.2 Volume Requirements Applicable to Battery PCB 1 System

7.2.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 4.0 mm from the -Z surface of the PC board within the area 0 to 4.0 mm from the +Y and +X edges of the board, and 1.0 mm from the -Z surface of the PC board in the rest of the board area.

7.2.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 17.0 mm from the +Z surface of the PC board.

7.3 Interface Control Documents Applicable to Battery PCB 1 System

AMSAT *Fox-1* IHU to Battery Interface Control Document

7.4 Battery PCB 1 System Bus Connections

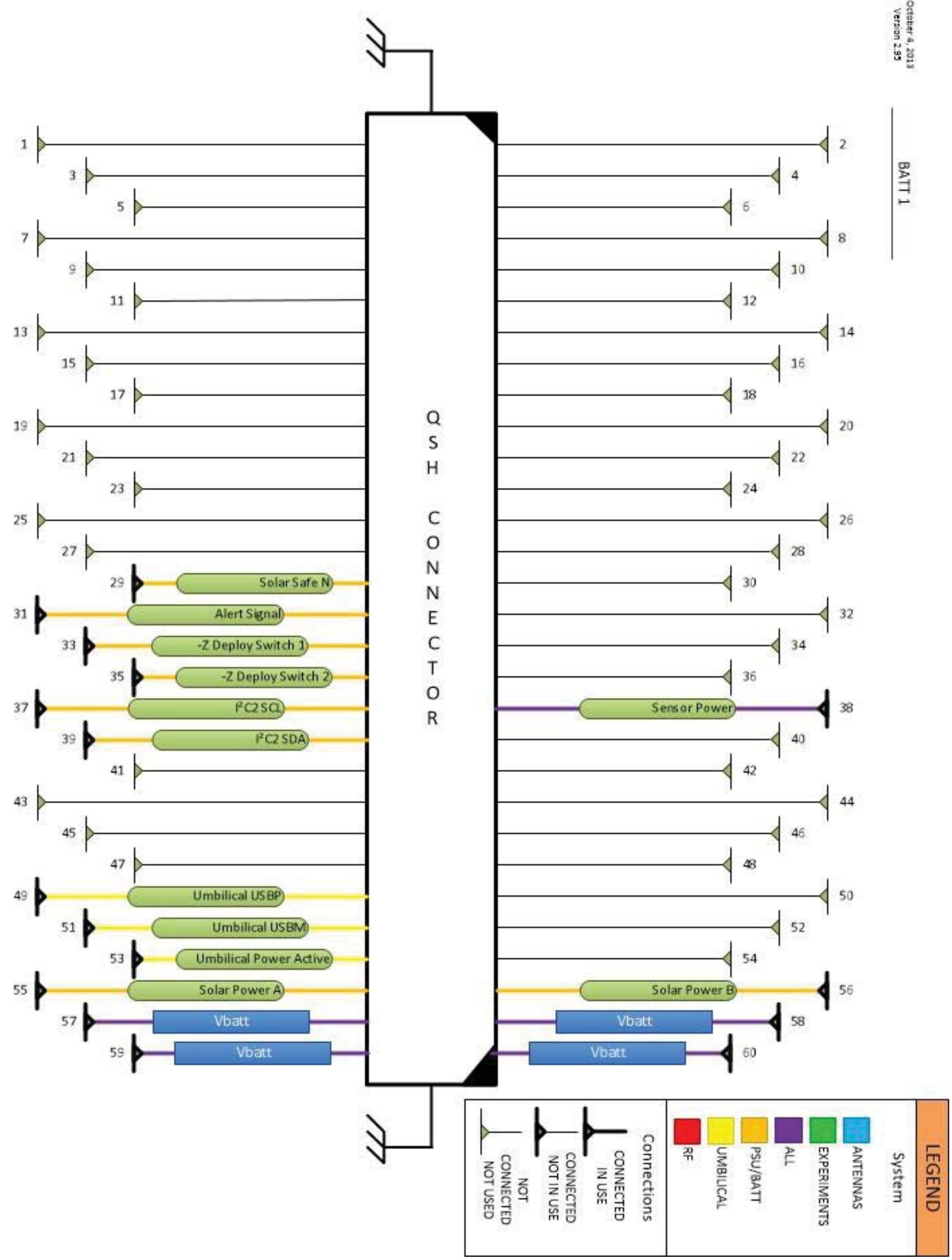


Figure 12: Battery 1 System Bus Connection Pin Assignments

7.5 Battery PCB 1 System External Connections

7.5.1 Umbilical as USB mini type B receptacle

7.5.2 Remove Before Flight as 3.5mm normally open TS jack

Table 9: Battery 1 External Connection Signal Characteristics

External Connection	Nomenclature	Type	Voltage/ Power	Source System	Load Z	Bus Pin
USB 1	USB +5 VDC	Analog	5 VDC	USB CONNECTOR	N/A	N/A
USB 2	USB Data - (USBM)	Digital	3.0 V CMOS logic	USB CONNECTOR	N/A	51
USB 3	USB Data + (USBP)	Digital	3.0 V CMOS logic	USB CONNECTOR	N/A	49
USB 4	Ground			USB CONNECTOR	N/A	Ground Plane
RBF 1	Solar Safe N	Analog	N/A	3.5mm N.O. TS jack	N/A	40

*When external supply is connected to USB port

7.6 Battery PCB 2 System Bus Connections

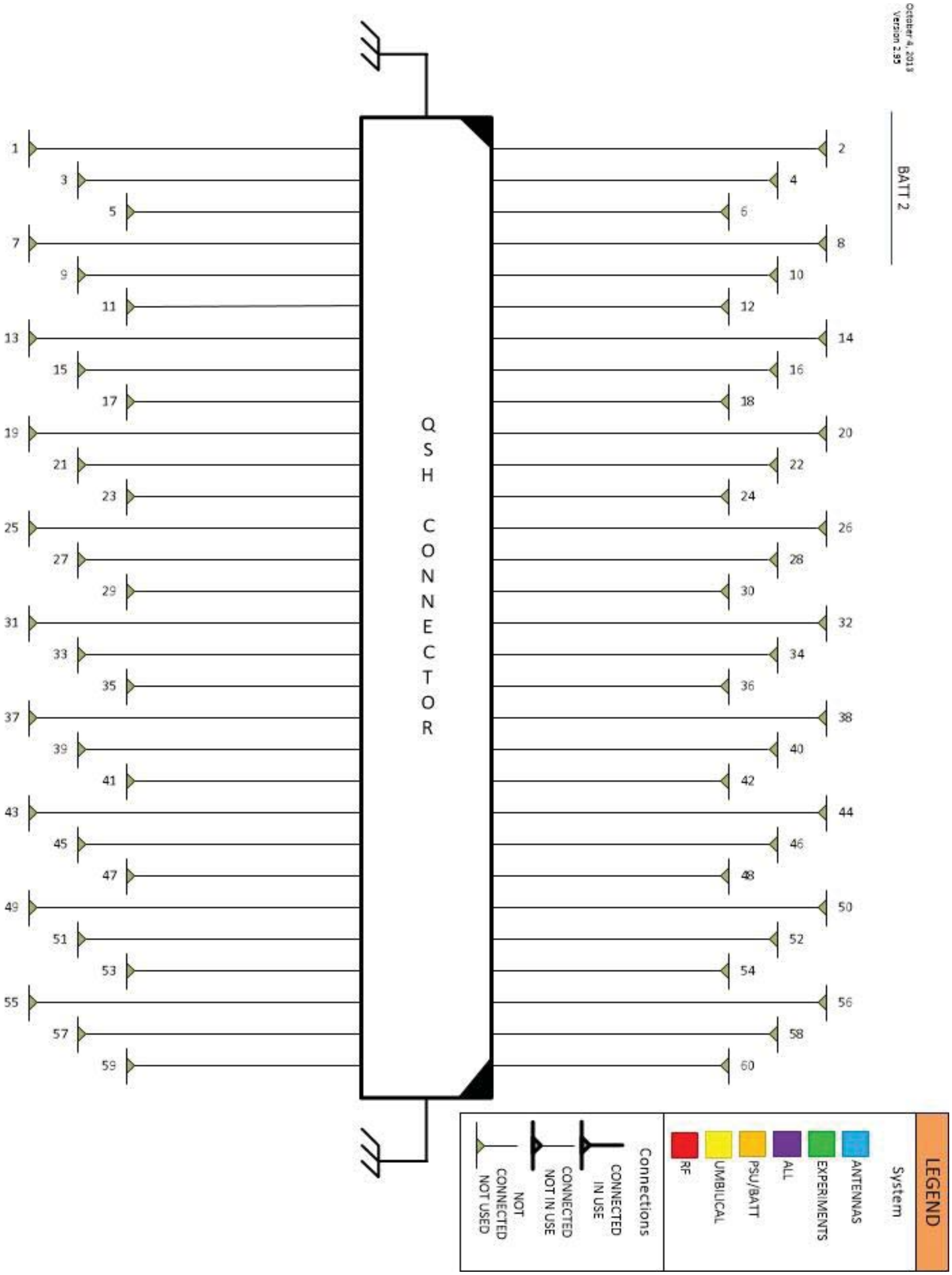


Figure 13: Battery 2 Bus Connection Pin Assignments

8 Experiment Payload Systems 1 through 4

8.1 System Requirements Applicable to Experiment Payload Systems 1-4

2.1.4	The satellite shall provide mass for an experiment payload up to 100 g.
2.1.5	The satellite shall provide volume for an experiment payload up to 95 x 95 x 15.7 mm.
2.2.1	The satellite avionics shall be designed for -40C to +70C operating temperature.
2.2.3	The satellite shall be designed to tolerate the radiation environment in orbit.
2.3.1	The satellite shall be designed for a minimum 5-year, on-orbit lifetime.
3.6.1	The satellite shall provide DC power for experiment payloads.
3.6.2	The satellite shall provide a means to activate and deactivate the experiment payloads.
3.6.3	The satellite shall provide a means to telemeter data from the experiment payloads.

8.2 Initial Surge Current Limits

8.2.1 All Experiment designs shall limit initial inrush current to 0.1 Amperes.

8.3 Volume Requirements Applicable to Experiment Payload System 1

8.3.1 No components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall protrude from the –Z surface of the PC board.

8.3.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 6.0 mm from the +Z surface of the PC board.

8.4 Interface Control Documents Applicable to Experiment 1 Payload System

AMSAT *Fox-1* IHU to Experiment 1 Interface Control Document

8.5 Volume Requirements Applicable to Experiment Payload Systems 2 and 3

8.5.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 1 mm from the –Z surface of the PC board.

8.5.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 6.0 mm from the +Z surface of the PC board.

8.6 Volume Requirements Applicable to Experiment System 4

8.6.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 1 mm from the –Z surface of the PC board.

8.6.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 5.0 mm from the +Z surface of the PC board.

8.7 Interface Control Documents Applicable to Experiment 4 Payload System

AMSAT *Fox-1* IHU to Experiment 4 Interface Control Document

8.8 Experiment Payload 1 Systems PCB Bus Connections

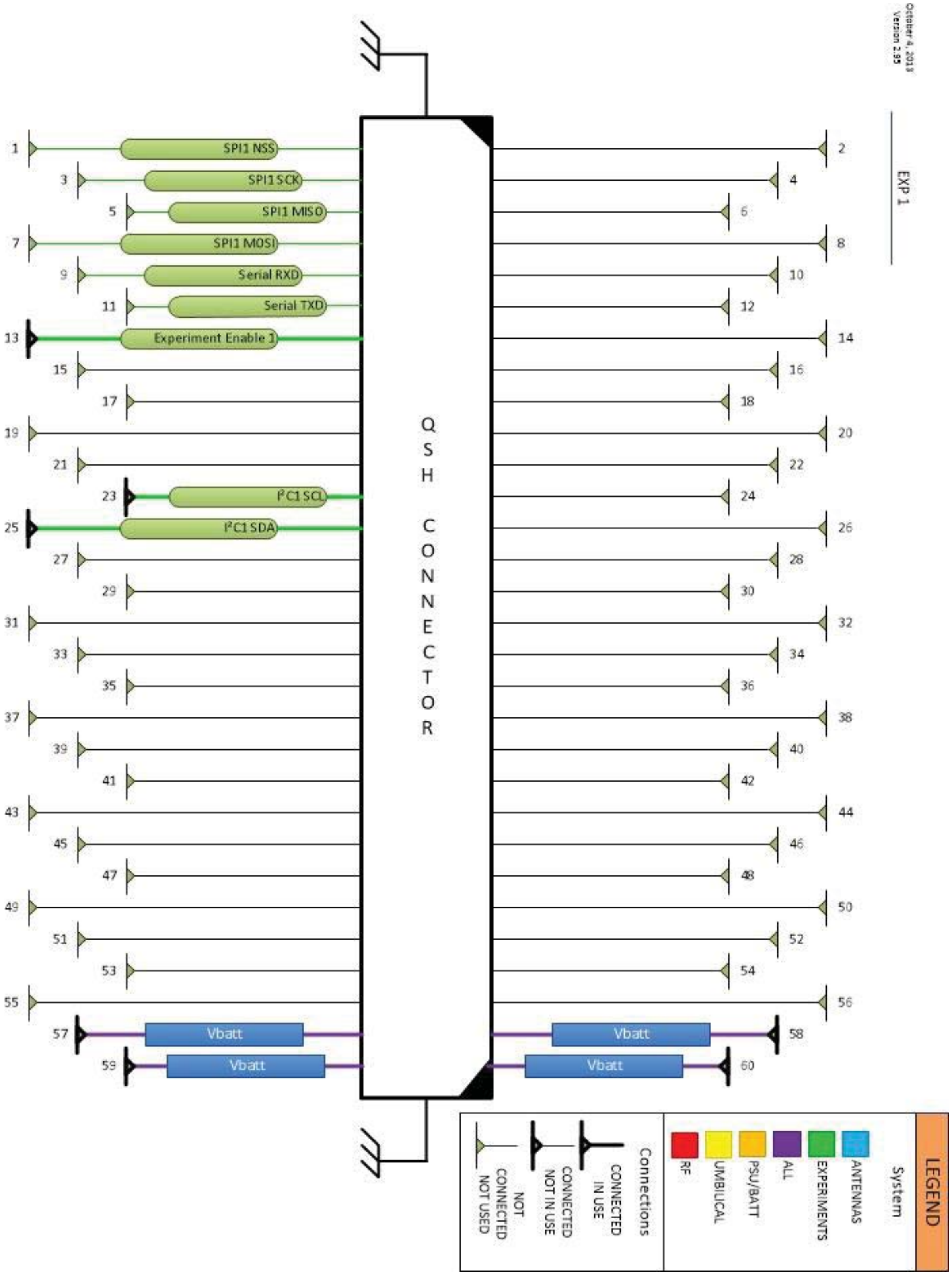


Figure 14: Experiment Payload 1-3 Systems Bus Connection Pin Assignments

8.9 Experiment Payload 4 System PCB Bus Connections

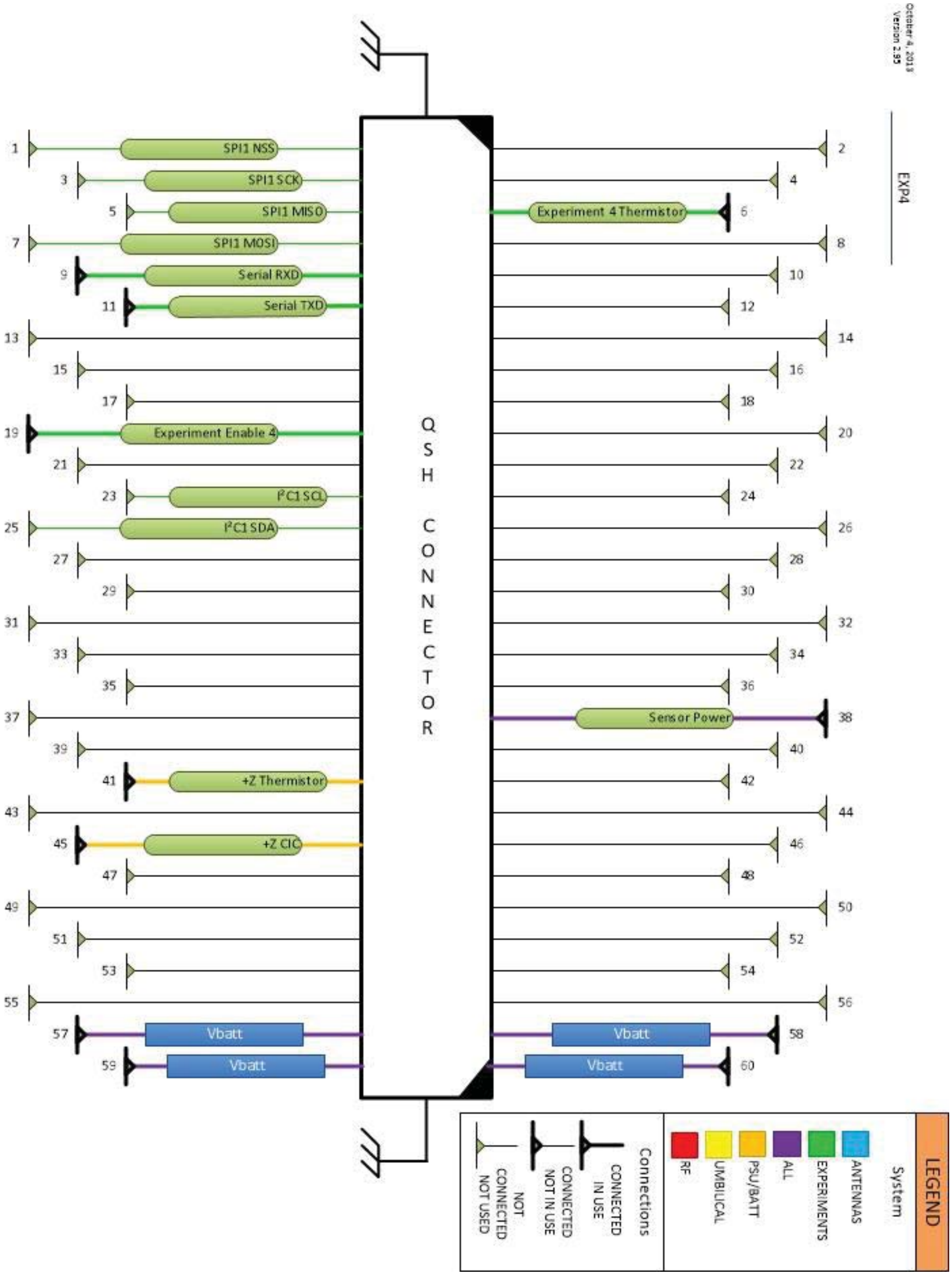


Figure 15: Experiment Payload 4 System Bus Connection Pin Assignments

8.10 Experiment Payload 4 System PCB External Connections

8.10.1 Three connections using Samtec FSI-105-06-L-S-AD connector

8.10.1.1 1 contact +Z Solar Panel Thermistor

8.10.1.2 1 contact +Z Solar Panel CIC +

8.10.1.3 1 contact common or - for above two connections

Table 10: +Z PCB face FSI-105-06-L-S-AD connector mates to pads on +Z Solar Panel

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Load System	Bus Pin
1	+Z Thermistor	Analog	N/A	N/A	N/A	PSU	41
2	N/C						
3	+Z Solar Panel Common						Ground Plane
4	N/C						
5	+Z CIC	Power	N/A	N/A	N/A	PSU	45

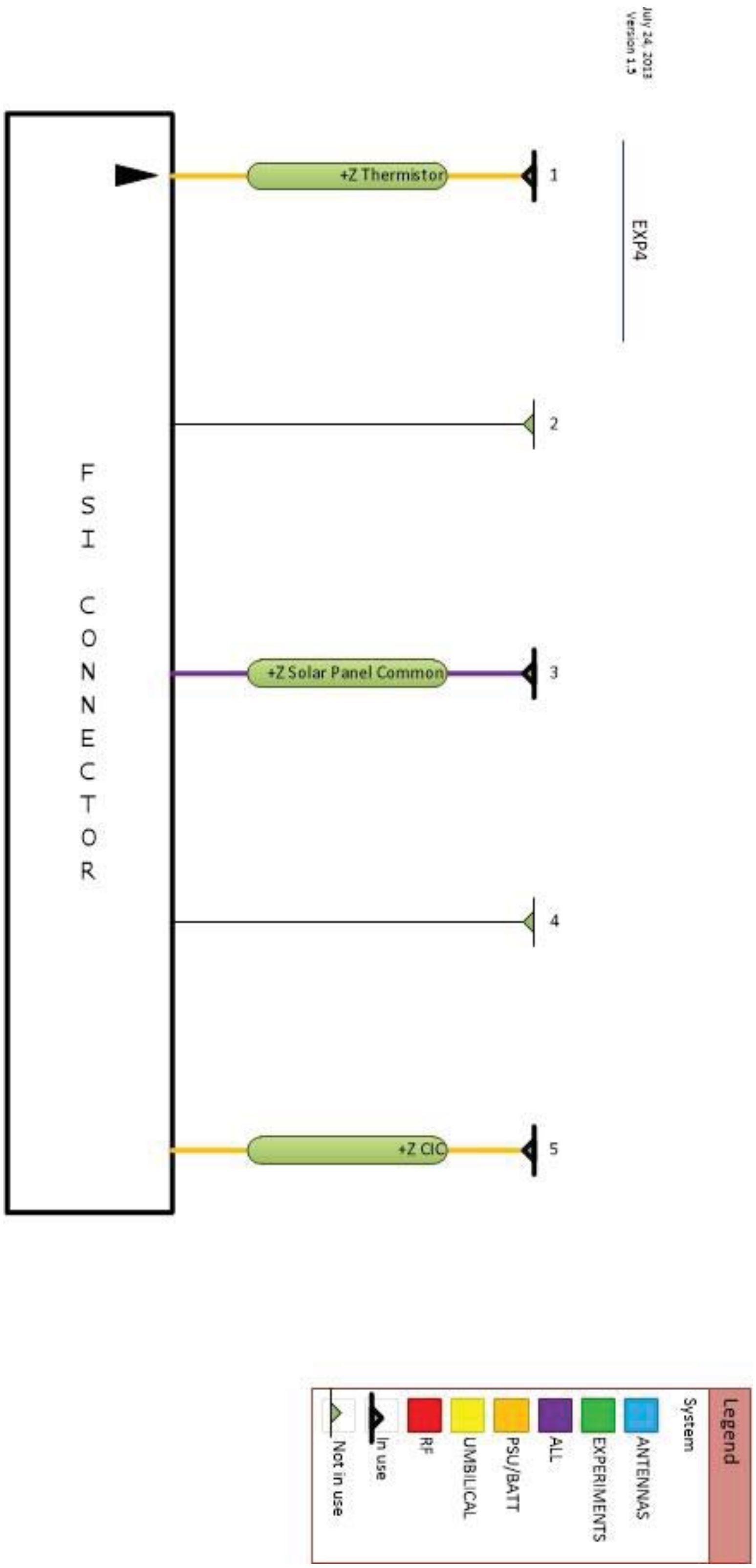
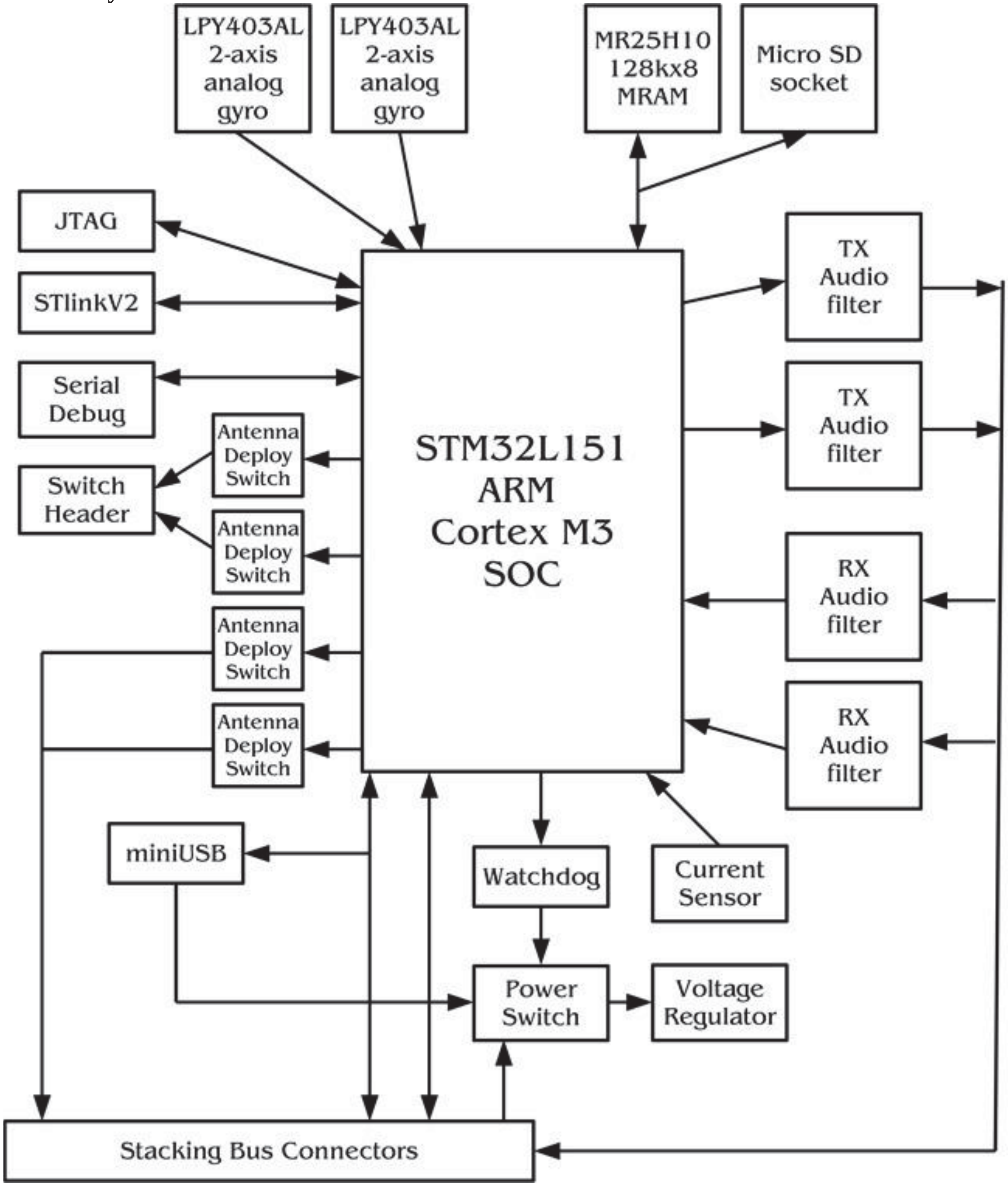


Figure 16: Experiment Payload 4 System FSI-105-06-L-S-AD Connection Pin Assignments

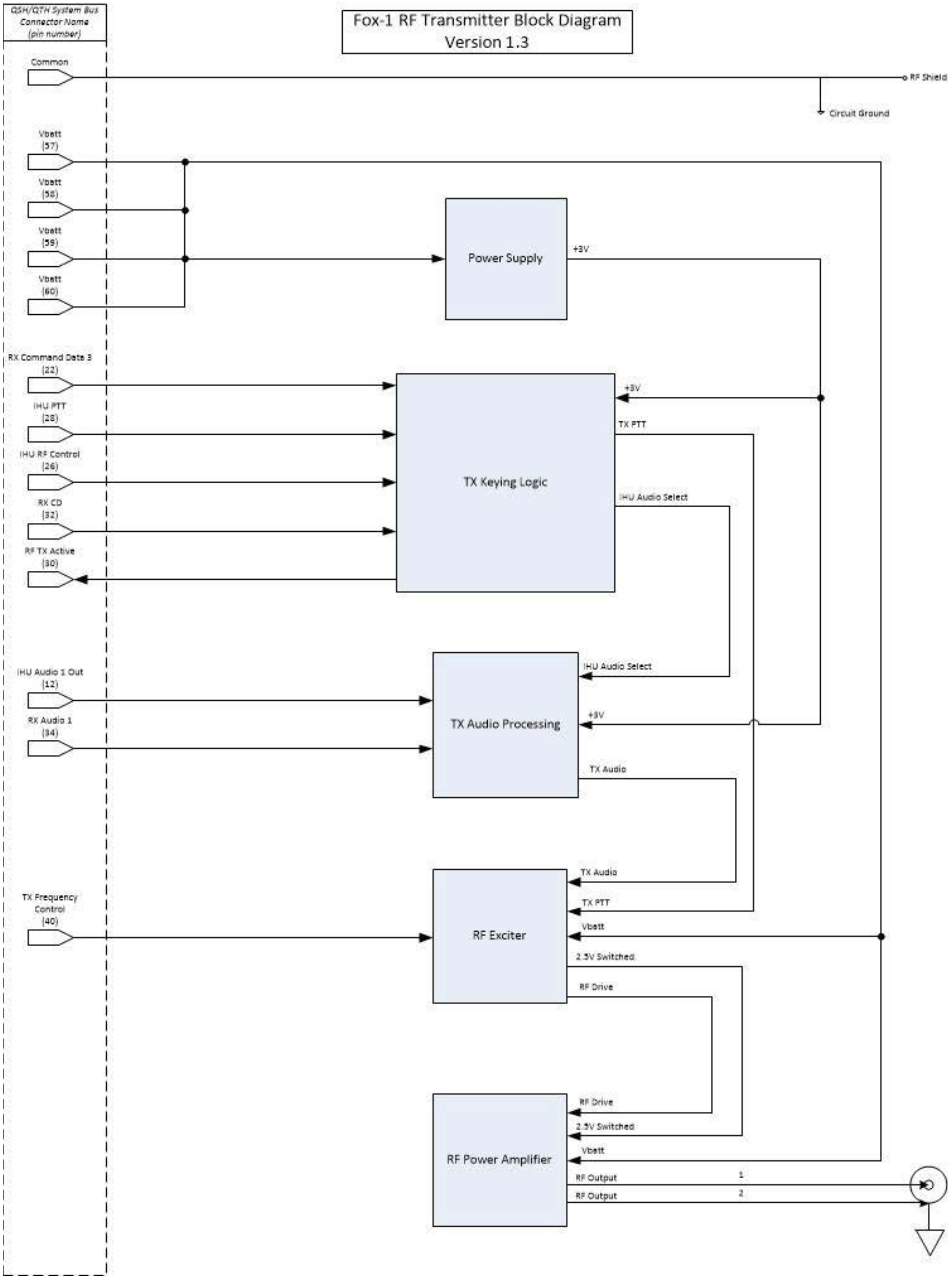
9 System Block Diagrams Reference

9.1 IHU System



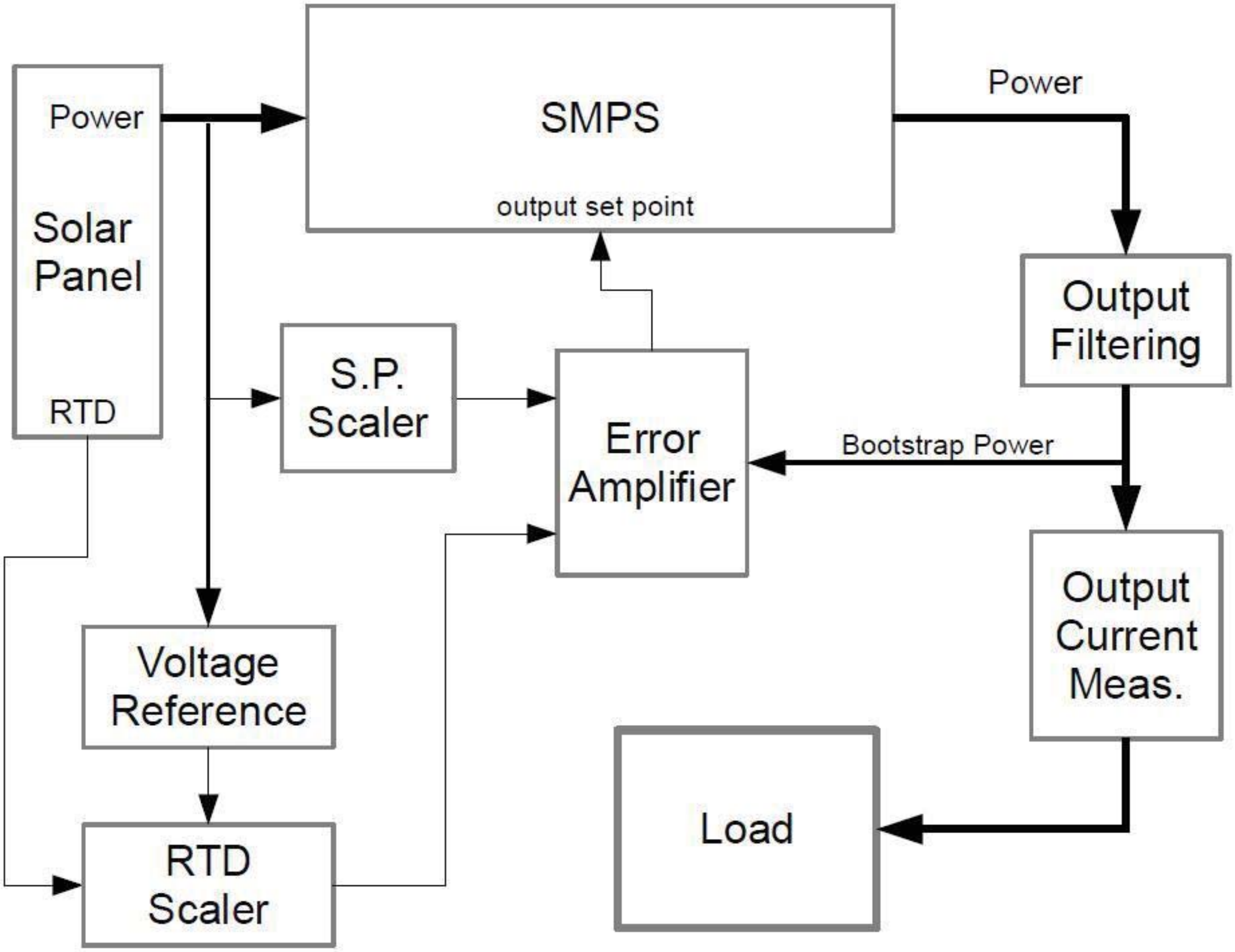
9.2 RF System

9.2.1 RF Transmitter Block Diagram



9.2.2 RF Receiver Block Diagram (TBR)

9.3 PSU System



10 System Interconnection References

10.1 Bus Connectors

10.1.1 Samtec QTH-030-02-L-D-A and QSH-030-01-L-D-A connectors
10.1.2 QTH connector shall be mounted on the +Z surface of each circuit board except the Receive Antenna PCB / GPS Payload circuit board
10.1.3 QSH connector shall be mounted on the –Z surface of each circuit board

10.2 Bus Connector Documentation

10.2.1 Samtec QSH
10.2.2 Samtec QTH
10.2.3 Samtec QxH High Speed Characterization Report
10.2.4 Samtec QxH Single Ended Channel Properties

10.3 External Connectors

10.3.1 Samtec MEC1-105-02-L-D-NP-A connector mounted on +X, -X, +Y, -Y Solar Panels
10.3.2 Samtec FSI-105-06-L-S-AD connector mounted on -Z face of RF Transmitter System PCB and +Z face of Experiment Payload 4 System PCB

10.4 External Connector Documentation

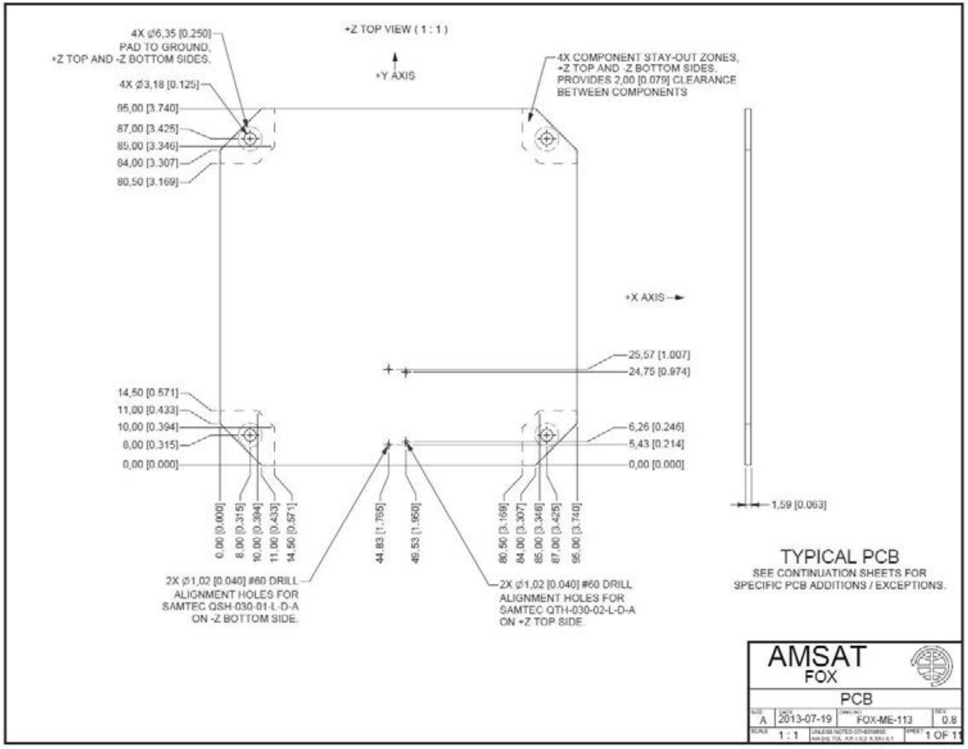
10.4.1 Samtec MEC1
10.4.2 Samtec MEC1 Qualification Testing
10.4.3 Samtec FSI

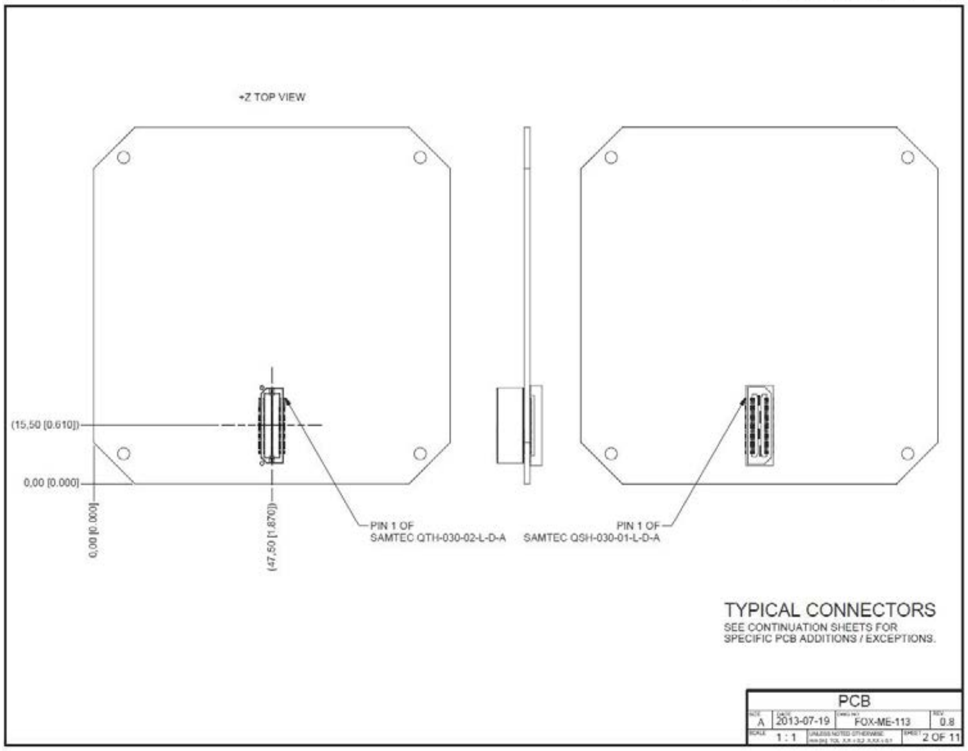
10.5 PCB Connector Layout Documentation

10.5.1 FOX-ME-113_PCB.pdf

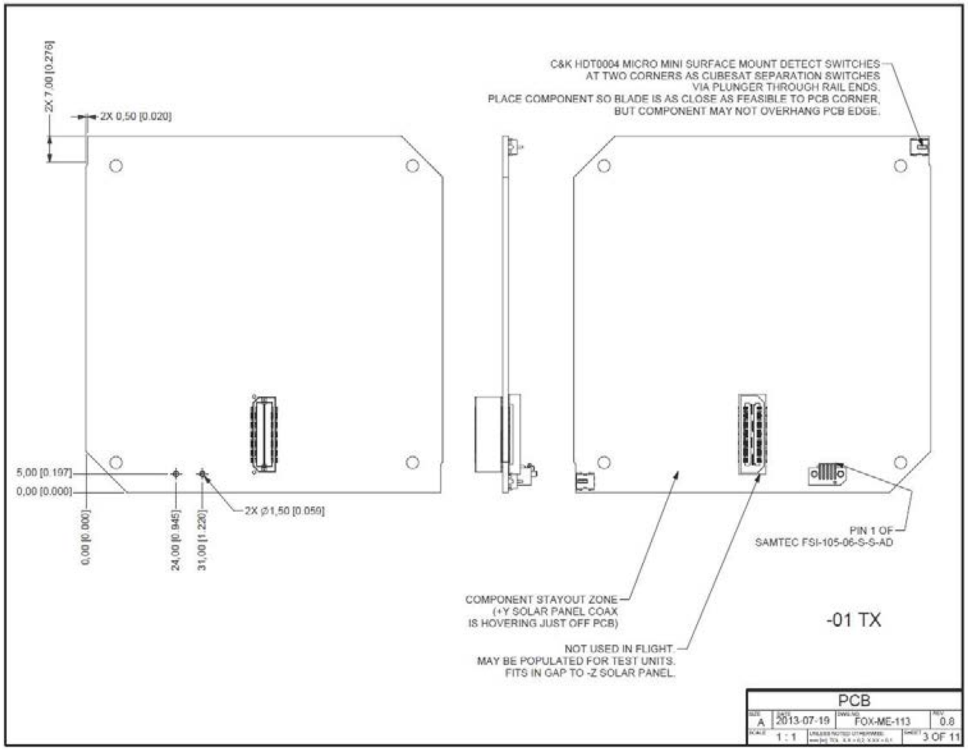
10.6 Systems PCB Connector Layout

10.6.1 Common to All Systems

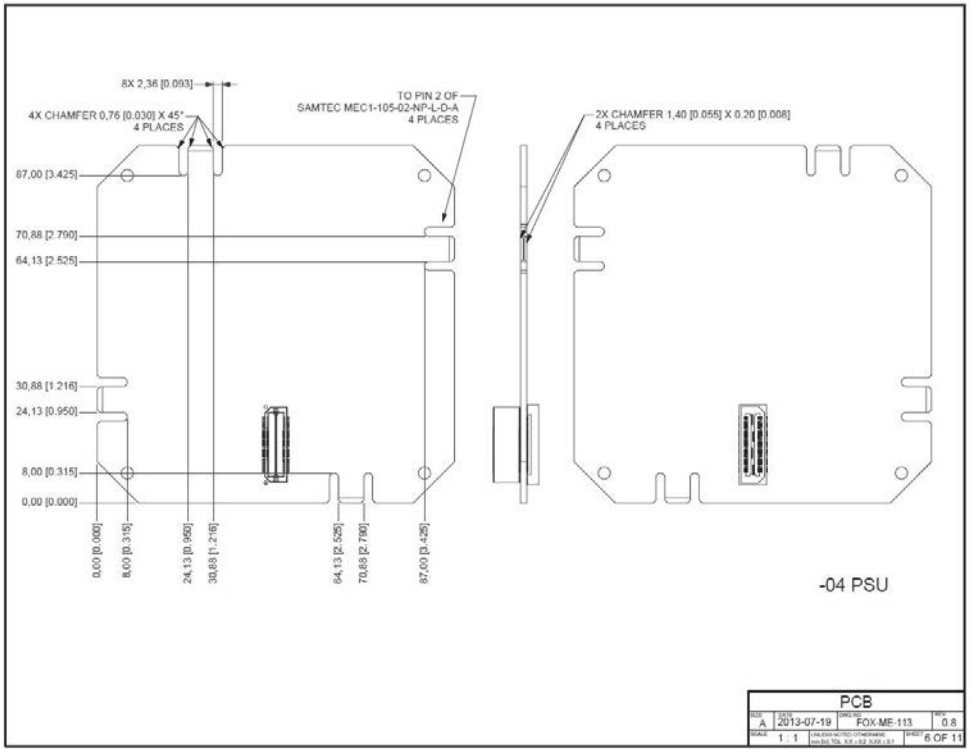




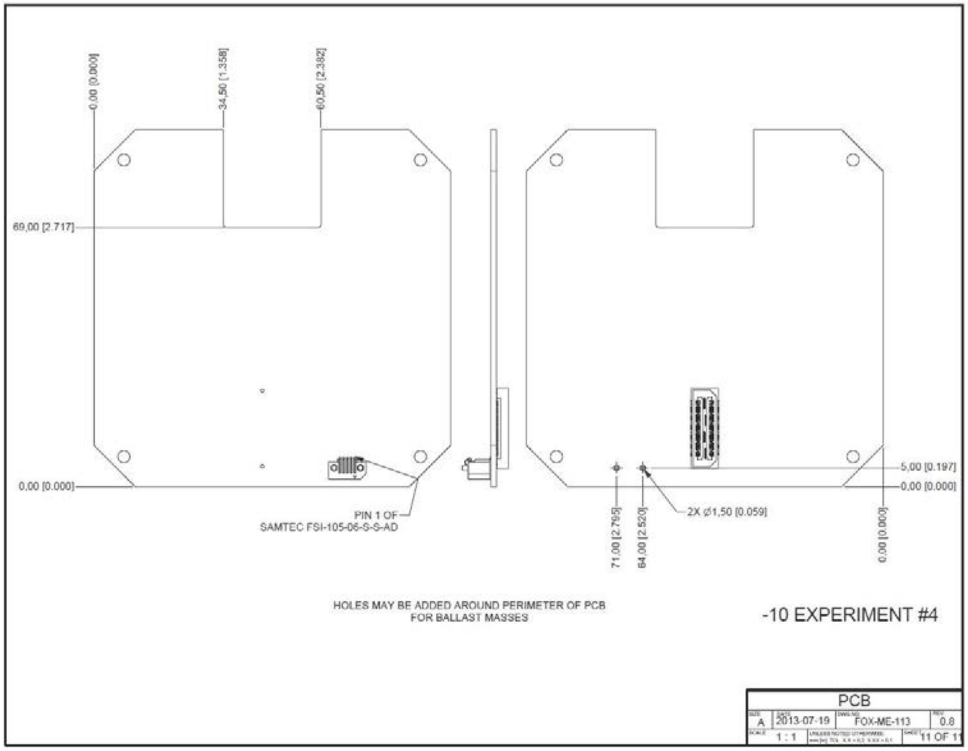
10.6.2 RF Transmitter System



10.6.3 PSU System



10.6.4 Experiment 4 System



Date: June 29, 2012
Version: 2.0

AMSAT *Fox-1*

Attitude Determination Experiment Payload System Requirements Specification

1 Introduction

This document specifies the system level technical requirements for the AMSAT *Fox-1* satellite project attitude determination experiment payload.

The *Fox*-1 satellite is a 1 Unit CubeSat with a primary mission of providing amateur radio communications. In addition to its mission as a communications satellite, *Fox-1* will host an experiment payload. The satellite will reserve mass and volume for the experiment and will provide DC power and a communications facility. The experiment is expected to be provided by students at Penn State University – Erie, through an AMSAT sponsored senior design project.

The goal of the experiment will be to measure the spin rate and direction, about the Z axis of the satellite, and any off Z-axis "wobble".

1.1 Document History

DATE	VERSION	SUMMARY
November 9, 2011	1.0	From Draft F
December 4, 2011	1.01	Fix formatting
December 23, 2011	1.03	Update references to other documents
December 27, 2011	1.04	Update 2.1.13 for QTH/QSH connectors
February 12, 2011	1.10	Change bus to SPI and add power signal Removed references to multiple PCBs and conflicting component placement Adjust PCB stay out zone and other requirements per latest mechanical revisions
June 29, 2012	2.0	Modified extensively due to move of experiment equipment to the IHU card

1.2 Document Scope

The purpose of this document is to specify the technical requirements of the experiment payload at the system (i.e. "black box") level. It is intended to be used to by the hardware, software and mechanical designers to develop the architecture/high-level design specifications. It is also intended to be used for test planning and development.

1.3 Document Format

This document provides the requirements in numbered format. Each requirement is assigned a unique number. Additional information such as comments or examples that are provided for guidance or clarity are *italicized* to distinguish them from requirements.

1.4 References

1. AMSAT *Fox-1*, Concept of Operations, Version 1.03, September 19, 2011
2. AMSAT *Fox-1*, System Requirements Specification, Version 1.1, April 29, 2012
3. AMSAT *Fox-1* IHU to Attitude Determination Experiment Interface Control Document, Version 2.0, June 29, 2012

2 General Requirements

2.1 Physical Requirements

2.1.1 The experiment payload shall be constructed on the satellite IHU system PCB.

2.2 Environmental Requirements

2.2.1 The experiment payload shall be designed for -40C to +70C operating temperature.

3 Functional Requirements

3.1 Experiment Data

3.1.1 The experiment payload shall measure the spin rate and direction about the Z axis of the satellite.

3.1.2 The experiment payload shall measure any deviation (*wobble*) of the Z axis of the satellite caused by the spin of the satellite.

3.1.3 The experiment payload data shall have an accuracy of 1 degree.

3.1.4 The experiment payload shall be able to resolve the rate of spin in the range of 0 to 50 degrees per second. The experiment payload shall be able to resolve the deviation of the Z axis (*wobble*) in the range of 0 to 50 degrees.

3.2 Satellite Interface

3.2.1 The experiment data shall be directly collected by the satellite IHU system.

3.3 Power

3.3.1 The experiment payload shall receive electrical power from the satellite battery and photovoltaic panels.

3.3.2 The electrical power voltage will be nominally DC 3.6 V.

3.3.3 The satellite IHU system will activate and deactivate the experiment payload as necessary.

3.3.4 The electrical power drawn by the experiment payload shall not exceed 200 mW.

3.4 Experiment Data

3.4.1 The IHU system shall process the experiment data for telemetry transmission†.

3.4.2 The IHU system shall sample the experiment data at a rate sufficient to provide telemetry data at least every 15 seconds.

3.4.3 The experiment payload data shall include the following measured and calculated parameters:

Parameter Name	**Description**
SPIN RATE	Rate of spin of the satellite about the Z axis, in degrees per minute
SPIN DIRECTION	Direction of spin of the satellite about the Z axis (+X or –X)
DEVIATION	Deviation (*wobble*) of +Z axis caused by satellite spin
UP TIME	Total seconds since experiment payload power-up or reset

†Note that the telemetry data frame is specified in the AMSAT Fox-1 IHU to Attitude Determination Experiment Interface Control Document.

4 External Interface Documents

To fully specify the experiment payload technical requirements, the following documents must also be provided;

1. AMSAT *Fox-1* IHU to Attitude Determination Experiment Interface Control Document

5 Summary

The *Fox-1* satellite attitude determination experiment payload will provide data on the spin and wobble of the passive-magnetically stabilized satellite. This includes the first known measurements of the wobble about the Z axis of a magnetically stabilized AMSAT satellite.

Date: June 29, 2012
Version: Version 2.0

AMSAT *Fox-1*

IHU to Attitude Determination Experiment Interface Control Document

1 Introduction

This document specifies the message interface and the power activation interface between the Internal Housekeeping Unit (IHU) system and the Experiment Payload, as required per the AMSAT *Fox-1* Attitude Determination Experiment Payload System Requirements Specification document.

The experiment is expected to be provided by students at Penn State University – Erie through an AMSAT sponsored senior design project.

1.1 Document History

DATE	VERSION	SUMMARY
February 12, 2012	1.0	From Draft and now SPI
February 15, 2012	1.01	Add SPI Bus Hardware Interface Requirements Change to DATA block types and values
February 20, 2012	1.02	Add SPI framing and CRC polynomial
February 20, 2012	1.03	Requirements Tracking Changes
February 21, 2012	1.04	Deviation corrected from 90 to 50 per Experiment System Requirement 3.1.5
February 26, 2012	1.05	Corrected description of SPIN RATE field in Table 6 to read seconds instead of minutes
March 7, 2012	1.06	Change 6.1.1.1 high state signal to ≥2.4V
April 5. 2012	1.07	Add new DATA field MEMS GYRO STATUS
April 9, 2012	1.08	Added requirement 2.2.4
April 11, 2012	1.1	Add bits to MEMS GYRO STATUS
April 24, 2012	1.11	Set logic level Low as ≤0.2V in 6.1.1.2
June 29, 2012	2.0	Modified extensively due to move of experiment equipment to the IHU card

1.2 Document Scope

The purpose of this document is to specify the data format for the communications between the Attitude Determination Experiment and the IHU system, as described in the

AMSAT *Fox-1* Attitude Determination Experiment Payload System Requirements Specification.

1.3 References

1. AMSAT *Fox-1* System Requirements Specification, Version 1.1, April 29, 2012
2. AMSAT *Fox-1* Experiment Payload System Requirements Specification, Version 2.0, June 29, 2012
3. AMSAT *Fox-1* IHU Software Architecture Specification, Draft E, January 19, 2012

2 Telemetry Content Requirements

2.1 Telemetry Data Block

2.1.1 The telemetry data block shall contain the data fields as shown in Table 1.

Table 1

Field	Size (Bytes)	Type	Value	Description
SPIN RATE	2	Signed integer	Variable -50 to +50	Rate of spin of the satellite about the Z axis, in degrees per second. Negative indicates -X spin direction, positive indicates +X spin direction.
DEVIATION	2	Unsigned integer	Variable 0 to +50	Deviation (wobble) of Z axis in degrees.
UP TIME	2	Unsigned integer	Variable 0 to 65535	Total seconds since experiment payload power-up or reset

Date: August 27, 2013
Version: Version 2.00

AMSAT *Fox-1*

IHU to RF System Interface Control Document

1 Introduction

This document specifies the message interface between the Internal Housekeeping Unit (IHU) and the RF System, as required per the AMSAT *Fox-1* System Requirements Specification document.

1.1 Document History

DATE	VERSION	SUMMARY
March 24, 2012	1.0	Initial version
March 24, 2012	1.1	Add 2nd RX Audio Out section 3.4.1
March 26, 2012	1.2	Section 3.2 rename Zombie to IHU Control, rename Audio to Audio 1, Section 3.4 remove RX Audio 2, section 4 removed entirely
March 26, 2012	1.3	Many updates using input from teams
March 30, 2012	1.4	Update 3.4.1.1 to clarify that receive signal CTCSS is responsible for state
March 31, 2012	1.5	3.3.1.3 updated to read no less than 100 mS
April 24, 2012	1.6	Update impedances and voltages to match SDS
June 18, 2012	1.7	Update 3.3.1.5 per PDR change to SRS, remove RESET add IHU OFF and IHU ON commands, signal characteristic updates per PDR, 3.4.1.2 to indicate command station signal strength
September 13, 2012	1.8	Remove IHU CONTROL signal, match signal characteristics to system design specification
September 16, 2012	1.9	Changes to 3.3.1.1 and Table 4 per Tony
September 18, 2012	1.91	Removed Command Table (section 3.3) and re-stated section 3.3 requirements accordingly
February 17, 2013	1.92	Incorporate system bus signal nomenclature and pin assignment changes
August 27, 2013	2.00	Move RX Command Decoder to IHU, give IHU more responsibility for RF System control, rename RSSI to RX CD, add RSSI to Pin 10

1.2 Document Scope

The purpose of this document is to specify the signal types, levels, and direction for connections between the IHU and the RF System as described in the AMSAT *Fox-1* System Requirements Specification.

1.3 References

1. AMSAT *Fox-1* System Requirements Specification
2. AMSAT *Fox-1* System Design Specification
3. AMSAT *Fox-1* IHU Software Architecture Specification

2 General Requirements

2.1 Telemetry

2.1.1 RF System Telemetry values shall be conveyed as analog voltage levels sent from the RF System to the IHU System.

2.1.2 The IHU System shall convert the analog signals to digital representations.

2.1.3 Audio signals for the purpose of conveying telemetry via sub-audible audio frequencies shall be sent from the IHU System to the RF System.

2.2 RF System Control

2.2.1 Control of the RF System shall be accomplished by means of digital signals sent from the IHU System to the RF System.

2.3 Satellite System Command

2.3.1 Command data for the purpose of controlling the satellite shall be processed by the IHU System and sent to the RF System.

2.3.2 Command data shall be conveyed to the RF System via digital signals.

2.4 Operational Components

2.4.1 Demodulated baseband audio signals shall be passed from the RF System to the IHU System for processing.

2.4.2 Baseband audio signals shall be passed from the IHU System to the RF System for transmission.

2.4.3 Operational Status signals shall be conveyed as digital signals sent from the RF System to the IHU System.

2.5 Signal Transmission

2.5.1 Signals shall use the pin assignments shown in the Fox-1 System Design Specification document.

2.5.2 Signal connections shall comply with the impedance and signal type shown in the parameters for each type of signaling.

2.6 Signal Type Definitions and Levels

2.6.1 **Analog**: 0 – 3.0 VDC analog voltage.

2.6.2 **Digital**: 3.0 VDC CMOS logic levels.

3 Signal Connection Requirements

3.1 Telemetry

3.1.1 The RF System shall provide raw telemetry values from the RF System components as shown in Table 1.

Table 1

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Load System	Notes
2	TX PA Current	Analog	0 - 3.0 V	TX	30 - 60 kΩ	IHU	
4	TX Temperature	Analog	0 - 3.0 V	TX	30 - 60 kΩ	IHU	Thermistor Circuit
8	RX Temperature	Analog	0 - 3.0 V	RX	30 - 60 kΩ	IHU	Thermistor Circuit

3.1.1.1 The values shall be updated at a rate to provide new samples at least every 15 seconds.

3.2 RF System Control

3.2.1 The IHU System shall provide control and audio signals to the RF System as shown in Table 2.

Table 2

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Load System	Notes
12	IHU Audio 1 Out	Analog	0 - 3 V (audio)	IHU	> 10 kΩ unbal.	TX	For 5 kHz deviation, 10 Hz - 7 kHz bandwidth
26	IHU RF Control	Digital		IHU		TX	HIGH = IHU Controls RF LOW = Standalone Analog Transponder
28	IHU PTT	Digital		IHU		TX	HIGH = TRANSMIT

3.2.1.1 IHU RF Control when High shall indicate IHU presence and control of the RF PTT and audio.

3.2.1.2 IHU RF Control when Low shall indicate loss of IHU control causing the RF System to operate as a standalone carrier operated transponder passing audio directly from the receiver uplink to the transmitter downlink.

3.2.1.3 IHU PTT signal when High shall key the RF transmitter on.

3.3 Satellite System Command

3.3.1 The IHU System shall provide ground station command signals to the RF System as shown in Table 3.

Table 3

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Load System	Notes
22	RX Command Data 3	Digital		IHU		TX	(Most Significan Bit) HIGH = Inhibit Transmit

3.3.2 An INHIBIT Command (RX Command Data 3 = HIGH) shall cause the RF System to cease RF transmissions without regard to the state of any other RF System Control signals.

Note that the control interface will be specified in a separate document.

3.4 Operational Components

3.4.1 The RF System shall provide operational and audio signals to the IHU System as shown in Table 4.

Table 4

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Load System	Notes
10	RSSI	Analog	0 - 3.0 V	RX	30 - 60 kΩ	IHU	Received Signal Strength Indication
30	RF TX Active	Digital		TX		IHU	HIGH = RF TX on
32	RX CD	Digital	0	RX	0	TX IHU	HIGH = valid receive signal
34	RX Audio 1	Analog	0 - 3 V (audio)	RX	> 10 kΩ unbal.	IHU	10 Hz - 7 kHz bandwidth

3.4.1.1 RSSI signal shall indicate the relative strength of the received signal on the uplink.

3.4.1.2 RF TX Active signal when High shall indicate that the transponder uplink signal CTCSS hang timer is activating the RF transmitter.

3.4.1.3 RX CD signal shall indicate a valid received signal on the uplink.

Date: October 4, 2013
Version: Version 2.00

AMSAT *Fox-1*

IHU to PSU Interface Control Document

1 Introduction

This document specifies the message interface between the Internal Housekeeping Unit (IHU) and the Power Supply (PSU) System, as required per the AMSAT *Fox-1* System Requirements Specification document.

1.1 Document History

DATE	VERSION	SUMMARY
February 21, 2012	1.0	Initial version
February 21, 2012	1.01	Clarify I^{2}C address
March 7, 2012	1.02	2.3.1 updated Vdd to 3.0V
August 7, 2012	1.03	Remove BATT1 data fields and adjust message accordingly
November 7, 2012	1.04	Added PSU CPU Temperature
December 27, 2012	1.10	Change from Bytes to Bits in Message Header Block, Message Data Block, Message Data (to allow for 12 bit ADC values)
January 2, 2013	1.11	Field sizes back to bytes account I^{2}C specifications
February 7, 2013	1.12	Correct typo in 3.3.1.1
August 22, 2013	1.13	Remove TOTAL I from Data block
August 22, 2013	1.14	Update I^{2}C speed to 10 kHz
October 4, 2013	2.00	Rework to eliminate STM32L and replace with ADS7828s

1.2 Document Scope

The purpose of this document is to specify the message format and the I^{2}C bus hardware operation for the communications between the IHU and the PSU as described in the AMSAT *Fox-1* System Requirements Specification.

1.3 References

1. AMSAT *Fox-1*, System Requirements Specification
2. AMSAT *Fox-1*, System Design Specification
3. AMSAT *Fox-1*, IHU Software Architecture Specification

2 General Messaging Requirements

2.1 Link Protocol Requirements

2.1.1 The IHU shall be the I²C Master.

2.1.2 The PSU shall be the I²C Slave.

2.1.2.1 The IHU shall request the PSU to send the data for a specific Device and channel.

2.1.2.2 The PSU shall send that specific Device and channel data.

2.1.3 The IHU shall test for the presence both PSU system Devices.

2.1.4 The IHU shall only poll the PSU system Device(s) present, for data.

2.2 General Message Requirements

2.2.1 The IHU shall sample data at a rate sufficient to provide downlink telemetry data at least every 15 seconds.

2.2.2 For both Devices the ADS 7820 A/D converter shall always be commanded on (PD-0 bit = 1).

2.2.3 For both Devices the ADS 7820 Internal Reference shall always be commanded on (PD-1 bit = 1).

2.2.4 TFor both Devices the ADS 7820 shall always be commanded for single-ended inputs.

2.3 I²C Bus Hardware Interface Requirements

2.3.1 The I²C Vdd shall be 3.0V.

2.3.2 The bus speed shall be Standard (10 kHz).

2.3.3 The PSU system Device 1 I²C 7 bit address shall be 0x49.

2.3.4 The PSU system Device 2 I²C 7 bit address shall be 0x4A.

3 Message Content Requirements

3.1 Measured Values

3.1.1 The measured data fields for Device 1 and their associated ADS 7828 channels shall be as shown in Table 1.

Table 1

Field	Channel	Type	Min Value	Max Value	Description
-X PANEL V	0	Unsigned	0x00	0xFFF	-X PANEL V
-Y PANEL V	1	Unsigned	0x00	0xFFF	-Y PANEL V
-Z PANEL V	2	Unsigned	0x00	0xFFF	-Z PANEL V
-X PANEL T	3	Unsigned	0x00	0xFFF	-X PANEL T
-Y PANEL T	4	Unsigned	0x00	0xFFF	-Y PANEL T
-Z PANEL T	5	Unsigned	0x00	0xFFF	-Z PANEL T
Not used	6	-	-	-	-
Not used	7	-	-	-	-

3.1.2 The measured data fields for Device 2 and their associated ADS 7828 channels shall be as shown in Table 2.

Table 2

Field	Channel	Type	Min Value	Max Value	Description
+X PANEL V	0	Unsigned	0x00	0xFFF	+X PANEL V
+Y PANEL V	1	Unsigned	0x00	0xFFF	+Y PANEL V
+Z PANEL V	2	Unsigned	0x00	0xFFF	+Z PANEL V
+X PANEL T	3	Unsigned	0x00	0xFFF	+X PANEL T
+Y PANEL T	4	Unsigned	0x00	0xFFF	+Y PANEL T
+Z PANEL T	5	Unsigned	0x00	0xFFF	+Z PANEL T
PSU PCB Temperature	6	Unsigned	0x00	0xFFF	Temperature of PSU card
Not used	7	-	-	-	-

3.1.3 Measurements shall be made in relation to the 2.5 VDC internal voltage reference for both ADS 7828 Devices.

3.1.4 For each Device the IHU shall poll each channel in channel number order.

Date: September 17, 2013
Version: Version 2.03

AMSAT *Fox-1*

IHU to Battery Interface Control Document

1 Introduction

This document specifies the message interface between the Internal Housekeeping Unit (IHU) and the Battery (BATT1) System, as required per the AMSAT *Fox-1* System Requirements Specification document.

1.1 Document History

DATE	VERSION	SUMMARY
August 7, 2012	1.00	Initial version
November 7, 2012	1.01	Added BATT CPU Temperature
December 27, 2012	1.10	Add Battery Groups Temperature, change from Bytes to Bits in Message Header Block, Message Data Block, Message Data
January 2, 2013	1.11	Field sizes back to bytes account I^{2}C specifications
February 7, 2013	1.12	Fix typo on 3.3.1.1
August 13, 2013	2.00	Updated for TI ADS 7828 replacing STM32L, straight I2C query/answer from IHU now for 8 channels of data.
August 22, 2013	2.01	Correct Battery Pair Temperature nomenclature
August 22, 2013	2.02	Update I^{2}C speed to 10 kHz
September 17, 2013	2.03	Fix formatting error that hid requirement 2.2.2, change type format to exclude code type, add Min/Max Values

1.2 Document Scope

The purpose of this document is to specify the message format and the I^{2}C bus hardware operation for the communications between the IHU and the BATT1 as described in the AMSAT *Fox-1* System Requirements Specification.

1.3 References

1. AMSAT *Fox-1*, System Requirements Specification
2. AMSAT *Fox-1*, System Design Specification
3. AMSAT *Fox-1*, IHU Software Architecture Specification
4. Texas Instruments SBAS181C – NOVEMBER 2001 - REVISED MARCH 2005

2 General Messaging Requirements

2.1 Link Protocol Requirements

2.1.1 The IHU shall be the I²C Master.

2.1.2 The BATT1 shall be the I²C Slave.

2.1.2.1 The IHU shall request the BATT1 to send the data for a specific channel.

2.1.2.2 The BATT1 shall send that specific channel data.

2.1.3 The IHU shall test for the presence of the BATT1 system.

2.1.3.1 If the presence of the BATT1 system is not detected, the IHU shall not poll the system for data.

2.2 General Message Requirements

2.2.1 The IHU shall sample data at a rate sufficient to provide downlink telemetry data at least every 15 seconds.

2.2.2 The ADS 7820 A/D converter shall always be commanded on (PD-0 bit = 1).

2.2.3 The ADS 7820 Internal Reference shall always be commanded on (PD-1 bit = 1).

2.2.4 The ADS 7820 shall always be commanded for single-ended inputs.

2.3 I²C Bus Hardware Interface Requirements

2.3.1 The I²C Vdd shall be 3.0V.

2.3.2 The bus speed shall be Standard (10 kHz).

2.3.3 The BATT1 I²C 7 bit address shall be 0x48.

3 Data Requirements

3.1 Measured Values

3.1.1 The measured data fields and their associated ADS 7828 channels shall be as shown in Table 1.

Table 1

Field	Channel	Type	Min Value	Max Value	Description
BATT I	0	Unsigned	0x00	0xFFF	Battery current raw value
BATT A V	1	Unsigned	0x00	0xFFF	Battery pair A voltage raw value
BATT B V	2	Unsigned	0x00	0xFFF	Battery pair B voltage raw value
BATT C V	3	Unsigned	0x00	0xFFF	Battery pair C voltage raw value
BATT A T	4	Unsigned	0x00	0xFFF	Battery pair A temperature raw value
BATT B T	5	Unsigned	0x00	0xFFF	Battery pair B temperature raw value
BATT C T	6	Unsigned	0x00	0xFFF	Battery pair C temperature raw value
BATT PCB Temperature	7	Unsigned	0x00	0xFFF	Temperature of BATT card

3.1.2 Measurements shall be in relation to the 2.5 VDC internal voltage reference of the ADS 7828.

3.1.3 The IHU shall poll each channel in channel number order.

Date: September 17, 2013
Version: Version 1.06

AMSAT *Fox-1A*

IHU to Experiment 1 Interface Control Document

1 Introduction

This document specifies the message interface between the Internal Housekeeping Unit (IHU) and the Experiment System in Position 1 of the satellite, known as the Vanderbilt University Vulcan Payload and abbreviated herein as EXP1.

1.1 Document History

DATE	VERSION	SUMMARY
March 3, 2013	1.00	Initial version
March 7, 2013	1.01	Correct use of I²C (1.2) and EXP1 (2.3.3)
March 31, 2013	1.02	Command Message CRC8 to include address byte, change to commands, modified figure 3, deleted figure 4
March 31, 2013	1.03	Delete TYPE from message tables, add SET TIME response return values
March 31, 2013	1.04	Add CMD_VERSION_ERR to Error Code table
April 2, 2013	1.05	Correct 6.5 Figure 3, remove 0x0005, 0x0201, 0x0210, 0x0281, 0x0300, and 0x0301 commands
September 17, 2013	1.06	Change type format to exclude code type, add Min/Max Values

1.2 Document Scope

This document will specify the control of EXP1, the messaging format, and the I²C bus hardware operation for the communications between the IHU and the EXP1.

1.3 References

1. AMSAT *Fox-1*, System Requirements Specification
2. AMSAT *Fox-1*, System Design Specification
3. AMSAT *Fox-1*, IHU Software Architecture Specification
4. Vanderbilt University Vulcan Payload Interface Control Document

2 General Messaging Requirements

2.1 Link Protocol Requirements

2.1.1 The IHU shall initiate a command to the EXP1.

2.1.2 The EXP1 shall send a reply to each IHU request.

2.1.3 Message bit order shall be Big Endian.

2.1.4 The IHU shall determine the action to be taken in the event of an invalid, improper, or missing message from the EXP1.

2.1.5 The EXP1 shall take no action in the event of an invalid or improper message from the IHU.

2.1.6 Message byte order shall be Big Endian.

2.2 General Message Requirements

2.2.1 Each message shall contain a header block.

2.2.2 Each message shall contain a packet error check (PEC) in the form of CRC8.

2.2.2.1 The message address byte shall be included when calculating the CRC8.

2.3 I²C 1 Bus Hardware Interface Requirements

2.3.1 The I^{2}C Vdd shall be 3.0V.

2.3.2 The bus speed shall be Fast (400kbit/s).

2.3.3 The EXP1 I^{2}C 7 bit address shall be 0x2A.

3 Experiment Operation

3.1 Experiment Power Control

3.1.1 The IHU shall exert control over the power state of the EXP1 by the Experiment Enable 1 pin on the satellite bus as shown in Table 1.

Table 1

Pin State	Description
High	Power On Experiment
Low	Power Off Experiment

3.2 Experiment Power On Sequence

3.2.1 The IHU shall set and hold the Experiment Enable 1 pin HIGH.

3.2.2 The IHU shall not send any message to the EXP1 for a minimum of 100 milliseconds.

3.2.3 The IHU shall send a Set Time command to the EXP1.

3.3 Experiment Begin Operation Sequence

3.3.1 Upon completion of the Power On sequence the IHU shall send a Set Run State Active command message to the EXP1.

3.4 Experiment Cease Operation Sequence

3.4.1 The IHU shall send a Set Run State Halt command message to the EXP1.

3.4.2 The IHU shall not send any message to the EXP1 for a minimum of 10000 milliseconds.

3.4.3 The IHU shall send a Set Run State Standby command message to the EXP1.

3.5 Experiment Power Off Sequence

3.5.1 The IHU shall set and hold the Experiment Enable 1 pin LOW.

4 Message Content Requirements

4.1 Command Message

4.1.1 The message header block shall be constructed as shown in table 2.

4.1.2 The message header block shall be sent with each Command and Response block.

Table 2

Field	Size (Bytes)	Type	Min Value	Max Value	Description
Message Version	2	Unsigned	0x01	0xFFFF	Message ICD version
Software Build	2	Unsigned	0x01	0xFFFF	Software Build version

4.1.2.1 The Message Version shall be an integer representing the IHU to EXP1 ICD document version number from which the message format is derived, having the decimal point removed (e.g. version 1.03 would be 103 decimal or 0x67).

4.1.2.2 The Software Build shall be an integer representing the software build version number of the system originating the message, having any decimal points removed (e.g. version 1.03 would be 103 decimal or 0x67).

4.2 Command Message Block

4.2.1 The command message block shall be constructed as shown in Table 3.

Table 3

Field	Size (Bytes)	Type	Min Value	Max Value	Description
COMMAND	2	Unsigned	0x0000	0x0280	Hexadecimal Command
ARGUMENT	Variable	Unsigned	-	-	Optional Arguments As Required

The command message block shall contain one command in the COMMAND COMMAND field as shown in Table 4.

Table 4

Command Name	Size (Bytes)	Type	Min Value	Max Value	Description
Nop	2	Unsigned	0x0000	0x0000	No effect; response undefined. Test for I²C acknowledgement only.
Echo	2	Unsigned	0x0001	0x0001	Echo this byte stream
Resend	2	Unsigned	0x0002	0x0002	Resend last result
Get UID	2	Unsigned	0x0003	0x0003	Controller 7 byte identifier
Get Status	2	Unsigned	0x0004	0x0004	Controller status indication
Get Diagnostics	2	Unsigned	0x0006	0x0006	Self-check Diagnostic
Get Telemetry	2	Unsigned	0x0010	0x0010	Send telemetry data
Set Run State	2	Unsigned	0x0080	0x0080	Enter specified Run State
Get Run State	2	Unsigned	0x0081	0x0081	Query current Run State
Set Time	2	Unsigned	0x0100	0x0100	Number of seconds since epoch
Get Time	2	Unsigned	0x0101	0x0101	Number of seconds since epoch
Get Data	2	Unsigned	0x0280	0x0280	Send (number of bytes) data

4.2.3 The command message shall contain arguments for the Echo command, as shown in Table 5.

Table 5

Field	Size (Bytes)	Type	Min Value	Max Value	Description
ARGUMENT	4	Unsigned	-	-	Data to be echoed

4.2.4 The command message shall contain one argument for the Set Run State command, as shown in Table 6.

Table 6

Run State	Size (Bytes)	Type	Min Value	Max Value	Description
STANDBY	2	Unsigned	0x0001	0x0001	Enter Standby State
ACTIVE	2	Unsigned	0x0003	0x0003	Activate Experiments
HALT	2	Unsigned	0x0004	0x0004	Terminate Experiments

4.2.5 The command message shall contain arguments for the Set Time command, as shown in Table 7.

Table 7

Argument	Size (Bytes)	Type	Min Value	Max Value	Description
IHU Reset Counter	16	Unsigned	0x00	-	Count of the number of IHU resets from non-volatile FRAM
MET Timestamp	32	Unsigned	-	-	MET timestamp (seconds since last IHU reset)

4.2.6 The command message shall contain arguments for the Get Data command, as shown in Table 8.

Table 8

Argument	Size (Bytes)	Type	Min Value	Max Value	Description
BYTES TO SEND	2	Unsigned	0x00	0xFFFF	Number of bytes to send (1-256)

4.3 Response Message Block

4.3.1 The response message block shall be constructed as shown in Table 9.

Table 9

Field	Size (Bytes)	Type	Min Value	Max Value	Description
RESERVED	1	Unsigned	-	-	Reserved, ignore
ERROR CODE	1	Unsigned	0x0000	0x0006	Response to Command
LENGTH	2	Unsigned	0x00	0xFFFF	Length of Return Value in Bytes
RETURN VALUE	Variable	Variable	-	-	Return Value

4.3.2 The Error Code shall contain one code as shown in table 10.

Table 10

Name	Size (Bytes)	Type	Min Value	Max Value	Description
CMD_OK	1	Unsigned	0x0000	0x0000	Command invoked successfully
CMD_OP_ERR	1	Unsigned	0x0001	0x0001	Command not recognized
CMD_FORMAT_ERR	1	Unsigned	0x0002	0x0002	Incorrect command argument length
CMD_RANGE_ERR	1	Unsigned	0x0003	0x0003	Argument(s) out of bounds
CMD_PEC_ERR	1	Unsigned	0x0004	0x0004	Error check (CRC) mismatch
CMD_EXEC_ERR	1	Unsigned	0x0005	0x0005	Execution error
CMD_VERSION_ERR	1	Unsigned	0x0006	0X0006	Header Message Version mismatch

4.3.3 The Status Flags for a GET STATUS response message shall be represented as individual bit values of a 16 bit RETURN VALUE as shown in Table 11.

Table 11

Name	Bit Number	Description
REBOOTED	0	1 = Experiment has rebooted – **NOT USED**
DATA READY	1	1 = Experiment data available
TIME REQUEST	2	1 = Request SET TIME
FAILED RUN STATE	3	1 = Failed the run state – **NOT USED**
COMPLETED RUN STATE	4	1 = Completed the run state – **NOT USED**
RESERVED	5-15	Always 0

4.3.4 The response message to a Set Time command shall contain one of the values as shown in Table 12.

Table 12

Response Name	Size (Bytes)	Type	Min Value	Max Value	Description
SUCCESS	2	Signed	0x00	0x00	Time Set successfully
FAILURE	2	Signed	0xFFFF	0xFFFF	Time Set failed

5 Message Integrity

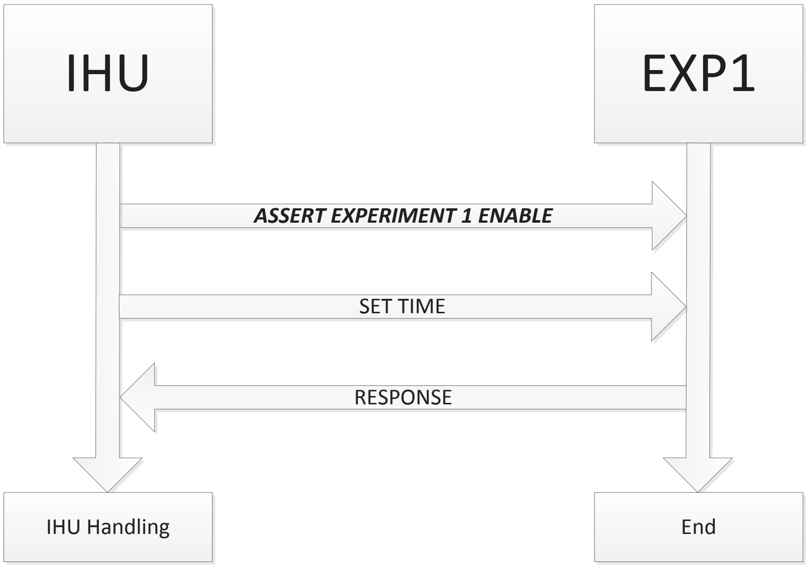
5.1 Invalid Messages

5.1.1 If the PEC (CRC8) fails, the message shall be considered invalid.

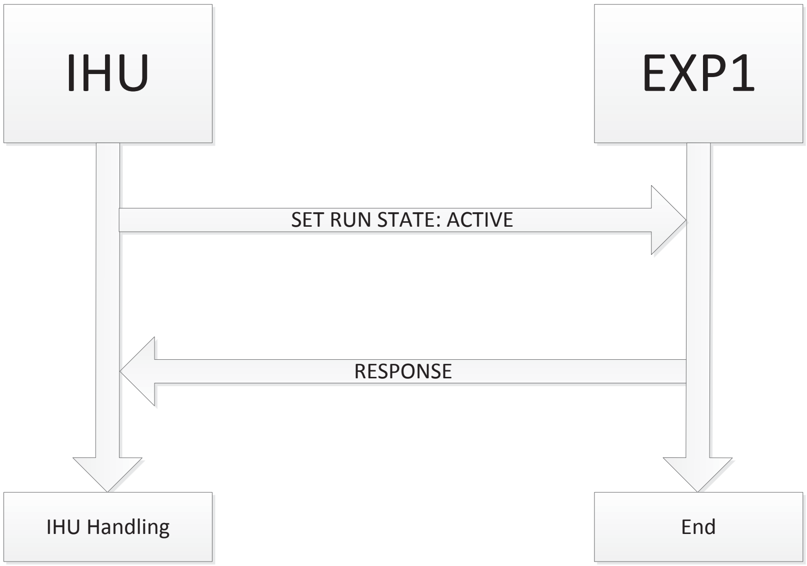
5.1.2 If the Message Version does not match the message version in use for the construction of messages on the receiving system, the message shall be considered invalid.

6 Message Flow Diagrams

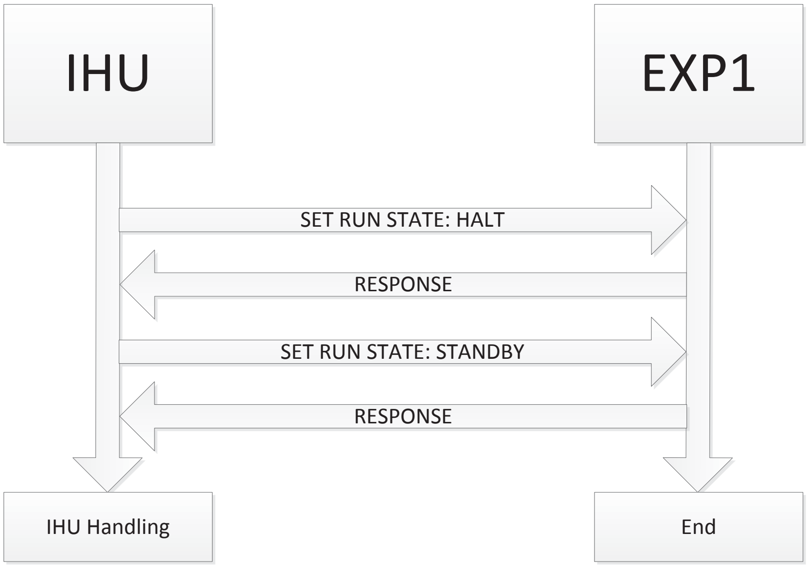
6.1 EXPERIMENT POWER ON SEQUENCE



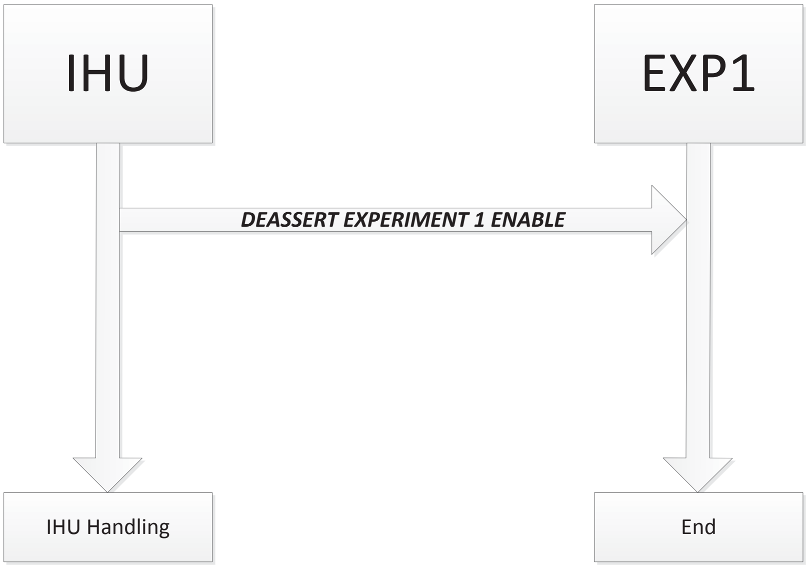
6.2 EXPERIMENT BEGIN OPERATION SEQUENCE



6.3 EXPERIMENT CEASE OPERATION SEQUENCE



6.4 EXPERIMENT POWER OFF SEQUENCE



6.5 SERVICING EXPERIMENT OPERATION

Figure 1

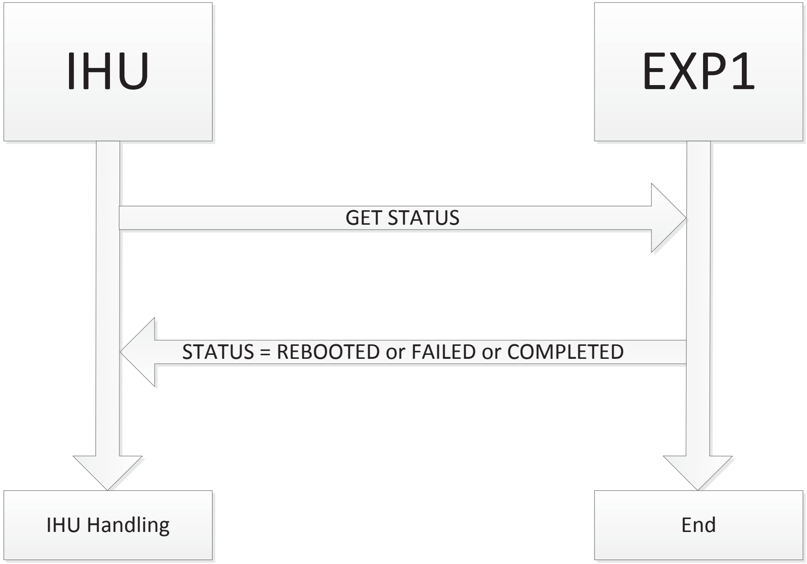


Figure 2

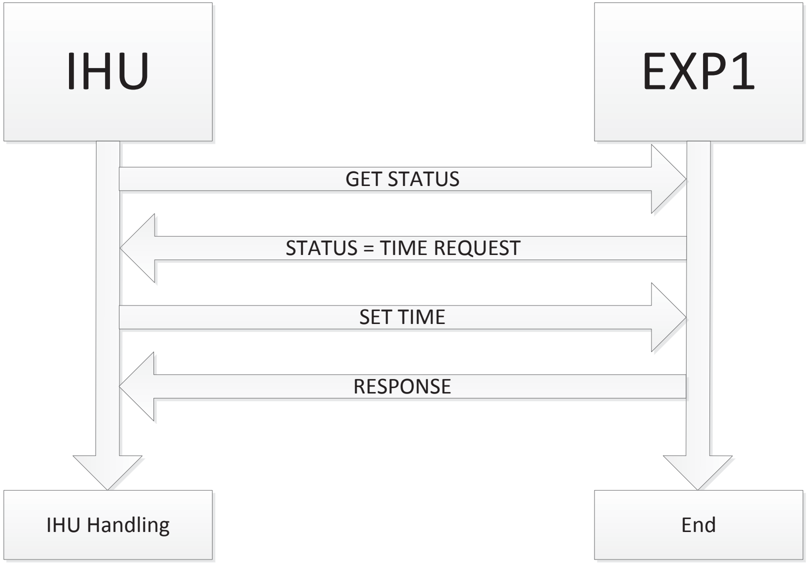
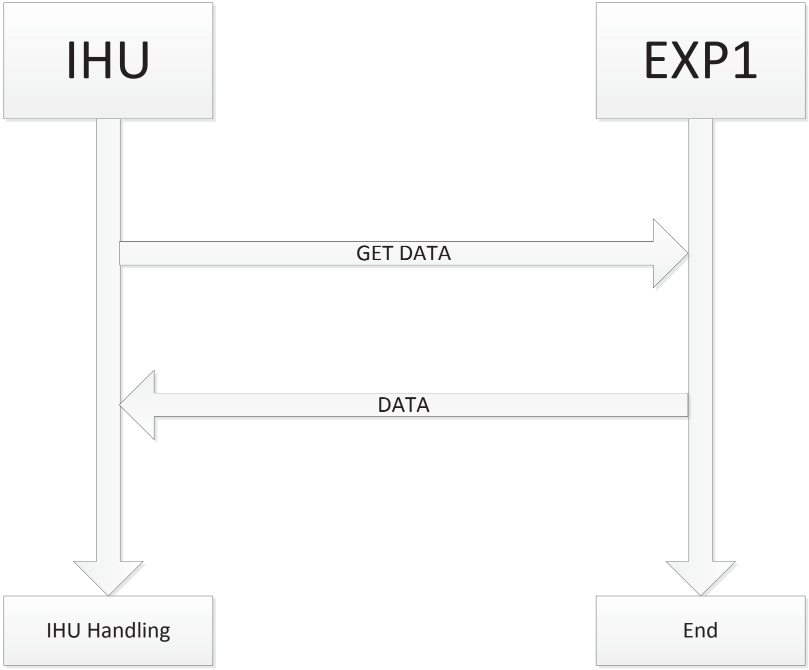


Figure 3



Date: October 4, 2013
Version: Version 1.11

AMSAT *Fox-1A*

IHU to Experiment 4 Interface Control Document

1 Introduction

This document specifies the message interface between the Internal Housekeeping Unit (IHU) and the Experiment System in Position 4 of the satellite, known as the VT Camera Experiment and abbreviated herein as EXP4.

1.1 Document History

DATE	VERSION	SUMMARY
January 24, 2013	1.00	Initial version
February 20, 2013	1.01	Specify byte order as little endian
May 21, 2013	1.10	Update data TYPE names
October 4, 2013	1.11	Change type format to exclude code type, add Min/Max Values, add thermistor circuit

1.2 Document Scope

This document will specify the control of EXP4, the messaging format, and the serial bus hardware operation for the communications between the IHU and the EXP4.

1.3 References

1. AMSAT *Fox-1*, System Requirements Specification
2. AMSAT *Fox-1*, System Design Specification
3. AMSAT *Fox-1*, IHU Software Architecture Specification

2 General Messaging Requirements

2.1 Link Protocol Requirements

2.1.1 The IHU shall initiate a command to the EXP4.

2.1.2 The EXP4 shall send a reply to each IHU request.

2.1.3 Message bit order shall be Little Endian.

2.1.4 The IHU shall determine the action to be taken in the event of an invalid, improper, or missing message from the EXP4.

2.1.5 The EXP4 shall take no action in the event of an invalid or improper message from the IHU.

2.1.6 Message byte order shall be Little Endian.

2.2 General Message Requirements

2.2.1 Each message shall contain a header block.

2.2.2 Each message shall contain one command, one reply, or one data block.

2.3 Serial Bus Hardware Interface Requirements

2.3.1 The bus levels shall be 3.0V.

2.3.2 The bus data speed shall be 38400 bit/s.

2.3.3 The serial bus communication shall be asynchronous.

2.3.4 The number of data bits shall be 8.

2.3.5 The number of stop bits shall be 1.

2.3.6 There shall be no parity bit.

3 Experiment Operation

3.1 Experiment Power Control

3.1.1 The IHU shall exert control over the power state of the EXP4 by the Experiment Enable 4 pin on the satellite bus as shown in Table 1.

Table 1

Pin State	Description
High	Power On Experiment
Low	Power Off Experiment

3.1.2 Upon signaling Power On to the EXP4, the IHU shall not send any message to the EXP4 for a minimum of 100 milliseconds.

3.2 Experiment Operation Sequence

3.2.1 Upon Power On the IHU shall determine the state of the EXP4 by sending an Is Camera Ready command message.

3.2.2 The IHU shall not send a Transmit Data Block command message prior to receiving a Camera Ready reply message from the EXP4.

4 Message Content Requirements

4.1 Message Header Block

4.1.1 The message header block shall be constructed as shown in table 2.

4.1.2 The message header block shall be sent with each Command, Reply, and Data block.

Table 2

Field	Size (Bytes)	Type	Min Value	Max Value	Description
Message Version	2	Unsigned	0x01	0xFFFF	Message ICD version
Software Build	2	Unsigned	0x01	0xFFFF	Software Build version

4.1.2.1 The Message Version shall be an integer representing the IHU to EXP4 ICD document version number from which the message format is derived, having the decimal point removed (e.g. version 1.03 would be 103 decimal or 0x67).

4.1.2.2 The Software Build shall be an integer representing the software build version number of the system originating the message, having any decimal points removed (e.g. version 1.03 would be 103 decimal or 0x67).

4.2 Command Message Block

4.2.1 The command message block shall be constructed as shown in Table 3.

Table 3

Field	Size (Bytes)	Type	Min Value	Max Value	Description
COMMAND	2	Alpha	RR TT	RR TT	Command

4.2.2 The command message block shall contain one command in the COMMAND field as shown in Table 4.

Table 4

Command	Description
RR	Is Camera Ready?
TT	Transmit Data Block

4.3 Reply Message Block

4.3.1 The reply message block shall be constructed as shown in Table 5.

Table 5

Field	Size (Bytes)	Type	Min Value	Max Value	Description
REPLY	2	Alpha	NN YY FF	NN YY FF	Reply

4.3.2 The reply message block shall contain one reply in the REPLY field as shown in table 6.

Table 6

Command	**Description**
NN	Camera Not Ready
YY	Camera Ready
FF	Camera Failed

4.4 Message Data Block

4.4.1 The message data block shall be constructed as shown in Table 7.

Table 7

Field	Size (Bytes)	Type	Min Value	Max Value	Description
DESCRIPTOR	2	Unsigned	-	-	Line ID and Payload Length
PAYLOAD	Variable	Unsigned	-	-	Array of (Payload Length) bytes
CHKSUM	2	Unsigned	-	-	16 bit accumulator sum of bytes in HEADER and PAYLOAD

4.4.2 The bits of the message data block DESCRIPTOR bytes shall be constructed as shown in Table 8.

Table 8

Field	Size (Bits)	Type	Min Value	Max Value	Description
Line ID	6	Unsigned	0x01	0x3C	640 x 8 pixel picture line number (1 is top, 60 is bottom)
Payload Length	10	Unsigned	0x01	0x3FF	Total number of bytes in PAYLOAD

4.4.2.1 The Line ID shall compose the 6 MSB and the Payload Length shall compose the 10 LSB.

5 Message Integrity

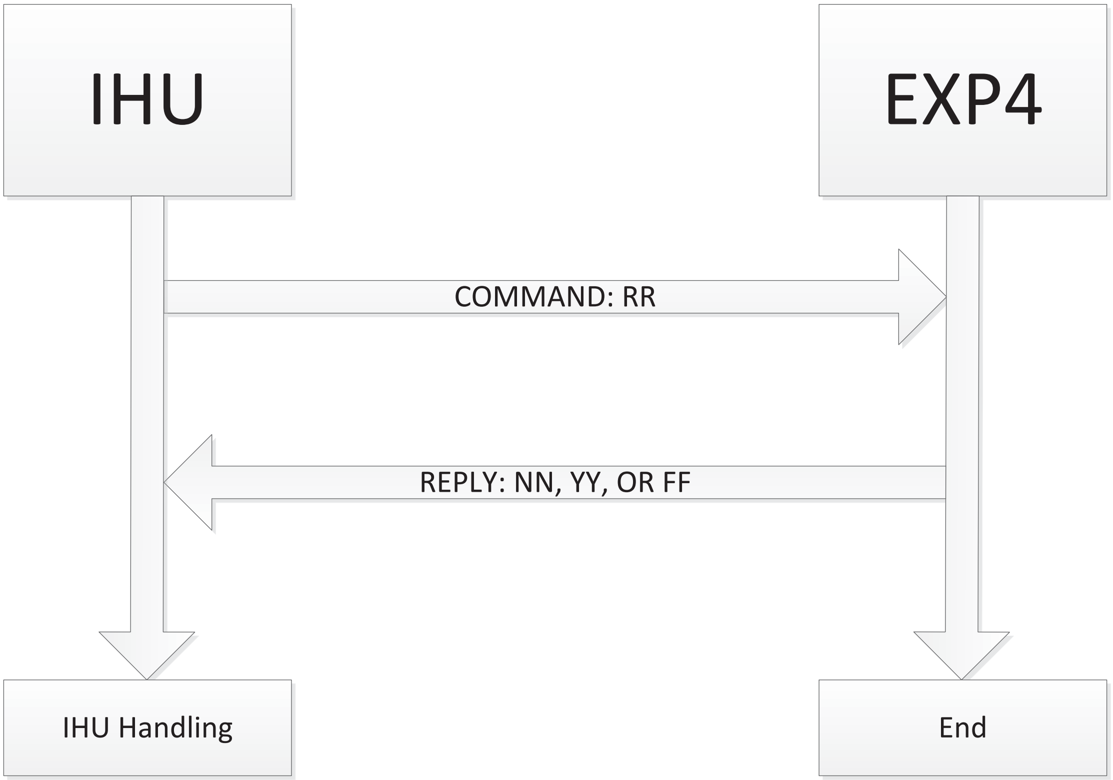
5.1 Invalid Messages

5.1.1 If the DATA block CHKSUM fails, the message shall be considered invalid.

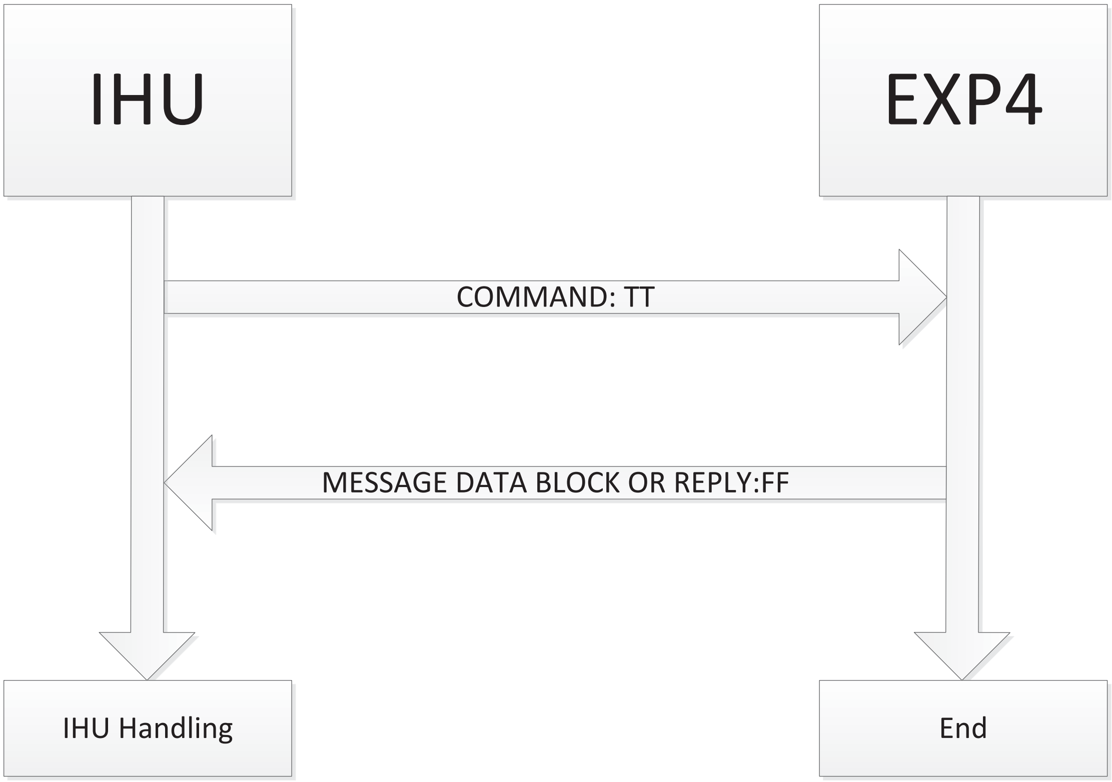
5.1.2 If the Message Version does not match the message version in use for the construction of messages on the receiving system, the message shall be considered invalid.

6 Message Flow Diagrams

6.1 RR COMMAND



6.2 TT COMMAND



7 Experiment Card Temperature Telemetry

7.1 Thermistor

7.1.1 The experiment shall provide a DC voltage derived from a thermistor circuit mounted on the experiment card, to the IHU via the system bus.

7.1.2 The voltage shall be the raw voltage value of the thermistor circuit.

Note: AMSAT shall provide the schematic and BOM for the thermistor circuit.

Date: August 26, 2013
Version: Version 1.41

AMSAT *Fox-1A*

Downlink Specification

1 Introduction

This document specifies downlink frame formats for the Fox-1A telemetry and experiment telemetry. This specification includes the both slow and high speed formats.

Document History

DATE	VERSION	SUMMARY
April 25, 2013	1.01	Remove TX PA Temperature and TX Osc Temperature, add TX Temperature
May 21, 2013	1.2	High speed downlink details added
May 27, 2013	1.3	Remove Radiation Experiment Telemetry Frame, resize Radiation Experiment Data Frame, renumber Payload Types, added Slow Speed Link Layer Transmission Scheduling, changed Reset Count to 16 bits
June 6, 2013	1.31	Reduce BATT CPU, PSU CPU, IHU CPU, TX Temp, RX Osc Temp from 12 to 8 bit value, add IHU Error Data field to Telemetry Minimum Values Frame
June 26, 2013	1.32	Correct Payload Type numbers in Table 6
August 13, 2013	1.40	Changes due to new BATT telemetry values, delete Type 4 from idle telemetry
August 26, 2013	1.41	Change Receiver Osc Temperature to Receiver Card Temperature, remove TOTAL MPPT I, update 2.2.9.1 and 2.2.9.1.1 to reflect variable size of Radiation Experiment Data available

1.1 Document Scope

The purpose of this document is to specify the downlink protocol on the AMSAT Fox-1A spacecraft.

1.2 References

1. Fox1 IHU to RF ICD
2. Fox1 IHU to Battery ICD
3. Fox1 IHU to PSU ICD
4. Fox1 IHU to Attitude Determination Experiment ICD

5. Fox1 IHU Software Architecture Specification
6. Fox1 IHU to Experiment 1 ICD
7. Fox1 IHU to Experiment 4 ICD

1.3 Definitions

1.3.1 Slow Speed Downlink – Data transmitted at approximately 100 bits per second in the audio portion below 300 Hz simultaneous with the transponder audio.

1.3.2 High Speed Downlink – Data transmitted at approximately 9600 bits per second using the entire downlink audio passband.

1.3.3 Spacecraft Telemetry – Downlink data containing specific information about spacecraft systems and health as defined in the System Requirements and related documents.

1.3.4 Experiment Telemetry – Downlink data containing specific information about the various experiment platforms flown on the satellite.

1.3.5 Frame – A defined set of data with a specific overall size comprised of fields of a specific bit or byte length.

2 Protocol Structure

2.1 Physical Layer

2.1.1 The physical layer includes options for slow-speed and high speed operation.

2.1.2 Slow speed operation uses frequency-shift keying and is transmitted in the sub-audible part of the audio downlink below 300 Hz. It may be transmitted simultaneously with voice or other audio signals. The details of the physical layer are shown in Table 1.

Table 1

Bit Rate	100 bps
Scrambler	TBR
Spectral efficiency	1 bps/Hz
Modulation type	Non-coherent Frequency Shift Keying (FSK)
Signal bandwidth	10 Hz to 200 Hz (-3 dB points)
FSK Deviation	500 Hz
Spectral Mask	-20 dB at 300 Hz
RF Channel Bandwidth	1200 Hz

2.1.3 High speed operation uses frequency-shift keying and is transmitted using the entire RF downlink bandwidth. The details of the physical layer are shown in Table 2. *Note that this is the same as the G3RUH modem.*

Table 2

Bit Rate	9600 bps
Scrambler	17 bit maximal length LFSR
Spectral efficiency	2 bps/Hz
Modulation type	non-coherent frequency shift keying (FSK)
Signal bandwidth	10 Hz to 4800 Hz (-3 dB points)
FSK Deviation	3 kHz
Spectral Mask	-60 dB at 7500 Hz
RF Channel Bandwidth	20 kHz

2.2 Link Layer

2.2.1 The link layer protocol provides multiplexing, packet identification and forward error correction.

2.2.2 The link layer shall include a header and a trailer surrounding the applications layer payload to form data packets as shown in Table 3.

Table 3

Header	Applications Payload	Trailer

2.2.3 The applications payload layer shall include satellite telemetry, experiment telemetry, high speed data, and debug frames.

2.2.4 Debug frames may be used during ground testing but shall not be transmitted for flight.

2.2.5 Bits shall be transmitted in the order of least significant bit first.

2.2.6 Bytes shall be transmitted in Little Endian order.

2.2.7 The Slow Speed link layer header structure shall be as shown in Table 4.

Table 4

Field	Size (Bits)	Type	Value	Description
Fox ID	3	Unsigned char	0x01	0x01 specifies Fox-1A (each Fox satellite will have a unique ID)
Reset Count	16	Unsigned short	Variable	Total number of times IHU has reset since initial on-orbit startup
Uptime	25	Unsigned int	Variable	This is the IHU uptime in seconds since the last reset
Type	4	Unsigned char	Variable	This identifies the payload type

2.2.7.1 Payload type shall be as specified in the application layer payload data.

2.2.7.2 Each Slow Speed link layer structure shall contain only one payload type.

2.2.8 The High Speed link layer header structure is shown in Table 5.

Table 5

Field	Size (Bits)	Type	Value	Description
Fox ID	3	Unsigned char	0x01	0x01 specifies Fox-1A (each Fox satellite will have a unique ID)
Reset Count	14	Unsigned short	Variable	Total number of times IHU has reset since initial on-orbit startup
Uptime	25	Unsigned int	Variable	This is the IHU uptime in seconds since the last reset

2.2.9 The High Speed link layer applications payload shall contain data from all payload types, as shown in table 6.

Table 6

Payload Type	Size (Bytes)	Description
1	60	Real-Time Telemetry Frame
2	60	Telemetry Maximum Values Frame
3	60	Telemetry Minimum Values Frame
5	Variable 1 - 4300	Camera JPEG Data Frame
4	58	Radiation Experiment High Speed Data Frame

2.2.9.1 A varying number of Radiation Experiment Data bytes shall be sent to fill the applications payload size to a total of 4600 bytes if the payload type 5 data is less than 4300 bytes.

2.2.9.1.1 When less than a sufficient number of bytes to contain a useful data frame remain to fill to 4600 bytes, the remaining bytes shall be filled with zeros.

2.2.9.2 Real-Time Telemetry Frame, Telemetry Maximum Values Frame, and Telemetry Minimum Values Frame data shall be padded with zeros to equal 60 bytes length each.

2.2.10 Forward error correction (FEC) code words shall be sent in the link layer trailer. The FEC shall be a Reed Solomon RS (TBR) code. (This provides TBR error detection and correction capability.)

3 Slow Speed Link Layer Transmission Scheduling

3.1 While IHU PTT is asserted Payload Types contained in the Link Layer Applications Payload shall rotate, changing type with each successive link layer transmitted, in the following order:

- Type 1
- Type 4
- Type 1
- Type 4
- Type 1
- Type 2
- Type 4
- Type 1
- Type 4
- Type 1
- Type 4
- Type 3

3.1.1 The above order shall be repeated so long as IHU PTT is asserted.

3.2 While beacon message is sent during idle timer expired the Payload Types contained in the Link Layer Applications Payload shall be transmitted only once in the following order:

- Type 1

4 Application Layer Payload Data

4.1 Payload Type 1 - Real-Time Telemetry Frame (Size = 334 bits)

Table 7

Field	Size (Bits)	Type	Value	Description
BATT A V	12	Unsigned short	Variable	Battery pair A voltage raw value
BATT B V	12	Unsigned short	Variable	Battery pair B voltage raw value
BATT C V	12	Unsigned short	Variable	Battery pair C voltage raw value
BATT A T	12	Unsigned short	Variable	Battery pair A temperature raw value
BATT B T	12	Unsigned short	Variable	Battery pair B temperature raw value
BATT C T	12	Unsigned short	Variable	Battery pair C temperature raw value
TOTAL BATT I	12	Signed short	Variable	Total Battery DC current raw value
BATT Board Temperature	8	Unsigned short	Variable	PC Board Temperature of BATT
+X PANEL V	12	Unsigned short	Variable	+X solar panel voltage raw value
-X PANEL V	12	Unsigned short	Variable	-X solar panel voltage raw value
+Y PANEL V	12	Unsigned short	Variable	+Y solar panel voltage raw value
-Y PANEL V	12	Unsigned short	Variable	-Y solar panel voltage raw value
+Z PANEL V	12	Unsigned short	Variable	+Z solar panel voltage raw value
-Z PANEL V	12	Unsigned short	Variable	-Z solar panel voltage raw value
+X PANEL T	12	Unsigned short	Variable	+X solar panel temperature raw value
-X PANEL T	12	Unsigned short	Variable	-X solar panel temperature raw value
+Y PANEL T	12	Unsigned short	Variable	+Y solar panel temperature raw value
-Y PANEL T	12	Unsigned short	Variable	-Y solar panel temperature raw value
+Z PANEL T	12	Unsigned short	Variable	+Z solar panel temperature raw value
- Z PANEL T	12	Unsigned short	Variable	-Z solar panel temperature raw value

Field	Size (Bits)	Type	Value	Description
PSU CPU Temperature	8	Unsigned short	Variable	CPU Temperature of PSU
SPIN	12	Signed char	Variable	PSU calculated spin rate RPM
TX PA Current	12	Unsigned short	Variable	Transmit power amplifier current
TX Temperature	8	Unsigned short	Variable	Transmitter card temperature
RX Temperature	8	Unsigned short	Variable	Receiver card temperature
IHU CPU Temperature	8	Unsigned short	Variable	CPU Temperature of IHU
Antenna Deploy Sensors	2	2x Unsigned char: 1	Variable	Bit 0 is RCV Bit 1 is XMT 0 = stowed 1 = deployed
Satellite X Axis Angular Velocity	12	Unsigned short	Variable	Raw Angle
Satellite Y Axis Angular Velocity	12	Unsigned short	Variable	Raw Angle
Satellite Z Axis Angular Velocity	12	Unsigned short	Variable	Raw Angle
Experiment Failure Indication	4	4x Unsigned char: 1	Variable	Bit 0 is Experiment 1 Bit 1 is Experiment 2 (N/A on Fox-1A) Bit 2 is Experiment 3 (N/A on Fox-1A) Bit 3 is Experiment 4 State: 0 = Working, 1 = Failed

4.2 Payload Type 2 - Telemetry Maximum Values Frame (Size = 342 bits)

Table 8

Field	Size (Bits)	Type	Value	Description
BATT A V	12	Unsigned short	Variable	Battery pair A high voltage raw value
BATT B V	12	Unsigned short	Variable	Battery pair B high voltage raw value
BATT C V	12	Unsigned short	Variable	Battery pair C high voltage raw value
BATT A T	12	Unsigned short	Variable	Battery pair A high temperature raw value
BATT B T	12	Unsigned short	Variable	Battery pair B high temperature raw value
BATT C T	12	Unsigned short	Variable	Battery pair C high temperature raw value
TOTAL BATT I	12	Signed short	Variable	Battery DC high current raw value
BATT Board Temperature	8	Unsigned short	Variable	High PC Board Temperature of BATT
+X PANEL V	12	Unsigned short	Variable	+X solar panel high voltage raw value
-X PANEL V	12	Unsigned short	Variable	-X solar panel high voltage raw value
+Y PANEL V	12	Unsigned short	Variable	+Y solar panel high voltage raw value
-Y PANEL V	12	Unsigned short	Variable	-Y solar panel high voltage raw value
+Z PANEL V	12	Unsigned short	Variable	+Z solar panel high voltage raw value
-Z PANEL V	12	Unsigned short	Variable	-Z solar panel high voltage raw value
+X PANEL T	12	Unsigned short	Variable	+X solar panel high temperature raw value
-X PANEL T	12	Unsigned short	Variable	-X solar panel high temperature raw value
+Y PANEL T	12	Unsigned short	Variable	+Y solar panel high temperature raw value
-Y PANEL T	12	Unsigned short	Variable	-Y solar panel high temperature raw value
+Z PANEL T	12	Unsigned short	Variable	+Z solar panel high temperature raw value
- Z PANEL T	12	Unsigned short	Variable	-Z solar panel high temperature raw value

Field	Size (Bits)	Type	Value	Description
PSU CPU Temperature	8	Unsigned short	Variable	High CPU Temperature of PSU
SPIN	12	Signed char	Variable	Highest PSU calculated spin rate
TX PA Current	12	Unsigned short	Variable	Transmit power amplifier high current
TX Temperature	8	Unsigned short	Variable	Transmitter card high temperature
RX Temperature	8	Unsigned short	Variable	Receiver card high temperature
IHU CPU Temperature	8	Unsigned short	Variable	High CPU Temperature of IHU
(No Value)	2	Unsigned char	Fixed	0x00 filler
Satellite X Axis Angular Velocity	12	Unsigned short	Variable	Highest Raw Angle
Satellite Y Axis Angular Velocity	12	Unsigned short	Variable	Highest Raw Angle
Satellite Z Axis Angular Velocity	12	Unsigned short	Variable	Highest Raw Angle
MRAM Error Count	12	Unsigned short	Variable	Total MRAM Errors

4.3 Payload Type 3 - Telemetry Minimum Values Frame (Size = 362 bits)

Table 9

Field	Size (Bits)	Type	Value	Description
BATT A V	12	Unsigned short	Variable	Battery pair A low voltage raw value
BATT B V	12	Unsigned short	Variable	Battery pair B low voltage raw value
BATT C V	12	Unsigned short	Variable	Battery pair C low voltage raw value
BATT A T	12	Unsigned short	Variable	Battery pair A low temperature raw value
BATT B T	12	Unsigned short	Variable	Battery pair B low temperature raw value
BATT C T	12	Unsigned short	Variable	Battery pair C low temperature raw value
TOTAL BATT I	12	Signed short	Variable	Battery DC low current raw value
BATT Board Temperature	8	Unsigned short	Variable	High PC Board Temperature of BATT
+X PANEL V	12	Unsigned short	Variable	+X solar panel low voltage raw value
-X PANEL V	12	Unsigned short	Variable	-X solar panel low voltage raw value
+Y PANEL V	12	Unsigned short	Variable	+Y solar panel low voltage raw value
-Y PANEL V	12	Unsigned short	Variable	-Y solar panel low voltage raw value
+Z PANEL V	12	Unsigned short	Variable	+Z solar panel low voltage raw value
-Z PANEL V	12	Unsigned short	Variable	-Z solar panel low voltage raw value
+X PANEL T	12	Unsigned short	Variable	+X solar panel low temperature raw value
-X PANEL T	12	Unsigned short	Variable	-X solar panel low temperature raw value
+Y PANEL T	12	Unsigned short	Variable	+Y solar panel low temperature raw value
-Y PANEL T	12	Unsigned short	Variable	-Y solar panel low temperature raw value
+Z PANEL T	12	Unsigned short	Variable	+Z solar panel low temperature raw value
- Z PANEL T	12	Unsigned short	Variable	-Z solar panel low temperature raw value

Field	Size (Bits)	Type	Value	Description
PSU CPU Temperature	8	Unsigned short	Variable	Low CPU Temperature of PSU
SPIN	12	Signed char	Variable	Lowest PSU calculated spin rate
TX PA Current	12	Unsigned short	Variable	Transmit power amplifier low current
TX Temperature	8	Unsigned short	Variable	Transmitter card low temperature
RX Temperature	8	Unsigned short	Variable	Receiver card low temperature
IHU CPU Temperature	8	Unsigned short	Variable	Low CPU Temperature of IHU
(No Value)	2	Unsigned char	Fixed	0x00 filler
Satellite X Axis Angular Velocity	12	Unsigned short	Variable	Lowest Raw Angle
Satellite Y Axis Angular Velocity	12	Unsigned short	Variable	Lowest Raw Angle
Satellite Z Axis Angular Velocity	12	Unsigned short	Variable	Lowest Raw Angle
IHU Error Data	20	Unsigned int	Variable	Data on Last IHU Error

4.4 Payload Type 4 - Radiation Experiment Data Frame (Size = 464 bits)

Table 10

Field	Size (Bytes)	Value	Description
Data	58	Variable	Experiment 1 Packets

4.5 Payload Type 5 - Camera JPEG Data Frame (Size is variable)

Table 11

Field	Size (Bytes)	Type	Value	Description
Picture Lines	4300	Unsigned int	Variable	Picture Data[1]

[1] See section 4 for Picture Data Structure

5 Picture Data Structure

5.1 Scan Line Segment

Table 12

Field	Size (Bits)	Type	Value	Description
Picture Counter	4	Unsigned char	Variable	0x00 through 0x0F, picture count indicator
Scan Line Number	5	Unsigned char	Variable	0x00 through 0x3B, 0x00 = top scan line
Scan Line Length	10	Unsigned short	Variable	0x001 through 0x3FF, count of bytes in the scan line
Scan Line Data	Variable	Unsigned int	Variable	(Fragment Length) Scan Line Data
End of JPEG Data	8	Unsigned char	0xAA	Indicates end of Picture Data for use in Applications Payload construction

5.1.1 Total Scan Line Segment data size for one Applications Payload frame including end of JPEG data indicator byte shall not exceed 4300 bytes.

Date: January 1, 2013
Version: *draft H*

AMSAT *Fox-1*

IHU Software Architecture Specification

1 Introduction

This software architecture document is a specification of the desired behavior of the IHU software and guidance on an overall structure for the implementation.

1.1 Document History

DATE	VERSION	SUMMARY

1.2 Document Notes

Process specifications are described in this document using a "C-like" psuedocode syntax. This is intended as high-level descriptions of the procedures and not compilable code.

1.3 References

1. Concept of Operations, Version 1.03, OCT 19, 2011
2. System Requirements Specification, Version 1.2, OCT 17, 2012
3. IHU to Battery Interface Control Document, Version 1.01, November 7, 2012
4. IHU to PSU Interface Control Document, Version 1.04, November 7, 2012
5. Radiation Experiment Interface Control Document ???
6. Camera Interface Control Document ??
7. Downlink Protocol Specification ???

2 Processing Environment

2.1 Microcontroller

The IHU software will run on an STMicroelectronics STM32L151VBT microcontroller. The CPU is an ARM® Cortex™-M3 processor with a maximum clock speed of 32 MHz. This is a 32-bit processor and it provides up to 33 MIPS of processing power. The microcontroller includes 128K bytes of FLASH program memory, 4K bytes of non-volatile EEPROM and 16K bytes of RAM.

2.2 MRAM

The IHU card includes an Everspin Technologies MR25H10 MRAM. This is a 128K byte, non-volatile, read-write memory. The MR25H10 is highly tolerant of space radiation and is expected to be error-free during on-orbit operation. However, it is connected to the microcontroller through an SPI bus interface which may be sensitive to space radiation effects. Therefore, as a minimum, a single-bit-error detection scheme should be used to detect errors that might be induced during SPI transfers. This can be easily accommodated with a 16-bit checksum of 8-bit bytes for each data structure stored in the memory. Writes to the MRAM should be immediately followed by a read-verify operation to insure that the write was successful. A retry scheme should be used to handle detected errors.

2.3 MicroSD Card

The IHU has the capability of hosting a microSD FLASH memory card. This is not expected to be used for the initial *Fox-1* satellite mission but is available for software development if desired.

2.4 I/O Interfaces

The IHU microcontroller includes the following types of on-chip I/O interfaces:

Type	**Description**
A/D	Analog to Digital Converter (input)
D/A	Digital to Analog Converter (output)
I2C	I2C bus
GPI	General Purpose IO (used as input)
GPO	General Purpose IO (used as output)
Serial-I	Asynchronous serial input
Serial-O	Asynchronous serial output
SPI	SPI Bus

The above "Type" codes are used in the next section to indicate how peripheral device signals are interfaced with the IHU microcontroller.

3 Peripheral Devices

This section describes the IHU peripherals and their interfaces to the microcontroller. See the IHU card documentation for the specific port and pin information. *It would probably be very helpful to create a cross-reference between the Fox-1 bus signals and the STM32 port/pins.*

3.1 MEMS Gyroscopes

The IHU card includes a pair of STMicroelectronics, LPY403AL, 2-axis MEMS gyroscopes. They are physically arranged so that 3-axis of angular velocity can be measured. The GPIO outputs on the microcontroller are used to control the operation of the gyros and the gyro outputs drive A/D inputs on the microcontroller.

The interface is as follows:

Name	**Type**
Gyro HP	GPO
Gyro ST	GPO
Gyro_Vref_1	A/D
Gyro_Vref_2	A/D
Gyro_X_1	A/D
Gyro_Z_1	A/D
Gyro_X_2	A/D
Gyro_Z_2	A/D

Note that the Gyro_Z_2 channel provides duplicate information and is not used.

Looking down at the top (+Z) of the satellite, a Gyro_Z_1 voltage above the Gyro_Vref_1 voltage indicates a counter-clockwise rotation about the satellite's Z axis.

Looking straight at the +Y solar panel of the satellite, a Gyro_X_1 voltage above the Gyro_Vref_1 voltage indicates a counter-clockwise rotation about the satellite's Y axis.

Looking straight at the +X solar panel of the satellite, a Gyro_X_2 voltage above the Gyro_Vref_2 voltage indicates a ***clockwise*** rotation about the satellite's X axis. This is opposite from the other axis and must be multiplied by -1 to be consistent when reported.

Refer to the LPY403AL spec sheet to understand how to test (for diagnostics) and operate the MEMS gyro devices.

3.2 Antenna Deployer Control

These signals activate the antenna deployment mechanisms and sense the deployment status. The precise sequencing and operation of these signals is TBD.

Name	**Type**
TX Antenna Sensor	GPI
RX Antenna Sensor	GPI
TX Antenna Deploy	GPO
RX Antenna Deploy	GPO

3.3 Radio Control

These are the signals used to operate the RF up and down links.

Name	**Type**
Command Mode	GPO
IHU_PTT	GPO
IHU_Audio_1_Out	D/A
IHU_Audio_2_Out *	D/A
RX_CD *	GPI
RX PTT *	GPI
Rx_Audio_1	A/D
Rx_Audio_2 *	A/D

* For *Fox-1*, the IHU_Audio_2_Out, RX_CD, RX_PTT and Rx_Audio_2 signals are not used by the IHU software.

3.4 IHU Card Telemetry

These are the telemetry parameters from sensors on the IHU card.

Name	**Type**
IHU CPU Temperature	A/D

3.5 External Watchdog Timer

In addition to the STM32 internal watchdog timer, the IHU card has an external watchdog timer. The IHU software must pulse the "Watchdog" lead at least once per second. Failure to do this will cause the IHU to be power-cycled.

Name	**Type**
Watchdog	GPO

3.6 Hardware Command Decoder

There is a 4-bit, hardware command decoder on the RF Rx card. The 4 output bits and a data valid strobe are available on the IHU card on GPIO leads. The decoder output bits 8-11 are latched. The data valid strobe is a rising edge and is not latched. At satellite power up, all signals will be 0.

Output	**Type**
RX Command Data11	GPI
RX Command Data10	GPI
RX Command Data9	GPI
RX Command Data8	GPI
RX Command Strobe	GPI

The most significant bit (Data 11) is used to inhibit the RF transmitter. The second most significant bit (Data 10) is used to inhibit the IHU (i.e. power off.) These are implemented in hardware and operate without any software intervention. The commands are coded as follows:

Bit Pattern	**Command**
1xxx	Inhibit TX
0xxx	Enable TX
x1xx	Inhibit IHU (power off)
x0xx	Enable IHU (power on)
xx00	Go To Transponder Mode
xx01	Go To Data Mode
xx10	Clear Telemetry Min/Max data
xx11	Send Test Message

3.7 RF System Telemetry

These are analog sensors on the RF cards that feed A/D inputs on the STM32.

Parameter	**Type**
TX PA Current	A/D
TX PA Temperature	A/D
TX Osc Temperature	A/D
RX Osc Temperature	A/D

3.8 Battery Card Telemetry

These data elements come from the Battery card via an I2C interface that is shared with the PSU card. See the IHU to Battery Interface Control Document for more details.

Parameter
Battery Cell 1 Volts
Battery Cell 2 Volts
Battery Cell 3 Volts
Battery Cell 4 Volts
Battery Cell 5 Volts
Battery Cell 6 Volts
Battery Pair 1 Temperature
Battery Pair 2 Temperature
Battery Pair 3 Temperature
Battery Card Current*
BAT CPU Temperature

*Note: Total current into (charge) or out of (discharge) the card.

3.9 PSU Card Telemetry

These parameters come from the PSU card via an I2C interface that is shared with the Battery card. See the IHU to PSU Interface Control Document for more details.

Parameter
+X Solar Panel Volts
-X Solar Panel Volts
+Y Solar Panel Volts
-Y Solar Panel Volts
+Z Solar Panel Volts
-Z Solar Panel Volts
+X Solar Panel Temperature
-X Solar Panel Temperature
+Y Solar Panel Temperature
-Y Solar Panel Temperature
+Z Solar Panel Temperature
-Z Solar Panel Temperature
Satellite Spin Rate*
Total Output Current
PSU CPU Temperature

*Note: the satellite spin rate is calculated on the PSU card from the solar panel voltages and is only meaningful when the satellite is in sunlight.

3.10 USB Umbilical Port

The umbilical port is functionally a USB port. The USB port can provide power to the satellite avionics and can be used to charge the satellite batteries. Since battery charging will exceed the standard USB current capability, a special power adapter will be used when charging the batteries. A GPIO input lead will indicate that the USB port is providing power to the satellite.

To the USB host, the satellite will look like a COM port and will allow use of the standard host USB COM driver. The intention is that the satellite can be easily used with common terminal emulation programs such as PuTTY. This port is used by the Diagnostics Subsystem that is described later in the document.

3.11 Debug Port

This is a serial port available for SW development use. It is not needed or used for the mission. It is expected that a call to a debug "printf()" would direct the output string to the debug port. It is expected this port would use asynchronous ASCII 8 Data bits, no parity, 1 stop bit, 19.2 k bps. As an alternative, the Umbilical port could be enhanced to display software debug messages rather than use a dedicated serial port. This port could be used for a debugger such as GDB if desired.

3.12 Radiation Experiment

Power to the radiation experiment cards is controlled via a GPIO output that drives the "Experiment Enable 1" bus signal.

An I2C bus is used to get the radiation experiment data. The specifics of this interface are defined in the *Fox-1* Experiment Interface Control Document.

3.13 Camera

Power to the camera card is controlled via a GPIO output that drives the "Experiment Enable 4" bus signal.

A serial port is used to send commands to the camera and to get the camera image data. The specifics of this interface are defined in the *Fox-1* Camera Interface Control Document.

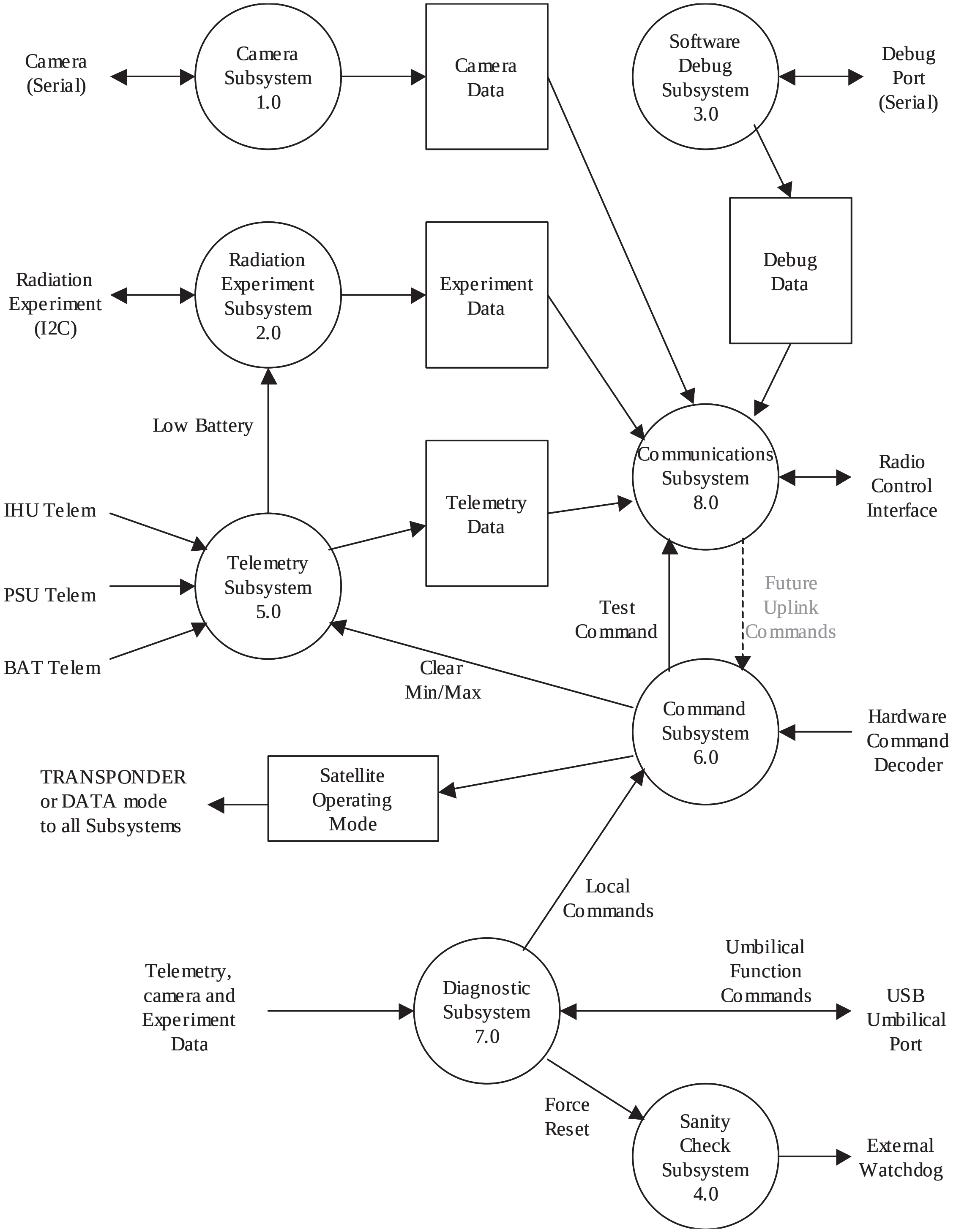
4 CPU Start Up Sequence

This is the sequence of events after a CPU reset or at power up.

```
// Run Power On Self Test (POST)
// Check the program FLASH and run a CPU test
// Remember to  pulse the external watchdog timer!

Run POST;
if (POST Failed) {
        halt and let external watchdog timer fire to try again
}

// POST passed
// See if we need to deploy the antennas
if (Umbilical Port is providing power) {
        break;          // do NOT deploy antennas!
}
else if (Both antennas are already deployed) {
        break;          // no need to deploy antennas
}
else if (One antenna is already deployed) {
        Deploy remaining antenna;
        break;
}
else {
        // Just released from P-POD
        // Antennas not deployed
        wait for 45 minutes;        // remember to pulse Watchdog
        Deploy RX antenna;
        Deploy TX antenna;
        break;
}

increment IHU Reset Count in MRAM;
set Command Mode to HIGH;
boot up system;
```

5 Application Software Data Flow Diagram

This shows the application software subsystems and their interfaces after the start up sequence has been executed (i.e. after system boot up.) The required functionality of each subsystem is specified in this section.



5.1 Camera Subsystem (1.0)

This subsystem runs the camera. The Camera is only used in DATA mode.

```
// Camera Processing
// Satellite in DATA mode

Turn ON power to Camera Card;
Initialize Camera parameters;

while (Satellite is in DATA mode) {
        Tell Camera to take a snapshot;

        while( Camera has data to send) {
                Get data from Camera;
                Store in Camera Data Buffer
        }
        Send Camera Data to Communications Subsystem;
}

// If Satellite switched to TRANSPONDER mode
Turn  Camera card OFF;
Clear Camera Data Buffer;
Do nothing until satellite switches to DATA mode;
```

5.2 Radiation Experiment Subsystem (2.0)

This subsystem is responsible for running the experiment, collecting the experiment data , putting the experiment data into the Experiment Data Buffer and sending it to the Communications Subsystem. The experiment must be turned off and processing stopped if the Low Battery indication is received from the Telemetry subsystem.

5.3 Software Debug Subsystem (3.0)

There are no flight requirements for this subsystem. It is available for software development purposes and will be disabled for flight. There is a serial debug port that may be used for simple messages (printf.) There is also a debug data store available that will allow data to be transmitted along with the telemetry data on the downlink. This will allow non-flight parameters to be provided during software development.

5.4 Sanity Check Subsystem (4.0)

This subsystem verifies the integrity of the running software and pulses the Watchdog signal to reset the external watchdog timer. It will stop pulsing the Watchdog signal if it detects a fault or if it receives a command from the Diagnostic subsystem to force a reset.

5.5 Telemetry Subsystem (5.0)

This module is responsible for collecting all of the telemetry information from the interfaces, doing the Min/Max processing and providing the complete set of real-time, minimum and maximum telemetry parameters in the Telemetry Data Buffer. Note that this data is to be in the packed binary format as specified in the Telemetry Data section of the Downlink Protocol Specification.

5.5.1 Telemetry Subsystem Processing Specification

```
// Telemetry Processing
Do this every 15 seconds;

Get all telemetry parameters;

// Check Battery
If (Bus Voltage < 3.5 volts) {
        Send LOW BATTERY indication to Radiation Experiment Subsystem;
}

// Do MinMax processing
Read Min/Max Data from MRAM memory;
If (any errors) {
        Increment MRAM memory error counter;
        Re-write data to clear errors;
}
if  (Clear Min/Max command was received) {
        Write current telemetry values to Min/Max;
        Clear MRAM memory error counter;
}
else {
        // Normal Min/Max processing
        Compare current values with stored Min/Max data;
        Write any new Min/Max data to  MRAM memory
}

Send telemetry data to Communications Subsystem
```

5.6 Command Subsystem (6.0)

This subsystem is responsible for interpreting and executing commands to the satellite. The commands can come from ground control stations via the Hardware Command Decoder interface or from the Diagnostics subsystem via the umbilical port. In the future, the satellite will also accept commands from the communications subsystem via the uplink (not implemented for *Fox-1*.)

The Local Commands from the Diagnostics subsystem are:

1. Clear Telemetry Min/Max data
2. Got to Transponder Mode
3. Go to Data Mode
4. Send Test Message

The Command subsystem is responsible for setting the satellite operating mode. This is used by several subsystems to control their operation. If the satellite is commanded into DATA Mode, it must automatically switch back to TRANSPONDER mode after 24 hours unless a new DATA Mode command has been received.

5.6.1 Command Subsystem Processing Specification

```
// Command Processing
Set Satellite Operating Mode to TRANSPONDER;  // This is the default at power-up

Do this continuously {

        Wait for a new command;
        switch(command) {

        case Clear Telemetry MinMax:
                Send Clear Min/Max message to Telemetry subsystem
                break;

        case Transponder Mode:
                Stop 24 Hour timer;
                Set Satellite Operating Mode to TRANSPONDER;
                break;

        case Data Mode:
                Start or re-start the 24 hour timer;
                Set Satellite Operating Mode to DATA;
                break;

        case Send Test Message:
                Send Test Command to Communications subsystem
                break;
```

```
        default:
                // No processing for TX and IHU INHIBIT or ENABLE  commands
                Do nothing;
        }

        if (24 hour timer expires) {
                Set Satellite Operating Mode to TRANSPONDER;
        }
}
```

5.7 Diagnostic Subsystem (7.0)

This subsystem implements a local user interface on the satellite through the Umbilical USB port. This is expected to be used for system testing and launch integration activities. The Diagnostic Subsystem can read data from any Data buffer and can send commands to the Command and Idle subsystems. It is also available for software development use. This subsystem is not used in orbit. Note that if the satellite is being powered by the USB Umbilical port, the antennas MUST NOT be deployed and the Communications subsystem will prevent the transmitter power amp from being activated.

The following functions are the minimal set that is required. Additional commands can be added as needed.

5.7.1 Umbilical Port Get Functions

1. Get Telemetry Data
2. Get Experiment Data (n= 1-4)
3. Get Satellite Mode (command or transponder mode)
4. Get Satellite Up time (MET)
5. Get IHU Reset Count
6. Get Software Versions (IHU, PSU, BAT)

5.7.2 Umbilical Port Set Functions

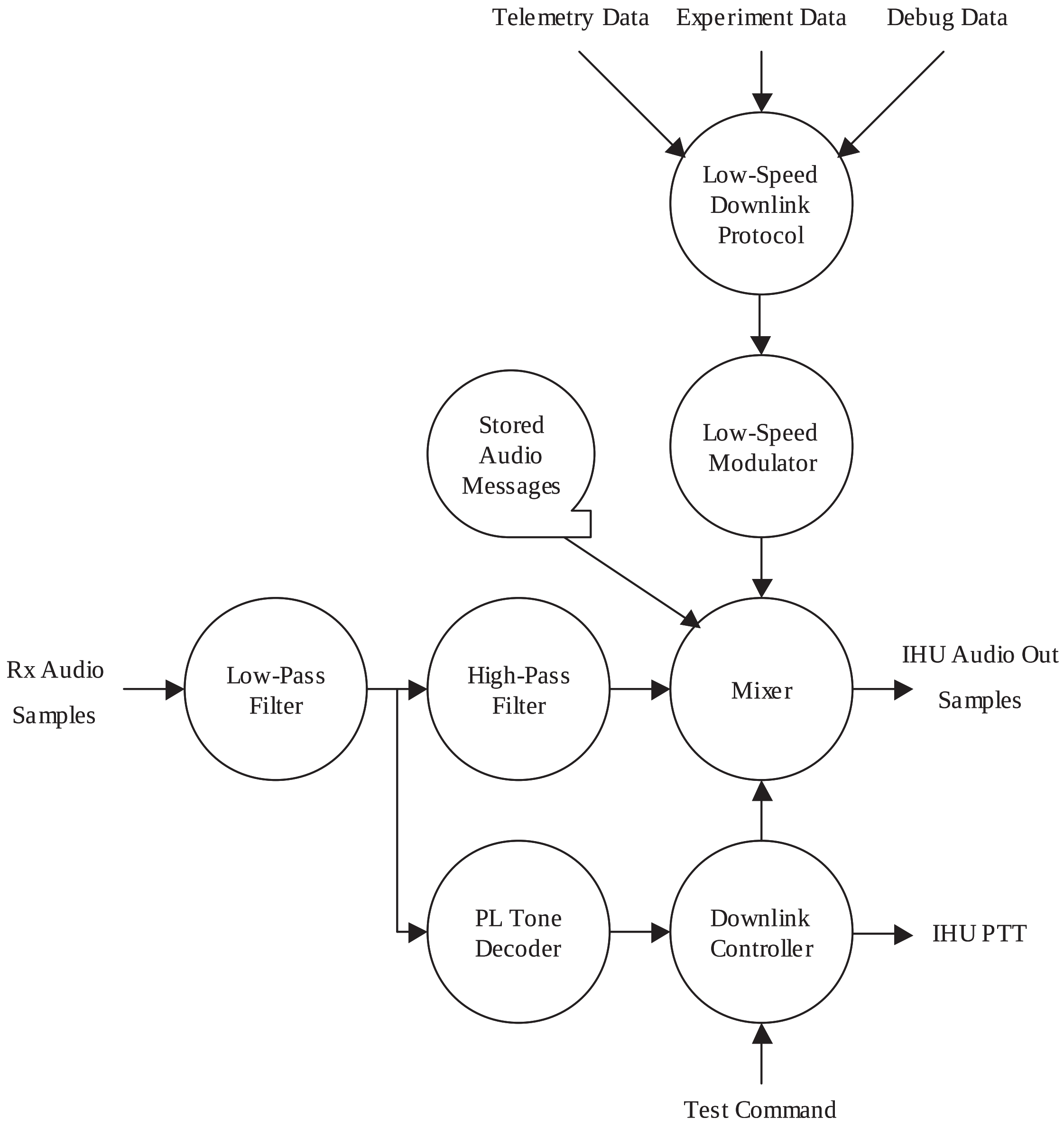
1. Load the CPU Program (FLASH) Memory
2. Clear Telemetry Min/Max data
3. Clear IHU Reset Count
4. Clear MRAM error count
5. Got to Transponder Mode
6. Go to Data Mode
7. Send Test Message
8. Reset CPU (let external watchdog timer fire)
9. Force Antenna Deployment (only if NOT powered by USB port)

5.8 Communications Subsystem (8.0)

This subsystem operates differently in TRANSPONDER and DATA modes.

5.8.1 Communications Subsystem TRANSPONDER Mode Operation

The diagram below shows the Communications subsystem data flow in TRANSPONDER mode.



The Low-Speed Downlink Protocol multiplexes the Telemetry, Experiment and Debug Data and adds the header and forward error correction (FEC) fields as specified in the Downlink Protocol Specification. The resulting bit-stream is fed to the Low Speed Modulator which creates the audio samples for transmission.

The Rx audio samples from the RF receiver are sent to a 3 kHz low-pass filter which feeds a 300 Hz high-pass filter and the PL Tone detector. The high-pass filter removes all of the audio components below 300 Hz so the spectrum is clean for the low-speed data downlink signal. The filtered audio signal is sent to the Mixer.

The Mixer can select and combine the low-speed data downlink signal and the filtered Rx audio signal or a Stored Audio Message under control of the Downlink Controller. The Stored Audio Messages include the Beacon message, Test message and Silence.

The PL Tone decoder detects the presence of a 67 Hz PL tone and sends an indication of this to the Downlink Controller.

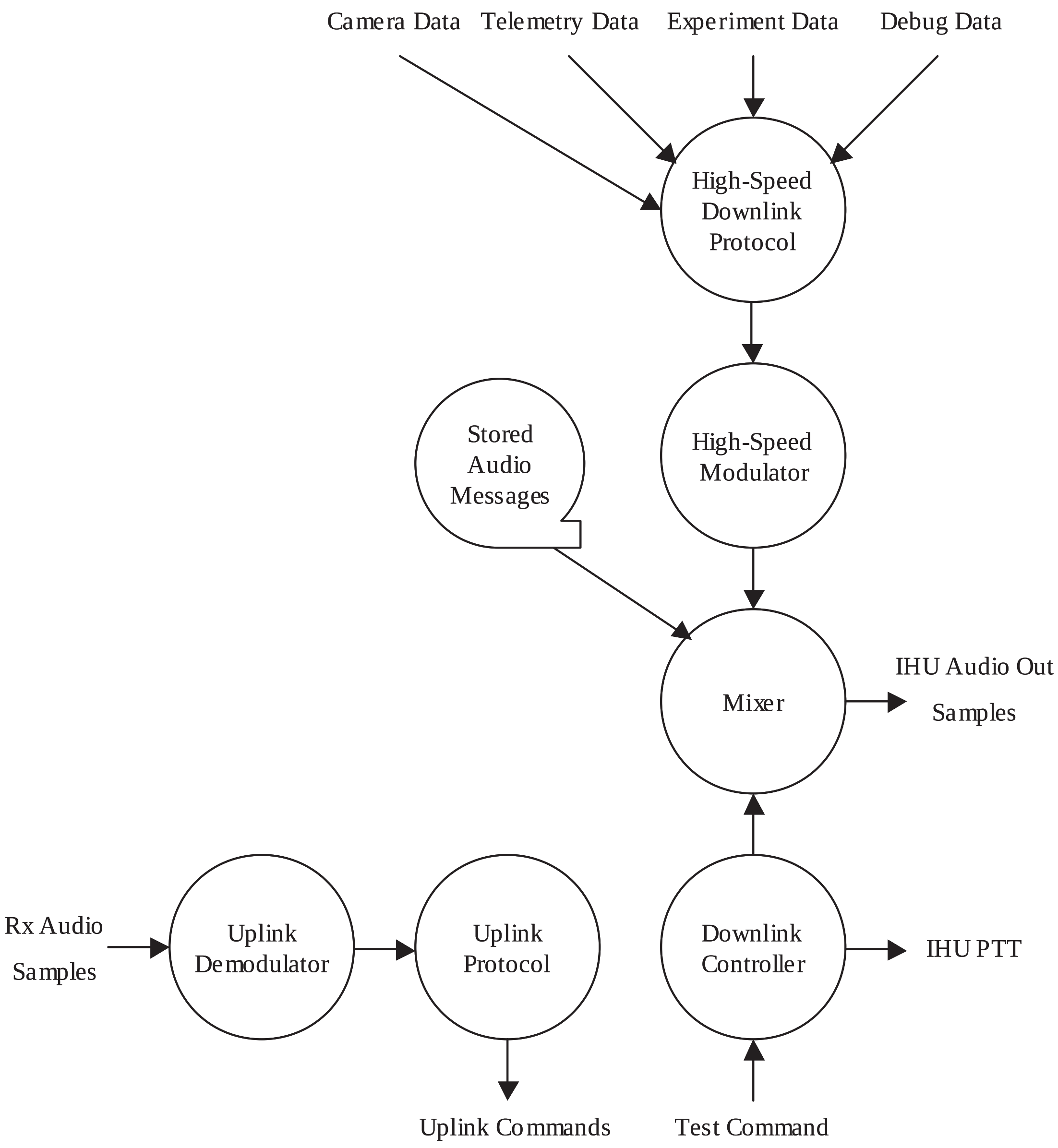
5.8.1.1 Downlink Controller - TRANSPONDER mode Processing Specification

```
// Downlink Controller TRANSPONDER mode Processing

When satellite enters TRANSPONDER mode {
        Turn off IHU PTT;
        Set Mixer source to Rx Audio and Low-Speed Modulator;

}

do {
        if (PL Tone Detected) {
                if( NOT powered from USB port ) {
                        Turn on IHU PTT;
                }
                Start or restart 2-minute Hang Timer;
                Stop Idle Timer;
        }

        if (Hang Timer Expires) {
                Turn off IHU PTT;
                Start 2 minute Idle Timer;
        }

        // continued on next page
```

```
        if (Idle Timer Expires) {
                Set Mixer source to Silence;
                if( NOT powered from USB port ) {
                        Turn on IHU PTT;
                }
                Wait 5 seconds;         // For Douglas!
                Set Mixer source to Low-Speed Modulator and Beacon Message;
                Wait until Beacon Message sent;
                Set Mixer source to Low-Speed Modulator and Silence;
                Wait 6 seconds;
                Turn off IHU PTT;
                Set Mixer source to Rx Audio and Low-Speed Modulator;
                Re-start Idle Timer;
        }

        if (Test Command received) {
                if( NOT powered from USB port ) {
                        Turn on IHU PTT;
                }
                Wait 1 second;
                Set Mixer source to Test Message and Low-Speed Modulator;
                Wait until Test Message sent;
                if (Hang Timer is not running) {
                        Wait 1 seconds;
                        Turn off IHU PTT;
                }
                Set Mixer source to Rx Audio and Low-Speed Modulator;
        }
}
// end of TRANSPONDER mode, downlink controller processing
```

5.8.2 Communications Subsystem Data Mode Operation

The diagram below shows the Communications subsystem data flow in DATA mode.



The High-Speed Downlink Protocol multiplexes the Camera, Telemetry, Experiment and Debug Data and adds the header and forward error correction (FEC) fields to create downlink frames. The resulting bit-stream is fed to the High-Speed Modulator which creates the audio samples for transmission. The Mixer can select the Modulator samples or a selected Stored Audio Message under control of the Downlink Controller. The Stored Audio Messages include the Beacon message, Test message and silence. The uplink demodulation and protocol functions are not implemented in *Fox-1* but are shown for completeness.

5.8.2.1 Downlink Controller DATA mode Processing Specification

```
// Downlink Controller DATA mode Processing

When Satellite enters DATA mode {
        Set Mixer Source to High-Speed Modulator only;
        if( NOT powered by USB port ) {
                Turn on IHU PTT;
        }
}

do {
        if (Test Command received) {
                Set Mixer source to Silence;
                Wait 1 second;
                Set Mixer source to Test Message;
                Wait until Test Message sent;
                Set Mixer source to Silence;
                Wait 1 second;
        }
        Set Mixer Source to High-Speed Modulator;

} while (satellite is in DATA mode)

// Satellite switched to TRANSPONDER mode
Turn off IHU PTT;
Do nothing until satellite goes back into DATA mode;
```

6 System Considerations

6.1 Operating System

The IHU software will use the free version of the FreeRTOS operating system.

6.2 Physical Device Drivers

These physical device drivers are needed to access and control the STM32 I/O interfaces.

1. I^2C Bus
2. SPI Bus
3. UART
4. A/D converter channels
5. D/A converter channels
6. GPIO inputs
7. GPIO outputs

6.3 Performance Requirements

The Rx Audio A/D and the IHU Audio D/A converters have hard real-time requirements. DMA should be considered to offload the CPU for these interfaces.

6.4 Operational Constraints

The software is intended to run on orbit but must also be able to run inside the P-Pod to support the launch integration activities. Inside the P-POD, the power for the satellite will come from the USB Umbilical port. When powered from this port (i.e. inside the P-POD,) the antennas MUST NOT be deployed and the RF transmitter power amp MUST NOT be turned on.

6.5 Modularity and Maintainability

The experiments will be different for each future *Fox-1* type satellite mission. The experiment and camera processing software needs to be modularized so that they are easy to change.

7 Closing Notes

This document provides the desired behavior and a structure for the IHU software. It is expected that appropriate design documentation will be provided in addition to this document to describe the implementation details.

Introduction to Fox1 Mechanical Drawings

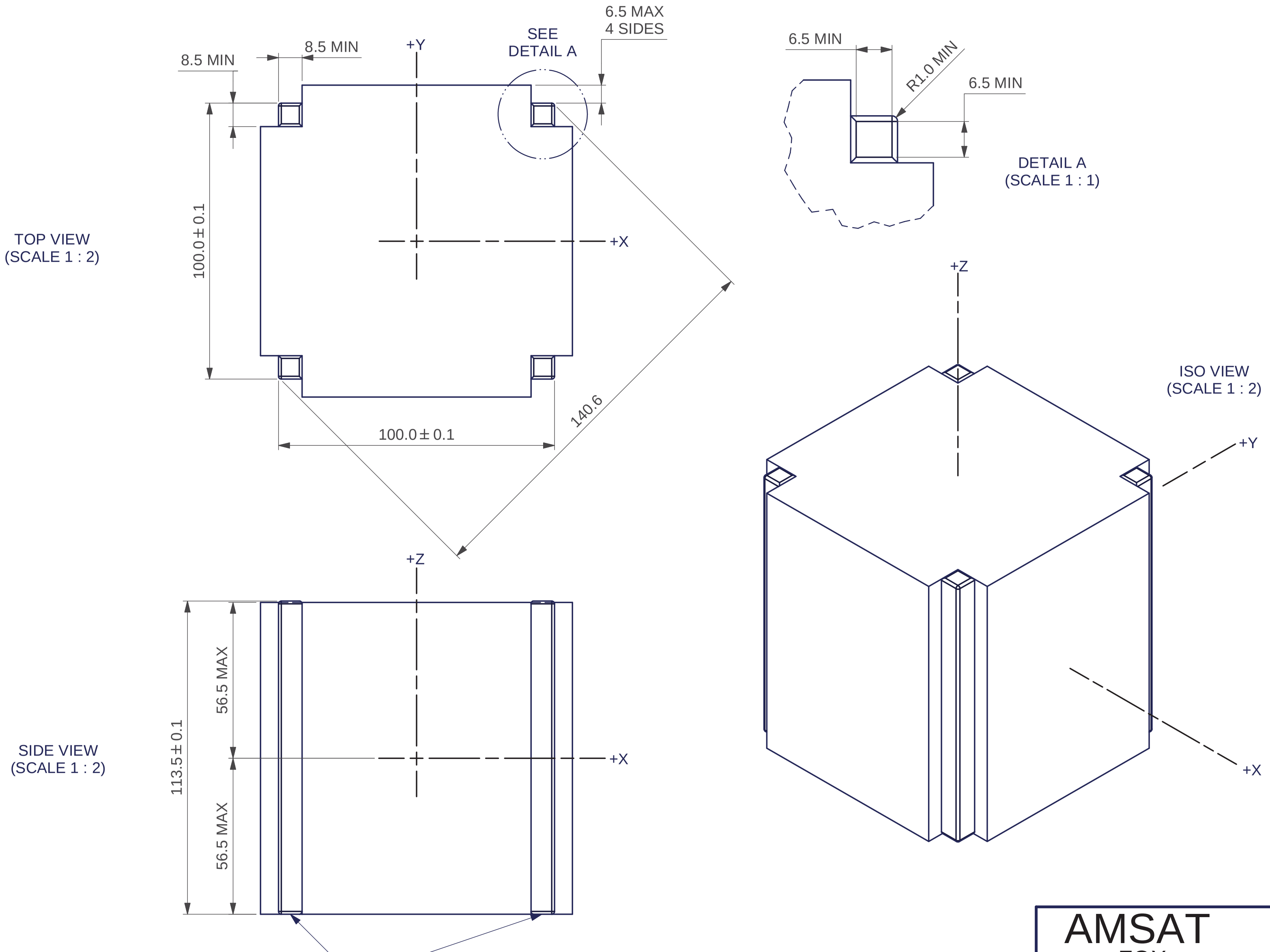
Robert Davis, KF4KSS

The following 54 pages are the current drawings for AMSAT's Fox1 cubesat. These are draft, and in a few circumstances, the design has been modified slightly from the drawings as currently updated. Some drawings use color, if meaningful information can be shared, like material or circuit board layout. All drawings should be considered draft, as we have not committed to fabrication of flight units yet. However, in many instances, the drawings represent a very mature design.

We are just about to assemble engineering units, which would be available for operational testing, mechanical fit checks, and prototype environmental tests. For some parts, earlier prototypes were also built. This year, prototypes were built that have helped mature the design of the PCB Stack, sheetmetal Walls, and Solar Panel printed circuit boards. We now have many pieces on hand, and we're looking out for things like assembled tolerances. Significant prototype effort has also been placed in the +Y and –Y Solar Panels, which share a common circuit board design but populated differently for the RX and TX antennas. Long-term stow, vibration resistance, and deploy tests will be starting soon on those antennas. A thermal vacuum test of the battery board is also imminent.

Our progress has only been possible through the efforts of multiple people,
within our small mechanical team and across many disciples and components.

Please consider volunteering!



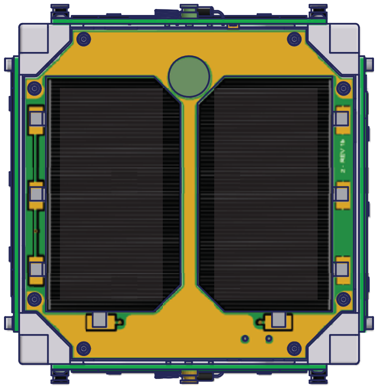
NOTES:
1) INTERPRETATION OF CUBESAT DESIGN SPECIFICATION REV 12.
2) ENVELOPE FOR ALL HARDWARE EXCEPT FREE STATE OF
   A) PLUNGER OF TWO SEPARATION SPRINGS
   B) PLUNGER OF ONE OR TWO CONTACT SWITCH(ES)

AMSAT
FOX

1U ENVELOPE

SIZE A
DATE 2011-04-04
DWG.NO. FOX-ME-101
REV. 0.2
SCALE 1 : 2
UNLESS NOTED OTHERWISE:
UNITS: mm [in] • TOLERANCE: +/-0.5
SHEET 1/1

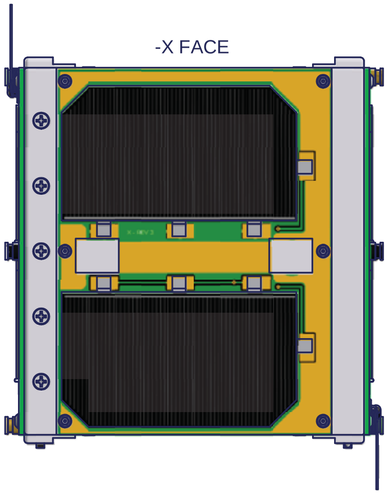
+Z FACE



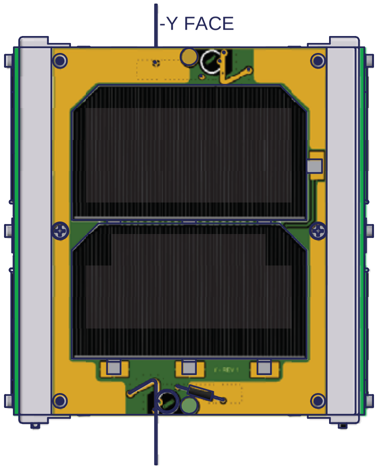
DEPLOYED

(ANTENNAS CROPPED)
SCALE 1 : 2

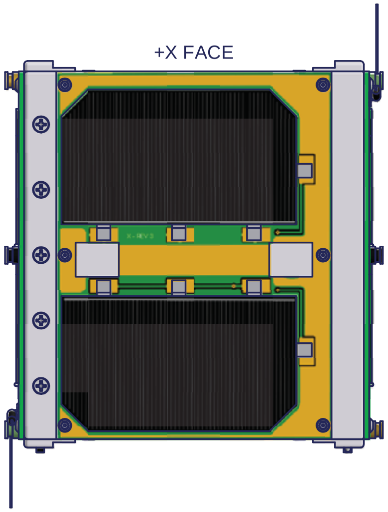
-X FACE



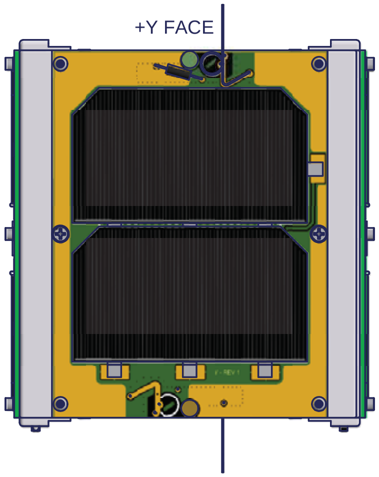
-Y FACE



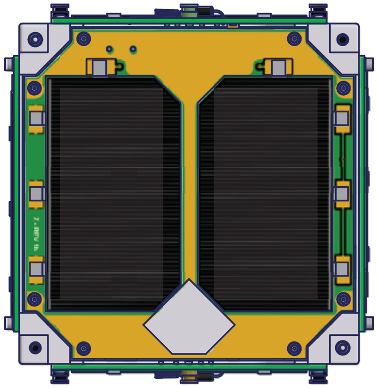
+X FACE



+Y FACE



-Z FACE



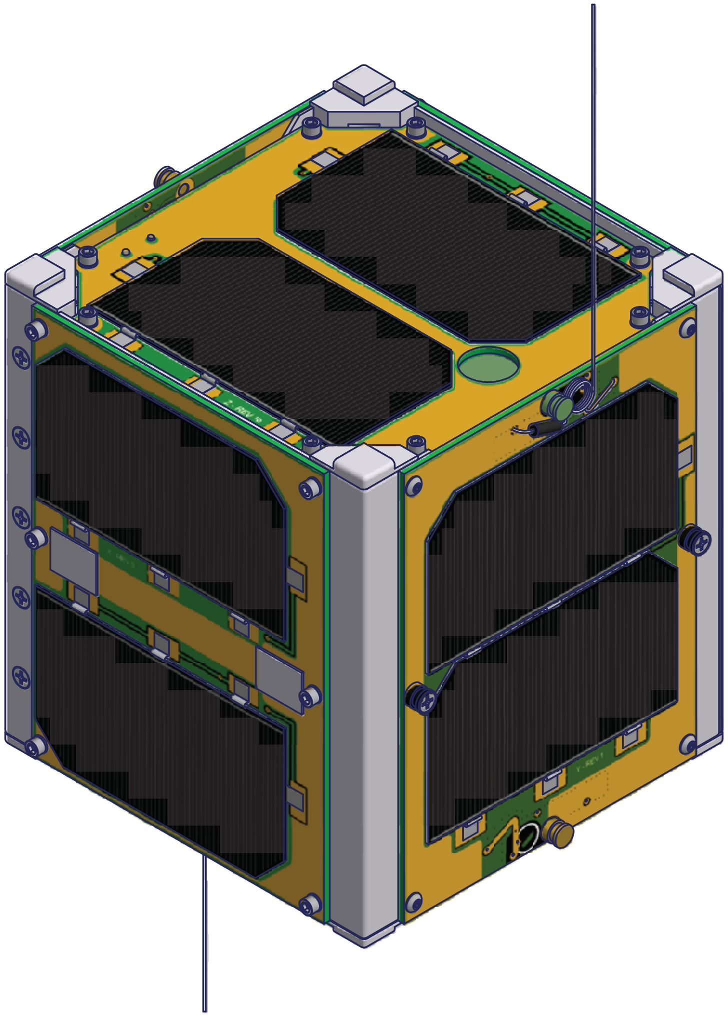
AMSAT
FOX

FOX1 ASSEMBLY

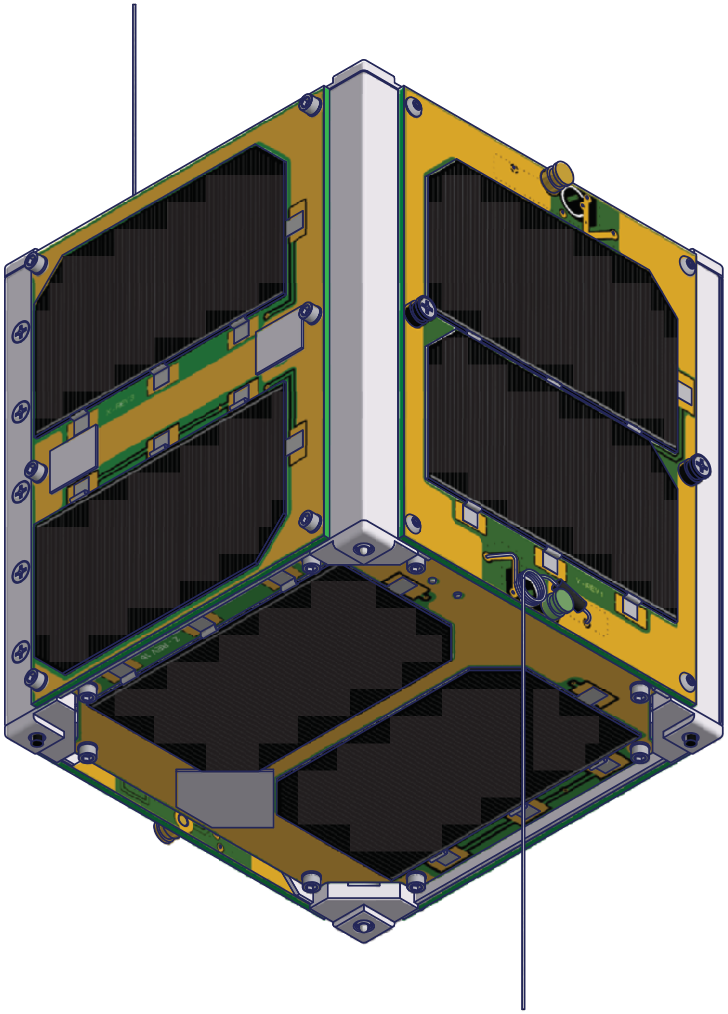
SIZE	DATE	DWG.NO.	REV.
A	2013-10-09	FOX-ME-103	0.4

SCALE	UNLESS NOTED OTHERWISE:	SHEET
1 : 2	mm [in]; TOL X.X ± 0,2 X.XX± 0,1	1 OF 5

ISO +X+Y+Z
SCALE 3 : 4



ISO -X-Y-Z
SCALE 3 : 4

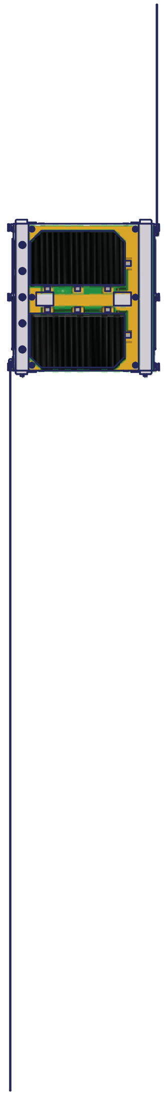


AMSAT
FOX

FOX1 ASSEMBLY

SIZE A	DATE 2013-10-09	DWG.NO. FOX-ME-103	REV. 0.4
SCALE 3 : 4	UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX± 0,1		SHEET 2 OF 5

+X FACE
TRUE ANTENNA LENGTHS
SCALE 0.2 : 1

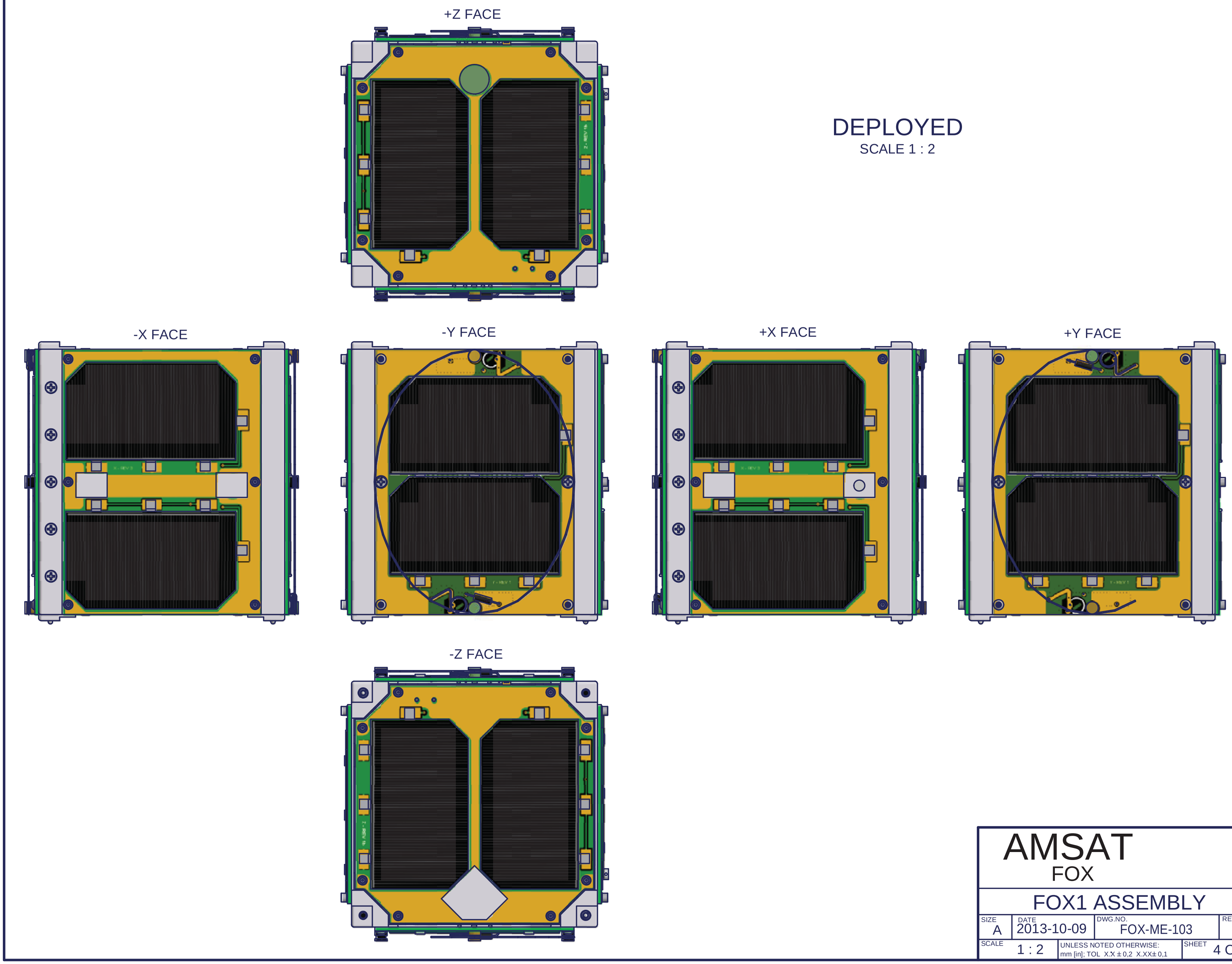


AMSAT
FOX

FOX1 ASSEMBLY

SIZE A	DATE 2013-10-09	DWG.NO. FOX-ME-103	REV. 0.4
SCALE 1 : 5	UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX± 0,1		SHEET 3 OF 5

DEPLOYED
SCALE 1 : 2



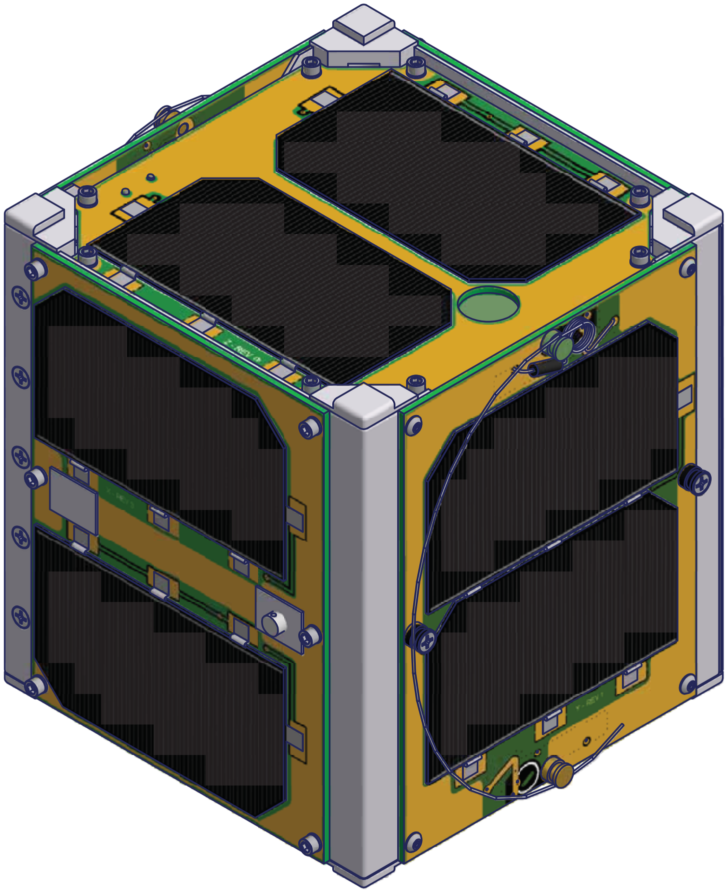
AMSAT
FOX

FOX1 ASSEMBLY

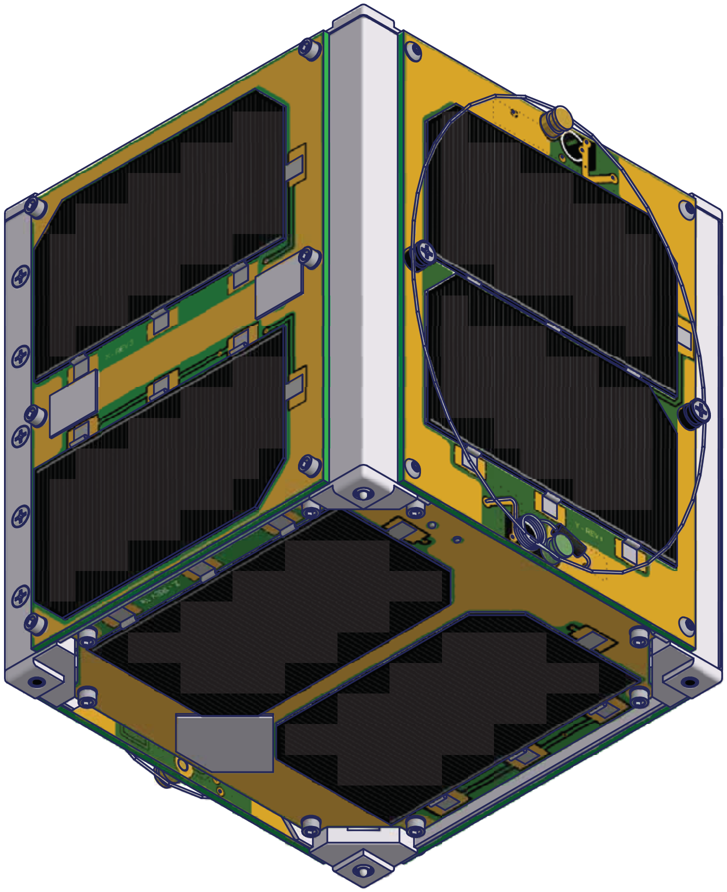
SIZE	DATE	DWG.NO.	REV.
A	2013-10-09	FOX-ME-103	0.4

SCALE 1 : 2
UNLESS NOTED OTHERWISE:
mm [in]; TOL X.X ± 0,2 X.XX± 0,1
SHEET 4 OF 5

ISO +X+Y+Z
SCALE 3 : 4



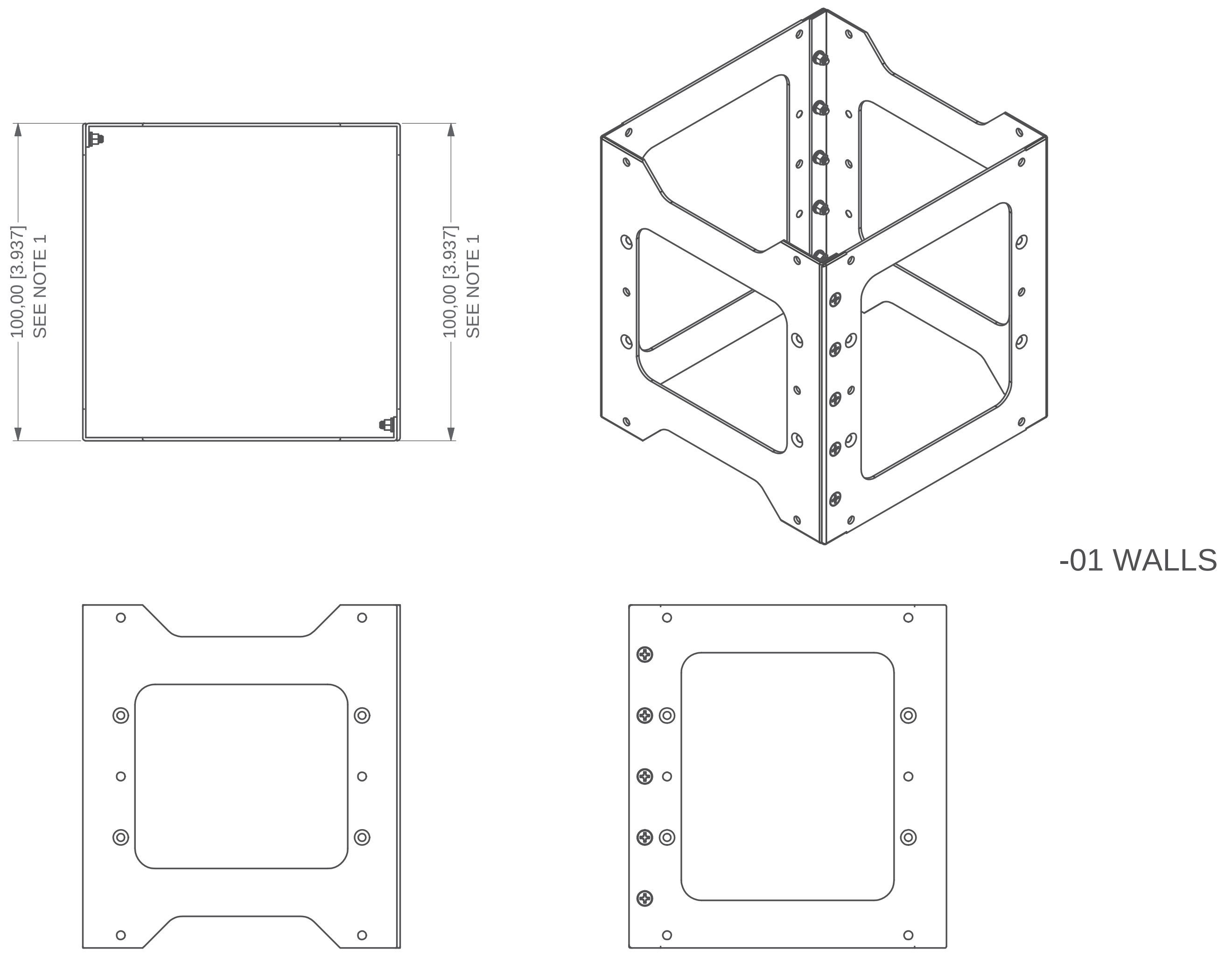
ISO -X-Y-Z
SCALE 3 : 4



AMSAT
FOX

FOX1 ASSEMBLY

SIZE A
DATE 2013-10-09
DWG.NO. FOX-ME-103
REV. 0.4
SCALE 3 : 4
UNLESS NOTED OTHERWISE:
mm [in]; TOL X.X ± 0,2 X.XX± 0,1
SHEET 5 OF 5



1	2	FOX-ME-111-03	WALLS, BENT
3	10	MS21042-02	LOCK NUT, #2-56
4	10	NAS662C2R4 / MCMASTER-CARR 93085A017	FHCS, #2-56 X 1/4" X 100° SS
5	10	90945A705	WASHER, #2 THIN, NAS620C2
ITEM	QTY	PART NUMBER	DESCRIPTION

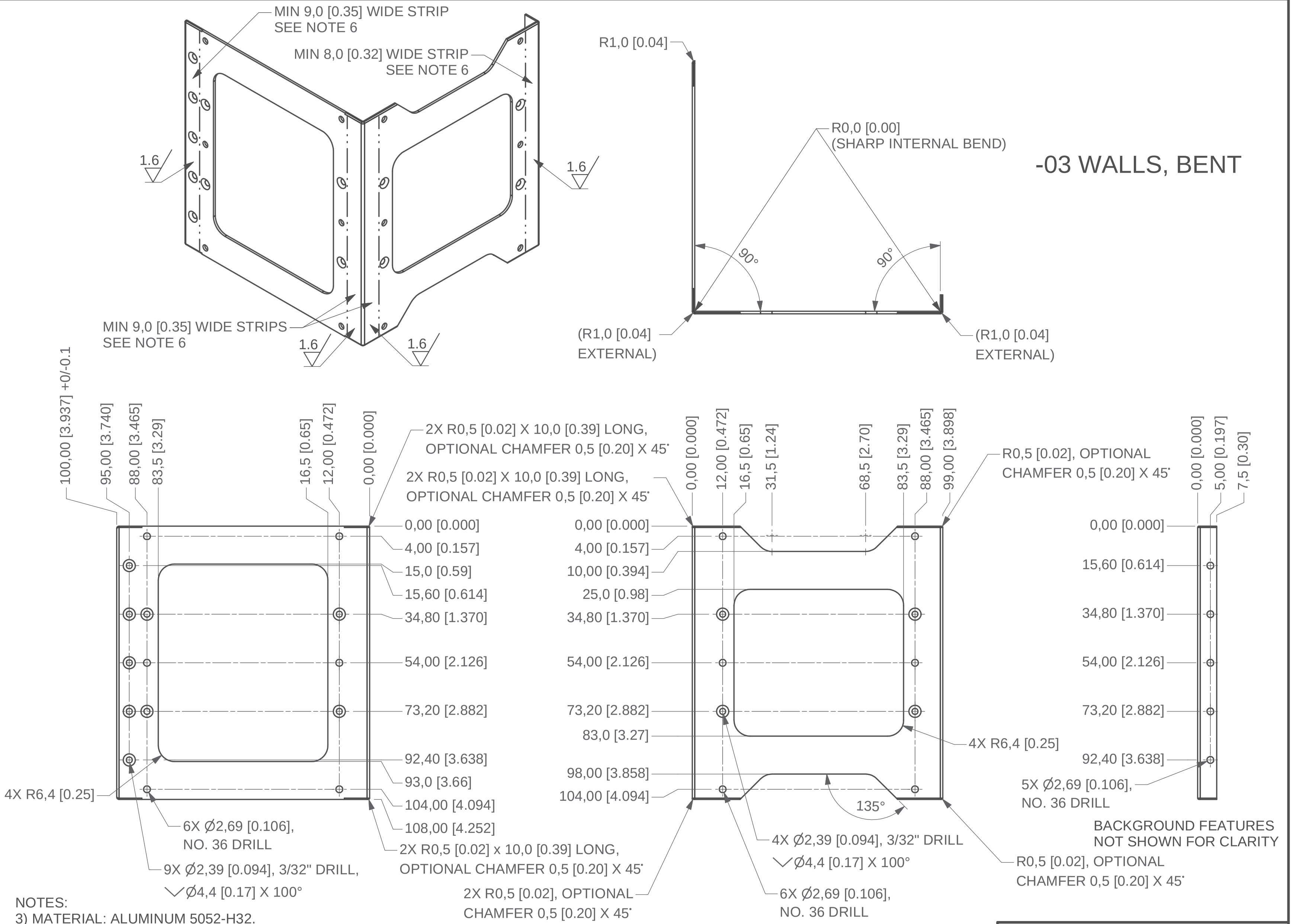
Parts List

NOTES:
1) AT ASSEMBLY, ALIGN BOTH DIMENSIONS.
TORQUE #2-56 NUTS TO 2.5 IN-LB, OR 40 IN-OZ.
2. CONFORMAL COAT OR EPOXY COAT
CAD-PLATED STEEL NUTS.

AMSAT
FOX

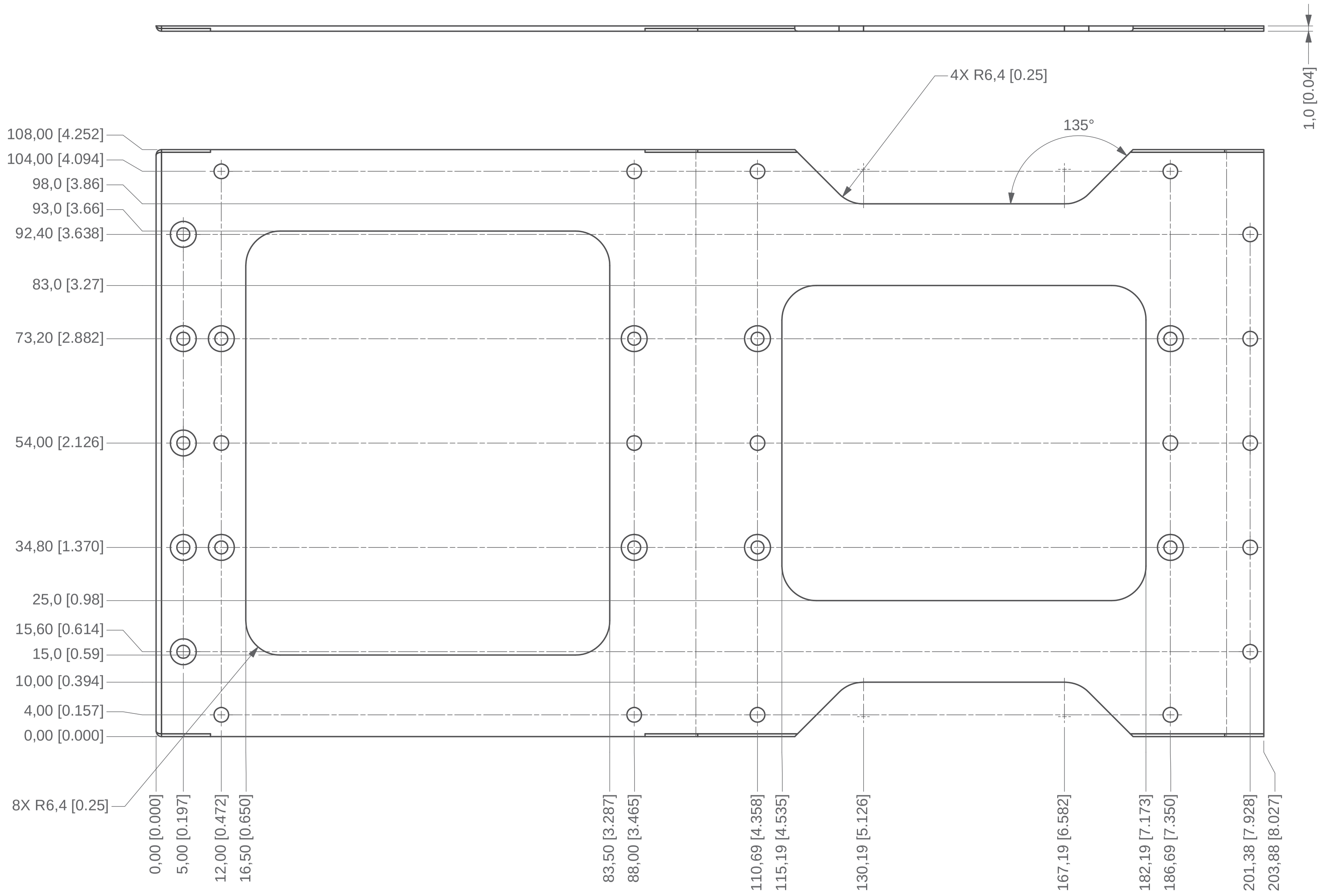
WALLS

SIZE	DATE	DWG.NO.	REV.
A	2013-04-25	FOX-ME-111	0.6
SCALE 1 : 2	UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX± 0,1		SHEET 1 OF 3



NOTES:
3) MATERIAL: ALUMINUM 5052-H32.
4) DO NOT SCUFF.
5) CHEMICAL CONVERSION COAT PER MIL-DTL-5541 CLASS 3, ELECTRICALLY CONDUCTIVE CLEAR.
6) HARD ANODIZE AREAS SHOWN PER MIL-A-8625 TYPE III, CLASS 1, CLEAR.
INCLUDE BEND/ROUND, CONSUMED HOLES AND SHEETMETAL EDGES.

WALLS			
SIZE A	DATE 2013-04-25	DWG.NO. FOX-ME-111	REV. 0.6
SCALE 1 : 2	UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX ± 0,1		SHEET 2 OF 3

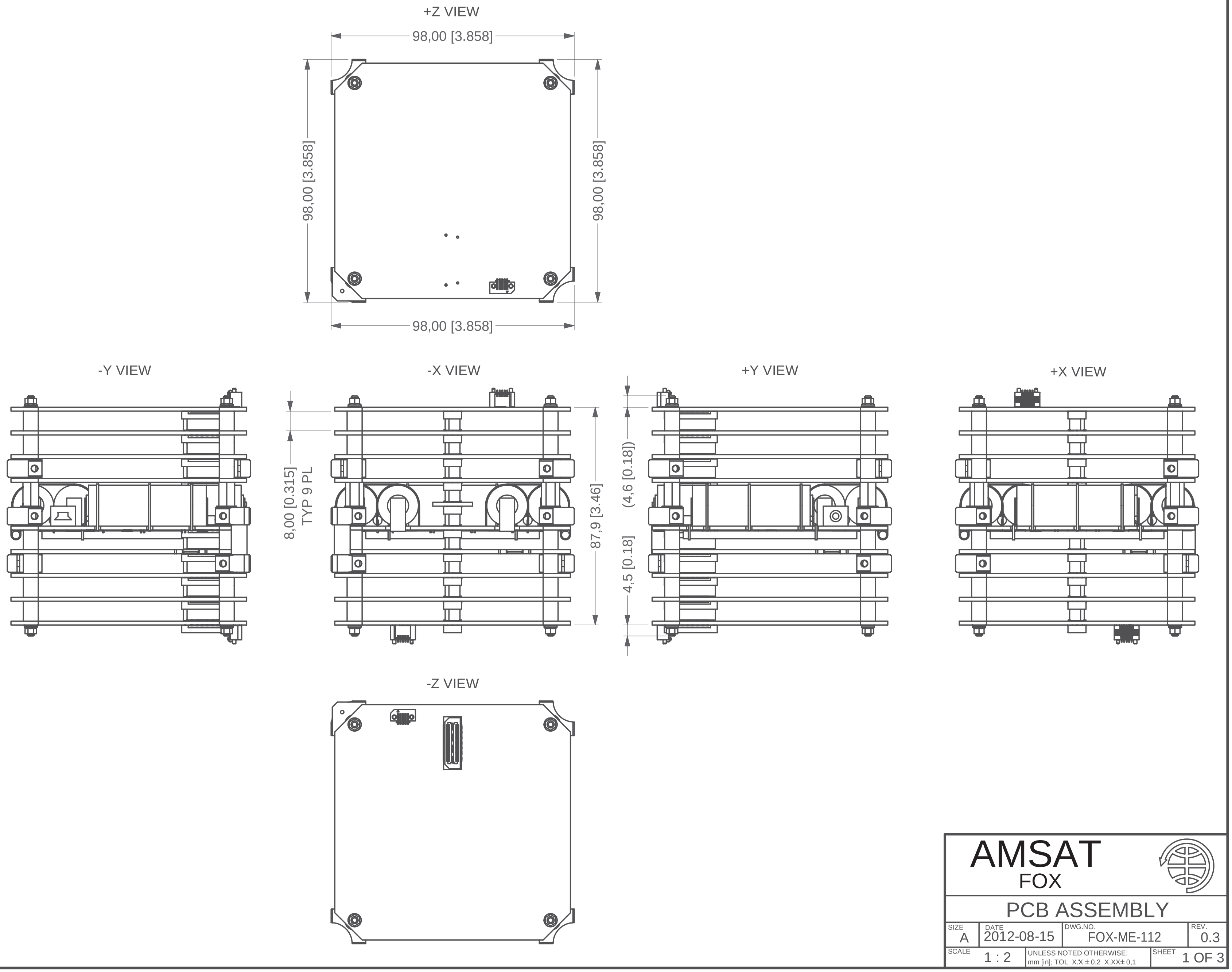


-03 WALLS, FLAT PATTERN

REFERENCE DIMENSIONS
POSITION/TOLERANCE FROM BENDS

WALLS

SIZE A
DATE 2013-04-25
DWG.NO. FOX-ME-111
REV. 0.6
SCALE 1 : 2
UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX ± 0,1
SHEET 3 OF 3



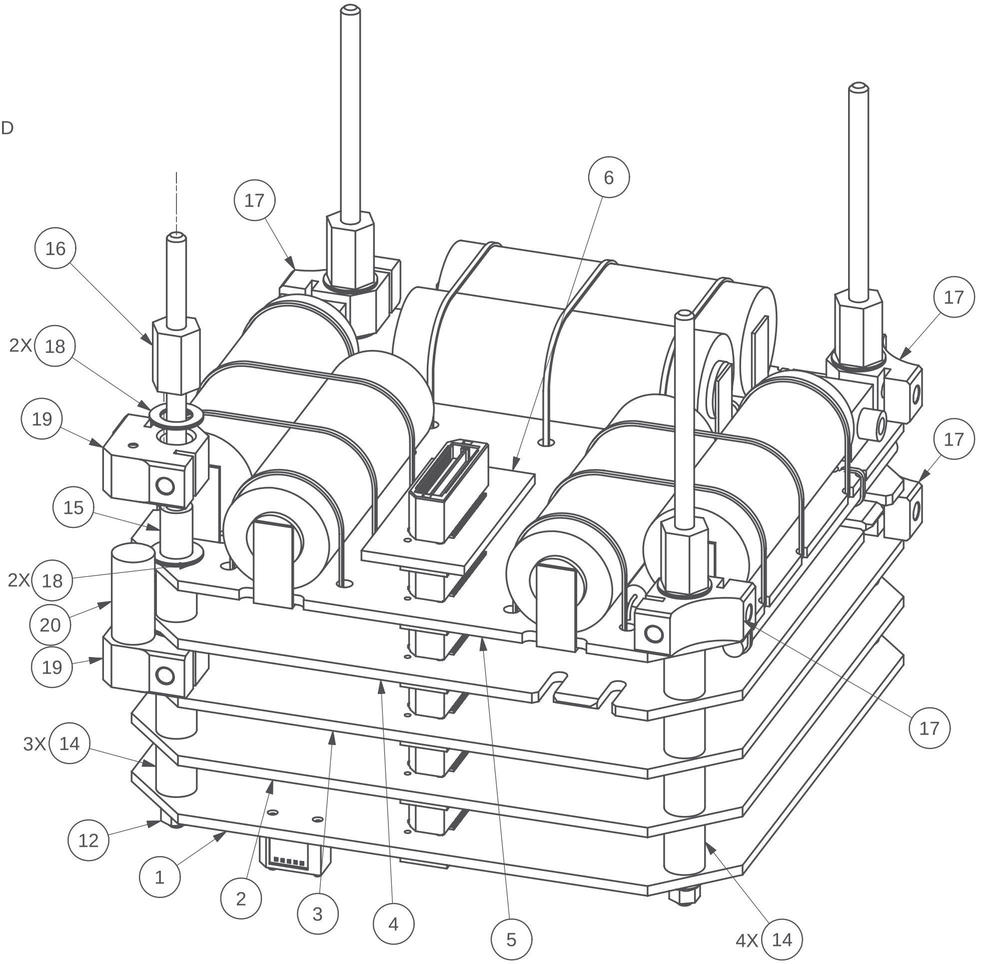
AMSAT
FOX

PCB ASSEMBLY

SIZE	DATE	DWG.NO.	REV.
A	2012-08-15	FOX-ME-112	0.3
SCALE 1 : 2	UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX± 0,1		SHEET 1 OF 3

ASSEMBLY OF AVIONICS PORTION OF PCB STACK

1) LOCATE ITEM 12 ON ITEM 11 TO PROTRUDE 4,5 [0.18] FROM PCB.
2) STACK PCBS ITEMS 1-5 AS SHOWN USING SPACERS ITEMS 14-16.
   CORNER -X-Y RECEIVES MAGNET BETWEEN 2X DELRIN ITEM 19.
   CORNERS -X+Y, +X+Y, +X-Y RECEIVES 2X DELRIN ITEM 17.
   VERTICAL SPACING BETWEEN DELRIN MOUNT SCREWS MAY BE ADJUSTED
   BY MOVING SHIM WASHERS, ITEM 18.
3) TORQUE ITEM 16 TO TBD IN-LB.
4) ITEM 6 MAY BE PLACED BUT HAS NO HARDWARE.



THIS AREA SHOWN EXPLODED
FOR CLARITY OF SPACER INSIDE DELRIN
AND SHIM WASHERS ABOVE AND BELOW.

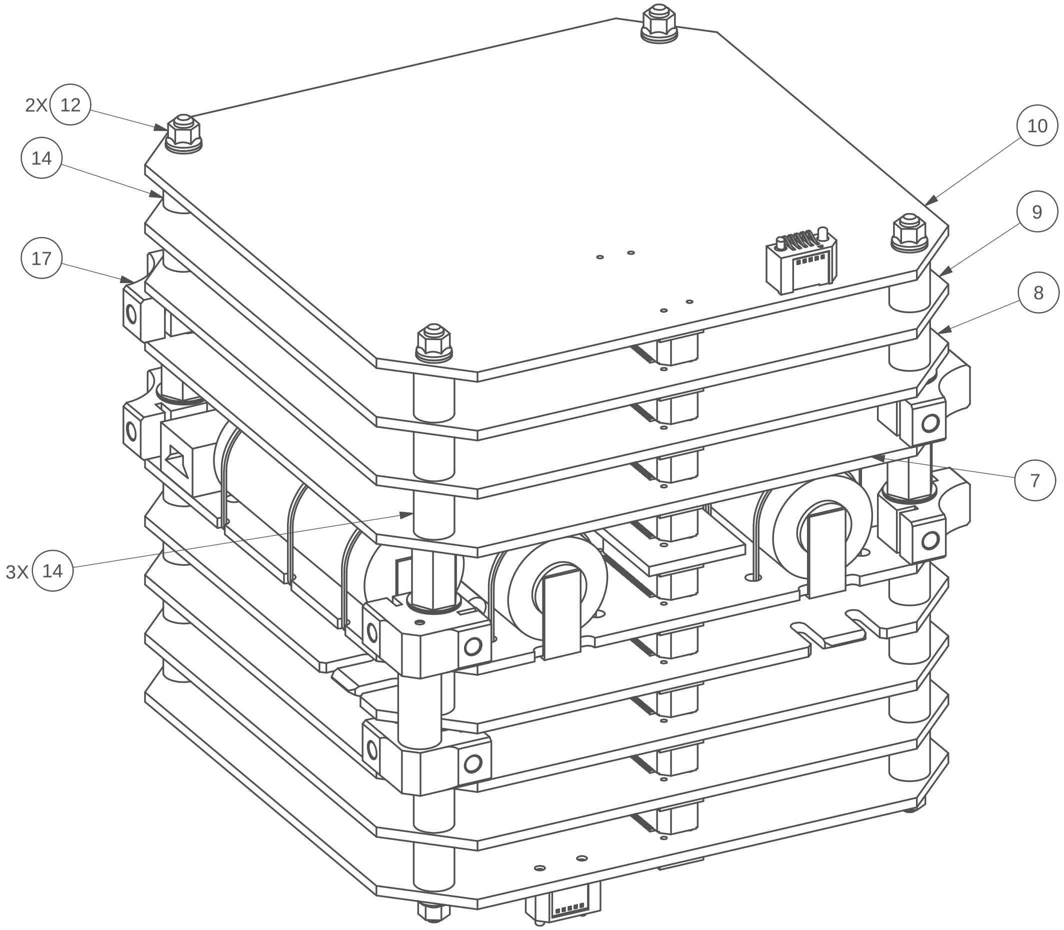
ITEM	QTY	PART NUMBER	DESCRIPTION
20	1	FOX-ME-124	MAGNET
19	2	FOX-ME-118-03	PCB DELRIN MOUNT
18	32	MCMASTER 90792A312	SHIM WASHER, 3/16" ID X 0.010"
17	6	FOX-ME-118-01	PCB DELRIN MOUNT
16	4	FOX-ME-117-05	AL THREADED SPACER
15	8	FOX-ME-117-03	CU SPACER FOR DELRIN
14	24	FOX-ME-117-01	AL SPACER
13	8	NAS620-C4L / MCMASTER-CARR 90945A710	WASHER, #4 THIN
12	8	MS21042-04	LOCKING NUT, #4-40
11	4	FOX-ME-123	THREADED ROD
10	1	FOX-ME-113-10	EXPERIMENT #4 PCB
9	1	FOX-ME-113-09	EXPERIMENT #3 PCB
8	1	FOX-ME-113-08	EXPERIMENT #2 PCB
7	1	FOX-ME-113-07	EXPERIMENT #1 PCB
6	1	FOX-ME-113-06	BATTERY #2 PCB
5	1	FOX-ME-113-05	BATTERY #1
4	1	FOX-ME-113-04	PSU PCB
3	1	FOX-ME-113-03	IHU PCB
2	1	FOX-ME-113-02	RX PCB
1	1	FOX-ME-113-01	TX PCB

Parts List

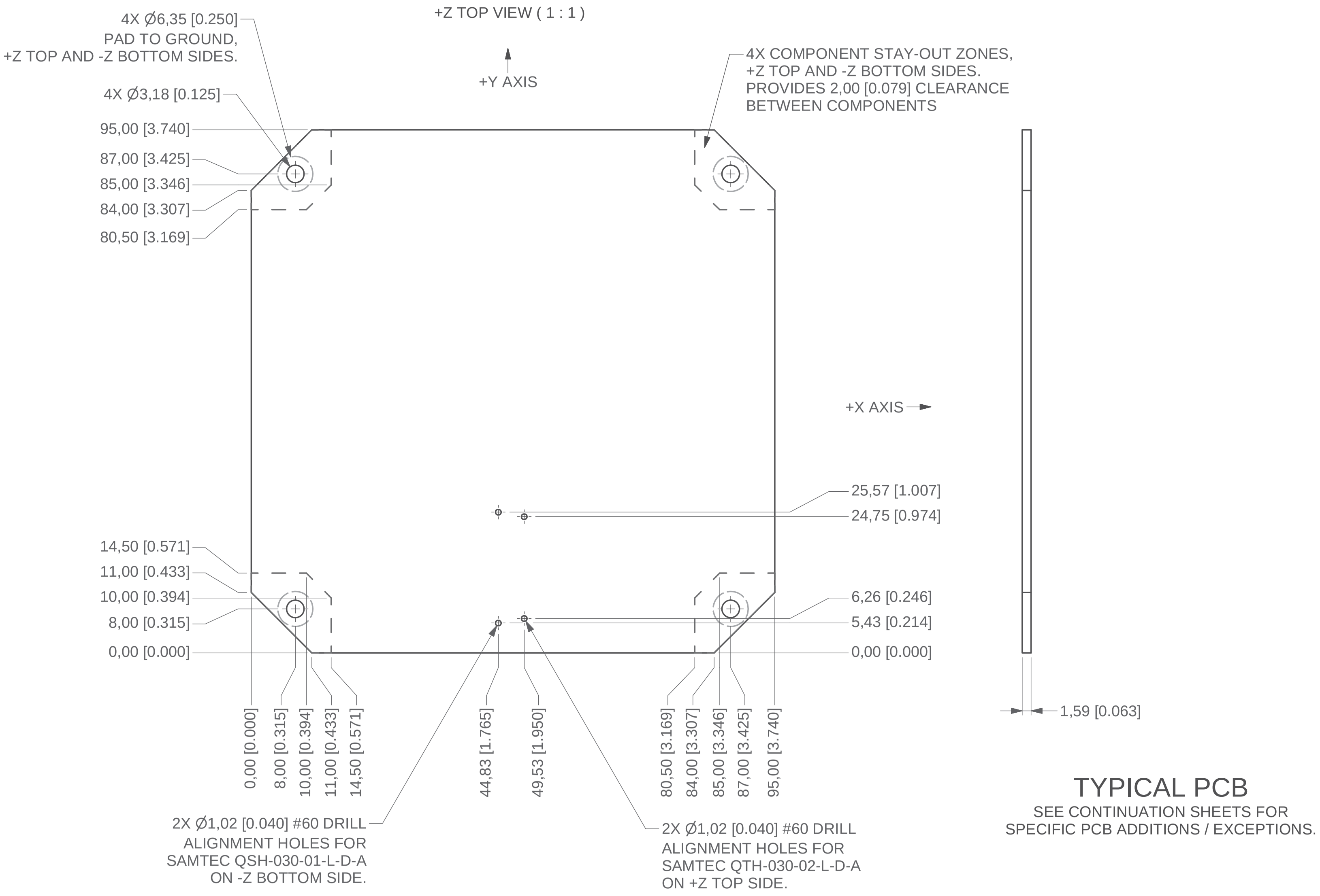
PCB ASSEMBLY			
SIZE A	DATE 2012-08-15	DWG.NO. FOX-ME-112	REV. 0.3
SCALE 1 : 1	UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX ± 0,1		SHEET 2 OF 3

ASSEMBLY OF AVIONICS PORTION OF PCB STACK

5) STACK PCBS ITEMS 7-10 AS SHOWN USING SPACERS ITEMS 14-16.
SPACING BETWEEN DELRIN MOUNT SCREWS MAY BE ADJUSTED
BY MOVING SHIM WASHERS, ITEM 18.
6) TORQUE ITEM 16 TO TBD IN-LB.
7) VERIFY PROTRUSION OF THREADED ROD IS SAME TOP/BOTTOM +/- 1,0 [0.04].



PCB ASSEMBLY
SIZE A
DATE 2012-08-15
DWG.NO. FOX-ME-112
REV. 0.3
SCALE 1 : 1
UNLESS NOTED OTHERWISE:
mm [in]; TOL X.X ± 0,2 X.XX ± 0,1
SHEET 3 OF 3



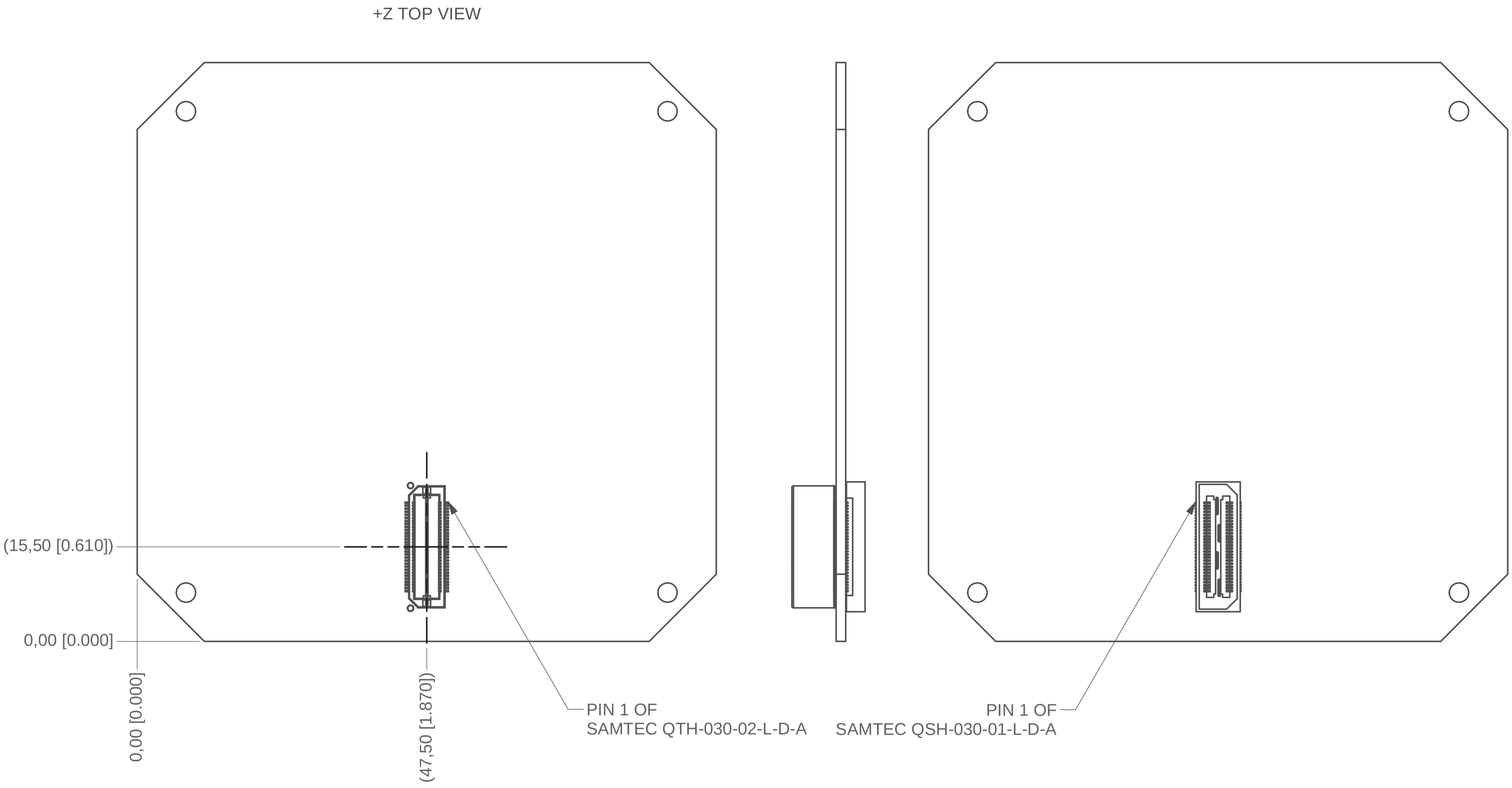
TYPICAL PCB

SEE CONTINUATION SHEETS FOR
SPECIFIC PCB ADDITIONS / EXCEPTIONS.

AMSAT
FOX

PCB

SIZE	DATE	DWG.NO.	REV.
A	2013-07-19	FOX-ME-113	0.8
SCALE 1 : 1		UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX± 0,1	SHEET 1 OF 11

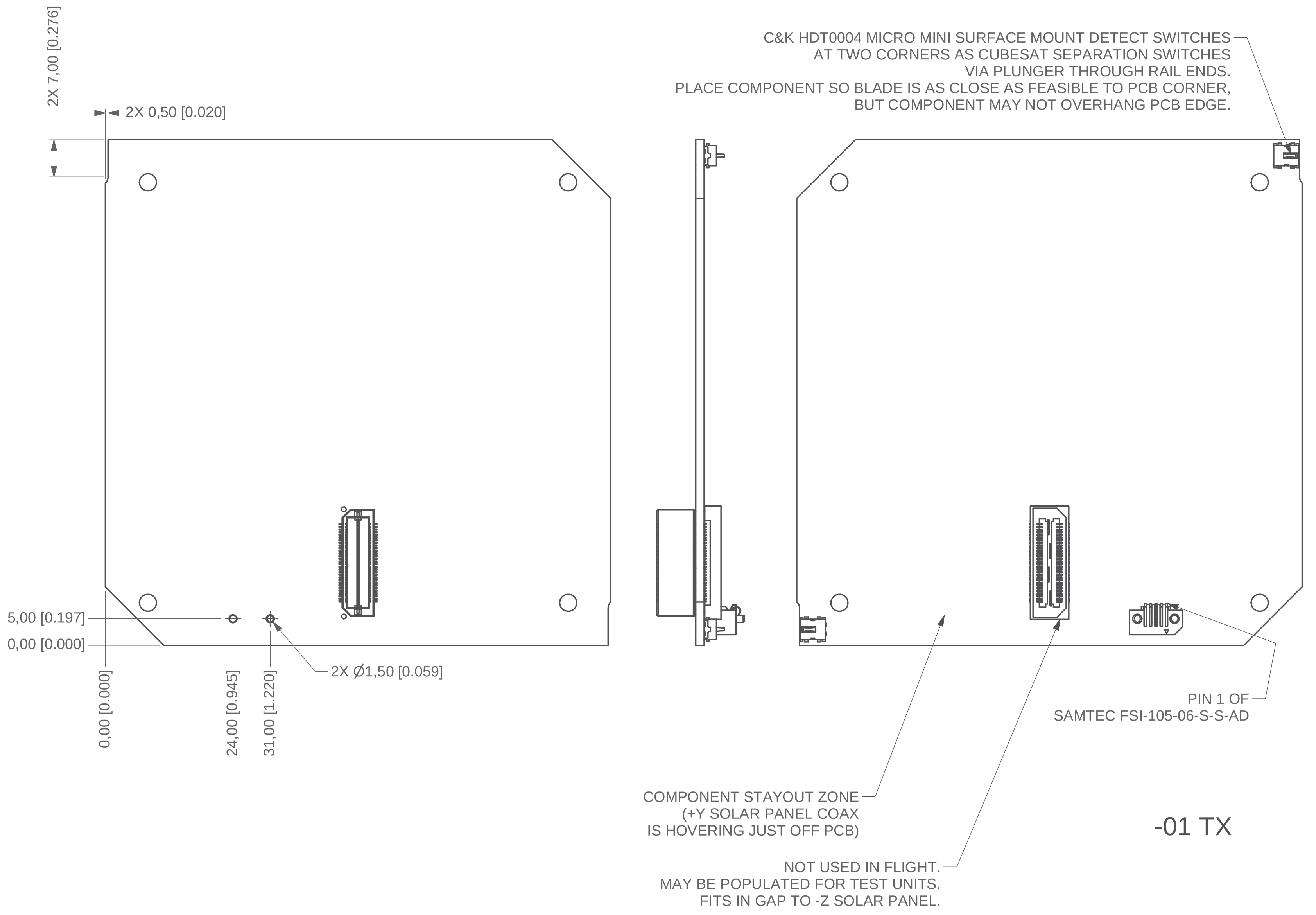


TYPICAL CONNECTORS

SEE CONTINUATION SHEETS FOR
SPECIFIC PCB ADDITIONS / EXCEPTIONS.

PCB

SIZE A	DATE 2013-07-19	DWG.NO. FOX-ME-113	REV. 0.8
SCALE	1 : 1	UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX ± 0,1	SHEET 2 OF 11



C&K HDT0004 MICRO MINI SURFACE MOUNT DETECT SWITCHES
AT TWO CORNERS AS CUBESAT SEPARATION SWITCHES
VIA PLUNGER THROUGH RAIL ENDS.
PLACE COMPONENT SO BLADE IS AS CLOSE AS FEASIBLE TO PCB CORNER,
BUT COMPONENT MAY NOT OVERHANG PCB EDGE.

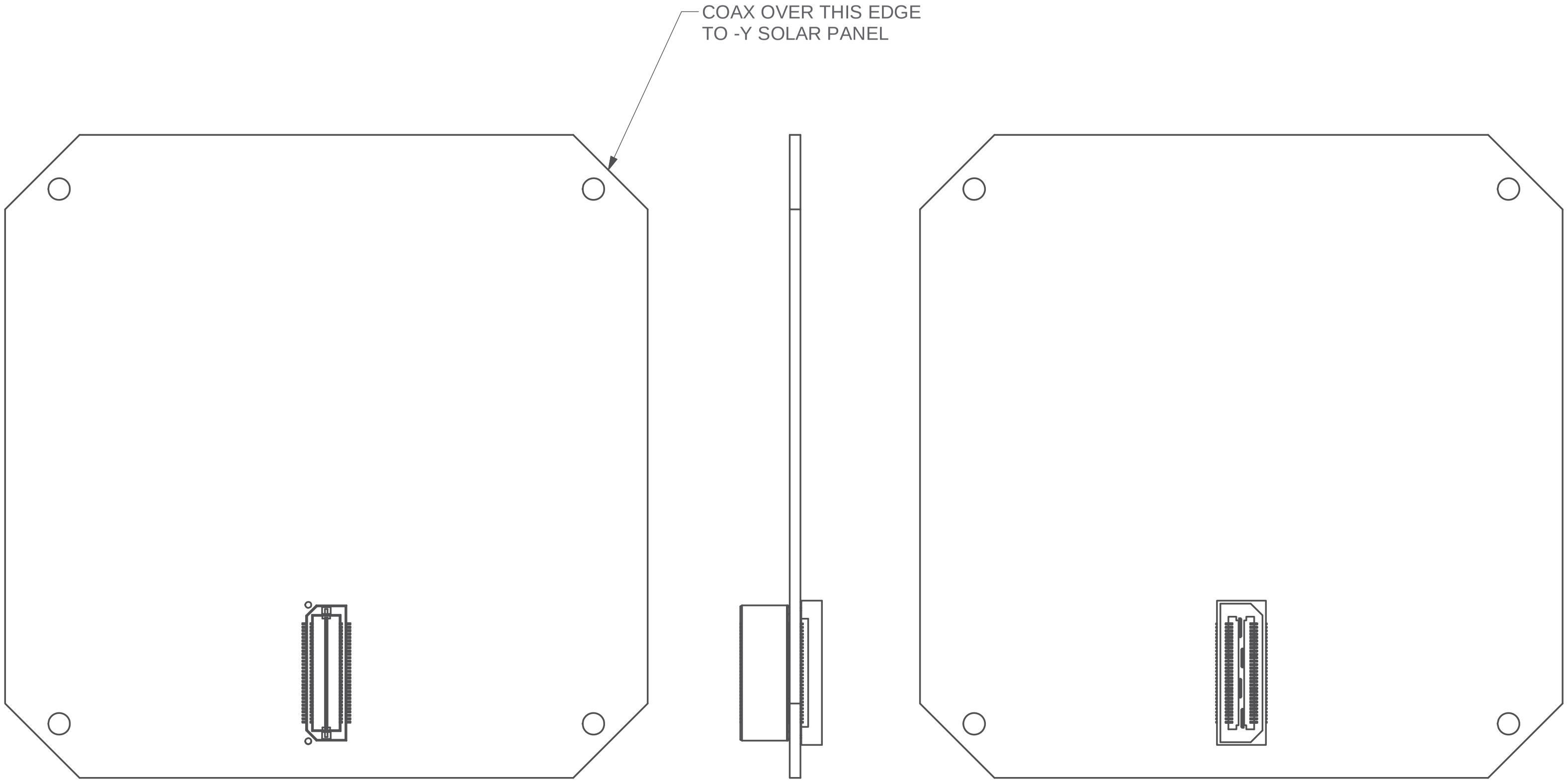
PIN 1 OF
SAMTEC FSI-105-06-S-S-AD

COMPONENT STAYOUT ZONE
(+Y SOLAR PANEL COAX
IS HOVERING JUST OFF PCB)

NOT USED IN FLIGHT.
MAY BE POPULATED FOR TEST UNITS.
FITS IN GAP TO -Z SOLAR PANEL.

-01 TX

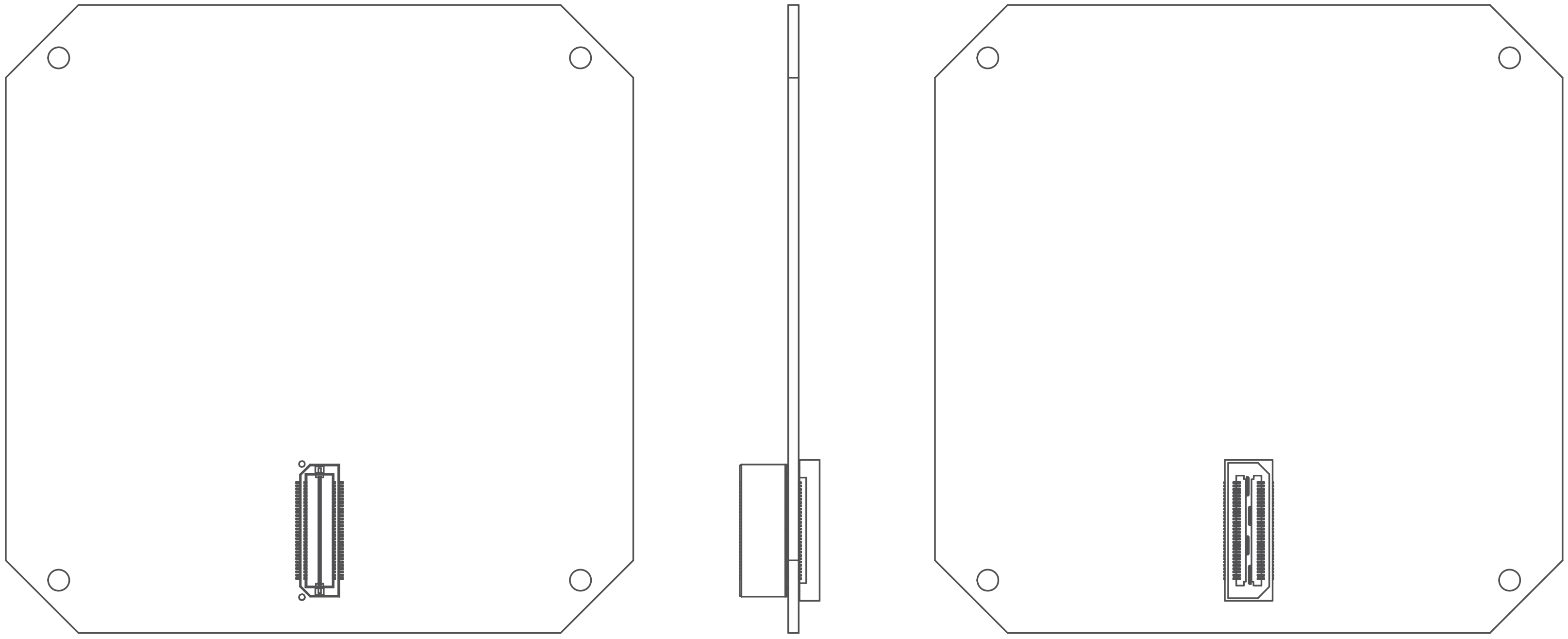
PCB			
SIZE A	DATE 2013-07-19	DWG.NO. FOX-ME-113	REV. 0.8
SCALE	1 : 1	UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX ± 0,1	SHEET 3 OF 11



-02 RX

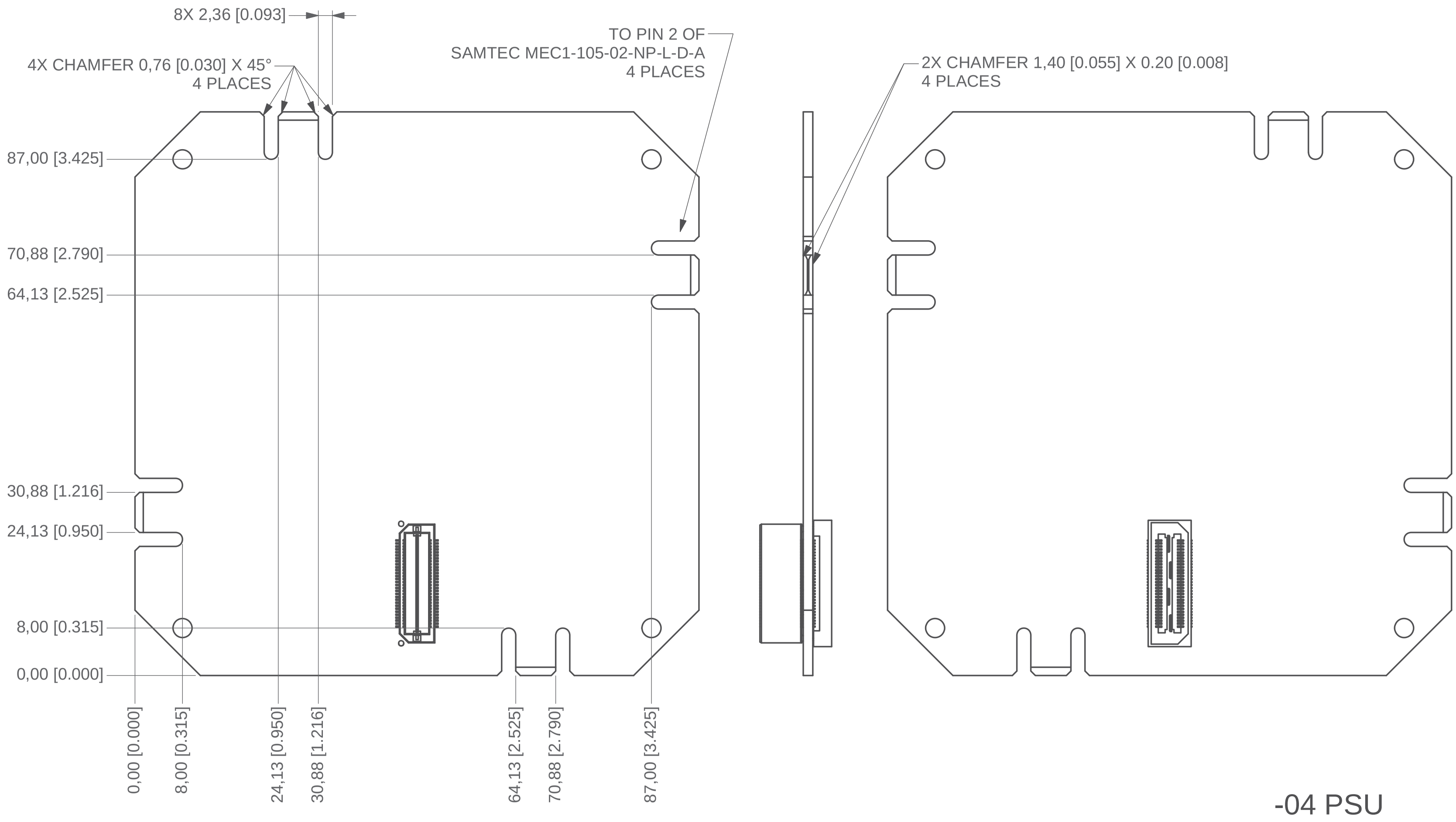
PCB

SIZE A	DATE 2013-07-19	DWG.NO. FOX-ME-113	REV. 0.8
SCALE 1 : 1	UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX ± 0,1		SHEET 4 OF 11

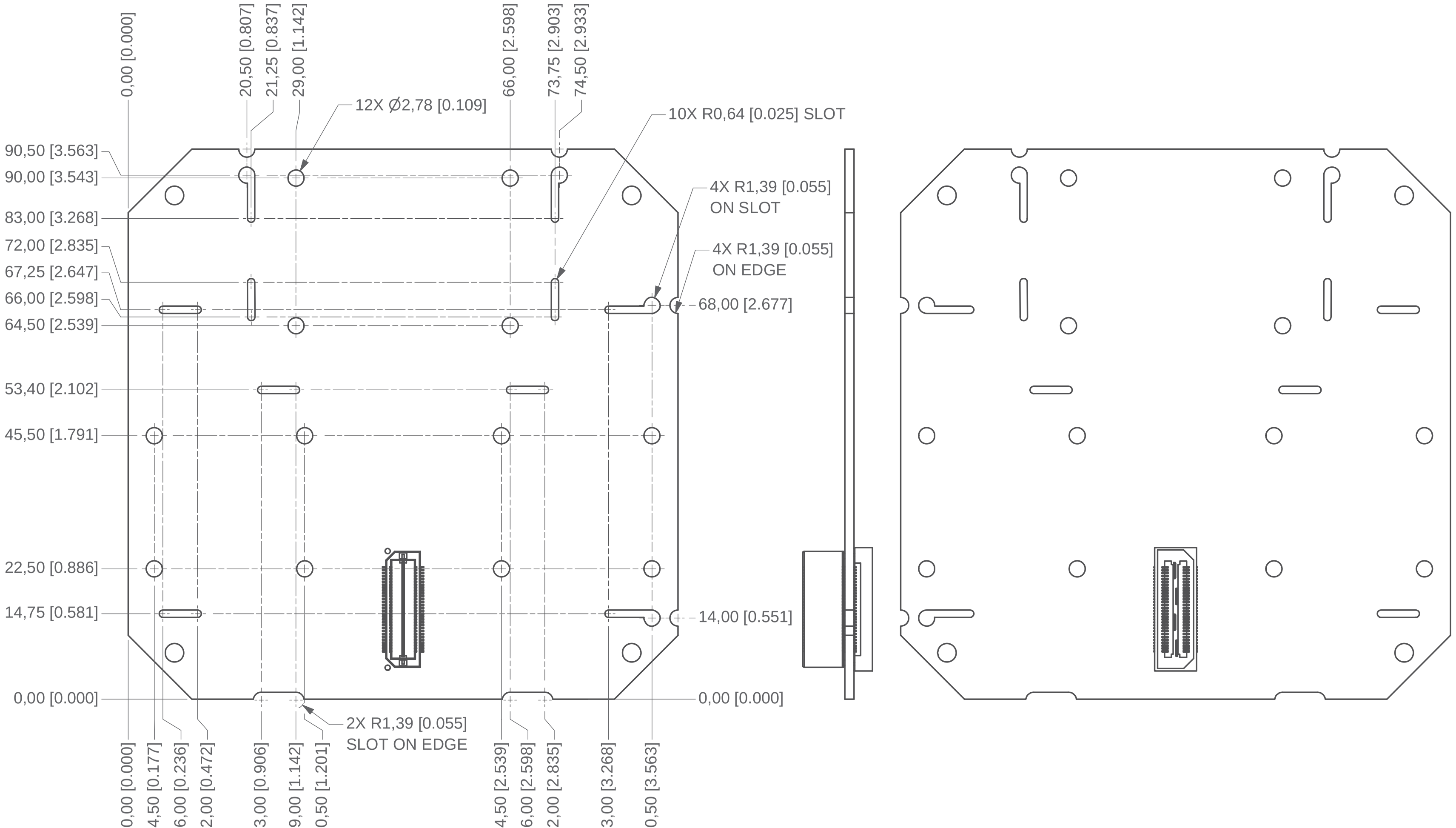


-03 IHU

PCB			
SIZE A	DATE 2013-07-19	DWG.NO. FOX-ME-113	REV. 0.8
SCALE 1 : 1	UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX ± 0,1	SHEET 5 OF 11	

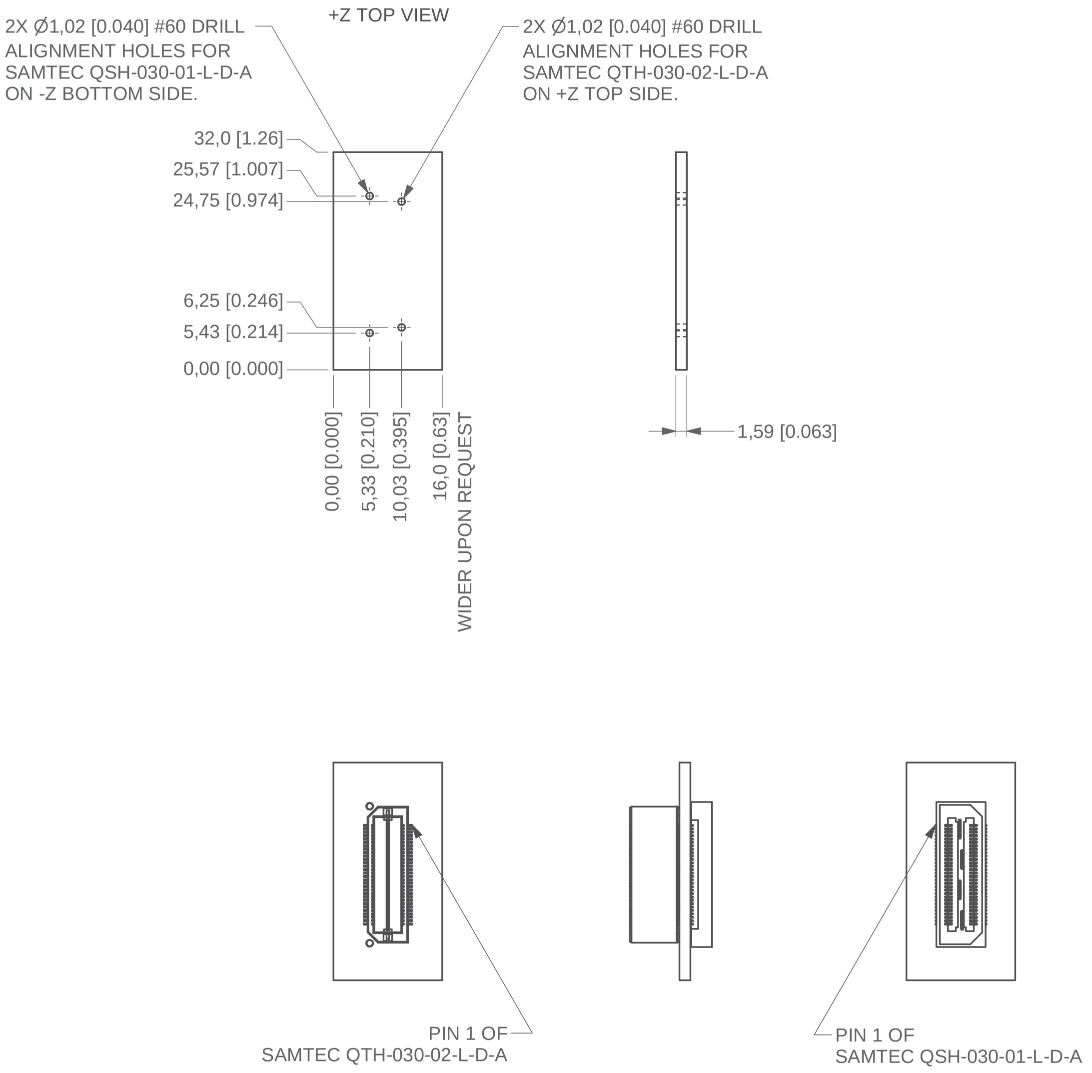


PCB			
SIZE A	DATE 2013-07-19	DWG.NO. FOX-ME-113	REV. 0.8
SCALE 1 : 1	UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX ± 0,1		SHEET 6 OF 11



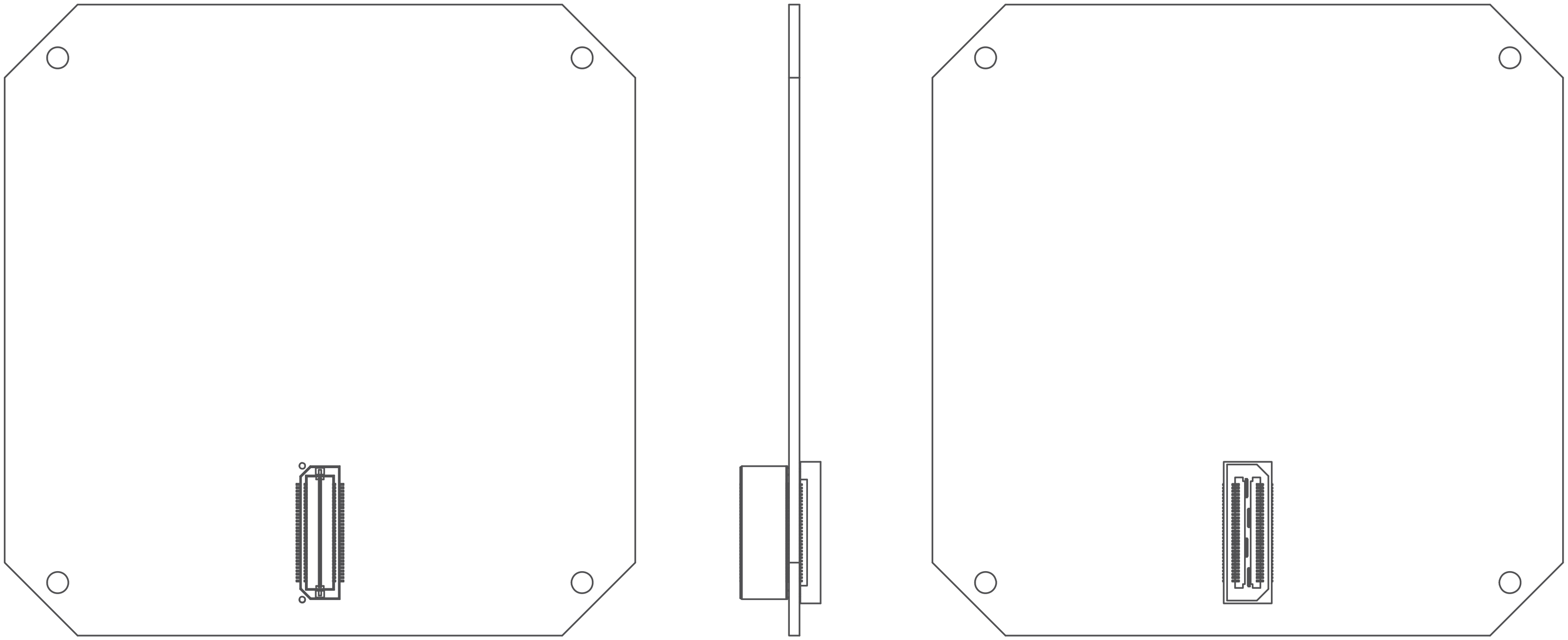
-05 BATTERY #1

PCB			
SIZE A	DATE 2013-07-19	DWG.NO. FOX-ME-113	REV. 0.8
SCALE 1 : 1	UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX ± 0,1		SHEET 7 OF 11



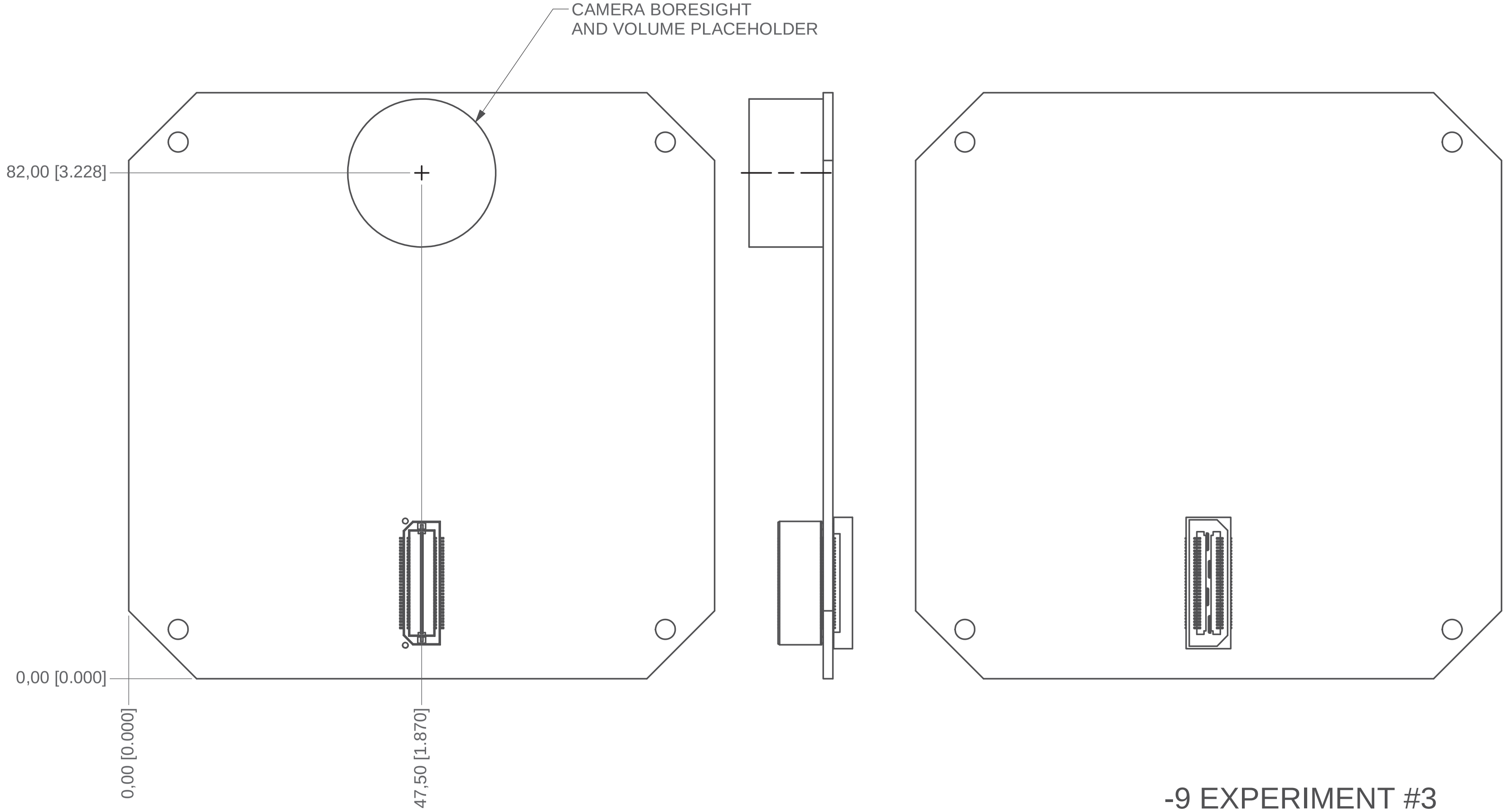
-06 BATTERY #2

PCB			
SIZE A	DATE 2013-07-19	DWG.NO. FOX-ME-113	REV. 0.8
SCALE 1 : 1	UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX ± 0,1		SHEET 8 OF 11



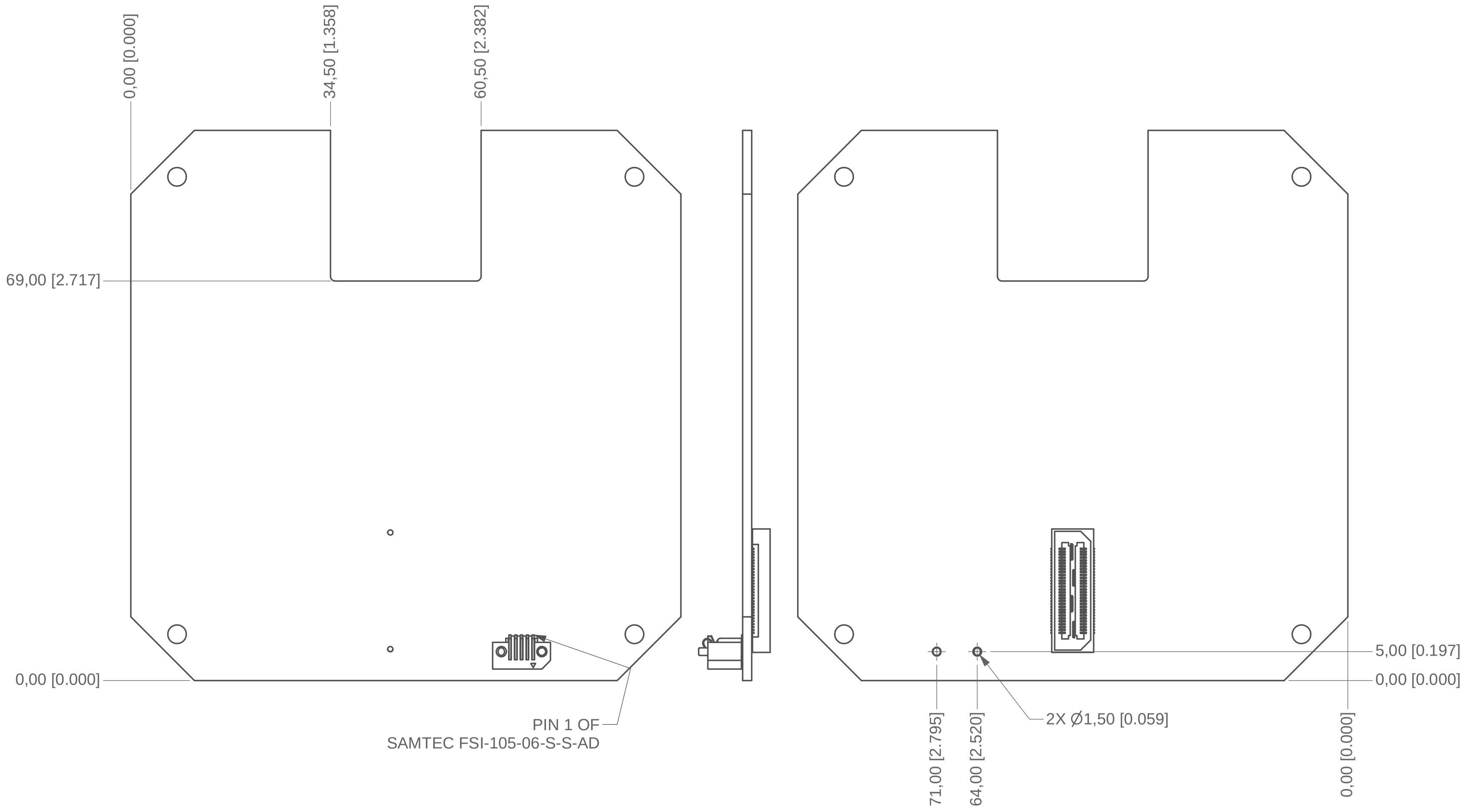
-07 EXPERIMENT #1
-08 EXPERIMENT #2

PCB			
SIZE A	DATE 2013-07-19	DWG.NO. FOX-ME-113	REV. 0.8
SCALE 1 : 1	UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX ± 0,1		SHEET 9 OF 11



-9 EXPERIMENT #3

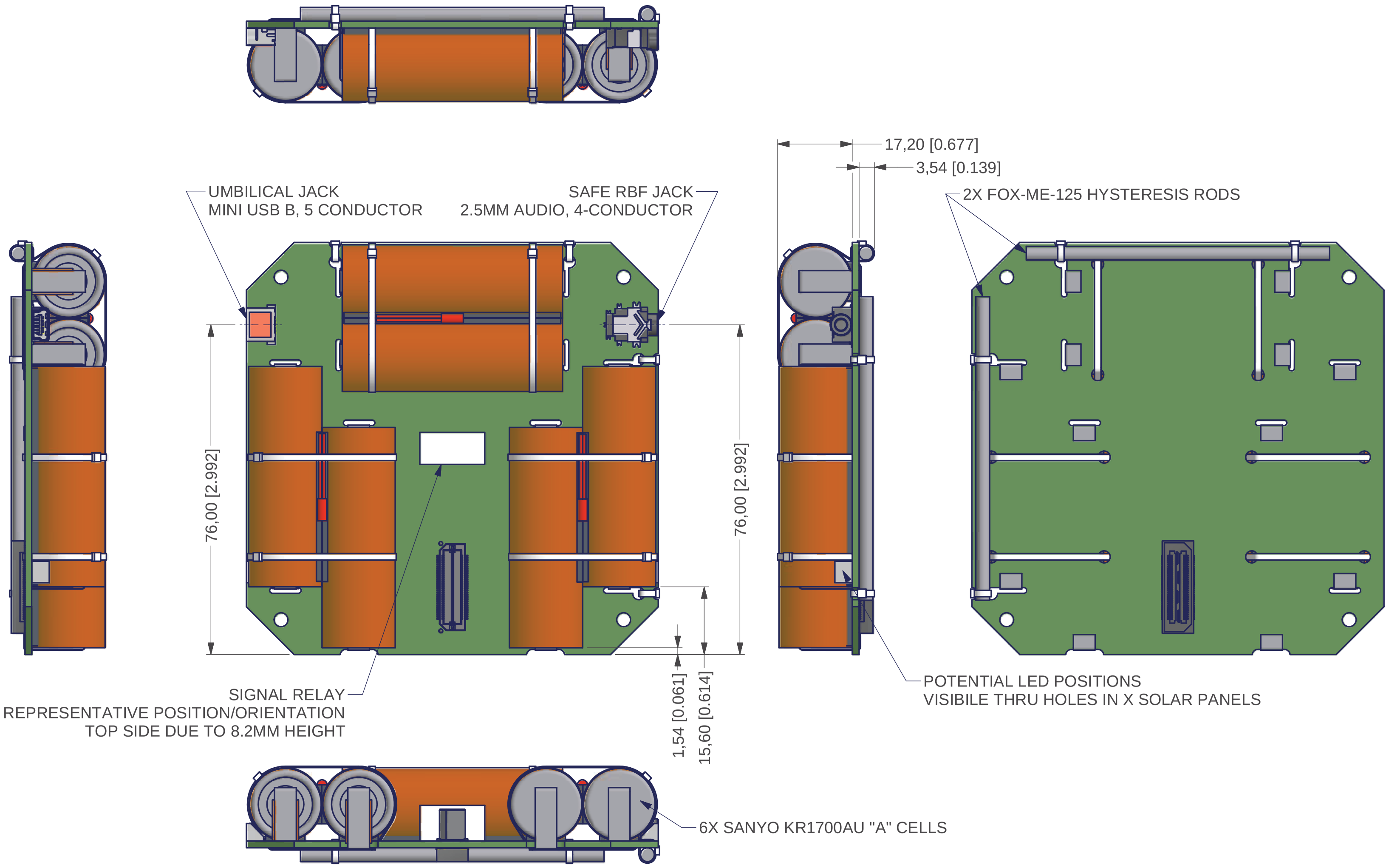
PCB			
SIZE A	DATE 2013-07-19	DWG.NO. FOX-ME-113	REV. 0.8
SCALE 1 : 1	UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX ± 0,1		SHEET 10 OF 11



HOLES MAY BE ADDED AROUND PERIMETER OF PCB
FOR BALLAST MASSES

-10 EXPERIMENT #4

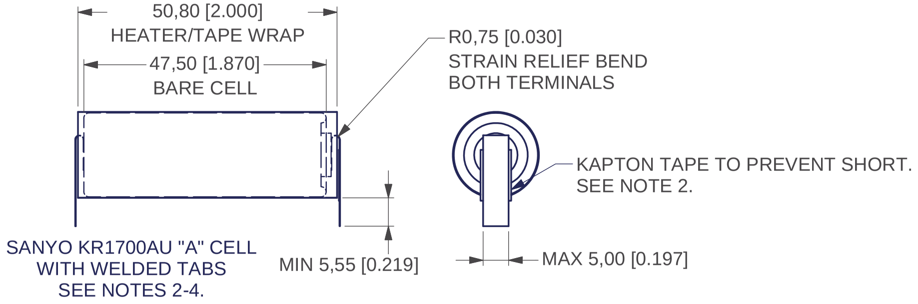
PCB			
SIZE A	DATE 2013-07-19	DWG.NO. FOX-ME-113	REV. 0.8
SCALE 1 : 1		UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX ± 0,1	SHEET 11 OF 11

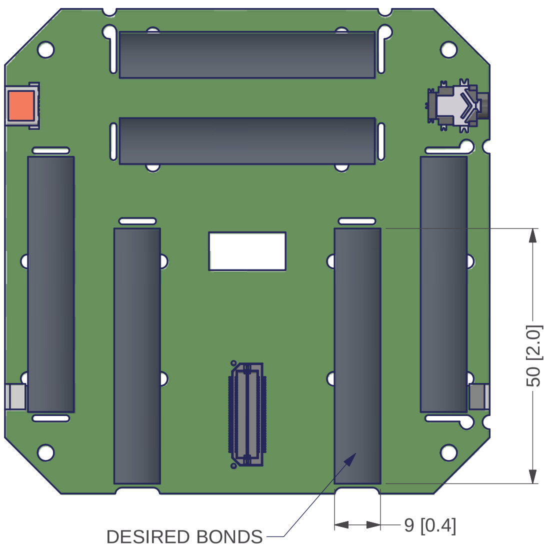


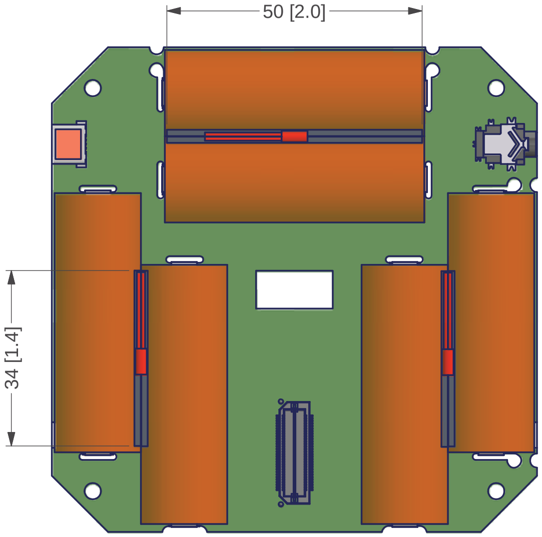
AMSAT
FOX

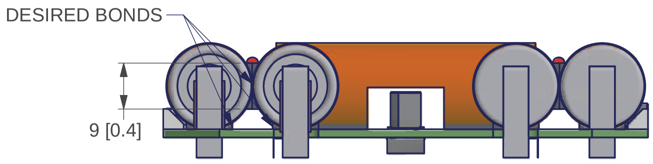
BATTERY ASSEMBLY

SIZE A
DATE 2013-09-11
DWG.NO. FOX-ME-114
REV. 0.3
SCALE 3 : 4
UNLESS NOTED OTHERWISE:
mm [in]; TOL X.X ± 0,2 X.XX± 0,1
SHEET 1 OF 4



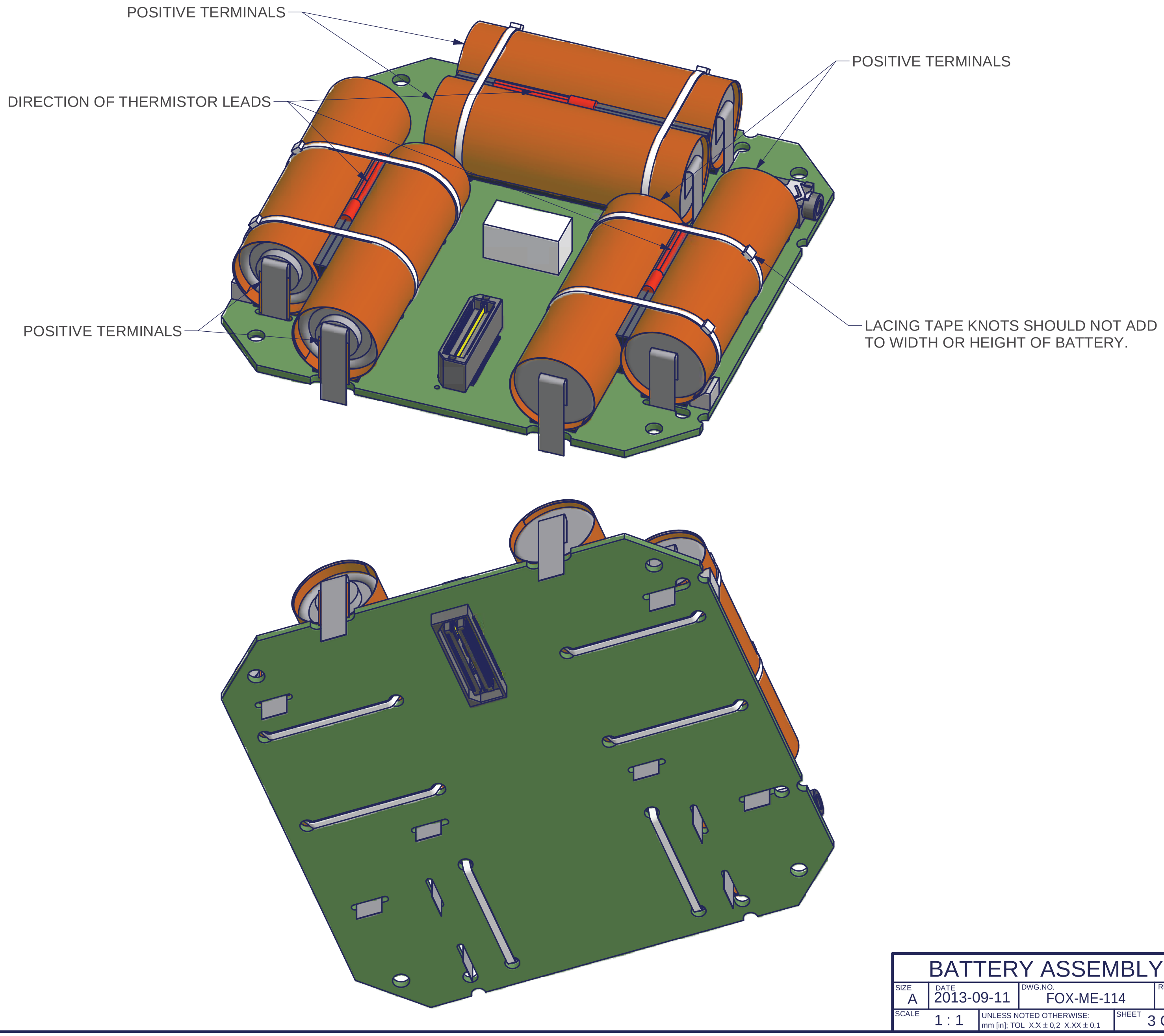






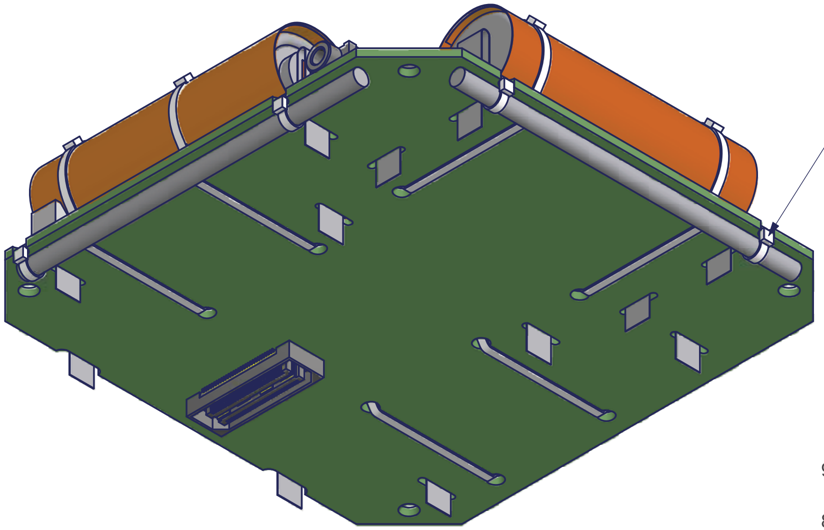
NOTES:
1) SOLDER REFLOW COMPONENTS ON PCB BEFORE BONDING BATTERIES.
2) DO NOT BEND BATTERY TABS UNDER PCB UNTIL ASSEMBLY SOLDER STEP.
3) REMOVE MANUFACTURER'S SHRINK-WRAP LABEL.
   APPLY KAPTON TAPE TO POSITIVE TAB TO PREVENT SHORTING TO CASE AFTER BENDING.
   CAUTION: TERMINAL SHORTING HAZARD. REMOVE COMPOSITE WASHER ON POSITIVE END.
   BEND BOTH TABS 180° FOR STRAIGHT RELIEF.
   WIPE WITH ISOPROPYL ALCOHOL.
4) APPLY KAPTON HEATER OMEGA KHLV-102/5-P. WRAPS APPROX 1/2 OF SURFACE AREA.
   DO NOT APPLY BETWEEN CELLS OR BETWEEN CELLS AND PCB.
   CLOCKING AROUND PERIMETER TBD. ORIENTATION OF LEADS TBD.
5) WRAP CELL WITH 1 LAYER OF 2 INCH WIDE 1 MIL PERMACEL P224 KAPTON POLYIMIDE TAPE WITH ACRYLIC ADHESIVE.
6) PREPARE KAPTON WRAPPED SURFACE OF CELL FOR BONDING BY ACETONE SOLVENT CLEANING.
7) USE HYSOL/LOCTITE EPOXI-PATCH 9340 TO BOND PAIRS OF CELLS, AND CELLS TO PCB. WET BOTH MATING SURFACES.
   SECURE WITH LACTING TAPE BREYDEN 104-3 IF POT LIFE PERMITS, OTHERWISE USE TEMPORARY 0.032" WIDE X 4" LONG ZIP TIES.
   KEEP HOLES CLEAR OF EPOXY.
   PRESS LEADED THERMISTOR INTO EPXOY. DIRECTION OF LEADS AS SHOWN.
   CURE ROOM TEMPERATURE FOR 24 HOURS, OR 50°C (122°F) FOR 6 HOURS.

BATTERY ASSEMBLY			
SIZE A	DATE 2013-09-11	DWG.NO. FOX-ME-114	REV. 0.3
SCALE 3 : 4	UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX ± 0,1		SHEET 2 OF 4

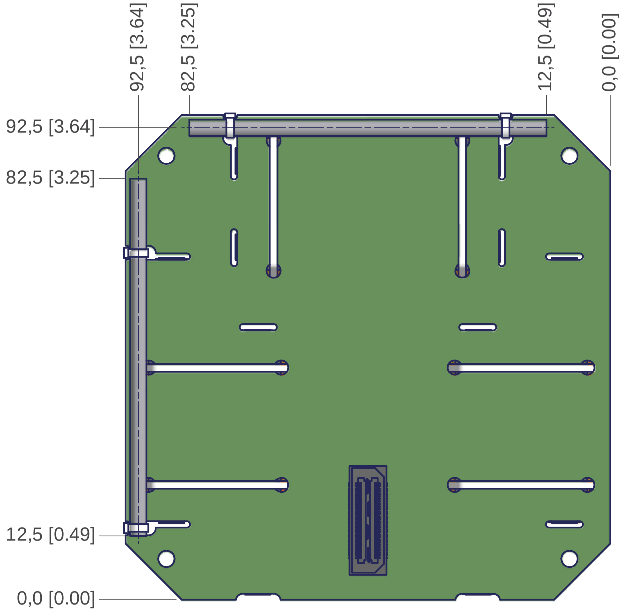


BATTERY ASSEMBLY

SIZE	DATE	DWG.NO.	REV.
A	2013-09-11	FOX-ME-114	0.3
SCALE 1 : 1	UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX ± 0,1		SHEET 3 OF 4



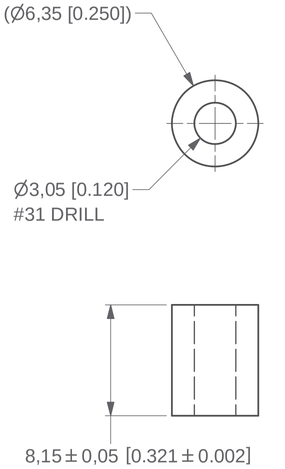
LACING TAPE KNOTS SHOULD NOT ADD TO HEIGHT OR WIDTH.

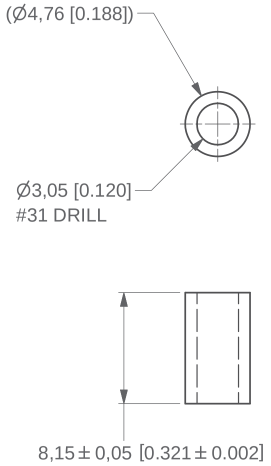


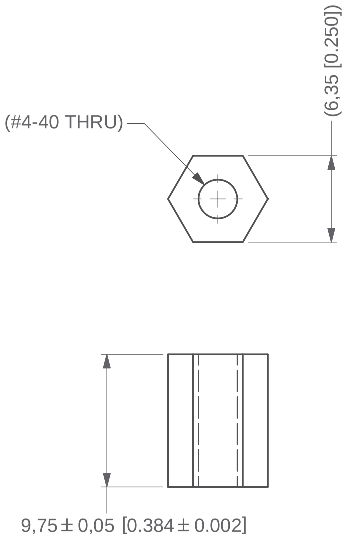
NOTES:
8) WRAP PERIMETER OF 2X FOX-ME-125 HYSTERESIS RODS WITH 1 LAYER OF 1 MIL PERMACEL P224 KAPTON POLYIMIDE TAPE WITH ACRYLIC ADHESIVE.
9) PREPARE KAPTON WRAPPED SURFACE OF RODS FOR BONDING BY ACETONE SOLVENT CLEANING.
10) BOND RODS USING HYSOL/LOCTITE EPOXI-PATCH 9340. SECURE WITH BREYDEN 204-3 LACING TAPE.
PLACE KNOT TO PREVENT INCREASING HEIGHT ABOVE PCB.
CURE ROOM TEMPERATURE FOR 24 HOURS, OR 50°C (122°F) FOR 6 HOURS.
11) SECURE ALL KNOTS WITH TBD URALANE.

BATTERY ASSEMBLY

SIZE A
DATE 2013-09-11
DWG.NO. FOX-ME-114
REV. 0.3
SCALE VARIES
UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX ± 0,1
SHEET 4 OF 4







-01 AL SPACER

MAT'L: ALUMINUM 6061-T6
MAKE FROM MCMASTER-CARR 8974K31 ROD.
CHEMICAL CONVERSION COAT PER MIL-C-5541
CLASS 3, ELECTRICALLY CONDUCTIVE CLEAR.

-07 DELRIN SPACER

MAT'L: BLACK DELRIN
MAKE FROM MCMASTER-CARR 8576K11 ROD.

-03 CU SPACER FOR MOUNT

MAT'L: COPPER ALLOY 110 H04 (HARD)
MAKE FROM MCMASTER-CARR 8966K88 ROD.
GOLD PLATE.

-09 DELRIN SPACER FOR MOUNT

MAT'L: BLACK DELRIN
MAKE FROM MCMASTER-CARR 8576K11 ROD.

-05 AL THREADED SPACER

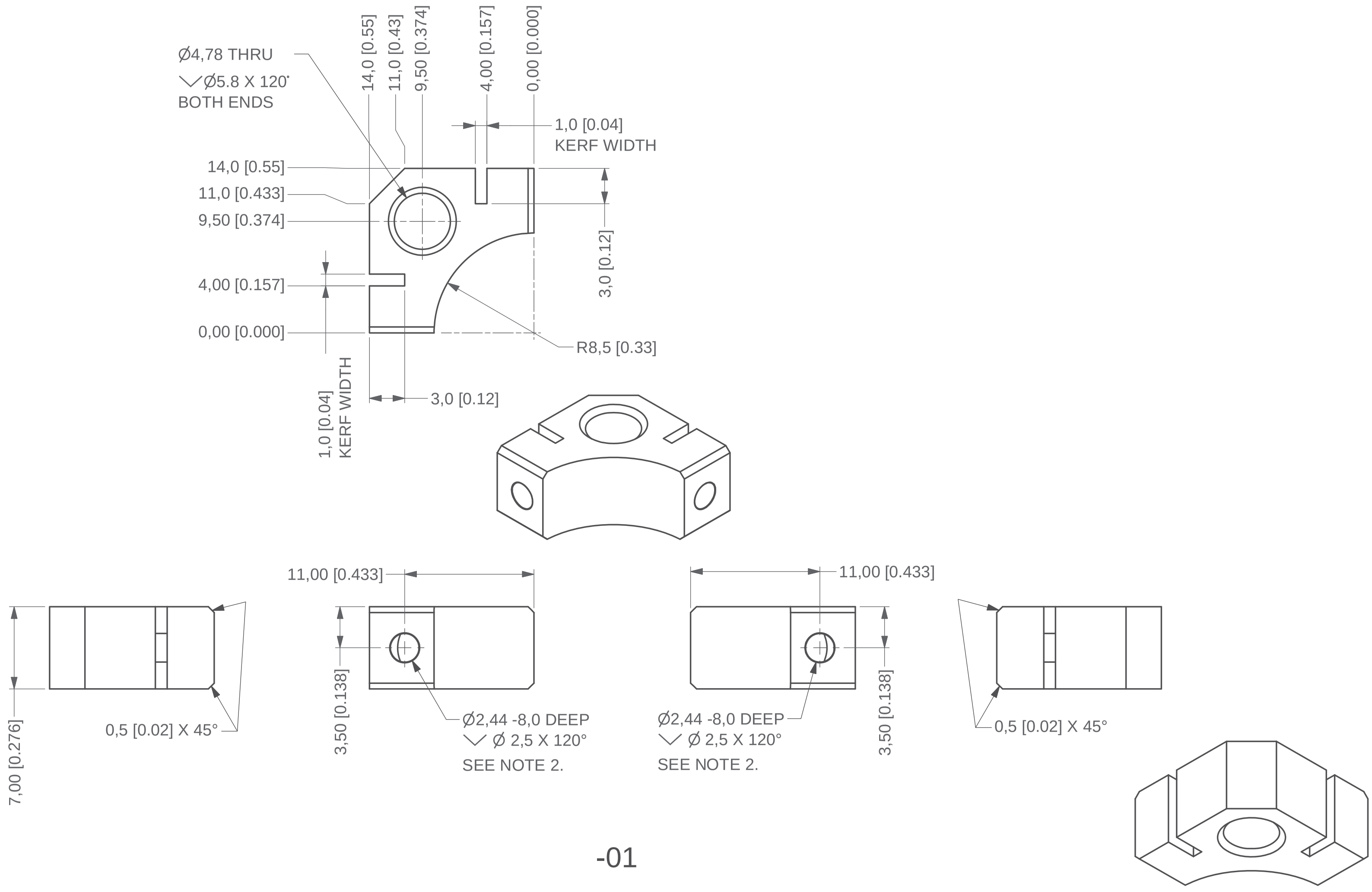
MAT'L: ALUMINUM 6061-T6
MAKE FROM MCMASTER-CARR 91780A427 STANDOFF.
CHEMICAL CONVERSION COAT PER MIL-C-5541
CLASS 3, ELECTRICALLY CONDUCTIVE CLEAR.

AMSAT
FOX

PCB SPACER

SIZE	DATE	DWG.NO.	REV.
A	2013-08-24	FOX-ME-117	0.5

SCALE	UNLESS NOTED OTHERWISE:	SHEET
2 : 1	mm [in]; TOL X.X ± 0,2 X.XX± 0,1	1 OF 1

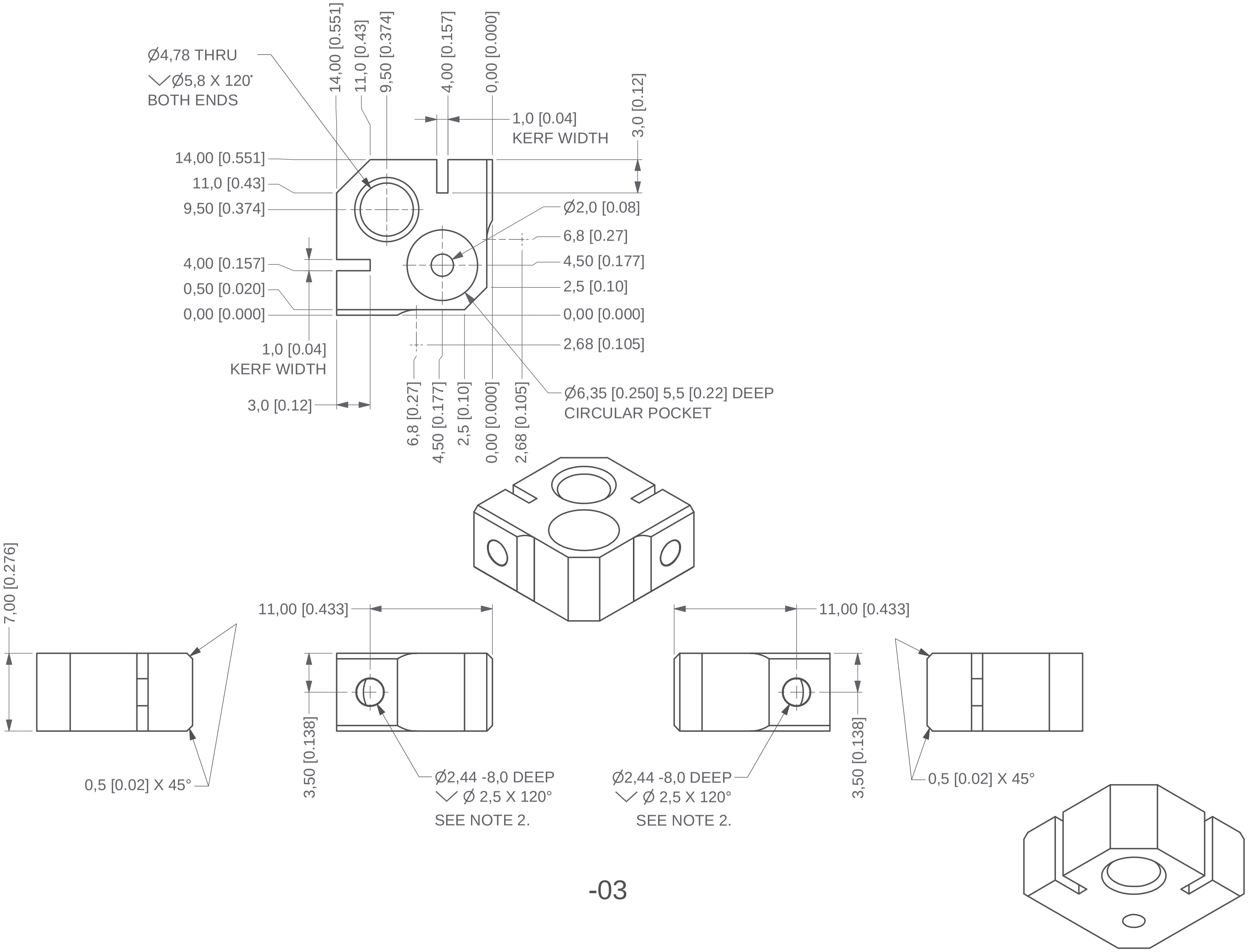


NOTES:
1) MATERIAL: BLACK DELRIN
2) STI TAP #2-56 MIN ↧4,0 [0.16] , USING HELICOIL BOTTOMING TAP 02CBB.
INSTALL HELICOIL #2-56 X 1 DIA 3585-02CN0086,
USING HELICOIL INSTALLATION TOOL 551-02.
REMOVE TANG USING HELICOIL TANG-BREAKOFF TOOL 3695-02.

AMSAT
FOX

PCB DELRIN MOUNT

SIZE	DATE	DWG.NO.	REV.
A	2013-03-27	FOX-ME-118	0.6
SCALE 2 : 1	UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX± 0,1		SHEET 1 OF 2



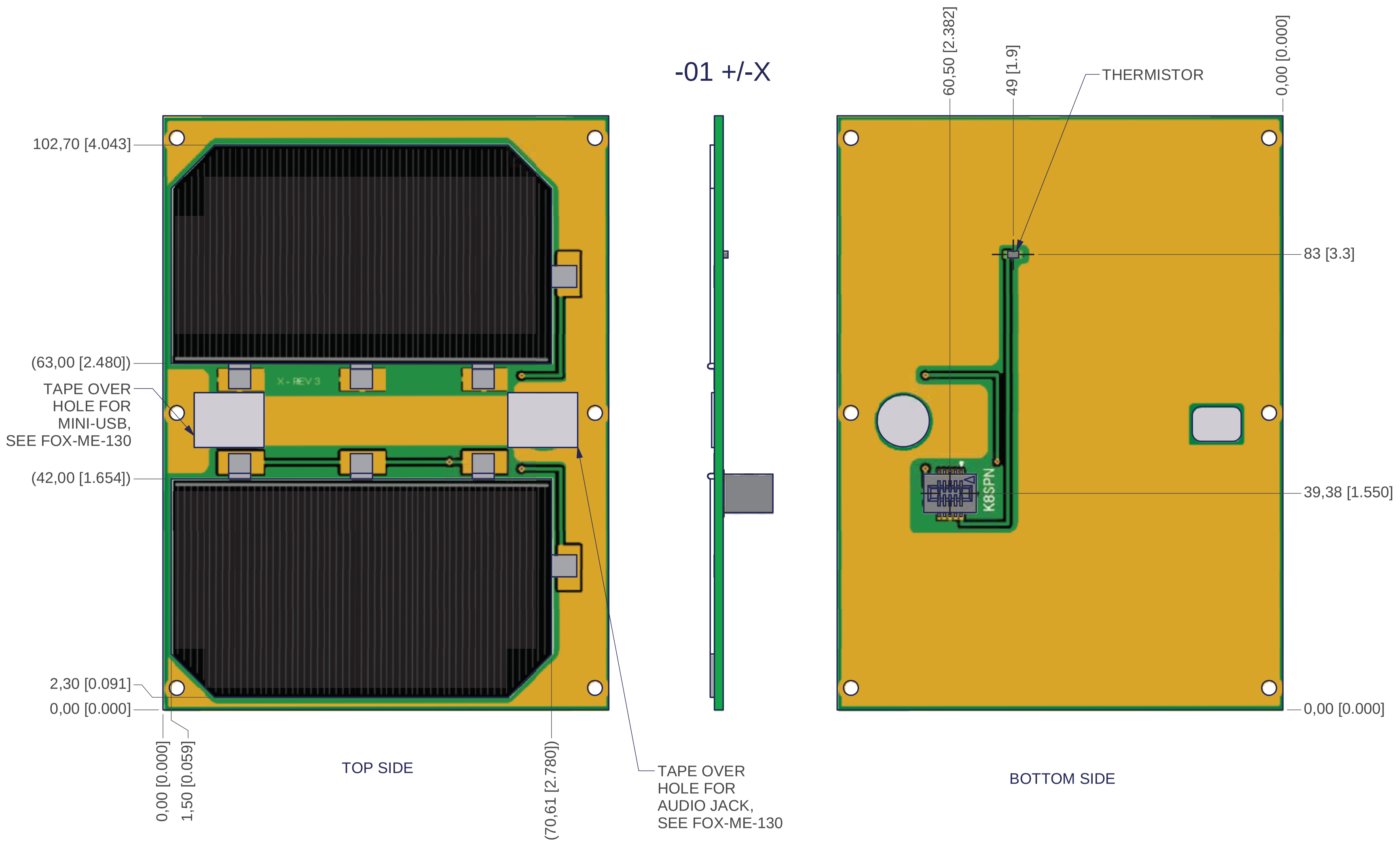
PCB DELRIN MOUNT

SIZE	DATE	DWG.NO.	REV.
A	2013-03-27	FOX-ME-118	0.6

SCALE 2 : 1

UNLESS NOTED OTHERWISE:
mm [in]; TOL X.X ± 0,2 X.XX ± 0,1

SHEET 2 OF 2



ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	FOX-ME-119-05	PCB
3	1	SAMTEC MEC1-105-02-S-D-NP-A	EDGE CARD CONNECTOR
4	1		THERMISTOR, 0805
5	2		1ST SURF METAL TAPE
7	2	FOX-ME-122	SpaceQuest UTJ

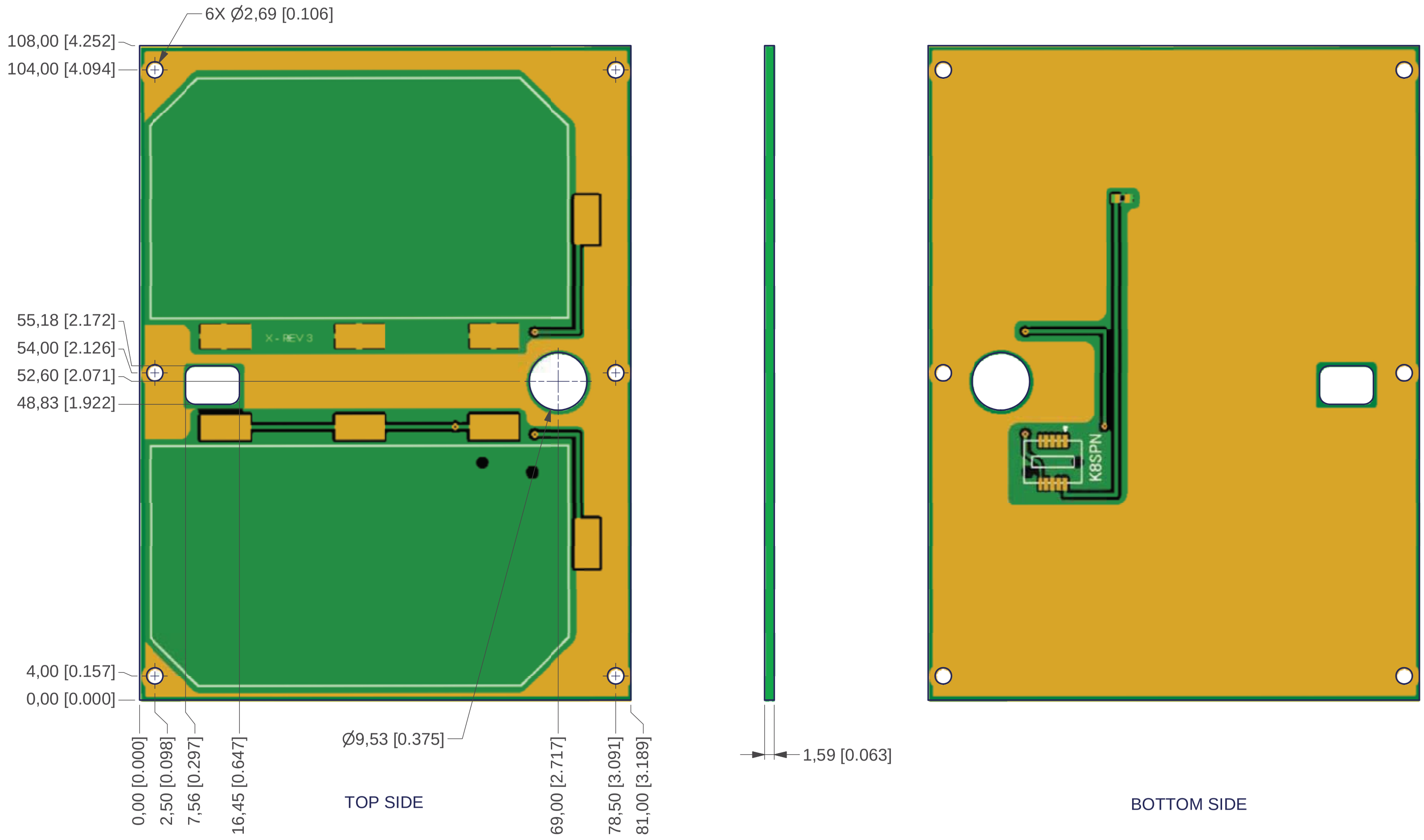
Parts List

AMSAT
FOX

X SIDE SOLAR PANEL

SIZE	DATE	DWG.NO.	REV.
A	2013-06-11	FOX-ME-119	0.8
SCALE 1 : 1	UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX± 0,1	SHEET 1 OF 3	

-05 PCB

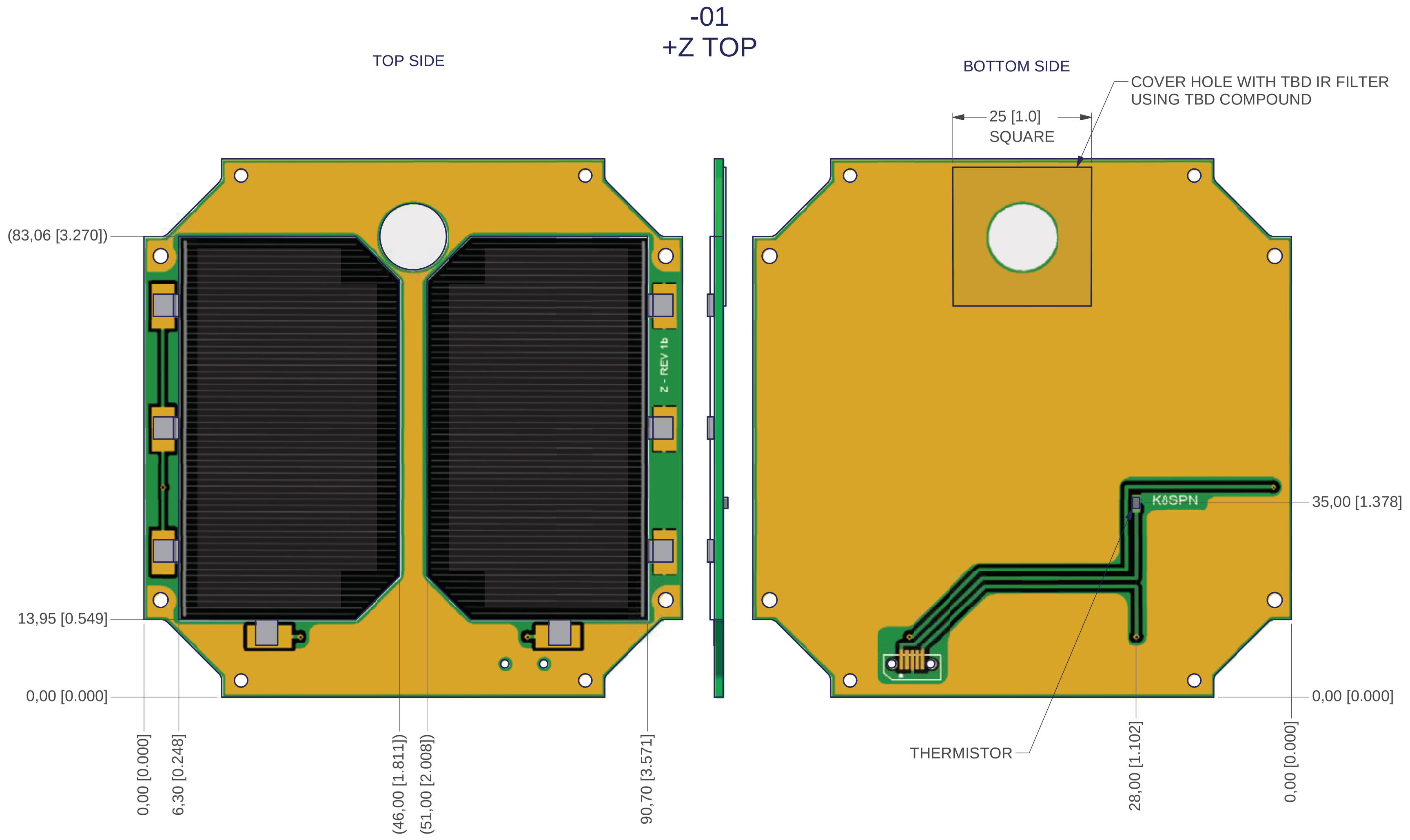


NOTES:
1) FLASH GOLD TOP AND BOTTOM SIDES, ANY AVAILABLE AREA.

AMSAT
FOX

X SIDE SOLAR PANEL

SIZE	DATE	DWG.NO.	REV.
A	2013-06-11	FOX-ME-119	0.8
SCALE 1 : 1	UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX± 0,1		SHEET 3 OF 3



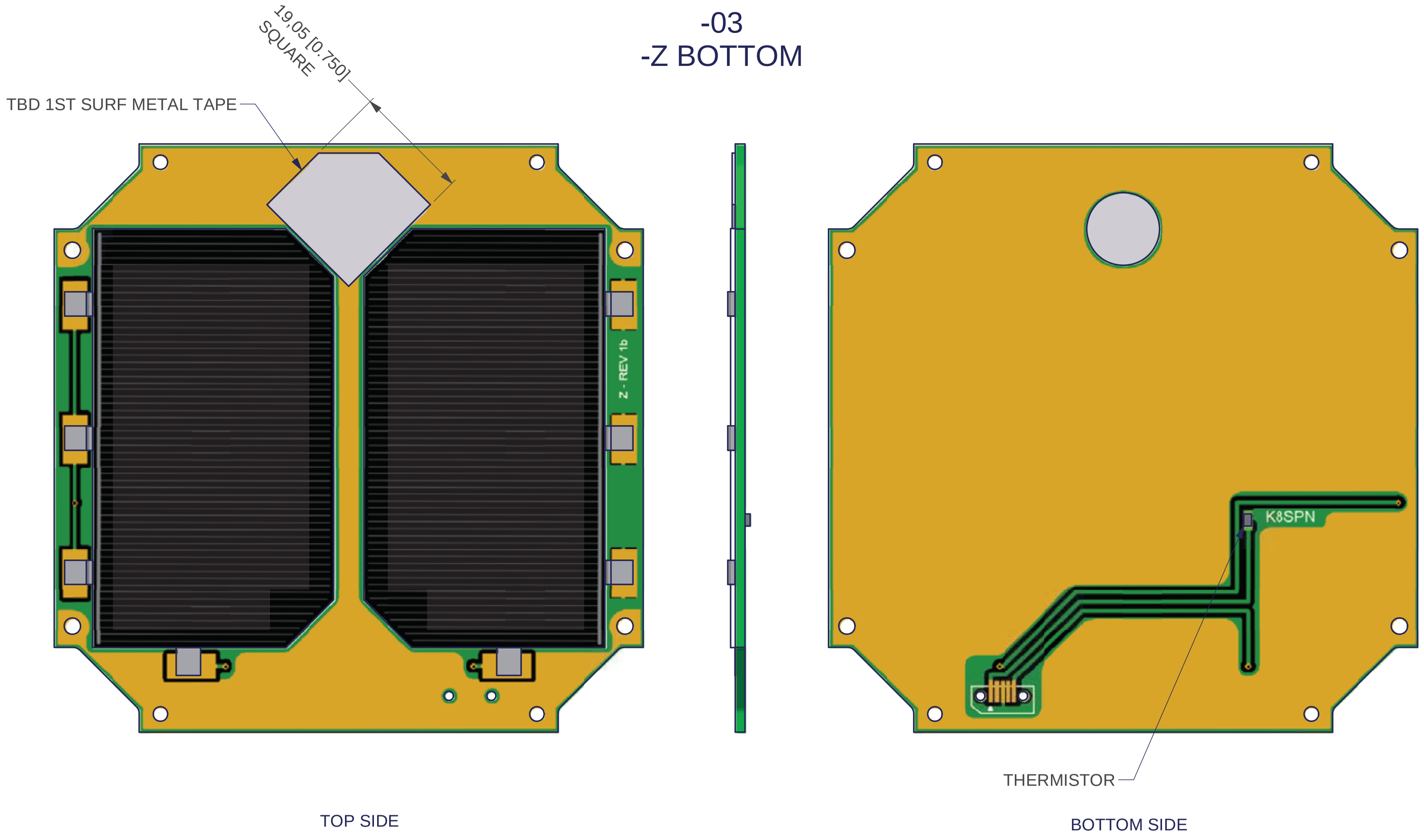
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	FOX-ME-120-03	PCB
6	2	FOX-ME-122	SpaceQuest UTJ
7	1		THERMISTOR, 0805
9	1		IR FILTER

Parts List

AMSAT
FOX

Z TOP/BOTT SOLAR PANEL

SIZE	DATE	DWG.NO.	REV.
A	2013-06-12	FOX-ME-120	0.9
SCALE 1 : 1	UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX± 0,1		SHEET 1 OF 3



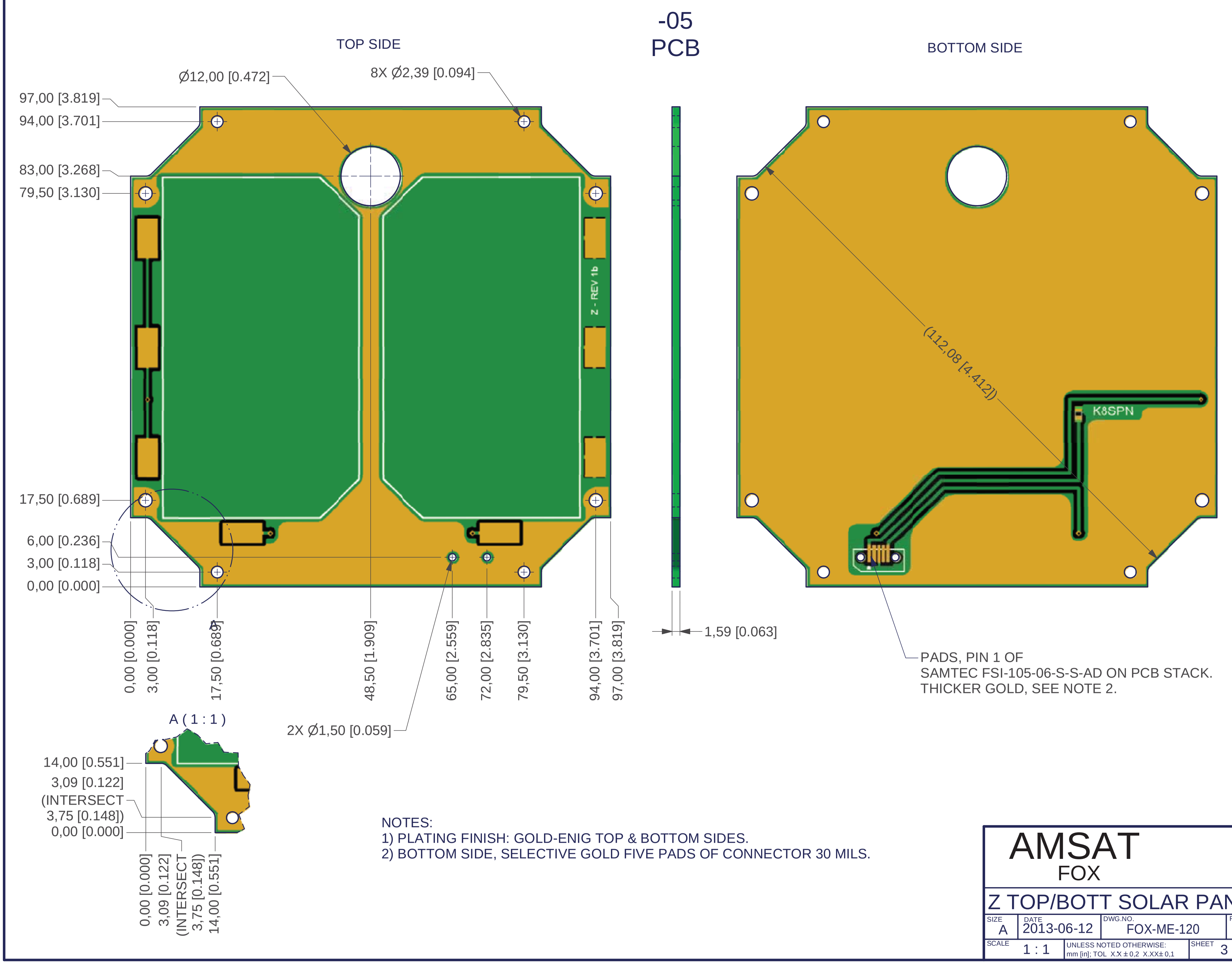
1	1	FOX-ME-120-03	PCB
6	2	FOX-ME-122	SpaceQuest UTJ
7	1		THERMISTOR, 0805
8	1		1ST SURF METAL TAPE
ITEM	QTY	PART NUMBER	DESCRIPTION

Parts List

AMSAT
FOX

Z TOP/BOTT SOLAR PANEL

SIZE	DATE	DWG.NO.	REV.
A	2013-06-12	FOX-ME-120	0.9
SCALE 1 : 1	UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX± 0,1		SHEET 2 OF 3

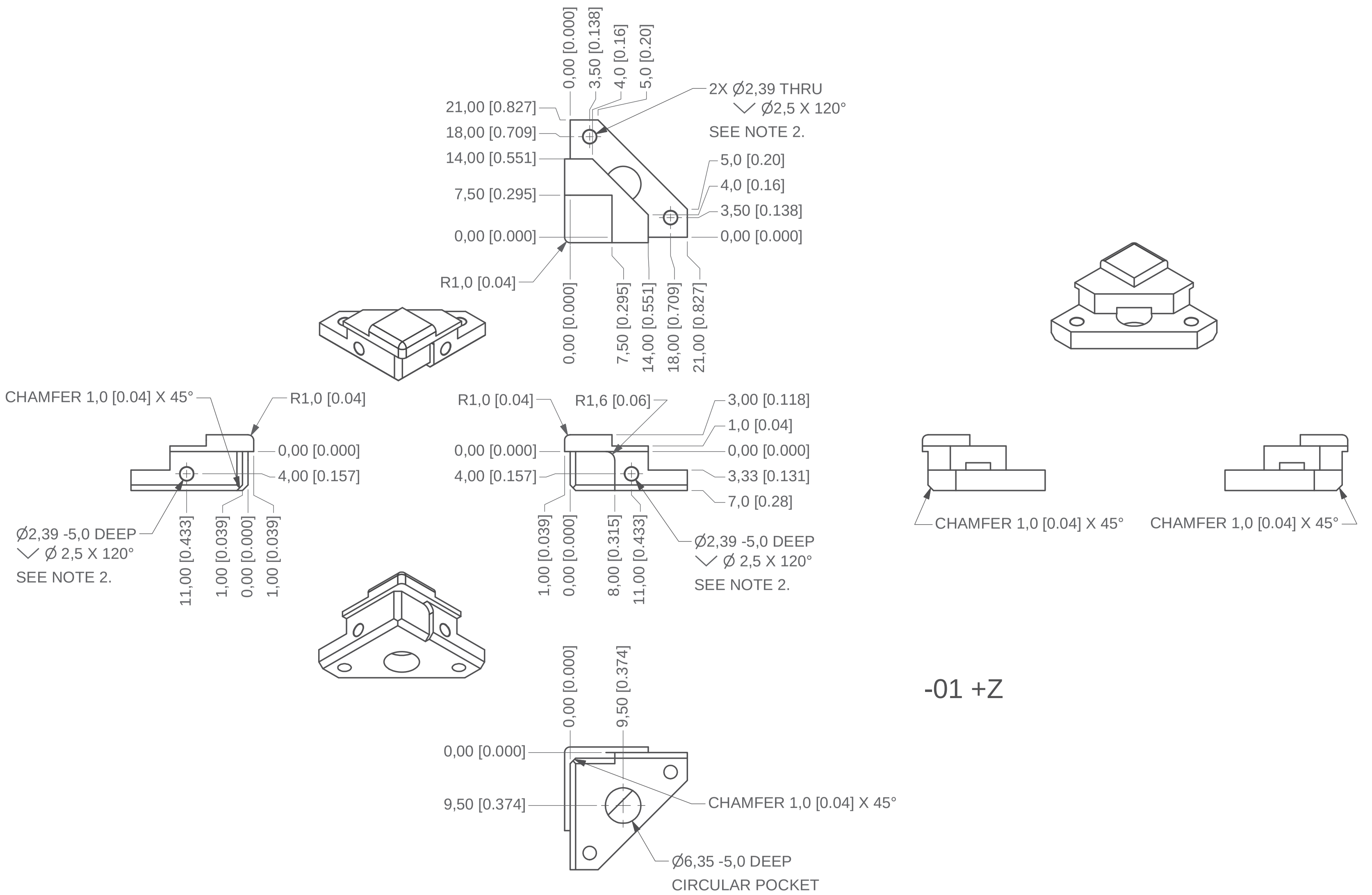


NOTES:
1) PLATING FINISH: GOLD-ENIG TOP & BOTTOM SIDES.
2) BOTTOM SIDE, SELECTIVE GOLD FIVE PADS OF CONNECTOR 30 MILS.

AMSAT
FOX

Z TOP/BOTT SOLAR PANEL

SIZE	DATE	DWG.NO.	REV.
A	2013-06-12	FOX-ME-120	0.9
SCALE 1 : 1	UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX± 0,1		SHEET 3 OF 3



NOTES:

1) -01, -03, -09 MATERIAL: 6061-T6

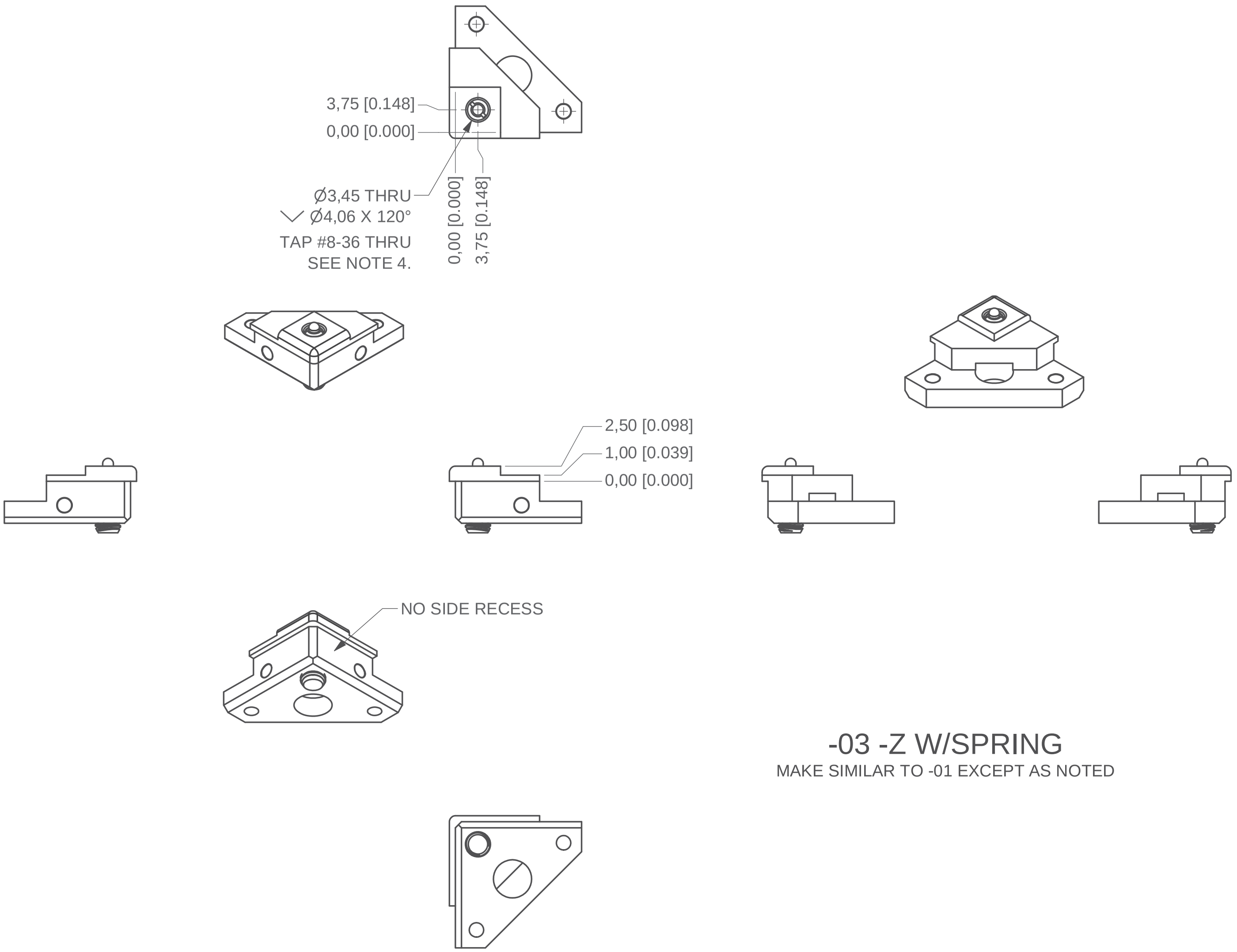
2) STI TAP #2-56 MIN ⩡4, USING HELICOIL BOTTOMING TAP 02CBB.
INSTALL HELICOIL #2-56 X 1 DIA 358502CN0086,
USING HELICOIL INSTALLATION TOOL 551-02.
REMOVE TANG USING HELICOIL TANG-BREAKOFF TOOL 3695-02.

3) -01, -03, -09: CHEMICAL CONVERSION COAT PER MIL-DTL-5541 CLASS 3, ELECTRICALLY CONDUCTIVE CLEAR.

AMSAT
FOX

RAIL ENDS

SIZE A	DATE 2013-06-06	DWG.NO. FOX-ME-121	REV. 1.1
SCALE 1 : 1	UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX± 0,1	SHEET 1 OF 6	



-03 -Z W/SPRING

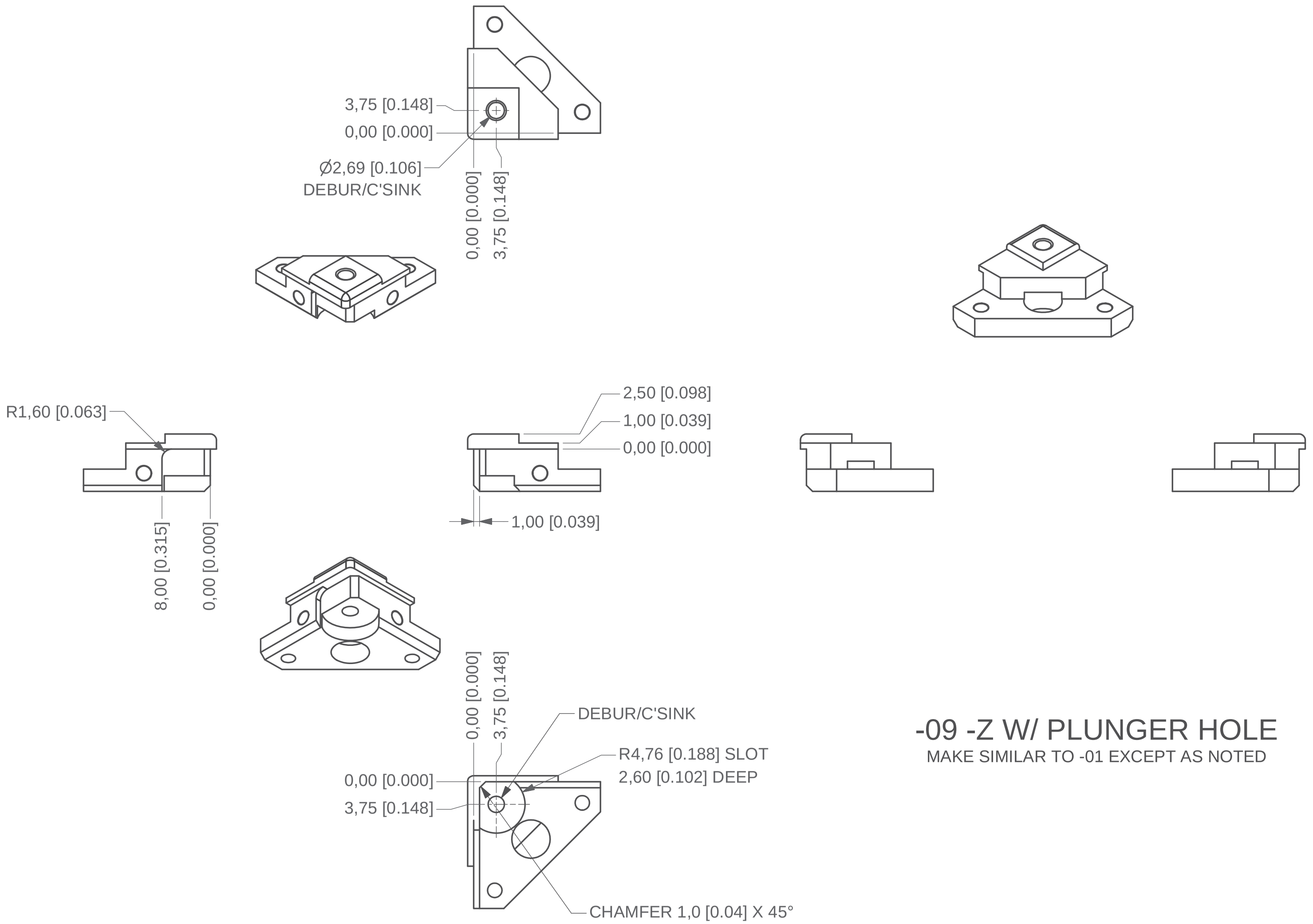
MAKE SIMILAR TO -01 EXCEPT AS NOTED

NOTES:
4) INSTALL MCMASTER-CARR 84985A76
SPRING PLUNGER W/LOCK ELEMENT,
USING SPANNER WRENCH 3382A12.
SPRING HOUSING FLUSH WITH ALUMINUM;
BUTTON PROTRUDES ABOVE TOP,
AND TAIL PROTRUDES OUT BOTTOM.

ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	FOX-ME-121-03	RAIL END, -Z W/SPRING
2	1	MCMASTER 84985A76	SPRING PLUNGER W/LOCK, #8-36 LONG

Parts List

RAIL ENDS			
SIZE A	DATE 2013-06-06	DWG.NO. FOX-ME-121	REV. 1.1
SCALE 1 : 1	UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX ± 0,1		SHEET 2 OF 6

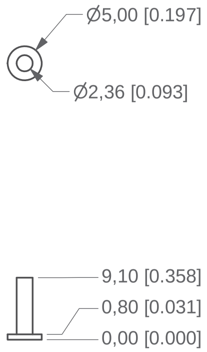


-09 -Z W/ PLUNGER HOLE

MAKE SIMILAR TO -01 EXCEPT AS NOTED

RAIL ENDS

SIZE A	DATE 2013-06-06	DWG.NO. FOX-ME-121	REV. 1.1
SCALE 1 : 1		UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX ± 0,1	SHEET 5 OF 6



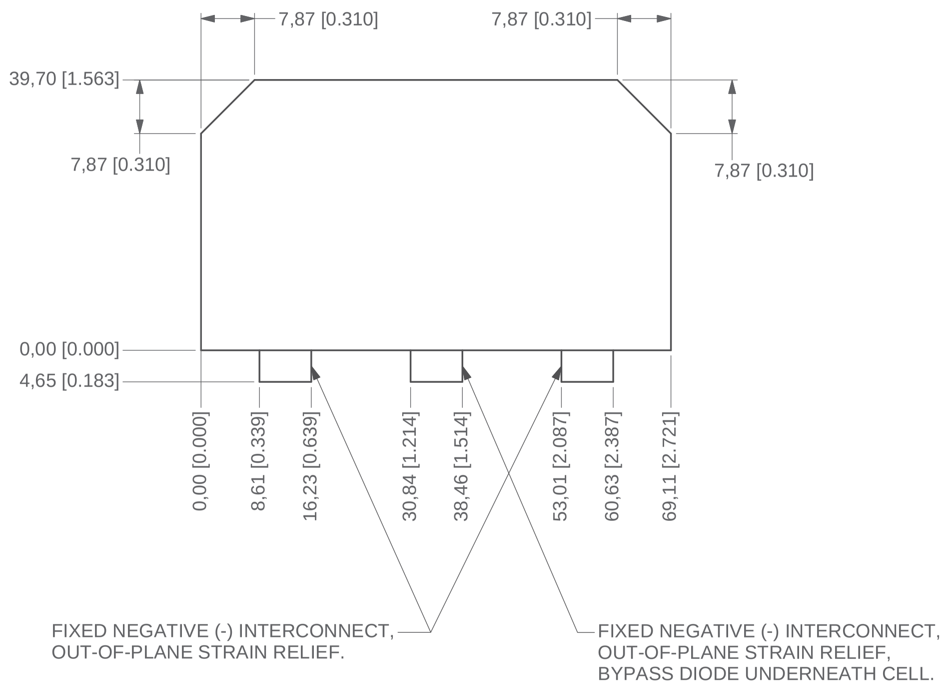
-11 SWITCH PLUNGER

NOTES:
5) -11 MATERIAL: BALCK DELRIN

RAIL ENDS

SIZE	DATE	DWG.NO.	REV.
A	2013-06-06	FOX-ME-121	1.1
SCALE 1 : 1		UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX ± 0,1	SHEET 6 OF 6

-01 CIC

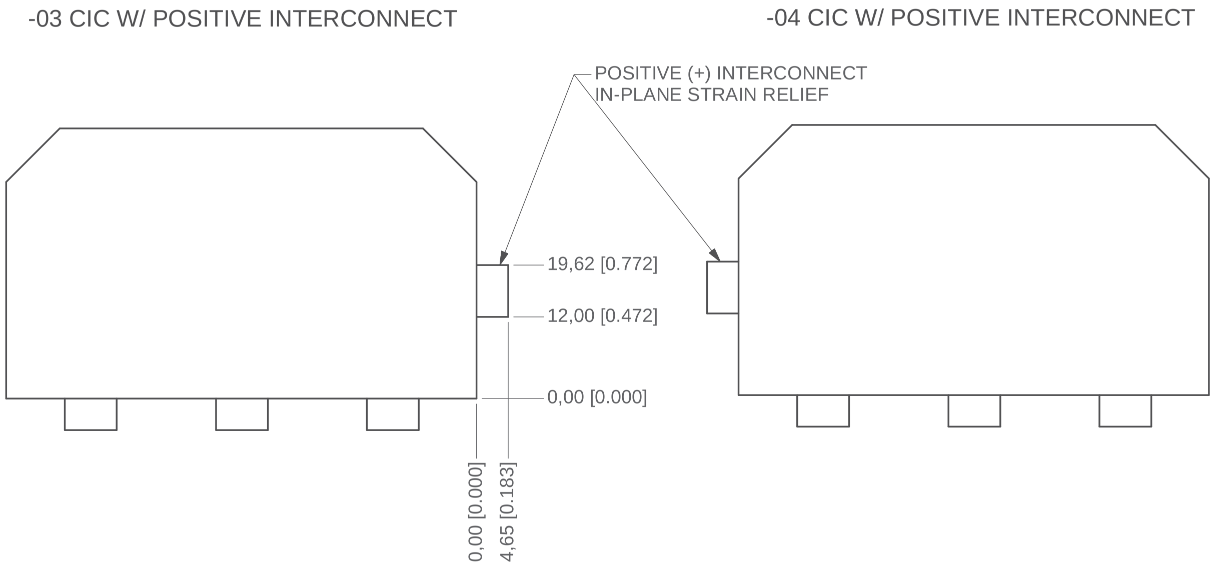


NOTES:
1) SOURCE: SPACEQUEST, LTD. FAIRFAX, VA.
2) MATERIALS/PRODUCTS:
   SOLAR CELL: SPECTROLAB UTJ, 28.3% 26.62CM^2
   RTV: TBD
   COVERGLASS: CERIA-DOPED GLASS
   INTERCONNECT: INVAR/KOVAR
3) APPLICATION NOTES:
   KEEP-OUT ZONE 1MM ALL SIDES TO PANEL EDGE, SOLDER PAD OR TRACE.
   BONDED TO PCB USING NUSIL CV-2289-1 RTV OR EQUIVALENT.
   FLOATING POSITIVE (+) INTERCONNECTS AN BE ADDED TO ANY OTHER EDGE.

AMSAT
FOX

UTJ CELL ICD

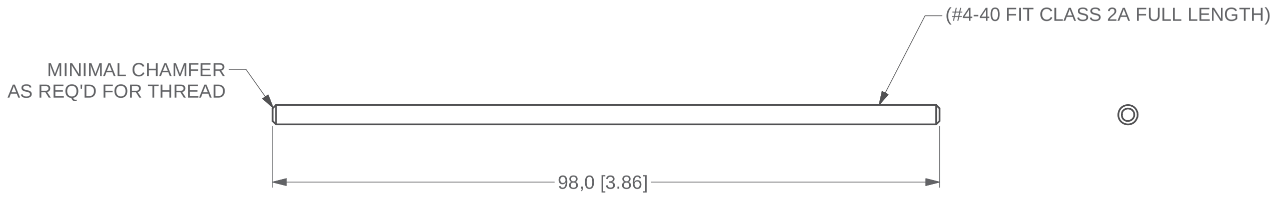
SIZE A	DATE 2013-06-04	DWG.NO. FOX-ME-122	REV. 0.2
SCALE 1 : 1		UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX± 0,1	SHEET 1 OF 2



AMSAT
FOX

UTJ CELL ICD

SIZE A	DATE 2013-06-04	DWG.NO. FOX-ME-122	REV. 0.2
SCALE 1 : 1	UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX± 0,1		SHEET 2 OF 2

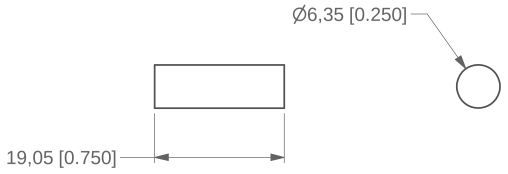


NOTES:
1) MATERIAL: 316 STAINLESS STEEL
2) MAKE FROM GRAINGER 21YN73 OR EQUIVALENT.

AMSAT
FOX

THREADED ROD

SIZE A
DATE 2013-08-16
DWG.NO. FOX-ME-123
REV. 0.2
SCALE 1 : 1
UNLESS NOTED OTHERWISE:
mm [in]; TOL X.X ± 0,2 X.XX± 0,1
SHEET 1 OF 1



AMSAT
FOX

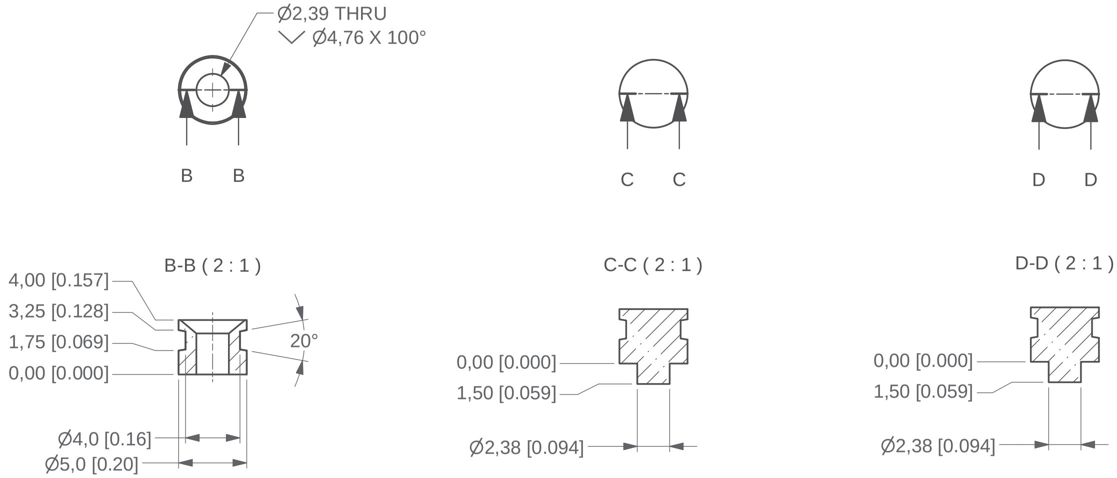
MAGNET

SIZE A	DATE 2013-05-22	DWG.NO. FOX-ME-124	REV. 0.1
SCALE 1 : 1	UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX± 0,1		SHEET 1 OF 1

AMSAT
FOX

HYSTERESIS ROD

SIZE A
DATE 2013-05-22
DWG.NO. FOX-ME-125
REV. 0.1
SCALE 1 : 1
UNLESS NOTED OTHERWISE:
mm [in]; TOL X.X ± 0,2 X.XX± 0,1
SHEET 1 OF 1



-01
DELETED

-03
BLACK DELRIN,
MCMASTER-CARR 8576K11

-05
DIMS SAME AS -03 EXCEPT AS NOTED.
COPPER ALLOY 110 H04 (HARD),
MCMASTER-CARR 8966K423.
GOLD PLATED.

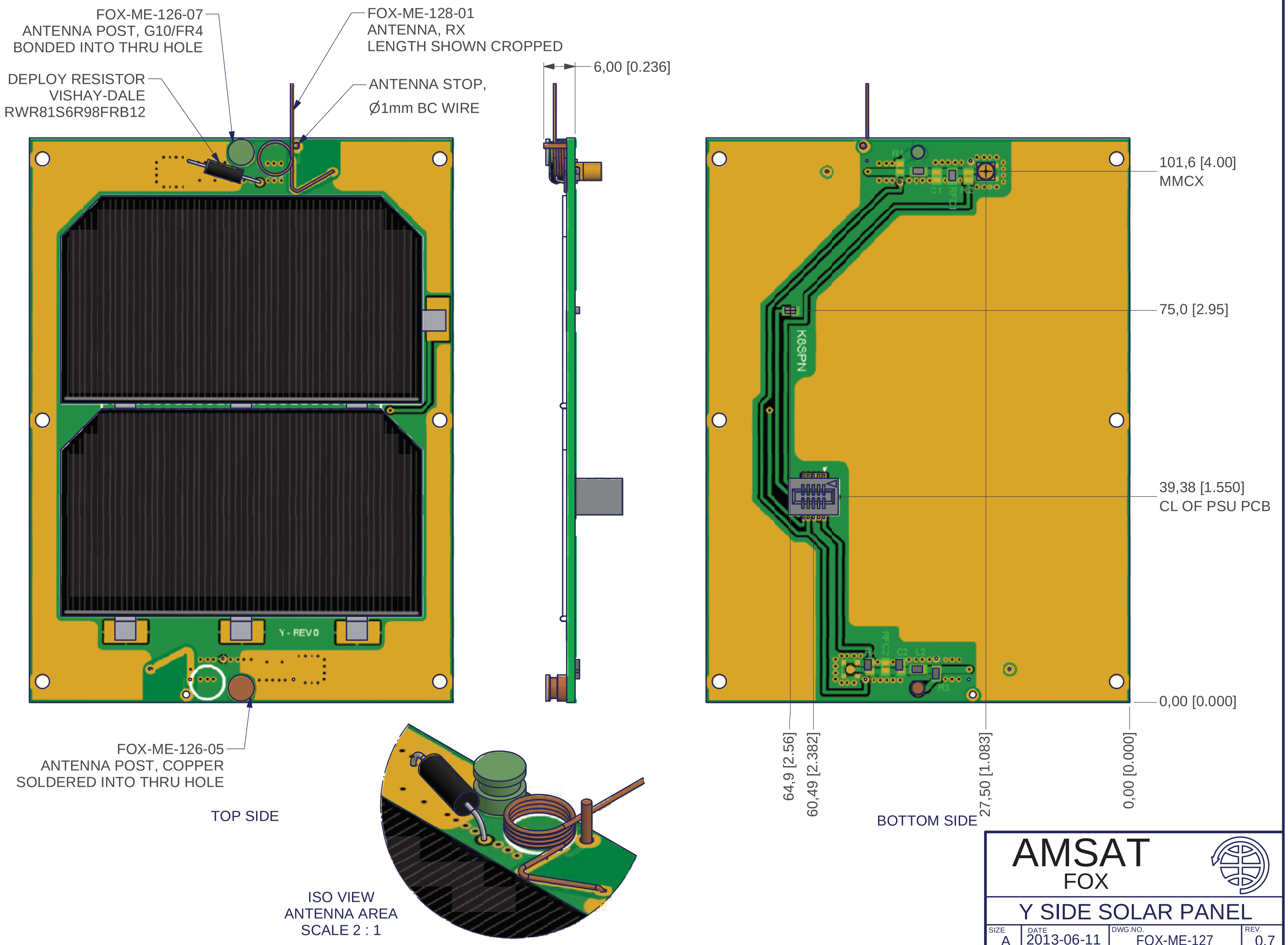
-07
DIMS SAME AS -03 EXCEPT AS NOTED.
G10/FR4 ROD,
MCMASTER-CARR 8669K891
OR EQUIVALENT.

AMSAT
FOX

ANTENNA POST

SIZE	DATE	DWG.NO.	REV.
A	2013-05-04	FOX-ME-126	0.4
SCALE 2 : 1	UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX± 0,1		SHEET 1 OF 1

-01 +Y (437MHZ RX ANTENNA POINTING +Z)

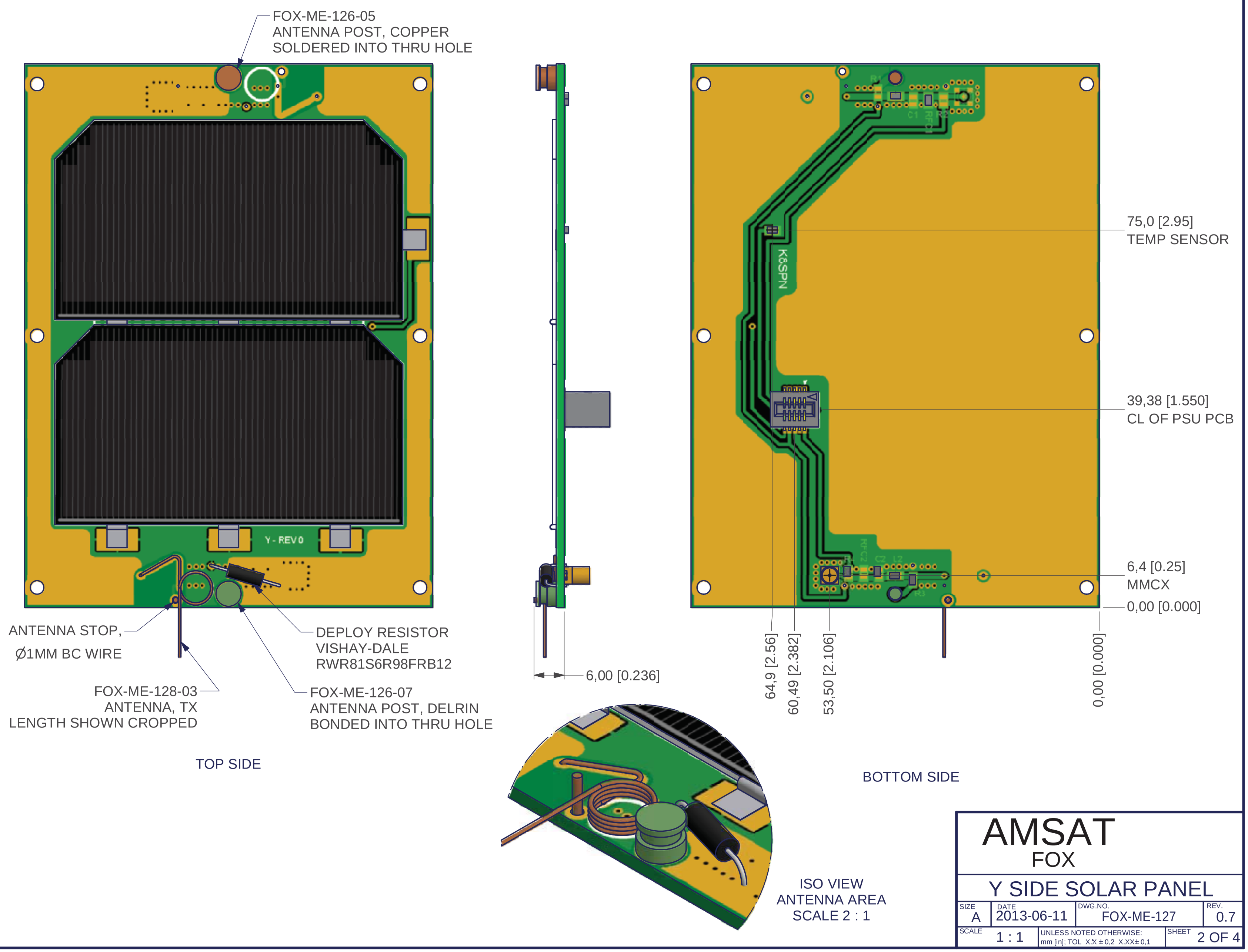


AMSAT
FOX

Y SIDE SOLAR PANEL

SIZE	DATE	DWG.NO.	REV.
A	2013-06-11	FOX-ME-127	0.7
SCALE 1 : 1	UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX± 0,1		SHEET 1 OF 4

-03 -Y (144 TX ANTENNA POINTING IN -Z)



AMSAT
FOX

Y SIDE SOLAR PANEL

SIZE A
DATE 2013-06-11
DWG.NO. FOX-ME-127
REV. 0.7
SCALE 1 : 1
UNLESS NOTED OTHERWISE:
mm [in]; TOL X.X ± 0,2 X.XX± 0,1
SHEET 2 OF 4

ASSEMBLY INSTRUCTIONS
-01 +Y (437MHZ RX ANTENNA POINTING +Z) OR -03 -Y (144 TX ANTENNA POINTING IN -Z)

1) SOLDER CONNECTOR, MMCX, RESISTOR, RF SMD COMPONENTS, THERMISTOR AND COPPER ANTENNA POST.
2) BOND G10/FR4 ANTENNA POSTS.
3) FILL CONNECTOR ALIGNMENT HOLES AS NECESSARY TO PREVENT VOID UNDER CIC.
4) BOND & SOLDER CICS.
5) SOLDER TORSION SPRING ANTENNA (ENTIRE LENGTH OF BENT LEG AND INTO THRU HOLE BUT NOT COIL) AND STOP WIRE (BEND AS REQUIRED FOR PROPER DEPLOYED ANGLE).

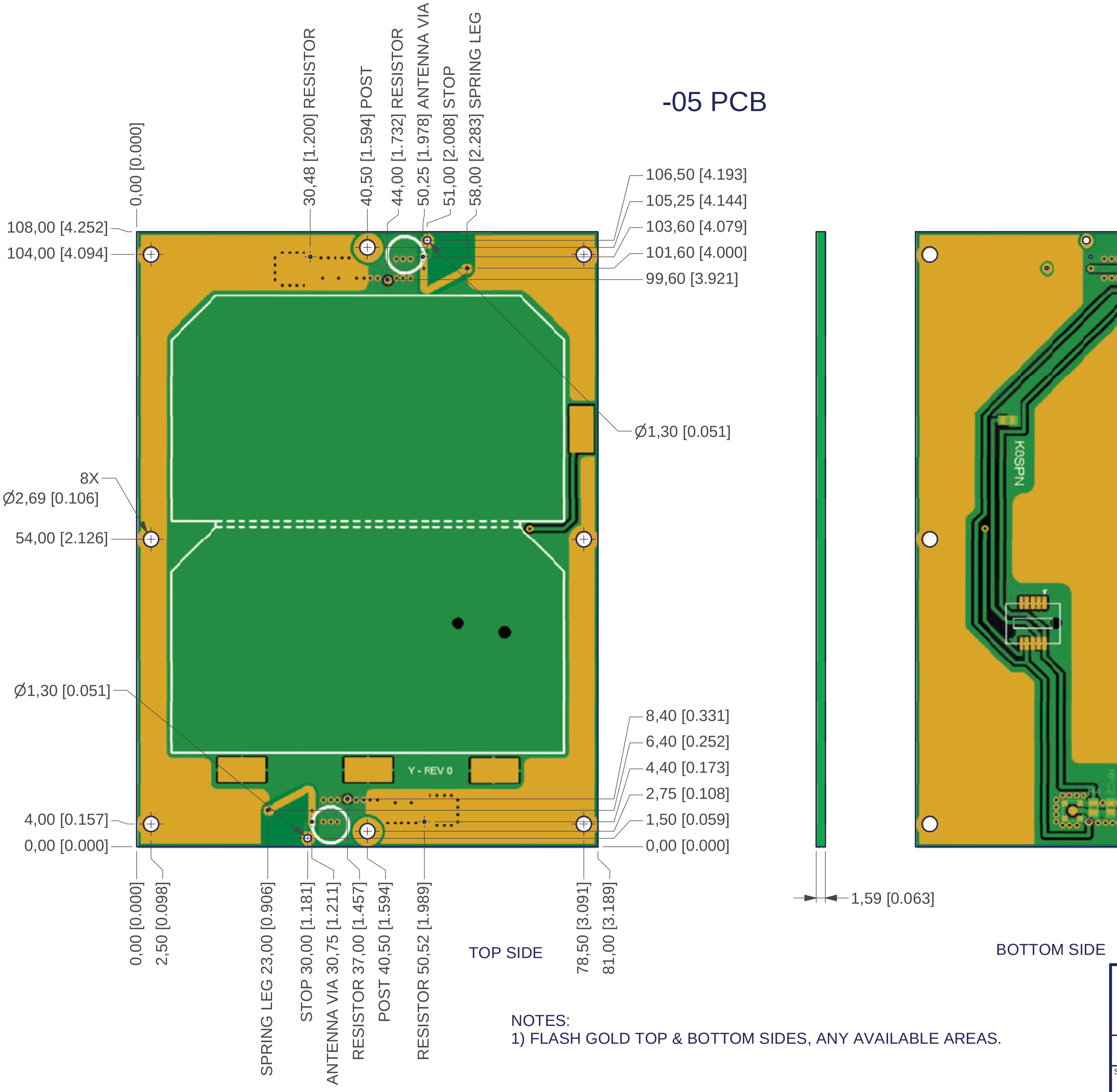
1	1	FOX-ME-127-05	PCB
4	1	SAMTEC MEC1-105-02-S-D-NP-A	EDGE CARD CONNECTOR
5	1		THERMISTOR, 0805
6	1	FOX-ME-126-05	ANTENNA POST, COPPER
7	1	FOX-ME-126-07	ANTENNA POST, G10/FR4
8	1	MOLEX 73415-2061	MMCX JACK, 50 OHM SMD
9	1	VISHAY-DALE RWR81S6R98FRB12	WIREWOUND RESISTOR, 6.98 OHM
10	1	FOX-ME-128	TORSION SPRING ANTENNA
20	2	ANTENNA STOP	Ø1MM BC WIRE
21	2	FOX-ME-122	SpaceQuest UTJ
ITEM	QTY	PART NUMBER	DESCRIPTION

Parts List

AMSAT
FOX

Y SIDE SOLAR PANEL

SIZE A
DATE 2013-06-11
DWG.NO. FOX-ME-127
REV. 0.7
SCALE 1 : 1
UNLESS NOTED OTHERWISE:
mm [in]; TOL X.X ± 0,2 X.XX± 0,1
SHEET 3 OF 4



NOTES:
1) FLASH GOLD TOP & BOTTOM SIDES, ANY AVAILABLE AREAS.

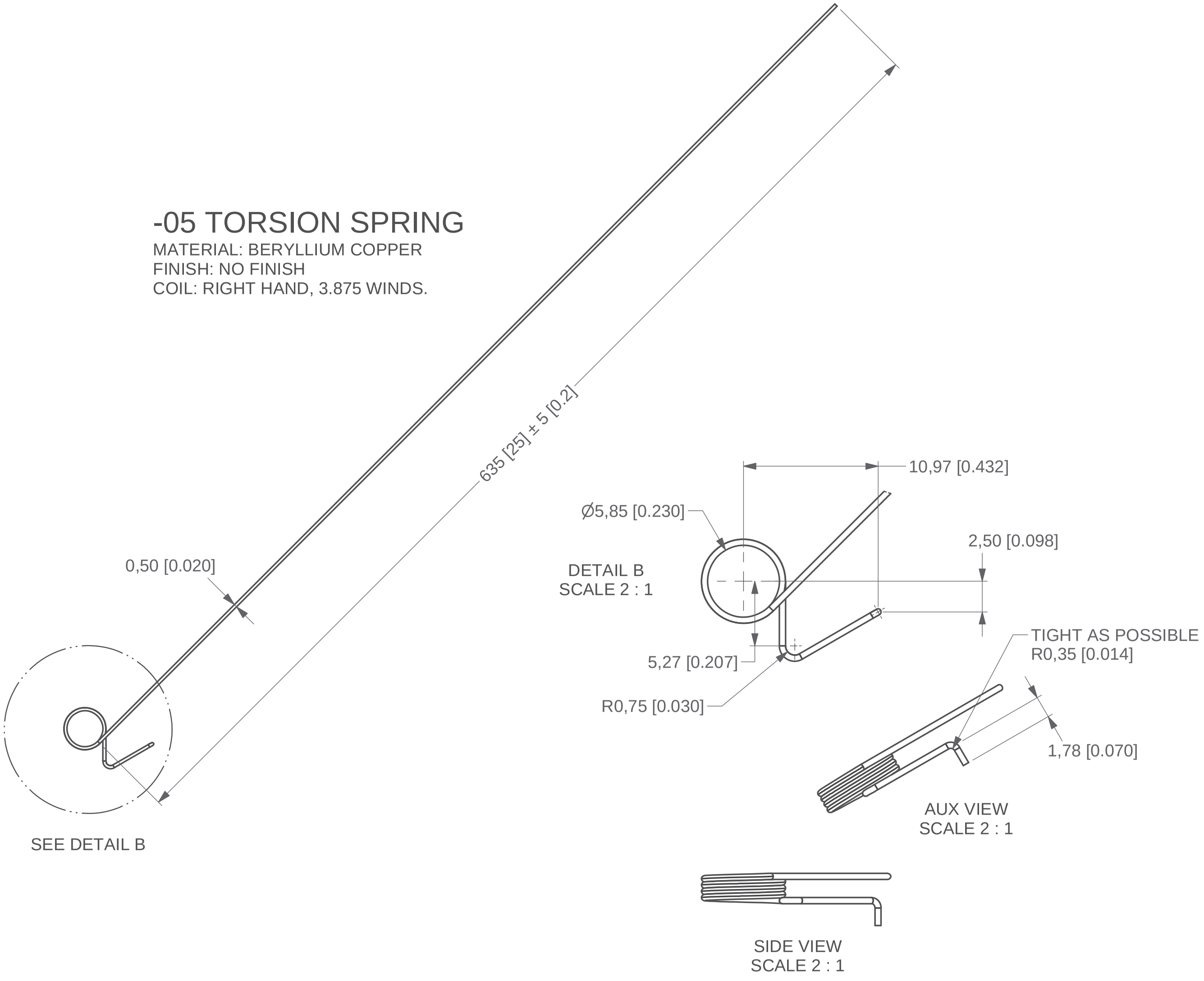
AMSAT
FOX

Y SIDE SOLAR PANEL

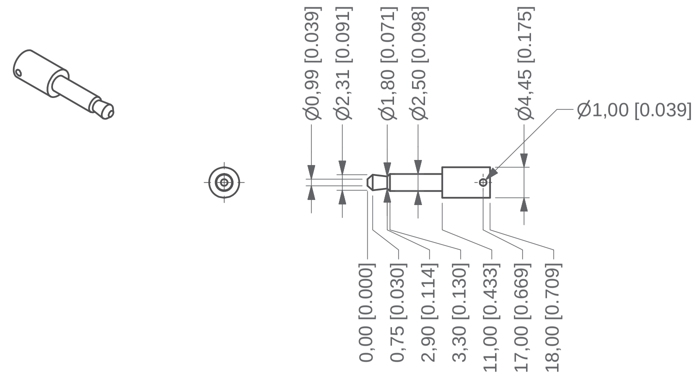
SIZE A
DATE 2013-06-11
DWG.NO. FOX-ME-127
REV. 0.7
SCALE 1 : 1
UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX± 0,1
SHEET 4 OF 4

-05 TORSION SPRING

MATERIAL: BERYLLIUM COPPER
FINISH: NO FINISH
COIL: RIGHT HAND, 3.875 WINDS.



ANTENNA			
SIZE A	DATE 2013-05-29	DWG.NO. FOX-ME-128	REV. 0.2
SCALE 1 : 1	UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX ± 0,1		SHEET 2 OF 3

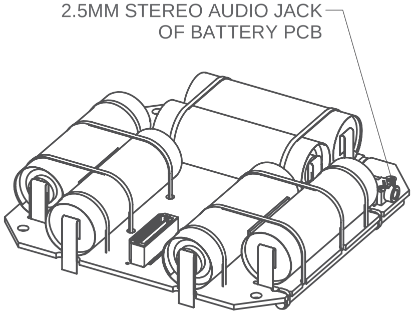


NOTES:
1) MATERIAL: NICKEL ALLOY 200/201
2) A FINGER-SIZED LOOP OF RED WIRE OR LACING CORD (NOT SHOWN) MAY BE USED THRU HOLE.

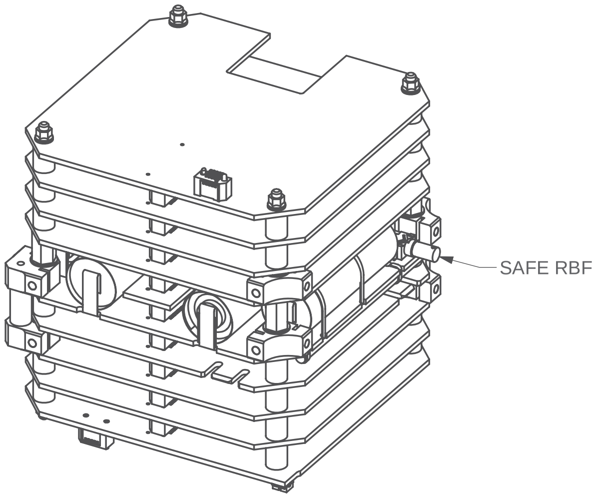
AMSAT
FOX

SAFE RBF

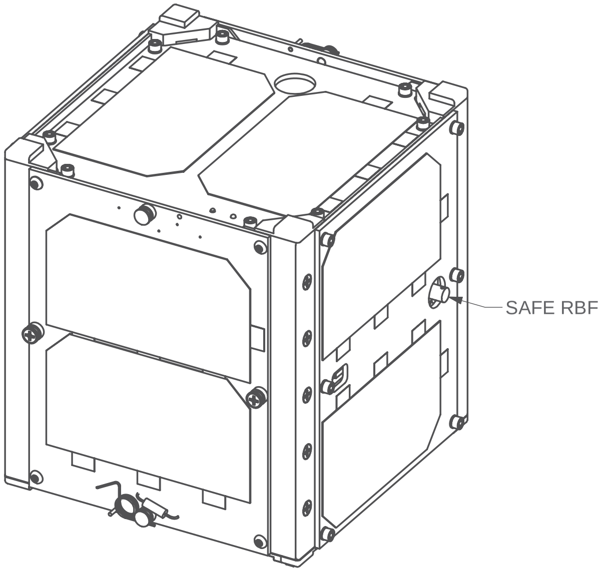
SIZE A	DATE 2013-06-06	DWG.NO. FOX-ME-130	REV. 0.1
SCALE 1 : 1	UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX± 0,1		SHEET 1 OF 4



ON PCB-STACK
(+X EDGE OF BATTERY PCB)



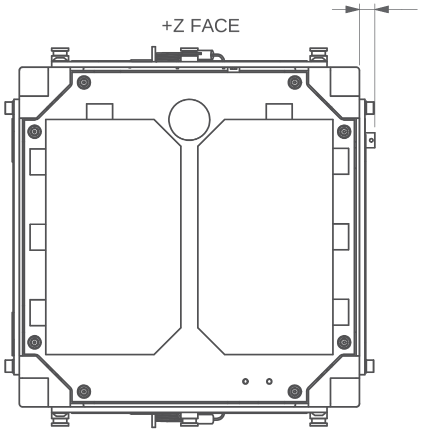
ON FOX-1
(ROUND HOLE IN +X SOLAR PANEL)



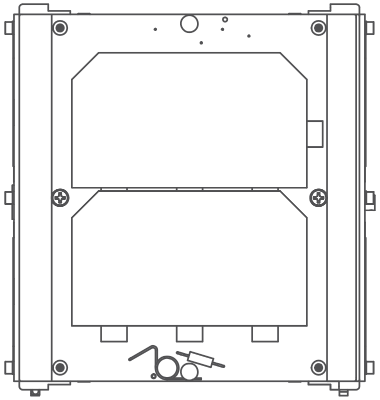
NOTES:
3) TO SAFE (DISABLE) ELECTRONICS:
FULLY INSERT INTO AUDIO JACK ON +X SIDE OF BATTERY BOARD
(ROUND HOLE IN +X SOLAR PANEL).
4) TO ARM (ENABLE) ELECTRONICS:
FULLY REMOVE.

SAFE RBF			
SIZE A	DATE 2013-06-06	DWG.NO. FOX-ME-130	REV. 0.1
SCALE 1 : 2	UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX ± 0,1		SHEET 2 OF 4

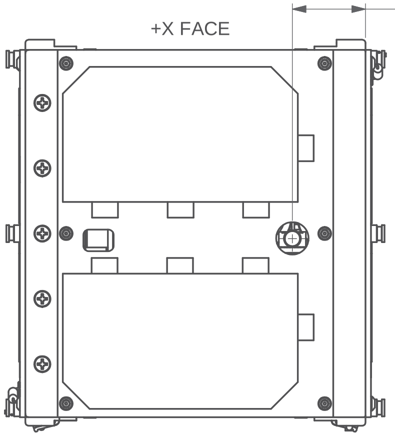
+Z FACE



-Y FACE



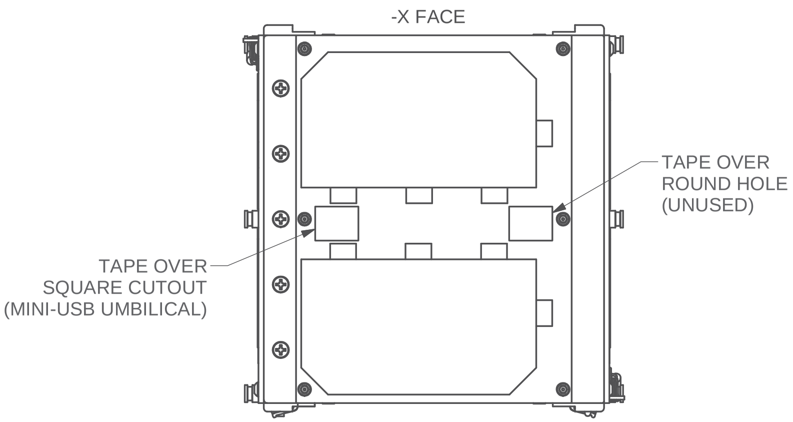
+X FACE

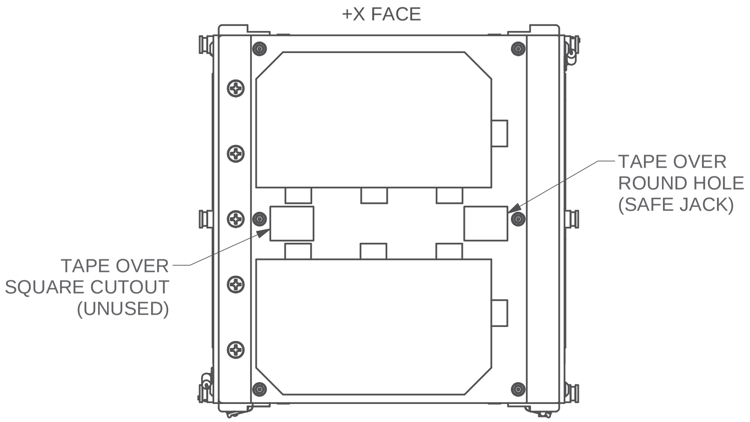


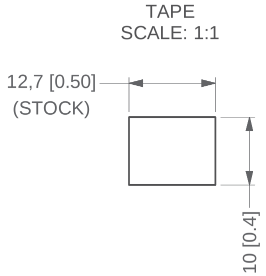
NOTES:
5) COMPATIBLE WITH P-POD ALLOWABLE ENVELOPE.
6) REMOVE BEFORE FLIGHT (RBF) ITEM.

SAFE RBF

SIZE A	DATE 2013-06-06	DWG.NO. FOX-ME-130	REV. 0.1
SCALE 1 : 2		UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX ± 0,1	SHEET 3 OF 4







NOTES:
7) UMBILICAL HOLES TO BE COVERED FOR FLIGHT USING APPROVED 1ST SURF METAL TAPE. FOR SAFE RBF, AND POSSIBLY ALSO THE MINI-USB, THIS MAY HAVE TO BE PERFORMED THROUGH ACCESS PORT(S) INSIDE P-POD.

SAFE RBF			
SIZE A	DATE 2013-06-06	DWG.NO. FOX-ME-130	REV. 0.1
SCALE 1 : 2		UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX ± 0,1	SHEET 4 OF 4

AMSAT Fox-1 Engineering Documentation Update

Compiled by Jerry Buxton, N0JY
AMSAT Vice President - Engineering
n0jy@amsat.org

AMSAT, as an educational organization, would like to publicly release the majority of our design documentation to serve as a learning tool to anyone interested in satellite development. However, this must be done in a specific way to meet the ITAR requirements. The information must first be released via an openly available publication. We would also like to be able to discuss our satellite projects with our own members, some of whom are not "US-persons" per ITAR. These AMSAT Space Symposium proceedings provide a convenient mechanism for the needed publication in order to make this information public domain and allow us to communicate with our members.

While many of the Fox-1 documents were published in the *Proceedings of the AMSAT-NA 30th Space Symposium and AMSAT-NA Annual Meeting* and the *Proceedings of the AMSAT-NA 31st Space Symposium and AMSAT-NA Annual Meeting*, some of these documents have undergone changes as the satellite design has progressed and evolved therefore the updated versions will be reproduced in these 2014 Space Symposium proceedings. In addition, these proceedings also present any new engineering documents that have been produced since the last publication.

Through publication in the three proceedings, the majority of the design documentation has now been introduced to the public domain.

Date: September 29, 2014
Version: Version 1.82

AMSAT *Fox-1*

System Requirements Specification

1 Introduction

This document specifies the system level technical requirements for the AMSAT *Fox-1* satellite project. This 1 Unit CubeSat is a part of the AMSAT Fox program and includes a subset of the technical capabilities envisioned for the overall program.

Fox-1 is specifically intended as a replacement for the failing AMSAT *Echo* (i.e. AO-51) satellite. *Echo* has been the most widely used amateur satellite due to its ability to provide basic radio communications with very simple ground station equipment. Its FM repeater provides very wide geographical coverage allowing amateur radio operators to communicate over substantial distances using just a handheld transceiver (i.e. a *walkie-talkie*) and a small handheld antenna. This so called "*EasySat*" mode is extremely valuable in providing an introduction to satellite communications and is often used for demonstrations given at schools, to scouting organizations and at amateur radio publicity events. *Fox-1* will not duplicate all of the features and modes of Echo but its primary mission is to provide an FM Transponder in order to allow continued access to this *EasySat* mode of communications.

In addition to its mission as a communications satellite, *Fox-1* will host an experiment payload. The satellite will reserve mass and volume for the experiment and will provide DC power and a communications facility. The experiment is expected to be provided by students at Penn State University – Erie through an AMSAT sponsored senior design project.

1.1 Document History

DATE	VERSION	SUMMARY
October 5, 2011	1.0	From Draft E
October 8, 2011	1.01	Fix typos in sections 1.2 and 3.5
October 9, 2011	1.02	Add Requirements Tracking
October 23, 2011	1.03	Additional Requirements Tracking
February 21, 2012	1.04	Update Section 3 and Formatting changes
April 18, 2012	1.05	Correction in Section 4
April 22, 2012	1.06	Correct link in Section 1.4 item 2
April 29, 2012	1.1	Revised 3.12.3, 3.12.7, 3.12.8, 3.13.3, 3.13.4, figure 1 to remove RESET and add IHU OFF and IHU ON commands
August 2, 2012	1.11	Added hidden text for requirements tracking to be shown in System Design Specification
September 4, 2012	1.12	Added the previously missing “Table 6” label
October 17, 2012	1.2	Changed mode descriptions in 3.13.1 Table 6; changed 3.9.2, 3.9.3, 3.9.4, 3.9.5, 3.9.6, 3.9.7 to reflect IHU involvement; changed COMMAND MODE to DATA MODE
April 25, 2013	1.3	3.10.2 Remove PA Temperature, add TX T as RF Transmitter Temperature, OSC T as referring to TX oscillator no longer measured changed to read RX oscillator only
August 20, 2013	1.4	Requirements 3.5.5, 3.6.1, 3.9.6, 3.10.2, 3.11.1, 3.12.4, 3.12.6, 3.13.7.1, 3.13.7.2, 3.13.8, 3.13.9 modified, removed or added to reflect the evolving satellite design
January 10, 2014	1.5	Changes to 3.12.3, 3.12.4, 3.13.2, 3.13.5, 3.13.5.1, 3.13.5.2, 3.13.7, 3.13.7.3, 3.13.7.3.1, 3.13.7.3.2, 3.13.11, 3.13.12 to add Safe Mode
January 20, 2014	1.6	Change 3.13.7.3 to go directly to Safe Mode, remove 3.13.7.3.1 and 3.13.7.3.2
January 23, 2014	1.7	Modified 3.13.2 (figure 1), 3.13.11, added 3.13.11.1
February 10, 2014	1.71	Added “Experiments are powered off” to Table 6 under Safe Mode

DATE	VERSION	SUMMARY
April 17, 2014	1.72	Bring Table 5 commands in line with Command and Control Document, remove PSU reference from 3.12.8 and 3.12.9
August 16, 2014	1.8	Update to actual operating values 3.13.11, 3.13.11.1, 3.12.3, 3.13.1, 3.13.7, 3.13.7.1, 3.13.7.2
September 8, 2014	1.81	Update to actual operating values 3.9.3, 3,9,6, update Table 5, add 3.12.12 and 3.12.13
September 29, 2014	1.82	Update 3.9.3, 3.9.4 to allow for variable hang timer

1.2 Document Scope

The purpose of this document is to specify the technical requirements of the satellite at the system (i.e. "black box") level. It is intended to be used by the hardware, software and mechanical designers to develop the architecture/high-level design specifications. It is also intended to be used for test planning and development.

1.3 Document Format

This document provides the requirements in numbered format. Each requirement is assigned a unique number. Additional information such as comments or examples that are provided for guidance or clarity is *italicized* to distinguish them from requirements.

1.4 References

1. AMSAT *Fox-1*, Concept of Operations, Version 1.0, September 19, 2011
2. CubeSat Design Specification Rev. 12. by The CubeSat Program Cal Poly SLO available from: http://www.cubesat.org/images/developers/cds_rev12.pdf
3. Launch Services Program, Program Level Poly Picosatellite Orbital Deployer (PPOD) and CubeSat Requirements Document LSP-REQ-317.01 Revision Basic (from NASA)
4. ITU Radio Regulations, Edition of 2008. available from http://www.itu.int/publ/R-REG-RR-2008/en

2 General Requirements

2.1 CubeSat Requirements

2.1.1 The satellite shall meet the requirements specified in the CubeSat Design Specification Rev. 12.

2.1.2 The satellite shall meet the requirements specified in the NASA LSP-REQ-317.01 Revision Basic.

2.1.3 The satellite shall meet the requirements for a 1 unit (single) CubeSat.

2.1.4 The satellite shall provide mass for an experiment payload up to 100 g.

2.1.5 The satellite shall provide volume for an experiment payload up to 95 x 95 x 15.7 mm.

2.2 Environmental Requirements

2.2.1 The satellite avionics shall be designed for -40C to +70C operating temperature.

2.2.2 The satellite shall be designed to operate in a 650 km, sun-synchronous, circular orbit.

2.2.3 The satellite shall be designed to tolerate the radiation environment in orbit.

2.3 Reliability Requirements

2.3.1 The satellite shall be designed for a minimum 5-year, on-orbit lifetime.

2.4 RF Frequency Requirements

2.4.1 All RF transmitters shall meet or exceed the requirements specified in the ITU Radio Regulations, Technical Characteristics, Volume 3, article 3.

2.4.2 All satellite uplinks shall be in the 70 cm band of the amateur satellite service.

2.4.3 All satellite downlinks shall be in the 2 meter band within the amateur satellite service.

2.4.4 All satellite transmitter and receiver frequencies shall deviate by no more than 5 parts-per-million from the specified values including initial accuracy and temperature variation.

2.4.5 All satellite frequencies shall be coordinated with the IARU.

Note that the band plan with the actual coordinated frequencies will be specified in a separate document.

3 Functional Requirements

3.1 Antenna System

3.1.1 The satellite shall include a deployable antenna system.

3.2 Attitude Control

3.2.1 The satellite shall incorporate passive magnetic stabilization to align the deployed antennas with the magnetic field of the earth.

3.3 Access Ports

3.3.1 The satellite shall include a "Remove Before Flight" pin as per the CubeSat Design Specification.

3.3.2 The satellite shall include an umbilical port as per the CubeSat Design Specification.

3.4 Pre-launch Features

3.4.1 The satellite battery and photovoltaic panels shall be electronically disconnected from the avionics when the "Remove Before Flight" pin is inserted, regardless of the state of the deployment switch(es).

3.4.2 The satellite shall provide the means to charge the battery via the umbilical port while integrated with the P-POD.

3.4.3 The satellite shall provide the means to run diagnostic tests via the umbilical port while integrated with the P-POD.

3.5 Power

3.5.1 The satellite shall produce electrical power from sunlight.

3.5.2 The satellite shall produce electrical power while in sunlight regardless of orientation and while tumbling or spinning.

3.5.3 The satellite shall produce sufficient average electrical power to operate continuously in the orbit of maximum eclipse.

3.5.4 The satellite shall provide sufficient battery capacity to operate continuously in the orbit of maximum eclipse.

3.6 Experiment

3.6.1 The satellite shall provide DC power for experiment payloads.

3.6.2 The satellite shall provide a means to activate and deactivate the experiment payloads.

3.6.3 The satellite shall provide a means to telemeter data from the experiment payloads.

Note that the experiment payloads will be specified in a separate documents.

3.7 RF Uplink

3.7.1 The satellite shall include an FM uplink receiver.

3.7.2 The receiver shall have specifications as shown in Table 1.

Table 1

Sensitivity	-120 dBm for 12 dB SINAD (min.)
FM Deviation	5 kHz
Audio Bandwidth	3 kHz
Input Frequency Acceptance	Receiver shall accept signals that are off frequency by ±2.5 kHz (min.)

3.8 RF Downlink

3.8.1 The satellite shall include an FM downlink transmitter.

3.8.2 The transmitter shall have specifications as shown in Table 2.

Table 2

Power Output	400 mW (min.)
FM Deviation	5 kHz
Audio Bandwidth	3 kHz

3.8.3 The transmitter shall provide a means to prevent over modulation.

3.9 FM Transponder

3.9.1 The satellite shall provide an FM transponder via the RF uplink and RF downlink.

3.9.2 In Transponder Mode, the IHU shall detect the presence of a 67 Hz CTCSS tone on the uplink.

3.9.3 In Transponder Mode, the downlink transmitter shall be keyed (*i.e. PTT-on*) by the IHU for a minimum of 30 seconds following detection of the 67 Hz CTCSS tone.

3.9.4 In Transponder Mode, the downlink transmitter shall stay on continuously as long as the 67 Hz CTCSS tone is detected at least once during the period the transmitter is being keyed (*i.e. PTT-on*).

3.9.5 In Transponder Mode, the 67 Hz CTCSS tone is not required for a received signal to be repeated on the downlink, once the transmitter has been keyed.

3.9.6 In Transponder Mode, if the downlink transmitter has been un-keyed for a period of 2 minutes, the satellite shall send "HI THIS IS AMATEUR RADIO SATELLITE FOX 1" as a voice announcement on the downlink transmitter.

3.9.7 In the event of shutdown or failure of the IHU, the satellite shall default to simple carrier operated repeater operation.

3.10 Telemetry Data

3.10.1 The satellite shall collect telemetry data.

3.10.2 The telemetry data shall include at a minimum, measured parameters as shown in Table 3.

Table 3

Parameter Name	Description
CELL V	Voltages of battery cells
PANEL V	Voltages of solar panels
TOTAL I	Total DC current out of power system
PA I	DC current into RF power amp
BATTERY T	Temperature of battery
PANEL T	Temperatures of solar panels
TX T	Temperature of RF transmitter card
RX T	Temperature of RF receiver card

3.10.3 The measured parameters shall be sampled at least every 15 seconds.

3.10.4 The minimum and maximum values of each of the measured parameters shall be saved in non-volatile memory.

3.10.5 The telemetry data shall also include at a minimum, calculated parameters as shown in Table 4.

Table 4

Parameter Name	**Description**
UP TIME	Total seconds since avionics power-up or reset
SPIN	Satellite spin rate and direction

3.10.6 A telemetry frame shall include the current measured values, the saved minimum and maximum values, and the current calculated values.

Note that the telemetry interface will be specified in a separate document.

3.11 Telemetry Transmission

3.11.1 The satellite shall send slow speed telemetry using FSK on the RF downlink.

3.11.2 The FSK shall use the frequency spectrum below the audible range.

3.11.3 The telemetry shall be transmitted simultaneously with any transponder communications.

3.11.4 The telemetry transmission shall include telemetry frames.

3.11.5 The telemetry transmission shall include experiment data.

3.12 Command Capability

3.12.1 The satellite shall provide the means to process commands sent via the RF uplink from a ground control station.

3.12.2 The commands received via the RF uplink shall not be repeated on the RF downlink.

3.12.3 The following commands shall be provided, as shown in Table 5.

Table 5

Command	**Operation**
SAFE MODE	Enter Safe Mode
INHIBIT TX	Inhibit RF transmission
ENABLE TX	Enable RF transmission
IHU OFF	Power off IHU
IHU ON	Power on IHU
CLEAR	Clear stored telemetry
TRANSPONDER MODE	Enter Transponder Mode
DATA MODE	Enter Data Mode
ENABLE AUTO-SAFE	Enable Auto-Safe Mode
DISABLE AUTO-SAFE	Disable Auto-Safe Mode

3.12.4 A SAFE MODE command shall cause the satellite to enter the Safe Mode.

3.12.5 An INHIBIT TX command shall disable the RF transmitter.

3.12.6 An ENABLE TX command shall enable the RF transmitter.

3.12.7 An IHU OFF command shall cause the IHU System to power off.

3.12.8 An IHU ON command shall cause the IHU System to power on.

3.12.9 A CLEAR command shall cause the satellite to clear the saved minimum and maximum telemetry parameter values.

3.12.10 A TRANSPONDER MODE command shall cause the satellite to enter the Transponder Mode.

3.12.11 A DATA MODE command shall cause the satellite to enter the Data Mode.

3.12.12 An ENABLE AUTO-SAFE command shall enable the auto-safe mode state.

3.12.13 A DISABLE AUTO-SAFE command shall disable the auto-safe mode state.

Note that the control interface will be specified in a separate document.

3.13 On-Orbit Operating Modes

3.13.1 The satellite shall provide on-orbit operating modes as shown in Table 6.

Table 6

Name	**Description**
Startup Mode	Wait 50 minutes and deploy antennas
Safe Mode	Wait 120 seconds then begin 10 second beacon sequence Experiments are powered off

Transponder Mode	FM transponder; PTT and low speed telemetry via IHU
Data Mode	FM transmitter; PTT and high speed telemetry via IHU

3.13.2 The satellite shall transition between modes as shown in Figure 1.

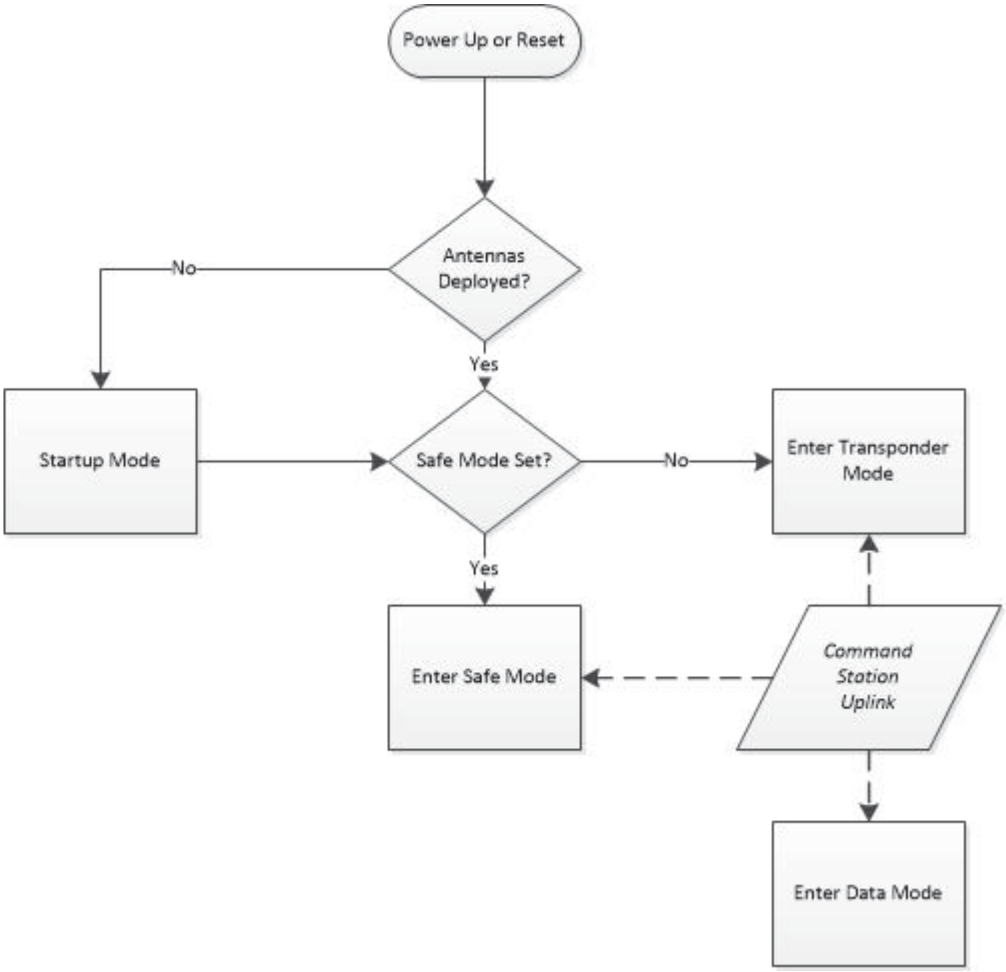


Figure 1. On-Orbit Operating Modes

3.13.3 Upon power-up of the avionics, the satellite shall begin operation from the "Power-up" state as shown in Figure 1.

3.13.4 An IHU ON Command shall cause the satellite to begin operation from the "Power-up" state as shown in Figure 1.

3.13.5 If the antennas have been deployed, the satellite shall determine whether the last state was Safe Mode.

3.13.5.1 If the last state was Safe Mode the satellite shall enter Safe Mode.

3.13.5.2 If the last state was not Safe Mode the satellite shall enter Transponder Mode.

3.13.6 If the antennas have not been deployed, the satellite shall enter the Startup Mode.

3.13.7 In Startup Mode, the satellite shall wait 50 minutes, then deploy the antennas.

3.13.7.1 During the 50 minute wait the IHU shall flash a red LED.

3.13.7.2 During the 50 minute wait the IHU shall sound a 1 kHz beeping tone.

3.13.7.3 After the antennas have been deployed the satellite shall enter Safe Mode.

3.13.8 In Transponder Mode, the transponder and the slow speed telemetry shall be active.

3.13.9 In Data Mode, the high speed telemetry shall be active and the transponder shall not be active. *(i.e. signals that appear on the uplink shall not be repeated on the downlink.)*

3.13.10 If another Data Mode command is not received, the satellite shall automatically enter Transponder Mode 24 hours after having entered Data Mode.

3.13.11 In Safe Mode the satellite shall wait 120 seconds then transmit a 10 second beacon.

3.13.11.1 The 120 second wait and 10 second beacon cycle will be repeated as long as the satellite is in Safe Mode.

3.13.12 The RF uplink shall be monitored for commands in all modes.

4 External Interface Documents

To fully specify the satellite technical requirements, the following documents must also be provided;

1. IARU Coordinated Frequency Plan
2. Downlink Specification
3. Control Interface Specification
4. Experiment Payload Specifications

5 Summary

The *Fox-1* satellite will be AMSAT's first CubeSat. Its primary mission is to provide an FM Transponder communications capability. The secondary mission is to host a university-provided experiment payload.

Date: September 29, 2014
Version: 3.92

AMSAT *Fox-1*
Avionics System Design Specification

1 Introduction

This document contains the system level design specifications for the AMSAT *Fox-1* satellite avionics systems. It is driven by the System Requirements Specification and other documents provided by the developers of the individual systems that make up the satellite system.

1.1. Document History

DATE	VERSION	SUMMARY
February 21, 2012	1.0	From Draft F
April 9, 2012	1.1	Add signal characteristics, update bus pin connections per System Team input
April 17, 2012	1.2	Add external connector specification in sections 2.6, 2.12 and 2.14 and references in section 6
April 18, 2012	1.21	Add MMCX connectors gender
April 22, 2012	1.3	Minor corrections in signal characteristics, remove +Z antenna deploy and sensor connections
July 10, 2012	2.0	Many revisions from PDR
July 11, 2012	2.01	One RBF pin removed from bus pin assignments, updated 2.1 interconnect diagram, updated 2.1 signal characteristics
July 21, 2012	2.1	Revised bus signals, bus pin assignments Updated RF block diagram
July 22, 2012	2.11	Revision to some RF signal descriptions, change antenna/coax connectors to UMCC type, updated RF block diagram, added driving and load system columns to signal characteristics
September 9, 2012	3.0	Major changes.
September 11, 2012	3.01	Defunct IHU block diagram pending update
September 12, 2012	3.1	Added PCB volume requirements
September 23, 2012	3.11	Change TX PTT to RX PTT, -Z Deploy switches to TX, update figures and tables accordingly
September 26, 2012	3.12	Update bus and pin assignment drawings
September 27, 2012	3.13	Update bus pin assignment drawings
September 30, 2012	3.14	Update RF block diagram to remove ITAR notice
October 17, 2012	3.15	Import changes to requirements from System Requirements
February 17, 2013	3.2	Incorporate system bus signal nomenclature and pin assignment changes
February 28, 2013	3.3	MEC connector changed orientation (flipped) on +X -X +Y -Y panels.

DATE	VERSION	SUMMARY
March 28, 2013	3.4	Add second –Z PPOD deploy switch (pin 54), PPOD deploy switches now on TX system card
March 31, 2013	3.41	Updates to the TX, RX, IHU, and BUS pin diagrams.
March 31, 2013	3.42	Adjusted RESERVED pin colors only
April 21, 2013	3.43	Addition of RX Frequency Control, TX Frequency Control, and Sensor Power signals Pin reassignments: Moved pins 52 and 54 to pins 33 and 35 respectively Moved pins 40 and 42 to pins 29 and 42 respectively Added the above new signals to pins 42, 40, and 38 respectively
April 25, 2013	3.5	Update per System Requirements 3.10.2 changes. Updated bus connection pin assignments, bus interconnect diagram, and system bus signal characteristics account removal of TX OSC Temp and TX PA Temp and addition of TX Temperature
June 26, 2013	3.6	Add requirements for PSU and BATT1 CPU reset from RX Command Data, updated IHU block diagram
July 24, 2013	3.7	Add ALERT signal, SENSOR POWER signal, remove RBF2, rename RBF1 to Solar Safe N, remove RX Command Data connection from BATT1, flip MEC connector orientation on +X, -X, +Y, -Y panels, update ME-113 mechanical drawings
August 26, 2013	3.8	Rename RX OSC TEMP to RX Temperature, add Initial Surge Current Limits for certain systems, move Command Decoder to IHU system (bus pin changes), update some bus nomenclature, update System Requirements for each system per changes to the System Requirements
August 27, 2013	3.81	Correct source and destination for RX Command Strobe in Table 1
September 17, 2013	3.82	Add (move) RSSI to Pin 10, rename Pin 32 as RX CD, add Solar Power A and Solar Power B to pins 55 and 56, update TX Block Diagram, remove RX Command Data connection from PSU, update hyperlinks.
October 8, 2013	3.83	Remove IHU AUDIO OUT 2, RX AUDIO 2 signals, rename IHU AUDIO OUT 1 to IHU AUDIO OUT, RX AUDIO 1 to RX AUDIO.
November 11, 2013	3.84	Updated IHU Block Diagram
January 23, 2014	3.85	Add Sensor Power connection to PSU
January 23, 2014	3.86	Several text (requirements) changes to match recent System Requirements change for Safe Mode.
April 27, 2014	3.87	Add PCB plating requirements for TX, RX, IHU, PSU, BATT, EXP systems
May 29, 2014	3.88	Correct 6.7 to read PSU System
August 16, 2014	3.9	Updates to 5.1, 6.1 to match updated system requirements
August 20, 2014	3.91	Correct 5.1 to show 120 seconds for Safe Mode beacon
September 29, 2014	3.92	Update PSU block diagram, add receiver block diagram, update commands in 5.1, update instances of system requirements 3.9.3, 3.9.4, 3.9.6

1.2. Document Scope

The purpose of this document is to specify the avionics systems and their connections to each other and to external components for the satellite. It is intended to be used by the hardware, software, and mechanical designers to develop the architecture and interconnections for the satellite avionics systems.

1.3. Document Format

This document provides these elements in a numbered format. The numbered sections specify each major system in the satellite while numbered items for each system specify the external connections required and the number of lines for each connection. Satellite bus and external connections are further described in figures and tables.

Where System Requirements are reproduced their numbers are from the AMSAT *Fox*-1 System Requirements Specification.

1.4. References

1. AMSAT *Fox-1* ConOps
2. AMSAT *Fox-1* System Requirements Specification
3. AMSAT *Fox-1* Bus (Signal Connections Diagram)
4. AMSAT *Fox-1* Bus Pin Assignment
5. AMSAT *Fox-1* Avionics System Design Specification Spreadsheet
6. AMSAT FOX-ME-120_Z_TOPBOTT_SOLAR_PANEL.pdf
7. AMSAT FOX-ME-127_Y_SIDE_SOLAR_PANEL.pdf

Contents

2 Avionics System Bus Signals, Characteristics, and Connections

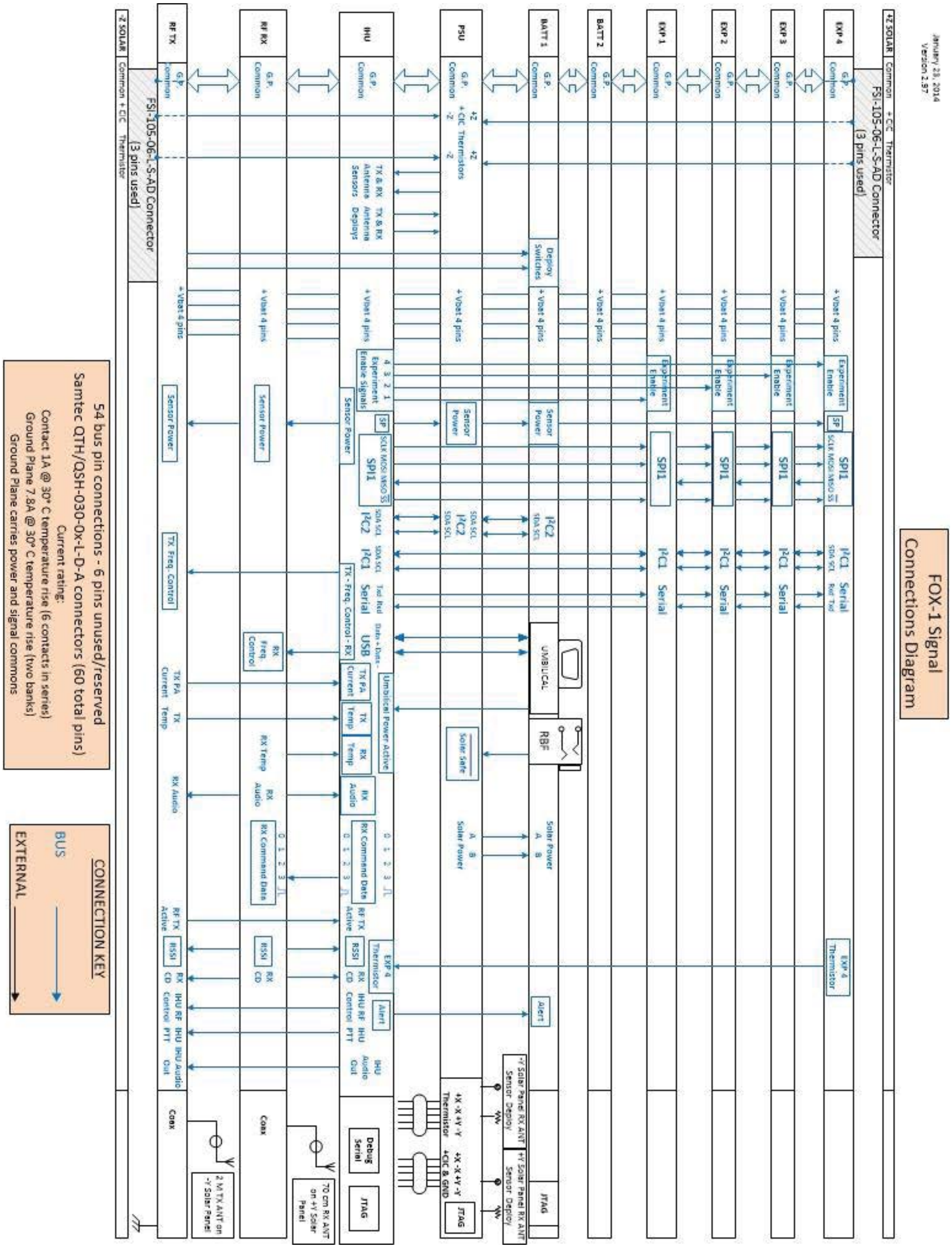


Figure 1: Interconnect Diagram

Table 1: System Bus Signal Characteristics

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Load System	Notes
1	SPI1 NSS	Digital	Note[1]	IHU		EXP 1-4	SPI Standard, IHU Master
2	TX PA Current	Analog	0 - 3.0 V	TX	30 - 60 kΩ	IHU	
3	SPI1 SCK	Digital	Note[1]	IHU		EXP 1-4	SPI Standard, IHU Master
4	TX Temperature	Analog	0 - 3.0 V	TX	30 - 60 kΩ	IHU	Thermistor Circuit
5	SPI1 MISO	Digital	Note[1]	IHU		EXP 1-4	SPI Standard, IHU Master
6	Experiment 4 Thermistor	Analog	N/A	EXP 4	N/A	IHU	Temperature from Experiment 4 position
7	SPI1 MOSI	Digital	Note[1]	IHU		EXP 1-4	SPI Standard, IHU Master
8	RX Temperature	Analog	0 - 3.0 V	RX	30 - 60 kΩ	IHU	Thermistor Circuit
9	Serial RXD	Digital	3.0 V	EXP 1-4		IHU	Async, Mark High
10	RSSI	Analog	0 - 3.0 V	RX	30 - 60 kΩ	IHU	Received Signal Strength Indication
11	Serial TXD	Digital	3.0 V	IHU		EXP 1-4	Async, Mark High
12	IHU Audio Out	Analog	0 - 3 V (audio)	IHU	> 10 kΩ unbal.	TX	For 5 kHz deviation, 10 Hz - 7 kHz bandwidth
13	Experiment Enable 1	Digital		IHU		EXP 1-4	HIGH = Enable EXP 1
14	Not Used						
15	Experiment Enable 2	Digital		IHU		EXP 2	HIGH = Enable EXP 2
16	RX Command Data 0	Digital		IHU			(Least Significant Bit) Not Used on Fox-1A
17	Experiment Enable 3	Digital		IHU		EXP 3	HIGH = Enable EXP 3
18	RX Command Data 1	Digital		IHU			Not Used on Fox-1A
19	Experiment Enable 4	Digital		IHU		EXP 4	HIGH = Enable EXP 4
20	RX Command Data 2	Digital		IHU			HIGH = IHU off
21	Not Used						
22	RX Command Data 3	Digital		IHU		TX	(Most Significan Bit) HIGH = Inhibit Transmit
23	I^{2}C1 SCL	Digital	Note[1]	IHU			I^{2}C Standard, IHU Master
24	RX Command Strobe	Digital		IHU			HIGH = Command Data change
25	I^{2}C1 SDA	Digital	Note[1]	IHU			I^{2}C Standard, IHU Master
26	IHU RF Control	Digital		IHU		TX	HIGH = IHU Controls RF LOW = Standalone Analog Transponder
27	Not Used						
28	IHU PTT	Digital		IHU		TX	HIGH = TRANSMIT
29	Solar Safe N	Switch	N/A	BATT	N/A	PSU	N.O. for operation
30	RF TX Active	Digital		TX		IHU	HIGH = RF TX on
31	Alert Signal	Digital		IHU		BATT	
32	RX CD	Digital		RX		TX IHU	HIGH = valid receive signal
33	-Z Deploy Switch 1	Switch	N/A	TX	N/A	PSU/BATT	N.O. when deployed
34	RX Audio	Analog	0 - 3 V (audio)	RX	> 10 kΩ unbal.	IHU	10 Hz - 7 kHz bandwidth
35	-Z Deploy Switch 2	Switch	N/A	TX	N/A	PSU/BATT	N.O. when deployed
36	Not Used						
37	I^{2}C2 SCL	Digital	Note[1]	IHU		PSU/BATT	I^{2}C Standard, IHU Master
38	Sensor Power	Analog	+3 VDC	IHU		TX RX BATT EXP4	Power for analog telemetry sensors
39	I^{2}C2 SDA	Digital	Note[1]	IHU		PSU/BATT	I^{2}C Standard, IHU Master
40	TX Frequency Control	Digital		IHU		TX	Not Used on Fox-1A
41	+Z Thermistor	Analog	N/A	EXP 4	N/A	PSU	
42	RX Frequency Control	Digital		IHU		RX	Not Used on Fox-1A
43	-Z Thermistor	Analog	N/A	TX	N/A	PSU	
44	-Y Antenna Deploy	Analog	Vbatt	IHU	7 Ω resistor	PSU	
45	+Z CIC	Power	N/A	EXP 4	N/A	PSU	
46	-Y Antenna Sensor	Switch	N/A	PSU	N.O.	IHU	N.O. when deployed
47	-Z CIC	Power	N/A	TX	N/A	PSU	
48	+Y Antenna Sensor	Switch	N/A	PSU	N.O.	IHU	N.O. when deployed
49	Umbilical USBP	Digital		BATT		IHU	USB Standard
50	+Y Antenna Deploy	Analog	Vbatt	IHU	7 Ω resistor	PSU	
51	Umbilical USBM	Digital		BATT		IHU	USB Standard
52	Not Used						
53	Umbilical Power Active	Digital		BATT		IHU	HIGH = Running on Umbilical Port Power
54	Not Used						
55	Solar Power A	Power	Vbatt	PSU		BATT	
56	Solar Power B	Power	Vbatt	PSU		BATT	
57	Vbatt	Power Bus	3.3 - 4.2 VDC	BATT/PSU		ALL	
58	Vbatt	Power Bus	3.3 - 4.2 VDC	BATT/PSU		ALL	
59	Vbatt	Power Bus	3.3 - 4.2 VDC	BATT/PSU		ALL	
60	Vbatt	Power Bus	3.3 - 4.2 VDC	BATT/PSU		ALL	
	Version 2.96						
	Note[1] All SPI and I^{2}C signals are 3.0 V levels			All Digital signals are 3.0 V CMOS logic levels high impedance load unless otherwise noted			

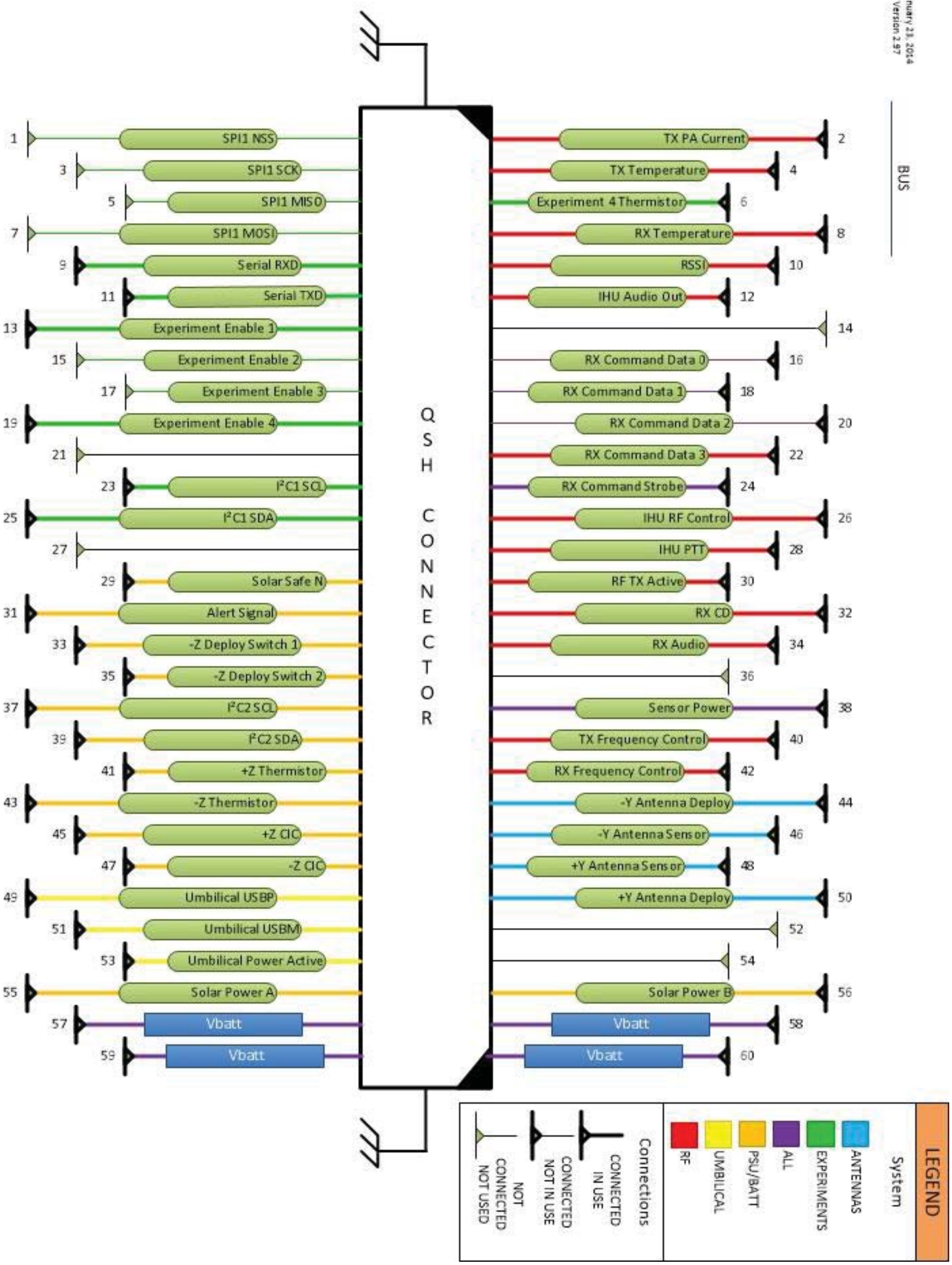


Figure 2: Complete Bus Connection Pin Assignments

3 RF Transmitter System

3.1 System Requirements Applicable to RF Transmitter System

<table>
<tr><td>2.2.1</td><td>The satellite avionics shall be designed for -40C to +70C operating temperature.</td></tr>
<tr><td>2.2.3</td><td>The satellite shall be designed to tolerate the radiation environment in orbit.</td></tr>
<tr><td>2.3.1</td><td>The satellite shall be designed for a minimum 5-year, on-orbit lifetime.</td></tr>
<tr><td>2.4.1</td><td>All RF transmitters shall meet or exceed the requirements specified in the ITU Radio Regulations, Technical Characteristics, Volume 3, article 3.</td></tr>
<tr><td>2.4.3</td><td>All satellite downlinks shall be in the 2 meter band within the amateur satellite service.</td></tr>
<tr><td>2.4.4</td><td>All satellite transmitter and receiver frequencies shall deviate by no more than 5 parts-per-million from the specified values including initial accuracy and temperature variation.</td></tr>
<tr><td>2.4.5</td><td>All satellite frequencies shall be coordinated with the IARU.</td></tr>
<tr><td>3.8.1</td><td>The satellite shall include an FM downlink transmitter.</td></tr>
<tr><td>3.8.2</td><td>The transmitter shall have specifications as shown in Table 2.
<table>
<tr><td>Power Output</td><td>400 mW (min.)</td></tr>
<tr><td>FM Deviation</td><td>5 kHz</td></tr>
<tr><td>Audio Bandwidth</td><td>3 kHz</td></tr>
</table></td></tr>
<tr><td>3.8.3</td><td>The transmitter shall provide a means to prevent over modulation.</td></tr>
<tr><td>3.9.1</td><td>The satellite shall provide an FM transponder via the RF uplink and RF downlink.</td></tr>
<tr><td>3.9.3</td><td>In Transponder Mode, the downlink transmitter shall be keyed (i.e. PTT-on) by the IHU for a minimum of 30 seconds following detection of the 67 Hz CTCSS tone.</td></tr>
<tr><td>3.9.5</td><td>In Transponder Mode, the 67 Hz CTCSS tone is not required for a received signal to be repeated on the downlink, once the transmitter has been keyed.</td></tr>
<tr><td>3.9.7</td><td>In the event of shutdown or failure of the IHU, the satellite shall default to simple carrier operated repeater operation.</td></tr>
<tr><td>3.10.1</td><td>The satellite shall collect telemetry data.</td></tr>
<tr><td>3.10.2</td><td>The telemetry data shall include at a minimum, measured parameters as shown in Table 3.
<table>
<tr><th>Parameter Name</th><th>Description</th></tr>
<tr><td>CELL V</td><td>Voltages of battery cells</td></tr>
<tr><td>PANEL V</td><td>Voltages of solar panels</td></tr>
<tr><td>TOTAL I</td><td>Total DC current out of power system</td></tr>
<tr><td>PA I</td><td>DC current into RF power amp</td></tr>
<tr><td>BATTERY T</td><td>Temperature of battery</td></tr>
<tr><td>PANEL T</td><td>Temperatures of solar panels</td></tr>
<tr><td>TX T</td><td>Temperature of RF transmitter card</td></tr>
</table></td></tr>
</table>

<table>
<tr><td></td><td><table><tr><td>RX T</td><td>Temperature of RF receiver card</td></tr></table></td></tr>
<tr><td>3.10.3</td><td>The measured parameters shall be sampled at least every 15 seconds.</td></tr>
<tr><td>3.11.1</td><td>The satellite shall send slow speed telemetry using FSK on the RF downlink.</td></tr>
<tr><td>3.11.2</td><td>The FSK shall use the frequency spectrum below the audible range.</td></tr>
<tr><td>3.11.3</td><td>The telemetry shall be transmitted simultaneously with any transponder communications.</td></tr>
<tr><td>3.12.1</td><td>The satellite shall provide the means to process commands sent via the RF uplink from a ground control station.</td></tr>
<tr><td>3.12.2</td><td>The commands received via the RF uplink shall not be repeated on the RF downlink.</td></tr>
<tr><td>3.12.3</td><td>The following commands shall be provided, as shown in Table 5.
<table>
<tr><th>Command</th><th>Operation</th></tr>
<tr><td>SAFE MODE</td><td>Enter Safe Mode</td></tr>
<tr><td>INHIBIT</td><td>Inhibit RF transmission</td></tr>
<tr><td>IHU OFF</td><td>Power off IHU & PSU</td></tr>
<tr><td>IHU ON</td><td>Power on IHU & PSU</td></tr>
<tr><td>CLEAR</td><td>Clear stored telemetry</td></tr>
<tr><td>TRANSPONDER MODE</td><td>Enter Transponder Mode</td></tr>
<tr><td>DATA MODE</td><td>Enter Data Mode</td></tr>
</table></td></tr>
<tr><td>3.12.5</td><td>An INHIBIT command shall cause the satellite to cease RF transmissions.</td></tr>
<tr><td>3.13.8</td><td>In Transponder Mode, the transponder and the slow speed telemetry shall be active.</td></tr>
<tr><td>3.13.9</td><td>In Data Mode, the high speed telemetry shall be active and the transponder shall not be active. (i.e. signals that appear on the uplink shall not be repeated on the downlink.)</td></tr>
</table>

3.2 Initial Surge Current Limits

3.2.1 The RF Transmitter design shall limit initial inrush current to 2.5 Amperes.

3.3 Volume Requirements Applicable to RF Transmitter System

3.3.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 5 mm from the –Z surface of the PC board.

3.3.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 6.0 mm from the +Z surface of the PC board.

3.4 Interface Control Documents Applicable to RF Transmitter System

AMSAT *Fox-1* IHU to RF System Interface Control Document

3.5 PCB Plating Requirements Applicable to RF Transmitter System

3.5.1 ENIG then selective flash gold four mounting pads.

3.6 RF Transmitter System PCB Bus Connections

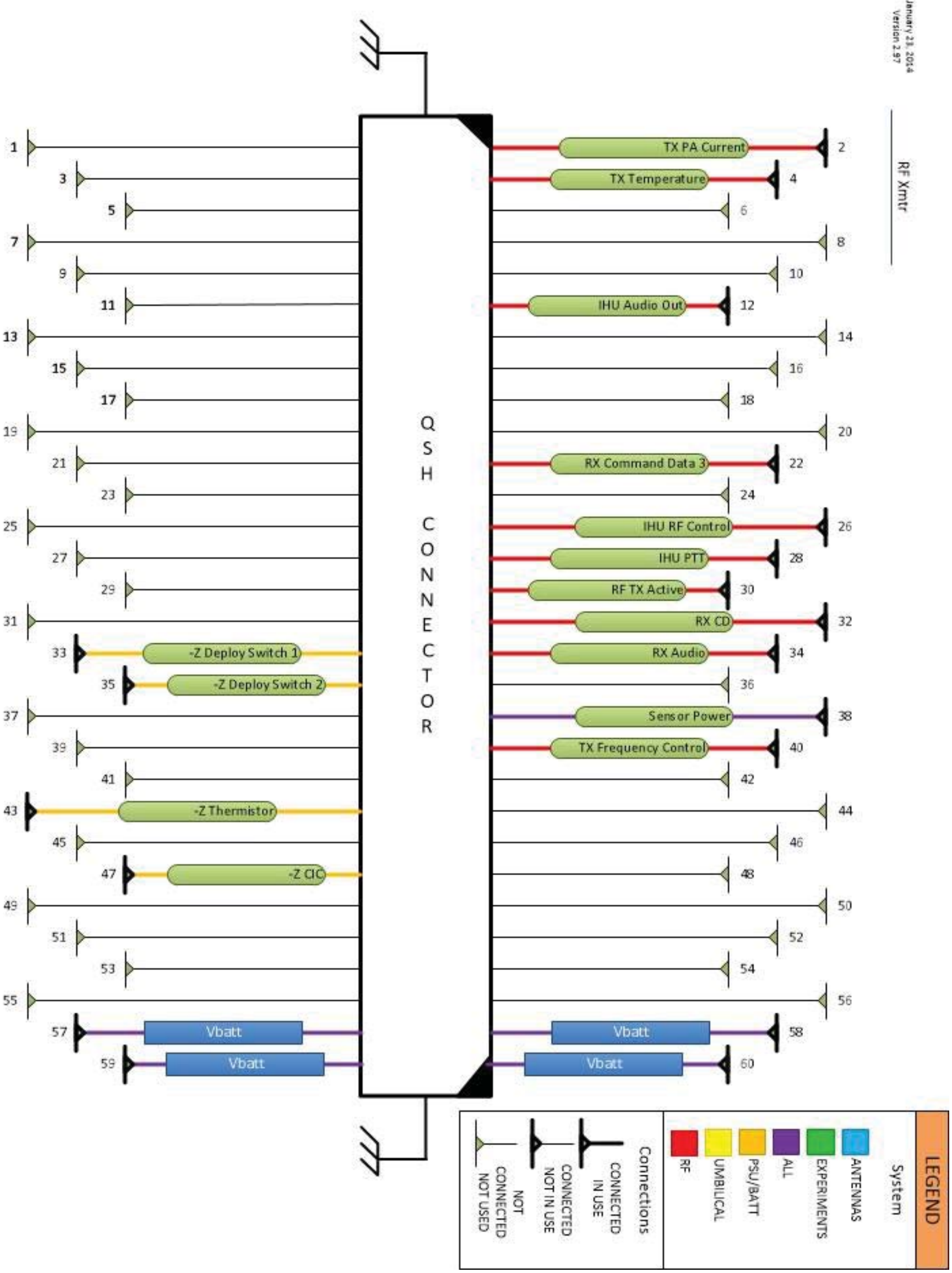


Figure 3: RF Transmitter System Bus Connection Pin Assignments

3.7 RF Transmitter System PCB External Connections

3.7.1 2 meter band RF output, coaxial cable to Transmit Antenna
3.7.2 Spacecraft deployment switches cable(s) TBR
3.7.3 Three connections via Samtec FSI-105-06-L-S-AD connector
  3.7.3.1 1 contact -Z Solar Panel Thermistor
  3.7.3.2 1 contact -Z Solar Panel CIC +
  3.7.3.3 1 contact common or - for above four connections

Table 2: External Connection Signal Characteristics

External Connection	Nomenclature	Type	Voltage/ Power	Source System	Load Z	Bus Pin
Coaxial Cable	2 meter Antenna ≈ 145.9 MHz	RF	0 to +30 dBm	2 meter Antenna	50 Ω unbal.	N/A

Table 3: -Z PCB face FSI-105-06-L-S-AD connector mates to pads on –Z Solar Panel

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Load System	Bus Pin
1	-Z Thermistor	Analog	N/A	N/A	N/A	PSU	43
2	N/C						
3	-Z Solar Panel Common						Ground Plane
4	N/C						
5	-Z CIC	Power	N/A	N/A	N/A	PSU	47

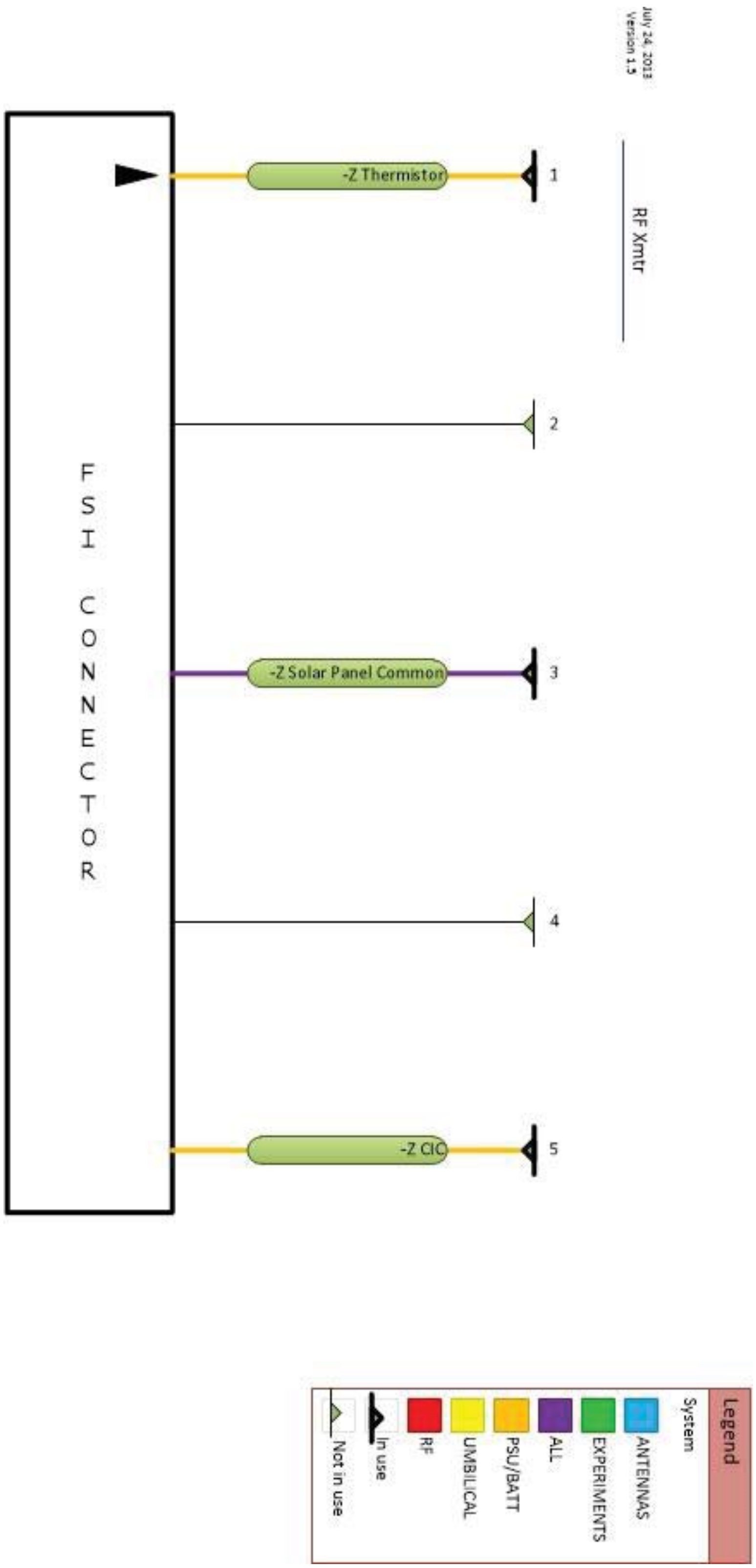


Figure 4: RF Transmitter System FSI-105-06-L-S-AD Connection Pin Assignments

4 RF Receiver System

4.1 System Requirements Applicable to RF Receiver System

<table>
<tr><td>2.2.1</td><td>The satellite avionics shall be designed for -40C to +70C operating temperature.</td></tr>
<tr><td>2.2.3</td><td>The satellite shall be designed to tolerate the radiation environment in orbit.</td></tr>
<tr><td>2.3.1</td><td>The satellite shall be designed for a minimum 5-year, on-orbit lifetime.</td></tr>
<tr><td>2.4.2</td><td>All satellite uplinks shall be in the 70 cm band of the amateur satellite service.</td></tr>
<tr><td>2.4.5</td><td>All satellite frequencies shall be coordinated with the IARU.</td></tr>
<tr><td>3.7.1</td><td>The satellite shall include an FM uplink receiver.</td></tr>
<tr><td>3.7.2</td><td>The receiver shall have specifications as shown in Table 1.
<table>
<tr><td>Sensitivity</td><td>-120 dBm for 12 dB SINAD (min.)</td></tr>
<tr><td>FM Deviation</td><td>5 kHz</td></tr>
<tr><td>Audio Bandwidth</td><td>3 kHz</td></tr>
<tr><td>Input Frequency Acceptance</td><td>Receiver shall accept signals that are off frequency by ±2.5 kHz (min.)</td></tr>
</table></td></tr>
<tr><td>3.8.3</td><td>The transmitter shall provide a means to prevent over modulation.</td></tr>
<tr><td>3.9.1</td><td>The satellite shall provide an FM transponder via the RF uplink and RF downlink.</td></tr>
<tr><td>3.9.7</td><td>In the event of shutdown or failure of the IHU, the satellite shall default to simple carrier operated repeater operation.</td></tr>
<tr><td>3.10.1</td><td>The satellite shall collect telemetry data.</td></tr>
<tr><td>3.10.2</td><td>The telemetry data shall include at a minimum, measured parameters as shown in Table 3.
<table>
<tr><th>Parameter Name</th><th>Description</th></tr>
<tr><td>CELL V</td><td>Voltages of battery cells</td></tr>
<tr><td>PANEL V</td><td>Voltages of solar panels</td></tr>
<tr><td>TOTAL I</td><td>Total DC current out of power system</td></tr>
<tr><td>PA I</td><td>DC current into RF power amp</td></tr>
<tr><td>BATTERY T</td><td>Temperature of battery</td></tr>
<tr><td>PANEL T</td><td>Temperatures of solar panels</td></tr>
<tr><td>TX T</td><td>Temperature of RF transmitter card</td></tr>
<tr><td>RX T</td><td>Temperature of RF receiver card</td></tr>
</table></td></tr>
<tr><td>3.10.3</td><td>The measured parameters shall be sampled at least every 15 seconds.</td></tr>
<tr><td>3.12.2</td><td>The commands received via the RF uplink shall not be repeated on the RF downlink.</td></tr>
<tr><td>3.13.12</td><td>The RF uplink shall be monitored for commands in all modes.</td></tr>
</table>

4.2 Initial Surge Current Limits

4.2.1 The RF Receiver design shall limit initial inrush current to 0.1 Amperes.

4.3 Volume Requirements Applicable to RF Receiver System

4.3.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 1 mm from the –Z surface of the PC board.

4.3.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 6.0 mm from the +Z surface of the PC board.

4.4 Interface Control Documents Applicable to RF Receiver System

AMSAT *Fox-1* IHU to RF System Interface Control Document

4.5 PCB Plating Requirements Applicable to RF Receiver System

4.5.1 ENIG then selective flash gold four mounting pads.

4.6 RF Receiver System PCB Bus Connections

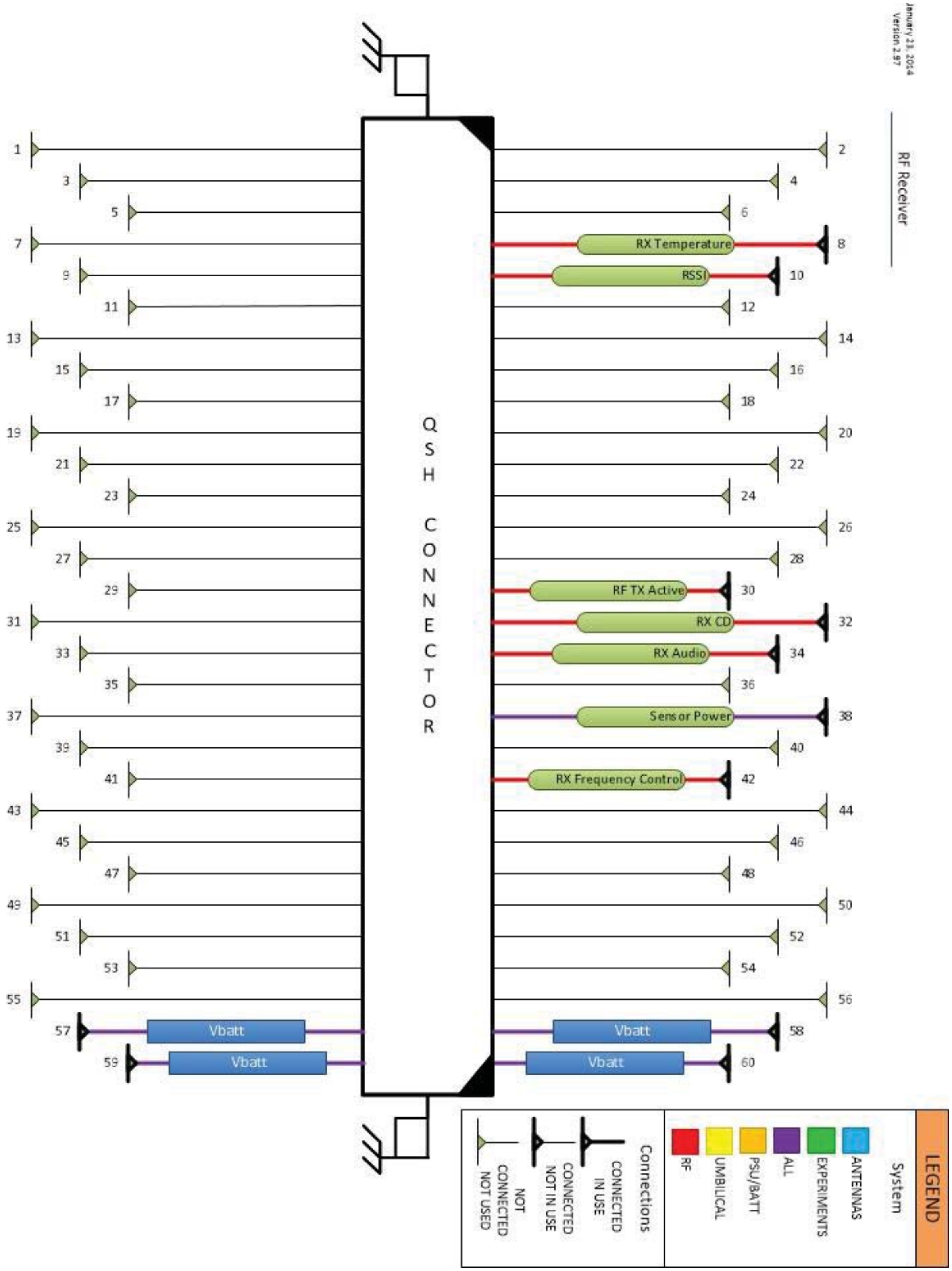


Figure 5: RF Receiver System Bus Connection Pin Assignments

4.7 RF Receiver System PCB External Connections

4.7.1 70cm band RF input, coaxial cable to Receive Antenna

Table 4: RF Receiver System External Connection Signal Characteristics

External Connection	Nomenclature	Type	Voltage/ Power	Source System	Load Z	Bus Pin
Coaxial Cable	70 cm RF Input 437 MHz	RF	-60 dBm to -140 dBm	70 cm Antenna	50 Ω unbal.	N/A

5 Internal Housekeeping Unit (IHU) System

5.1 System Requirements Applicable to Internal Housekeeping Unit (IHU) System

<table>
<tr><td>2.2.1</td><td>The satellite avionics shall be designed for -40C to +70C operating temperature.</td></tr>
<tr><td>2.2.3</td><td>The satellite shall be designed to tolerate the radiation environment in orbit.</td></tr>
<tr><td>2.3.1</td><td>The satellite shall be designed for a minimum 5-year, on-orbit lifetime.</td></tr>
<tr><td>3.3.2</td><td>The satellite shall include an umbilical port as per the CubeSat Design Specification.</td></tr>
<tr><td>3.4.3</td><td>The satellite shall provide the means to run diagnostic tests via the umbilical port while integrated with the P-POD.</td></tr>
<tr><td>3.6.2</td><td>The satellite shall provide a means to activate and deactivate the experiment payloads.</td></tr>
<tr><td>3.6.3</td><td>The satellite shall provide a means to telemeter data from the experiment payloads.</td></tr>
<tr><td>3.9.2</td><td>In Transponder Mode, the IHU shall detect the presence of a 67 Hz CTCSS tone on the uplink.</td></tr>
<tr><td>3.9.3</td><td>In Transponder Mode, the downlink transmitter shall be keyed (i.e. PTT-on) by the IHU for a minimum of 30 seconds following detection of the 67 Hz CTCSS tone.</td></tr>
<tr><td>3.9.4</td><td>In Transponder Mode, the downlink transmitter shall stay on continuously as long as the 67 Hz CTCSS tone is detected at least once during the period the transmitter is being keyed (i.e. PTT-on).</td></tr>
<tr><td>3.9.5</td><td>In Transponder Mode, the 67 Hz CTCSS tone is not required for a received signal to be repeated on the downlink, once the transmitter has been keyed.</td></tr>
<tr><td>3.9.6</td><td>In Transponder Mode, if the downlink transmitter has been un-keyed for a period of 2 minutes, the satellite shall send "HI THIS IS AMATEUR RADIO SATELLITE FOX 1" as a voice announcement on the downlink transmitter.</td></tr>
<tr><td>3.9.7</td><td>In the event of shutdown or failure of the IHU, the satellite shall default to simple carrier operated repeater operation.</td></tr>
<tr><td>3.10.1</td><td>The satellite shall collect telemetry data.</td></tr>
<tr><td>3.10.2</td><td>The telemetry data shall include at a minimum, measured parameters as shown in Table 3.
<table>
<tr><th>Parameter Name</th><th>Description</th></tr>
<tr><td>CELL V</td><td>Voltages of battery cells</td></tr>
<tr><td>PANEL V</td><td>Voltages of solar panels</td></tr>
<tr><td>TOTAL I</td><td>Total DC current out of power system</td></tr>
<tr><td>PA I</td><td>DC current into RF power amp</td></tr>
<tr><td>BATTERY T</td><td>Temperature of battery</td></tr>
<tr><td>PANEL T</td><td>Temperatures of solar panels</td></tr>
<tr><td>TX T</td><td>Temperature of RF transmitter card</td></tr>
<tr><td>RX T</td><td>Temperature of RF receiver card</td></tr>
</table>
</td></tr>
<tr><td>3.10.3</td><td>The measured parameters shall be sampled at least every 15 seconds.</td></tr>
<tr><td>3.10.4</td><td>The minimum and maximum values of each of the measured parameters shall be saved in non-</td></tr>
</table>

volatile memory.

3.10.5 The telemetry data shall also include at a minimum, calculated parameters as shown in Table 4.

Parameter Name	**Description**
UP TIME	Total seconds since avionics power-up or reset
SPIN	Satellite spin rate and direction

3.10.6 A telemetry frame shall include the current measured values, the saved minimum and maximum values, and the current calculated values.

3.11.1 The satellite shall send slow speed telemetry using FSK on the RF downlink.

3.11.2 The FSK shall use the frequency spectrum below the audible range.

3.11.3 The telemetry shall be transmitted simultaneously with any transponder communications.

3.11.4 The telemetry transmission shall include telemetry frames.

3.11.5 The telemetry transmission shall include experiment data.

3.12.1 The satellite shall provide the means to process commands sent via the RF uplink from a ground control station.

3.12.3 The following commands shall be provided, as shown in Table 5.

Command	**Operation**
SAFE MODE	Enter Safe Mode
INHIBIT TX	Inhibit RF transmission
ENABLE TX	Enable RF transmission
IHU OFF	Power off IHU
IHU ON	Power on IHU
CLEAR	Clear stored telemetry
TRANSPONDER MODE	Enter Transponder Mode
DATA MODE	Enter Data Mode
ENABLE AUTO-SAFE	Enable Auto-Safe Mode
DISABLE AUTO-SAFE	Disable Auto-Safe Mode

3.12.4 A SAFE MODE command shall cause the satellite to enter the Safe Mode.

3.12.5 An INHIBIT TX command shall disable the RF transmitter.

3.12.6 An ENABLE TX command shall enable the RF transmitter.

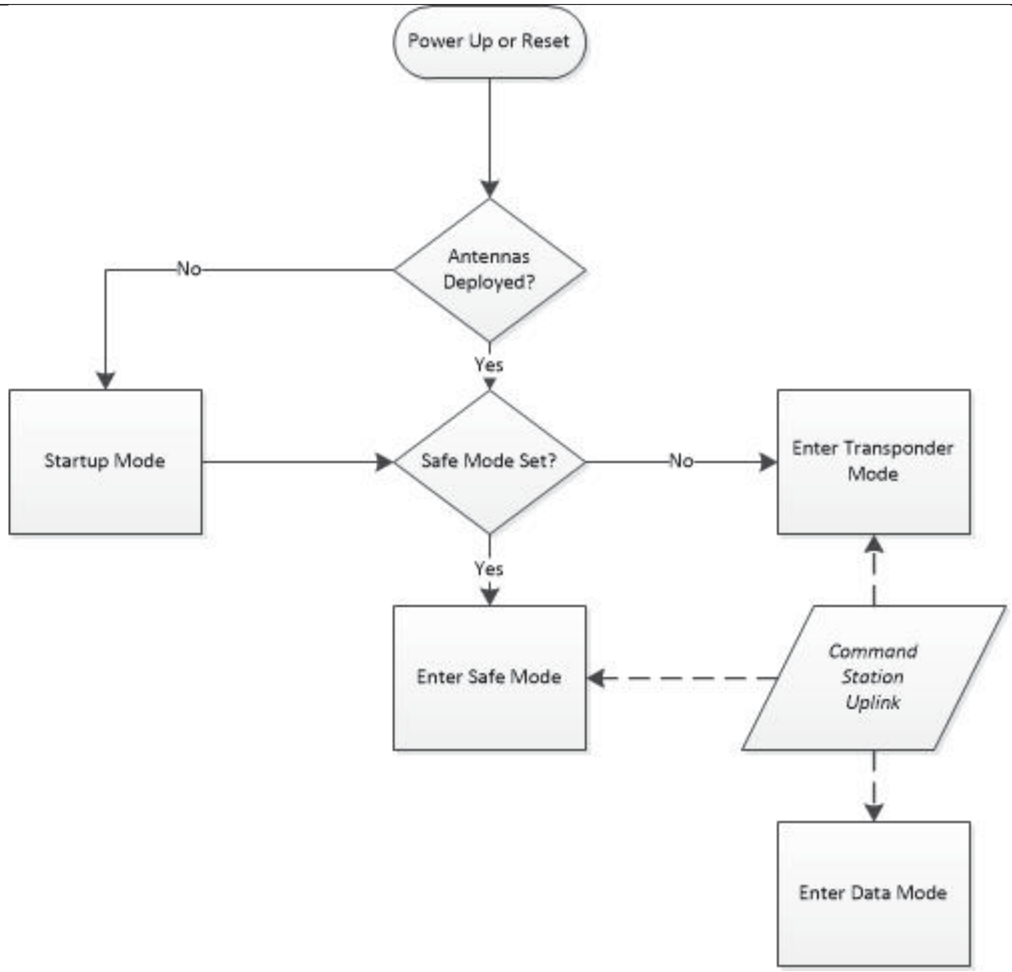
3.12.7 An IHU OFF command shall cause the IHU System to power off.

3.12.8 An IHU ON command shall cause the IHU System to power on.

3.12.9 A CLEAR command shall cause the satellite to clear the saved minimum and maximum telemetry parameter values.

3.12.10 A TRANSPONDER MODE command shall cause the satellite to enter the Transponder Mode.

<table>
<tr><td>3.12.11</td><td>A DATA MODE command shall cause the satellite to enter the Data Mode.</td></tr>
<tr><td>3.12.12</td><td>An ENABLE AUTO-SAFE command shall enable the auto-safe mode state.</td></tr>
<tr><td>3.12.13</td><td>A DISABLE AUTO-SAFE command shall disable the auto-safe mode state.</td></tr>
<tr><td>3.13.1</td><td>The satellite shall provide on-orbit operating modes as shown in Table 6.
<table>
<tr><th>Name</th><th>Description</th></tr>
<tr><td>Startup Mode</td><td>Wait 45 minutes and deploy antennas</td></tr>
<tr><td>Safe Mode</td><td>Wait 120 seconds then begin 10 second beacon sequence</td></tr>
<tr><td>Transponder Mode</td><td>FM transponder; PTT and low speed telemetry via IHU</td></tr>
<tr><td>Data Mode</td><td>FM transmitter; PTT and high speed telemetry via IHU</td></tr>
</table></td></tr>
<tr><td>3.13.2</td><td>The satellite shall transition between modes as shown in Figure 1.</td></tr>
<tr><td>3.13.3</td><td>Upon power-up of the avionics, the satellite shall begin operation from the "Power-up" state as shown in Figure 1.</td></tr>
<tr><td>3.13.4</td><td>An IHU ON Command shall cause the satellite to begin operation from the "Power-up" state as shown in Figure 1.</td></tr>
</table>

	
3.13.5	If the antennas have been deployed, the satellite shall determine whether the last state was Safe Mode.
3.13.5.1	If the last state was Safe Mode the satellite shall enter Safe Mode
3.13.5.2	If the last state was not Safe Mode the satellite shall enter Transponder Mode.
3.13.6	If the antennas have not been deployed, the satellite shall enter the Startup Mode.
3.13.7	In Startup Mode, the satellite shall wait 50 minutes, then deploy the antennas.
3.13.7.1	During the 50 minute wait the IHU shall flash a red LED.
3.13.7.2	During the 50 minute wait the IHU shall sound a 1 kHz beeping tone.
3.13.7.3	After the antennas have been deployed the satellite shall enter Safe Mode.
3.13.8	In Transponder Mode, the transponder and the slow speed telemetry shall be active.
3.13.9	In Data Mode, the high speed telemetry shall be active and the transponder shall not be active. (i.e. signals that appear on the uplink shall not be repeated on the downlink.)
3.13.10	If another Data Mode command is not received, the satellite shall automatically enter Transponder Mode 30 minutes after having entered Data Mode.
3.13.11	In Safe Mode the satellite shall wait 120 seconds then transmit a 10 second beacon.
3.13.11.1	The 120 second wait and 10 second beacon cycle will be repeated as long as the satellite is in Safe Mode.
3.13.12	The RF uplink shall be monitored for commands in all modes.

5.3 Initial Surge Current Limits

5.3.1 The IHU design shall limit initial inrush current to 0.1 Amperes.

5.4 Volume Requirements Applicable to IHU System

5.4.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 1 mm from the –Z surface of the PC board.

5.4.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 6.0 mm from the +Z surface of the PC board.

5.5 Interface Control Documents Applicable to IHU System

AMSAT *Fox-1* IHU to RF System Interface Control Document
AMSAT *Fox-1* IHU to PSU Interface Control Document
AMSAT *Fox-1* IHU to Battery Interface Control Document
AMSAT *Fox-1* IHU to Attitude Determination Experiment Interface Control Document
AMSAT *Fox-1* IHU to Experiment 1 Interface Control Document
AMSAT *Fox-1* IHU to Experiment 4 Interface Control Document

5.6 PCB Plating Requirements Applicable to IHU System

5.6.1 ENIG then selective flash gold four mounting pads.

5.7 Internal Housekeeping Unit (IHU) System PCB Bus Connections

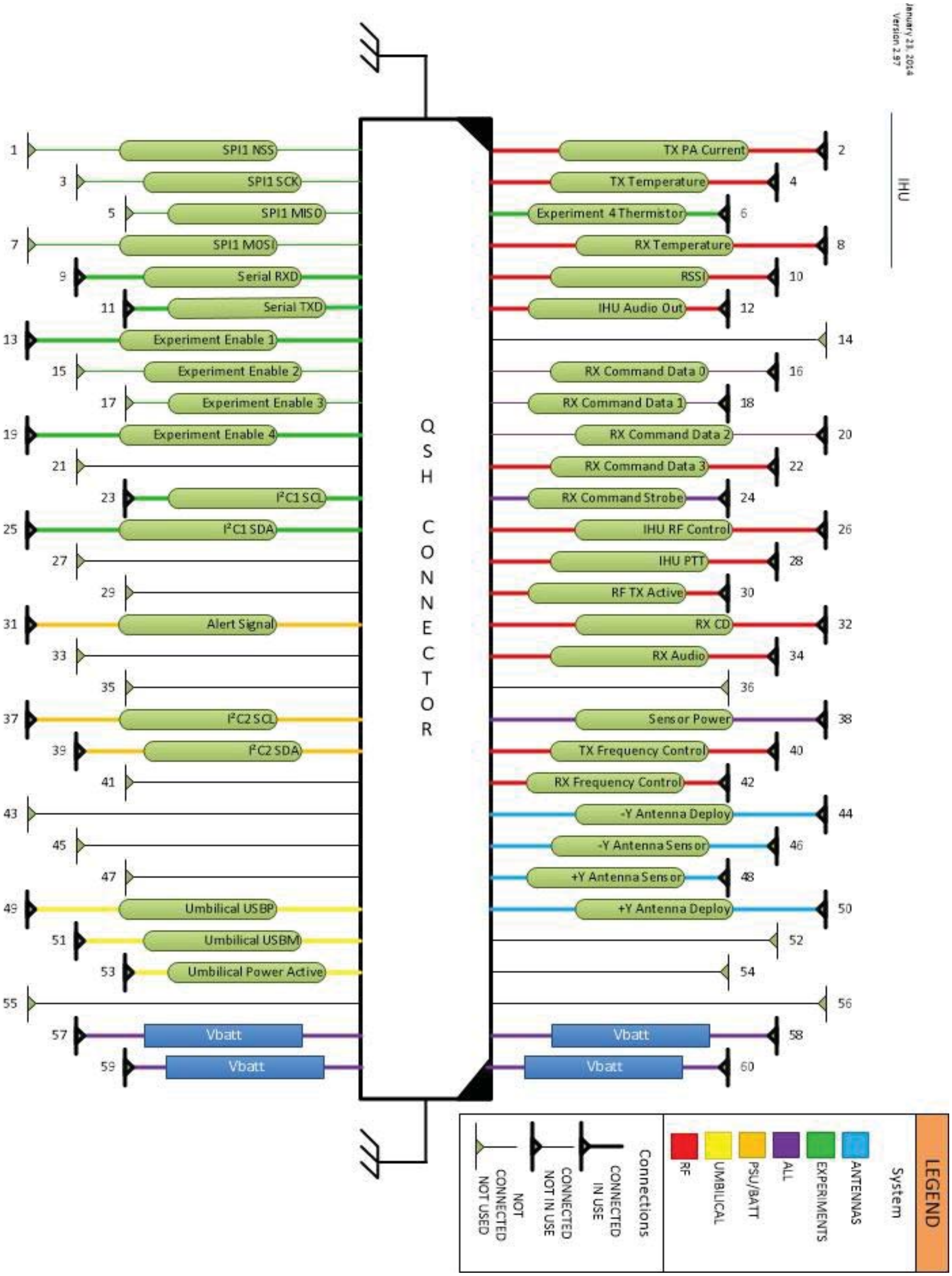


Figure 6: IHU System Bus Connection Pin Assignments

6 Power Supply System (PSU)

6.1 System Requirements Applicable to Power Supply System (PSU)

<table>
<tr><td>2.2.1</td><td>The satellite avionics shall be designed for -40C to +70C operating temperature.</td></tr>
<tr><td>2.2.3</td><td>The satellite shall be designed to tolerate the radiation environment in orbit.</td></tr>
<tr><td>2.3.1</td><td>The satellite shall be designed for a minimum 5-year, on-orbit lifetime.</td></tr>
<tr><td>3.3.1</td><td>The satellite shall include a "Remove Before Flight" pin as per the CubeSat Design Specification.</td></tr>
<tr><td>3.4.1</td><td>The satellite battery and photovoltaic panels shall be electronically disconnected from the avionics when the "Remove Before Flight" pin is inserted, regardless of the state of the deployment switch(es).</td></tr>
<tr><td>3.4.2</td><td>The satellite shall provide the means to charge the battery via the umbilical port while integrated with the P-POD.</td></tr>
<tr><td>3.5.1</td><td>The satellite shall produce electrical power from sunlight.</td></tr>
<tr><td>3.5.2</td><td>The satellite shall produce electrical power while in sunlight regardless of orientation and while tumbling or spinning.</td></tr>
<tr><td>3.5.3</td><td>The satellite shall produce sufficient average electrical power to operate continuously in the orbit of maximum eclipse.</td></tr>
<tr><td>3.5.4</td><td>The satellite shall provide sufficient battery capacity to operate continuously in the orbit of maximum eclipse.</td></tr>
<tr><td>3.6.1</td><td>The satellite shall provide DC power for experiment payloads.</td></tr>
<tr><td>3.10.1</td><td>The satellite shall collect telemetry data.</td></tr>
<tr><td>3.10.2</td><td>The telemetry data shall include at a minimum, measured parameters as shown in Table 3.
<table>
<tr><th>Parameter Name</th><th>Description</th></tr>
<tr><td>CELL V</td><td>Voltages of battery cells</td></tr>
<tr><td>PANEL V</td><td>Voltages of solar panels</td></tr>
<tr><td>TOTAL I</td><td>Total DC current out of power system</td></tr>
<tr><td>PA I</td><td>DC current into RF power amp</td></tr>
<tr><td>BATTERY T</td><td>Temperature of battery</td></tr>
<tr><td>PANEL T</td><td>Temperatures of solar panels</td></tr>
<tr><td>TX T</td><td>Temperature of RF transmitter card</td></tr>
<tr><td>RX T</td><td>Temperature of RF receiver card</td></tr>
</table></td></tr>
<tr><td>3.10.3</td><td>The measured parameters shall be sampled at least every 15 seconds.</td></tr>
<tr><td>3.13.7.1</td><td>During the 45 minute wait the IHU shall flash a red LED.</td></tr>
</table>

6.2 Initial Surge Current Limits

6.2.1 The PSU design shall limit initial inrush current to 0.1 Amperes.

6.3 Volume Requirements Applicable to PSU System

6.3.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 1 mm from the –Z surface of the PC board.

6.3.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 3.0 mm from the +Z surface of the PC board within the area 0 to 4.0 mm from the +Y and +X edges of the board, and 6.0 mm from the +Z surface of the PC board in the rest of the board area.

6.4 Interface Control Documents Applicable to PSU System

AMSAT *Fox-1* IHU to PSU Interface Control Document

6.5 PCB Plating Requirements Applicable to PSU System

6.5.1 ENIG then selective flash hard gold 30 micro-inch four mounting pads and four edge fingers.

6.6 Power Supply System (PSU) PCB Bus Connections

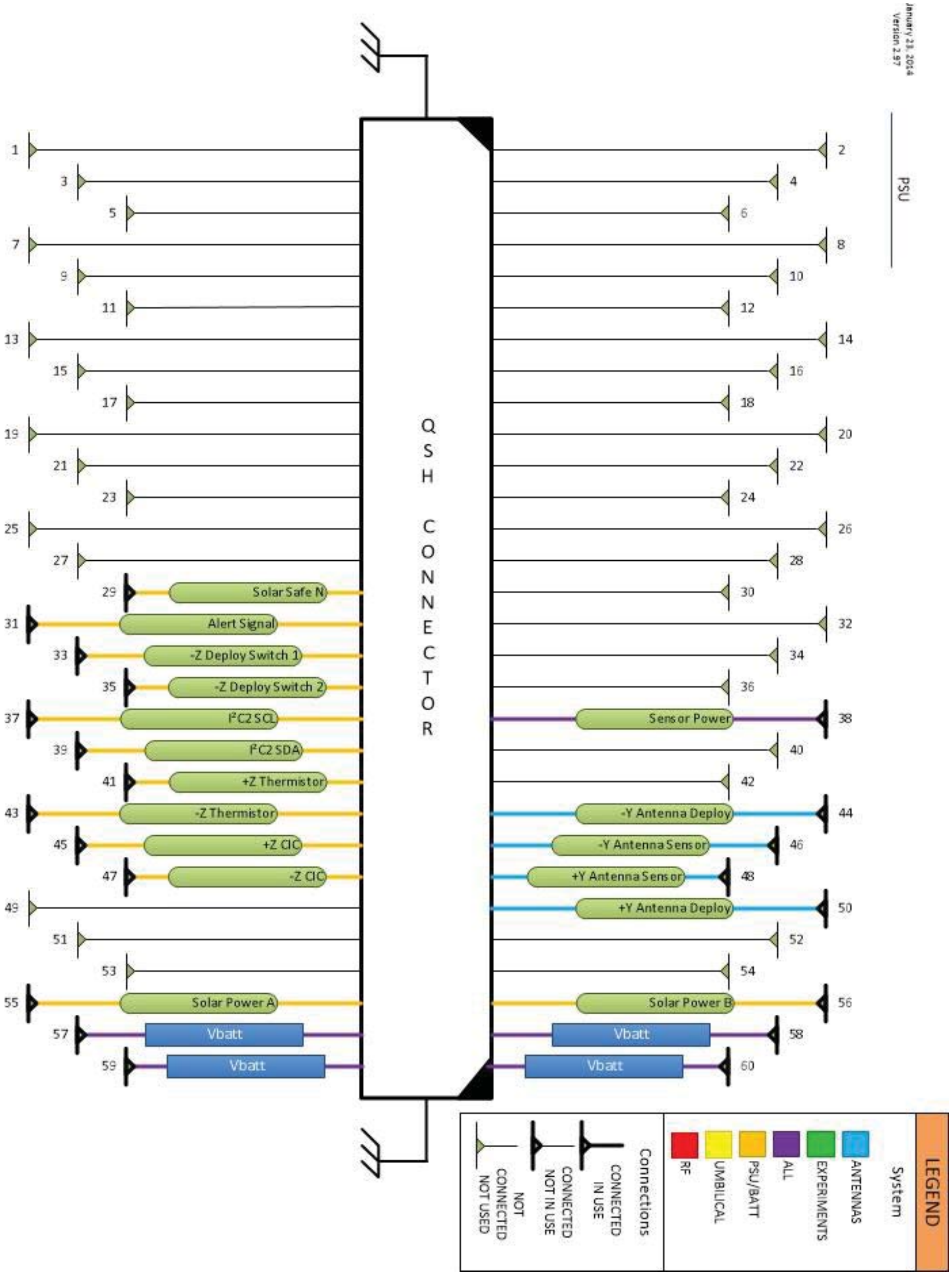


Figure 7: PSU Bus Connection Pin Assignments

6.7 Power Supply System (PSU) PCB External Connections

6.7.1 Three connections to +X Solar Panel using Samtec MEC1-105-02-L-D-NP-A connector
  6.7.1.1 1 contact +X Solar Panel Thermistor
  6.7.1.2 1 contact +X Solar Panel CIC +
  6.7.1.3 1 contact common or - for above two connections
6.7.2 Three connections to -X Solar Panel using Samtec MEC1-105-02-L-D-NP-A connector
  6.7.2.1 1 contact -X Solar Panel Thermistor
  6.7.2.2 1 contact -X Solar Panel CIC +
  6.7.2.3 1 contact common or - for above two connections
6.7.3 Five connections to +Y Solar Panel using Samtec MEC1-105-02-L-D-NP-A connector
  6.7.3.1 1 contact +Y Solar Panel Thermistor
  6.7.3.2 1 contact +Y Solar Panel CIC +
  6.7.3.3 1 contact TX Antenna Deploy
  6.7.3.4 1 contact TX Antenna Sensor
  6.7.3.5 1 contact common or - for above connections
6.7.4 Five connections to -Y Solar Panel using Samtec MEC1-105-02-L-D-NP-A connector
  6.7.4.1 1 contact -Y Solar Panel Thermistor
  6.7.4.2 1 contact -Y Solar Panel CIC +
  6.7.4.3 1 contact RX Antenna Deploy
  6.7.4.4 1 contact RX Antenna Sensor
  6.7.4.5 1 contact common or - for above connections
6.7.5 All PCB edges that connect to solar panel MEC1-105-02-L-D-NP-A connectors shall have contact pads on the PCB for all connector pins, whether connected to a trace or not.

Table 5: +X PCB edge mates to MEC1-105-02-L-D-NP-A connector on +X Solar Panel

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Bus Pin
1	N/C					
2	+X Solar Panel Thermistor	Analog	N/A	N/A	N/A	N/A
3	N/C					
4	N/C					
5	N/C					
6	+X Solar Panel Common					Ground Plane
7	N/C					
8	N/C					
9	N/C					
10	+X Solar Panel CIC (+)	Power	N/A	N/A	N/A	N/A

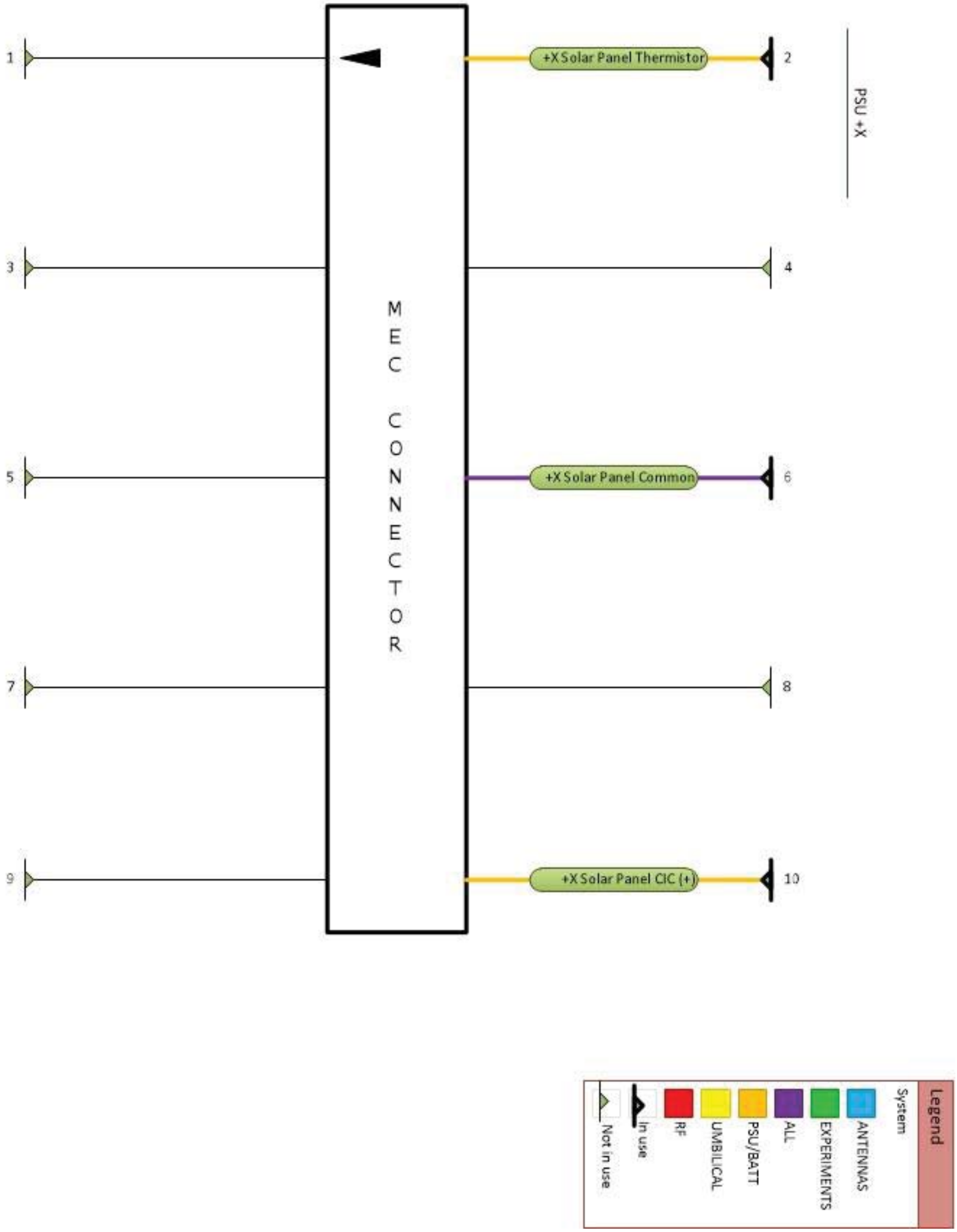


Figure 8: PSU System +X Edge MEC1-105-02-L-D-NP-A Connection Pin Assignments

Table 6: -X PCB edge mates to MEC1-105-02-L-D-NP-A connector on -X Solar Panel

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Bus Pin
1	N/C					
2	-X Solar Panel Thermistor	Analog	N/A	N/A	N/A	N/A
3	N/C					
4	N/C					
5	N/C					
6	-X Solar Panel Common					Ground Plane
7	N/C					
8	N/C					
9	N/C					
10	-X Solar Panel CIC (+)	Power	N/A	N/A	N/A	N/A

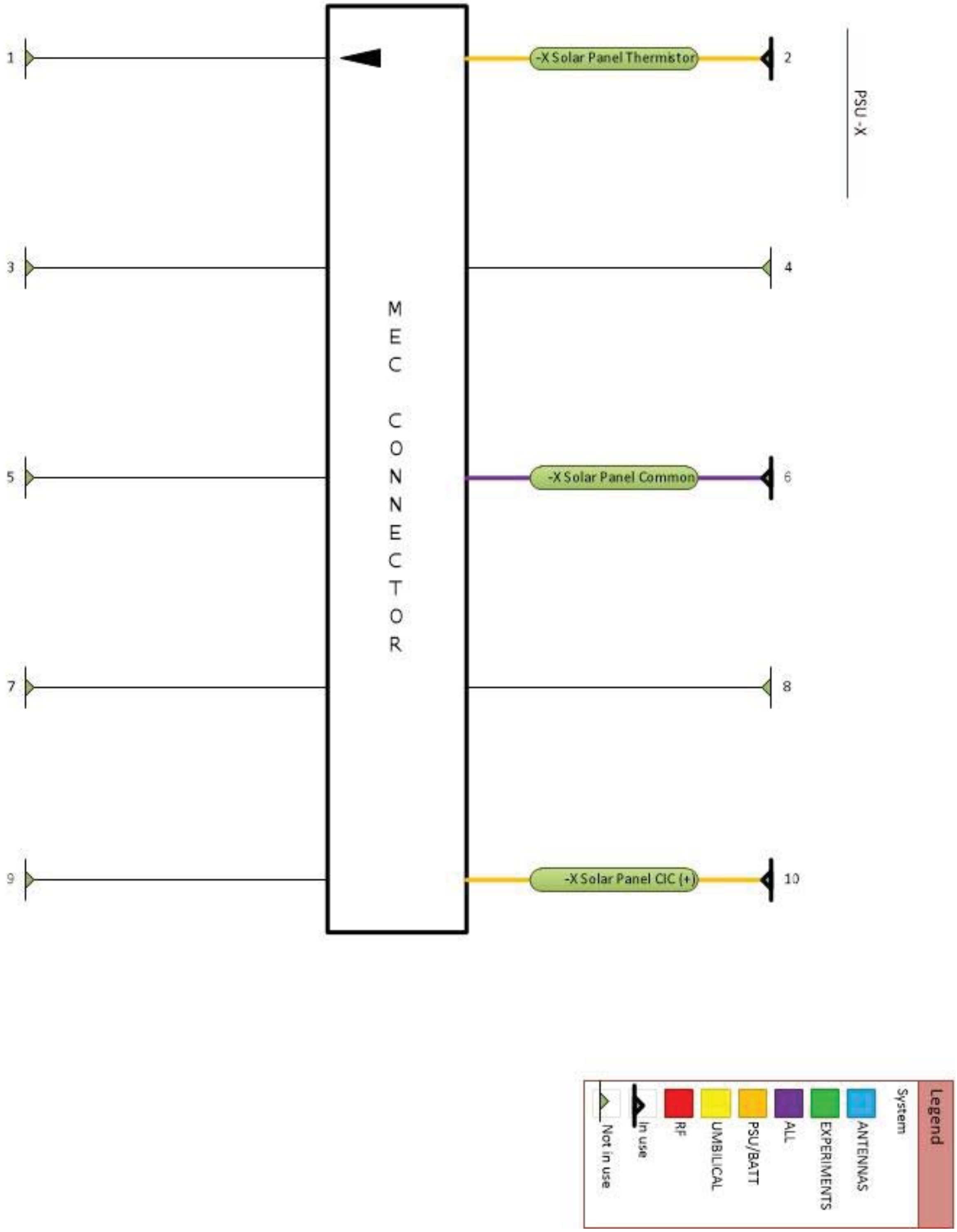


Figure 9: PSU System -X Edge MEC1-105-02-L-D-NP-A Connection Pin Assignments

Table 7: +Y PCB edge mates to MEC1-105-02-L-D-NP-A connector on +Y Solar Panel

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Bus Pin
1	N/C					
2	+Y Solar Panel Thermistor	Analog	N/A	N/A	N/A	N/A
3	N/C					
4	+Y Antenna Sensor	Switch	N/A	PSU	N.O.	48
5	N/C					
6	+Y Solar Panel Common					Ground Plane
7	N/C					
8	+Y Antenna Deploy	Analog	Vbatt	IHU	7 Ω resistor	50
9	N/C					
10	+Y Solar Panel CIC (+)	Power	N/A	N/A	N/A	N/A

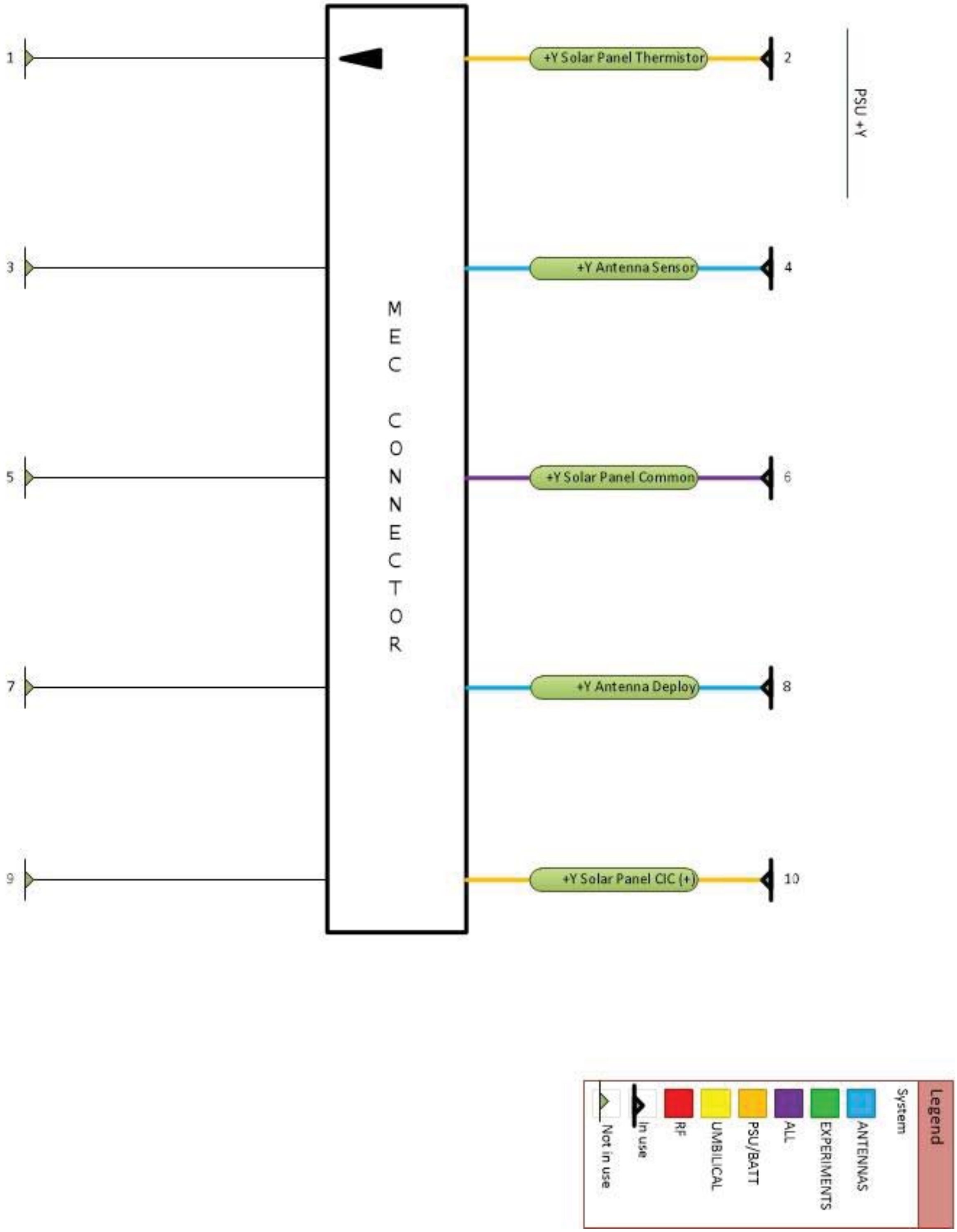


Figure 10: PSU System +Y Edge MEC1-105-02-L-D-NP-A Connection Pin Assignments

Table 8: -Y PCB edge mates to MEC1-105-02-L-D-NP-A connector on -Y Solar Panel

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Bus Pin
1	N/C					
2	-Y Solar Panel Thermistor	Analog	N/A	N/A	N/A	N/A
3	N/C					
4	-Y Antenna Sensor	Switch	N/A	PSU	N.O.	46
5	N/C					
6	-Y Solar Panel Common					Ground Plane
7	N/C					
8	-Y Antenna Deploy	Analog	Vbatt	IHU	7 Ω resistor	44
9	N/C					
10	-Y Solar Panel CIC (+)	Power	N/A	N/A	N/A	N/A

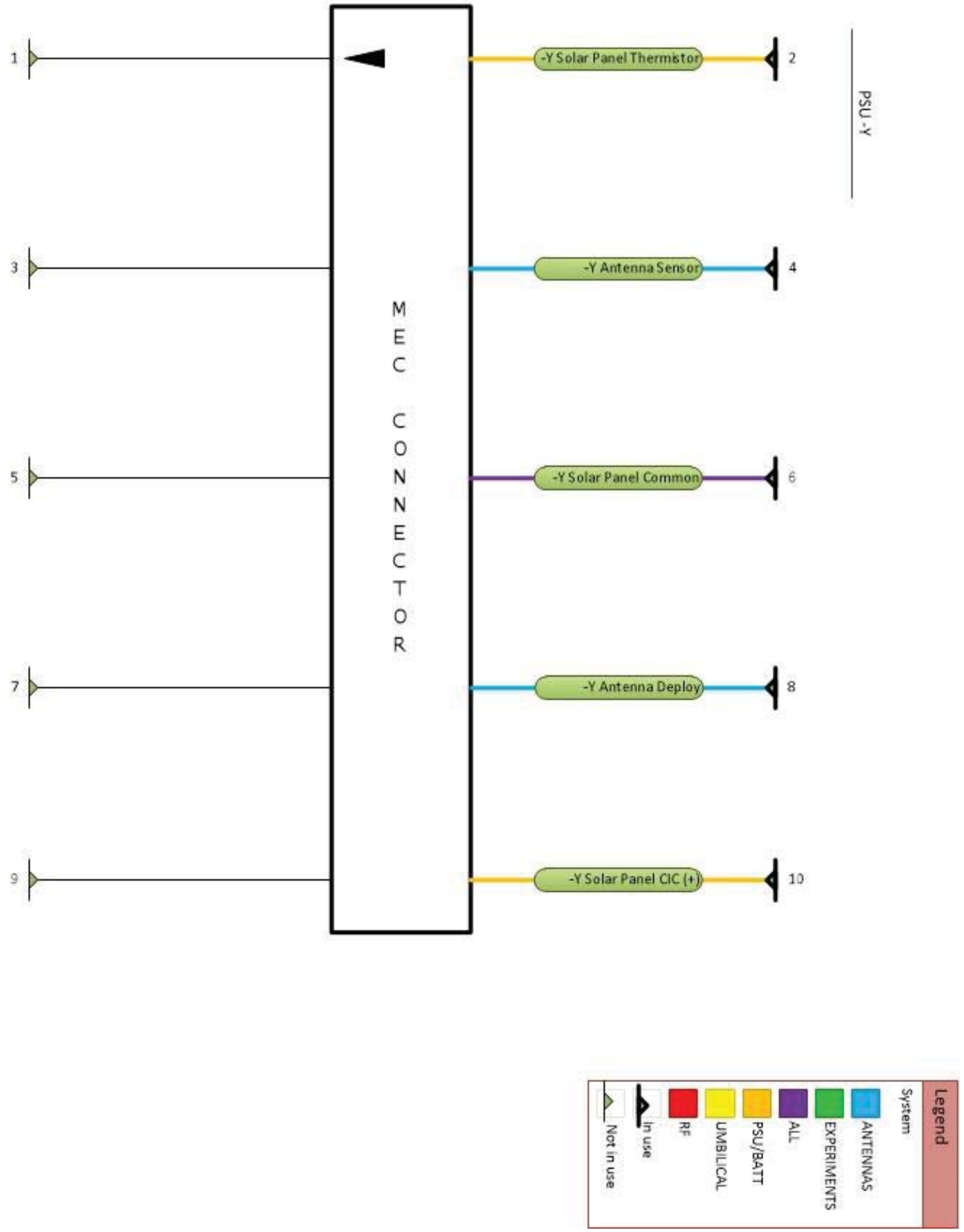


Figure 11: PSU System -Y Edge MEC1-105-02-L-D-NP-A Connection Pin Assignments

7 Battery System

7.1 System Requirements Applicable to Battery PCB 1 System (BATT1)

<table>
<tr><td>2.2.1</td><td>The satellite avionics shall be designed for -40C to +70C operating temperature.</td></tr>
<tr><td>2.2.3</td><td>The satellite shall be designed to tolerate the radiation environment in orbit.</td></tr>
<tr><td>2.3.1</td><td>The satellite shall be designed for a minimum 5-year, on-orbit lifetime.</td></tr>
<tr><td>3.3.1</td><td>The satellite shall include a "Remove Before Flight" pin as per the CubeSat Design Specification.</td></tr>
<tr><td>3.4.1</td><td>The satellite battery and photovoltaic panels shall be electronically disconnected from the avionics when the "Remove Before Flight" pin is inserted, regardless of the state of the deployment switch(es).</td></tr>
<tr><td>3.4.2</td><td>The satellite shall provide the means to charge the battery via the umbilical port while integrated with the P-POD.</td></tr>
<tr><td>3.5.3</td><td>The satellite shall produce sufficient average electrical power to operate continuously in the orbit of maximum eclipse.</td></tr>
<tr><td>3.5.4</td><td>The satellite shall provide sufficient battery capacity to operate continuously in the orbit of maximum eclipse.</td></tr>
<tr><td>3.10.1</td><td>The satellite shall collect telemetry data.</td></tr>
<tr><td>3.10.2</td><td>The telemetry data shall include at a minimum, measured parameters as shown in Table 3.
<table>
<tr><th>Parameter Name</th><th>Description</th></tr>
<tr><td>CELL V</td><td>Voltages of battery cells</td></tr>
<tr><td>PANEL V</td><td>Voltages of solar panels</td></tr>
<tr><td>TOTAL I</td><td>Total DC current out of power system</td></tr>
<tr><td>PA I</td><td>DC current into RF power amp</td></tr>
<tr><td>BATTERY T</td><td>Temperature of battery</td></tr>
<tr><td>PANEL T</td><td>Temperatures of solar panels</td></tr>
<tr><td>TX T</td><td>Temperature of RF transmitter card</td></tr>
<tr><td>RX T</td><td>Temperature of RF receiver card</td></tr>
</table></td></tr>
<tr><td>3.10.3</td><td>The measured parameters shall be sampled at least every 15 seconds.</td></tr>
</table>

7.2 Volume Requirements Applicable to Battery PCB 1 System

7.2.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 4.0 mm from the -Z surface of the PC board within the area 0 to 4.0 mm from the +Y and +X edges of the board, and 1.0 mm from the -Z surface of the PC board in the rest of the board area.

7.2.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 17.0 mm from the +Z surface of the PC board.

7.3 Interface Control Documents Applicable to Battery PCB 1 System

AMSAT *Fox-1* IHU to Battery Interface Control Document

7.4 PCB Plating Requirements Applicable to Battery PCB 1 System

7.4.1 ENIG then selective flash gold four mounting pads.

7.5 Battery PCB 1 System Bus Connections

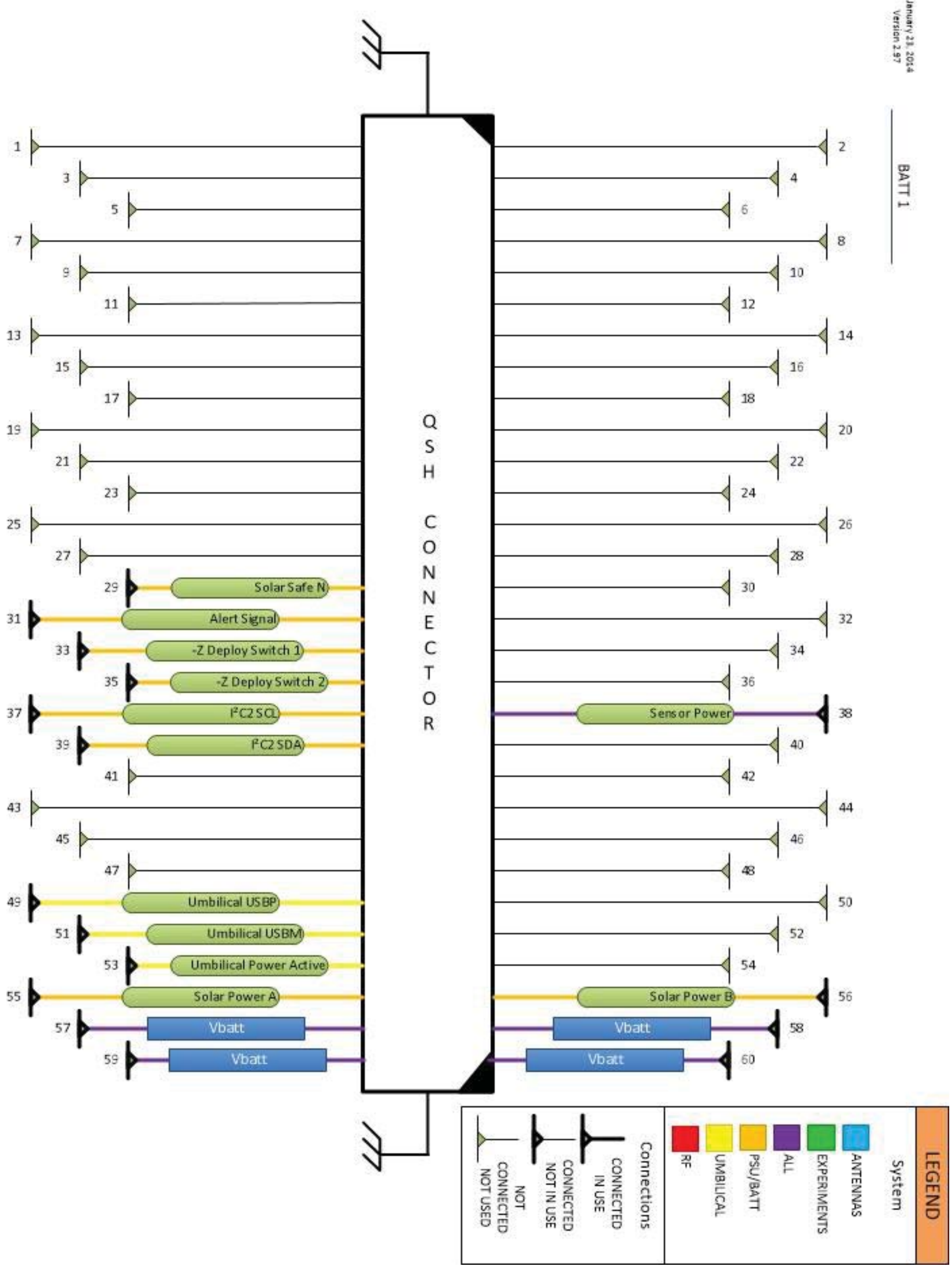


Figure 12: Battery 1 System Bus Connection Pin Assignments

7.6 Battery PCB 1 System External Connections

7.6.1 Umbilical as USB mini type B receptacle
7.6.2 Remove Before Flight as 3.5mm normally open TS jack

Table 9: Battery 1 External Connection Signal Characteristics

External Connection	Nomenclature	Type	Voltage/ Power	Source System	Load Z	Bus Pin
USB 1	USB +5 VDC	Analog	5 VDC	USB CONNECTOR	N/A	N/A
USB 2	USB Data - (USBM)	Digital	3.0 V CMOS logic	USB CONNECTOR	N/A	51
USB 3	USB Data + (USBP)	Digital	3.0 V CMOS logic	USB CONNECTOR	N/A	49
USB 4	Ground			USB CONNECTOR	N/A	Ground Plane
RBF 1	Solar Safe N	Analog	N/A	3.5mm N.O. TS jack	N/A	40

*When external supply is connected to USB port

7.7 Battery PCB 2 System Bus Connections

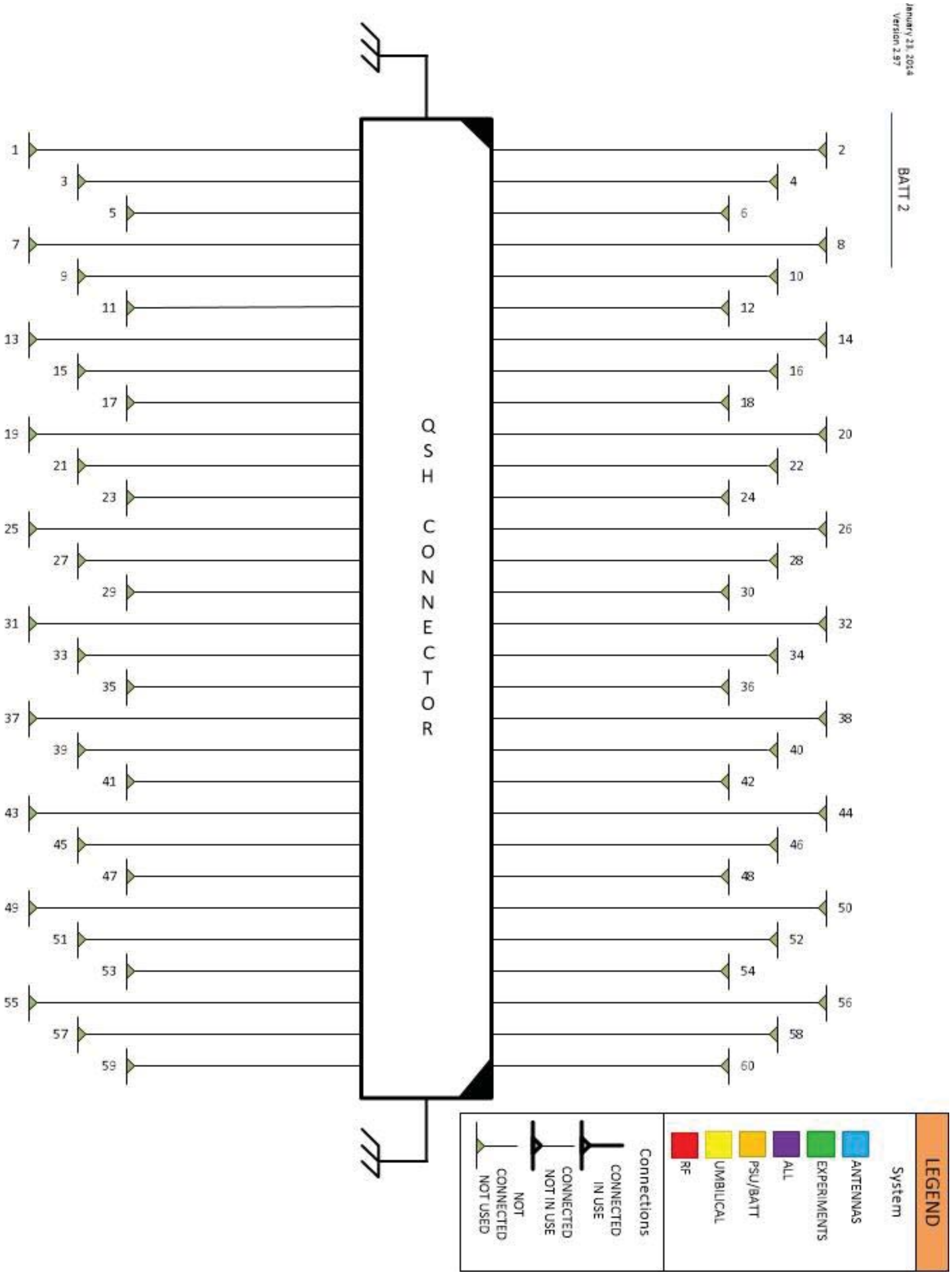


Figure 13: Battery 2 Bus Connection Pin Assignments

8 Experiment Payload Systems 1 through 4

8.1 System Requirements Applicable to Experiment Payload Systems 1-4

2.1.4	The satellite shall provide mass for an experiment payload up to 100 g.
2.1.5	The satellite shall provide volume for an experiment payload up to 95 x 95 x 15.7 mm.
2.2.1	The satellite avionics shall be designed for -40C to +70C operating temperature.
2.2.3	The satellite shall be designed to tolerate the radiation environment in orbit.
2.3.1	The satellite shall be designed for a minimum 5-year, on-orbit lifetime.
3.6.1	The satellite shall provide DC power for experiment payloads.
3.6.2	The satellite shall provide a means to activate and deactivate the experiment payloads.
3.6.3	The satellite shall provide a means to telemeter data from the experiment payloads.

8.2 Initial Surge Current Limits

8.2.1 All Experiment designs shall limit initial inrush current to 0.1 Amperes.

8.3 Volume Requirements Applicable to Experiment Payload System 1

8.3.1 No components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall protrude from the –Z surface of the PC board.

8.3.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 6.0 mm from the +Z surface of the PC board.

8.4 Interface Control Documents Applicable to Experiment 1 Payload System

AMSAT *Fox-1* IHU to Experiment 1 Interface Control Document

8.5 Volume Requirements Applicable to Experiment Payload Systems 2 and 3

8.5.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 1 mm from the –Z surface of the PC board.

8.5.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 6.0 mm from the +Z surface of the PC board.

8.6 Volume Requirements Applicable to Experiment System 4

8.6.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 1 mm from the –Z surface of the PC board.

8.6.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 5.0 mm from the +Z surface of the PC board.

8.7 Interface Control Documents Applicable to Experiment 4 Payload System

AMSAT *Fox-1* IHU to Experiment 4 Interface Control Document

8.8 PCB Plating Requirements Applicable to Experiment 1 Payload System

8.8.1 ENIG then selective flash gold four mounting pads. ENIG only will also be accepted if already fabricated.

8.9 PCB Plating Requirements Applicable to Experiment 2 Payload System

8.9.1 ENIG then selective flash gold four mounting pads. ENIG only will also be accepted if already fabricated.

8.10 PCB Plating Requirements Applicable to Experiment 3 Payload System

8.10.1 ENIG then selective flash gold four mounting pads. ENIG only will also be accepted if already fabricated.

8.11 PCB Plating Requirements Applicable to Experiment 4 Payload System

8.11.1 ENIG then selective flash gold four mounting pads..

8.12 Experiment Payload 1 Systems PCB Bus Connections

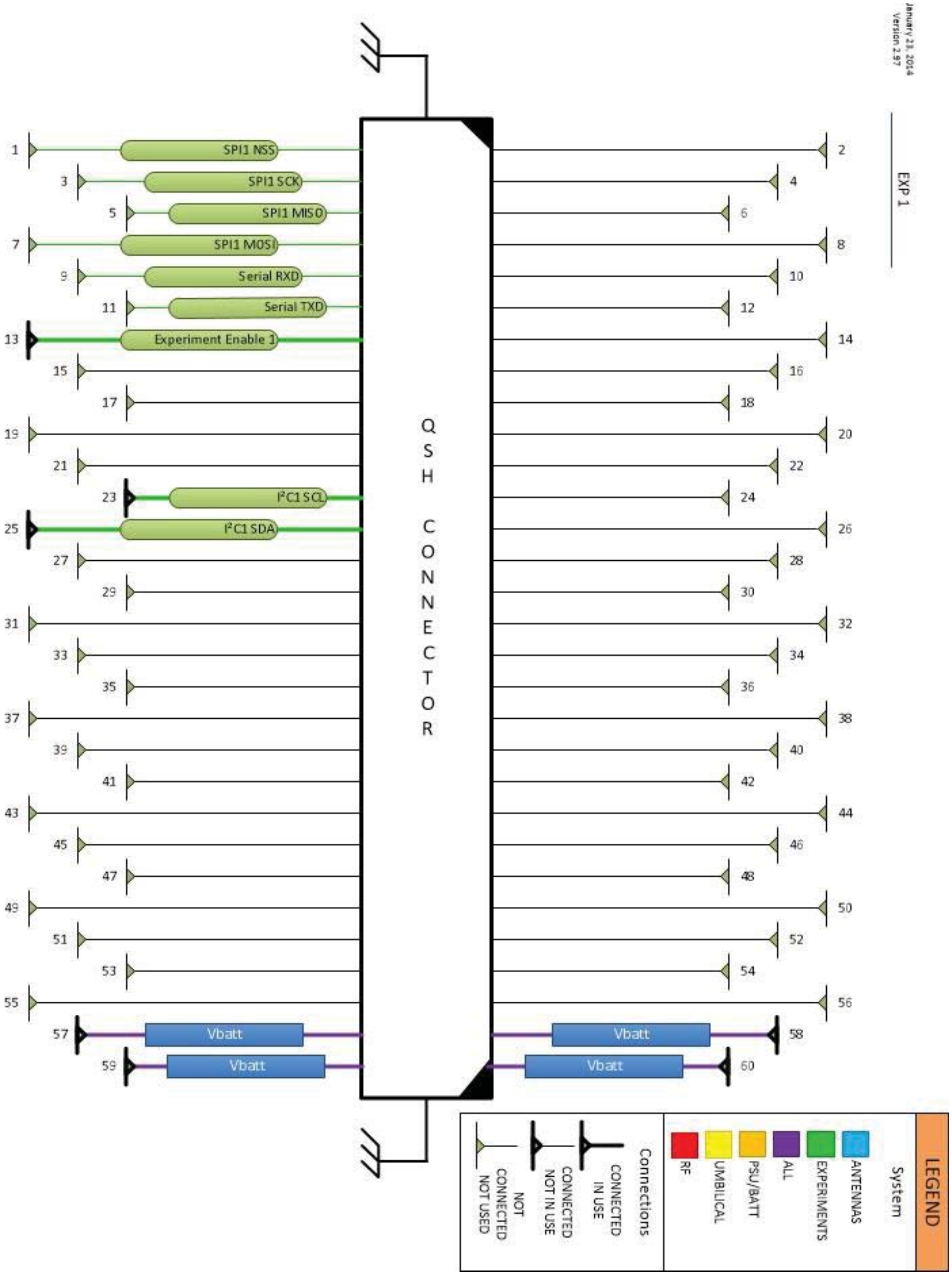


Figure 14: Experiment Payload 1-3 Systems Bus Connection Pin Assignments

8.13 Experiment Payload 4 System PCB Bus Connections

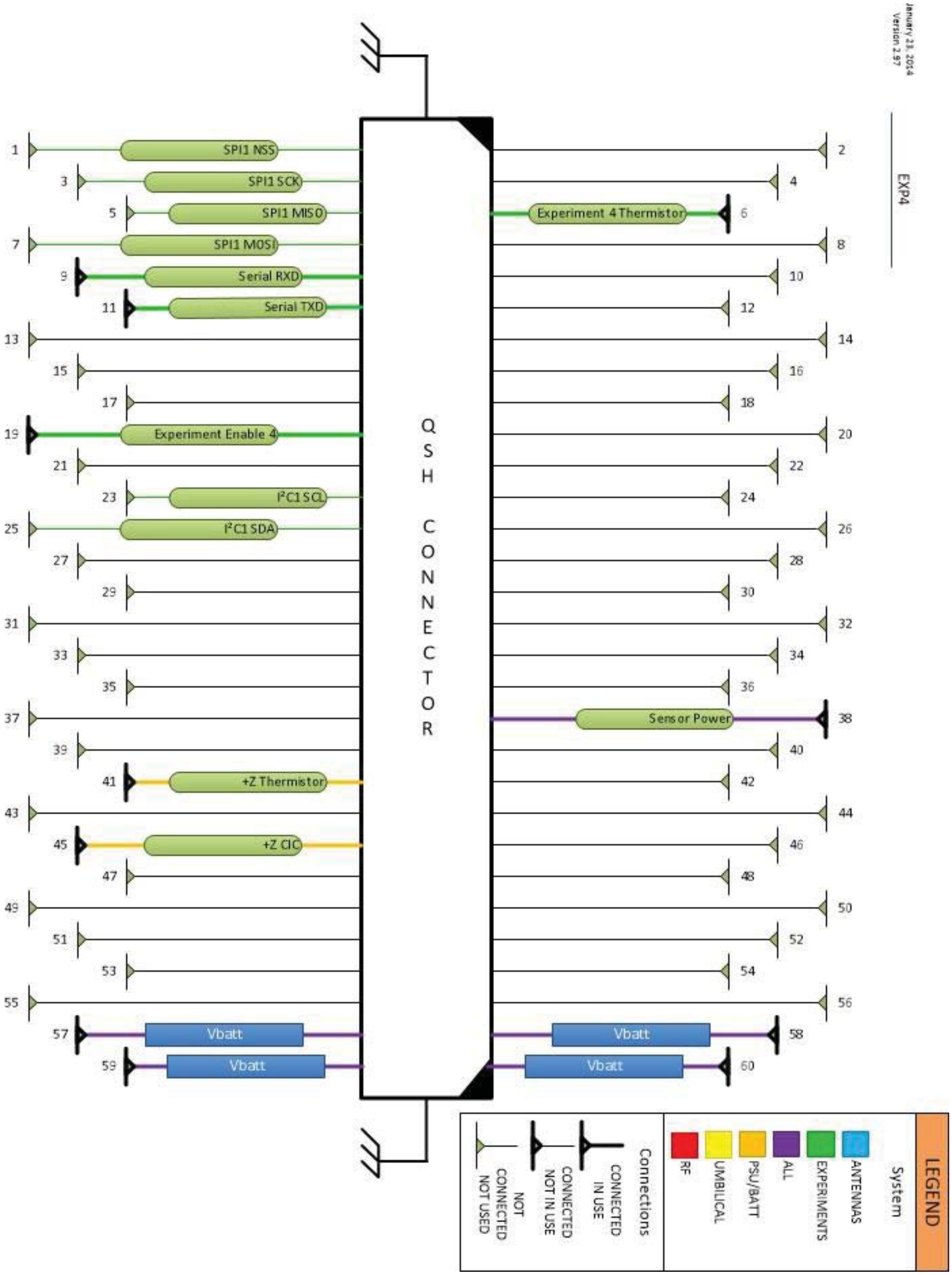


Figure 15: Experiment Payload 4 System Bus Connection Pin Assignments

8.14 Experiment Payload 4 System PCB External Connections

8.14.1 Three connections using Samtec FSI-105-06-L-S-AD connector

- **8.14.1.1** 1 contact +Z Solar Panel Thermistor
- **8.14.1.2** 1 contact +Z Solar Panel CIC +
- **8.14.1.3** 1 contact common or - for above two connections

Table 10: +Z PCB face FSI-105-06-L-S-AD connector mates to pads on +Z Solar Panel

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Load System	Bus Pin
1	+Z Thermistor	Analog	N/A	N/A	N/A	PSU	41
2	N/C						
3	+Z Solar Panel Common						Ground Plane
4	N/C						
5	+Z CIC	Power	N/A	N/A	N/A	PSU	45

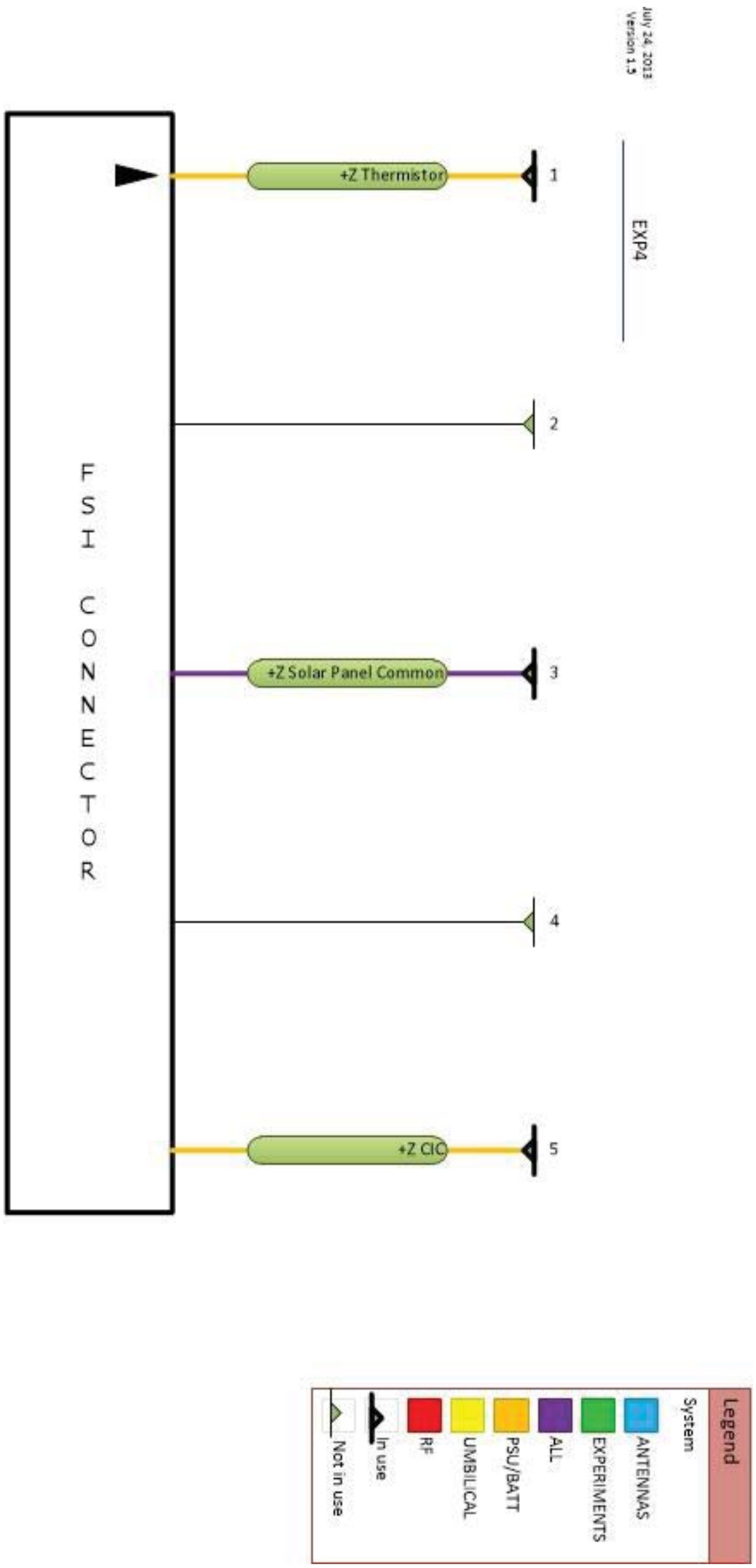
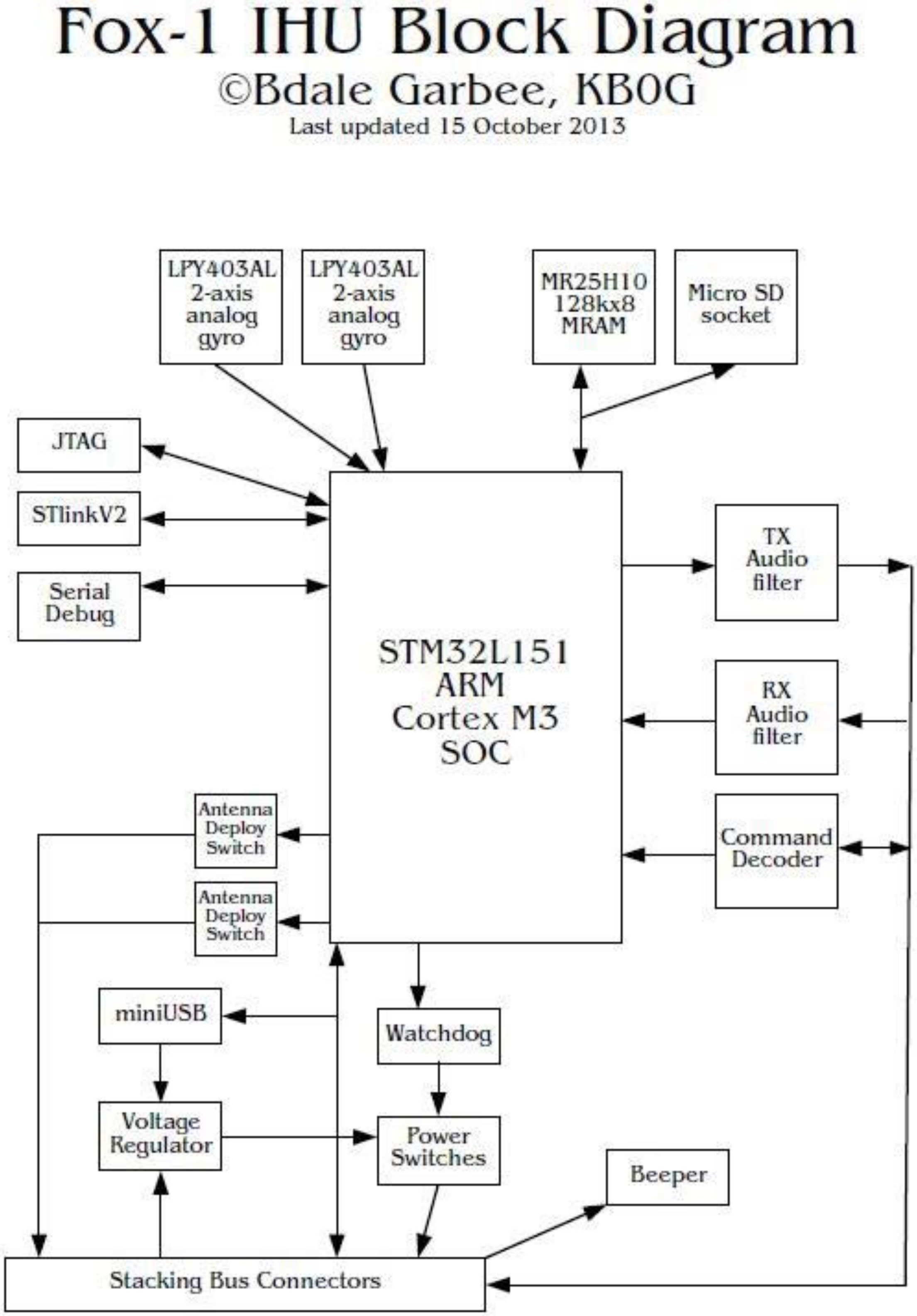


Figure 16: Experiment Payload 4 System FSI-105-06-L-S-AD Connection Pin Assignments

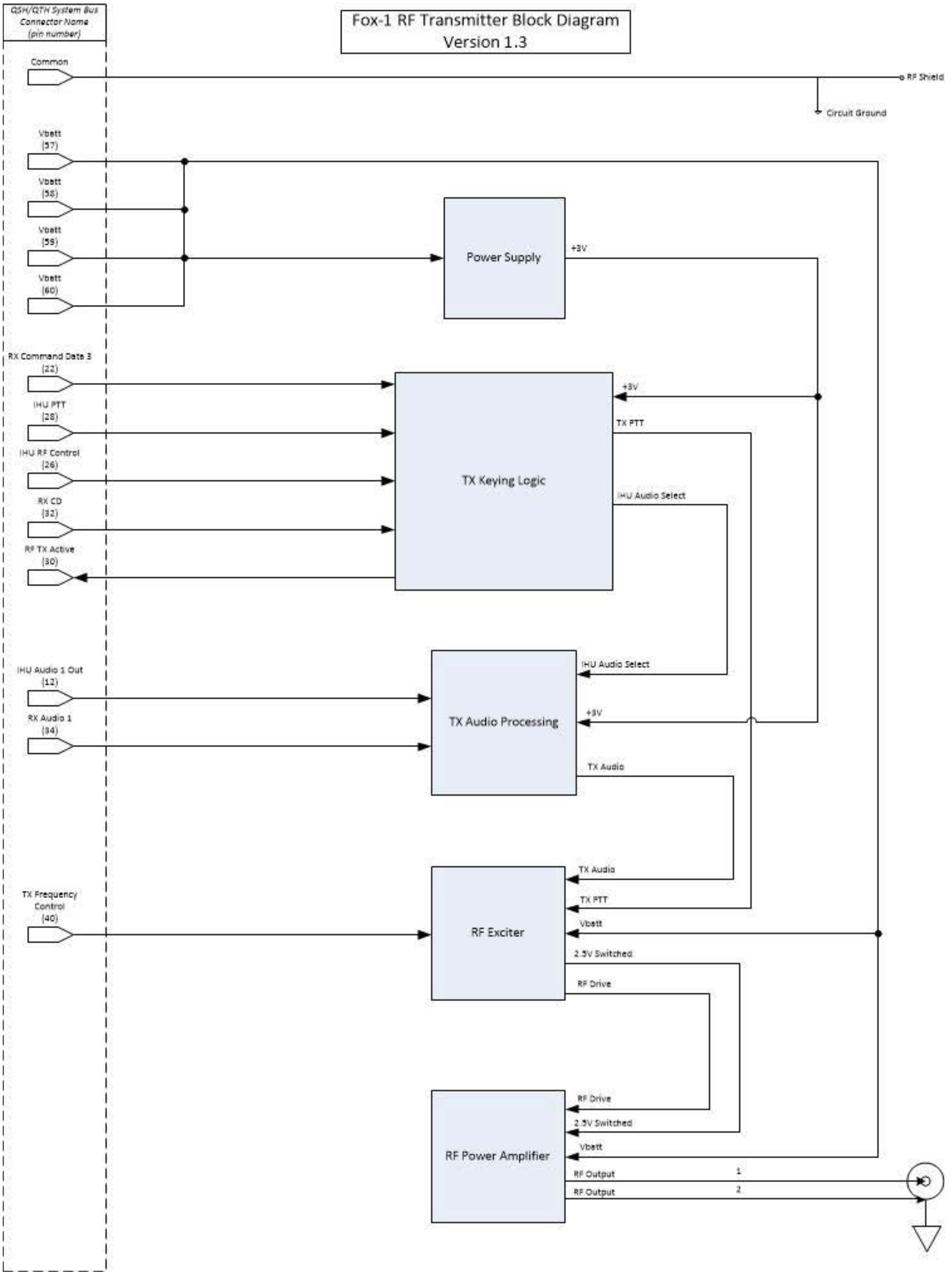
9 System Block Diagrams Reference

9.1 IHU System

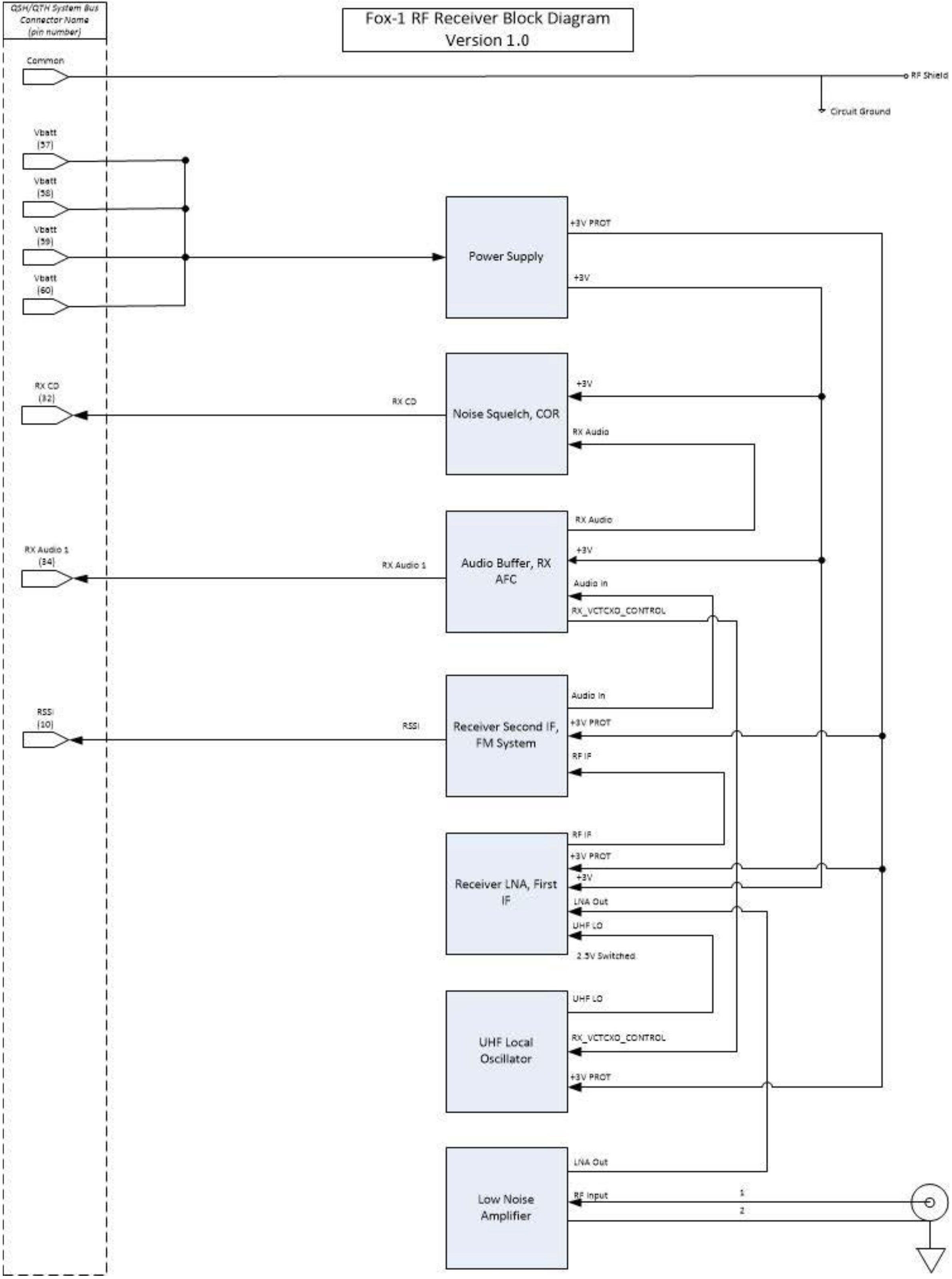


9.2 RF System

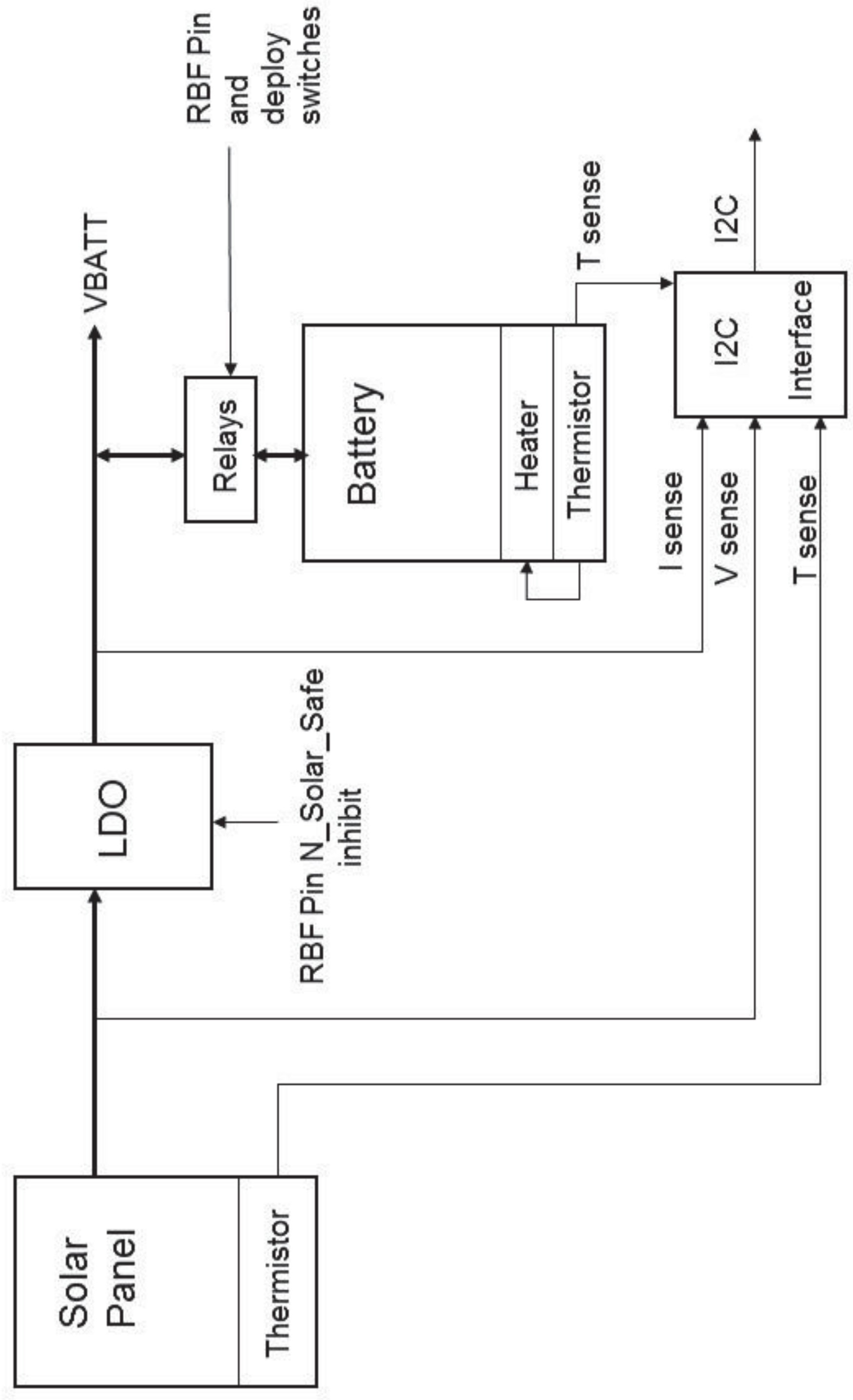
9.2.1 RF Transmitter Block Diagram



9.2.2 RF Receiver Block Diagram



9.3 PSU System



10 System Interconnection References

10.1 Bus Connectors

10.1.1 Samtec QTH-030-02-L-D-A and QSH-030-01-L-D-A connectors
10.1.2 QTH connector shall be mounted on the +Z surface of each circuit board except the Receive Antenna PCB / GPS Payload circuit board
10.1.3 QSH connector shall be mounted on the –Z surface of each circuit board

10.2 Bus Connector Documentation

10.2.1 Samtec QSH
10.2.2 Samtec QTH
10.2.3 Samtec QxH High Speed Characterization Report
10.2.4 Samtec QxH Single Ended Channel Properties

10.3 External Connectors

10.3.1 Samtec MEC1-105-02-L-D-NP-A connector mounted on +X, -X, +Y, -Y Solar Panels
10.3.2 Samtec FSI-105-06-L-S-AD connector mounted on -Z face of RF Transmitter System PCB and +Z face of Experiment Payload 4 System PCB

10.4 External Connector Documentation

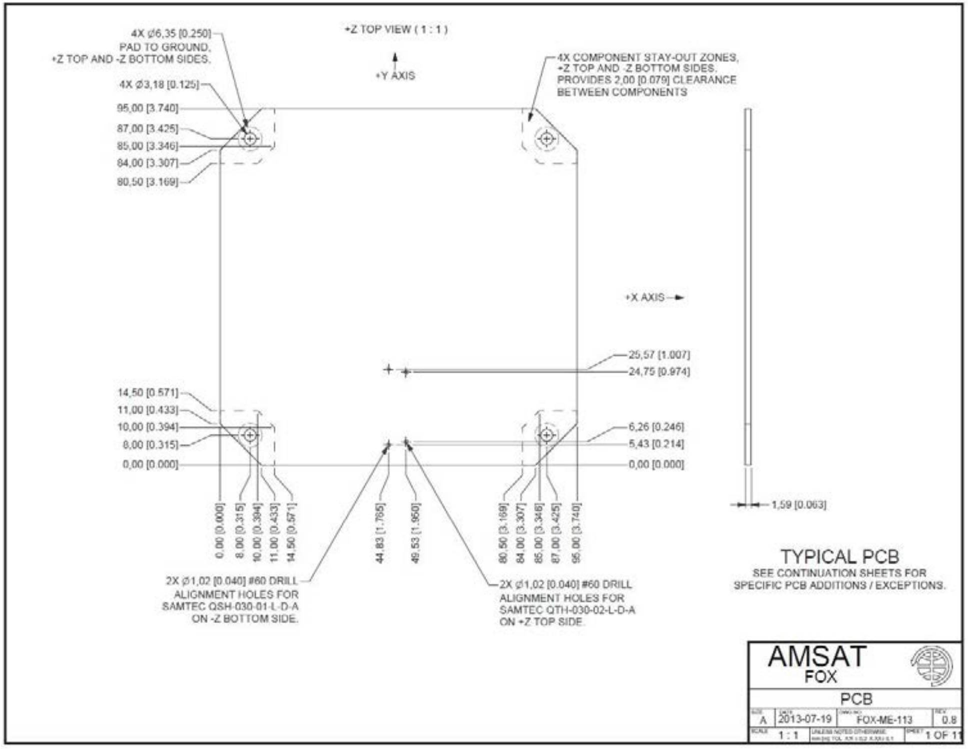
10.4.1 Samtec MEC1
10.4.2 Samtec MEC1 Qualification Testing
10.4.3 Samtec FSI

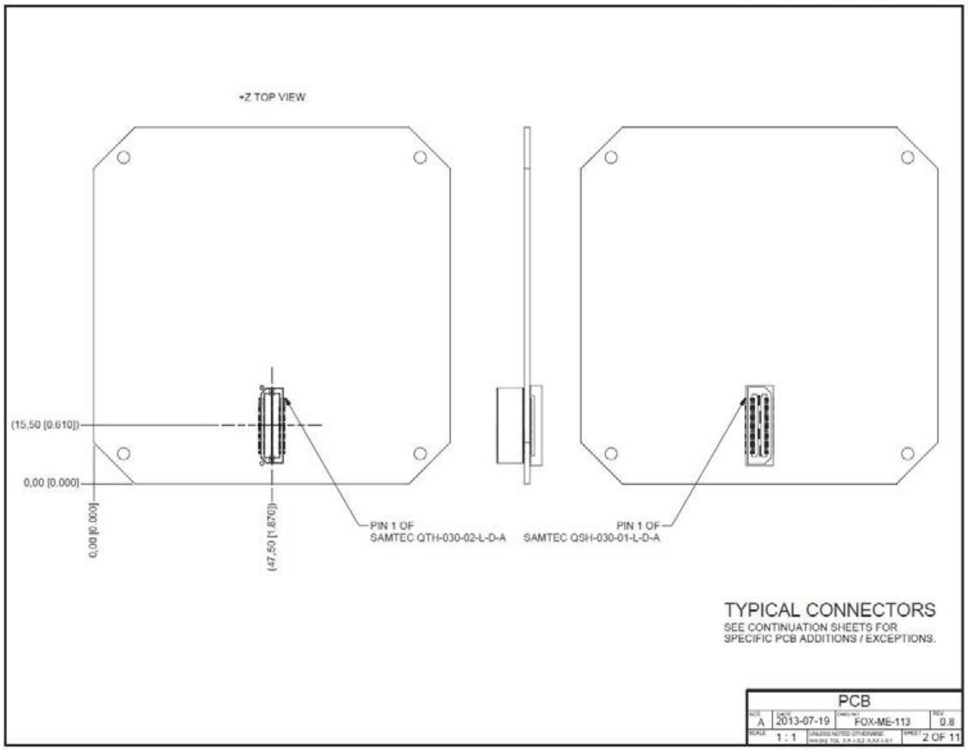
10.5 PCB Connector Layout Documentation

10.5.1 FOX-ME-113_PCB.pdf

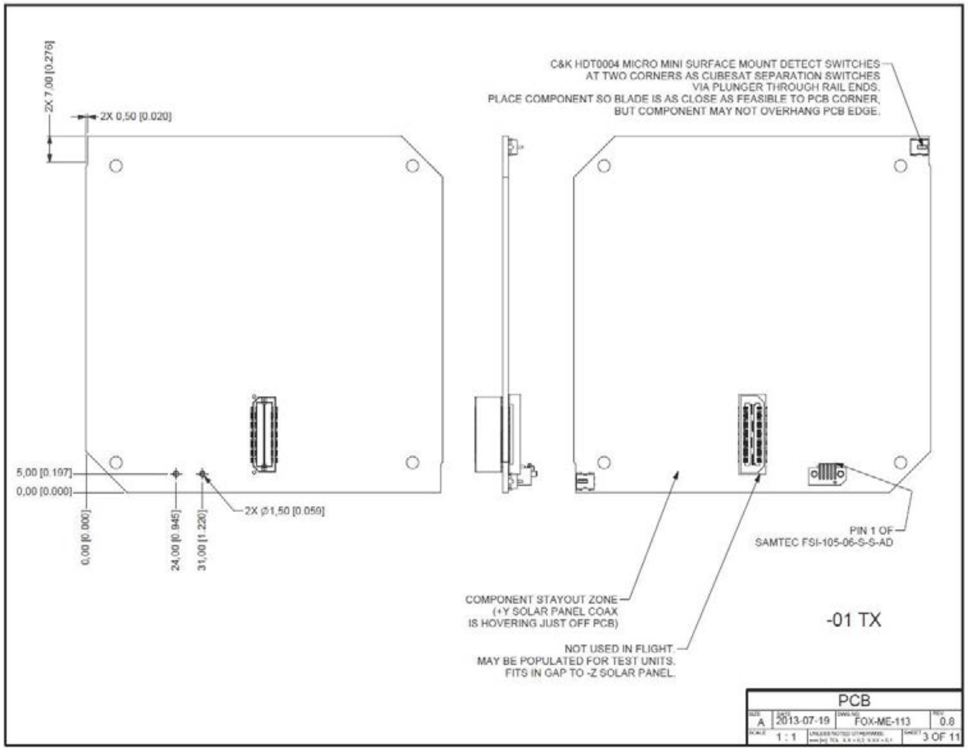
10.6 Systems PCB Connector Layout

10.6.1 Common to All Systems

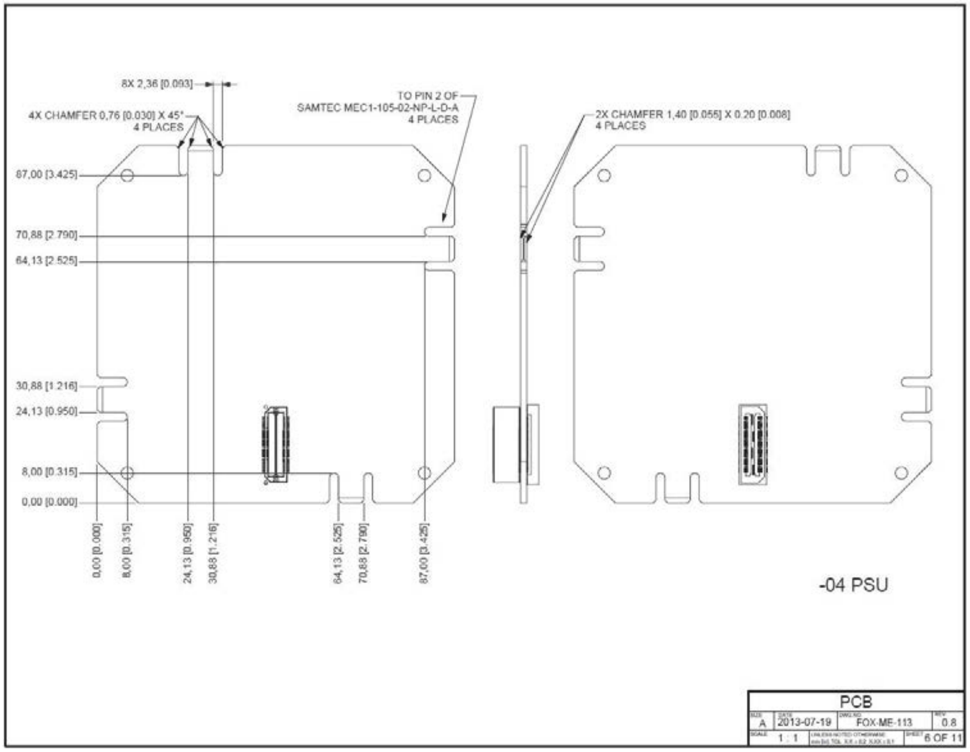




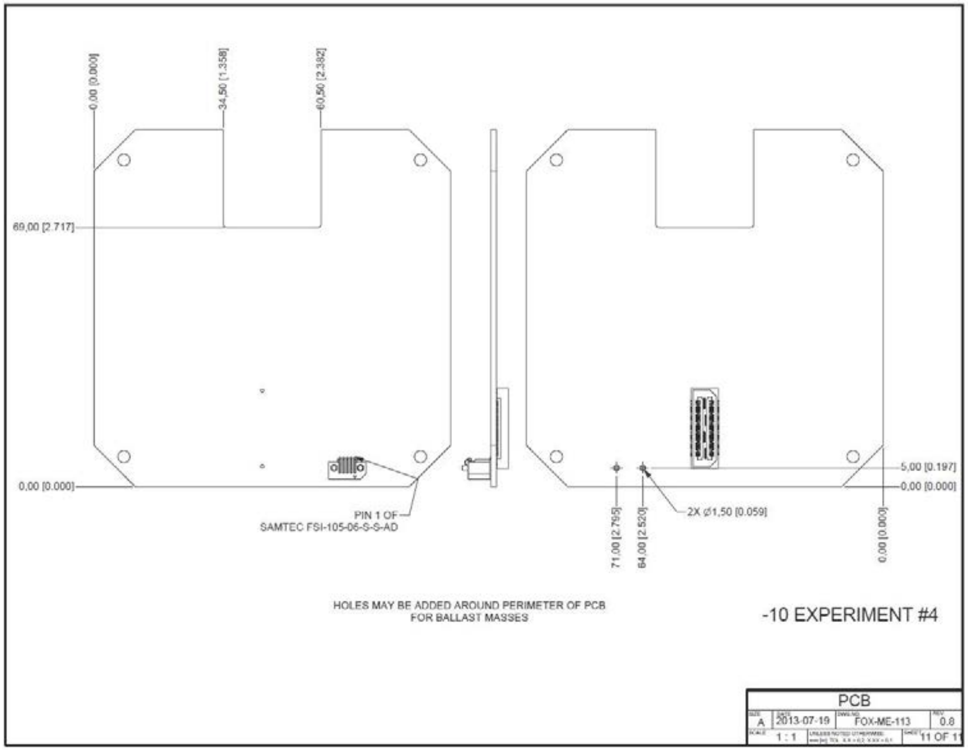
10.6.2 RF Transmitter System



10.6.3 PSU System



10.6.4 Experiment 4 System



Date: November 18, 2013
Version: Version 2.06

AMSAT *Fox-1*

IHU to Battery Interface Control Document

1 Introduction

This document specifies the message interface between the Internal Housekeeping Unit (IHU) and the Battery (BATT1) System, as required per the AMSAT *Fox-1* System Requirements Specification document.

1.1 Document History

DATE	VERSION	SUMMARY
August 7, 2012	1.00	Initial version
November 7, 2012	1.01	Added BATT CPU Temperature
December 27, 2012	1.10	Add Battery Groups Temperature, change from Bytes to Bits in Message Header Block, Message Data Block, Message Data
January 2, 2013	1.11	Field sizes back to bytes account I^2C specifications
February 7, 2013	1.12	Fix typo on 3.3.1.1
August 13, 2013	2.00	Updated for TI ADS 7828 replacing STM32L, straight I2C query/answer from IHU now for 8 channels of data.
August 22, 2013	2.01	Correct Battery Pair Temperature nomenclature
August 22, 2013	2.02	Update I^2C speed to 10 kHz
September 17, 2013	2.03	Fix formatting error that hid requirement 2.2.2, change type format to exclude code type, add Min/Max Values
November 7, 2013	2.04	Add battery voltage scaling in Table 1
November 7, 2013	2.05	Add verbiage about power bus voltage on Battery Pair C to Table 1
November 18, 2013	2.06	Revise battery voltage scale verbiage in Table 1, add raw value notation to BATT PCB Temp

1.2 Document Scope

The purpose of this document is to specify the message format and the I²C bus hardware operation for the communications between the IHU and the BATT1 as described in the AMSAT *Fox-1* System Requirements Specification.

1.3 References

1. AMSAT *Fox-1*, System Requirements Specification
2. AMSAT *Fox-1*, System Design Specification
3. AMSAT *Fox-1*, IHU Software Architecture Specification
4. Texas Instruments SBAS181C – NOVEMBER 2001 - REVISED MARCH 2005

2 General Messaging Requirements

2.1 Link Protocol Requirements

2.1.1 The IHU shall be the I²C Master.

2.1.2 The BATT1 shall be the I²C Slave.

2.1.2.1 The IHU shall request the BATT1 to send the data for a specific channel.

2.1.2.2 The BATT1 shall send that specific channel data.

2.1.3 The IHU shall test for the presence of the BATT1 system.

2.1.3.1 If the presence of the BATT1 system is not detected, the IHU shall not poll the system for data.

2.2 General Message Requirements

2.2.1 The IHU shall sample data at a rate sufficient to provide downlink telemetry data at least every 15 seconds.

2.2.2 The ADS 7820 A/D converter shall always be commanded on (PD-0 bit = 1).

2.2.3 The ADS 7820 Internal Reference shall always be commanded on (PD-1 bit = 1).

2.2.4 The ADS 7820 shall always be commanded for single-ended inputs.

2.3 I²C Bus Hardware Interface Requirements

2.3.1 The I²C Vdd shall be 3.0V.

2.3.2 The bus speed shall be Standard (10 kHz).

2.3.3 The BATT1 I²C 7 bit address shall be 0x48.

3 Data Requirements

3.1 Measured Values

3.1.1 The measured data fields and their associated ADS 7828 channels shall be as shown in Table 1.

Table 1

Field	Channel	Type	Min Value	Max Value	Description
BATT I	0	Unsigned	0x00	0xFFF	Battery current raw value
BATT A V	1	Unsigned	0x00	0xFFF	Battery pair A voltage raw value (0-2.5V scale)
BATT B V	2	Unsigned	0x00	0xFFF	Battery pairs A+B voltage raw value (0-3.3V scale)
BATT C V	3	Unsigned	0x00	0xFFF	Battery pairs A+B+C voltage raw value (0-5.0V scale) This value also represents the power bus voltage (VBATT)
BATT A T	4	Unsigned	0x00	0xFFF	Battery pair A temperature raw value
BATT B T	5	Unsigned	0x00	0xFFF	Battery pair B temperature raw value
BATT C T	6	Unsigned	0x00	0xFFF	Battery pair C temperature raw value
BATT PCB Temperature	7	Unsigned	0x00	0xFFF	Temperature of BATT card raw value

3.1.2 Measurements shall be in relation to the 2.5 VDC internal voltage reference of the ADS 7828.

3.1.3 The IHU shall poll each channel in channel number order.

Date: June 11, 2014
Version: Version 2.21

AMSAT *Fox-1*

IHU to PSU Interface Control Document

1 Introduction

This document specifies the message interface between the Internal Housekeeping Unit (IHU) and the Power Supply (PSU) System, as required per the AMSAT *Fox-1* System Requirements Specification document.

1.1 Document History

DATE	VERSION	SUMMARY
February 21, 2012	1.0	Initial version
February 21, 2012	1.01	Clarify I^{2}C address
March 7, 2012	1.02	2.3.1 updated Vdd to 3.0V
August 7, 2012	1.03	Remove BATT1 data fields and adjust message accordingly
November 7, 2012	1.04	Added PSU CPU Temperature
December 27, 2012	1.10	Change from Bytes to Bits in Message Header Block, Message Data Block, Message Data (to allow for 12 bit ADC values)
January 2, 2013	1.11	Field sizes back to bytes account I^{2}C specifications
February 7, 2013	1.12	Correct typo in 3.3.1.1
August 22, 2013	1.13	Remove TOTAL I from Data block
August 22, 2013	1.14	Update I^{2}C speed to 10 kHz
October 4, 2013	2.00	Rework to eliminate STM32L and replace with ADS7828s
November 18, 2013	2.01	Change telemetry sample rate in 2.2.1 to 4 seconds
April 21, 2014	2.1	Table 1 and Table 2 redone to use actual connections from PSU construction, 3.1.3 changed to show use of regulated Sensor Power source as 7828 voltage reference
June 10, 2014	2.2	Added PSU Output Current to Table 2
June 11, 2014	2.21	Swap Device 1 and Device 2 addresses to account for construction error

DATE	VERSION	SUMMARY
June 30, 2014	2.22	Modify 2.2.3 to command OFF rather than ON account internal reference not used on actual hardware build

1.2 Document Scope

The purpose of this document is to specify the message format and the I^{2}C bus hardware operation for the communications between the IHU and the PSU as described in the AMSAT *Fox-1* System Requirements Specification.

1.3 References

1. AMSAT *Fox-1*, System Requirements Specification
2. AMSAT *Fox-1*, System Design Specification
3. AMSAT *Fox-1*, IHU Software Architecture Specification

2 General Messaging Requirements

2.1 Link Protocol Requirements

2.1.1 The IHU shall be the I²C Master.

2.1.2 The PSU shall be the I²C Slave.

2.1.2.1 The IHU shall request the PSU to send the data for a specific Device and channel.

2.1.2.2 The PSU shall send that specific Device and channel data.

2.1.3 The IHU shall test for the presence both PSU system Devices.

2.1.4 The IHU shall only poll the PSU system Device(s) present, for data.

2.2 General Message Requirements

2.2.1 The IHU shall sample data at a rate sufficient to provide downlink telemetry data every 4 seconds.

2.2.2 For both Devices the ADS 7820 A/D converter shall always be commanded on (PD-0 bit = 1).

2.2.3 For both Devices the ADS 7820 Internal Reference shall always be commanded off (PD-1 bit = 0).

2.2.4 TFor both Devices the ADS 7820 shall always be commanded for single-ended inputs.

2.3 I²C Bus Hardware Interface Requirements

2.3.1 The I²C Vdd shall be 3.0V.

2.3.2 The bus speed shall be Standard (10 kHz).

2.3.3 The PSU system Device 1 I²C 7 bit address shall be 0x4A.

2.3.4 The PSU system Device 2 I²C 7 bit address shall be 0x49.

3 Message Content Requirements

3.1 Measured Values

3.1.1 The measured data fields for Device 1 and their associated ADS 7828 channels shall be as shown in Table 1.

Table 1

Field	Channel	Type	Min Value	Max Value	Description
+X PANEL V	0	Unsigned	0x00	0xFFF	+X PANEL V
-X PANEL V	1	Unsigned	0x00	0xFFF	-X PANEL V
+Y PANEL V	2	Unsigned	0x00	0xFFF	+Y PANEL V
-Y PANEL V	3	Unsigned	0x00	0xFFF	-Y PANEL V
+Z PANEL V	4	Unsigned	0x00	0xFFF	+Z PANEL V
-Z PANEL V	5	Unsigned	0x00	0xFFF	-Z PANEL V
Not used	6	-	-	-	-
Not used	7	-	-	-	-

3.1.2 The measured data fields for Device 2 and their associated ADS 7828 channels shall be as shown in Table 2.

Table 2

Field	Channel	Type	Min Value	Max Value	Description
PSU PCB Temperature	0	Unsigned	0x00	0xFFF	Temperature of PSU card
+X PANEL T	1	Unsigned	0x00	0xFFF	+X PANEL T
-X PANEL T	2	Unsigned	0x00	0xFFF	-X PANEL T
+Y PANEL T	3	Unsigned	0x00	0xFFF	+Y PANEL T
-Y PANEL T	4	Unsigned	0x00	0xFFF	-Y PANEL T
+Z PANEL T	5	Unsigned	0x00	0xFFF	+Z PANEL T
-Z PANEL T	6	Unsigned	0x00	0xFFF	-Z PANEL T
PSU Current	7	Unsigned	0x00	0xFFF	PSU Output Current

3.1.3 Measurements shall be made in relation to the v_regulated voltage on the IHU.

3.1.4 For each Device the IHU shall poll each channel in channel number order.

Date: May 21, 2014
Version: Version 1.09

AMSAT *Fox-1A*

IHU to Experiment 1 Interface Control Document

1 Introduction

This document specifies the message interface between the Internal Housekeeping Unit (IHU) and the Experiment System in Position 1 of the satellite, known as the Vanderbilt University Vulcan Payload and abbreviated herein as EXP1.

1.1 Document History

DATE	VERSION	SUMMARY
March 3, 2013	1.00	Initial version
March 7, 2013	1.01	Correct use of I^{2}C (1.2) and EXP1 (2.3.3)
March 31, 2013	1.02	Command Message CRC8 to include address byte, change to commands, modified figure 3, deleted figure 4
March 31, 2013	1.03	Delete TYPE from message tables, add SET TIME response return values
March 31, 2013	1.04	Add CMD_VERSION_ERR to Error Code table
April 2, 2013	1.05	Correct 6.5 Figure 3, remove 0x0005, 0x0201, 0x0210, 0x0281, 0x0300, and 0x0301 commands
September 17, 2013	1.06	Change type format to exclude code type, add Min/Max Values
October 7, 2013	1.07	Revised Table 1 and 3.2.1 added 3.5.1.1 for clarification on Experiment Enable 1 states
November 7, 2013	1.08	Added 3.1.2 and 3.1.3 regarding minimum power levels for experiment operation
May 21, 2014	1.09	Revised 3.1.2 and 3.1.3 to read <= 3.3V

1.2 Document Scope

This document will specify the control of EXP1, the messaging format, and the I^{2}C bus hardware operation for the communications between the IHU and the EXP1.

1.3 References

1. AMSAT *Fox-1*, System Requirements Specification
2. AMSAT *Fox-1*, System Design Specification
3. AMSAT *Fox-1*, IHU Software Architecture Specification
4. Vanderbilt University Vulcan Payload Interface Control Document

2 General Messaging Requirements

2.1 Link Protocol Requirements

2.1.1 The IHU shall initiate a command to the EXP1.

2.1.2 The EXP1 shall send a reply to each IHU request.

2.1.3 Message bit order shall be Big Endian.

2.1.4 The IHU shall determine the action to be taken in the event of an invalid, improper, or missing message from the EXP1.

2.1.5 The EXP1 shall take no action in the event of an invalid or improper message from the IHU.

2.1.6 Message byte order shall be Big Endian.

2.2 General Message Requirements

2.2.1 Each message shall contain a header block.

2.2.2 Each message shall contain a packet error check (PEC) in the form of CRC8.

2.2.2.1 The message address byte shall be included when calculating the CRC8.

2.3 I²C 1 Bus Hardware Interface Requirements

2.3.1 The I²C Vdd shall be 3.0V.

2.3.2 The bus speed shall be Fast (400kbit/s).

2.3.3 The EXP1 I²C 7 bit address shall be 0x2A.

3 Experiment Operation

3.1 Experiment Power Control

3.1.1 The IHU shall exert control over the power state of the EXP1 by the Experiment Enable 1 pin on the satellite bus as shown in Table 1.

Table 1

Pin State	Description
High	Power On Experiment
Low or high-impedance	Power Off Experiment

3.1.2 The IHU shall not power on the experiment if the power bus voltage (VBATT) is less than or equal to 3.3 Volts.

3.1.3 The IHU shall perform the Experiment Cease Operation Sequence and the Experiment Power Off Sequence if the power bus voltage (VBATT) falls to less than or equal to 3.3 Volts while the experiment is powered on.

3.2 Experiment Power On Sequence

3.2.1 The IHU shall set and hold the Experiment Enable 1 pin HIGH.

3.2.2 The IHU shall not send any message to the EXP1 for a minimum of 100 milliseconds.

3.2.3 The IHU shall send a Set Time command to the EXP1.

3.3 Experiment Begin Operation Sequence

3.3.1 Upon completion of the Power On sequence the IHU shall send a Set Run State Active command message to the EXP1.

3.4 Experiment Cease Operation Sequence

3.4.1 The IHU shall send a Set Run State Halt command message to the EXP1.

3.4.2 The IHU shall not send any message to the EXP1 for a minimum of 10000 milliseconds.

3.4.3 The IHU shall send a Set Run State Standby command message to the EXP1.

3.5 Experiment Power Off Sequence

3.5.1 The IHU shall set the Experiment Enable 1 pin LOW.

3.5.1.1 The absence of a HIGH state on the Experiment Enable 1 pin shall be construed as a LOW state whether the pin is actually LOW, or in a high-impedance state.

4 Message Content Requirements

4.1 Command Message

4.1.1 The message header block shall be constructed as shown in table 2.

4.1.2 The message header block shall be sent with each Command and Response block.

Table 2

Field	Size (Bytes)	Type	Min Value	Max Value	Description
Message Version	2	Unsigned	0x01	0xFFFF	Message ICD version
Software Build	2	Unsigned	0x01	0xFFFF	Software Build version

4.1.2.1 The Message Version shall be an integer representing the IHU to EXP1 ICD document version number from which the message format is derived, having the decimal point removed (e.g. version 1.03 would be 103 decimal or 0x67).

4.1.2.2 The Software Build shall be an integer representing the software build version number of the system originating the message, having any decimal points removed (e.g. version 1.03 would be 103 decimal or 0x67).

4.2 Command Message Block

4.2.1 The command message block shall be constructed as shown in Table 3.

Table 3

Field	Size (Bytes)	Type	Min Value	Max Value	Description
COMMAND	2	Unsigned	0x0000	0x0280	Hexadecimal Command
ARGUMENT	Variable	Unsigned	-	-	Optional Arguments As Required

The command message block shall contain one command in the COMMAND COMMAND field as shown in Table 4.

Table 4

Command Name	**Size (Bytes)**	**Type**	**Min Value**	**Max Value**	**Description**
Nop	2	Unsigned	0x0000	0x0000	No effect; response undefined. Test for I²C acknowledgement only.
Echo	2	Unsigned	0x0001	0x0001	Echo this byte stream
Resend	2	Unsigned	0x0002	0x0002	Resend last result
Get UID	2	Unsigned	0x0003	0x0003	Controller 7 byte identifier
Get Status	2	Unsigned	0x0004	0x0004	Controller status indication
Get Diagnostics	2	Unsigned	0x0006	0x0006	Self-check Diagnostic
Get Telemetry	2	Unsigned	0x0010	0x0010	Send telemetry data
Set Run State	2	Unsigned	0x0080	0x0080	Enter specified Run State
Get Run State	2	Unsigned	0x0081	0x0081	Query current Run State
Set Time	2	Unsigned	0x0100	0x0100	Number of seconds since epoch
Get Time	2	Unsigned	0x0101	0x0101	Number of seconds since epoch
Get Data	2	Unsigned	0x0280	0x0280	Send (number of bytes) data

4.2.3 The command message shall contain arguments for the Echo command, as shown in Table 5.

Table 5

Field	**Size (Bytes)**	**Type**	**Min Value**	**Max Value**	**Description**
ARGUMENT	4	Unsigned	-	-	Data to be echoed

4.2.4 The command message shall contain one argument for the Set Run State command, as shown in Table 6.

Table 6

Run State	Size (Bytes)	Type	Min Value	Max Value	Description
STANDBY	2	Unsigned	0x0001	0x0001	Enter Standby State
ACTIVE	2	Unsigned	0x0003	0x0003	Activate Experiments
HALT	2	Unsigned	0x0004	0x0004	Terminate Experiments

4.2.5 The command message shall contain arguments for the Set Time command, as shown in Table 7.

Table 7

Argument	Size (Bytes)	Type	Min Value	Max Value	Description
IHU Reset Counter	16	Unsigned	0x00	-	Count of the number of IHU resets from non-volatile FRAM
MET Timestamp	32	Unsigned	-	-	MET timestamp (seconds since last IHU reset)

4.2.6 The command message shall contain arguments for the Get Data command, as shown in Table 8.

Table 8

Argument	Size (Bytes)	Type	Min Value	Max Value	Description
BYTES TO SEND	2	Unsigned	0x00	0xFFFF	Number of bytes to send (1-256)

4.3 Response Message Block

4.3.1 The response message block shall be constructed as shown in Table 9.

Table 9

Field	Size (Bytes)	Type	Min Value	Max Value	Description
RESERVED	1	Unsigned	-	-	Reserved, ignore
ERROR CODE	1	Unsigned	0x0000	0x0006	Response to Command
LENGTH	2	Unsigned	0x00	0xFFFF	Length of Return Value in Bytes
RETURN VALUE	Variable	Variable	-	-	Return Value

4.3.2 The Error Code shall contain one code as shown in table 10.

Table 10

Name	Size (Bytes)	Type	Min Value	Max Value	Description
CMD_OK	1	Unsigned	0x0000	0x0000	Command invoked successfully
CMD_OP_ERR	1	Unsigned	0x0001	0x0001	Command not recognized
CMD_FORMAT_ERR	1	Unsigned	0x0002	0x0002	Incorrect command argument length
CMD_RANGE_ERR	1	Unsigned	0x0003	0x0003	Argument(s) out of bounds
CMD_PEC_ERR	1	Unsigned	0x0004	0x0004	Error check (CRC) mismatch
CMD_EXEC_ERR	1	Unsigned	0x0005	0x0005	Execution error
CMD_VERSION_ERR	1	Unsigned	0x0006	0X0006	Header Message Version mismatch

4.3.3 The Status Flags for a GET STATUS response message shall be represented as individual bit values of a 16 bit RETURN VALUE as shown in Table 11.

Table 11

Name	Bit Number	Description
REBOOTED	0	1 = Experiment has rebooted – **NOT USED**
DATA READY	1	1 = Experiment data available
TIME REQUEST	2	1 = Request SET TIME
FAILED RUN STATE	3	1 = Failed the run state – **NOT USED**
COMPLETED RUN STATE	4	1 = Completed the run state – **NOT USED**
RESERVED	5-15	Always 0

4.3.4 The response message to a Set Time command shall contain one of the values as shown in Table 12.

Table 12

Response Name	Size (Bytes)	Type	Min Value	Max Value	Description
SUCCESS	2	Signed	0x00	0x00	Time Set successfully
FAILURE	2	Signed	0xFFFF	0xFFFF	Time Set failed

5 Message Integrity

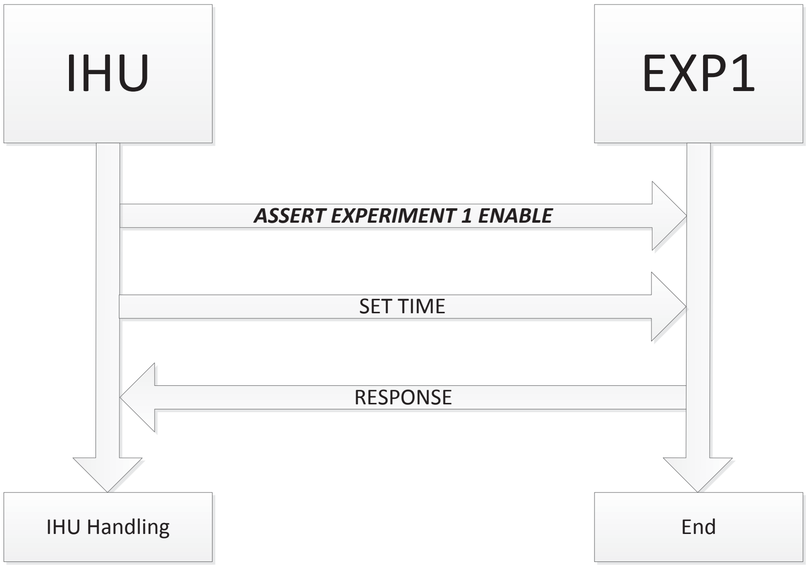
5.1 Invalid Messages

5.1.1 If the PEC (CRC8) fails, the message shall be considered invalid.

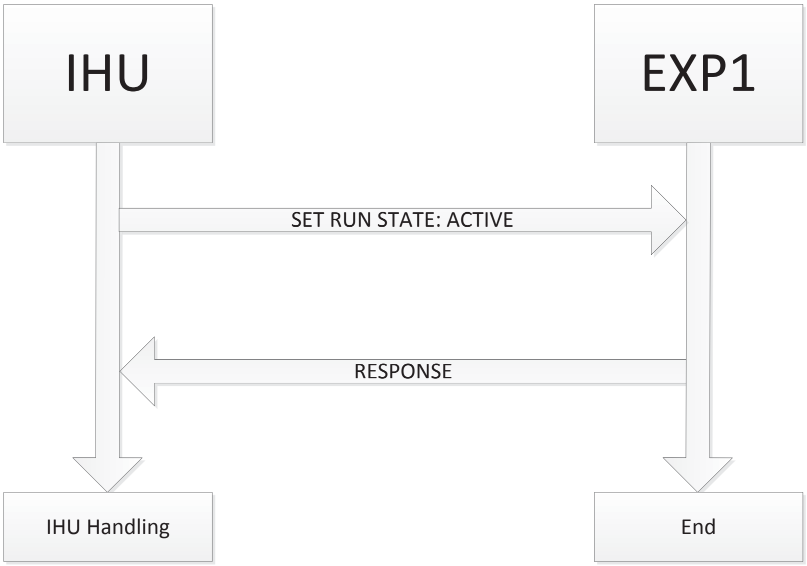
5.1.2 If the Message Version does not match the message version in use for the construction of messages on the receiving system, the message shall be considered invalid.

6 Message Flow Diagrams

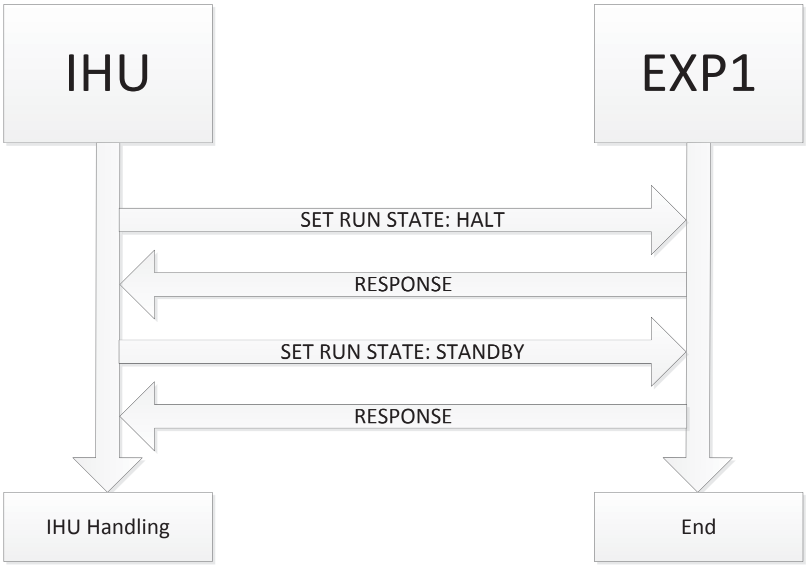
6.1 EXPERIMENT POWER ON SEQUENCE



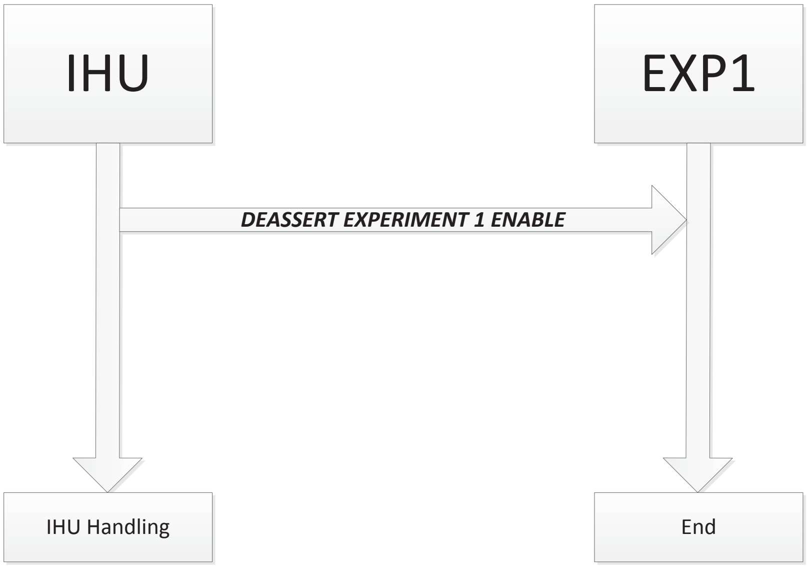
6.2 EXPERIMENT BEGIN OPERATION SEQUENCE



6.3 EXPERIMENT CEASE OPERATION SEQUENCE



6.4 EXPERIMENT POWER OFF SEQUENCE



6.5 SERVICING EXPERIMENT OPERATION

Figure 1

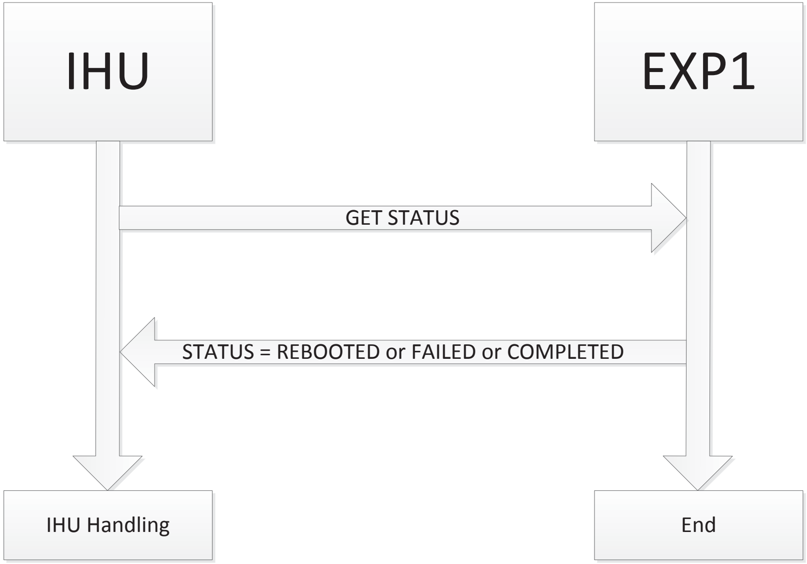


Figure 2

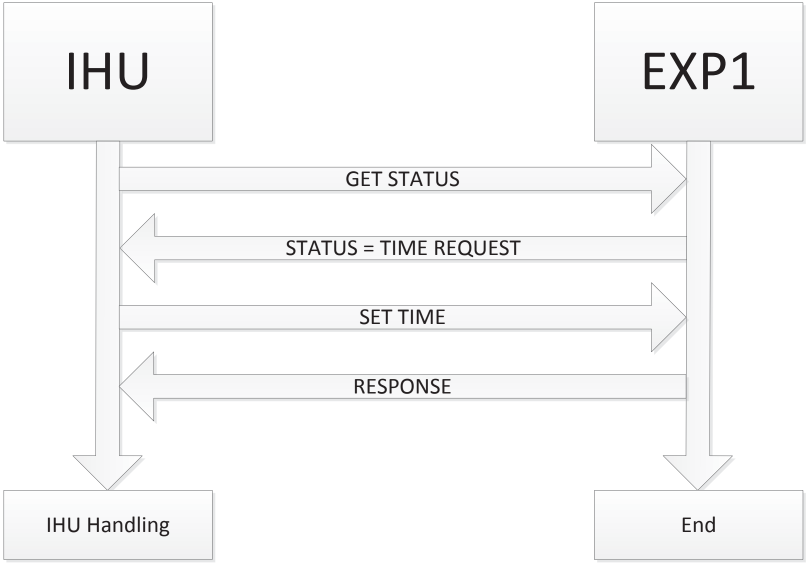
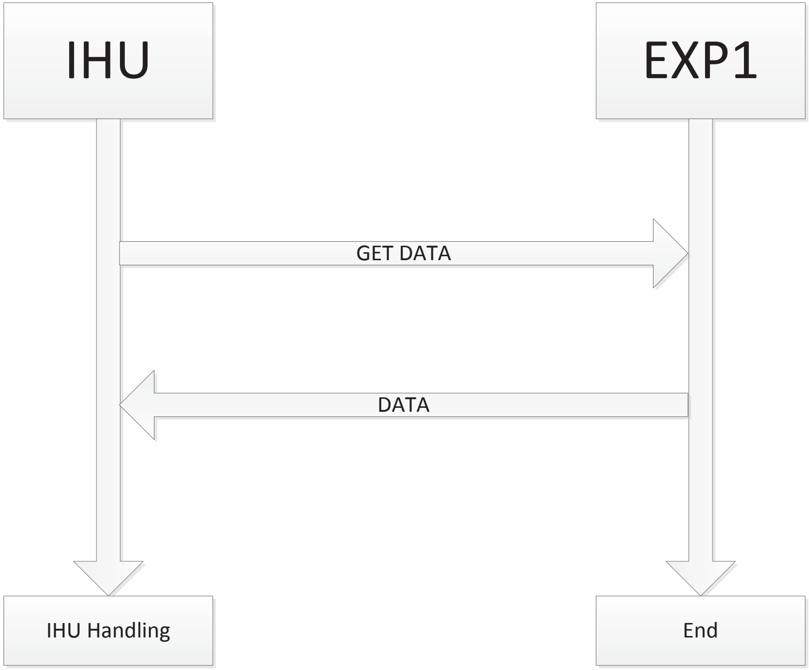


Figure 3



Date: June 26, 2014
Version: Version 1.20

AMSAT *Fox-1A*

IHU to Experiment 4 Interface Control Document

1 Introduction

This document specifies the message interface between the Internal Housekeeping Unit (IHU) and the Experiment System in Position 3 of the satellite, known as the VT Camera Experiment and abbreviated herein as EXP3.

1.1 Document History

DATE	VERSION	SUMMARY
January 24, 2013	1.00	Initial version
February 20, 2013	1.01	Specify byte order as little endian
May 21, 2013	1.10	Update data TYPE names
October 4, 2013	1.11	Change type format to exclude code type, add Min/Max Values, add thermistor circuit
October 7, 2013	1.12	Modify Table 1 to clarify Experiment Enable 4 pin states
June 26, 2014	1.20	Add "No Earth Image Available" to NN description in Table 6, remove section 7 thermistor requirement no longer applicable, change all references to EXP4 to read EXP3 reflecting proper location of experiment

1.2 Document Scope

This document will specify the control of EXP3, the messaging format, and the serial bus hardware operation for the communications between the IHU and the EXP3.

1.3 References

1. AMSAT *Fox-1*, System Requirements Specification
2. AMSAT *Fox-1*, System Design Specification
3. AMSAT *Fox-1*, IHU Software Architecture Specification

2 General Messaging Requirements

2.1 Link Protocol Requirements

2.1.1 The IHU shall initiate a command to the EXP3.

2.1.2 The EXP3 shall send a reply to each IHU request.

2.1.3 Message bit order shall be Little Endian.

2.1.4 The IHU shall determine the action to be taken in the event of an invalid, improper, or missing message from the EXP3.

2.1.5 The EXP3 shall take no action in the event of an invalid or improper message from the IHU.

2.1.6 Message byte order shall be Little Endian.

2.2 General Message Requirements

2.2.1 Each message shall contain a header block.

2.2.2 Each message shall contain one command, one reply, or one data block.

2.3 Serial Bus Hardware Interface Requirements

2.3.1 The bus levels shall be 3.0V.

2.3.2 The bus data speed shall be 38400 bit/s.

2.3.3 The serial bus communication shall be asynchronous.

2.3.4 The number of data bits shall be 8.

2.3.5 The number of stop bits shall be 1.

2.3.6 There shall be no parity bit.

3 Experiment Operation

3.1 Experiment Power Control

3.1.1 The IHU shall exert control over the power state of the EXP3 by the Experiment Enable 4 pin on the satellite bus as shown in Table 1.

Table 1

Pin State	Description
High	Power On Experiment
Low or high-impedance	Power Off Experiment

3.1.2 Upon signaling Power On to the EXP3, the IHU shall not send any message to the EXP3 for a minimum of 100 milliseconds.

3.2 Experiment Operation Sequence

3.2.1 Upon Power On the IHU shall determine the state of the EXP3 by sending an Is Camera Ready command message.

3.2.2 The IHU shall not send a Transmit Data Block command message prior to receiving a Camera Ready reply message from the EXP3.

4 Message Content Requirements

4.1 Message Header Block

4.1.1 The message header block shall be constructed as shown in table 2.

4.1.2 The message header block shall be sent with each Command, Reply, and Data block.

Table 2

Field	Size (Bytes)	Type	Min Value	Max Value	Description
Message Version	2	Unsigned	0x01	0xFFFF	Message ICD version
Software Build	2	Unsigned	0x01	0xFFFF	Software Build version

4.1.2.1 The Message Version shall be an integer representing the IHU to EXP3 ICD document version number from which the message format is derived, having the decimal point removed (e.g. version 1.03 would be 103 decimal or 0x67).

4.1.2.2 The Software Build shall be an integer representing the software build version number of the system originating the message, having any decimal points removed (e.g. version 1.03 would be 103 decimal or 0x67).

4.2 Command Message Block

4.2.1 The command message block shall be constructed as shown in Table 3.

Table 3

Field	Size (Bytes)	Type	Min Value	Max Value	Description
COMMAND	2	Alpha	RR TT	RR TT	Command

4.2.2 The command message block shall contain one command in the COMMAND field as shown in Table 4.

Table 4

Command	Description
RR	Is Camera Ready?
TT	Transmit Data Block

4.3 Reply Message Block

4.3.1 The reply message block shall be constructed as shown in Table 5.

Table 5

Field	Size (Bytes)	Type	Min Value	Max Value	Description
REPLY	2	Alpha	NN YY FF	NN YY FF	Reply

4.3.2 The reply message block shall contain one reply in the REPLY field as shown in table 6.

Table 6

Command	**Description**
NN	Camera Not Ready or No Earth Image Available
YY	Camera Ready
FF	Camera Failed

4.4 Message Data Block

4.4.1 The message data block shall be constructed as shown in Table 7.

Table 7

Field	Size (Bytes)	Type	Min Value	Max Value	Description
DESCRIPTOR	2	Unsigned	-	-	Line ID and Payload Length
PAYLOAD	Variable	Unsigned	-	-	Array of (Payload Length) bytes
CHKSUM	2	Unsigned	-	-	16 bit accumulator sum of bytes in HEADER and PAYLOAD

4.4.2 The bits of the message data block DESCRIPTOR bytes shall be constructed as shown in Table 8.

Table 8

Field	Size (Bits)	Type	Min Value	Max Value	Description
Line ID	6	Unsigned	0x01	0x3C	640 x 8 pixel picture line number (1 is top, 60 is bottom)
Payload Length	10	Unsigned	0x01	0x3FF	Total number of bytes in PAYLOAD

4.4.2.1 The Line ID shall compose the 6 MSB and the Payload Length shall compose the 10 LSB.

5 Message Integrity

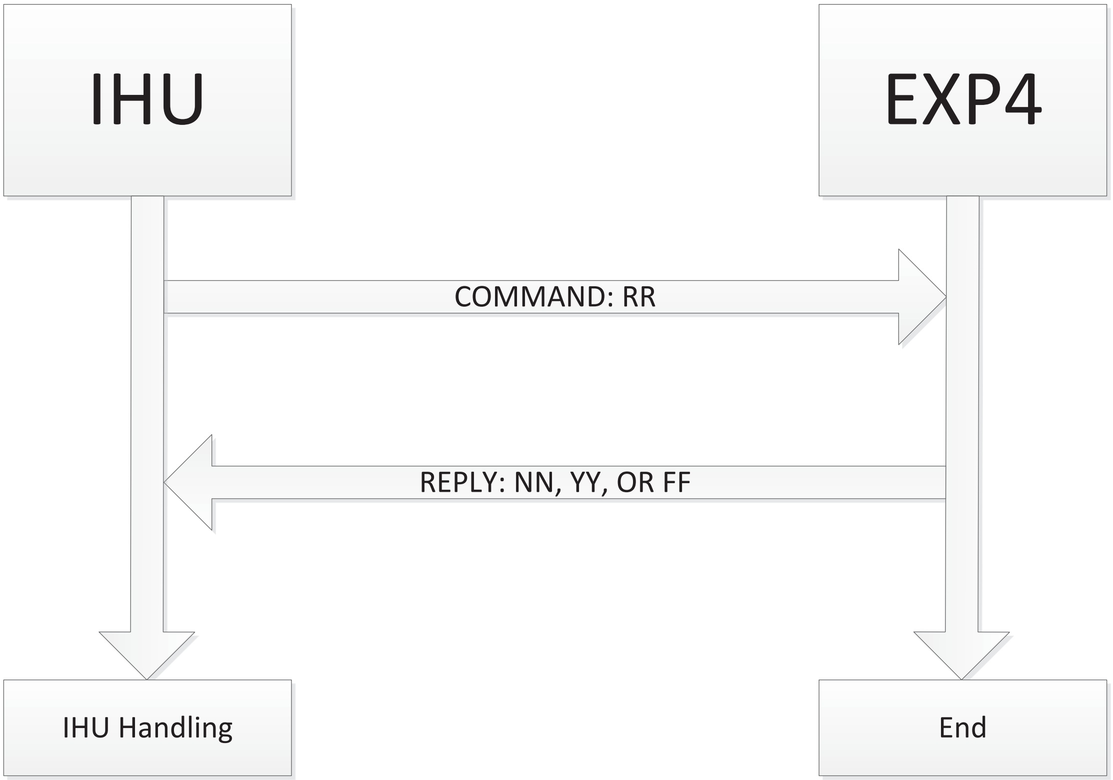
5.1 Invalid Messages

5.1.1 If the DATA block CHKSUM fails, the message shall be considered invalid.

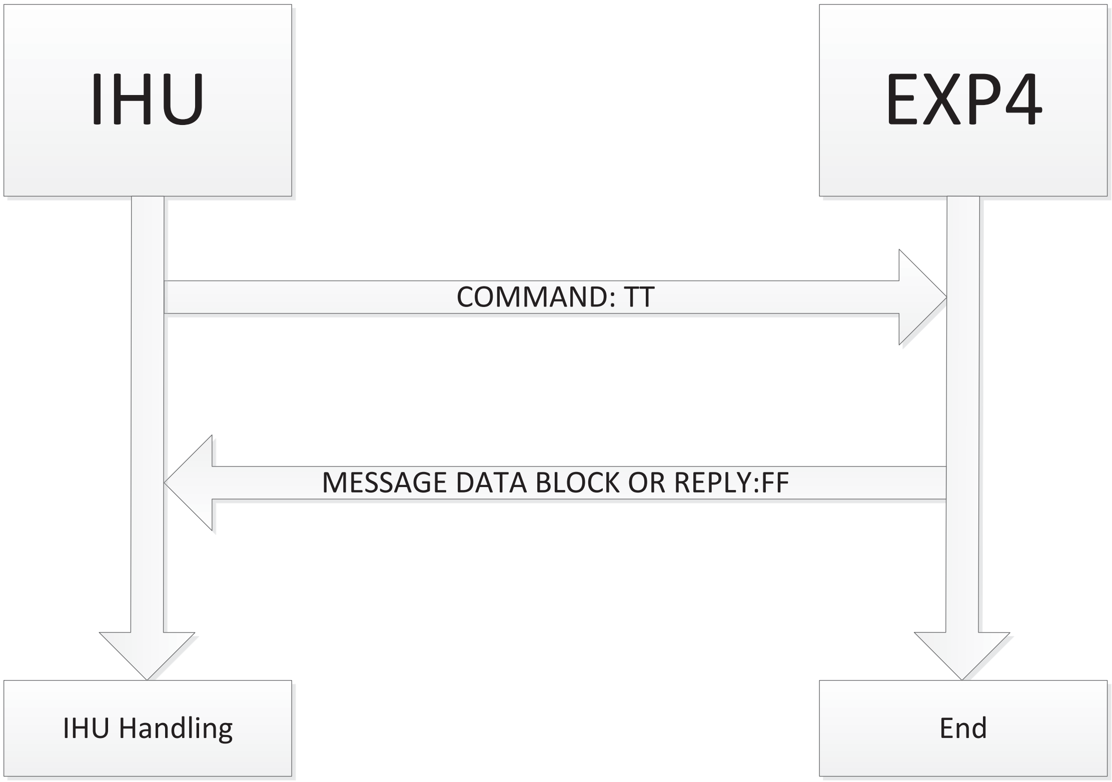
5.1.2 If the Message Version does not match the message version in use for the construction of messages on the receiving system, the message shall be considered invalid.

6 Message Flow Diagrams

6.1 RR COMMAND



6.2 TT COMMAND



Date: September 30, 2014
Version: Version 2.00

AMSAT *Fox-1A*
Downlink Specification

1 Introduction

This document specifies downlink frame formats for the Fox-1A telemetry and experiment telemetry. This specification includes the both slow and high speed formats.

Document History

DATE	VERSION	SUMMARY
April 25, 2013	1.01	Remove TX PA Temperature and TX Osc Temperature, add TX Temperature
May 21, 2013	1.2	High speed downlink details added
May 27, 2013	1.3	Remove Radiation Experiment Telemetry Frame, resize Radiation Experiment Data Frame, renumber Payload Types, added Slow Speed Link Layer Transmission Scheduling, changed Reset Count to 16 bits
June 6, 2013	1.31	Reduce BATT CPU, PSU CPU, IHU CPU, TX Temp, RX Osc Temp from 12 to 8 bit value, add IHU Error Data field to Telemetry Minimum Values Frame
June 26, 2013	1.32	Correct Payload Type numbers in Table 6
August 13, 2013	1.40	Changes due to new BATT telemetry values, delete Type 4 from idle telemetry
August 26, 2013	1.41	Change Receiver Osc Temperature to Receiver Card Temperature, remove TOTAL MPPT I, update 2.2.9.1 and 2.2.9.1.1 to reflect variable size of Radiation Experiment Data available
September 14, 2013	1.42	Added 3.1.2, Payload type 0 debug frame, made Scan Line Segment – Picture Count size 8 bits, add RSSI to Payloads 1, 2, and 3, change type format to exclude code type, add Min/Max Values
September 16, 2013	1.43	Added EXP4 temperature to Payloads 1, 2, and 3, changed PSU CPU temp to PSU card temp

DATE	VERSION	SUMMARY
October 15, 2013	1.44	Correct bit count for frame Type 3, change calculated spin rate to remove PSU reference
November 18, 2013	1.45	Expanded all temperature fields to 12 bits, redo 3.1 payload order, add 2.2.7.3 and 2.2.7.4, update SPIN to show bit pattern, add System I²C Failure indications, add Ground Command TLM reset count, add IHU Soft Error Data, add IHU Hard Error Data, increase IHU Error Data to 32 bits, clarify which fields are raw values, added 2.2.7 5 padding slow speed frames, 2.2.8 for slow speed trailer info
January 13, 2014	1.50	Redo 3.2 beacon payloads
January 13, 2014	1.51	Change 3.2.1 to allow payload type 2 and 3 only with the voice ID
January 13, 2014	1.52	Correct 2.2.9 high speed link layer header structure to show 16 bits on the Reset Count
January 14, 2014	1.53	Correct Table 4 and Table 5 Reset Count Max Value to 0xFFFF to match use of 16 bits
February 10, 2014	1.54	Modify Table 11 to read “Experiment 1 Data” in the description, added Safe Mode Indication bit to payload 2 and 3, changed Filler bit size to 1 in payload 2 and 3.
March 19, 2014	1.55	Move IHU Soft Error Data to Payload Type 3, Move IHU Error Data to Payload Type 1 and rename to IHU Diagnostic Data, update Table 1 Bit Rate to 200 bps and Spectral Efficiency to 2 bps/Hz, remove Scrambler reference from Table 1 and Table 2.
March 24, 2014	1.56	Add timestamp elements to Payload 2 and Payload 3 for specific MAX or MIN last changed
April 23, 2014	1.57	Fix 4.4 BATT Board Temperature description to read Low instead of High
June 10, 2014	1.58	Remove Payload Type 2 MRAM Error Count, Add PSU DC current, PSU DC high current, PSU DC low current to Payload Type 1, 2, 3 respectively
September 30, 2014	2.00	Reorder fields in Payload Type 1, 2, 3, delete filler fields, add filler bits to Table 5

1.1 Document Scope

The purpose of this document is to specify the downlink protocol on the AMSAT Fox-1A spacecraft.

1.2 References

1. Fox1 IHU to RF ICD
2. Fox1 IHU to Battery ICD
3. Fox1 IHU to PSU ICD
4. Fox1 IHU to Attitude Determination Experiment ICD
5. Fox1 IHU Software Architecture Specification
6. Fox1 IHU to Experiment 1 ICD
7. Fox1 IHU to Experiment 4 ICD

1.3 Definitions

1.3.1 Slow Speed Downlink – Data transmitted at approximately 100 bits per second in the audio portion below 300 Hz simultaneous with the transponder audio.

1.3.2 High Speed Downlink – Data transmitted at approximately 9600 bits per second using the entire downlink audio passband.

1.3.3 Spacecraft Telemetry – Downlink data containing specific information about spacecraft systems and health as defined in the System Requirements and related documents.

1.3.4 Experiment Telemetry – Downlink data containing specific information about the various experiment platforms flown on the satellite.

1.3.5 Frame – A defined set of data with a specific overall size comprised of fields of a specific bit or byte length.

2 Protocol Structure

2.1 Physical Layer

2.1.1 The physical layer includes options for slow-speed and high speed operation.

2.1.2 Slow speed operation uses frequency-shift keying and is transmitted in the sub-audible part of the audio downlink below 300 Hz. It may be transmitted simultaneously with voice or other audio signals. The details of the physical layer are shown in Table 1.

Table 1

Bit Rate	200 bps
Spectral efficiency	2 bps/Hz
Modulation type	Non-coherent Frequency Shift Keying (FSK)
Signal bandwidth	10 Hz to 200 Hz (-3 dB points)
FSK Deviation	500 Hz
Spectral Mask	-20 dB at 300 Hz
RF Channel Bandwidth	1200 Hz

2.1.3 High speed operation uses frequency-shift keying and is transmitted using the entire RF downlink bandwidth. The details of the physical layer are shown in Table 2. *Note that this is the same as the G3RUH modem.*

Table 2

Bit Rate	9600 bps
Spectral efficiency	2 bps/Hz
Modulation type	non-coherent frequency shift keying (FSK)
Signal bandwidth	10 Hz to 4800 Hz (-3 dB points)
FSK Deviation	3 kHz
Spectral Mask	-60 dB at 7500 Hz
RF Channel Bandwidth	20 kHz

2.2 Link Layer

2.2.1 The link layer protocol provides multiplexing, packet identification and forward error correction.

2.2.2 The link layer shall include a header and a trailer surrounding the applications layer payload to form data packets as shown in Table 3.

Table 3

Header	Applications Payload	Trailer

2.2.3 The applications payload layer shall include satellite telemetry, experiment telemetry, high speed data, and debug frames.

2.2.4 Debug frames may be used during ground testing but shall not be transmitted for flight.

2.2.5 Bits shall be transmitted in the order of most significant bit first.

2.2.6 Bytes shall be transmitted in Little Endian order.

2.2.7 The Slow Speed link layer header structure shall be as shown in Table 4.

Table 4

Field	Size (Bits)	Type	Min Value	Max Value	Description
Fox ID	3	Unsigned	0x01	0x01	0x01 specifies Fox-1A (each Fox satellite will have a unique ID)
Reset Count	16	Unsigned	0x00	0xFFFF	Total number of times IHU has reset since initial on-orbit startup
Uptime	25	Unsigned	0x00	0x1FFFFFF	This is the IHU uptime in seconds since the last reset
Type	4	Unsigned	0x00	0x0F	This identifies the payload type

2.2.7.1 Payload type shall be as specified in the application layer payload data.

2.2.7.2 Each Slow Speed link layer structure shall contain only one payload type.

2.2.7.3 Reset Count and Uptime shall reflect the time at which the payload data was collected.

2.2.7.4 Reset Count and Uptime shall not be changed if the payload data has not been updated.

2.2.7.5 Real-Time Telemetry Frame, Telemetry Maximum Values Frame, and Telemetry Minimum Values Frame data shall be padded with zeros to equal 58 bytes length for each.

2.2.8 Forward error correction (FEC) code words shall be sent in the link layer trailer. The FEC shall be a Reed Solomon RS 255,223 code. (This provides 32 parity bytes per code word allowing error detection and correction capability.)

2.2.9 The High Speed link layer header structure is shown in Table 5.

Table 5

Field	Size (Bits)	Type	Min Value	Max Value	Description
Fox ID	3	Unsigned	0x01	0x01	0x01 specifies Fox-1A (each Fox satellite will have a unique ID)
Reset Count	16	Unsigned	0x00	0xFFFF	Total number of times IHU has reset since initial on-orbit startup
Uptime	25	Unsigned	0x00	0x1FFFFFF	This is the IHU uptime in seconds since the last reset
(No Value)	4	Unsigned	0x00	0x00	4 bit filler

2.2.10 The High Speed link layer applications payload shall contain data from all payload types, as shown in table 6.

Table 6

Payload Type	Size (Bytes)	Description
1	60	Real-Time Telemetry Frame
2	60	Telemetry Maximum Values Frame
3	60	Telemetry Minimum Values Frame
5	Variable 1 - 4300	Camera JPEG Data Frame
4	58	Radiation Experiment High Speed Data Frame

2.2.10.1 A varying number of Radiation Experiment Data bytes shall be sent to fill the applications payload size to a total of 4600 bytes if the payload type 5 data is less than 4300 bytes.

2.2.10.1.1 When less than a sufficient number of bytes to contain a useful data frame remain to fill to 4600 bytes, the remaining bytes shall be filled with zeros.

2.2.10.2 Real-Time Telemetry Frame, Telemetry Maximum Values Frame, and Telemetry Minimum Values Frame data shall be padded with zeros to equal 60 bytes length for each.

2.2.11 Forward error correction (FEC) code words shall be sent in the link layer trailer. The FEC shall be a Reed Solomon RS 255,223 code. (This provides 32 parity bytes per code word allowing error detection and correction capability.) Twenty one code words will be populated in parallel, with 1 byte being added to each code word in sequence until all bytes have been processed. The last code word will be partially filled and should be virtually padded with 77 bytes. The data will then be sent sequentially with 8b10b coding. Twenty one sets of 32 parity bytes will follow after all data has been sent for the high speed frame.

3 Slow Speed Link Layer Transmission Scheduling

3.1 While IHU PTT is asserted Payload Types contained in the Link Layer Applications Payload shall rotate, changing type with each successive link layer transmitted, in the following order:

- Type 1
- Type 4
- Type 4
- Type 1
- Type 4
- Type 4
- Type 1
- Type 4
- Type 4
- Type 1
- Type 2
- Type 4
- Type 1
- Type 4
- Type 4
- Type 1
- Type 4
- Type 4
- Type 1
- Type 4
- Type 4
- Type 1
- Type 3
- Type 4

3.1.1 The above order shall be repeated so long as IHU PTT is asserted.

3.1.2 Each time IHU PTT is asserted the order shall begin at the top.

3.1.3 The IHU PTT shall not be de-asserted during transmission of a Link Layer.

3.2 While beacon message is sent during idle timer expired the Payload Types contained in the Link Layer Applications Payload shall be transmitted in alternating sets, one set per beacon message:

Set 1:
- Type 1
- Type 2

Set 2:
- Type 1
- Type 3

3.2.1 The payload type 2 or 3 data shall be sent simultaneously with the voice ID.

4 Application Layer Payload Data

4.1 Payload Type 0 – Debug Frame (NOT TO BE TRANSMITTED FOR FLIGHT)

Table 7

Field	Size (Bits)	Type	Min Value	Max Value	Description
UNDEFINED	1 - 464	Undefined	-	-	Debug data for ground testing

4.2 Payload Type 1 - Real-Time Telemetry Frame (Size = 429 bits)

Table 8

Field	Size (Bits)	Type	Min Value	Max Value	Description	Bit Offset
BATT A V	12	Unsigned	0x00	0xFFF	Battery pair A voltage raw value (0-2.5V scale)	0
BATT B V	12	Unsigned	0x00	0xFFF	Battery pairs A+B voltage raw value (0-3.3V scale)	12
BATT C V	12	Unsigned	0x00	0xFFF	Battery pairs A+B+C voltage raw value (0-5.0V scale) This value also represents the power bus voltage (VBATT)	24
BATT A T	12	Unsigned	0x00	0xFFF	Battery pair A temperature raw value	36
BATT B T	12	Unsigned	0x00	0xFFF	Battery pair B temperature raw value	48
BATT C T	12	Unsigned	0x00	0xFFF	Battery pair C temperature raw value	60
TOTAL BATT I	12	Signed	0x00	0xFFF	Total Battery DC current raw value	72
BATT Board Temperature	12	Unsigned	0x00	0xFFF	PC Board Temperature of BATT raw value	84
+X PANEL V	12	Unsigned	0x00	0xFFF	+X solar panel voltage raw value	96
-X PANEL V	12	Unsigned	0x00	0xFFF	-X solar panel voltage raw value	108
+Y PANEL V	12	Unsigned	0x00	0xFFF	+Y solar panel voltage raw value	120
-Y PANEL V	12	Unsigned	0x00	0xFFF	-Y solar panel voltage raw value	132
+Z PANEL V	12	Unsigned	0x00	0xFFF	+Z solar panel voltage raw value	144
-Z PANEL V	12	Unsigned	0x00	0xFFF	-Z solar panel voltage raw value	156
+X PANEL T	12	Unsigned	0x00	0xFFF	+X solar panel temperature raw value	168
-X PANEL T	12	Unsigned	0x00	0xFFF	-X solar panel temperature raw value	180
+Y PANEL T	12	Unsigned	0x00	0xFFF	+Y solar panel temperature raw value	192
-Y PANEL T	12	Unsigned	0x00	0xFFF	-Y solar panel temperature raw value	204
+Z PANEL T	12	Unsigned	0x00	0xFFF	+Z solar panel temperature raw value	216

Field	Size (Bits)	Type	Min Value	Max Value	Description	Bit Offset
-Z PANEL T	12	Unsigned	0x00	0xFFF	-Z solar panel temperature raw value	228
PSU Temperature	12	Unsigned	0x00	0xFFF	PSU card temperature raw value	240
SPIN	12	Signed	0x00	0xFFF	Calculated spin rate RPM using solar cells Bit 11 = sign Bits 10 to 8 = integer Bits 7 to 0 = fraction	252
TX PA Current	12	Unsigned	0x00	0xFFF	Transmit power amplifier current raw value	264
TX Temperature	12	Unsigned	0x00	0xFFF	Transmitter card temperature raw value	276
RX Temperature	12	Unsigned	0x00	0xFFF	Receiver card temperature raw value	288
RSSI	12	Unsigned	0x00	0xFFF	Received Signal Strength Indication raw value	300
IHU CPU Temperature	12	Unsigned	0x00	0xFFF	CPU Temperature of IHU raw value	312
Satellite X Axis Angular Velocity	12	Unsigned	0x00	0xFFF	Raw Angle	324
Satellite Y Axis Angular Velocity	12	Unsigned	0x00	0xFFF	Raw Angle	336
Satellite Z Axis Angular Velocity	12	Unsigned	0x00	0xFFF	Raw Angle	348
EXP 4 Temperature	12	Unsigned	0x00	0xFFF	Experiment 4 card temperature raw value	360
PSU Current	12	Unsigned	0x00	0xFFF	PSU DC current	372
IHU Diagnostic Data	32	Unsigned	-	-	Diagnostic Data on IHU Performance	384
Experiment Failure Indication	4	Unsigned	0x00 0x08	0x01 0x09	Bit 0 is Experiment 1 Bit 1 is Experiment 2 (N/A on Fox-1A) Bit 2 is Experiment 3 (N/A on Fox-1A) Bit 3 is Experiment 4 State: 0 = Working, 1 = Failed	416

Field	Size (Bits)	Type	Min Value	Max Value	Description	Bit Offset
System I2C Failure Indications	3	Unsigned	0x00	0x07	Bit 0 is BATT Bit 1 is PSU Device 1 Bit 2 is PSU Device 2 State: 0 = Working, 1 = Failed	420
Number of Ground Commanded TLM Resets	4	Unsigned	0x00	0x0F	Number of times command stations reset stored telemetry	423
Antenna Deploy Sensors	2	Unsigned	0x00	0x03	Bit 0 is RCV Bit 1 is XMT State: 0 = stowed 1 = deployed	427

4.3 Payload Type 2 - Telemetry Maximum Values Frame (Size = 458 bits)

Table 9

Field	Size (Bits)	Type	Min Value	Max Value	Description	Bit Offset
BATT A V	12	Unsigned	0x00	0xFFF	Battery pair A high voltage raw value (0-2.5V scale)	0
BATT B V	12	Unsigned	0x00	0xFFF	Battery pairs A+B high voltage raw value (0-3.3V scale)	12
BATT C V	12	Unsigned	0x00	0xFFF	Battery pairs A+B+C high voltage raw value (0-5.0V scale) This value also represents the power bus voltage (VBATT)	24
BATT A T	12	Unsigned	0x00	0xFFF	Battery pair A high temperature raw value	36
BATT B T	12	Unsigned	0x00	0xFFF	Battery pair B high temperature raw value	48
BATT C T	12	Unsigned	0x00	0xFFF	Battery pair C high temperature raw value	60
TOTAL BATT I	12	Signed	0x00	0xFFF	Battery DC high current raw value	72
BATT Board Temperature	12	Unsigned	0x00	0xFFF	High PC Board Temperature of BATT raw value	84
+X PANEL V	12	Unsigned	0x00	0xFFF	+X solar panel high voltage raw value	96
-X PANEL V	12	Unsigned	0x00	0xFFF	-X solar panel high voltage raw value	108
+Y PANEL V	12	Unsigned	0x00	0xFFF	+Y solar panel high voltage raw value	120
-Y PANEL V	12	Unsigned	0x00	0xFFF	-Y solar panel high voltage raw value	132
+Z PANEL V	12	Unsigned	0x00	0xFFF	+Z solar panel high voltage raw value	144
-Z PANEL V	12	Unsigned	0x00	0xFFF	-Z solar panel high voltage raw value	156
+X PANEL T	12	Unsigned	0x00	0xFFF	+X solar panel high temperature raw value	168

Field	Size (Bits)	Type	Min Value	Max Value	Description	Bit Offset
-X PANEL T	12	Unsigned	0x00	0xFFF	-X solar panel high temperature raw value	180
+Y PANEL T	12	Unsigned	0x00	0xFFF	+Y solar panel high temperature raw value	192
-Y PANEL T	12	Unsigned	0x00	0xFFF	-Y solar panel high temperature raw value	204
+Z PANEL T	12	Unsigned	0x00	0xFFF	+Z solar panel high temperature raw value	216
-Z PANEL T	12	Unsigned	0x00	0xFFF	-Z solar panel high temperature raw value	228
PSU Temperature	12	Unsigned	0x00	0xFFF	PSU card high temperature raw value	240
SPIN	12	Signed	0x00	0xFFF	Highest calculated spin rate RPM using solar cells	252
TX PA Current	12	Unsigned	0x00	0xFFF	Transmit power amplifier high current raw value	264
TX Temperature	12	Unsigned	0x00	0xFFF	Transmitter card high temperature raw value	276
RX Temperature	12	Unsigned	0x00	0xFFF	Receiver card high temperature raw value	288
RSSI	12	Unsigned	0x00	0xFFF	High Received Signal Strength Indication raw value	300
IHU CPU Temperature	12	Unsigned	0x00	0xFFF	High CPU Temperature of IHU raw value	312
Satellite X Axis Angular Velocity	12	Unsigned	0x00	0xFFF	Highest Raw Angle	324
Satellite Y Axis Angular Velocity	12	Unsigned	0x00	0xFFF	Highest Raw Angle	336
Satellite Z Axis Angular Velocity	12	Unsigned	0x00	0xFFF	Highest Raw Angle	348

Field	Size (Bits)	Type	Min Value	Max Value	Description	Bit Offset
EXP 4 Temperature	12	Unsigned	0x00	0xFFF	Experiment 4 card high temperature raw value	360
PSU Current	12	Unsigned	0x00	0xFFF	PSU DC high current	372
IHU Hard Error Data	32	Unsigned	-	-	Diagnostic Data on IHU Hard Errors	384
MAX Timestamp Reset Count	16	Unsigned	0x00	0xFFFF	At last MAX, total number of times IHU has reset since initial on-orbit startup	416
MAX Timestamp Uptime	25	Unsigned	0x00	0x1FFFFFF	At last MAX, the IHU uptime in seconds since the last reset	432
Safe Mode Indication	1	Unsigned	0x00	0x01	State: 1 = Safe Mode Active	457

4.4 Payload Type 3 - Telemetry Minimum Values Frame (Size = 458 bits)

Table 10

Field	Size (Bits)	Type	Min Value	Max Value	Description	Bit Offset
BATT A V	12	Unsigned	0x00	0xFFF	Battery pair A low voltage raw value (0-2.5V scale)	0
BATT B V	12	Unsigned	0x00	0xFFF	Battery pair A+B low voltage raw value (0-3.3V scale)	12
BATT C V	12	Unsigned	0x00	0xFFF	Battery pair A+B+C low voltage raw value (0-5.0V scale) This value also represents the power bus voltage (VBATT)	24
BATT A T	12	Unsigned	0x00	0xFFF	Battery pair A low temperature raw value	36
BATT B T	12	Unsigned	0x00	0xFFF	Battery pair B low temperature raw value	48
BATT C T	12	Unsigned	0x00	0xFFF	Battery pair C low temperature raw value	60
TOTAL BATT I	12	Signed	0x00	0xFFF	Battery DC low current raw value	72
BATT Board Temperature	12	Unsigned	0x00	0xFFF	Low PC Board Temperature of BATT raw value	84
+X PANEL V	12	Unsigned	0x00	0xFFF	+X solar panel low voltage raw value	96
-X PANEL V	12	Unsigned	0x00	0xFFF	-X solar panel low voltage raw value	108
+Y PANEL V	12	Unsigned	0x00	0xFFF	+Y solar panel low voltage raw value	120
-Y PANEL V	12	Unsigned	0x00	0xFFF	-Y solar panel low voltage raw value	132
+Z PANEL V	12	Unsigned	0x00	0xFFF	+Z solar panel low voltage raw value	144
-Z PANEL V	12	Unsigned	0x00	0xFFF	-Z solar panel low voltage raw value	156
+X PANEL T	12	Unsigned	0x00	0xFFF	+X solar panel low temperature raw value	168

Field	Size (Bits)	Type	Min Value	Max Value	Description	Bit Offset
-X PANEL T	12	Unsigned	0x00	0xFFF	-X solar panel low temperature raw value	180
+Y PANEL T	12	Unsigned	0x00	0xFFF	+Y solar panel low temperature raw value	192
-Y PANEL T	12	Unsigned	0x00	0xFFF	-Y solar panel low temperature raw value	204
+Z PANEL T	12	Unsigned	0x00	0xFFF	+Z solar panel low temperature raw value	216
-Z PANEL T	12	Unsigned	0x00	0xFFF	-Z solar panel low temperature raw value	228
PSU Temperature	12	Unsigned	0x00	0xFFF	PSU card low temperature raw value	240
SPIN	12	Signed	0x00	0xFFF	Lowest calculated spin rate RPM using solar cells	252
TX PA Current	12	Unsigned	0x00	0xFFF	Transmit power amplifier low current raw value	264
TX Temperature	12	Unsigned	0x00	0xFFF	Transmitter card low temperature raw value	276
RX Temperature	12	Unsigned	0x00	0xFFF	Receiver card low temperature raw value	288
RSSI	12	Unsigned	0x00	0xFFF	Low Received Signal Strength Indication raw value	300
IHU CPU Temperature	12	Unsigned	0x00	0xFFF	Low CPU Temperature of IHU raw value	312
Satellite X Axis Angular Velocity	12	Unsigned	0x00	0xFFF	Lowest Raw Angle	324
Satellite Y Axis Angular Velocity	12	Unsigned	0x00	0xFFF	Lowest Raw Angle	336
Satellite Z Axis Angular Velocity	12	Unsigned	0x00	0xFFF	Lowest Raw Angle	348

Field	Size (Bits)	Type	Min Value	Max Value	Description	Bit Offset
EXP 4 Temperature	12	Unsigned	0x00	0xFFF	Experiment 4 card low temperature raw value	360
PSU Current	12	Unsigned	0x00	0xFFF	PSU DC low current	372
IHU Soft Error Data	32	Unsigned	-	-	Diagnostic Data on IHU Soft Errors	384
MIN Timestamp Reset Count	16	Unsigned	0x00	0xFFFF	At last MIN, total number of times IHU has reset since initial on-orbit startup	416
MIN Timestamp Uptime	25	Unsigned	0x00	0x1FFFFFF	At last MIN, the IHU uptime in seconds since the last reset	432
Safe Mode Indication	1	Unsigned	0x00	0x01	State: 1 = Safe Mode Active	457

4.5 Payload Type 4 - Radiation Experiment Data Frame (Size = 464 bits)

Table 11

Field	Size (Bytes)	Type	Min Value	Max Value	Description
Data	58	Unsigned	-	-	Experiment 1 Data

4.6 Payload Type 5 - Camera JPEG Data Frame (Size is variable)

Table 12

Field	Size (Bytes)	Type	Min Value	Max Value	Description
Picture Lines	8	Unsigned	-	-	Picture Data[1]

[1] See section 5 for Picture Data Structure

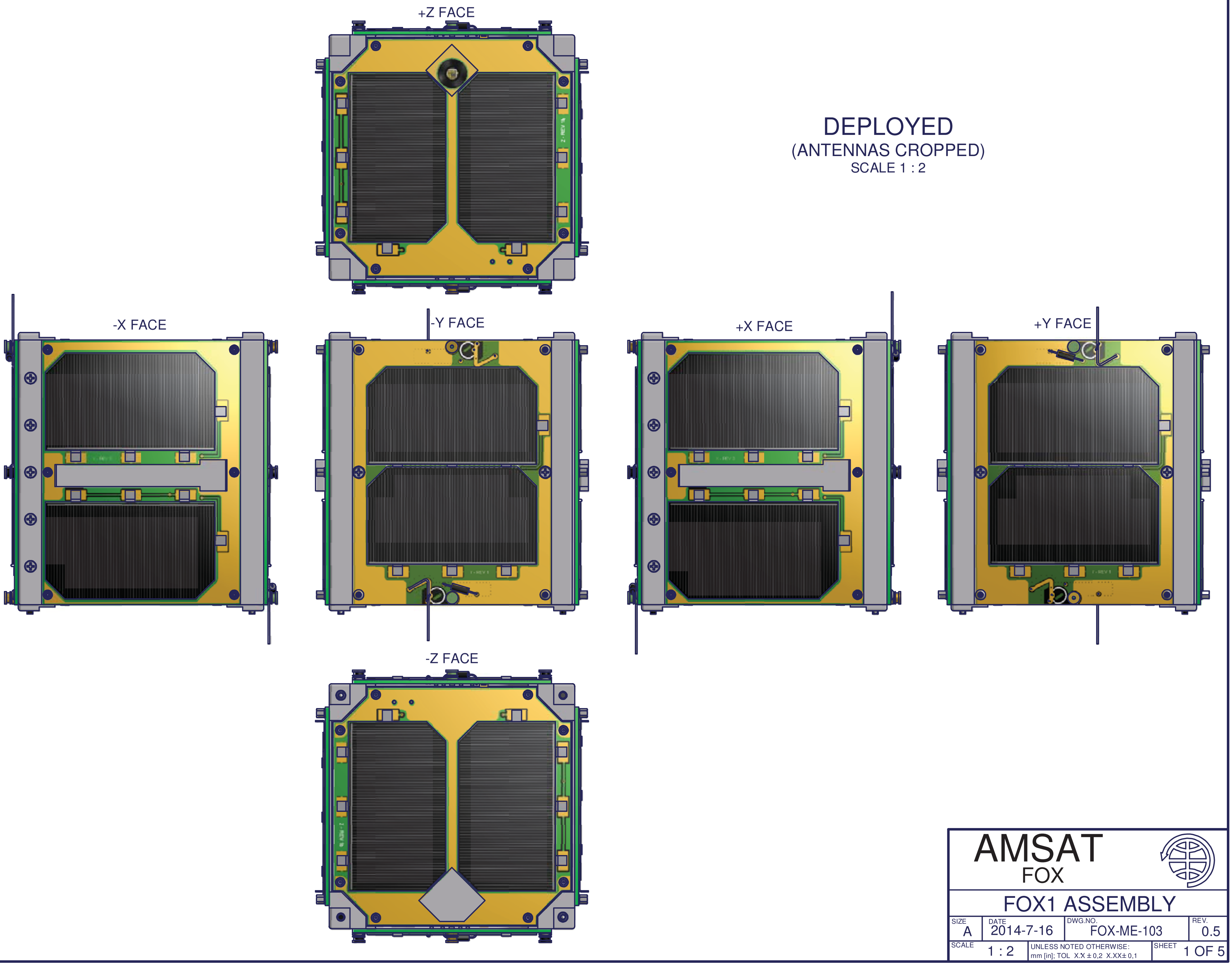
5 Picture Data Structure

5.1 Scan Line Segment

Table 13

Field	Size (Bits)	Type	Min Value	Max Value	Description
Picture Counter	8	Unsigned	0x00	0xFF	Picture count indicator
Scan Line Number	6	Unsigned	0x00	0x3B	0x00 = top scan line
Scan Line Length	10	Unsigned	0x001	0x3FF	Count of bytes in the scan line
Scan Line Data	Variable	Unsigned	-	-	(Fragment Length) Scan Line Data
End of JPEG Data	8	Unsigned	0xAA	0xAA	Indicates end of Picture Data for use in Applications Payload construction

5.1.1 Total Scan Line Segment data size for one Applications Payload frame including end of JPEG data indicator byte shall not exceed 4300 bytes.



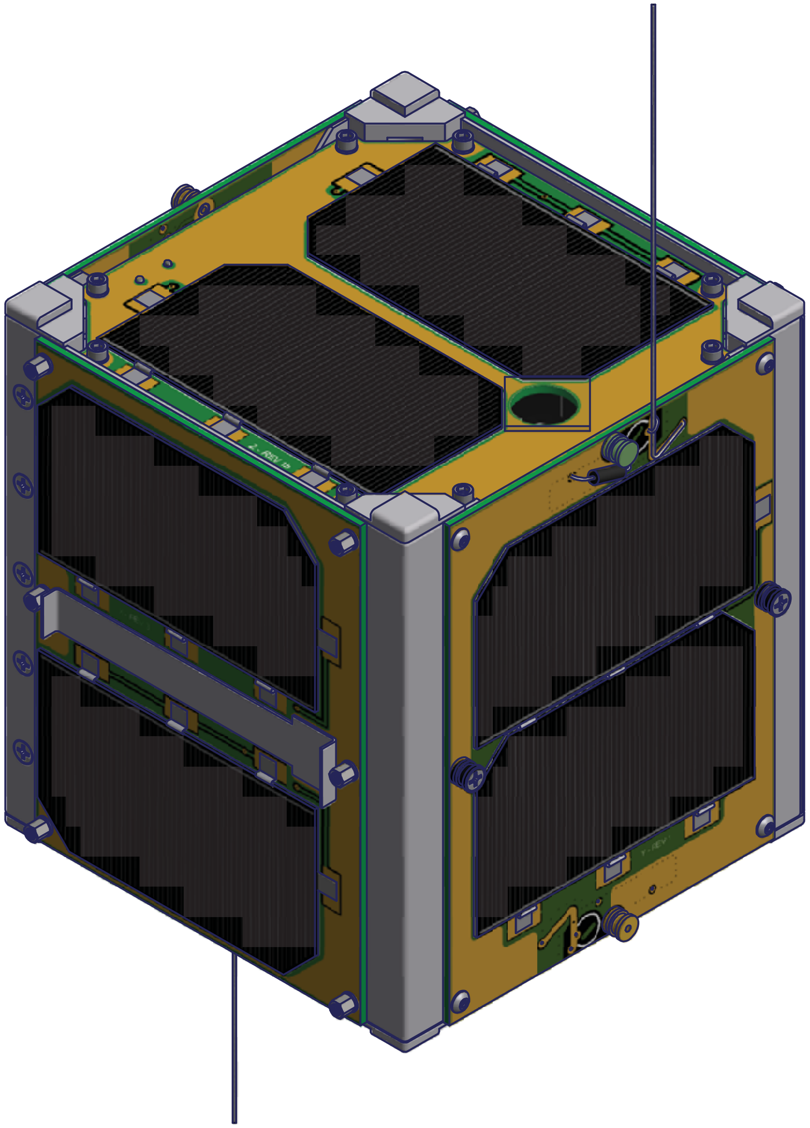
DEPLOYED
(ANTENNAS CROPPED)
SCALE 1 : 2

AMSAT
FOX

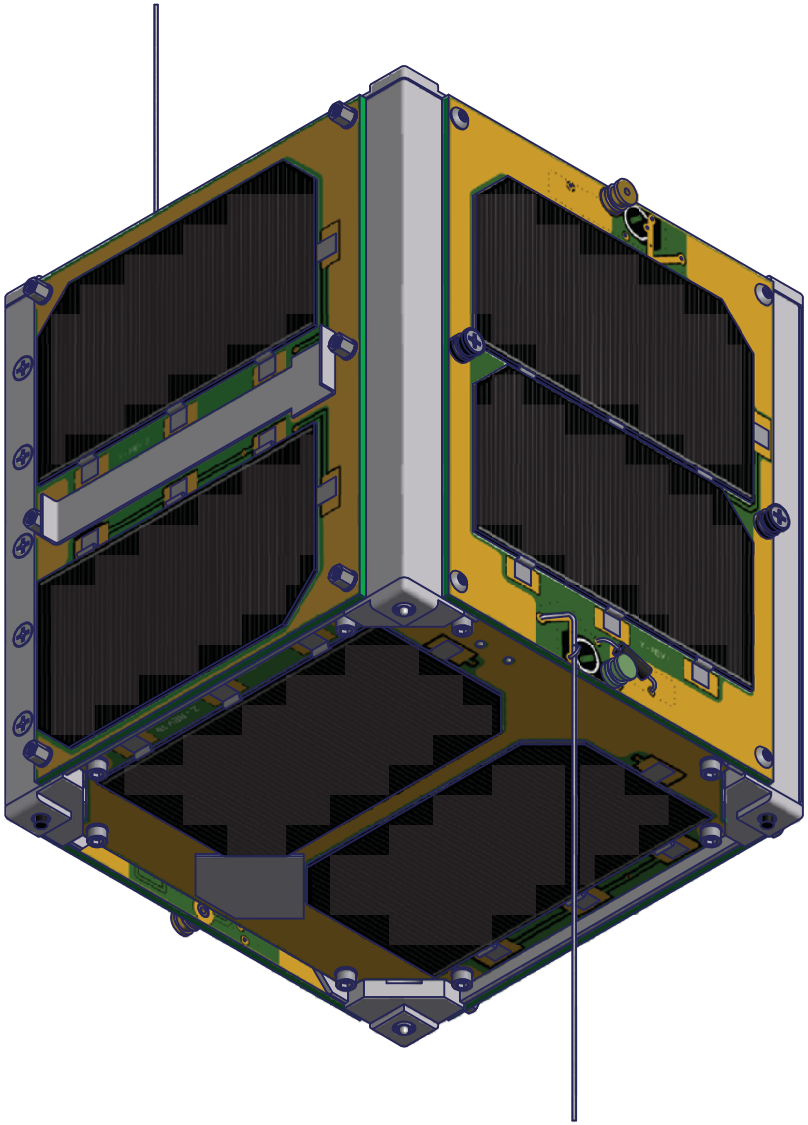
FOX1 ASSEMBLY

SIZE	DATE	DWG.NO.	REV.
A	2014-7-16	FOX-ME-103	0.5
SCALE 1 : 2	UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX± 0,1		SHEET 1 OF 5

ISO +X+Y+Z
SCALE 3 : 4



ISO -X-Y-Z
SCALE 3 : 4

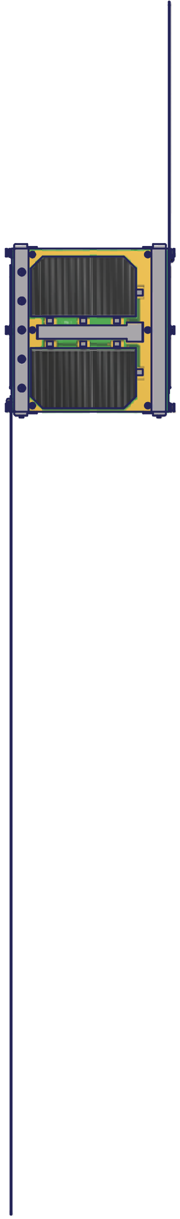


AMSAT
FOX

FOX1 ASSEMBLY

SIZE A	DATE 2014-7-16	DWG.NO. FOX-ME-103	REV. 0.5
SCALE 3 : 4	UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX± 0,1	SHEET 2 OF 5	

+X FACE
TRUE ANTENNA LENGTHS
SCALE 0.2 : 1

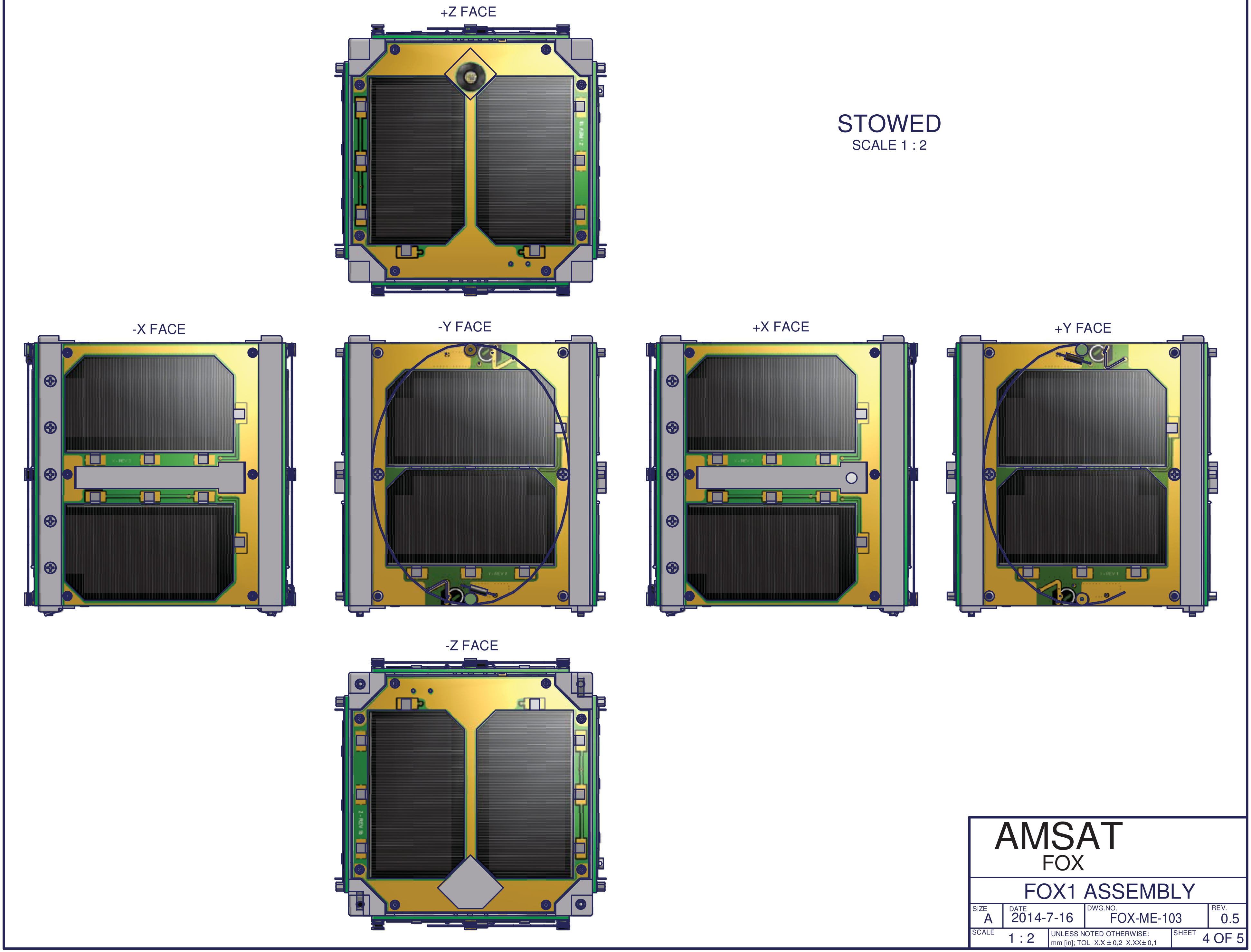


AMSAT
FOX

FOX1 ASSEMBLY

SIZE A
DATE 2014-7-16
DWG.NO. FOX-ME-103
REV. 0.5
SCALE 1 : 5
UNLESS NOTED OTHERWISE:
mm [in]; TOL X.X ± 0,2 X.XX± 0,1
SHEET 3 OF 5

STOWED
SCALE 1 : 2

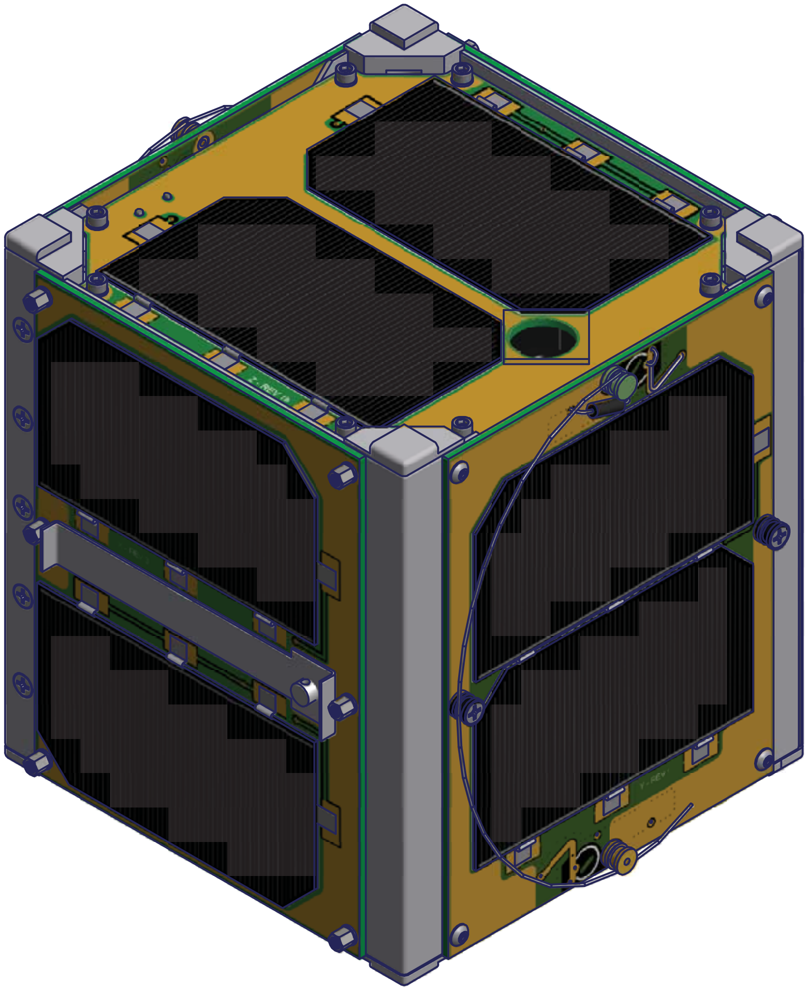


AMSAT
FOX

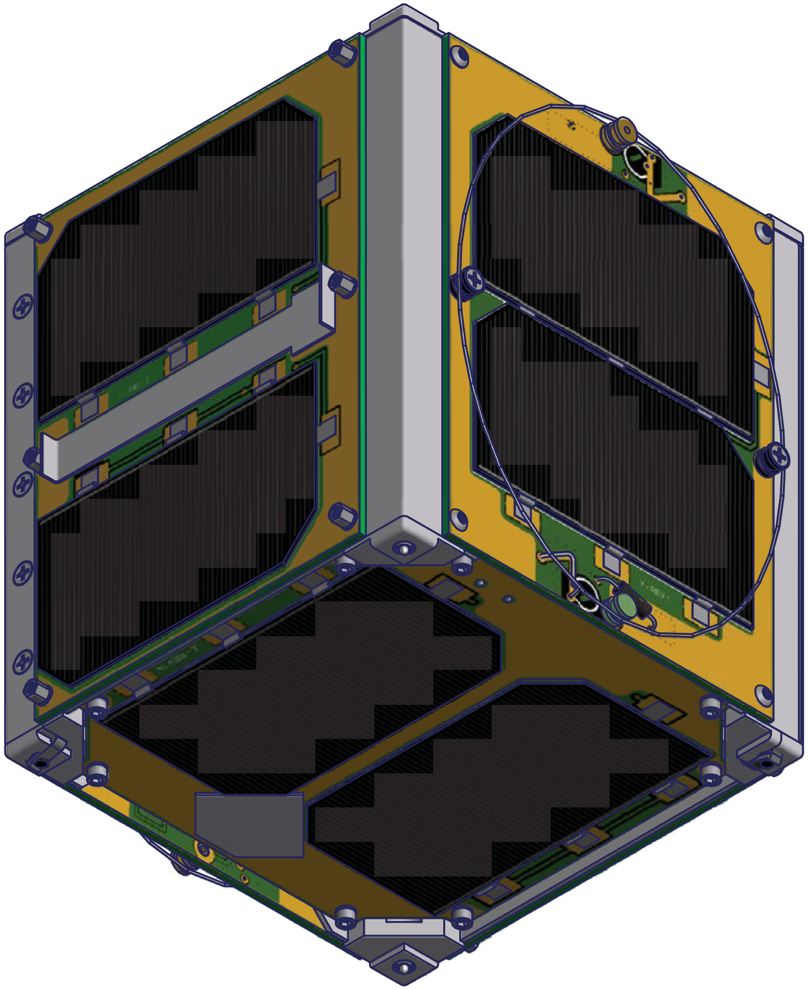
FOX1 ASSEMBLY

SIZE	DATE	DWG.NO.	REV.
A	2014-7-16	FOX-ME-103	0.5
SCALE 1 : 2	UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX± 0,1	SHEET 4 OF 5	

ISO +X+Y+Z
SCALE 3 : 4



ISO -X-Y-Z
SCALE 3 : 4



AMSAT
FOX

FOX1 ASSEMBLY

SIZE	DATE	DWG.NO.	REV.
A	2014-7-16	FOX-ME-103	0.5
SCALE 3 : 4	UNLESS NOTED OTHERWISE: mm [in]; TOL X.X ± 0,2 X.XX± 0,1		SHEET 5 OF 5

AMSAT Fox-1 Engineering Documentation Update

Compiled by Jerry Buxton, N0JY
AMSAT Vice President - Engineering
n0jy@amsat.org

AMSAT, as an educational organization, would like to publicly release the majority of our design documentation to serve as a learning tool to anyone interested in satellite development. However, in order to avoid complications with ITAR and Export Administration Rules, the information must first be released via an openly available publication. We would also like to be able to discuss our satellite projects with our own members, some of whom are not "US-persons" per those regulations. These AMSAT Space Symposium proceedings provide a convenient mechanism for the needed publication in order to make this information public domain and allow us to communicate with our members.

While many of the Fox-1 documents were published in previous *Proceedings*, some of these documents have undergone changes as the satellite design has progressed and evolved therefore the updated versions will be reproduced in these 2015 Space Symposium proceedings. In addition, these proceedings also present any new engineering documents that have been produced since the last publication which include some of the documentation for the Fox-1Cliff and Fox-1D satellites.

Through publication in the three proceedings, the majority of the Fox-1A documentation has now been introduced to the public domain.

Date: September 29, 2014
Version: 3.92

AMSAT *Fox-1*
Avionics System Design Specification

1 Introduction

This document contains the system level design specifications for the AMSAT *Fox-1* satellite avionics systems. It is driven by the System Requirements Specification and other documents provided by the developers of the individual systems that make up the satellite system.

1.1. Document History

DATE	VERSION	SUMMARY
February 21, 2012	1.0	From Draft F
April 9, 2012	1.1	Add signal characteristics, update bus pin connections per System Team input
April 17, 2012	1.2	Add external connector specification in sections 2.6, 2.12 and 2.14 and references in section 6
April 18, 2012	1.21	Add MMCX connectors gender
April 22, 2012	1.3	Minor corrections in signal characteristics, remove +Z antenna deploy and sensor connections
July 10, 2012	2.0	Many revisions from PDR
July 11, 2012	2.01	One RBF pin removed from bus pin assignments, updated 2.1 interconnect diagram, updated 2.1 signal characteristics
July 21, 2012	2.1	Revised bus signals, bus pin assignments Updated RF block diagram
July 22, 2012	2.11	Revision to some RF signal descriptions, change antenna/coax connectors to UMCC type, updated RF block diagram, added driving and load system columns to signal characteristics
September 9, 2012	3.0	Major changes.
September 11, 2012	3.01	Defunct IHU block diagram pending update
September 12, 2012	3.1	Added PCB volume requirements
September 23, 2012	3.11	Change TX PTT to RX PTT, -Z Deploy switches to TX, update figures and tables accordingly
September 26, 2012	3.12	Update bus and pin assignment drawings
September 27, 2012	3.13	Update bus pin assignment drawings
September 30, 2012	3.14	Update RF block diagram to remove ITAR notice
October 17, 2012	3.15	Import changes to requirements from System Requirements
February 17, 2013	3.2	Incorporate system bus signal nomenclature and pin assignment changes
February 28, 2013	3.3	MEC connector changed orientation (flipped) on +X -X +Y -Y panels.

DATE	VERSION	SUMMARY
March 28, 2013	3.4	Add second –Z PPOD deploy switch (pin 54), PPOD deploy switches now on TX system card
March 31, 2013	3.41	Updates to the TX, RX, IHU, and BUS pin diagrams.
March 31, 2013	3.42	Adjusted RESERVED pin colors only
April 21, 2013	3.43	Addition of RX Frequency Control, TX Frequency Control, and Sensor Power signals Pin reassignments: Moved pins 52 and 54 to pins 33 and 35 respectively Moved pins 40 and 42 to pins 29 and 42 respectively Added the above new signals to pins 42, 40, and 38 respectively
April 25, 2013	3.5	Update per System Requirements 3.10.2 changes. Updated bus connection pin assignments, bus interconnect diagram, and system bus signal characteristics account removal of TX OSC Temp and TX PA Temp and addition of TX Temperature
June 26, 2013	3.6	Add requirements for PSU and BATT1 CPU reset from RX Command Data, updated IHU block diagram
July 24, 2013	3.7	Add ALERT signal, SENSOR POWER signal, remove RBF2, rename RBF1 to Solar Safe N, remove RX Command Data connection from BATT1, flip MEC connector orientation on +X, -X, +Y, -Y panels, update ME-113 mechanical drawings
August 26, 2013	3.8	Rename RX OSC TEMP to RX Temperature, add Initial Surge Current Limits for certain systems, move Command Decoder to IHU system (bus pin changes), update some bus nomenclature, update System Requirements for each system per changes to the System Requirements
August 27, 2013	3.81	Correct source and destination for RX Command Strobe in Table 1
September 17, 2013	3.82	Add (move) RSSI to Pin 10, rename Pin 32 as RX CD, add Solar Power A and Solar Power B to pins 55 and 56, update TX Block Diagram, remove RX Command Data connection from PSU, update hyperlinks.
October 8, 2013	3.83	Remove IHU AUDIO OUT 2, RX AUDIO 2 signals, rename IHU AUDIO OUT 1 to IHU AUDIO OUT, RX AUDIO 1 to RX AUDIO.
November 11, 2013	3.84	Updated IHU Block Diagram
January 23, 2014	3.85	Add Sensor Power connection to PSU
January 23, 2014	3.86	Several text (requirements) changes to match recent System Requirements change for Safe Mode.
April 27, 2014	3.87	Add PCB plating requirements for TX, RX, IHU, PSU, BATT, EXP systems
May 29, 2014	3.88	Correct 6.7 to read PSU System
August 16, 2014	3.9	Updates to 5.1, 6.1 to match updated system requirements
August 20, 2014	3.91	Correct 5.1 to show 120 seconds for Safe Mode beacon
September 29, 2014	3.92	Update PSU block diagram, add receiver block diagram, update commands in 5.1, update instances of system requirements 3.9.3, 3.9.4, 3.9.6

1.2. Document Scope

The purpose of this document is to specify the avionics systems and their connections to each other and to external components for the satellite. It is intended to be used by the hardware, software, and mechanical designers to develop the architecture and interconnections for the satellite avionics systems.

1.3. Document Format

This document provides these elements in a numbered format. The numbered sections specify each major system in the satellite while numbered items for each system specify the external connections required and the number of lines for each connection. Satellite bus and external connections are further described in figures and tables.

Where System Requirements are reproduced their numbers are from the AMSAT *Fox*-1 System Requirements Specification.

1.4. References

1. AMSAT *Fox-1* ConOps
2. AMSAT *Fox-1* System Requirements Specification
3. AMSAT *Fox-1* Bus (Signal Connections Diagram)
4. AMSAT *Fox-1* Bus Pin Assignment
5. AMSAT *Fox-1* Avionics System Design Specification Spreadsheet
6. AMSAT FOX-ME-120_Z_TOPBOTT_SOLAR_PANEL.pdf
7. AMSAT FOX-ME-127_Y_SIDE_SOLAR_PANEL.pdf

Contents

2 Avionics System Bus Signals, Characteristics, and Connections

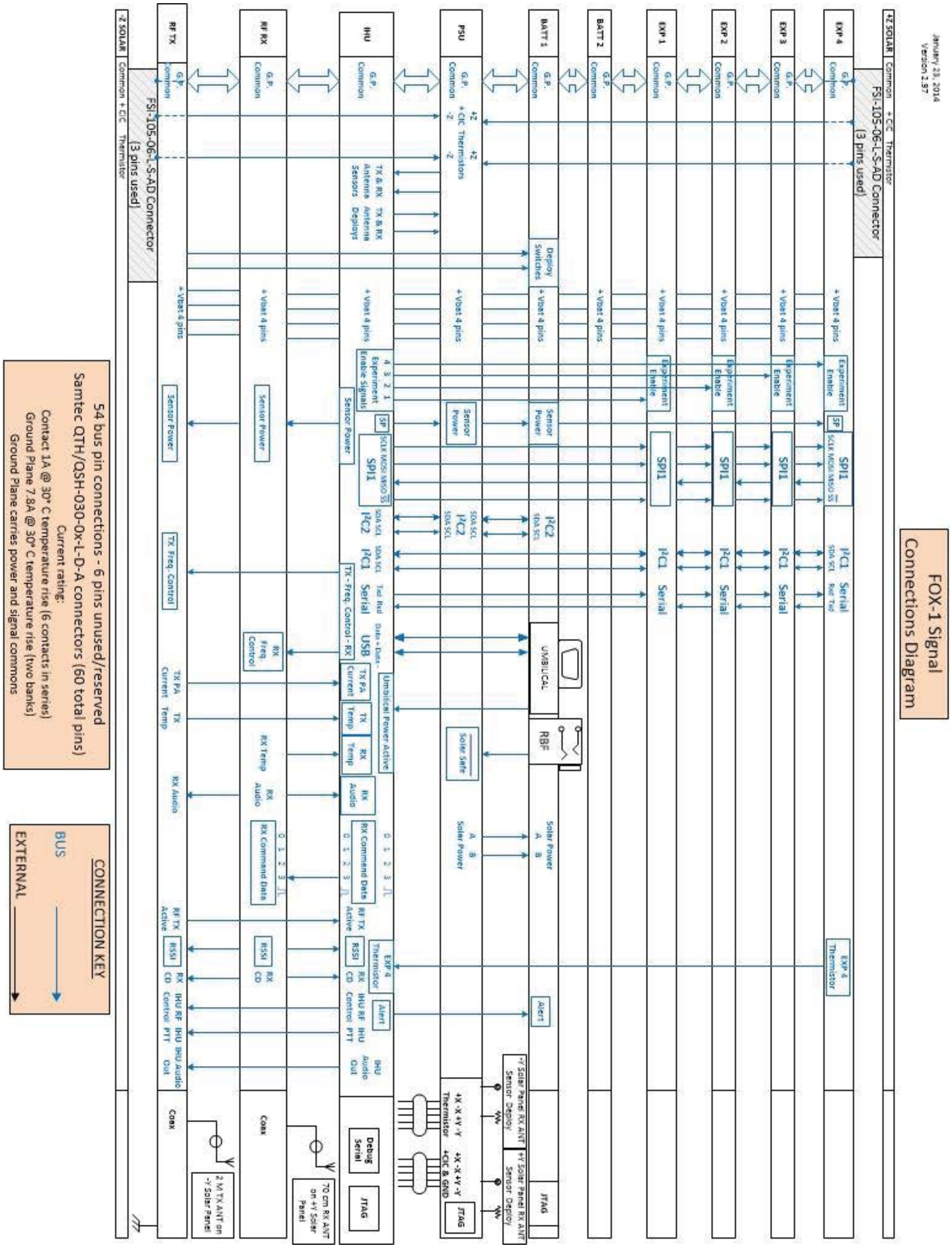


Figure 1: Interconnect Diagram

Table 1: System Bus Signal Characteristics

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Load System	Notes
1	SPI1 NSS	Digital	Note[1]	IHU		EXP 1-4	SPI Standard, IHU Master
2	TX PA Current	Analog	0 - 3.0 V	TX	30 - 60 kΩ	IHU	
3	SPI1 SCK	Digital	Note[1]	IHU		EXP 1-4	SPI Standard, IHU Master
4	TX Temperature	Analog	0 - 3.0 V	TX	30 - 60 kΩ	IHU	Thermistor Circuit
5	SPI1 MISO	Digital	Note[1]	IHU		EXP 1-4	SPI Standard, IHU Master
6	Experiment 4 Thermistor	Analog	N/A	EXP 4	N/A	IHU	Temperature from Experiment 4 position
7	SPI1 MOSI	Digital	Note[1]	IHU		EXP 1-4	SPI Standard, IHU Master
8	RX Temperature	Analog	0 - 3.0 V	RX	30 - 60 kΩ	IHU	Thermistor Circuit
9	Serial RXD	Digital	3.0 V	EXP 1-4		IHU	Async, Mark High
10	RSSI	Analog	0 - 3.0 V	RX	30 - 60 kΩ	IHU	Received Signal Strength Indication
11	Serial TXD	Digital	3.0 V	IHU		EXP 1-4	Async, Mark High
12	IHU Audio Out	Analog	0 - 3 V (audio)	IHU	> 10 kΩ unbal.	TX	For 5 kHz deviation, 10 Hz - 7 kHz bandwidth
13	Experiment Enable 1	Digital		IHU		EXP 1-4	HIGH = Enable EXP 1
14	Not Used						
15	Experiment Enable 2	Digital		IHU		EXP 2	HIGH = Enable EXP 2
16	RX Command Data 0	Digital		IHU			(Least Significant Bit) Not Used on Fox-1A
17	Experiment Enable 3	Digital		IHU		EXP 3	HIGH = Enable EXP 3
18	RX Command Data 1	Digital		IHU			Not Used on Fox-1A
19	Experiment Enable 4	Digital		IHU		EXP 4	HIGH = Enable EXP 4
20	RX Command Data 2	Digital		IHU			HIGH = IHU off
21	Not Used						
22	RX Command Data 3	Digital		IHU		TX	(Most Significan Bit) HIGH = Inhibit Transmit
23	I^{2}C1 SCL	Digital	Note[1]	IHU			I^{2}C Standard, IHU Master
24	RX Command Strobe	Digital		IHU			HIGH = Command Data change
25	I^{2}C1 SDA	Digital	Note[1]	IHU			I^{2}C Standard, IHU Master
26	IHU RF Control	Digital		IHU		TX	HIGH = IHU Controls RF LOW = Standalone Analog Transponder
27	Not Used						
28	IHU PTT	Digital		IHU		TX	HIGH = TRANSMIT
29	Solar Safe N	Switch	N/A	BATT	N/A	PSU	N.O. for operation
30	RF TX Active	Digital		TX		IHU	HIGH = RF TX on
31	Alert Signal	Digital		IHU		BATT	
32	RX CD	Digital		RX		TX IHU	HIGH = valid receive signal
33	-Z Deploy Switch 1	Switch	N/A	TX	N/A	PSU/BATT	N.O. when deployed
34	RX Audio	Analog	0 - 3 V (audio)	RX	> 10 kΩ unbal.	IHU	10 Hz - 7 kHz bandwidth
35	-Z Deploy Switch 2	Switch	N/A	TX	N/A	PSU/BATT	N.O. when deployed
36	Not Used						
37	I^{2}C2 SCL	Digital	Note[1]	IHU		PSU/BATT	I^{2}C Standard, IHU Master
38	Sensor Power	Analog	+3 VDC	IHU		TX RX BATT EXP4	Power for analog telemetry sensors
39	I^{2}C2 SDA	Digital	Note[1]	IHU		PSU/BATT	I^{2}C Standard, IHU Master
40	TX Frequency Control	Digital		IHU		TX	Not Used on Fox-1A
41	+Z Thermistor	Analog	N/A	EXP 4	N/A	PSU	
42	RX Frequency Control	Digital		IHU		RX	Not Used on Fox-1A
43	-Z Thermistor	Analog	N/A	TX	N/A	PSU	
44	-Y Antenna Deploy	Analog	Vbatt	IHU	7 Ω resistor	PSU	
45	+Z CIC	Power	N/A	EXP 4	N/A	PSU	
46	-Y Antenna Sensor	Switch	N/A	PSU	N.O.	IHU	N.O. when deployed
47	-Z CIC	Power	N/A	TX	N/A	PSU	
48	+Y Antenna Sensor	Switch	N/A	PSU	N.O.	IHU	N.O. when deployed
49	Umbilical USBP	Digital		BATT		IHU	USB Standard
50	+Y Antenna Deploy	Analog	Vbatt	IHU	7 Ω resistor	PSU	
51	Umbilical USBM	Digital		BATT		IHU	USB Standard
52	Not Used						
53	Umbilical Power Active	Digital		BATT		IHU	HIGH = Running on Umbilical Port Power
54	Not Used						
55	Solar Power A	Power	Vbatt	PSU		BATT	
56	Solar Power B	Power	Vbatt	PSU		BATT	
57	Vbatt	Power Bus	3.3 - 4.2 VDC	BATT/PSU		ALL	
58	Vbatt	Power Bus	3.3 - 4.2 VDC	BATT/PSU		ALL	
59	Vbatt	Power Bus	3.3 - 4.2 VDC	BATT/PSU		ALL	
60	Vbatt	Power Bus	3.3 - 4.2 VDC	BATT/PSU		ALL	
	Version 2.96						
	Note[1] All SPI and I^{2}C signals are 3.0 V levels			All Digital signals are 3.0 V CMOS logic levels high impedance load unless otherwise noted			

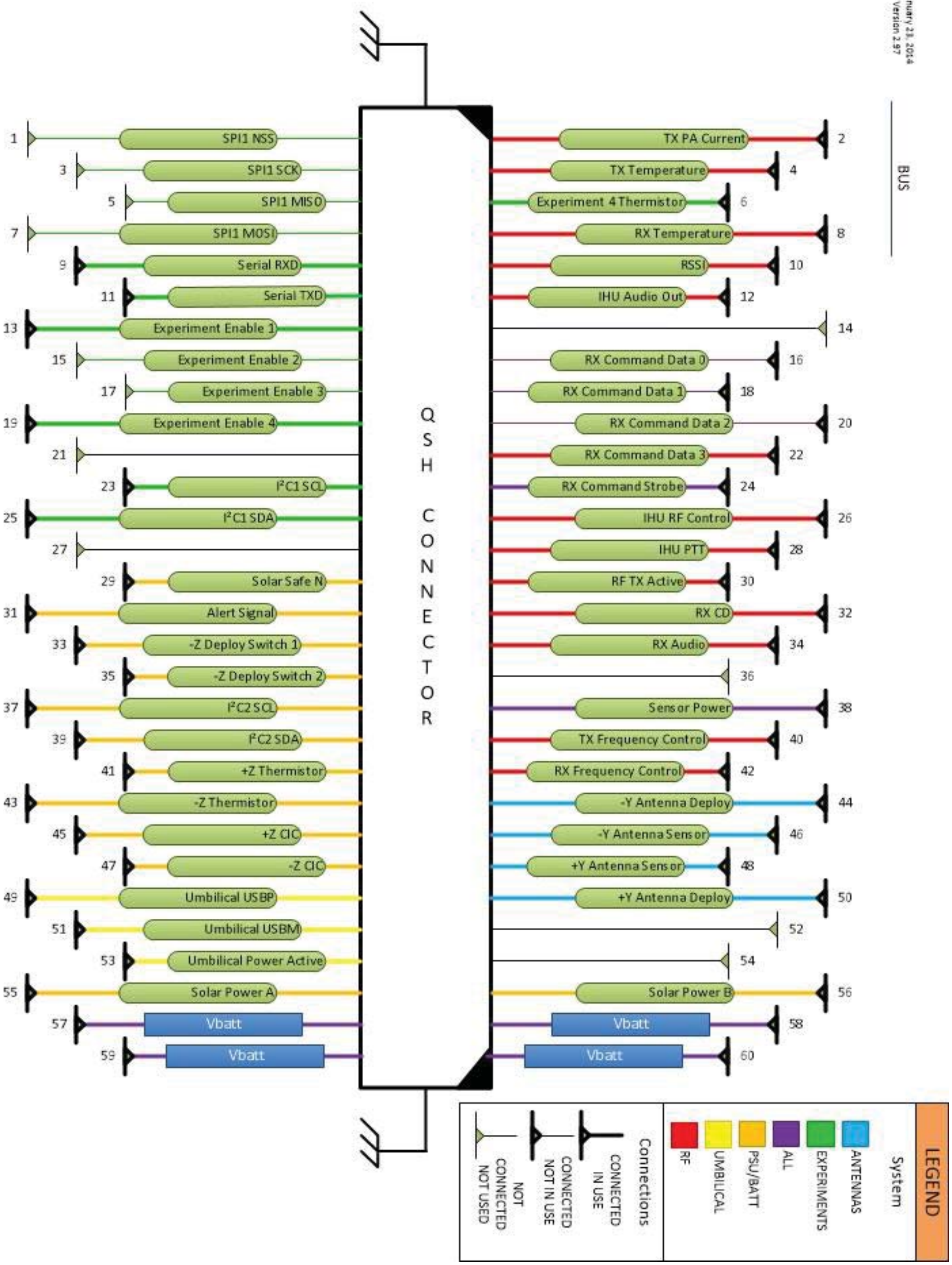


Figure 2: Complete Bus Connection Pin Assignments

3 RF Transmitter System

3.1 System Requirements Applicable to RF Transmitter System

<table>
<tr><td>2.2.1</td><td>The satellite avionics shall be designed for -40C to +70C operating temperature.</td></tr>
<tr><td>2.2.3</td><td>The satellite shall be designed to tolerate the radiation environment in orbit.</td></tr>
<tr><td>2.3.1</td><td>The satellite shall be designed for a minimum 5-year, on-orbit lifetime.</td></tr>
<tr><td>2.4.1</td><td>All RF transmitters shall meet or exceed the requirements specified in the ITU Radio Regulations, Technical Characteristics, Volume 3, article 3.</td></tr>
<tr><td>2.4.3</td><td>All satellite downlinks shall be in the 2 meter band within the amateur satellite service.</td></tr>
<tr><td>2.4.4</td><td>All satellite transmitter and receiver frequencies shall deviate by no more than 5 parts-per-million from the specified values including initial accuracy and temperature variation.</td></tr>
<tr><td>2.4.5</td><td>All satellite frequencies shall be coordinated with the IARU.</td></tr>
<tr><td>3.8.1</td><td>The satellite shall include an FM downlink transmitter.</td></tr>
<tr><td>3.8.2</td><td>The transmitter shall have specifications as shown in Table 2.
<table>
<tr><td>Power Output</td><td>400 mW (min.)</td></tr>
<tr><td>FM Deviation</td><td>5 kHz</td></tr>
<tr><td>Audio Bandwidth</td><td>3 kHz</td></tr>
</table></td></tr>
<tr><td>3.8.3</td><td>The transmitter shall provide a means to prevent over modulation.</td></tr>
<tr><td>3.9.1</td><td>The satellite shall provide an FM transponder via the RF uplink and RF downlink.</td></tr>
<tr><td>3.9.3</td><td>In Transponder Mode, the downlink transmitter shall be keyed (i.e. PTT-on) by the IHU for a minimum of 30 seconds following detection of the 67 Hz CTCSS tone.</td></tr>
<tr><td>3.9.5</td><td>In Transponder Mode, the 67 Hz CTCSS tone is not required for a received signal to be repeated on the downlink, once the transmitter has been keyed.</td></tr>
<tr><td>3.9.7</td><td>In the event of shutdown or failure of the IHU, the satellite shall default to simple carrier operated repeater operation.</td></tr>
<tr><td>3.10.1</td><td>The satellite shall collect telemetry data.</td></tr>
<tr><td>3.10.2</td><td>The telemetry data shall include at a minimum, measured parameters as shown in Table 3.
<table>
<tr><th>Parameter Name</th><th>Description</th></tr>
<tr><td>CELL V</td><td>Voltages of battery cells</td></tr>
<tr><td>PANEL V</td><td>Voltages of solar panels</td></tr>
<tr><td>TOTAL I</td><td>Total DC current out of power system</td></tr>
<tr><td>PA I</td><td>DC current into RF power amp</td></tr>
<tr><td>BATTERY T</td><td>Temperature of battery</td></tr>
<tr><td>PANEL T</td><td>Temperatures of solar panels</td></tr>
<tr><td>TX T</td><td>Temperature of RF transmitter card</td></tr>
</table></td></tr>
</table>

<table>
<tr><td></td><td><table><tr><td>RX T</td><td>Temperature of RF receiver card</td></tr></table></td></tr>
<tr><td>3.10.3</td><td>The measured parameters shall be sampled at least every 15 seconds.</td></tr>
<tr><td>3.11.1</td><td>The satellite shall send slow speed telemetry using FSK on the RF downlink.</td></tr>
<tr><td>3.11.2</td><td>The FSK shall use the frequency spectrum below the audible range.</td></tr>
<tr><td>3.11.3</td><td>The telemetry shall be transmitted simultaneously with any transponder communications.</td></tr>
<tr><td>3.12.1</td><td>The satellite shall provide the means to process commands sent via the RF uplink from a ground control station.</td></tr>
<tr><td>3.12.2</td><td>The commands received via the RF uplink shall not be repeated on the RF downlink.</td></tr>
<tr><td>3.12.3</td><td>The following commands shall be provided, as shown in Table 5.
<table>
<tr><th>Command</th><th>Operation</th></tr>
<tr><td>SAFE MODE</td><td>Enter Safe Mode</td></tr>
<tr><td>INHIBIT</td><td>Inhibit RF transmission</td></tr>
<tr><td>IHU OFF</td><td>Power off IHU & PSU</td></tr>
<tr><td>IHU ON</td><td>Power on IHU & PSU</td></tr>
<tr><td>CLEAR</td><td>Clear stored telemetry</td></tr>
<tr><td>TRANSPONDER MODE</td><td>Enter Transponder Mode</td></tr>
<tr><td>DATA MODE</td><td>Enter Data Mode</td></tr>
</table></td></tr>
<tr><td>3.12.5</td><td>An INHIBIT command shall cause the satellite to cease RF transmissions.</td></tr>
<tr><td>3.13.8</td><td>In Transponder Mode, the transponder and the slow speed telemetry shall be active.</td></tr>
<tr><td>3.13.9</td><td>In Data Mode, the high speed telemetry shall be active and the transponder shall not be active. (i.e. signals that appear on the uplink shall not be repeated on the downlink.)</td></tr>
</table>

3.2 Initial Surge Current Limits

3.2.1 The RF Transmitter design shall limit initial inrush current to 2.5 Amperes.

3.3 Volume Requirements Applicable to RF Transmitter System

3.3.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 5 mm from the –Z surface of the PC board.

3.3.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 6.0 mm from the +Z surface of the PC board.

3.4 Interface Control Documents Applicable to RF Transmitter System

AMSAT *Fox-1* IHU to RF System Interface Control Document

3.5 PCB Plating Requirements Applicable to RF Transmitter System

3.5.1 ENIG then selective flash gold four mounting pads.

3.6 RF Transmitter System PCB Bus Connections

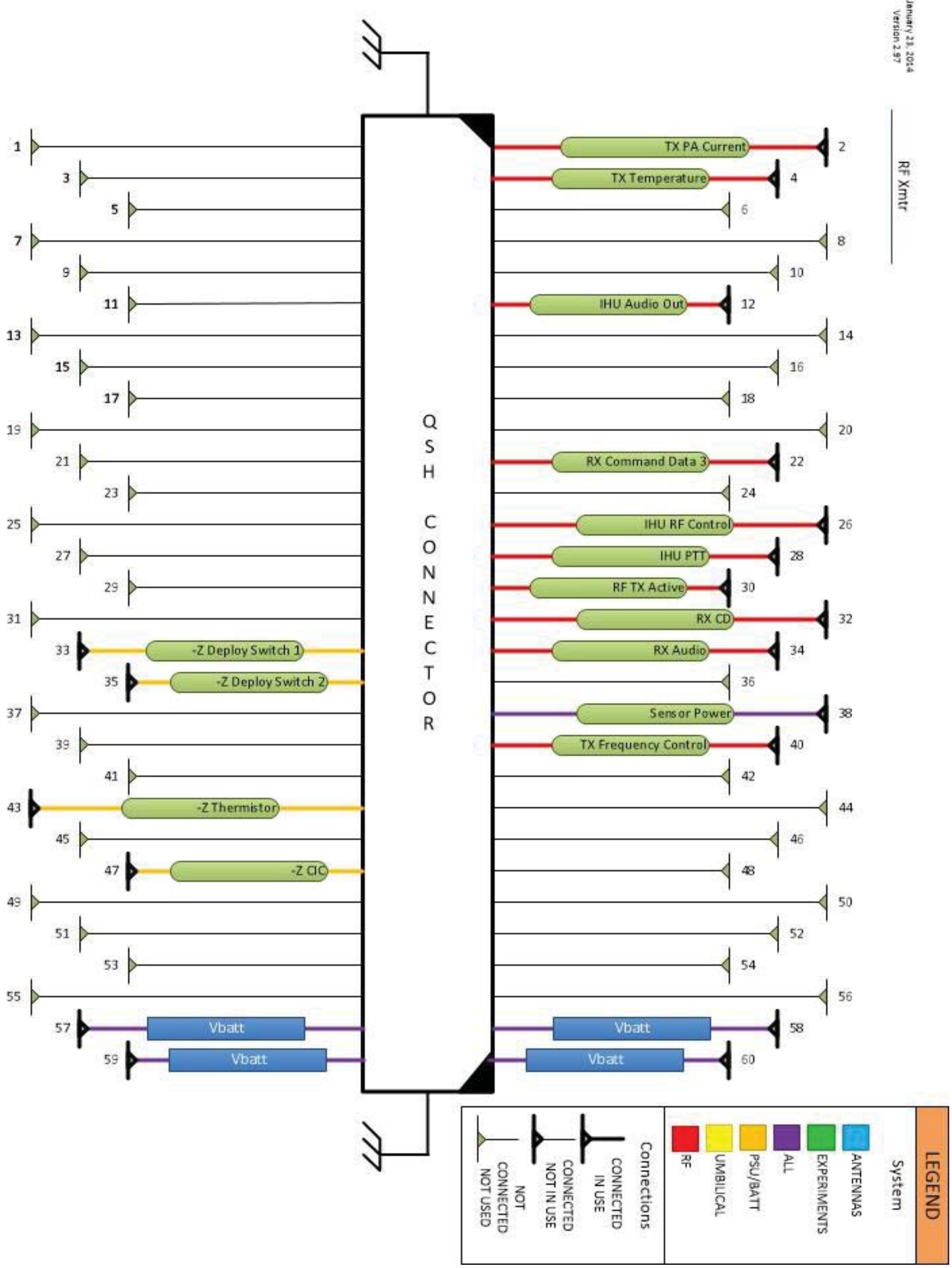


Figure 3: RF Transmitter System Bus Connection Pin Assignments

3.7 RF Transmitter System PCB External Connections

3.7.1 2 meter band RF output, coaxial cable to Transmit Antenna
3.7.2 Spacecraft deployment switches cable(s) TBR
3.7.3 Three connections via Samtec FSI-105-06-L-S-AD connector
  3.7.3.1 1 contact -Z Solar Panel Thermistor
  3.7.3.2 1 contact -Z Solar Panel CIC +
  3.7.3.3 1 contact common or - for above four connections

Table 2: External Connection Signal Characteristics

External Connection	Nomenclature	Type	Voltage/ Power	Source System	Load Z	Bus Pin
Coaxial Cable	2 meter Antenna ≈ 145.9 MHz	RF	0 to +30 dBm	2 meter Antenna	50 Ω unbal.	N/A

Table 3: -Z PCB face FSI-105-06-L-S-AD connector mates to pads on –Z Solar Panel

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Load System	Bus Pin
1	-Z Thermistor	Analog	N/A	N/A	N/A	PSU	43
2	N/C						
3	-Z Solar Panel Common						Ground Plane
4	N/C						
5	-Z CIC	Power	N/A	N/A	N/A	PSU	47

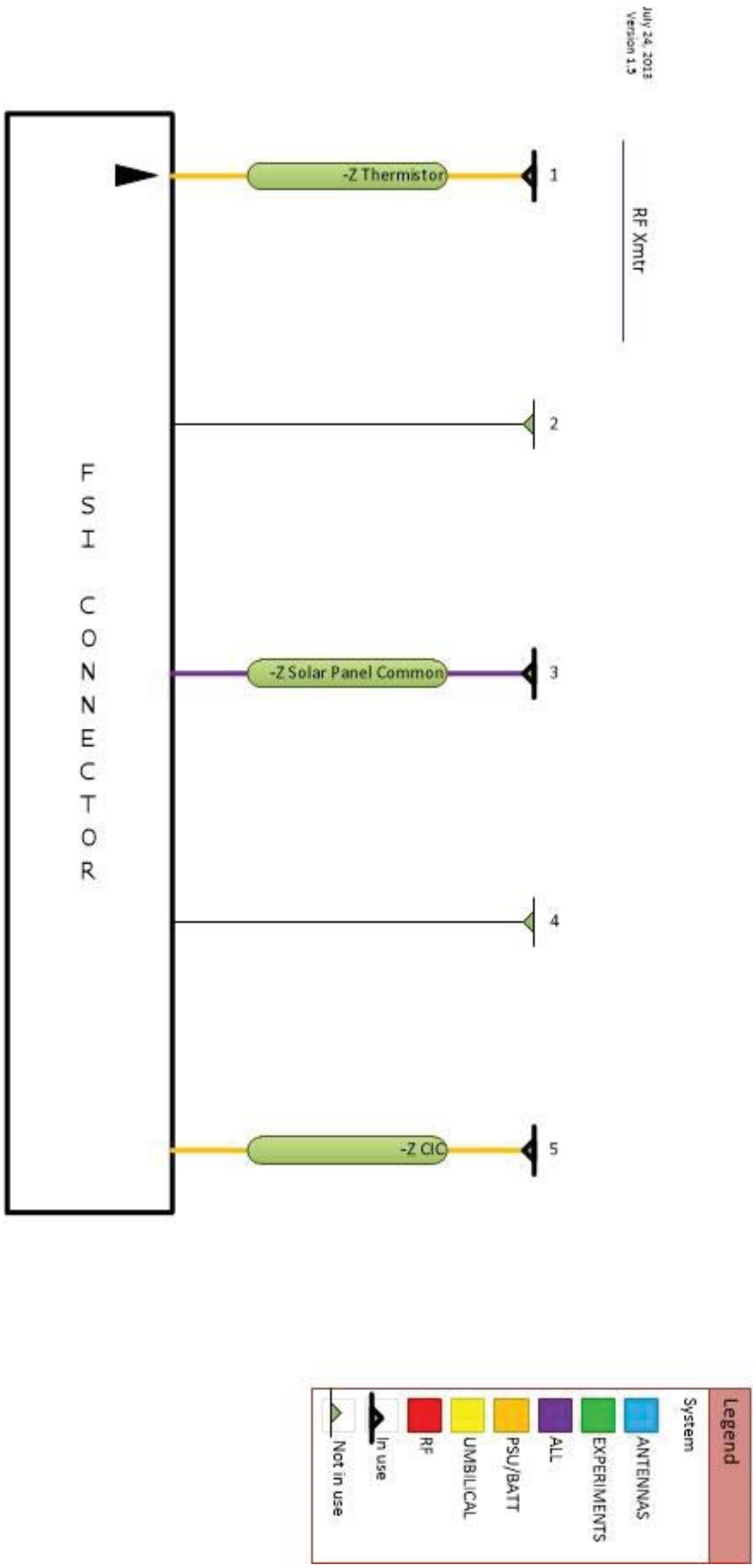


Figure 4: RF Transmitter System FSI-105-06-L-S-AD Connection Pin Assignments

4 RF Receiver System

4.1 System Requirements Applicable to RF Receiver System

<table>
<tr><td>2.2.1</td><td>The satellite avionics shall be designed for -40C to +70C operating temperature.</td></tr>
<tr><td>2.2.3</td><td>The satellite shall be designed to tolerate the radiation environment in orbit.</td></tr>
<tr><td>2.3.1</td><td>The satellite shall be designed for a minimum 5-year, on-orbit lifetime.</td></tr>
<tr><td>2.4.2</td><td>All satellite uplinks shall be in the 70 cm band of the amateur satellite service.</td></tr>
<tr><td>2.4.5</td><td>All satellite frequencies shall be coordinated with the IARU.</td></tr>
<tr><td>3.7.1</td><td>The satellite shall include an FM uplink receiver.</td></tr>
<tr><td>3.7.2</td><td>The receiver shall have specifications as shown in Table 1.
<table>
<tr><td>Sensitivity</td><td>-120 dBm for 12 dB SINAD (min.)</td></tr>
<tr><td>FM Deviation</td><td>5 kHz</td></tr>
<tr><td>Audio Bandwidth</td><td>3 kHz</td></tr>
<tr><td>Input Frequency Acceptance</td><td>Receiver shall accept signals that are off frequency by ±2.5 kHz (min.)</td></tr>
</table>
</td></tr>
<tr><td>3.8.3</td><td>The transmitter shall provide a means to prevent over modulation.</td></tr>
<tr><td>3.9.1</td><td>The satellite shall provide an FM transponder via the RF uplink and RF downlink.</td></tr>
<tr><td>3.9.7</td><td>In the event of shutdown or failure of the IHU, the satellite shall default to simple carrier operated repeater operation.</td></tr>
<tr><td>3.10.1</td><td>The satellite shall collect telemetry data.</td></tr>
<tr><td>3.10.2</td><td>The telemetry data shall include at a minimum, measured parameters as shown in Table 3.
<table>
<tr><th>Parameter Name</th><th>Description</th></tr>
<tr><td>CELL V</td><td>Voltages of battery cells</td></tr>
<tr><td>PANEL V</td><td>Voltages of solar panels</td></tr>
<tr><td>TOTAL I</td><td>Total DC current out of power system</td></tr>
<tr><td>PA I</td><td>DC current into RF power amp</td></tr>
<tr><td>BATTERY T</td><td>Temperature of battery</td></tr>
<tr><td>PANEL T</td><td>Temperatures of solar panels</td></tr>
<tr><td>TX T</td><td>Temperature of RF transmitter card</td></tr>
<tr><td>RX T</td><td>Temperature of RF receiver card</td></tr>
</table>
</td></tr>
<tr><td>3.10.3</td><td>The measured parameters shall be sampled at least every 15 seconds.</td></tr>
<tr><td>3.12.2</td><td>The commands received via the RF uplink shall not be repeated on the RF downlink.</td></tr>
<tr><td>3.13.12</td><td>The RF uplink shall be monitored for commands in all modes.</td></tr>
</table>

4.2 Initial Surge Current Limits

4.2.1 The RF Receiver design shall limit initial inrush current to 0.1 Amperes.

4.3 Volume Requirements Applicable to RF Receiver System

4.3.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 1 mm from the –Z surface of the PC board.

4.3.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 6.0 mm from the +Z surface of the PC board.

4.4 Interface Control Documents Applicable to RF Receiver System

AMSAT *Fox-1* IHU to RF System Interface Control Document

4.5 PCB Plating Requirements Applicable to RF Receiver System

4.5.1 ENIG then selective flash gold four mounting pads.

4.6 RF Receiver System PCB Bus Connections

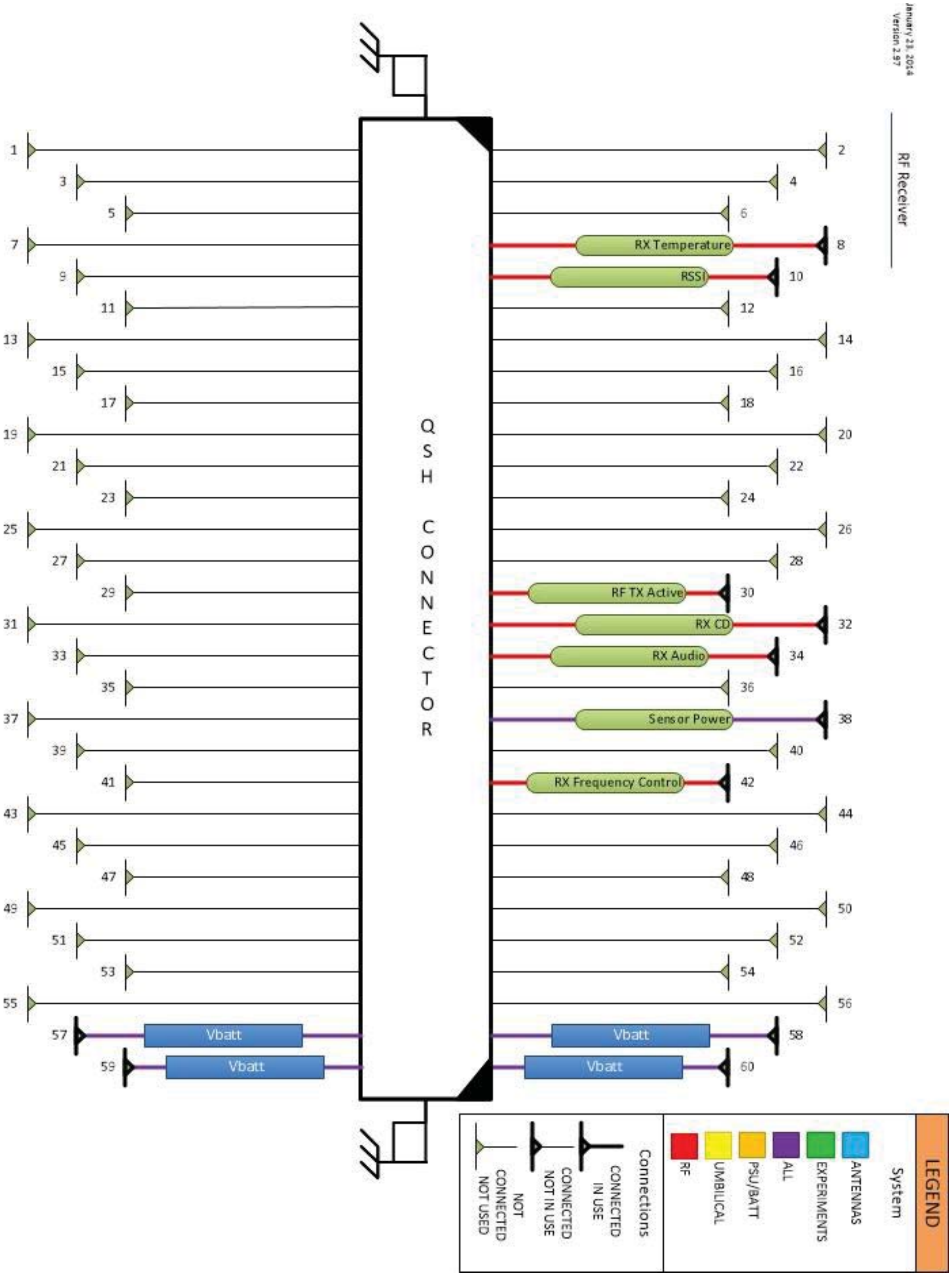


Figure 5: RF Receiver System Bus Connection Pin Assignments

4.7 RF Receiver System PCB External Connections

4.7.1 70cm band RF input, coaxial cable to Receive Antenna

Table 4: RF Receiver System External Connection Signal Characteristics

External Connection	Nomenclature	Type	Voltage/ Power	Source System	Load Z	Bus Pin
Coaxial Cable	70 cm RF Input 437 MHz	RF	-60 dBm to -140 dBm	70 cm Antenna	50 Ω unbal.	N/A

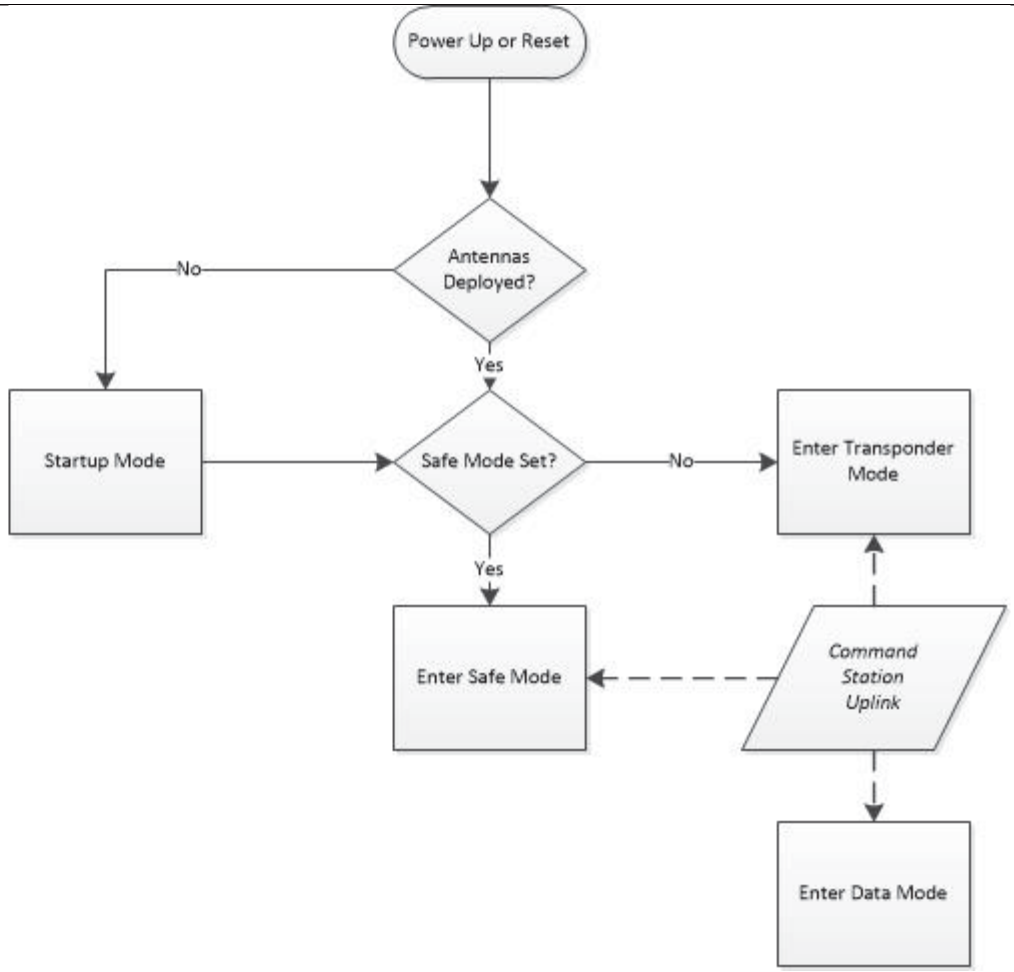
5 Internal Housekeeping Unit (IHU) System

5.1 System Requirements Applicable to Internal Housekeeping Unit (IHU) System

<table>
<tr><td>2.2.1</td><td>The satellite avionics shall be designed for -40C to +70C operating temperature.</td></tr>
<tr><td>2.2.3</td><td>The satellite shall be designed to tolerate the radiation environment in orbit.</td></tr>
<tr><td>2.3.1</td><td>The satellite shall be designed for a minimum 5-year, on-orbit lifetime.</td></tr>
<tr><td>3.3.2</td><td>The satellite shall include an umbilical port as per the CubeSat Design Specification.</td></tr>
<tr><td>3.4.3</td><td>The satellite shall provide the means to run diagnostic tests via the umbilical port while integrated with the P-POD.</td></tr>
<tr><td>3.6.2</td><td>The satellite shall provide a means to activate and deactivate the experiment payloads.</td></tr>
<tr><td>3.6.3</td><td>The satellite shall provide a means to telemeter data from the experiment payloads.</td></tr>
<tr><td>3.9.2</td><td>In Transponder Mode, the IHU shall detect the presence of a 67 Hz CTCSS tone on the uplink.</td></tr>
<tr><td>3.9.3</td><td>In Transponder Mode, the downlink transmitter shall be keyed (i.e. PTT-on) by the IHU for a minimum of 30 seconds following detection of the 67 Hz CTCSS tone.</td></tr>
<tr><td>3.9.4</td><td>In Transponder Mode, the downlink transmitter shall stay on continuously as long as the 67 Hz CTCSS tone is detected at least once during the period the transmitter is being keyed (i.e. PTT-on).</td></tr>
<tr><td>3.9.5</td><td>In Transponder Mode, the 67 Hz CTCSS tone is not required for a received signal to be repeated on the downlink, once the transmitter has been keyed.</td></tr>
<tr><td>3.9.6</td><td>In Transponder Mode, if the downlink transmitter has been un-keyed for a period of 2 minutes, the satellite shall send "HI THIS IS AMATEUR RADIO SATELLITE FOX 1" as a voice announcement on the downlink transmitter.</td></tr>
<tr><td>3.9.7</td><td>In the event of shutdown or failure of the IHU, the satellite shall default to simple carrier operated repeater operation.</td></tr>
<tr><td>3.10.1</td><td>The satellite shall collect telemetry data.</td></tr>
<tr><td>3.10.2</td><td>The telemetry data shall include at a minimum, measured parameters as shown in Table 3.
<table>
<tr><th>Parameter Name</th><th>Description</th></tr>
<tr><td>CELL V</td><td>Voltages of battery cells</td></tr>
<tr><td>PANEL V</td><td>Voltages of solar panels</td></tr>
<tr><td>TOTAL I</td><td>Total DC current out of power system</td></tr>
<tr><td>PA I</td><td>DC current into RF power amp</td></tr>
<tr><td>BATTERY T</td><td>Temperature of battery</td></tr>
<tr><td>PANEL T</td><td>Temperatures of solar panels</td></tr>
<tr><td>TX T</td><td>Temperature of RF transmitter card</td></tr>
<tr><td>RX T</td><td>Temperature of RF receiver card</td></tr>
</table></td></tr>
<tr><td>3.10.3</td><td>The measured parameters shall be sampled at least every 15 seconds.</td></tr>
<tr><td>3.10.4</td><td>The minimum and maximum values of each of the measured parameters shall be saved in non-</td></tr>
</table>

<table>
<tr><td></td><td>volatile memory.</td></tr>
<tr><td>3.10.5</td><td>The telemetry data shall also include at a minimum, calculated parameters as shown in Table 4.
<table>
<tr><th>Parameter Name</th><th>Description</th></tr>
<tr><td>UP TIME</td><td>Total seconds since avionics power-up or reset</td></tr>
<tr><td>SPIN</td><td>Satellite spin rate and direction</td></tr>
</table></td></tr>
<tr><td>3.10.6</td><td>A telemetry frame shall include the current measured values, the saved minimum and maximum values, and the current calculated values.</td></tr>
<tr><td>3.11.1</td><td>The satellite shall send slow speed telemetry using FSK on the RF downlink.</td></tr>
<tr><td>3.11.2</td><td>The FSK shall use the frequency spectrum below the audible range.</td></tr>
<tr><td>3.11.3</td><td>The telemetry shall be transmitted simultaneously with any transponder communications.</td></tr>
<tr><td>3.11.4</td><td>The telemetry transmission shall include telemetry frames.</td></tr>
<tr><td>3.11.5</td><td>The telemetry transmission shall include experiment data.</td></tr>
<tr><td>3.12.1</td><td>The satellite shall provide the means to process commands sent via the RF uplink from a ground control station.</td></tr>
<tr><td>3.12.3</td><td>The following commands shall be provided, as shown in Table 5.
<table>
<tr><th>Command</th><th>Operation</th></tr>
<tr><td>SAFE MODE</td><td>Enter Safe Mode</td></tr>
<tr><td>INHIBIT TX</td><td>Inhibit RF transmission</td></tr>
<tr><td>ENABLE TX</td><td>Enable RF transmission</td></tr>
<tr><td>IHU OFF</td><td>Power off IHU</td></tr>
<tr><td>IHU ON</td><td>Power on IHU</td></tr>
<tr><td>CLEAR</td><td>Clear stored telemetry</td></tr>
<tr><td>TRANSPONDER MODE</td><td>Enter Transponder Mode</td></tr>
<tr><td>DATA MODE</td><td>Enter Data Mode</td></tr>
<tr><td>ENABLE AUTO-SAFE</td><td>Enable Auto-Safe Mode</td></tr>
<tr><td>DISABLE AUTO-SAFE</td><td>Disable Auto-Safe Mode</td></tr>
</table></td></tr>
<tr><td>3.12.4</td><td>A SAFE MODE command shall cause the satellite to enter the Safe Mode.</td></tr>
<tr><td>3.12.5</td><td>An INHIBIT TX command shall disable the RF transmitter.</td></tr>
<tr><td>3.12.6</td><td>An ENABLE TX command shall enable the RF transmitter.</td></tr>
<tr><td>3.12.7</td><td>An IHU OFF command shall cause the IHU System to power off.</td></tr>
<tr><td>3.12.8</td><td>An IHU ON command shall cause the IHU System to power on.</td></tr>
<tr><td>3.12.9</td><td>A CLEAR command shall cause the satellite to clear the saved minimum and maximum telemetry parameter values.</td></tr>
<tr><td>3.12.10</td><td>A TRANSPONDER MODE command shall cause the satellite to enter the Transponder Mode.</td></tr>
</table>

<table>
<tr><td>3.12.11</td><td>A DATA MODE command shall cause the satellite to enter the Data Mode.</td></tr>
<tr><td>3.12.12</td><td>An ENABLE AUTO-SAFE command shall enable the auto-safe mode state.</td></tr>
<tr><td>3.12.13</td><td>A DISABLE AUTO-SAFE command shall disable the auto-safe mode state.</td></tr>
<tr><td>3.13.1</td><td>The satellite shall provide on-orbit operating modes as shown in Table 6.
<table>
<tr><th>Name</th><th>Description</th></tr>
<tr><td>Startup Mode</td><td>Wait 45 minutes and deploy antennas</td></tr>
<tr><td>Safe Mode</td><td>Wait 120 seconds then begin 10 second beacon sequence</td></tr>
<tr><td>Transponder Mode</td><td>FM transponder; PTT and low speed telemetry via IHU</td></tr>
<tr><td>Data Mode</td><td>FM transmitter; PTT and high speed telemetry via IHU</td></tr>
</table></td></tr>
<tr><td>3.13.2</td><td>The satellite shall transition between modes as shown in Figure 1.</td></tr>
<tr><td>3.13.3</td><td>Upon power-up of the avionics, the satellite shall begin operation from the "Power-up" state as shown in Figure 1.</td></tr>
<tr><td>3.13.4</td><td>An IHU ON Command shall cause the satellite to begin operation from the "Power-up" state as shown in Figure 1.</td></tr>
</table>

	
3.13.5	If the antennas have been deployed, the satellite shall determine whether the last state was Safe Mode.
3.13.5.1	If the last state was Safe Mode the satellite shall enter Safe Mode
3.13.5.2	If the last state was not Safe Mode the satellite shall enter Transponder Mode.
3.13.6	If the antennas have not been deployed, the satellite shall enter the Startup Mode.
3.13.7	In Startup Mode, the satellite shall wait 50 minutes, then deploy the antennas.
3.13.7.1	During the 50 minute wait the IHU shall flash a red LED.
3.13.7.2	During the 50 minute wait the IHU shall sound a 1 kHz beeping tone.
3.13.7.3	After the antennas have been deployed the satellite shall enter Safe Mode.
3.13.8	In Transponder Mode, the transponder and the slow speed telemetry shall be active.
3.13.9	In Data Mode, the high speed telemetry shall be active and the transponder shall not be active. (i.e. signals that appear on the uplink shall not be repeated on the downlink.)
3.13.10	If another Data Mode command is not received, the satellite shall automatically enter Transponder Mode 30 minutes after having entered Data Mode.
3.13.11	In Safe Mode the satellite shall wait 120 seconds then transmit a 10 second beacon.
3.13.11.1	The 120 second wait and 10 second beacon cycle will be repeated as long as the satellite is in Safe Mode.
3.13.12	The RF uplink shall be monitored for commands in all modes.

5.3 Initial Surge Current Limits

5.3.1 The IHU design shall limit initial inrush current to 0.1 Amperes.

5.4 Volume Requirements Applicable to IHU System

5.4.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 1 mm from the –Z surface of the PC board.

5.4.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 6.0 mm from the +Z surface of the PC board.

5.5 Interface Control Documents Applicable to IHU System

AMSAT *Fox-1* IHU to RF System Interface Control Document
AMSAT *Fox-1* IHU to PSU Interface Control Document
AMSAT *Fox-1* IHU to Battery Interface Control Document
AMSAT *Fox-1* IHU to Attitude Determination Experiment Interface Control Document
AMSAT *Fox-1* IHU to Experiment 1 Interface Control Document
AMSAT *Fox-1* IHU to Experiment 4 Interface Control Document

5.6 PCB Plating Requirements Applicable to IHU System

5.6.1 ENIG then selective flash gold four mounting pads.

5.7 Internal Housekeeping Unit (IHU) System PCB Bus Connections

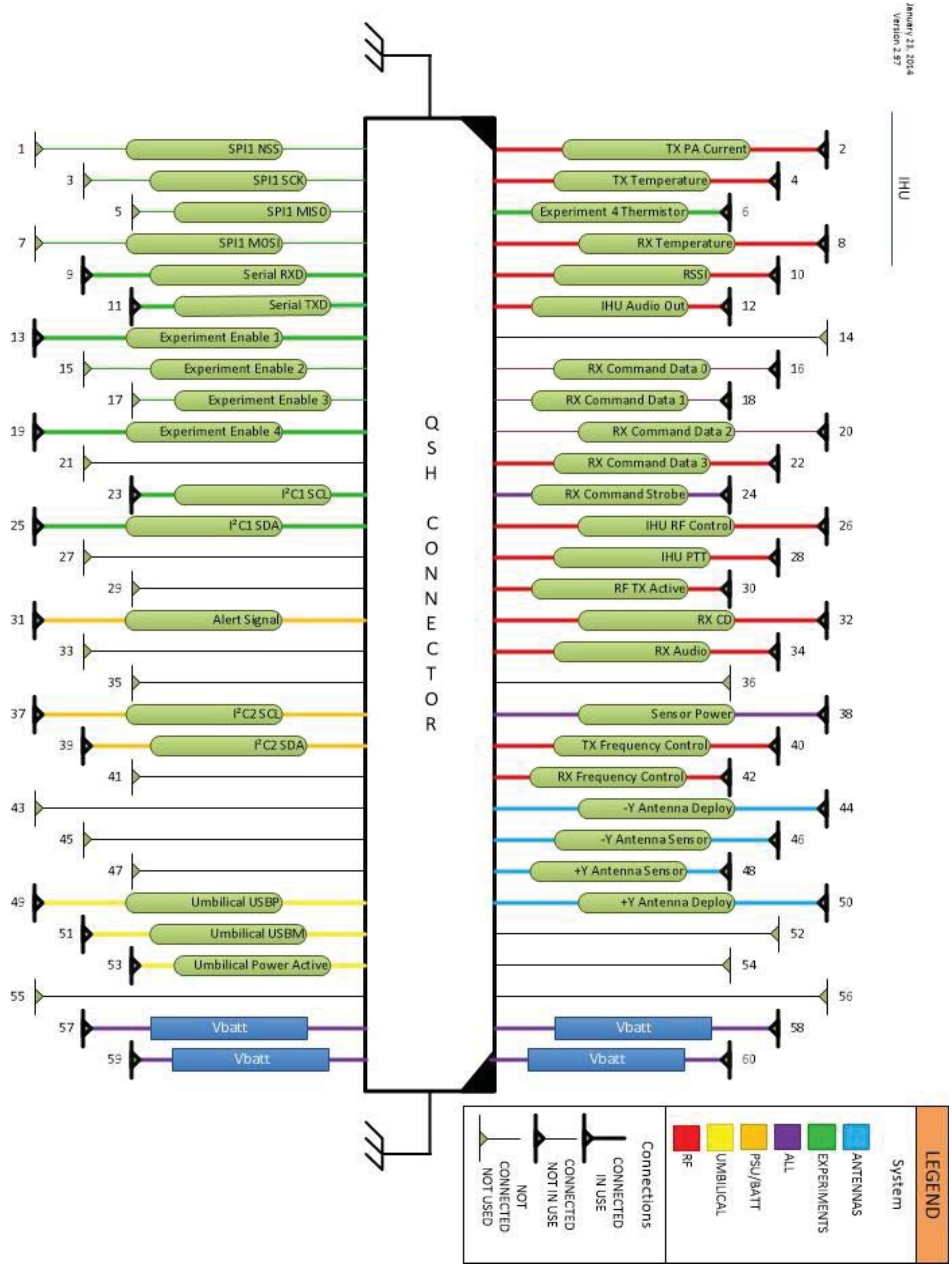


Figure 6: IHU System Bus Connection Pin Assignments

6 Power Supply System (PSU)

6.1 System Requirements Applicable to Power Supply System (PSU)

<table>
<tr><td>2.2.1</td><td>The satellite avionics shall be designed for -40C to +70C operating temperature.</td></tr>
<tr><td>2.2.3</td><td>The satellite shall be designed to tolerate the radiation environment in orbit.</td></tr>
<tr><td>2.3.1</td><td>The satellite shall be designed for a minimum 5-year, on-orbit lifetime.</td></tr>
<tr><td>3.3.1</td><td>The satellite shall include a "Remove Before Flight" pin as per the CubeSat Design Specification.</td></tr>
<tr><td>3.4.1</td><td>The satellite battery and photovoltaic panels shall be electronically disconnected from the avionics when the "Remove Before Flight" pin is inserted, regardless of the state of the deployment switch(es).</td></tr>
<tr><td>3.4.2</td><td>The satellite shall provide the means to charge the battery via the umbilical port while integrated with the P-POD.</td></tr>
<tr><td>3.5.1</td><td>The satellite shall produce electrical power from sunlight.</td></tr>
<tr><td>3.5.2</td><td>The satellite shall produce electrical power while in sunlight regardless of orientation and while tumbling or spinning.</td></tr>
<tr><td>3.5.3</td><td>The satellite shall produce sufficient average electrical power to operate continuously in the orbit of maximum eclipse.</td></tr>
<tr><td>3.5.4</td><td>The satellite shall provide sufficient battery capacity to operate continuously in the orbit of maximum eclipse.</td></tr>
<tr><td>3.6.1</td><td>The satellite shall provide DC power for experiment payloads.</td></tr>
<tr><td>3.10.1</td><td>The satellite shall collect telemetry data.</td></tr>
<tr><td>3.10.2</td><td>The telemetry data shall include at a minimum, measured parameters as shown in Table 3.
<table>
<tr><th>Parameter Name</th><th>Description</th></tr>
<tr><td>CELL V</td><td>Voltages of battery cells</td></tr>
<tr><td>PANEL V</td><td>Voltages of solar panels</td></tr>
<tr><td>TOTAL I</td><td>Total DC current out of power system</td></tr>
<tr><td>PA I</td><td>DC current into RF power amp</td></tr>
<tr><td>BATTERY T</td><td>Temperature of battery</td></tr>
<tr><td>PANEL T</td><td>Temperatures of solar panels</td></tr>
<tr><td>TX T</td><td>Temperature of RF transmitter card</td></tr>
<tr><td>RX T</td><td>Temperature of RF receiver card</td></tr>
</table>
</td></tr>
<tr><td>3.10.3</td><td>The measured parameters shall be sampled at least every 15 seconds.</td></tr>
<tr><td>3.13.7.1</td><td>During the 45 minute wait the IHU shall flash a red LED.</td></tr>
</table>

6.2 Initial Surge Current Limits

6.2.1 The PSU design shall limit initial inrush current to 0.1 Amperes.

6.3 Volume Requirements Applicable to PSU System

6.3.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 1 mm from the –Z surface of the PC board.

6.3.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 3.0 mm from the +Z surface of the PC board within the area 0 to 4.0 mm from the +Y and +X edges of the board, and 6.0 mm from the +Z surface of the PC board in the rest of the board area.

6.4 Interface Control Documents Applicable to PSU System

AMSAT *Fox-1* IHU to PSU Interface Control Document

6.5 PCB Plating Requirements Applicable to PSU System

6.5.1 ENIG then selective flash hard gold 30 micro-inch four mounting pads and four edge fingers.

6.6 Power Supply System (PSU) PCB Bus Connections

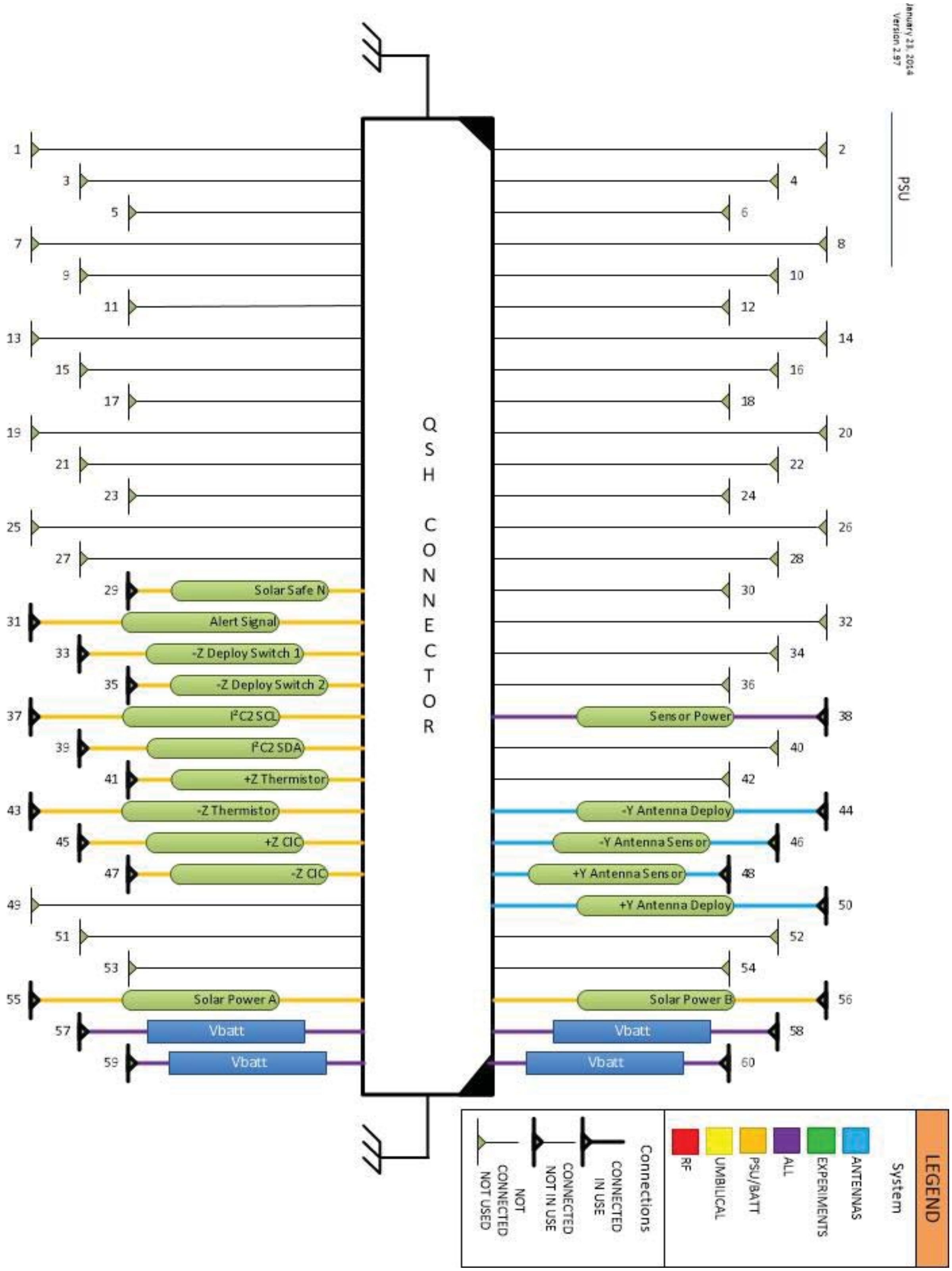


Figure 7: PSU Bus Connection Pin Assignments

6.7 Power Supply System (PSU) PCB External Connections

6.7.1 Three connections to +X Solar Panel using Samtec MEC1-105-02-L-D-NP-A connector
  6.7.1.1 1 contact +X Solar Panel Thermistor
  6.7.1.2 1 contact +X Solar Panel CIC +
  6.7.1.3 1 contact common or - for above two connections
6.7.2 Three connections to -X Solar Panel using Samtec MEC1-105-02-L-D-NP-A connector
  6.7.2.1 1 contact -X Solar Panel Thermistor
  6.7.2.2 1 contact -X Solar Panel CIC +
  6.7.2.3 1 contact common or - for above two connections
6.7.3 Five connections to +Y Solar Panel using Samtec MEC1-105-02-L-D-NP-A connector
  6.7.3.1 1 contact +Y Solar Panel Thermistor
  6.7.3.2 1 contact +Y Solar Panel CIC +
  6.7.3.3 1 contact TX Antenna Deploy
  6.7.3.4 1 contact TX Antenna Sensor
  6.7.3.5 1 contact common or - for above connections
6.7.4 Five connections to -Y Solar Panel using Samtec MEC1-105-02-L-D-NP-A connector
  6.7.4.1 1 contact -Y Solar Panel Thermistor
  6.7.4.2 1 contact -Y Solar Panel CIC +
  6.7.4.3 1 contact RX Antenna Deploy
  6.7.4.4 1 contact RX Antenna Sensor
  6.7.4.5 1 contact common or - for above connections
6.7.5 All PCB edges that connect to solar panel MEC1-105-02-L-D-NP-A connectors shall have contact pads on the PCB for all connector pins, whether connected to a trace or not.

Table 5: +X PCB edge mates to MEC1-105-02-L-D-NP-A connector on +X Solar Panel

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Bus Pin
1	N/C					
2	+X Solar Panel Thermistor	Analog	N/A	N/A	N/A	N/A
3	N/C					
4	N/C					
5	N/C					
6	+X Solar Panel Common					Ground Plane
7	N/C					
8	N/C					
9	N/C					
10	+X Solar Panel CIC (+)	Power	N/A	N/A	N/A	N/A

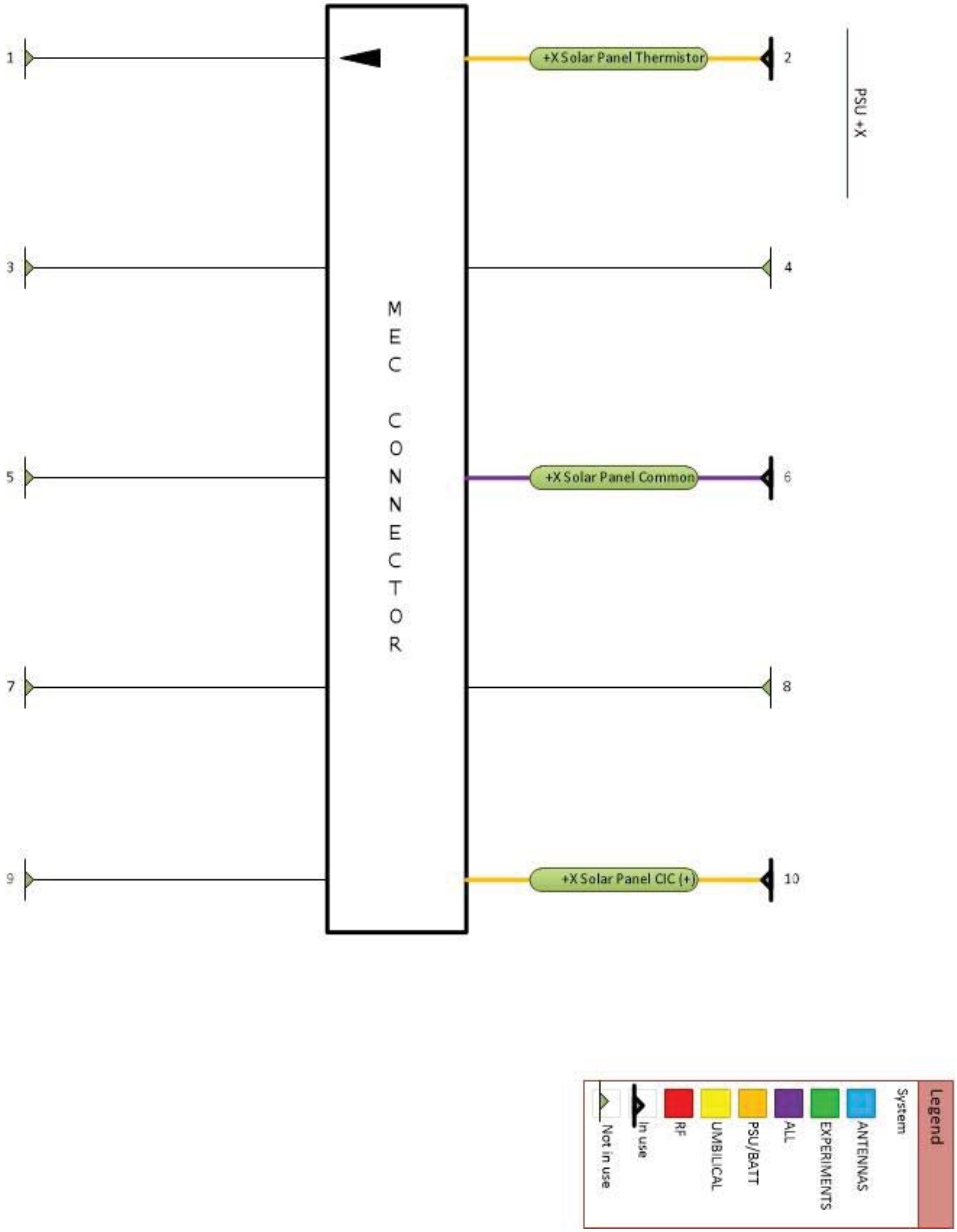


Figure 8: PSU System +X Edge MEC1-105-02-L-D-NP-A Connection Pin Assignments

Table 6: -X PCB edge mates to MEC1-105-02-L-D-NP-A connector on -X Solar Panel

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Bus Pin
1	N/C					
2	-X Solar Panel Thermistor	Analog	N/A	N/A	N/A	N/A
3	N/C					
4	N/C					
5	N/C					
6	-X Solar Panel Common					Ground Plane
7	N/C					
8	N/C					
9	N/C					
10	-X Solar Panel CIC (+)	Power	N/A	N/A	N/A	N/A

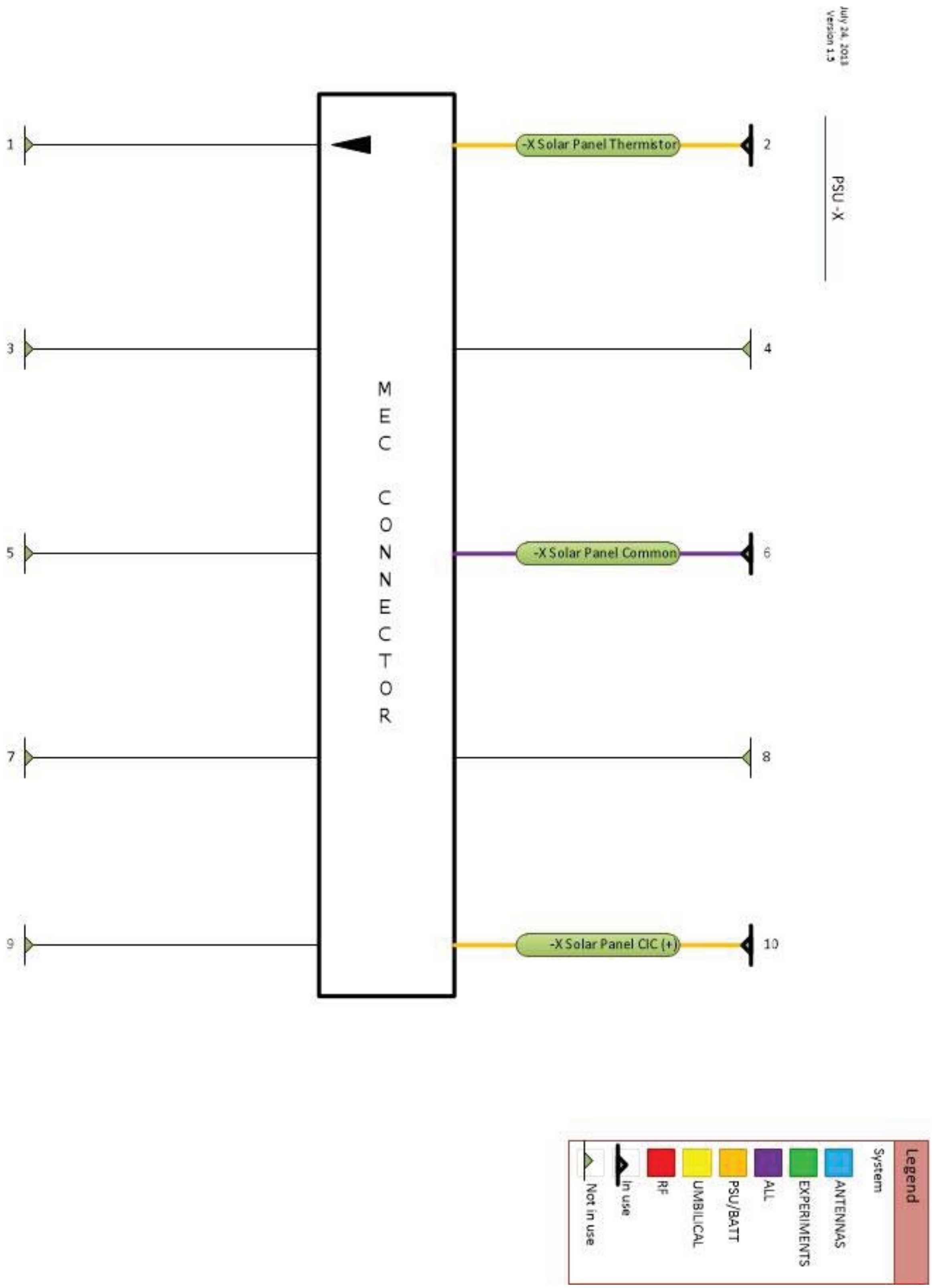


Figure 9: PSU System -X Edge MEC1-105-02-L-D-NP-A Connection Pin Assignments

Table 7: +Y PCB edge mates to MEC1-105-02-L-D-NP-A connector on +Y Solar Panel

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Bus Pin
1	N/C					
2	+Y Solar Panel Thermistor	Analog	N/A	N/A	N/A	N/A
3	N/C					
4	+Y Antenna Sensor	Switch	N/A	PSU	N.O.	48
5	N/C					
6	+Y Solar Panel Common					Ground Plane
7	N/C					
8	+Y Antenna Deploy	Analog	Vbatt	IHU	7 Ω resistor	50
9	N/C					
10	+Y Solar Panel CIC (+)	Power	N/A	N/A	N/A	N/A

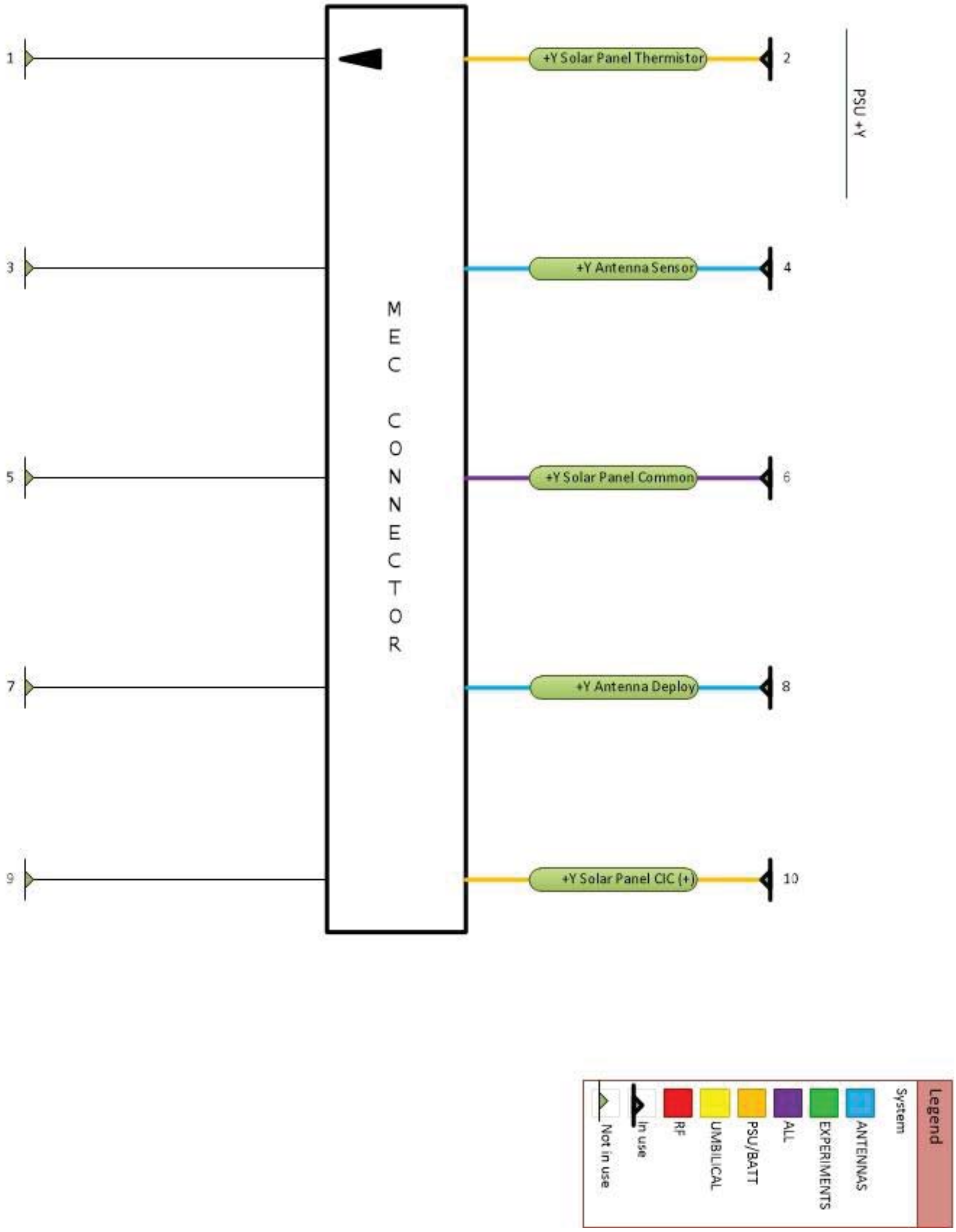


Figure 10: PSU System +Y Edge MEC1-105-02-L-D-NP-A Connection Pin Assignments

Table 8: -Y PCB edge mates to MEC1-105-02-L-D-NP-A connector on -Y Solar Panel

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Bus Pin
1	N/C					
2	-Y Solar Panel Thermistor	Analog	N/A	N/A	N/A	N/A
3	N/C					
4	-Y Antenna Sensor	Switch	N/A	PSU	N.O.	46
5	N/C					
6	-Y Solar Panel Common					Ground Plane
7	N/C					
8	-Y Antenna Deploy	Analog	Vbatt	IHU	7 Ω resistor	44
9	N/C					
10	-Y Solar Panel CIC (+)	Power	N/A	N/A	N/A	N/A

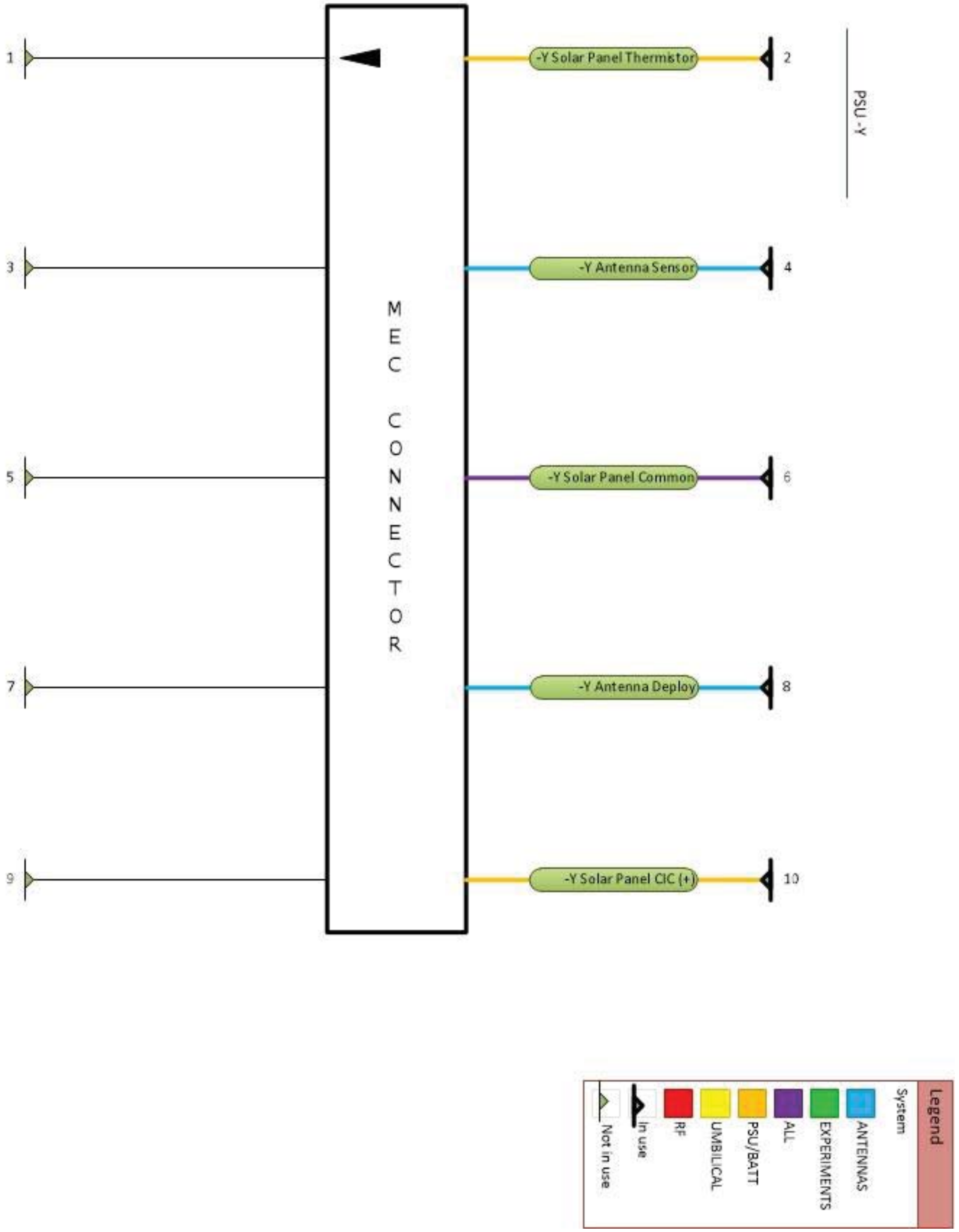


Figure 11: PSU System -Y Edge MEC1-105-02-L-D-NP-A Connection Pin Assignments

7 Battery System

7.1 System Requirements Applicable to Battery PCB 1 System (BATT1)

<table>
<tr><td>2.2.1</td><td>The satellite avionics shall be designed for -40C to +70C operating temperature.</td></tr>
<tr><td>2.2.3</td><td>The satellite shall be designed to tolerate the radiation environment in orbit.</td></tr>
<tr><td>2.3.1</td><td>The satellite shall be designed for a minimum 5-year, on-orbit lifetime.</td></tr>
<tr><td>3.3.1</td><td>The satellite shall include a "Remove Before Flight" pin as per the CubeSat Design Specification.</td></tr>
<tr><td>3.4.1</td><td>The satellite battery and photovoltaic panels shall be electronically disconnected from the avionics when the "Remove Before Flight" pin is inserted, regardless of the state of the deployment switch(es).</td></tr>
<tr><td>3.4.2</td><td>The satellite shall provide the means to charge the battery via the umbilical port while integrated with the P-POD.</td></tr>
<tr><td>3.5.3</td><td>The satellite shall produce sufficient average electrical power to operate continuously in the orbit of maximum eclipse.</td></tr>
<tr><td>3.5.4</td><td>The satellite shall provide sufficient battery capacity to operate continuously in the orbit of maximum eclipse.</td></tr>
<tr><td>3.10.1</td><td>The satellite shall collect telemetry data.</td></tr>
<tr><td>3.10.2</td><td>The telemetry data shall include at a minimum, measured parameters as shown in Table 3.
<table>
<tr><th>Parameter Name</th><th>Description</th></tr>
<tr><td>CELL V</td><td>Voltages of battery cells</td></tr>
<tr><td>PANEL V</td><td>Voltages of solar panels</td></tr>
<tr><td>TOTAL I</td><td>Total DC current out of power system</td></tr>
<tr><td>PA I</td><td>DC current into RF power amp</td></tr>
<tr><td>BATTERY T</td><td>Temperature of battery</td></tr>
<tr><td>PANEL T</td><td>Temperatures of solar panels</td></tr>
<tr><td>TX T</td><td>Temperature of RF transmitter card</td></tr>
<tr><td>RX T</td><td>Temperature of RF receiver card</td></tr>
</table></td></tr>
<tr><td>3.10.3</td><td>The measured parameters shall be sampled at least every 15 seconds.</td></tr>
</table>

7.2 Volume Requirements Applicable to Battery PCB 1 System

7.2.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 4.0 mm from the -Z surface of the PC board within the area 0 to 4.0 mm from the +Y and +X edges of the board, and 1.0 mm from the -Z surface of the PC board in the rest of the board area.

7.2.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 17.0 mm from the +Z surface of the PC board.

7.3 Interface Control Documents Applicable to Battery PCB 1 System

AMSAT *Fox-1* IHU to Battery Interface Control Document

7.4 PCB Plating Requirements Applicable to Battery PCB 1 System

7.4.1 ENIG then selective flash gold four mounting pads.

7.5 Battery PCB 1 System Bus Connections

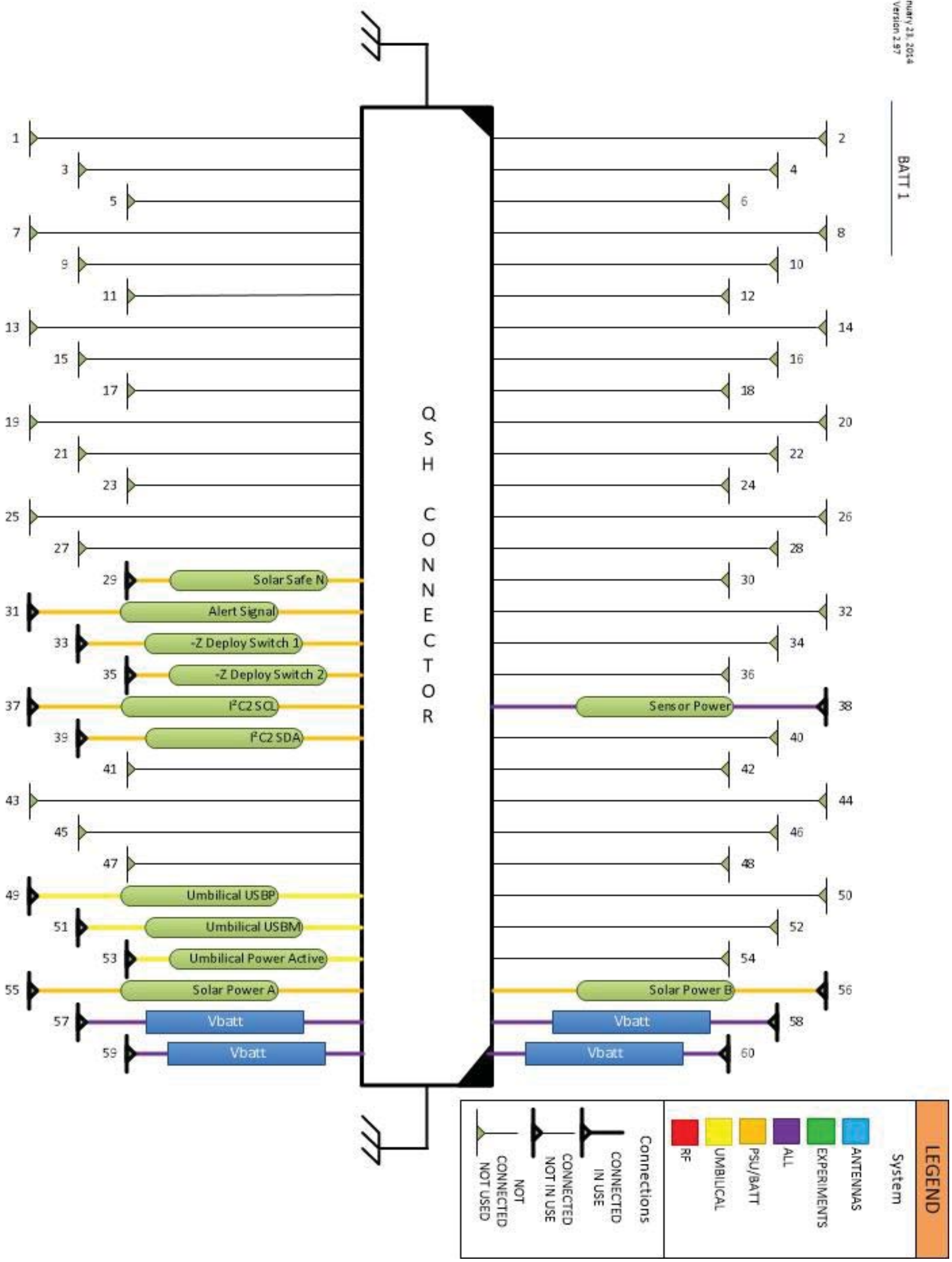


Figure 12: Battery 1 System Bus Connection Pin Assignments

7.6 Battery PCB 1 System External Connections

7.6.1 Umbilical as USB mini type B receptacle
7.6.2 Remove Before Flight as 3.5mm normally open TS jack

Table 9: Battery 1 External Connection Signal Characteristics

External Connection	Nomenclature	Type	Voltage/ Power	Source System	Load Z	Bus Pin
USB 1	USB +5 VDC	Analog	5 VDC	USB CONNECTOR	N/A	N/A
USB 2	USB Data - (USBM)	Digital	3.0 V CMOS logic	USB CONNECTOR	N/A	51
USB 3	USB Data + (USBP)	Digital	3.0 V CMOS logic	USB CONNECTOR	N/A	49
USB 4	Ground			USB CONNECTOR	N/A	Ground Plane
RBF 1	Solar Safe N	Analog	N/A	3.5mm N.O. TS jack	N/A	40

*When external supply is connected to USB port

7.7 Battery PCB 2 System Bus Connections

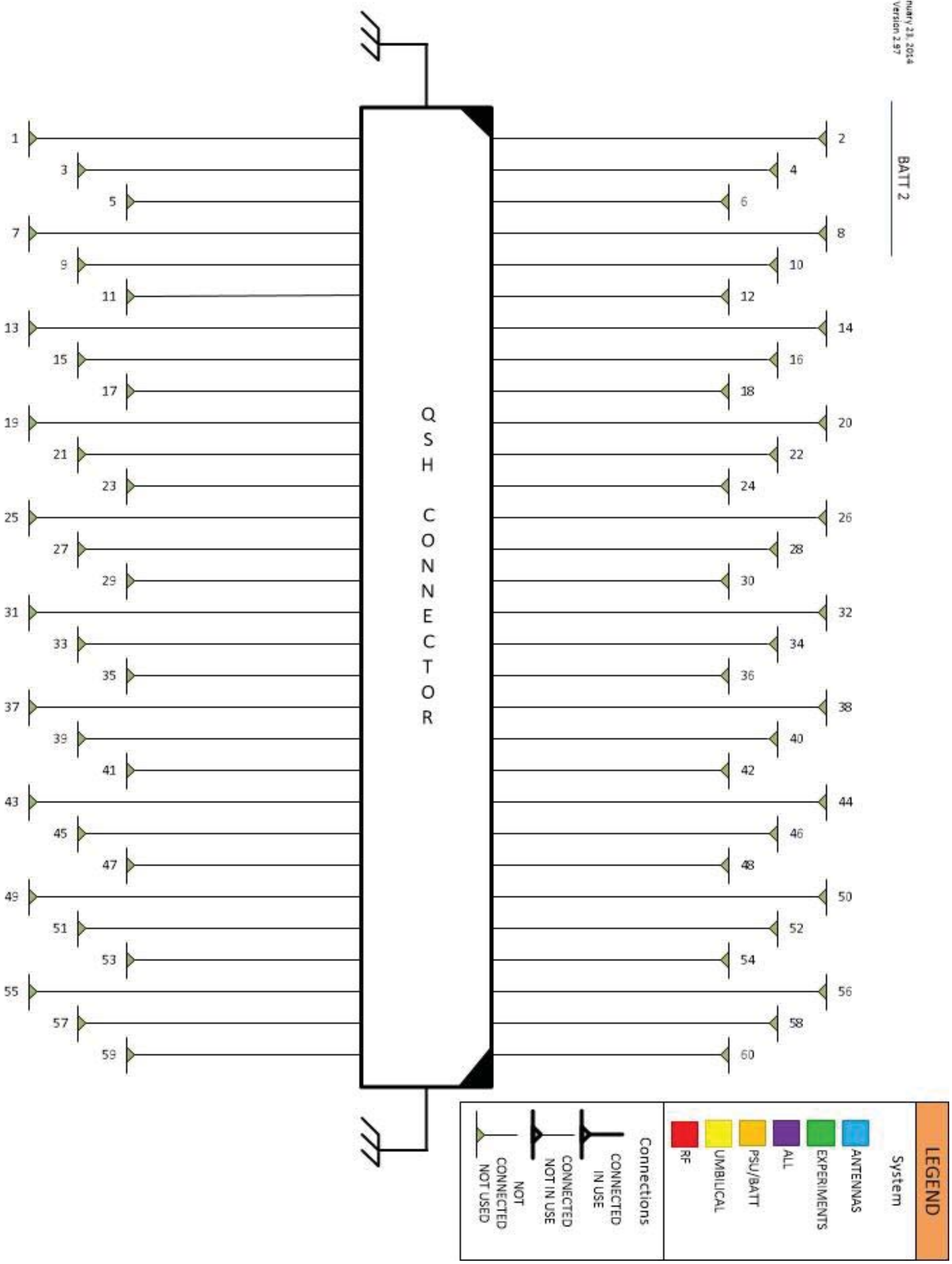


Figure 13: Battery 2 Bus Connection Pin Assignments

8 Experiment Payload Systems 1 through 4

8.1 System Requirements Applicable to Experiment Payload Systems 1-4

2.1.4	The satellite shall provide mass for an experiment payload up to 100 g.
2.1.5	The satellite shall provide volume for an experiment payload up to 95 x 95 x 15.7 mm.
2.2.1	The satellite avionics shall be designed for -40C to +70C operating temperature.
2.2.3	The satellite shall be designed to tolerate the radiation environment in orbit.
2.3.1	The satellite shall be designed for a minimum 5-year, on-orbit lifetime.
3.6.1	The satellite shall provide DC power for experiment payloads.
3.6.2	The satellite shall provide a means to activate and deactivate the experiment payloads.
3.6.3	The satellite shall provide a means to telemeter data from the experiment payloads.

8.2 Initial Surge Current Limits

8.2.1 All Experiment designs shall limit initial inrush current to 0.1 Amperes.

8.3 Volume Requirements Applicable to Experiment Payload System 1

8.3.1 No components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall protrude from the –Z surface of the PC board.

8.3.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 6.0 mm from the +Z surface of the PC board.

8.4 Interface Control Documents Applicable to Experiment 1 Payload System

AMSAT *Fox-1* IHU to Experiment 1 Interface Control Document

8.5 Volume Requirements Applicable to Experiment Payload Systems 2 and 3

8.5.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 1 mm from the –Z surface of the PC board.

8.5.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 6.0 mm from the +Z surface of the PC board.

8.6 Volume Requirements Applicable to Experiment System 4

8.6.1 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 1 mm from the –Z surface of the PC board.

8.6.2 Components, connections other than those connectors stipulated in section 10, and structures such as shielding or enclosures shall not protrude more than 5.0 mm from the +Z surface of the PC board.

8.7 Interface Control Documents Applicable to Experiment 4 Payload System

AMSAT *Fox-1* IHU to Experiment 4 Interface Control Document

8.8 PCB Plating Requirements Applicable to Experiment 1 Payload System

8.8.1 ENIG then selective flash gold four mounting pads. ENIG only will also be accepted if already fabricated.

8.9 PCB Plating Requirements Applicable to Experiment 2 Payload System

8.9.1 ENIG then selective flash gold four mounting pads. ENIG only will also be accepted if already fabricated.

8.10 PCB Plating Requirements Applicable to Experiment 3 Payload System

8.10.1 ENIG then selective flash gold four mounting pads. ENIG only will also be accepted if already fabricated.

8.11 PCB Plating Requirements Applicable to Experiment 4 Payload System

8.11.1 ENIG then selective flash gold four mounting pads..

8.12 Experiment Payload 1 Systems PCB Bus Connections

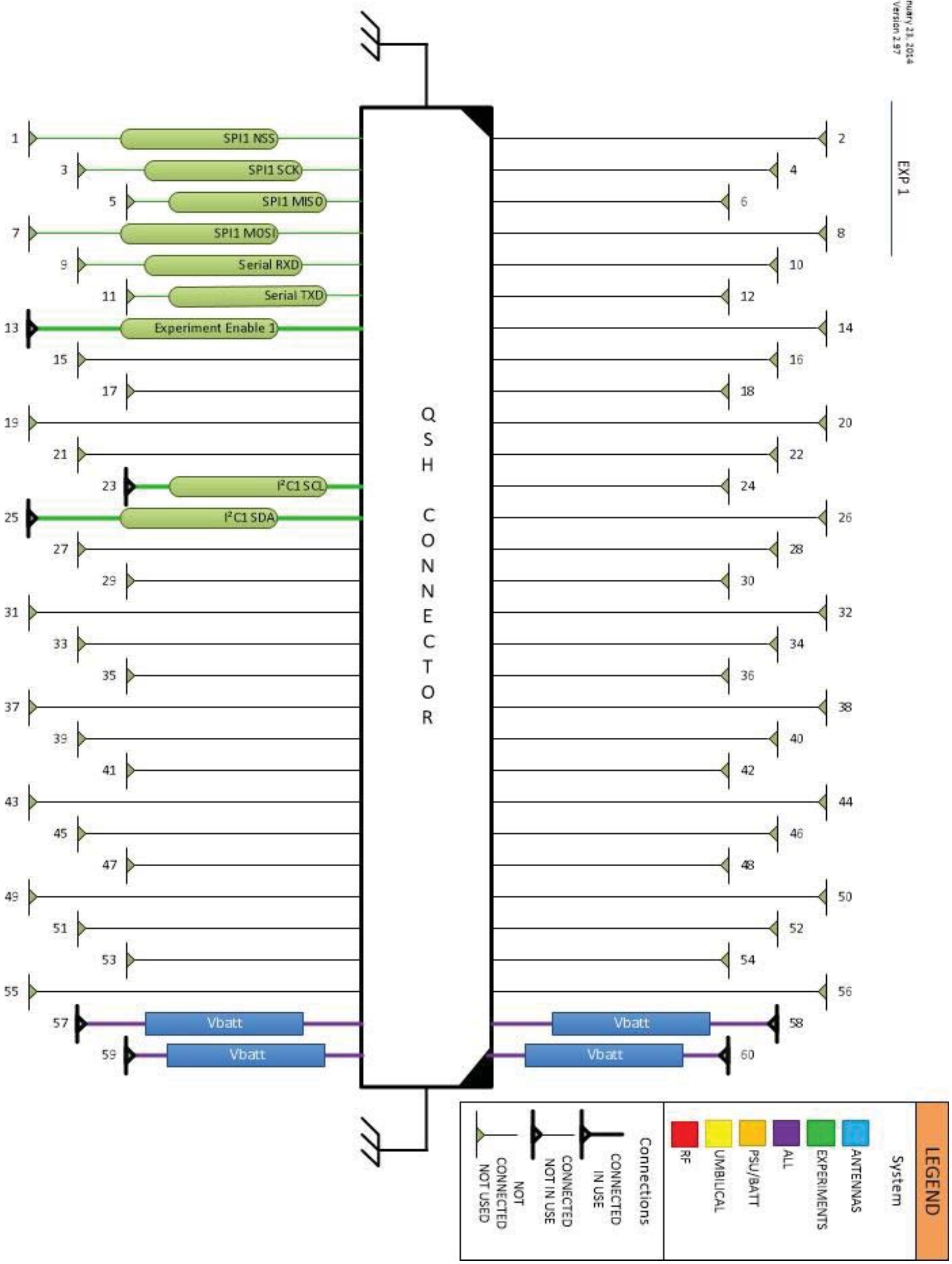


Figure 14: Experiment Payload 1-3 Systems Bus Connection Pin Assignments

8.13 Experiment Payload 4 System PCB Bus Connections

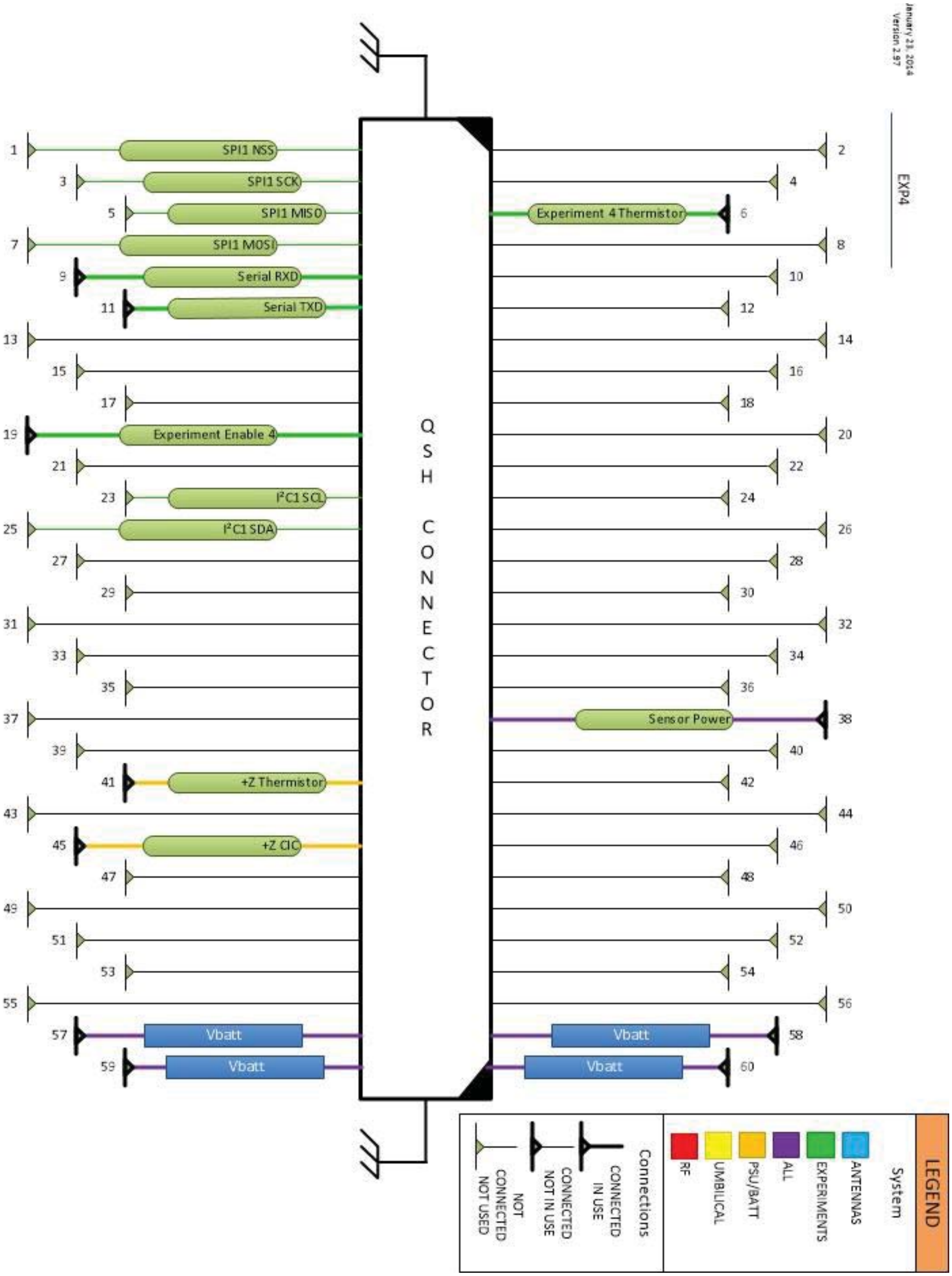


Figure 15: Experiment Payload 4 System Bus Connection Pin Assignments

8.14 Experiment Payload 4 System PCB External Connections

8.14.1 Three connections using Samtec FSI-105-06-L-S-AD connector

8.14.1.1 1 contact +Z Solar Panel Thermistor

8.14.1.2 1 contact +Z Solar Panel CIC +

8.14.1.3 1 contact common or - for above two connections

Table 10: +Z PCB face FSI-105-06-L-S-AD connector mates to pads on +Z Solar Panel

Pin	Nomenclature	Type	Voltage	Source System	Load Z	Load System	Bus Pin
1	+Z Thermistor	Analog	N/A	N/A	N/A	PSU	41
2	N/C						
3	+Z Solar Panel Common						Ground Plane
4	N/C						
5	+Z CIC	Power	N/A	N/A	N/A	PSU	45

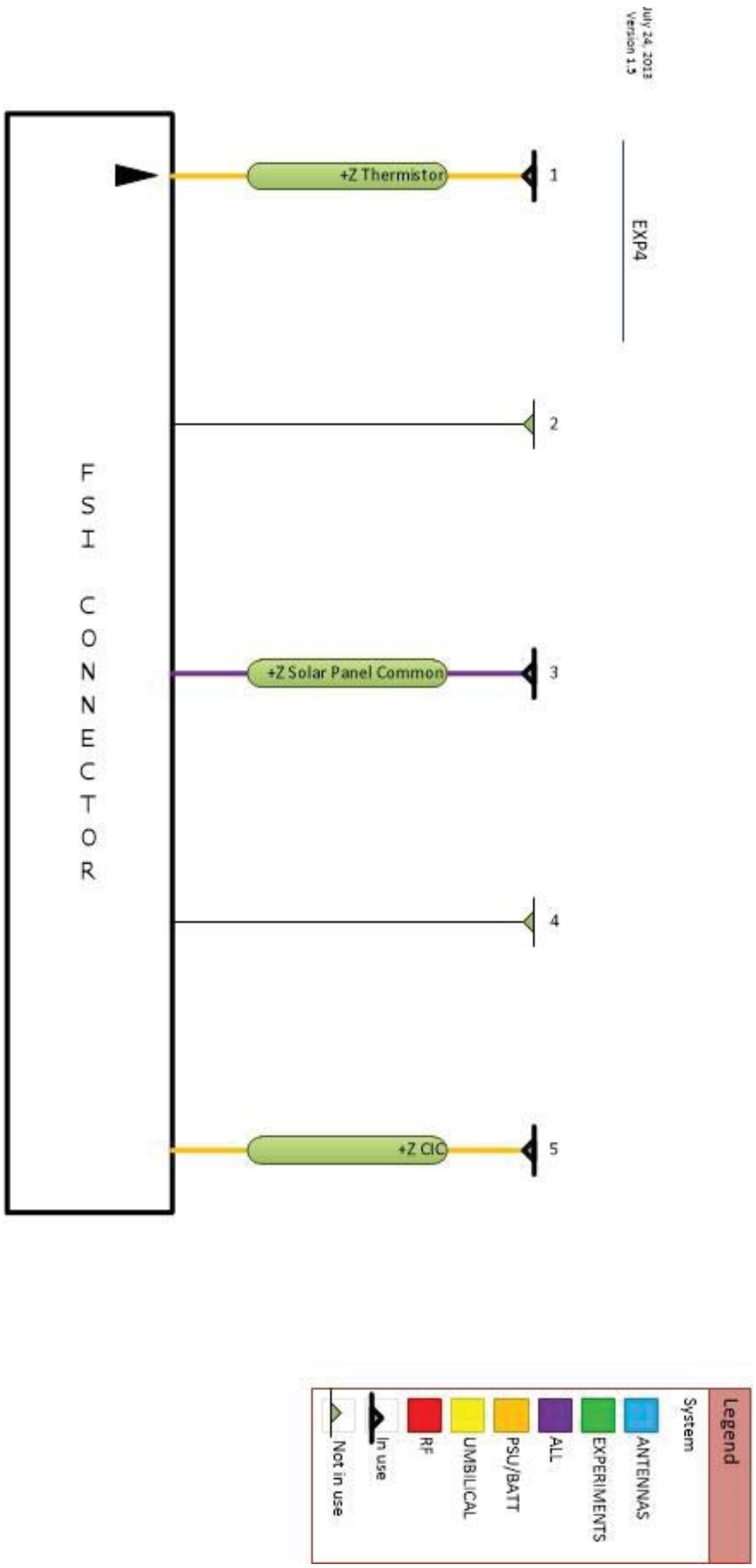
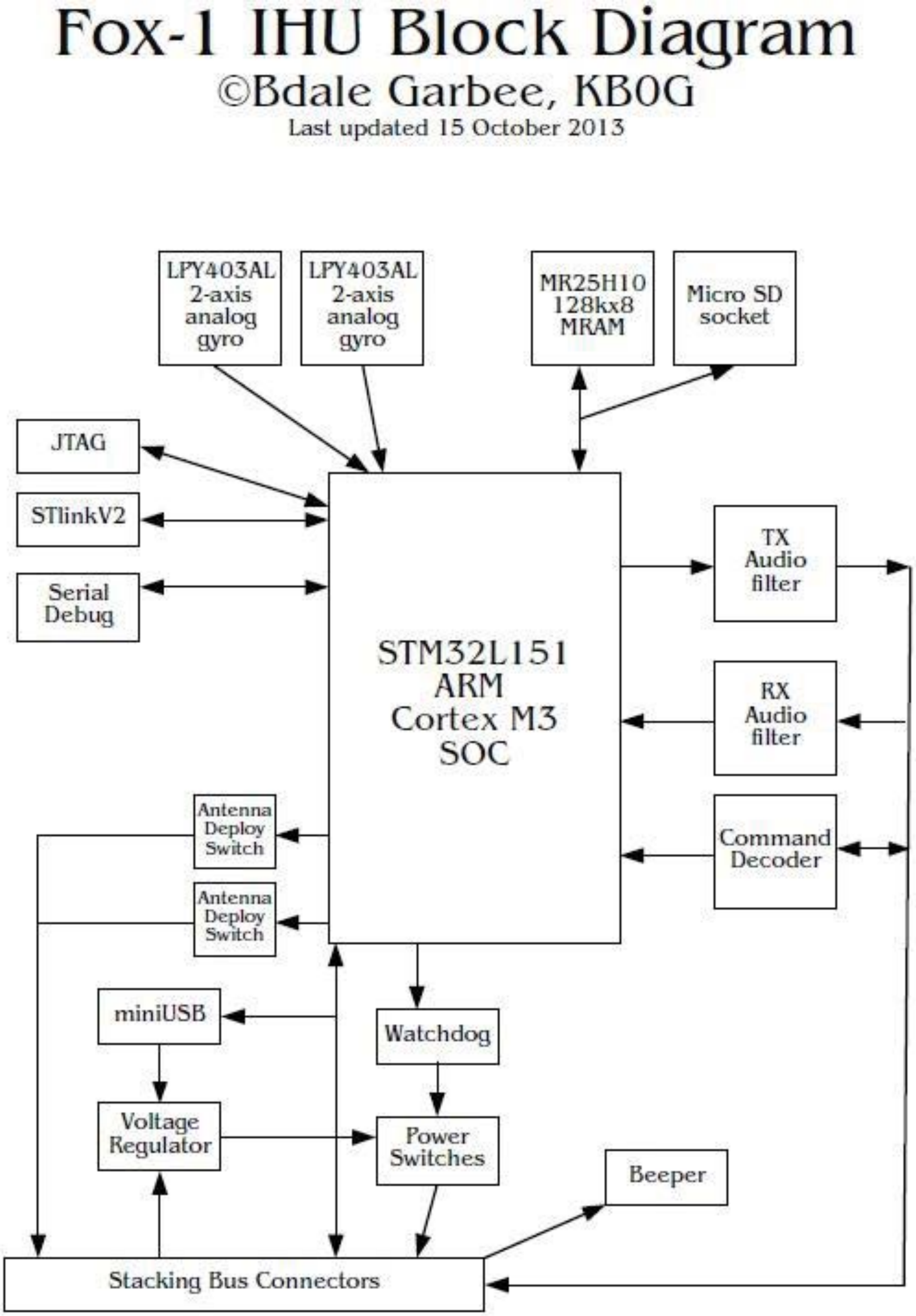


Figure 16: Experiment Payload 4 System FSI-105-06-L-S-AD Connection Pin Assignments

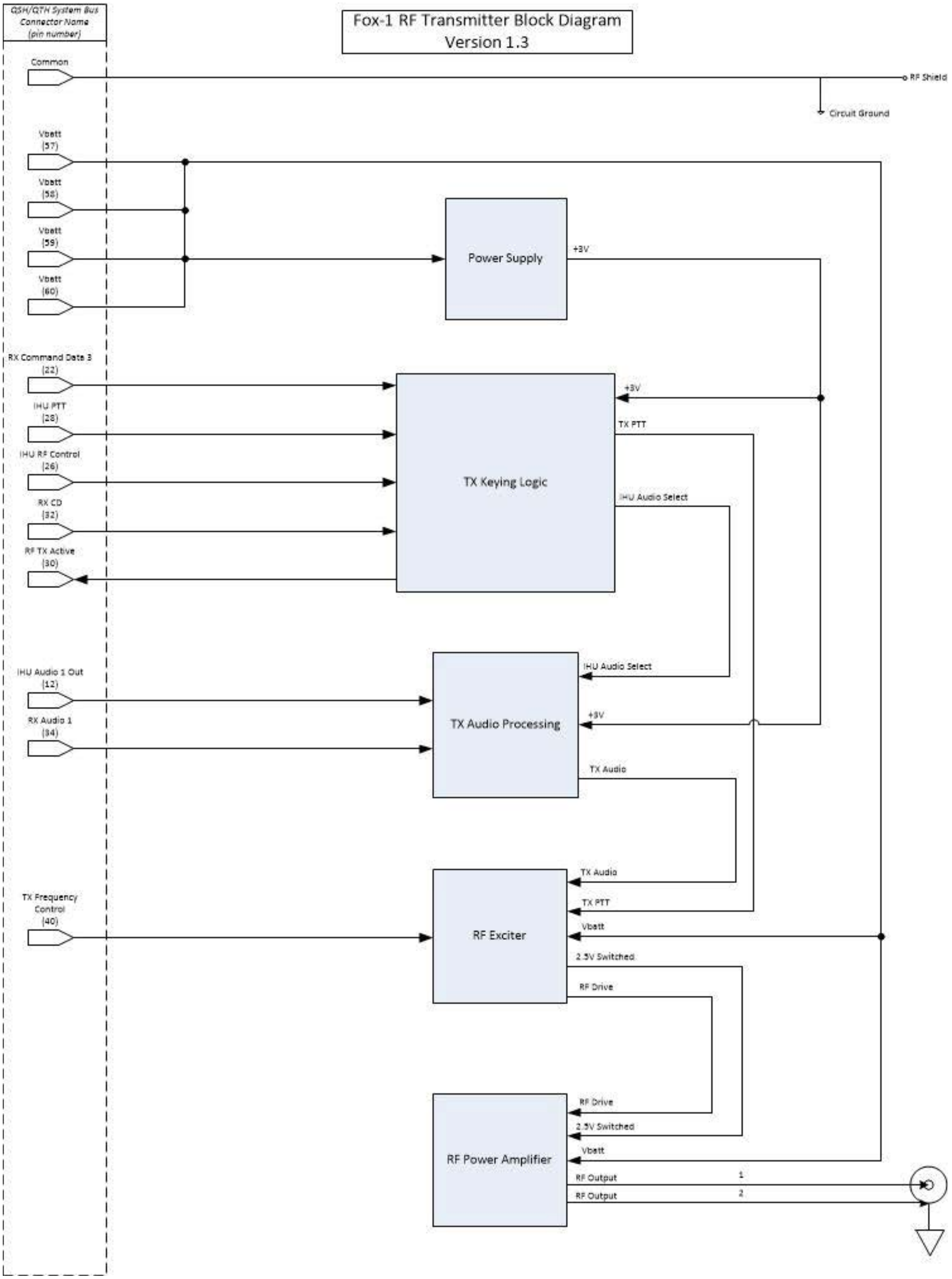
9 System Block Diagrams Reference

9.1 IHU System

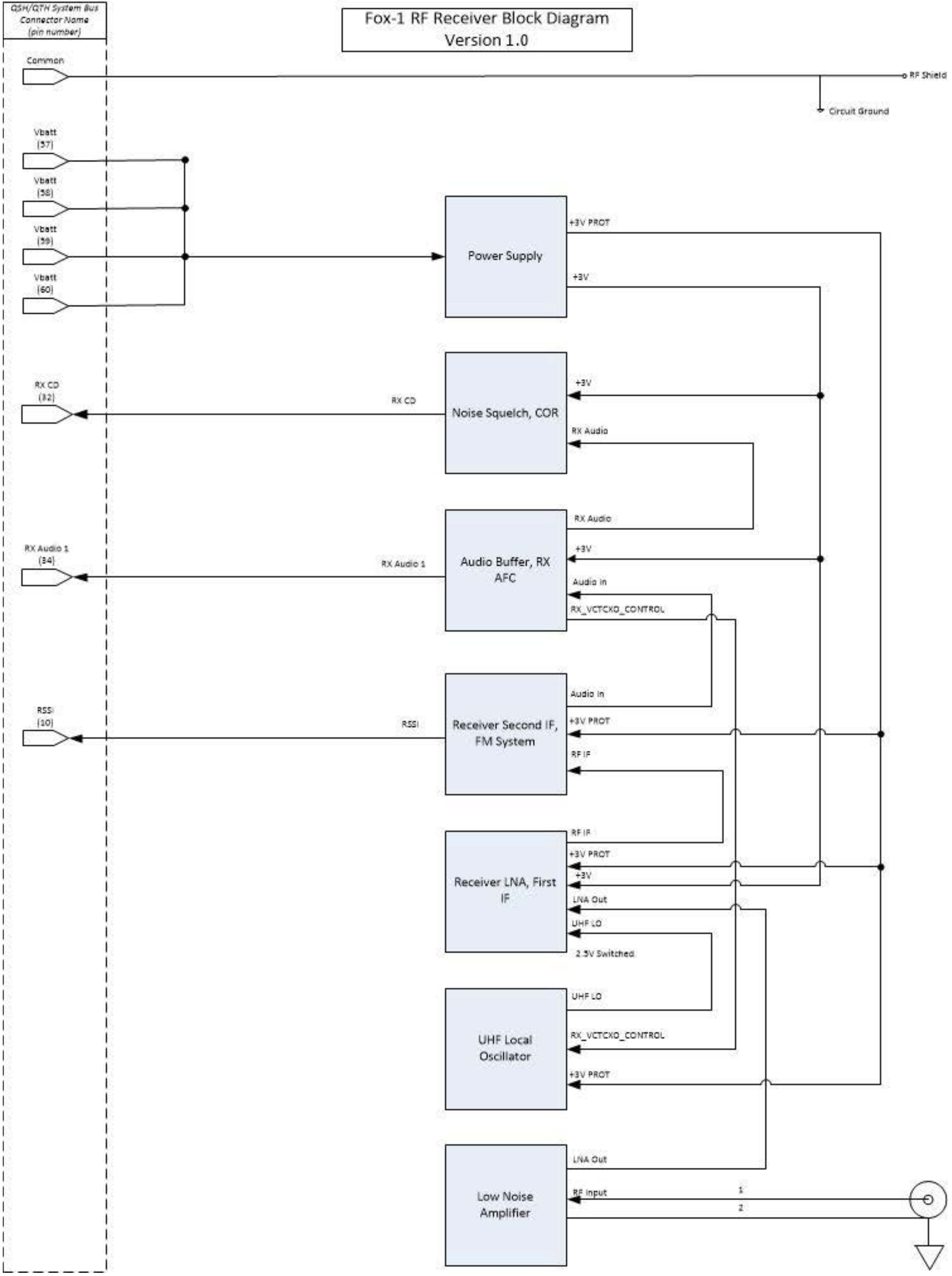


9.2 RF System

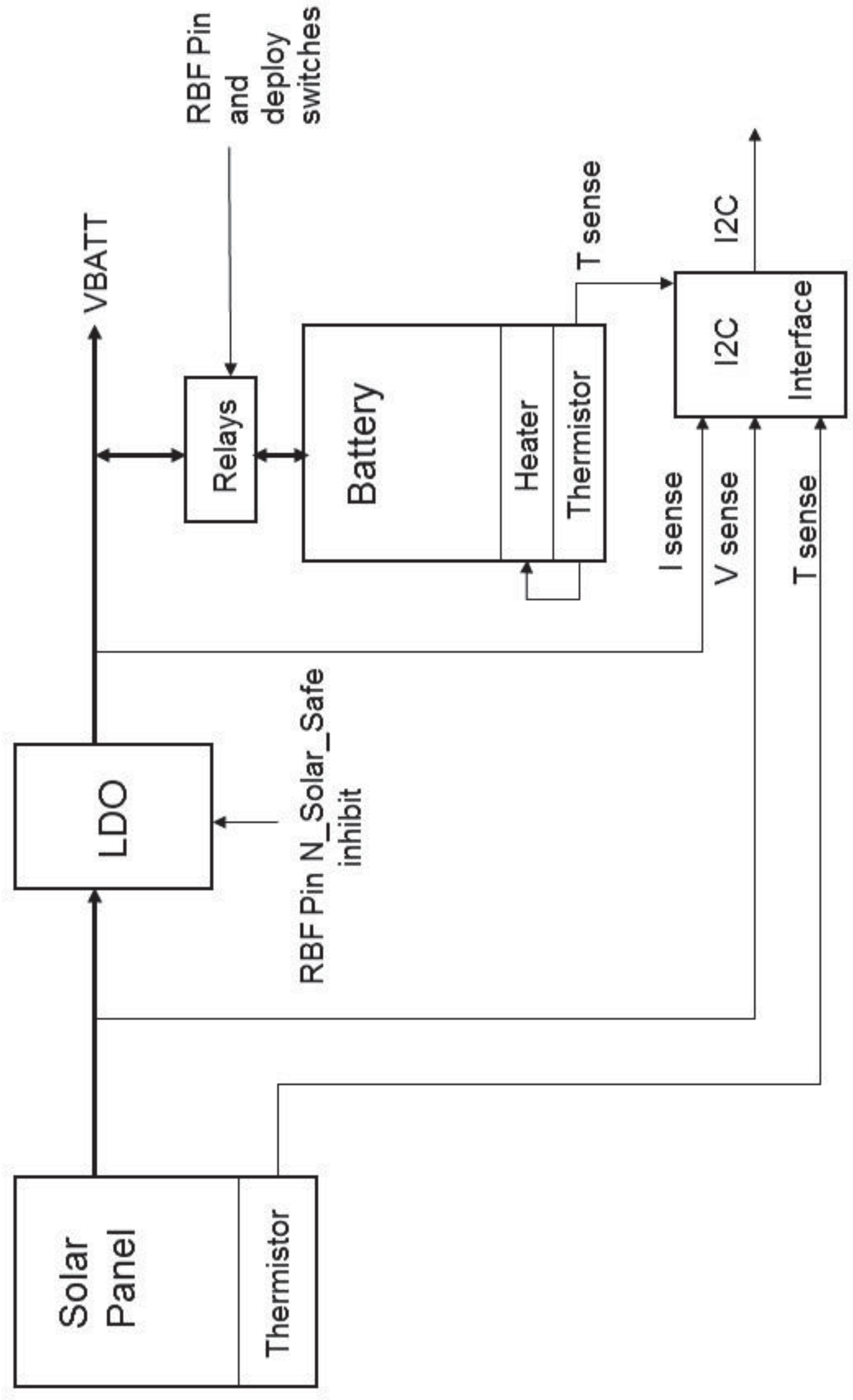
9.2.1 RF Transmitter Block Diagram



9.2.2 RF Receiver Block Diagram



9.3 PSU System



10 System Interconnection References

10.1 Bus Connectors

10.1.1 Samtec QTH-030-02-L-D-A and QSH-030-01-L-D-A connectors
10.1.2 QTH connector shall be mounted on the +Z surface of each circuit board except the Receive Antenna PCB / GPS Payload circuit board
10.1.3 QSH connector shall be mounted on the –Z surface of each circuit board

10.2 Bus Connector Documentation

10.2.1 Samtec QSH
10.2.2 Samtec QTH
10.2.3 Samtec QxH High Speed Characterization Report
10.2.4 Samtec QxH Single Ended Channel Properties

10.3 External Connectors

10.3.1 Samtec MEC1-105-02-L-D-NP-A connector mounted on +X, -X, +Y, -Y Solar Panels
10.3.2 Samtec FSI-105-06-L-S-AD connector mounted on -Z face of RF Transmitter System PCB and +Z face of Experiment Payload 4 System PCB

10.4 External Connector Documentation

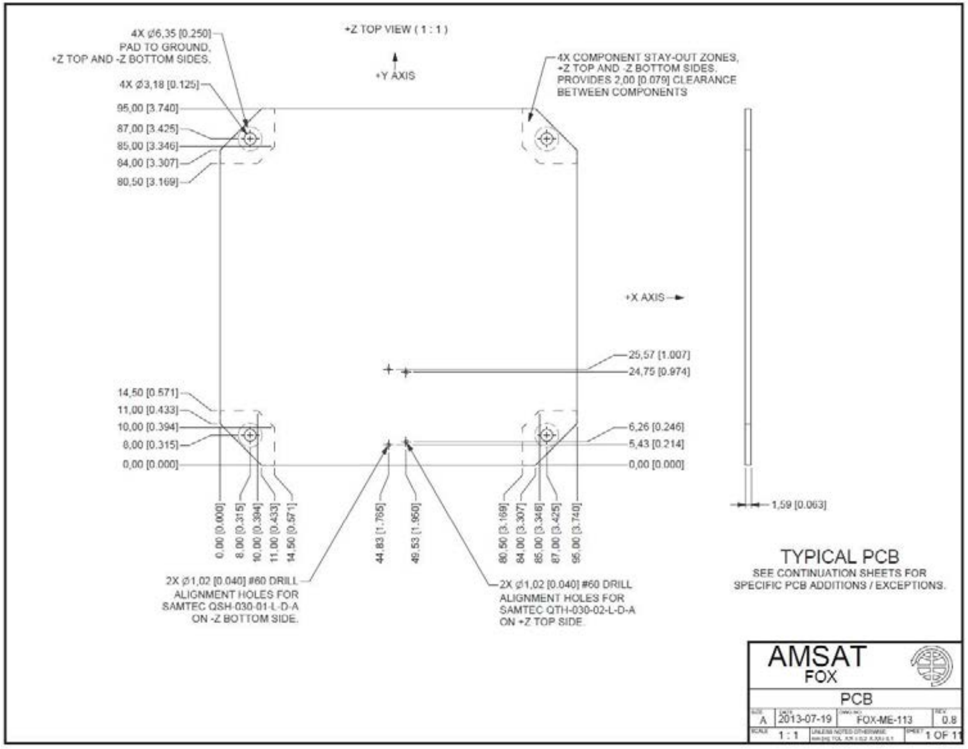
10.4.1 Samtec MEC1
10.4.2 Samtec MEC1 Qualification Testing
10.4.3 Samtec FSI

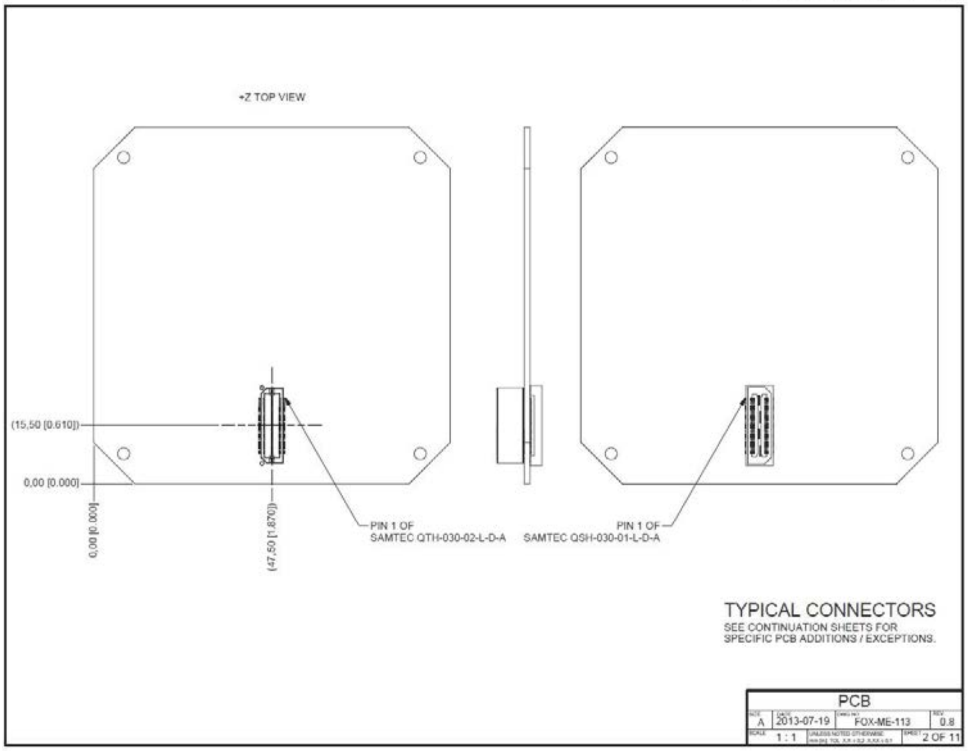
10.5 PCB Connector Layout Documentation

10.5.1 FOX-ME-113_PCB.pdf

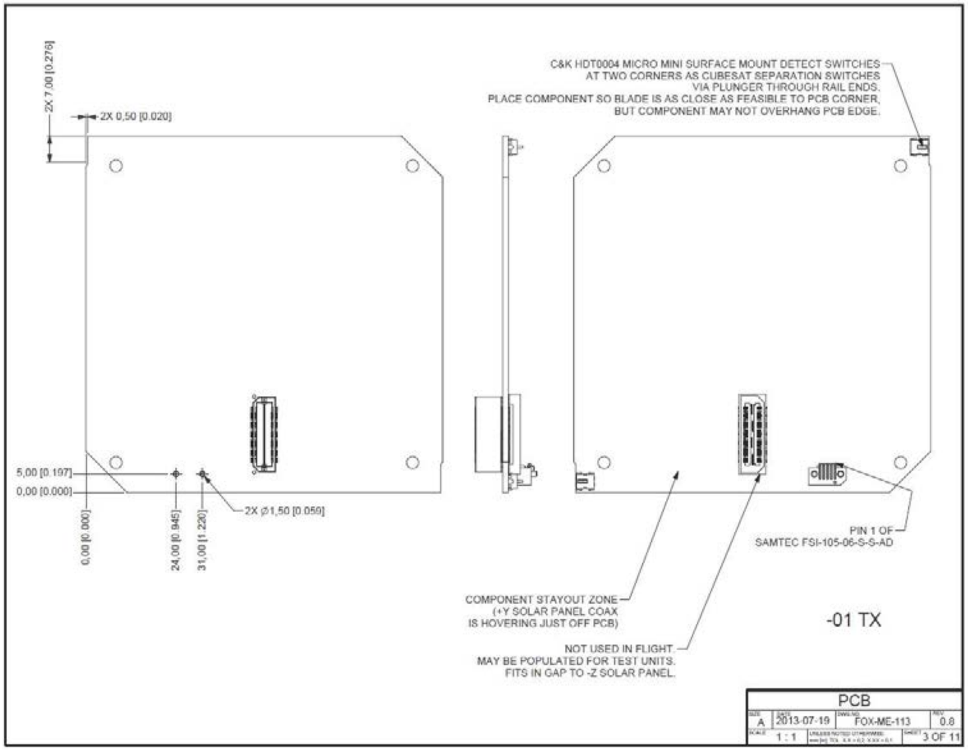
10.6 Systems PCB Connector Layout

10.6.1 Common to All Systems

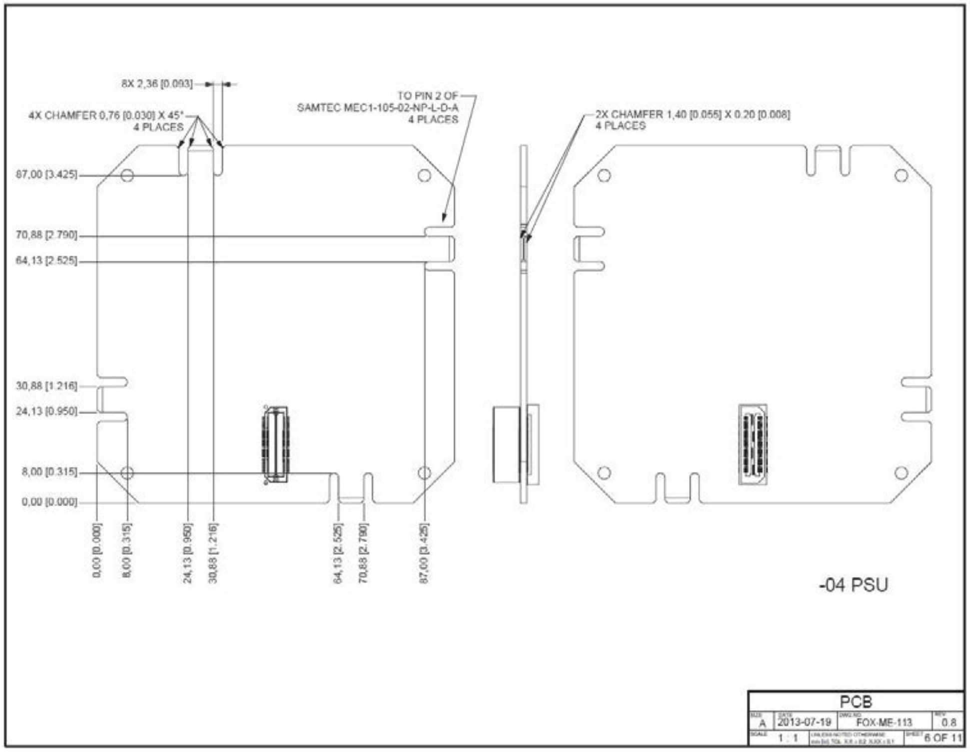




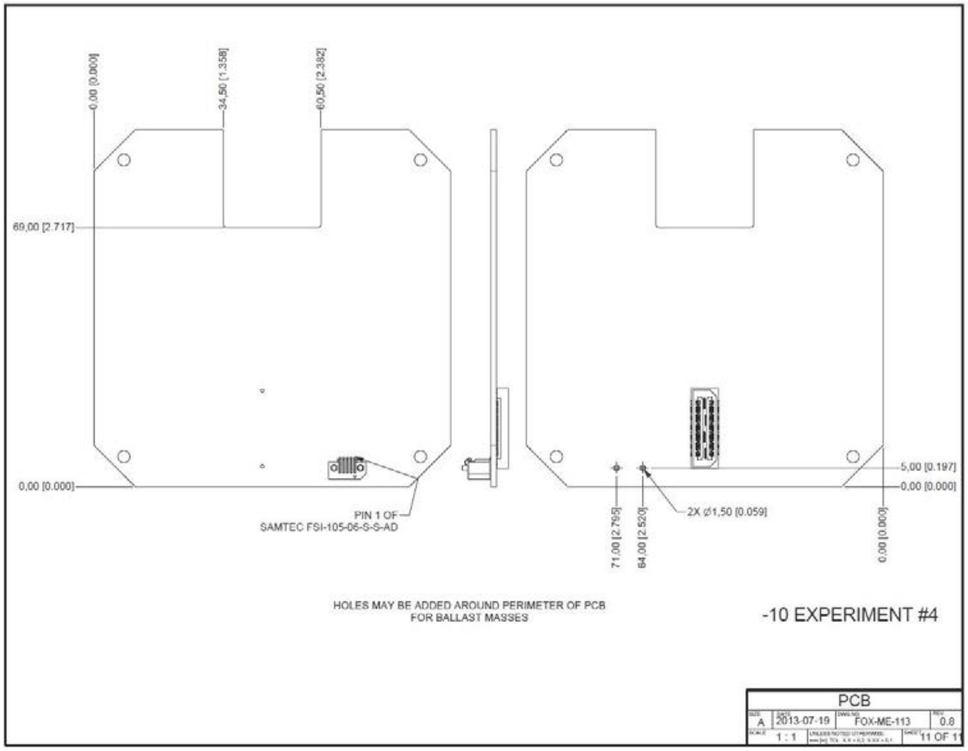
10.6.2 RF Transmitter System



10.6.3 PSU System



10.6.4 Experiment 4 System



Date: September 29, 2014
Version: Version 1.82

AMSAT *Fox-1*

System Requirements Specification

1 Introduction

This document specifies the system level technical requirements for the AMSAT *Fox-1* satellite project. This 1 Unit CubeSat is a part of the AMSAT Fox program and includes a subset of the technical capabilities envisioned for the overall program.

Fox-1 is specifically intended as a replacement for the failing AMSAT *Echo* (i.e. AO-51) satellite. *Echo* has been the most widely used amateur satellite due to its ability to provide basic radio communications with very simple ground station equipment. Its FM repeater provides very wide geographical coverage allowing amateur radio operators to communicate over substantial distances using just a handheld transceiver (i.e. a *walkie-talkie*) and a small handheld antenna. This so called "*EasySat*" mode is extremely valuable in providing an introduction to satellite communications and is often used for demonstrations given at schools, to scouting organizations and at amateur radio publicity events. *Fox-1* will not duplicate all of the features and modes of Echo but its primary mission is to provide an FM Transponder in order to allow continued access to this *EasySat* mode of communications.

In addition to its mission as a communications satellite, *Fox-1* will host an experiment payload. The satellite will reserve mass and volume for the experiment and will provide DC power and a communications facility. The experiment is expected to be provided by students at Penn State University – Erie through an AMSAT sponsored senior design project.

1.1 Document History

DATE	VERSION	SUMMARY
October 5, 2011	1.0	From Draft E
October 8, 2011	1.01	Fix typos in sections 1.2 and 3.5
October 9, 2011	1.02	Add Requirements Tracking
October 23, 2011	1.03	Additional Requirements Tracking
February 21, 2012	1.04	Update Section 3 and Formatting changes
April 18, 2012	1.05	Correction in Section 4
April 22, 2012	1.06	Correct link in Section 1.4 item 2
April 29, 2012	1.1	Revised 3.12.3, 3.12.7, 3.12.8, 3.13.3, 3.13.4, figure 1 to remove RESET and add IHU OFF and IHU ON commands
August 2, 2012	1.11	Added hidden text for requirements tracking to be shown in System Design Specification
September 4, 2012	1.12	Added the previously missing “Table 6” label
October 17, 2012	1.2	Changed mode descriptions in 3.13.1 Table 6; changed 3.9.2, 3.9.3, 3.9.4, 3.9.5, 3.9.6, 3.9.7 to reflect IHU involvement; changed COMMAND MODE to DATA MODE
April 25, 2013	1.3	3.10.2 Remove PA Temperature, add TX T as RF Transmitter Temperature, OSC T as referring to TX oscillator no longer measured changed to read RX oscillator only
August 20, 2013	1.4	Requirements 3.5.5, 3.6.1, 3.9.6, 3.10.2, 3.11.1, 3.12.4, 3.12.6, 3.13.7.1, 3.13.7.2, 3.13.8, 3.13.9 modified, removed or added to reflect the evolving satellite design
January 10, 2014	1.5	Changes to 3.12.3, 3.12.4, 3.13.2, 3.13.5, 3.13.5.1, 3.13.5.2, 3.13.7, 3.13.7.3, 3.13.7.3.1, 3.13.7.3.2, 3.13.11, 3.13.12 to add Safe Mode
January 20, 2014	1.6	Change 3.13.7.3 to go directly to Safe Mode, remove 3.13.7.3.1 and 3.13.7.3.2
January 23, 2014	1.7	Modified 3.13.2 (figure 1), 3.13.11, added 3.13.11.1
February 10, 2014	1.71	Added “Experiments are powered off” to Table 6 under Safe Mode

DATE	VERSION	SUMMARY
April 17, 2014	1.72	Bring Table 5 commands in line with Command and Control Document, remove PSU reference from 3.12.8 and 3.12.9
August 16, 2014	1.8	Update to actual operating values 3.13.11, 3.13.11.1, 3.12.3, 3.13.1, 3.13.7, 3.13.7.1, 3.13.7.2
September 8, 2014	1.81	Update to actual operating values 3.9.3, 3,9,6, update Table 5, add 3.12.12 and 3.12.13
September 29, 2014	1.82	Update 3.9.3, 3.9.4 to allow for variable hang timer

1.2 Document Scope

The purpose of this document is to specify the technical requirements of the satellite at the system (i.e. "black box") level. It is intended to be used by the hardware, software and mechanical designers to develop the architecture/high-level design specifications. It is also intended to be used for test planning and development.

1.3 Document Format

This document provides the requirements in numbered format. Each requirement is assigned a unique number. Additional information such as comments or examples that are provided for guidance or clarity is *italicized* to distinguish them from requirements.

1.4 References

1. AMSAT *Fox-1*, Concept of Operations, Version 1.0, September 19, 2011
2. CubeSat Design Specification Rev. 12. by The CubeSat Program Cal Poly SLO available from: http://www.cubesat.org/images/developers/cds_rev12.pdf
3. Launch Services Program, Program Level Poly Picosatellite Orbital Deployer (PPOD) and CubeSat Requirements Document LSP-REQ-317.01 Revision Basic (from NASA)
4. ITU Radio Regulations, Edition of 2008. available from http://www.itu.int/publ/R-REG-RR-2008/en

2 General Requirements

2.1 CubeSat Requirements

2.1.1 The satellite shall meet the requirements specified in the CubeSat Design Specification Rev. 12.

2.1.2 The satellite shall meet the requirements specified in the NASA LSP-REQ-317.01 Revision Basic.

2.1.3 The satellite shall meet the requirements for a 1 unit (single) CubeSat.

2.1.4 The satellite shall provide mass for an experiment payload up to 100 g.

2.1.5 The satellite shall provide volume for an experiment payload up to 95 x 95 x 15.7 mm.

2.2 Environmental Requirements

2.2.1 The satellite avionics shall be designed for -40C to +70C operating temperature.

2.2.2 The satellite shall be designed to operate in a 650 km, sun-synchronous, circular orbit.

2.2.3 The satellite shall be designed to tolerate the radiation environment in orbit.

2.3 Reliability Requirements

2.3.1 The satellite shall be designed for a minimum 5-year, on-orbit lifetime.

2.4 RF Frequency Requirements

2.4.1 All RF transmitters shall meet or exceed the requirements specified in the ITU Radio Regulations, Technical Characteristics, Volume 3, article 3.

2.4.2 All satellite uplinks shall be in the 70 cm band of the amateur satellite service.

2.4.3 All satellite downlinks shall be in the 2 meter band within the amateur satellite service.

2.4.4 All satellite transmitter and receiver frequencies shall deviate by no more than 5 parts-per-million from the specified values including initial accuracy and temperature variation.

2.4.5 All satellite frequencies shall be coordinated with the IARU.

Note that the band plan with the actual coordinated frequencies will be specified in a separate document.

3 Functional Requirements

3.1 Antenna System

3.1.1 The satellite shall include a deployable antenna system.

3.2 Attitude Control

3.2.1 The satellite shall incorporate passive magnetic stabilization to align the deployed antennas with the magnetic field of the earth.

3.3 Access Ports

3.3.1 The satellite shall include a "Remove Before Flight" pin as per the CubeSat Design Specification.

3.3.2 The satellite shall include an umbilical port as per the CubeSat Design Specification.

3.4 Pre-launch Features

3.4.1 The satellite battery and photovoltaic panels shall be electronically disconnected from the avionics when the "Remove Before Flight" pin is inserted, regardless of the state of the deployment switch(es).

3.4.2 The satellite shall provide the means to charge the battery via the umbilical port while integrated with the P-POD.

3.4.3 The satellite shall provide the means to run diagnostic tests via the umbilical port while integrated with the P-POD.

3.5 Power

3.5.1 The satellite shall produce electrical power from sunlight.

3.5.2 The satellite shall produce electrical power while in sunlight regardless of orientation and while tumbling or spinning.

3.5.3 The satellite shall produce sufficient average electrical power to operate continuously in the orbit of maximum eclipse.

3.5.4 The satellite shall provide sufficient battery capacity to operate continuously in the orbit of maximum eclipse.

3.6 Experiment

3.6.1 The satellite shall provide DC power for experiment payloads.

3.6.2 The satellite shall provide a means to activate and deactivate the experiment payloads.

3.6.3 The satellite shall provide a means to telemeter data from the experiment payloads.

Note that the experiment payloads will be specified in a separate documents.

3.7 RF Uplink

3.7.1 The satellite shall include an FM uplink receiver.

3.7.2 The receiver shall have specifications as shown in Table 1.

Table 1

Sensitivity	-120 dBm for 12 dB SINAD (min.)
FM Deviation	5 kHz
Audio Bandwidth	3 kHz
Input Frequency Acceptance	Receiver shall accept signals that are off frequency by ±2.5 kHz (min.)

3.8 RF Downlink

3.8.1 The satellite shall include an FM downlink transmitter.

3.8.2 The transmitter shall have specifications as shown in Table 2.

Table 2

Power Output	400 mW (min.)
FM Deviation	5 kHz
Audio Bandwidth	3 kHz

3.8.3 The transmitter shall provide a means to prevent over modulation.

3.9 FM Transponder

3.9.1 The satellite shall provide an FM transponder via the RF uplink and RF downlink.

3.9.2 In Transponder Mode, the IHU shall detect the presence of a 67 Hz CTCSS tone on the uplink.

3.9.3 In Transponder Mode, the downlink transmitter shall be keyed (*i.e. PTT-on*) by the IHU for a minimum of 30 seconds following detection of the 67 Hz CTCSS tone.

3.9.4 In Transponder Mode, the downlink transmitter shall stay on continuously as long as the 67 Hz CTCSS tone is detected at least once during the period the transmitter is being keyed (*i.e. PTT-on*).

3.9.5 In Transponder Mode, the 67 Hz CTCSS tone is not required for a received signal to be repeated on the downlink, once the transmitter has been keyed.

3.9.6 In Transponder Mode, if the downlink transmitter has been un-keyed for a period of 2 minutes, the satellite shall send "HI THIS IS AMATEUR RADIO SATELLITE FOX 1" as a voice announcement on the downlink transmitter.

3.9.7 In the event of shutdown or failure of the IHU, the satellite shall default to simple carrier operated repeater operation.

3.10 Telemetry Data

3.10.1 The satellite shall collect telemetry data.

3.10.2 The telemetry data shall include at a minimum, measured parameters as shown in Table 3.

Table 3

Parameter Name	Description
CELL V	Voltages of battery cells
PANEL V	Voltages of solar panels
TOTAL I	Total DC current out of power system
PA I	DC current into RF power amp
BATTERY T	Temperature of battery
PANEL T	Temperatures of solar panels
TX T	Temperature of RF transmitter card
RX T	Temperature of RF receiver card

3.10.3 The measured parameters shall be sampled at least every 15 seconds.

3.10.4 The minimum and maximum values of each of the measured parameters shall be saved in non-volatile memory.

3.10.5 The telemetry data shall also include at a minimum, calculated parameters as shown in Table 4.

Table 4

Parameter Name	**Description**
UP TIME	Total seconds since avionics power-up or reset
SPIN	Satellite spin rate and direction

3.10.6 A telemetry frame shall include the current measured values, the saved minimum and maximum values, and the current calculated values.

Note that the telemetry interface will be specified in a separate document.

3.11 Telemetry Transmission

3.11.1 The satellite shall send slow speed telemetry using FSK on the RF downlink.

3.11.2 The FSK shall use the frequency spectrum below the audible range.

3.11.3 The telemetry shall be transmitted simultaneously with any transponder communications.

3.11.4 The telemetry transmission shall include telemetry frames.

3.11.5 The telemetry transmission shall include experiment data.

3.12 Command Capability

3.12.1 The satellite shall provide the means to process commands sent via the RF uplink from a ground control station.

3.12.2 The commands received via the RF uplink shall not be repeated on the RF downlink.

3.12.3 The following commands shall be provided, as shown in Table 5.

Table 5

Command	**Operation**
SAFE MODE	Enter Safe Mode
INHIBIT TX	Inhibit RF transmission
ENABLE TX	Enable RF transmission
IHU OFF	Power off IHU
IHU ON	Power on IHU
CLEAR	Clear stored telemetry
TRANSPONDER MODE	Enter Transponder Mode
DATA MODE	Enter Data Mode
ENABLE AUTO-SAFE	Enable Auto-Safe Mode
DISABLE AUTO-SAFE	Disable Auto-Safe Mode

3.12.4 A SAFE MODE command shall cause the satellite to enter the Safe Mode.

3.12.5 An INHIBIT TX command shall disable the RF transmitter.

3.12.6 An ENABLE TX command shall enable the RF transmitter.

3.12.7 An IHU OFF command shall cause the IHU System to power off.

3.12.8 An IHU ON command shall cause the IHU System to power on.

3.12.9 A CLEAR command shall cause the satellite to clear the saved minimum and maximum telemetry parameter values.

3.12.10 A TRANSPONDER MODE command shall cause the satellite to enter the Transponder Mode.

3.12.11 A DATA MODE command shall cause the satellite to enter the Data Mode.

3.12.12 An ENABLE AUTO-SAFE command shall enable the auto-safe mode state.

3.12.13 A DISABLE AUTO-SAFE command shall disable the auto-safe mode state.

Note that the control interface will be specified in a separate document.

3.13 On-Orbit Operating Modes

3.13.1 The satellite shall provide on-orbit operating modes as shown in Table 6.

Table 6

Name	**Description**
Startup Mode	Wait 50 minutes and deploy antennas
Safe Mode	Wait 120 seconds then begin 10 second beacon sequence Experiments are powered off

Transponder Mode	FM transponder; PTT and low speed telemetry via IHU
Data Mode	FM transmitter; PTT and high speed telemetry via IHU

3.13.2 The satellite shall transition between modes as shown in Figure 1.

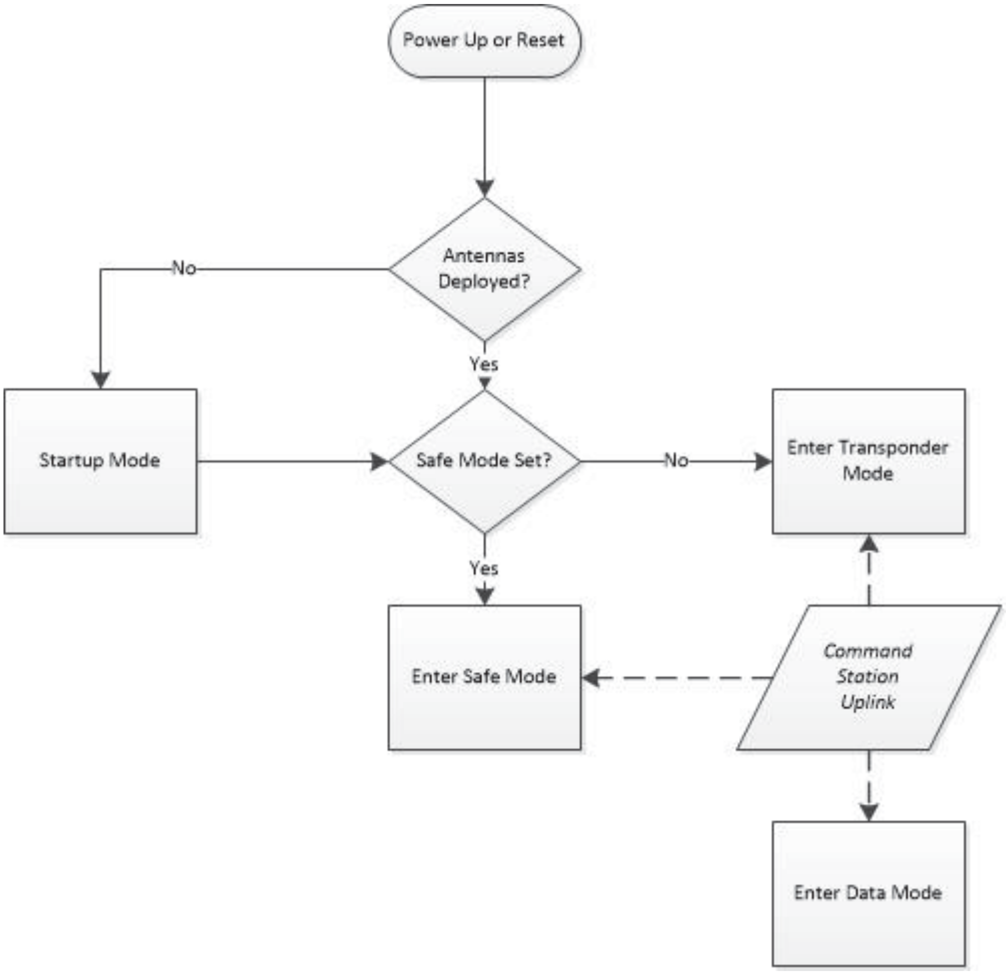


Figure 1. On-Orbit Operating Modes

3.13.3 Upon power-up of the avionics, the satellite shall begin operation from the "Power-up" state as shown in Figure 1.

3.13.4 An IHU ON Command shall cause the satellite to begin operation from the "Power-up" state as shown in Figure 1.

3.13.5 If the antennas have been deployed, the satellite shall determine whether the last state was Safe Mode.

3.13.5.1 If the last state was Safe Mode the satellite shall enter Safe Mode.

3.13.5.2 If the last state was not Safe Mode the satellite shall enter Transponder Mode.

3.13.6 If the antennas have not been deployed, the satellite shall enter the Startup Mode.

3.13.7 In Startup Mode, the satellite shall wait 50 minutes, then deploy the antennas.

3.13.7.1 During the 50 minute wait the IHU shall flash a red LED.

3.13.7.2 During the 50 minute wait the IHU shall sound a 1 kHz beeping tone.

3.13.7.3 After the antennas have been deployed the satellite shall enter Safe Mode.

3.13.8 In Transponder Mode, the transponder and the slow speed telemetry shall be active.

3.13.9 In Data Mode, the high speed telemetry shall be active and the transponder shall not be active. *(i.e. signals that appear on the uplink shall not be repeated on the downlink.)*

3.13.10 If another Data Mode command is not received, the satellite shall automatically enter Transponder Mode 24 hours after having entered Data Mode.

3.13.11 In Safe Mode the satellite shall wait 120 seconds then transmit a 10 second beacon.

3.13.11.1 The 120 second wait and 10 second beacon cycle will be repeated as long as the satellite is in Safe Mode.

3.13.12 The RF uplink shall be monitored for commands in all modes.

4 External Interface Documents

To fully specify the satellite technical requirements, the following documents must also be provided;

1. IARU Coordinated Frequency Plan
2. Downlink Specification
3. Control Interface Specification
4. Experiment Payload Specifications

5 Summary

The *Fox-1* satellite will be AMSAT's first CubeSat. Its primary mission is to provide an FM Transponder communications capability. The secondary mission is to host a university-provided experiment payload.

Date: November 7, 2014
Version: Version 1.10

AMSAT *Fox-1A*

IHU to Experiment 1 Interface Control Document

1 Introduction

This document specifies the message interface between the Internal Housekeeping Unit (IHU) and the Experiment System in Position 1 of the satellite, known as the Vanderbilt University Vulcan Payload and abbreviated herein as EXP1.

1.1 Document History

DATE	VERSION	SUMMARY
March 3, 2013	1.00	Initial version
March 7, 2013	1.01	Correct use of I²C (1.2) and EXP1 (2.3.3)
March 31, 2013	1.02	Command Message CRC8 to include address byte, change to commands, modified figure 3, deleted figure 4
March 31, 2013	1.03	Delete TYPE from message tables, add SET TIME response return values
March 31, 2013	1.04	Add CMD_VERSION_ERR to Error Code table
April 2, 2013	1.05	Correct 6.5 Figure 3, remove 0x0005, 0x0201, 0x0210, 0x0281, 0x0300, and 0x0301 commands
September 17, 2013	1.06	Change type format to exclude code type, add Min/Max Values
October 7, 2013	1.07	Revised Table 1 and 3.2.1 added 3.5.1.1 for clarification on Experiment Enable 1 states
November 7, 2013	1.08	Added 3.1.2 and 3.1.3 regarding minimum power levels for experiment operation
May 21, 2014	1.09	Revised 3.1.2 and 3.1.3 to read <= 3.3V
November 7, 2014	1.10	Update HALT value to 0x05 in Table 6

1.2 Document Scope

This document will specify the control of EXP1, the messaging format, and the I²C bus hardware operation for the communications between the IHU and the EXP1.

1.3 References

1. AMSAT *Fox-1*, System Requirements Specification
2. AMSAT *Fox-1*, System Design Specification
3. AMSAT *Fox-1*, IHU Software Architecture Specification
4. Vanderbilt University Vulcan Payload Interface Control Document

2 General Messaging Requirements

2.1 Link Protocol Requirements

2.1.1 The IHU shall initiate a command to the EXP1.

2.1.2 The EXP1 shall send a reply to each IHU request.

2.1.3 Message bit order shall be Big Endian.

2.1.4 The IHU shall determine the action to be taken in the event of an invalid, improper, or missing message from the EXP1.

2.1.5 The EXP1 shall take no action in the event of an invalid or improper message from the IHU.

2.1.6 Message byte order shall be Big Endian.

2.2 General Message Requirements

2.2.1 Each message shall contain a header block.

2.2.2 Each message shall contain a packet error check (PEC) in the form of CRC8.

2.2.2.1 The message address byte shall be included when calculating the CRC8.

2.3 I²C 1 Bus Hardware Interface Requirements

2.3.1 The I²C Vdd shall be 3.0V.

2.3.2 The bus speed shall be Fast (400kbit/s).

2.3.3 The EXP1 I²C 7 bit address shall be 0x2A.

3 Experiment Operation

3.1 Experiment Power Control

3.1.1 The IHU shall exert control over the power state of the EXP1 by the Experiment Enable 1 pin on the satellite bus as shown in Table 1.

Table 1

Pin State	Description
High	Power On Experiment
Low or high-impedance	Power Off Experiment

3.1.2 The IHU shall not power on the experiment if the power bus voltage (VBATT) is less than or equal to 3.3 Volts.

3.1.3 The IHU shall perform the Experiment Cease Operation Sequence and the Experiment Power Off Sequence if the power bus voltage (VBATT) falls to less than or equal to 3.3 Volts while the experiment is powered on.

3.2 Experiment Power On Sequence

3.2.1 The IHU shall set and hold the Experiment Enable 1 pin HIGH.

3.2.2 The IHU shall not send any message to the EXP1 for a minimum of 100 milliseconds.

3.2.3 The IHU shall send a Set Time command to the EXP1.

3.3 Experiment Begin Operation Sequence

3.3.1 Upon completion of the Power On sequence the IHU shall send a Set Run State Active command message to the EXP1.

3.4 Experiment Cease Operation Sequence

3.4.1 The IHU shall send a Set Run State Halt command message to the EXP1.

3.4.2 The IHU shall not send any message to the EXP1 for a minimum of 10000 milliseconds.

3.4.3 The IHU shall send a Set Run State Standby command message to the EXP1.

3.5 Experiment Power Off Sequence

3.5.1 The IHU shall set the Experiment Enable 1 pin LOW.

3.5.1.1 The absence of a HIGH state on the Experiment Enable 1 pin shall be construed as a LOW state whether the pin is actually LOW, or in a high-impedance state.

4 Message Content Requirements

4.1 Command Message

4.1.1 The message header block shall be constructed as shown in table 2.

4.1.2 The message header block shall be sent with each Command and Response block.

Table 2

Field	Size (Bytes)	Type	Min Value	Max Value	Description
Message Version	2	Unsigned	0x01	0xFFFF	Message ICD version
Software Build	2	Unsigned	0x01	0xFFFF	Software Build version

4.1.2.1 The Message Version shall be an integer representing the IHU to EXP1 ICD document version number from which the message format is derived, having the decimal point removed (e.g. version 1.03 would be 103 decimal or 0x67).

4.1.2.2 The Software Build shall be an integer representing the software build version number of the system originating the message, having any decimal points removed (e.g. version 1.03 would be 103 decimal or 0x67).

4.2 Command Message Block

4.2.1 The command message block shall be constructed as shown in Table 3.

Table 3

Field	Size (Bytes)	Type	Min Value	Max Value	Description
COMMAND	2	Unsigned	0x0000	0x0280	Hexadecimal Command
ARGUMENT	Variable	Unsigned	-	-	Optional Arguments As Required

The command message block shall contain one command in the COMMAND COMMAND field as shown in Table 4.

Table 4

Command Name	**Size (Bytes)**	**Type**	**Min Value**	**Max Value**	**Description**
Nop	2	Unsigned	0x0000	0x0000	No effect; response undefined. Test for I²C acknowledgement only.
Echo	2	Unsigned	0x0001	0x0001	Echo this byte stream
Resend	2	Unsigned	0x0002	0x0002	Resend last result
Get UID	2	Unsigned	0x0003	0x0003	Controller 7 byte identifier
Get Status	2	Unsigned	0x0004	0x0004	Controller status indication
Get Diagnostics	2	Unsigned	0x0006	0x0006	Self-check Diagnostic
Get Telemetry	2	Unsigned	0x0010	0x0010	Send telemetry data
Set Run State	2	Unsigned	0x0080	0x0080	Enter specified Run State
Get Run State	2	Unsigned	0x0081	0x0081	Query current Run State
Set Time	2	Unsigned	0x0100	0x0100	Number of seconds since epoch
Get Time	2	Unsigned	0x0101	0x0101	Number of seconds since epoch
Get Data	2	Unsigned	0x0280	0x0280	Send (number of bytes) data

4.2.3 The command message shall contain arguments for the Echo command, as shown in Table 5.

Table 5

Field	**Size (Bytes)**	**Type**	**Min Value**	**Max Value**	**Description**
ARGUMENT	4	Unsigned	-	-	Data to be echoed

4.2.4 The command message shall contain one argument for the Set Run State command, as shown in Table 6.

Table 6

Run State	Size (Bytes)	Type	Min Value	Max Value	Description
STANDBY	2	Unsigned	0x01	0x01	Enter Standby State
ACTIVE	2	Unsigned	0x03	0x03	Activate Experiments
HALT	2	Unsigned	0x05	0x05	Terminate Experiments

4.2.5 The command message shall contain arguments for the Set Time command, as shown in Table 7.

Table 7

Argument	Size (Bytes)	Type	Min Value	Max Value	Description
IHU Reset Counter	16	Unsigned	0x00	-	Count of the number of IHU resets from non-volatile FRAM
MET Timestamp	32	Unsigned	-	-	MET timestamp (seconds since last IHU reset)

4.2.6 The command message shall contain arguments for the Get Data command, as shown in Table 8.

Table 8

Argument	Size (Bytes)	Type	Min Value	Max Value	Description
BYTES TO SEND	2	Unsigned	0x00	0xFFFF	Number of bytes to send (1-256)

4.3 Response Message Block

4.3.1 The response message block shall be constructed as shown in Table 9.

Table 9

Field	Size (Bytes)	Type	Min Value	Max Value	Description
RESERVED	1	Unsigned	-	-	Reserved, ignore
ERROR CODE	1	Unsigned	0x0000	0x0006	Response to Command
LENGTH	2	Unsigned	0x00	0xFFFF	Length of Return Value in Bytes
RETURN VALUE	Variable	Variable	-	-	Return Value

4.3.2 The Error Code shall contain one code as shown in table 10.

Table 10

Name	Size (Bytes)	Type	Min Value	Max Value	Description
CMD_OK	1	Unsigned	0x0000	0x0000	Command invoked successfully
CMD_OP_ERR	1	Unsigned	0x0001	0x0001	Command not recognized
CMD_FORMAT_ERR	1	Unsigned	0x0002	0x0002	Incorrect command argument length
CMD_RANGE_ERR	1	Unsigned	0x0003	0x0003	Argument(s) out of bounds
CMD_PEC_ERR	1	Unsigned	0x0004	0x0004	Error check (CRC) mismatch
CMD_EXEC_ERR	1	Unsigned	0x0005	0x0005	Execution error
CMD_VERSION_ERR	1	Unsigned	0x0006	0X0006	Header Message Version mismatch

4.3.3 The Status Flags for a GET STATUS response message shall be represented as individual bit values of a 16 bit RETURN VALUE as shown in Table 11.

Table 11

Name	Bit Number	Description
REBOOTED	0	1 = Experiment has rebooted – **NOT USED**
DATA READY	1	1 = Experiment data available
TIME REQUEST	2	1 = Request SET TIME
FAILED RUN STATE	3	1 = Failed the run state – **NOT USED**
COMPLETED RUN STATE	4	1 = Completed the run state – **NOT USED**
RESERVED	5-15	Always 0

4.3.4 The response message to a Set Time command shall contain one of the values as shown in Table 12.

Table 12

Response Name	Size (Bytes)	Type	Min Value	Max Value	Description
SUCCESS	2	Signed	0x00	0x00	Time Set successfully
FAILURE	2	Signed	0xFFFF	0xFFFF	Time Set failed

5 Message Integrity

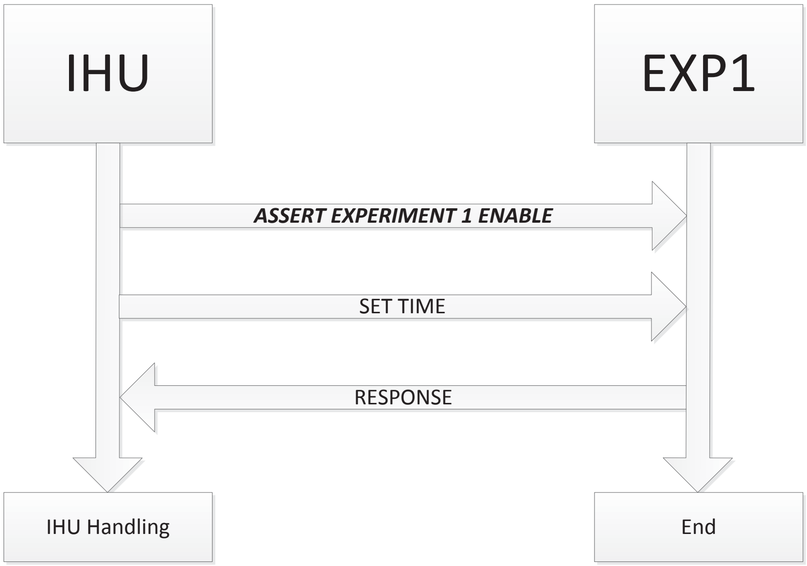
5.1 Invalid Messages

5.1.1 If the PEC (CRC8) fails, the message shall be considered invalid.

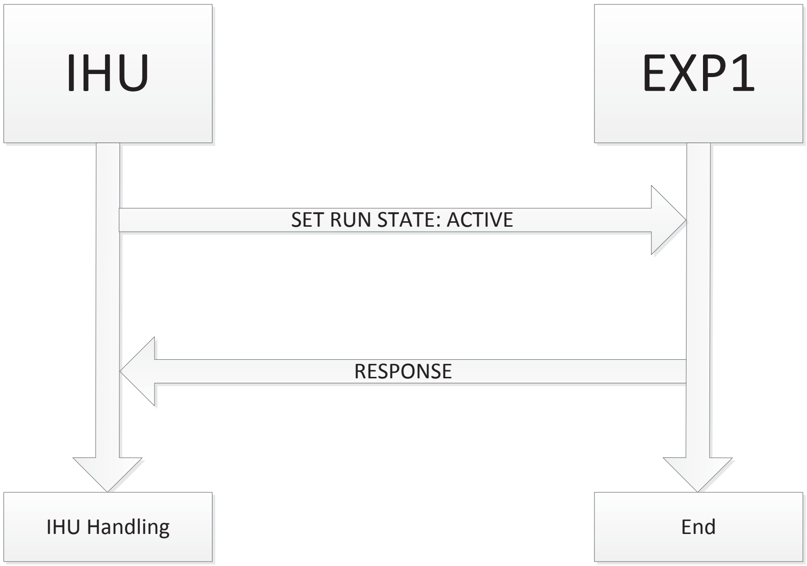
5.1.2 If the Message Version does not match the message version in use for the construction of messages on the receiving system, the message shall be considered invalid.

6 Message Flow Diagrams

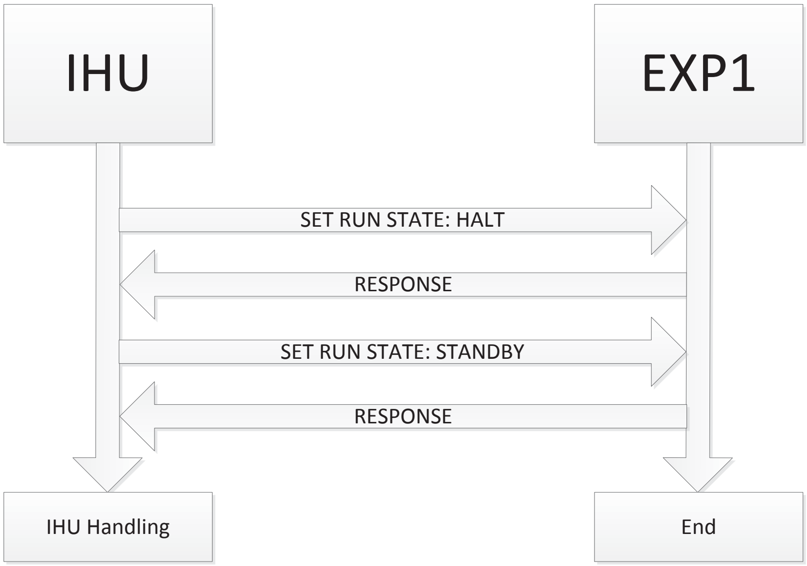
6.1 EXPERIMENT POWER ON SEQUENCE



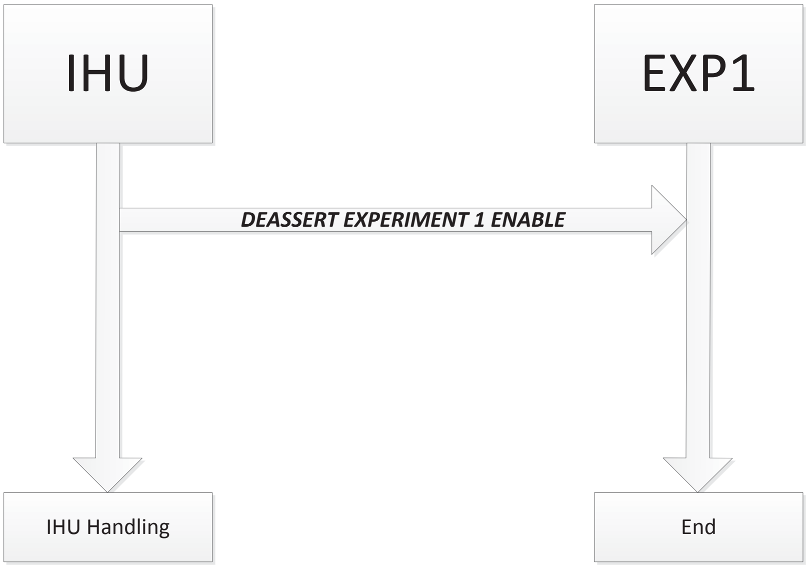
6.2 EXPERIMENT BEGIN OPERATION SEQUENCE



6.3 EXPERIMENT CEASE OPERATION SEQUENCE



6.4 EXPERIMENT POWER OFF SEQUENCE



6.5 SERVICING EXPERIMENT OPERATION

Figure 1

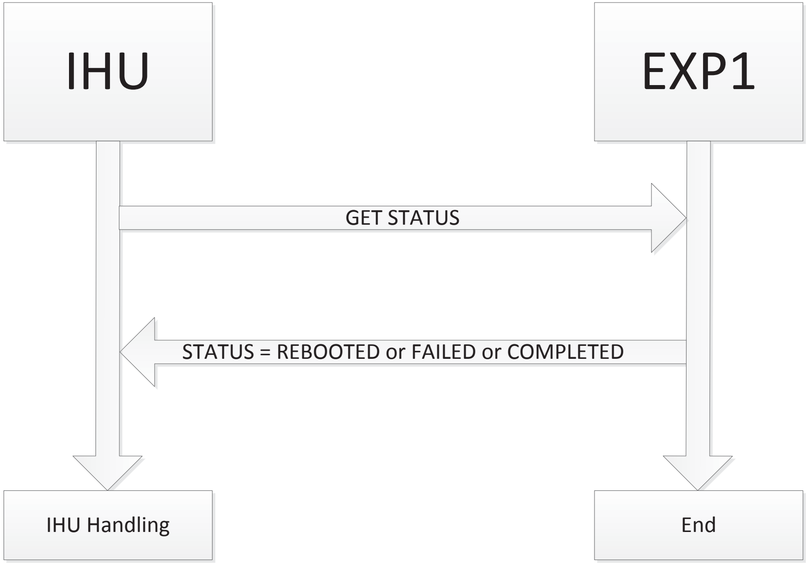


Figure 2

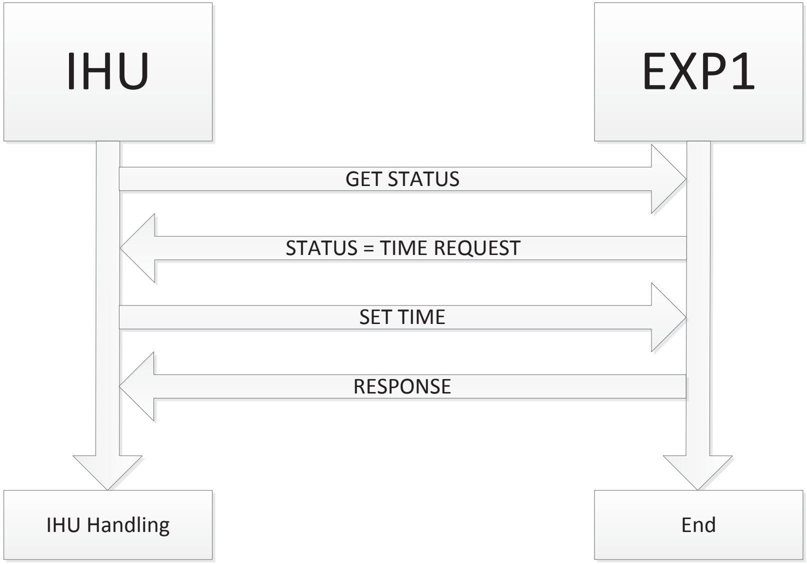
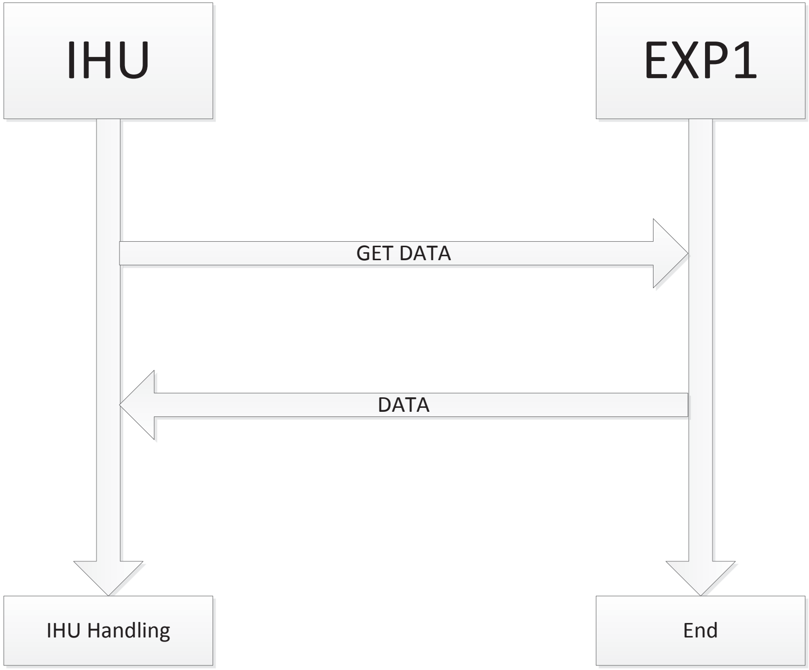


Figure 3



Date: June 26, 2014
Version: Version 1.20

AMSAT *Fox-1A*

IHU to Experiment 4 Interface Control Document

1 Introduction

This document specifies the message interface between the Internal Housekeeping Unit (IHU) and the Experiment System in Position 3 of the satellite, known as the VT Camera Experiment and abbreviated herein as EXP3.

1.1 Document History

DATE	VERSION	SUMMARY
January 24, 2013	1.00	Initial version
February 20, 2013	1.01	Specify byte order as little endian
May 21, 2013	1.10	Update data TYPE names
October 4, 2013	1.11	Change type format to exclude code type, add Min/Max Values, add thermistor circuit
October 7, 2013	1.12	Modify Table 1 to clarify Experiment Enable 4 pin states
June 26, 2014	1.20	Add “No Earth Image Available” to NN description in Table 6, remove section 7 thermistor requirement no longer applicable, change all references to EXP4 to read EXP3 reflecting proper location of experiment

1.2 Document Scope

This document will specify the control of EXP3, the messaging format, and the serial bus hardware operation for the communications between the IHU and the EXP3.

1.3 References

1. AMSAT *Fox-1*, System Requirements Specification
2. AMSAT *Fox-1*, System Design Specification
3. AMSAT *Fox-1*, IHU Software Architecture Specification

2 General Messaging Requirements

2.1 Link Protocol Requirements

2.1.1 The IHU shall initiate a command to the EXP3.

2.1.2 The EXP3 shall send a reply to each IHU request.

2.1.3 Message bit order shall be Little Endian.

2.1.4 The IHU shall determine the action to be taken in the event of an invalid, improper, or missing message from the EXP3.

2.1.5 The EXP3 shall take no action in the event of an invalid or improper message from the IHU.

2.1.6 Message byte order shall be Little Endian.

2.2 General Message Requirements

2.2.1 Each message shall contain a header block.

2.2.2 Each message shall contain one command, one reply, or one data block.

2.3 Serial Bus Hardware Interface Requirements

2.3.1 The bus levels shall be 3.0V.

2.3.2 The bus data speed shall be 38400 bit/s.

2.3.3 The serial bus communication shall be asynchronous.

2.3.4 The number of data bits shall be 8.

2.3.5 The number of stop bits shall be 1.

2.3.6 There shall be no parity bit.

3 Experiment Operation

3.1 Experiment Power Control

3.1.1 The IHU shall exert control over the power state of the EXP3 by the Experiment Enable 4 pin on the satellite bus as shown in Table 1.

Table 1

Pin State	Description
High	Power On Experiment
Low or high-impedance	Power Off Experiment

3.1.2 Upon signaling Power On to the EXP3, the IHU shall not send any message to the EXP3 for a minimum of 100 milliseconds.

3.2 Experiment Operation Sequence

3.2.1 Upon Power On the IHU shall determine the state of the EXP3 by sending an Is Camera Ready command message.

3.2.2 The IHU shall not send a Transmit Data Block command message prior to receiving a Camera Ready reply message from the EXP3.

4 Message Content Requirements

4.1 Message Header Block

4.1.1 The message header block shall be constructed as shown in table 2.

4.1.2 The message header block shall be sent with each Command, Reply, and Data block.

Table 2

Field	Size (Bytes)	Type	Min Value	Max Value	Description
Message Version	2	Unsigned	0x01	0xFFFF	Message ICD version
Software Build	2	Unsigned	0x01	0xFFFF	Software Build version

4.1.2.1 The Message Version shall be an integer representing the IHU to EXP3 ICD document version number from which the message format is derived, having the decimal point removed (e.g. version 1.03 would be 103 decimal or 0x67).

4.1.2.2 The Software Build shall be an integer representing the software build version number of the system originating the message, having any decimal points removed (e.g. version 1.03 would be 103 decimal or 0x67).

4.2 Command Message Block

4.2.1 The command message block shall be constructed as shown in Table 3.

Table 3

Field	Size (Bytes)	Type	Min Value	Max Value	Description
COMMAND	2	Alpha	RR TT	RR TT	Command

4.2.2 The command message block shall contain one command in the COMMAND field as shown in Table 4.

Table 4

Command	Description
RR	Is Camera Ready?
TT	Transmit Data Block

4.3 Reply Message Block

4.3.1 The reply message block shall be constructed as shown in Table 5.

Table 5

Field	Size (Bytes)	Type	Min Value	Max Value	Description
REPLY	2	Alpha	NN YY FF	NN YY FF	Reply

4.3.2 The reply message block shall contain one reply in the REPLY field as shown in table 6.

Table 6

Command	Description
NN	Camera Not Ready or No Earth Image Available
YY	Camera Ready
FF	Camera Failed

4.4 Message Data Block

4.4.1 The message data block shall be constructed as shown in Table 7.

Table 7

Field	Size (Bytes)	Type	Min Value	Max Value	Description
DESCRIPTOR	2	Unsigned	-	-	Line ID and Payload Length
PAYLOAD	Variable	Unsigned	-	-	Array of (Payload Length) bytes
CHKSUM	2	Unsigned	-	-	16 bit accumulator sum of bytes in HEADER and PAYLOAD

4.4.2 The bits of the message data block DESCRIPTOR bytes shall be constructed as shown in Table 8.

Table 8

Field	Size (Bits)	Type	Min Value	Max Value	Description
Line ID	6	Unsigned	0x01	0x3C	640 x 8 pixel picture line number (1 is top, 60 is bottom)
Payload Length	10	Unsigned	0x01	0x3FF	Total number of bytes in PAYLOAD

4.4.2.1 The Line ID shall compose the 6 MSB and the Payload Length shall compose the 10 LSB.

5 Message Integrity

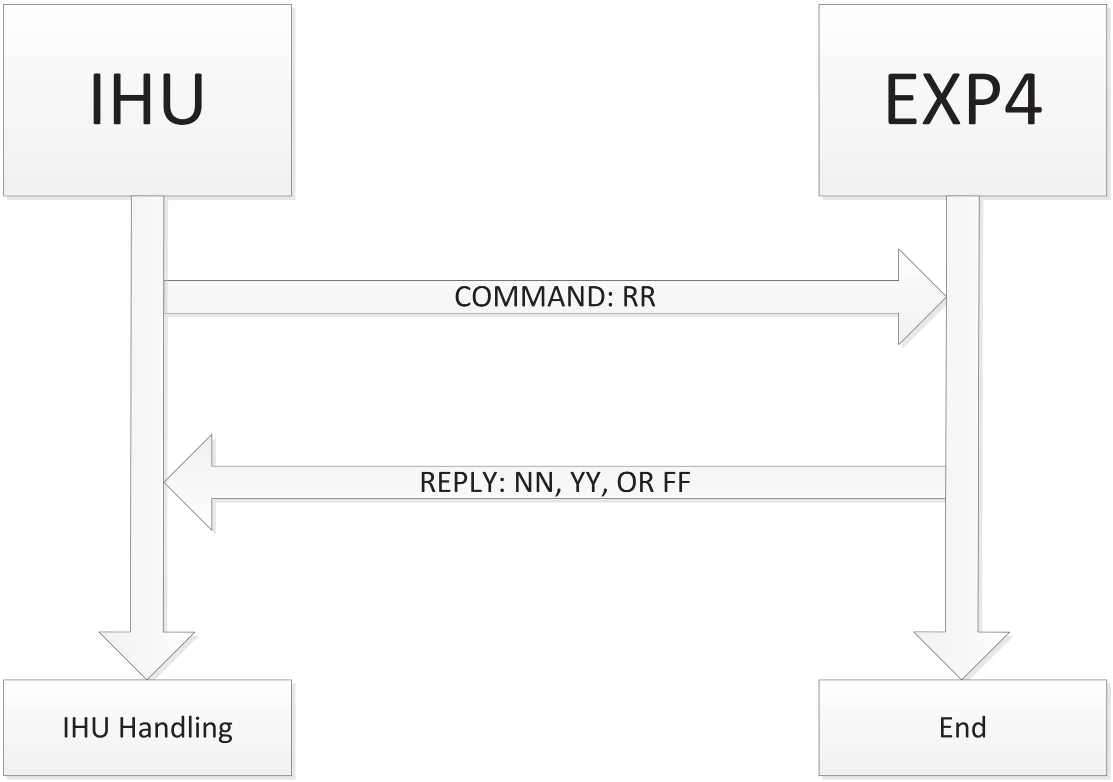
5.1 Invalid Messages

5.1.1 If the DATA block CHKSUM fails, the message shall be considered invalid.

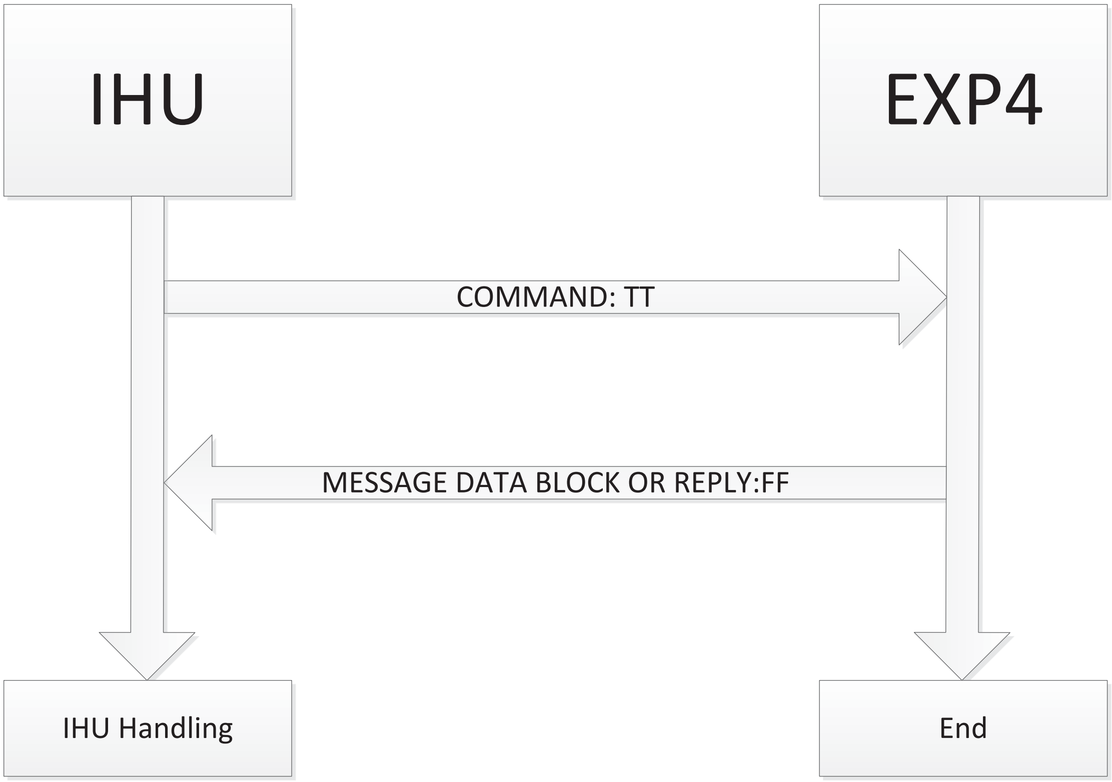
5.1.2 If the Message Version does not match the message version in use for the construction of messages on the receiving system, the message shall be considered invalid.

6 Message Flow Diagrams

6.1 RR COMMAND



6.2 TT COMMAND



Date: May 6, 2015
Version: Version 2.10

AMSAT *Fox-1A*

Downlink Specification

1 Introduction

This document specifies downlink frame formats for the Fox-1A telemetry and experiment telemetry. This specification includes the both slow and high speed formats.

Document History

DATE	VERSION	SUMMARY
April 25, 2013	1.01	Remove TX PA Temperature and TX Osc Temperature, add TX Temperature
May 21, 2013	1.2	High speed downlink details added
May 27, 2013	1.3	Remove Radiation Experiment Telemetry Frame, resize Radiation Experiment Data Frame, renumber Payload Types, added Slow Speed Link Layer Transmission Scheduling, changed Reset Count to 16 bits
June 6, 2013	1.31	Reduce BATT CPU, PSU CPU, IHU CPU, TX Temp, RX Osc Temp from 12 to 8 bit value, add IHU Error Data field to Telemetry Minimum Values Frame
June 26, 2013	1.32	Correct Payload Type numbers in Table 6
August 13, 2013	1.40	Changes due to new BATT telemetry values, delete Type 4 from idle telemetry
August 26, 2013	1.41	Change Receiver Osc Temperature to Receiver Card Temperature, remove TOTAL MPPT I, update 2.2.9.1 and 2.2.9.1.1 to reflect variable size of Radiation Experiment Data available
September 14, 2013	1.42	Added 3.1.2, Payload type 0 debug frame, made Scan Line Segment – Picture Count size 8 bits, add RSSI to Payloads 1, 2, and 3, change type format to exclude code type, add Min/Max Values
September 16, 2013	1.43	Added EXP4 temperature to Payloads 1, 2, and 3, changed PSU CPU temp to PSU card temp

DATE	VERSION	SUMMARY
October 15, 2013	1.44	Correct bit count for frame Type 3, change calculated spin rate to remove PSU reference
November 18, 2013	1.45	Expanded all temperature fields to 12 bits, redo 3.1 payload order, add 2.2.7.3 and 2.2.7.4, update SPIN to show bit pattern, add System I²C Failure indications, add Ground Command TLM reset count, add IHU Soft Error Data, add IHU Hard Error Data, increase IHU Error Data to 32 bits, clarify which fields are raw values, added 2.2.7 5 padding slow speed frames, 2.2.8 for slow speed trailer info
January 13, 2014	1.50	Redo 3.2 beacon payloads
January 13, 2014	1.51	Change 3.2.1 to allow payload type 2 and 3 only with the voice ID
January 13, 2014	1.52	Correct 2.2.9 high speed link layer header structure to show 16 bits on the Reset Count
January 14, 2014	1.53	Correct Table 4 and Table 5 Reset Count Max Value to 0xFFFF to match use of 16 bits
February 10, 2014	1.54	Modify Table 11 to read “Experiment 1 Data” in the description, added Safe Mode Indication bit to payload 2 and 3, changed Filler bit size to 1 in payload 2 and 3.
March 19, 2014	1.55	Move IHU Soft Error Data to Payload Type 3, Move IHU Error Data to Payload Type 1 and rename to IHU Diagnostic Data, update Table 1 Bit Rate to 200 bps and Spectral Efficiency to 2 bps/Hz, remove Scrambler reference from Table 1 and Table 2.
March 24, 2014	1.56	Add timestamp elements to Payload 2 and Payload 3 for specific MAX or MIN last changed
April 23, 2014	1.57	Fix 4.4 BATT Board Temperature description to read Low instead of High
June 10, 2014	1.58	Remove Payload Type 2 MRAM Error Count, Add PSU DC current, PSU DC high current, PSU DC low current to Payload Type 1, 2, 3 respectively
September 30, 2014	2.00	Reorder fields in Payload Type 1, 2, 3, delete filler fields, add filler bits to Table 5

DATE	VERSION	SUMMARY
May 6, 2015	2.10	Revised Payload Type 5 and Picture Data Structure to conform with actual implementation

1.1 Document Scope

The purpose of this document is to specify the downlink protocol on the AMSAT Fox-1A spacecraft.

1.2 References

1. Fox1 IHU to RF ICD
2. Fox1 IHU to Battery ICD
3. Fox1 IHU to PSU ICD
4. Fox1 IHU to Attitude Determination Experiment ICD
5. Fox1 IHU Software Architecture Specification
6. Fox1 IHU to Experiment 1 ICD
7. Fox1 IHU to Experiment 4 ICD

1.3 Definitions

1.3.1 Slow Speed Downlink – Data transmitted at approximately 100 bits per second in the audio portion below 300 Hz simultaneous with the transponder audio.

1.3.2 High Speed Downlink – Data transmitted at approximately 9600 bits per second using the entire downlink audio passband.

1.3.3 Spacecraft Telemetry – Downlink data containing specific information about spacecraft systems and health as defined in the System Requirements and related documents.

1.3.4 Experiment Telemetry – Downlink data containing specific information about the various experiment platforms flown on the satellite.

1.3.5 Frame – A defined set of data with a specific overall size comprised of fields of a specific bit or byte length.

2 Protocol Structure

2.1 Physical Layer

2.1.1 The physical layer includes options for slow-speed and high speed operation.

2.1.2 Slow speed operation uses frequency-shift keying and is transmitted in the sub-audible part of the audio downlink below 300 Hz. It may be transmitted simultaneously with voice or other audio signals. The details of the physical layer are shown in Table 1.

Table 1

Bit Rate	200 bps
Spectral efficiency	2 bps/Hz
Modulation type	Non-coherent Frequency Shift Keying (FSK)
Signal bandwidth	10 Hz to 200 Hz (-3 dB points)
FSK Deviation	500 Hz
Spectral Mask	-20 dB at 300 Hz
RF Channel Bandwidth	1200 Hz

2.1.3 High speed operation uses frequency-shift keying and is transmitted using the entire RF downlink bandwidth. The details of the physical layer are shown in Table 2. *Note that this is the same as the G3RUH modem.*

Table 2

Bit Rate	9600 bps
Spectral efficiency	2 bps/Hz
Modulation type	non-coherent frequency shift keying (FSK)
Signal bandwidth	10 Hz to 4800 Hz (-3 dB points)
FSK Deviation	3 kHz
Spectral Mask	-60 dB at 7500 Hz
RF Channel Bandwidth	20 kHz

2.2 Link Layer

2.2.1 The link layer protocol provides multiplexing, packet identification and forward error correction.

2.2.2 The link layer shall include a header and a trailer surrounding the applications layer payload to form data packets as shown in Table 3.

Table 3

Header	Applications Payload	Trailer

2.2.3 The applications payload layer shall include satellite telemetry, experiment telemetry, high speed data, and debug frames.

2.2.4 Debug frames may be used during ground testing but shall not be transmitted for flight.

2.2.5 Bits shall be transmitted in the order of most significant bit first.

2.2.6 Bytes shall be transmitted in Little Endian order.

2.2.7 The Slow Speed link layer header structure shall be as shown in Table 4.

Table 4

Field	Size (Bits)	Type	Min Value	Max Value	Description
Fox ID	3	Unsigned	0x01	0x01	0x01 specifies Fox-1A (each Fox satellite will have a unique ID)
Reset Count	16	Unsigned	0x00	0xFFFF	Total number of times IHU has reset since initial on-orbit startup
Uptime	25	Unsigned	0x00	0x1FFFFFF	This is the IHU uptime in seconds since the last reset
Type	4	Unsigned	0x00	0x0F	This identifies the payload type

2.2.7.1 Payload type shall be as specified in the application layer payload data.

2.2.7.2 Each Slow Speed link layer structure shall contain only one payload type.

2.2.7.3 Reset Count and Uptime shall reflect the time at which the payload data was collected.

2.2.7.4 Reset Count and Uptime shall not be changed if the payload data has not been updated.

2.2.7.5 Real-Time Telemetry Frame, Telemetry Maximum Values Frame, and Telemetry Minimum Values Frame data shall be padded with zeros to equal 58 bytes length for each.

2.2.8 Forward error correction (FEC) code words shall be sent in the link layer trailer. The FEC shall be a Reed Solomon RS 255,223 code. (This provides 32 parity bytes per code word allowing error detection and correction capability.)

2.2.9 The High Speed link layer header structure is shown in Table 5.

Table 5

Field	Size (Bits)	Type	Min Value	Max Value	Description
Fox ID	3	Unsigned	0x01	0x01	0x01 specifies Fox-1A (each Fox satellite will have a unique ID)
Reset Count	16	Unsigned	0x00	0xFFFF	Total number of times IHU has reset since initial on-orbit startup
Uptime	25	Unsigned	0x00	0x1FFFFFF	This is the IHU uptime in seconds since the last reset
(No Value)	4	Unsigned	0x00	0x00	4 bit filler

2.2.10 The High Speed link layer applications payload shall contain data from all payload types, as shown in table 6.

Table 6

Payload Type	Size (Bytes)	Description
1	60	Real-Time Telemetry Frame
2	60	Telemetry Maximum Values Frame
3	60	Telemetry Minimum Values Frame
5	Variable 1 - 4300	Camera JPEG Data Frame
4	58	Radiation Experiment High Speed Data Frame

2.2.10.1 A varying number of Radiation Experiment Data bytes shall be sent to fill the applications payload size to a total of 4600 bytes if the payload type 5 data is less than 4300 bytes.

2.2.10.1.1 When less than a sufficient number of bytes to contain a useful data frame remain to fill to 4600 bytes, the remaining bytes shall be filled with zeros.

2.2.10.2 Real-Time Telemetry Frame, Telemetry Maximum Values Frame, and Telemetry Minimum Values Frame data shall be padded with zeros to equal 60 bytes length for each.

2.2.11 Forward error correction (FEC) code words shall be sent in the link layer trailer. The FEC shall be a Reed Solomon RS 255,223 code. (This provides 32 parity bytes per code word allowing error detection and correction capability.) Twenty one code words will be populated in parallel, with 1 byte being added to each code word in sequence until all bytes have been processed. The last code word will be partially filled and should be virtually padded with 77 bytes. The data will then be sent sequentially with 8b10b coding. Twenty one sets of 32 parity bytes will follow after all data has been sent for the high speed frame.

3 Slow Speed Link Layer Transmission Scheduling

3.1 While IHU PTT is asserted Payload Types contained in the Link Layer Applications Payload shall rotate, changing type with each successive link layer transmitted, in the following order:

- Type 1
- Type 4
- Type 4
- Type 1
- Type 4
- Type 4
- Type 1
- Type 4
- Type 4
- Type 1
- Type 2
- Type 4
- Type 1
- Type 4
- Type 4
- Type 1
- Type 4
- Type 4
- Type 1
- Type 4
- Type 4
- Type 1
- Type 3
- Type 4

3.1.1 The above order shall be repeated so long as IHU PTT is asserted.

3.1.2 Each time IHU PTT is asserted the order shall begin at the top.

3.1.3 The IHU PTT shall not be de-asserted during transmission of a Link Layer.

3.2 While beacon message is sent during idle timer expired the Payload Types contained in the Link Layer Applications Payload shall be transmitted in alternating sets, one set per beacon message:

Set 1:
- Type 1
- Type 2

Set 2:
- Type 1
- Type 3

3.2.1 The payload type 2 or 3 data shall be sent simultaneously with the voice ID.

4 Application Layer Payload Data

4.1 Payload Type 0 – Debug Frame (NOT TO BE TRANSMITTED FOR FLIGHT)

Table 7

Field	Size (Bits)	Type	Min Value	Max Value	Description
UNDEFINED	1 - 464	Undefined	-	-	Debug data for ground testing

4.2 Payload Type 1 - Real-Time Telemetry Frame (Size = 429 bits)

Table 8

Field	Size (Bits)	Type	Min Value	Max Value	Description	Bit Offset
BATT A V	12	Unsigned	0x00	0xFFF	Battery pair A voltage raw value (0-2.5V scale)	0
BATT B V	12	Unsigned	0x00	0xFFF	Battery pairs A+B voltage raw value (0-3.3V scale)	12
BATT C V	12	Unsigned	0x00	0xFFF	Battery pairs A+B+C voltage raw value (0-5.0V scale) This value also represents the power bus voltage (VBATT)	24
BATT A T	12	Unsigned	0x00	0xFFF	Battery pair A temperature raw value	36
BATT B T	12	Unsigned	0x00	0xFFF	Battery pair B temperature raw value	48
BATT C T	12	Unsigned	0x00	0xFFF	Battery pair C temperature raw value	60
TOTAL BATT I	12	Signed	0x00	0xFFF	Total Battery DC current raw value	72
BATT Board Temperature	12	Unsigned	0x00	0xFFF	PC Board Temperature of BATT raw value	84
+X PANEL V	12	Unsigned	0x00	0xFFF	+X solar panel voltage raw value	96
-X PANEL V	12	Unsigned	0x00	0xFFF	-X solar panel voltage raw value	108
+Y PANEL V	12	Unsigned	0x00	0xFFF	+Y solar panel voltage raw value	120
-Y PANEL V	12	Unsigned	0x00	0xFFF	-Y solar panel voltage raw value	132
+Z PANEL V	12	Unsigned	0x00	0xFFF	+Z solar panel voltage raw value	144
-Z PANEL V	12	Unsigned	0x00	0xFFF	-Z solar panel voltage raw value	156
+X PANEL T	12	Unsigned	0x00	0xFFF	+X solar panel temperature raw value	168
-X PANEL T	12	Unsigned	0x00	0xFFF	-X solar panel temperature raw value	180
+Y PANEL T	12	Unsigned	0x00	0xFFF	+Y solar panel temperature raw value	192
-Y PANEL T	12	Unsigned	0x00	0xFFF	-Y solar panel temperature raw value	204
+Z PANEL T	12	Unsigned	0x00	0xFFF	+Z solar panel temperature raw value	216

Field	Size (Bits)	Type	Min Value	Max Value	Description	Bit Offset
-Z PANEL T	12	Unsigned	0x00	0xFFF	-Z solar panel temperature raw value	228
PSU Temperature	12	Unsigned	0x00	0xFFF	PSU card temperature raw value	240
SPIN	12	Signed	0x00	0xFFF	Calculated spin rate RPM using solar cells Bit 11 = sign Bits 10 to 8 = integer Bits 7 to 0 = fraction	252
TX PA Current	12	Unsigned	0x00	0xFFF	Transmit power amplifier current raw value	264
TX Temperature	12	Unsigned	0x00	0xFFF	Transmitter card temperature raw value	276
RX Temperature	12	Unsigned	0x00	0xFFF	Receiver card temperature raw value	288
RSSI	12	Unsigned	0x00	0xFFF	Received Signal Strength Indication raw value	300
IHU CPU Temperature	12	Unsigned	0x00	0xFFF	CPU Temperature of IHU raw value	312
Satellite X Axis Angular Velocity	12	Unsigned	0x00	0xFFF	Raw Angle	324
Satellite Y Axis Angular Velocity	12	Unsigned	0x00	0xFFF	Raw Angle	336
Satellite Z Axis Angular Velocity	12	Unsigned	0x00	0xFFF	Raw Angle	348
EXP 4 Temperature	12	Unsigned	0x00	0xFFF	Experiment 4 card temperature raw value	360
PSU Current	12	Unsigned	0x00	0xFFF	PSU DC current	372
IHU Diagnostic Data	32	Unsigned	-	-	Diagnostic Data on IHU Performance	384
Experiment Failure Indication	4	Unsigned	0x00 0x08	0x01 0x09	Bit 0 is Experiment 1 Bit 1 is Experiment 2 (N/A on Fox-1A) Bit 2 is Experiment 3 (N/A on Fox-1A) Bit 3 is Experiment 4 State: 0 = Working, 1 = Failed	416

Field	Size (Bits)	Type	Min Value	Max Value	Description	Bit Offset
System I2C Failure Indications	3	Unsigned	0x00	0x07	Bit 0 is BATT Bit 1 is PSU Device 1 Bit 2 is PSU Device 2 State: 0 = Working, 1 = Failed	420
Number of Ground Commanded TLM Resets	4	Unsigned	0x00	0x0F	Number of times command stations reset stored telemetry	423
Antenna Deploy Sensors	2	Unsigned	0x00	0x03	Bit 0 is RCV Bit 1 is XMT State: 0 = stowed 1 = deployed	427

4.3 Payload Type 2 - Telemetry Maximum Values Frame (Size = 460 bits)

Table 9

Field	Size (Bits)	Type	Min Value	Max Value	Description	Bit Offset
BATT A V	12	Unsigned	0x00	0xFFF	Battery pair A high voltage raw value (0-2.5V scale)	0
BATT B V	12	Unsigned	0x00	0xFFF	Battery pairs A+B high voltage raw value (0-3.3V scale)	12
BATT C V	12	Unsigned	0x00	0xFFF	Battery pairs A+B+C high voltage raw value (0-5.0V scale) This value also represents the power bus voltage (VBATT)	24
BATT A T	12	Unsigned	0x00	0xFFF	Battery pair A high temperature raw value	36
BATT B T	12	Unsigned	0x00	0xFFF	Battery pair B high temperature raw value	48
BATT C T	12	Unsigned	0x00	0xFFF	Battery pair C high temperature raw value	60
TOTAL BATT I	12	Signed	0x00	0xFFF	Battery DC high current raw value	72
BATT Board Temperature	12	Unsigned	0x00	0xFFF	High PC Board Temperature of BATT raw value	84
+X PANEL V	12	Unsigned	0x00	0xFFF	+X solar panel high voltage raw value	96
-X PANEL V	12	Unsigned	0x00	0xFFF	-X solar panel high voltage raw value	108
+Y PANEL V	12	Unsigned	0x00	0xFFF	+Y solar panel high voltage raw value	120
-Y PANEL V	12	Unsigned	0x00	0xFFF	-Y solar panel high voltage raw value	132
+Z PANEL V	12	Unsigned	0x00	0xFFF	+Z solar panel high voltage raw value	144
-Z PANEL V	12	Unsigned	0x00	0xFFF	-Z solar panel high voltage raw value	156
+X PANEL T	12	Unsigned	0x00	0xFFF	+X solar panel high temperature raw value	168

Field	Size (Bits)	Type	Min Value	Max Value	Description	Bit Offset
-X PANEL T	12	Unsigned	0x00	0xFFF	-X solar panel high temperature raw value	180
+Y PANEL T	12	Unsigned	0x00	0xFFF	+Y solar panel high temperature raw value	192
-Y PANEL T	12	Unsigned	0x00	0xFFF	-Y solar panel high temperature raw value	204
+Z PANEL T	12	Unsigned	0x00	0xFFF	+Z solar panel high temperature raw value	216
-Z PANEL T	12	Unsigned	0x00	0xFFF	-Z solar panel high temperature raw value	228
PSU Temperature	12	Unsigned	0x00	0xFFF	PSU card high temperature raw value	240
SPIN	12	Signed	0x00	0xFFF	Highest calculated spin rate RPM using solar cells	252
TX PA Current	12	Unsigned	0x00	0xFFF	Transmit power amplifier high current raw value	264
TX Temperature	12	Unsigned	0x00	0xFFF	Transmitter card high temperature raw value	276
RX Temperature	12	Unsigned	0x00	0xFFF	Receiver card high temperature raw value	288
RSSI	12	Unsigned	0x00	0xFFF	High Received Signal Strength Indication raw value	300
IHU CPU Temperature	12	Unsigned	0x00	0xFFF	High CPU Temperature of IHU raw value	312
Satellite X Axis Angular Velocity	12	Unsigned	0x00	0xFFF	Highest Raw Angle	324
Satellite Y Axis Angular Velocity	12	Unsigned	0x00	0xFFF	Highest Raw Angle	336
Satellite Z Axis Angular Velocity	12	Unsigned	0x00	0xFFF	Highest Raw Angle	348

Field	**Size (Bits)**	**Type**	**Min Value**	**Max Value**	**Description**	**Bit Offset**
EXP 4 Temperature	12	Unsigned	0x00	0xFFF	Experiment 4 card high temperature raw value	360
PSU Current	12	Unsigned	0x00	0xFFF	PSU DC high current	372
IHU Hard Error Data	32	Unsigned	-	-	Diagnostic Data on IHU Hard Errors	384
MAX Timestamp Reset Count	16	Unsigned	0x00	0xFFFF	At last MAX, total number of times IHU has reset since initial on-orbit startup	416
MAX Timestamp Uptime	25	Unsigned	0x00	0x1FFFFFF	At last MAX, the IHU uptime in seconds since the last reset	432
Safe Mode Indication	1	Unsigned	0x00	0x01	State: 1 = Safe Mode Active	457
Auto-Safe Mode Indication	1	Unsigned	0x00	0x01	State: 1 = Safe Mode activated by Auto-Safe	458
Auto-Safe Enabled	1	Unsigned	0x00	0x01	State: 1 = Auto-Safe Mode enabled	459

4.4 Payload Type 3 - Telemetry Minimum Values Frame (Size = 460 bits)

Table 10

Field	Size (Bits)	Type	Min Value	Max Value	Description	Bit Offset
BATT A V	12	Unsigned	0x00	0xFFF	Battery pair A low voltage raw value (0-2.5V scale)	0
BATT B V	12	Unsigned	0x00	0xFFF	Battery pair A+B low voltage raw value (0-3.3V scale)	12
BATT C V	12	Unsigned	0x00	0xFFF	Battery pair A+B+C low voltage raw value (0-5.0V scale) This value also represents the power bus voltage (VBATT)	24
BATT A T	12	Unsigned	0x00	0xFFF	Battery pair A low temperature raw value	36
BATT B T	12	Unsigned	0x00	0xFFF	Battery pair B low temperature raw value	48
BATT C T	12	Unsigned	0x00	0xFFF	Battery pair C low temperature raw value	60
TOTAL BATT I	12	Signed	0x00	0xFFF	Battery DC low current raw value	72
BATT Board Temperature	12	Unsigned	0x00	0xFFF	Low PC Board Temperature of BATT raw value	84
+X PANEL V	12	Unsigned	0x00	0xFFF	+X solar panel low voltage raw value	96
-X PANEL V	12	Unsigned	0x00	0xFFF	-X solar panel low voltage raw value	108
+Y PANEL V	12	Unsigned	0x00	0xFFF	+Y solar panel low voltage raw value	120
-Y PANEL V	12	Unsigned	0x00	0xFFF	-Y solar panel low voltage raw value	132
+Z PANEL V	12	Unsigned	0x00	0xFFF	+Z solar panel low voltage raw value	144
-Z PANEL V	12	Unsigned	0x00	0xFFF	-Z solar panel low voltage raw value	156
+X PANEL T	12	Unsigned	0x00	0xFFF	+X solar panel low temperature raw value	168

Field	Size (Bits)	Type	Min Value	Max Value	Description	Bit Offset
-X PANEL T	12	Unsigned	0x00	0xFFF	-X solar panel low temperature raw value	180
+Y PANEL T	12	Unsigned	0x00	0xFFF	+Y solar panel low temperature raw value	192
-Y PANEL T	12	Unsigned	0x00	0xFFF	-Y solar panel low temperature raw value	204
+Z PANEL T	12	Unsigned	0x00	0xFFF	+Z solar panel low temperature raw value	216
-Z PANEL T	12	Unsigned	0x00	0xFFF	-Z solar panel low temperature raw value	228
PSU Temperature	12	Unsigned	0x00	0xFFF	PSU card low temperature raw value	240
SPIN	12	Signed	0x00	0xFFF	Lowest calculated spin rate RPM using solar cells	252
TX PA Current	12	Unsigned	0x00	0xFFF	Transmit power amplifier low current raw value	264
TX Temperature	12	Unsigned	0x00	0xFFF	Transmitter card low temperature raw value	276
RX Temperature	12	Unsigned	0x00	0xFFF	Receiver card low temperature raw value	288
RSSI	12	Unsigned	0x00	0xFFF	Low Received Signal Strength Indication raw value	300
IHU CPU Temperature	12	Unsigned	0x00	0xFFF	Low CPU Temperature of IHU raw value	312
Satellite X Axis Angular Velocity	12	Unsigned	0x00	0xFFF	Lowest Raw Angle	324
Satellite Y Axis Angular Velocity	12	Unsigned	0x00	0xFFF	Lowest Raw Angle	336
Satellite Z Axis Angular Velocity	12	Unsigned	0x00	0xFFF	Lowest Raw Angle	348

Field	Size (Bits)	Type	Min Value	Max Value	Description	Bit Offset
EXP 4 Temperature	12	Unsigned	0x00	0xFFF	Experiment 4 card low temperature raw value	360
PSU Current	12	Unsigned	0x00	0xFFF	PSU DC low current	372
IHU Soft Error Data	32	Unsigned	-	-	Diagnostic Data on IHU Soft Errors	384
MIN Timestamp Reset Count	16	Unsigned	0x00	0xFFFF	At last MIN, total number of times IHU has reset since initial on-orbit startup	416
MIN Timestamp Uptime	25	Unsigned	0x00	0x1FFFFFF	At last MIN, the IHU uptime in seconds since the last reset	432
Safe Mode Indication	1	Unsigned	0x00	0x01	State: 1 = Safe Mode Active	457
Auto-Safe Mode Indication	1	Unsigned	0x00	0x01	State: 1 = Safe Mode activated by Auto-Safe	458
Auto-Safe Enabled	1	Unsigned	0x00	0x01	State: 1 = Auto-Safe Mode enabled	459

4.5 Payload Type 4 - Radiation Experiment Data Frame (Size = 464 bits)

Table 11

Field	Size (Bytes)	Type	Min Value	Max Value	Description
Data	58	Unsigned	-	-	Experiment 1 Data

4.6 Payload Type 5 - Camera JPEG Data Frame (Size is variable)

Table 12

Field	Size (Bits)	Type	Min Value	Max Value	Description
Scan Line Count	8	Unsigned	0x00	0xFF	Count of scan lines in payload
Picture Data	Variable	Unsigned	--	--	Picture Data Structure (Section 5)

5 Picture Data Structure

5.1 Scan Line Segment

Table 13

Field	Size (Bits)	Type	Min Value	Max Value	Description
Picture Counter	8	Unsigned	0x00	0xFF	Picture count indicator
Scan Line Number	6	Unsigned	0x00	0x3B	0x00 = top scan line
Scan Line Length	10	Unsigned	0x001	0x3FF	Count of bytes in the scan line
Scan Line Data	Variable	Unsigned	-	-	(Fragment Length) Scan Line Data

5.1.1 Total Scan Line Segment data size for one Applications Payload frame shall not exceed 4299 bytes.

Date: February 21, 2015
Version: Version 1.04

AMSAT *Fox-1D*

IHU to Experiment 1 Interface Control Document

1 Introduction

This document specifies the message interface between the Internal Housekeeping Unit (IHU) and the University of Iowa Experiment System, EXP 1 of the satellite, known as the High-Energy Radiation CubeSat Instrument and abbreviated as HERCI.

1.1 Document History

DATE	VERSION	SUMMARY
November 13, 2014	0.5	Draft version
November 14, 2014	0.6	Draft update
November 30, 2014	0.6	Draft update #2
December 2, 2014	0.7	Changed source template to reflect SPI, replaced EXP4 with EXP1
December 2, 2014	0.7	Changed CAMERA to DETECTOR (provisional) throughout and added “No Detector Data Available” reply in Table 6
December 15, 2014	0.8	Incorporated changes from U of I, renamed EXP to HERCI, etc..
January 1, 2015	0.81	Changed Experiment Enable 4 to Experiment Enable 1
January 9, 2015	0.9	Added CLOCK field to Table 3, added STATUS field to Table 5, CUT LINE ID from Table 7, 8
January 14, 2015	0.91	Added HOUSEKEEPING to op sequence, HK, EE (provisional) to command message block and flow diagrams.
January 19, 2015	0.92	Cut 4.4.2 – LINE ID + Length descriptor bits
January 22, 2015	0.95	Changed Reply to Failure
February 10, 2015	0.97	Swapped CLOCK field in favor of separate time fields, temp add “PP” command
February 13, 2015	0.98	Cleaned up formatting, added ZZ command, diagram, expanded on STATUS codes
February 13, 2015	0.99	Added RR command text & flows, added DD message block, Power On sequence flows, added draft power cycle criteria.
February 16, 2015	1.00	Revised message header, added Safe Mode exception to Power Off sequence, added ICD version code (later removed).
February 17, 2015	1.01	Added subrequirements for compound cases.
February 17, 2015	1.02	Deleted text from Power On diagram.
February 19, 2015	1.03	Deleted DD and EE commands, deleted STATUS code. Cleaned up formatting.
February 21, 2015	1.04	Changed bus voltage to 3.3 (based on email thread), reordered message header information for clarity, reformatted, renumbered.

1.2 Document Scope

This document will specify the control of HERCI, the messaging format, and the serial bus hardware operation for the communications between the IHU and HERCI.

References

1. AMSAT *Fox-1,* System Requirements Specification
2. AMSAT *Fox-1*, System Design Specification
3. AMSAT *Fox-1*, IHU Software Architecture Specification

2 General Messaging Requirements

2.1 Link Protocol Requirements

2.1.1 The IHU shall initiate a command to HERCI.

2.1.2 HERCI shall send a reply to each IHU request.

2.1.3 Message bit order shall be least significant bit first.

2.1.4 The IHU shall determine the action to be taken in the event of an invalid, improper, or missing message from the HERCI.

2.1.5 HERCI shall take no action in the event of an invalid or improper message from the IHU.

2.1.6 Message byte order shall be Little Endian.

2.2 General Message Requirements

2.2.1 Each message shall contain a header block.

2.2.2 Each message shall contain one command, one reply, or one data block.

2.3 Serial Bus Hardware Interface Requirements

2.3.1 The bus levels shall be 3.3V.

2.3.2 The bus data speed shall be 38400 bit/s.

2.3.3 The serial bus communication shall be asynchronous.

2.3.4 The number of data bits shall be 8.

2.3.5 The number of stop bits shall be 1.

2.3.6 There shall be no parity bit.

3 Experiment Operation

3.1 Experiment Power Control

3.1.1 The IHU shall exert control over the power state of HERCI by the Experiment Enable 1 pin on the satellite bus as shown in Table 1.

Table 1

Pin State	Description
High	Power On Experiment
Low or high-impedance	Power Off Experiment

3.1.2 Upon signaling Power On to HERCI, the IHU shall not power down HERCI for a minimum of 90 seconds

3.1.2.1 If the satellite is commanded into Safe Mode during the 90 second interval, the IHU shall not wait for the remainder of the interval before signaling Power Off.

3.1.3 Upon signaling Power On to HERCI, IHU will wait up to 45 seconds for an unsolicited FF reply message block, indicating HERCI has failed self-test. After waiting the 45 seconds, IHU will send HH housekeeping request messages every 10 seconds for an additional 50 seconds. If HERCI does not respond to one of those HH request messages with a housekeeping data reply message, HERCI shall be considered failed and the IHU shall perform the following Power Cycle Sequence:

3.1.3.1 The IHU shall signal Power Off to HERCI.

3.1.3.2 The IHU shall wait 30 seconds.

3.1.3.3 The IHU shall signal Power On to HERCI.

3.1.3.4 The IHU shall perform this Power Cycle (3.1.3.1 to 3.1.3.3) up to three total cycles.

3.1.3.5 This state shall be reset when the IHU is reset (power cycle) and HERCI will be powered up again using the cycle in 3.1.3.1 to 3.1.3.4.

3.1.4 If at any time after 90 seconds following Power On HERCI exhibits any of the following behaviors, the IHU shall perform a Power Cycle Sequence.

3.1.4.1 Failure to respond to three consecutive Data Block commands.

3.1.4.2 DETECTOR Not Ready (NN) responses to three consecutive Data Block commands.

3.1.4.3 DETECTOR Failed (FF) responses to three consecutive Data Block commands.

3.1.5 When entering Safe Mode, the IHU shall perform the following actions:

3.1.5.1 The IHU shall send a Safe Mode Notification command to HERCI.

3.1.5.2 The IHU shall wait 5 seconds.

3.1.5.3 The IHU will signal Power Off to HERCI.

3.2 Experiment Operation Sequence

3.2.1 The IHU shall request housekeeping telemetry by sending a Transmit HOUSEKEEPING Data Block command message at least once every 30 seconds while in transponder mode, but no more than once every 10 seconds.

3.2.2 The IHU shall send updated time in the CLOCK fields of each command message.

4 Message Content Requirements

4.1 Message Header Block

4.1.1 The message header block shall be constructed as shown in table 2.

4.1.2 The message header block shall precede each command message.

Table 2

Field	Size (Bytes)	Type	Min Value	Max Value	Description
Message Version	2	Unsigned	0x01	0xFFFF	Message ICD version
Software Build	2	Unsigned	0x01	0xFFFF	Software Build version

4.1.2.1 The Message Version shall be an integer representing the IHU to HERCI ICD document version number from which the message format is derived, having the decimal point removed (e.g. version 1.03 would be 103 decimal or 0x67.

4.1.2.2 The Software Build shall be an integer representing the software build version number of the system originating the message, having any decimal points removed (e.g. version 1.03 would be 103 decimal or 0x67).

4.2 Reply Message Block

4.2.1 The Reply Message block shall be constructed as shown in Table 3.

4.2.2 The Reply Message Block shall precede each command message.

Table 3

Field	Size (Bytes)	Type	Min Value	Max Value	Description
MESSAGE VERSION	2	Unsigned	0x01	0xFFFF	Message ICD version
SOFTWARE BUILD	2	Unsigned	0x01	0xFFFF	Software Build version
REPLY CODE	2	Alpha	YY NN FF UU	YY NN FF UU	REPLY CODE
PAYLOAD SIZE	2	Unsigned	0x00	0xFFFF	Number of bytes following this reply message block

4.2.2.1 The Message Version shall be an integer representing the IHU to HERCI ICD document version number from which the message format is derived, having the decimal point removed (e.g. version 1.03 would be 103 decimal or 0x67).

4.2.2.2 The Software Build shall be an integer representing the software build version number of the system originating the message, having any decimal points removed (e.g. version 1.03 would be 103 decimal or 0x67).

4.2.2.3 The Reply Message block shall contain one REPLY CODE in the REPLY CODE field as shown in table 4.

Table 4

Reply Code	Description
NN	DETECTOR Not Ready or No Detector Data Available
FF	DETECTOR Failed
YY	EE, ZZ Command message acknowledged
UU	Message from IHU unexpected or otherwise malformed

4.3 Command Message Block

4.3.1 The command message block shall be constructed as shown in Table 5.

Table 5

Field	Size (Bytes)	Type	Min Value	Max Value	Description
COMMAND	2	Alpha	HH PP RR ZZ	HH PP RR ZZ	Command
RESET COUNT	2	Unsigned	0x00	0xFFFF	Total number of times IHU has reset since initial on-orbit startup
UPTIME WHOLE SECONDS	4	Unsigned	0x0000	0xFFFFFFFF	Uptime in seconds since the last IHU reset
UPTIME FRACTIONAL SECONDS	2	Unsigned	0x0000	0xFFFF	This is the fractional seconds since the last IHU reset. (**Note:** this value may be slightly delayed based on its position in the task queue)
CHECKSUM	2	Unsigned	0x0000	0xFFFF	16 bit rollover accumulator

4.3.2 The command message block shall contain one command in the COMMAND field as shown in Table 6.

Table 6

Command	Description
HH	Transmit HOUSEKEEPING Data Block
PP	Transmit PACKET (of DETECTOR) Data Block
RR	RESEND previous PACKET Data Block
ZZ	Safe Mode Notification

4.4 Message Data Block

4.4.1 The message data block for HOUSEKEEPING and PACKET Data Blocks shall be constructed as shown in Table 7.

Table 7

Field	**Size (Bytes)**	**Type**	**Min Value**	**Max Value**	**Description**
TYPE	2	Alpha	DD HH	DD HH	Data or Housekeeping Data Block
PAYLOAD	Variable - max of 58 bytes for Housekeeping, 868 bytes for Detector Data	Unsigned	-	-	Payload
CHKSUM	2	Unsigned	0x00	0xFFFF	16 bit rollover accumulator sum of bytes in HEADER and PAYLOAD

5 Message Integrity

5.1 Invalid Messages

5.1.1 If the DATA block CHKSUM fails in a response to a Transmit HOUSEKEEPING Data Block command, the message shall be considered invalid.

5.1.2 If the Message Version does not match the message version in use for the construction of messages on the receiving system, the message shall be considered invalid.

5.1.3 The IHU shall consider a UU response an “invalid” message.

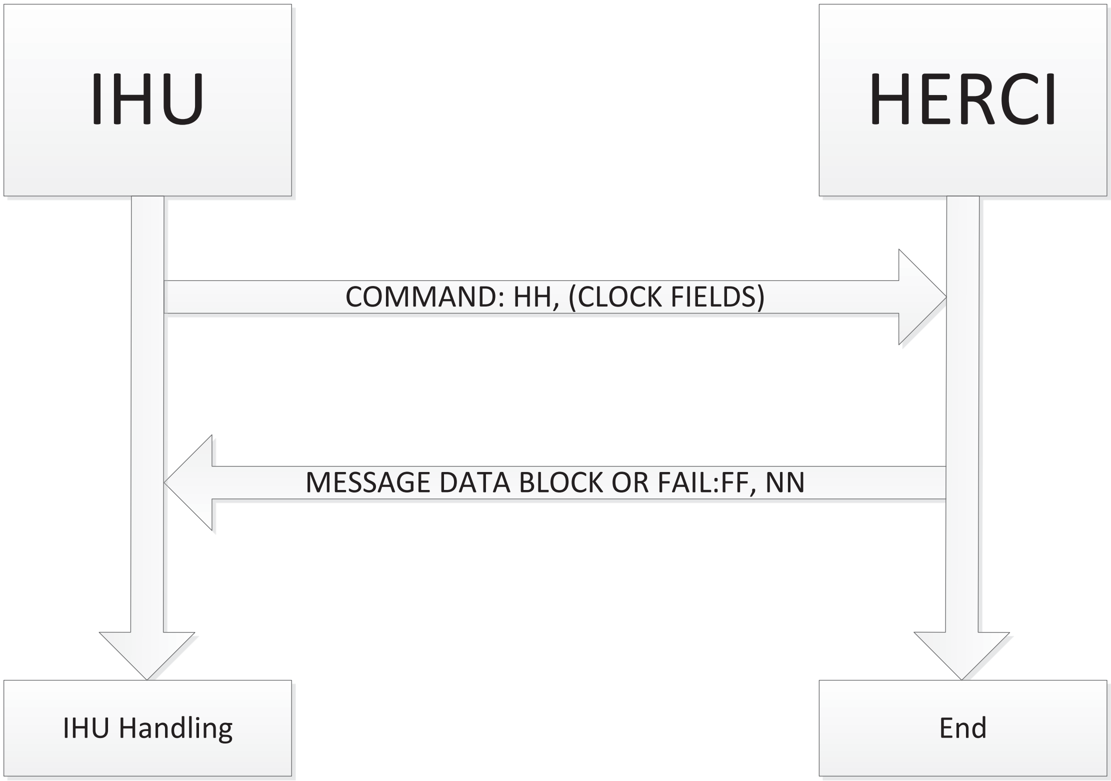
5.1.4 In the event of 3 consecutive invalid messages, the IHU shall power cycle HERCI as described in 3.1.3.1 to 3.1.3.4

5.1.5 If the DATA block CHKSUM fails in a response to a Transmit Packet Data Block command, the IHU shall send a Resend Packet command. After 3 consecutive failed responses to a PP or RR command, the IHU shall power cycle HERCI as described in 3.1.3.1 – 3.1.3.4

6 Message Flow Diagrams

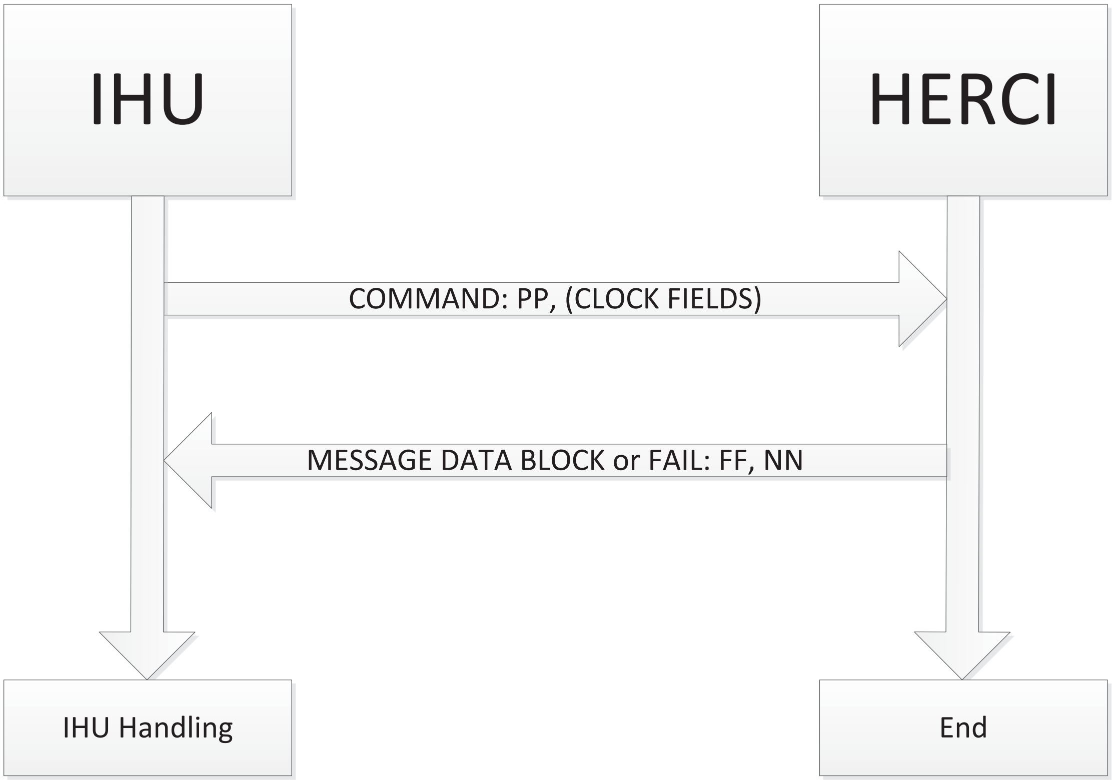
6.1 HH COMMAND

HERCI responds to the HH command by returning a housekeeping record embedded in the response. HH command may occur at any time.



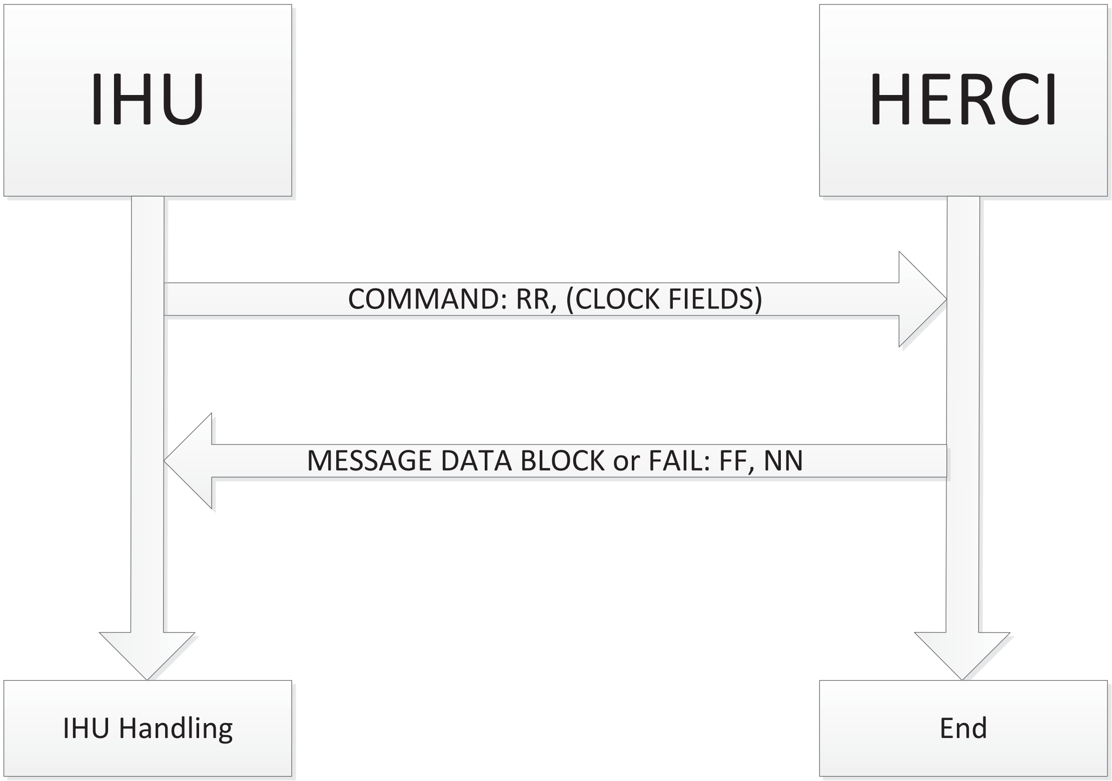
6.2 PP COMMAND

HERCI responds to the PP command by returning a telemetry transport frame embedded in the response.



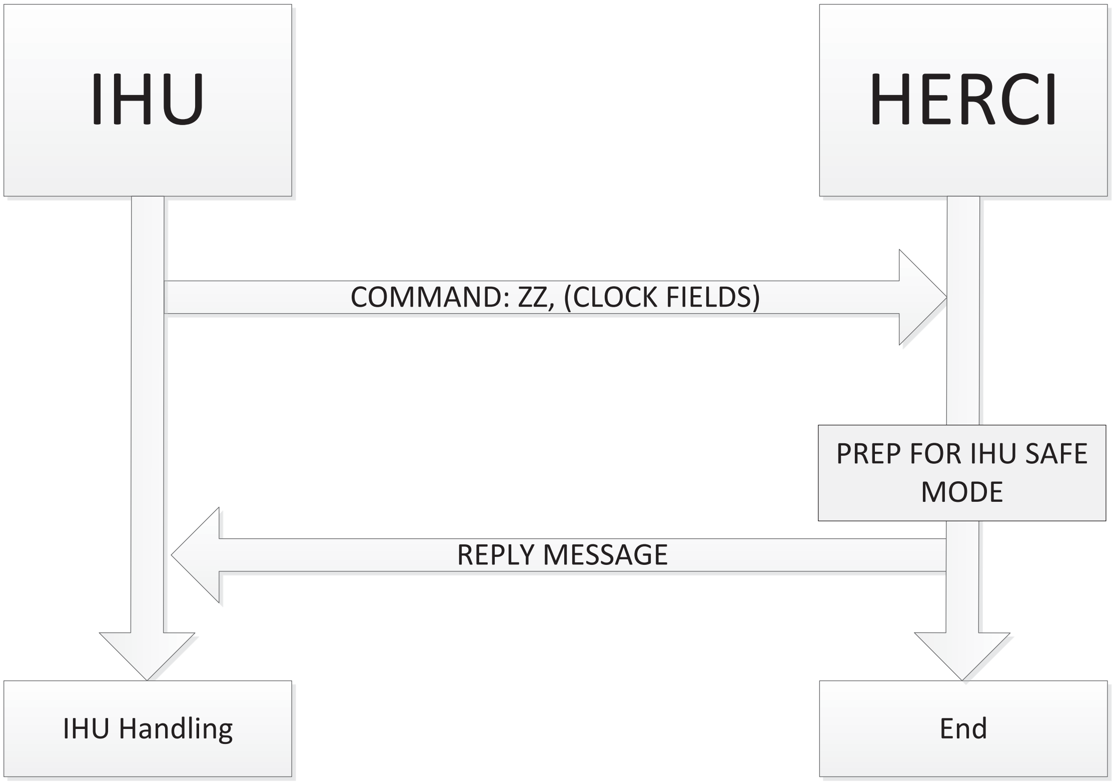
6.3 RR COMMAND

HERCI responds to the RR command by returning the last telemetry transport frame sent to IHU embeddedin the response. The RR command will only occur immediately following a PP command.



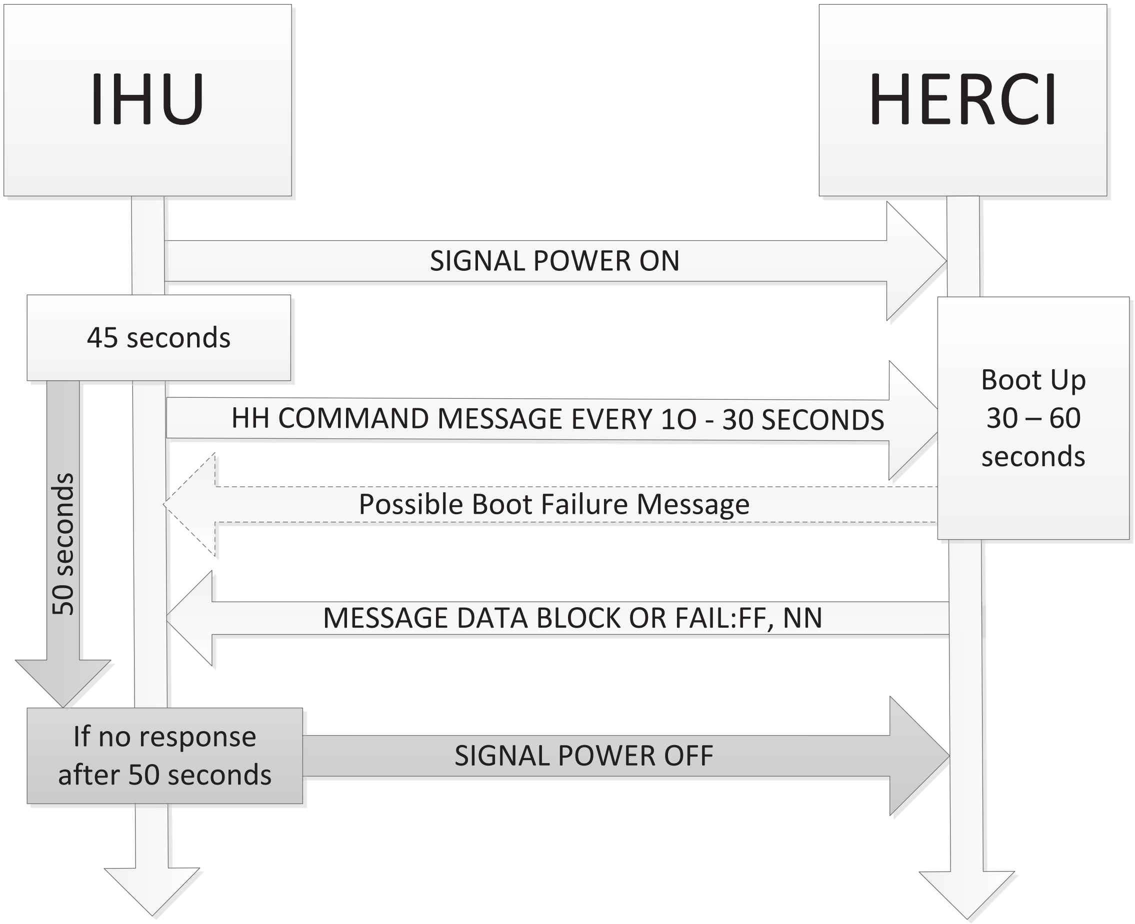
6.4 ZZ COMMAND

HERCI responds to the ZZ command by stopping data collection and closing its data file system.The ZZ command may occur at any time.



7 Power On Diagram

7.1 Power On Sequence



Date: March 2, 2015
Version: Version 2.11

AMSAT *Fox-1*

IHU to MPPT PSU Interface Control Document

1 Introduction

This document specifies the message interface between the Internal Housekeeping Unit (IHU) and the MPPT Power Supply (PSU) System, as required per the AMSAT *Fox-1* System Requirements Specification document.

1.1 Document History

DATE	VERSION	SUMMARY
February 21, 2012	1.0	Initial version
February 21, 2012	1.01	Clarify I²C address
March 7, 2012	1.02	2.3.1 updated Vdd to 3.0V
August 7, 2012	1.03	Remove BATT1 data fields and adjust message accordingly
November 7, 2012	1.04	Added PSU CPU Temperature
December 27, 2012	1.10	Change from Bytes to Bits in Message Header Block, Message Data Block, Message Data (to allow for 12 bit ADC values)
January 2, 2013	1.11	Field sizes back to bytes account I²C specifications
February 7, 2013	1.12	Correct typo in 3.3.1.1
August 22, 2013	1.13	Remove TOTAL I from Data block
August 22, 2013	1.14	Update I²C speed to 10 kHz
October 4, 2013	2.00	Rework to eliminate STM32L and replace with ADS7828s
November 18, 2013	2.01	Change telemetry sample rate in 2.2.1 to 4 seconds
June 10, 2014	2.1	Update Table 1 and Table 2 to reflect actual construction, add PSU Output Current to Table 1, swap addresses for Device 1 and Device 2 to account for construction error
March 2, 2015	2.11	Updated ADC Channel tables

1.2 Document Scope

The purpose of this document is to specify the message format and the I²C bus hardware operation for the communications between the IHU and the MPPT PSU as described in the AMSAT *Fox-1* System Requirements Specification.

1.3 References

1. AMSAT *Fox-1*, System Requirements Specification
2. AMSAT *Fox-1*, System Design Specification
3. AMSAT *Fox-1*, IHU Software Architecture Specification

2 General Messaging Requirements

2.1 Link Protocol Requirements

2.1.1 The IHU shall be the I²C Master.

2.1.2 The MPPT PSU shall be the I²C Slave.

2.1.2.1 The IHU shall request the MPPT PSU to send the data for a specific Device and channel.

2.1.2.2 The MPPT PSU shall send that specific Device and channel data.

2.1.3 The IHU shall test for the presence both MPPT PSU system Devices.

2.1.4 The IHU shall only poll the MPPT PSU system Device(s) present, for data.

2.2 General Message Requirements

2.2.1 The IHU shall sample data at a rate sufficient to provide downlink telemetry data every 4 seconds.

2.2.2 For both Devices the ADS 7820 A/D converter shall always be commanded on (PD-0 bit = 1).

2.2.3 For both Devices the ADS 7820 Internal Reference shall always be commanded on (PD-1 bit = 1).

2.2.4 TFor both Devices the ADS 7820 shall always be commanded for single-ended inputs.

2.3 I²C Bus Hardware Interface Requirements

2.3.1 The I²C Vdd shall be 3.0V.

2.3.2 The bus speed shall be Standard (10 kHz).

2.3.3 The MPPT PSU system Device 1 I²C 7 bit address shall be 0x4A.

2.3.4 The MPPT PSU system Device 2 I²C 7 bit address shall be 0x49.

3 Message Content Requirements

3.1 Measured Values

3.1.1 The measured data fields for Device 1 and their associated ADS 7828 channels shall be as shown in Table 1.

Table 1

Field	Channel	Type	Min Value	Max Value	Description
+X PANEL V	0	Unsigned	0x00	0xFFF	+X PANEL V
-X PANEL V	1	Unsigned	0x00	0xFFF	-X PANEL V
+Y PANEL V	2	Unsigned	0x00	0xFFF	+Y PANEL V
-Y PANEL V	3	Unsigned	0x00	0xFFF	-Y PANEL V
+Z PANEL V	4	Unsigned	0x00	0xFFF	+Z PANEL V
-Z PANEL V	5	Unsigned	0x00	0xFFF	-Z PANEL V
MPPT VOUT	6	Unsigned	0x00	0xFFF	MPPT VBATT V
Not used	7	-	-	-	-

3.1.2 The measured data fields for Device 2 and their associated ADS 7828 channels shall be as shown in Table 2.

Table 2

Field	Channel	Type	Min Value	Max Value	Description
MPPT PCB Temperature	0	Unsigned	0x00	0xFFF	Temperature of MPPT card
-Y PANEL T	1	Unsigned	0x00	0xFFF	-Y PANEL T
+Z PANEL T	2	Unsigned	0x00	0xFFF	+Z PANEL T
+X PANEL T	3	Unsigned	0x00	0xFFF	+X PANEL T
MPPT Current	4	Unsigned	0x00	0xFFF	MPPT Output Current
+Y PANEL T	5	Unsigned	0x00	0xFFF	+Y PANEL T
-X PANEL T	6	Unsigned	0x00	0xFFF	-X PANEL T
-Z PANEL T	7	Unsigned	0x00	0xFFF	-Z PANEL T

3.1.3 Measurements shall be made in relation to the 2.5 VDC internal voltage reference for both ADS 7828 Devices.

3.1.4 For each Device the IHU shall poll each channel in channel number order.

Date: June 9, 2015
Version: Version 1.10

AMSAT *Fox-1C/D*

IHU to "L-Band DOWNSHIFTER" Interface Control Document

1 Introduction

This document specifies the message interface between the Internal Housekeeping Unit (IHU) and the payload in Experiment Position 4 of the satellite, known as the L-Band DOWNSHIFTER and abbreviated herein as EXP4.

1.1 Document History

DATE	VERSION	SUMMARY
June 7, 2015	1.00	Initial version
June 9, 2015	1.10	Added 2.1.2

1.2 Document Scope

This document will specify the control of EXP4, and the IHU operation of EXP4.

1.3 References

1. AMSAT *Fox-1*, System Requirements Specification
2. AMSAT *Fox-1*, System Design Specification
3. AMSAT *Fox-1*, IHU Software Architecture Specification

2 EXP4 Operation

2.1 EXP4 Power Control

2.1.1 The IHU shall exert control over the power state of the EXP4 by the Experiment Enable 3 pin on the satellite bus as shown in Table 1.

Table 1

Pin State	Voltage	Description
High	≥ 2.4	Power On Experiment
Low, or high-impedance	< 2.4	Power Off Experiment

2.1.2 EXP4 may draw current from the system bus while in the OFF state in order to power the antenna path switching circuits required for its operation.

2.2 EXP4 Power On Sequence

2.2.1 Upon receiving an L-BAND MODE command the IHU shall set and hold the Experiment Enable 3 pin HIGH.

2.3 EXP4 Operation

2.3.1 Upon receiving an L-BAND MODE command the IHU shall perform the following actions.

2.3.1.1 Operating mode shall be set to TRANSPONDER MODE.

2.3.1.2 A software timer shall be started to count down 86400 seconds.

2.3.1.2.1 At the expiration of the timer, the IHU shall perform the EXP4 Power Off Sequence.

2.3.2 Upon receiving an L-BAND MODE command while the software timer is running, the software timer shall begin counting down from 86400 seconds.

2.3.3 Upon receiving any command other than an L-BAND MODE command the IHU shall perform the EXP4 Power Off Sequence.

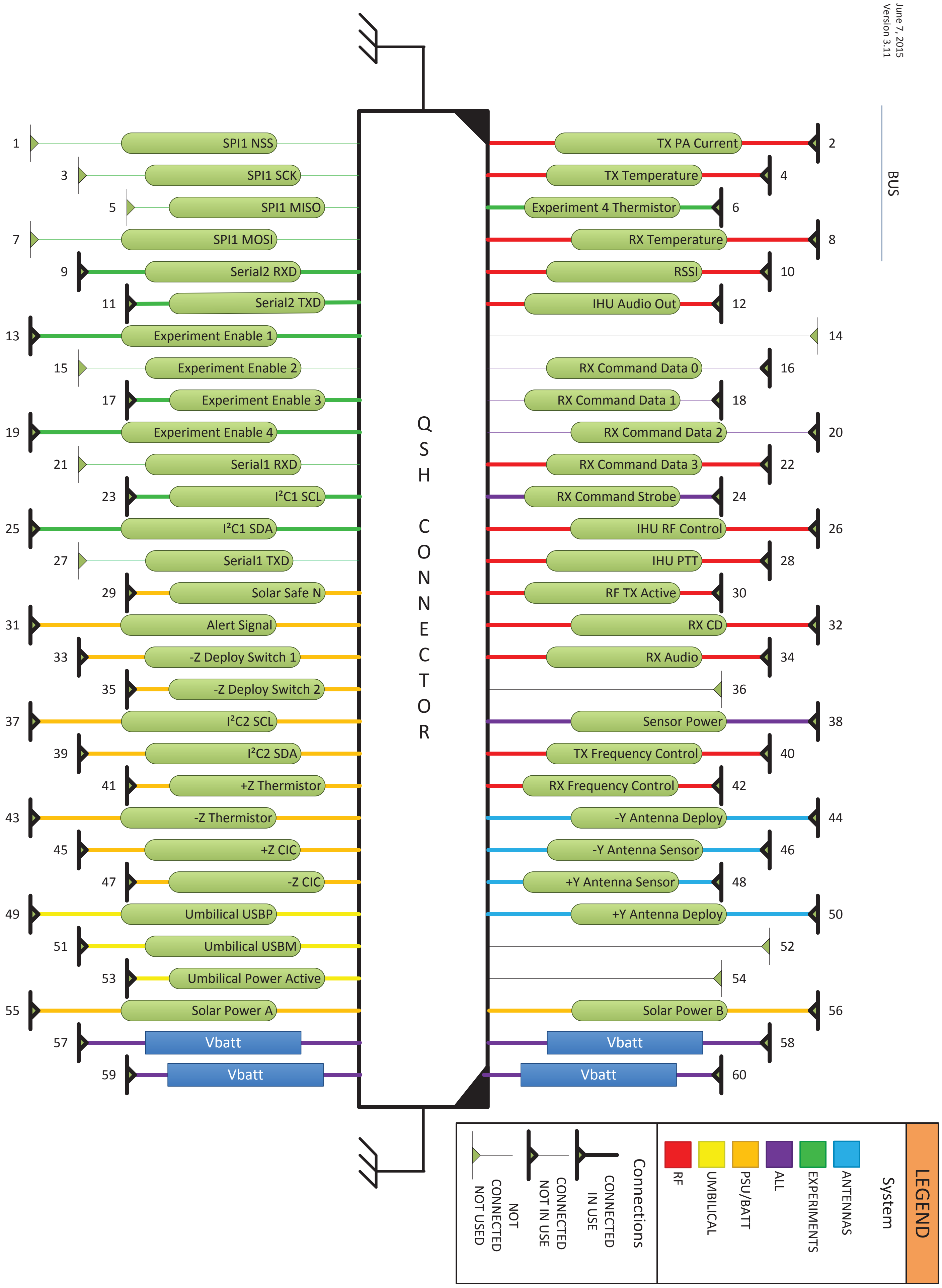
2.3.4 The default power state for EXP4 on IHU restart shall be OFF.

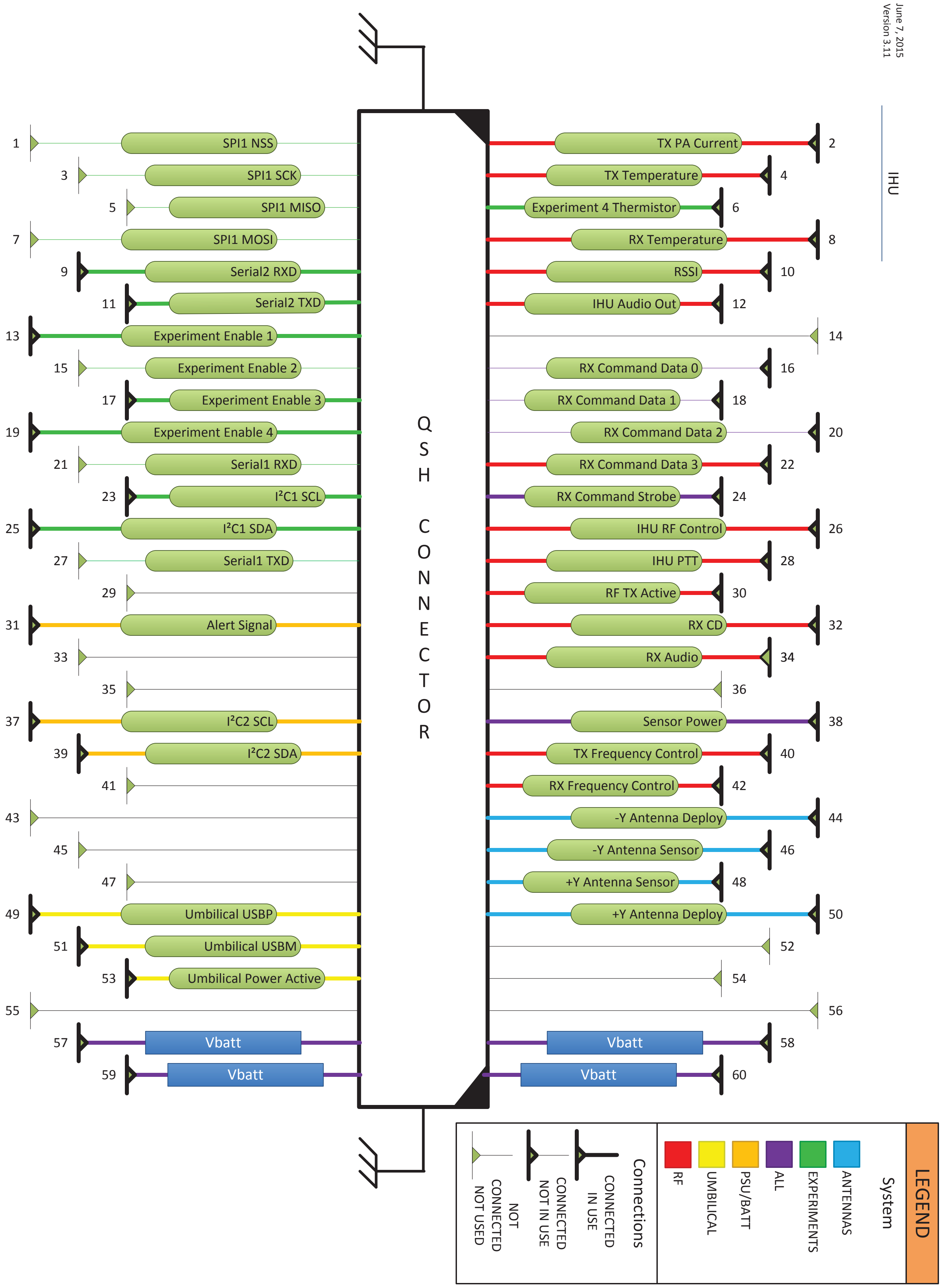
2.4 EXP4 Power Off Sequence

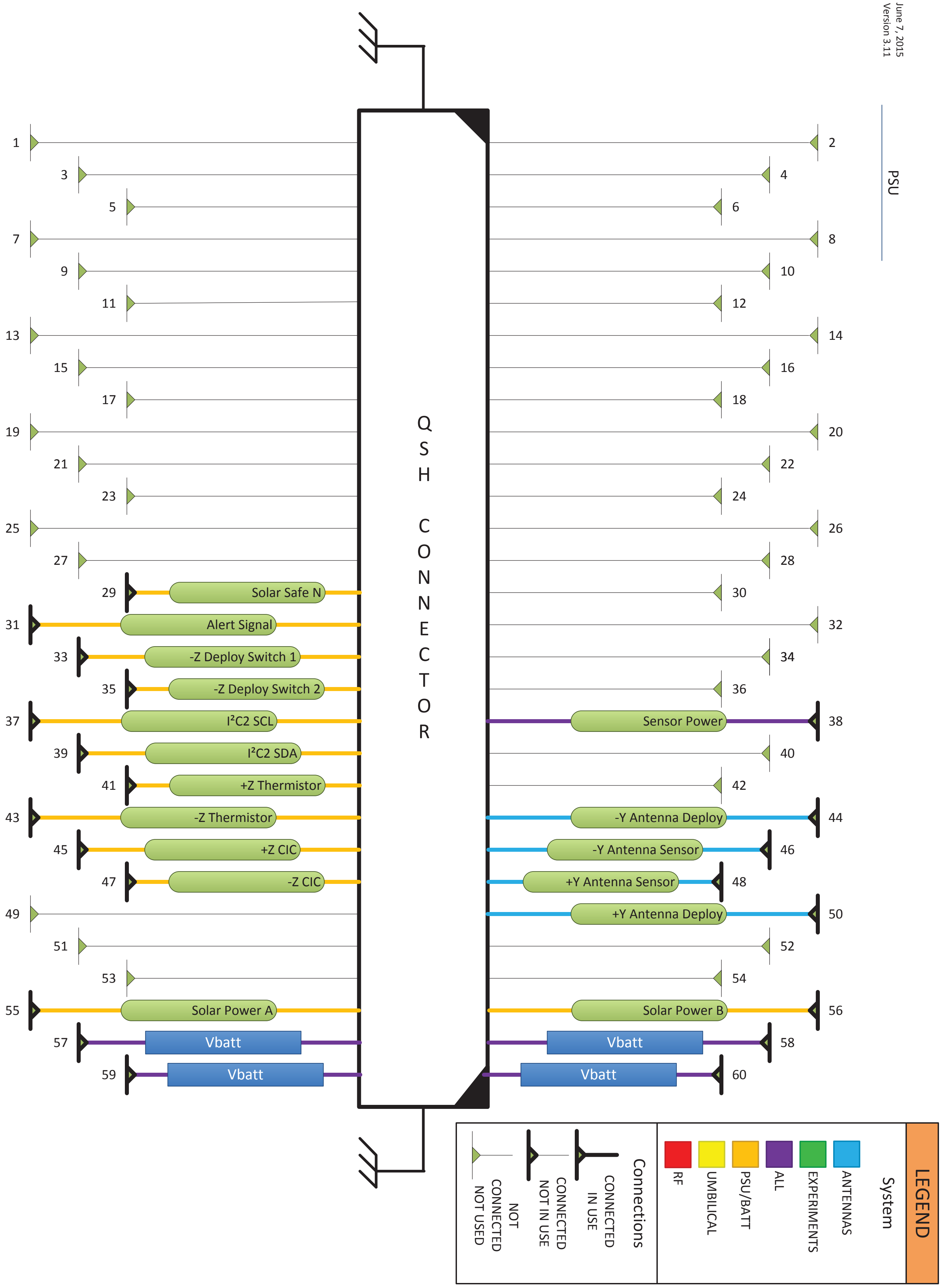
2.4.1 The IHU shall set the Experiment Enable 3 pin LOW.

2.4.1.1 The absence of a HIGH state on the Experiment Enable 3 pin shall be construed as a LOW state whether the pin is actually LOW, or in a high-impedance state.

2.4.2 The software timer shall be stopped.

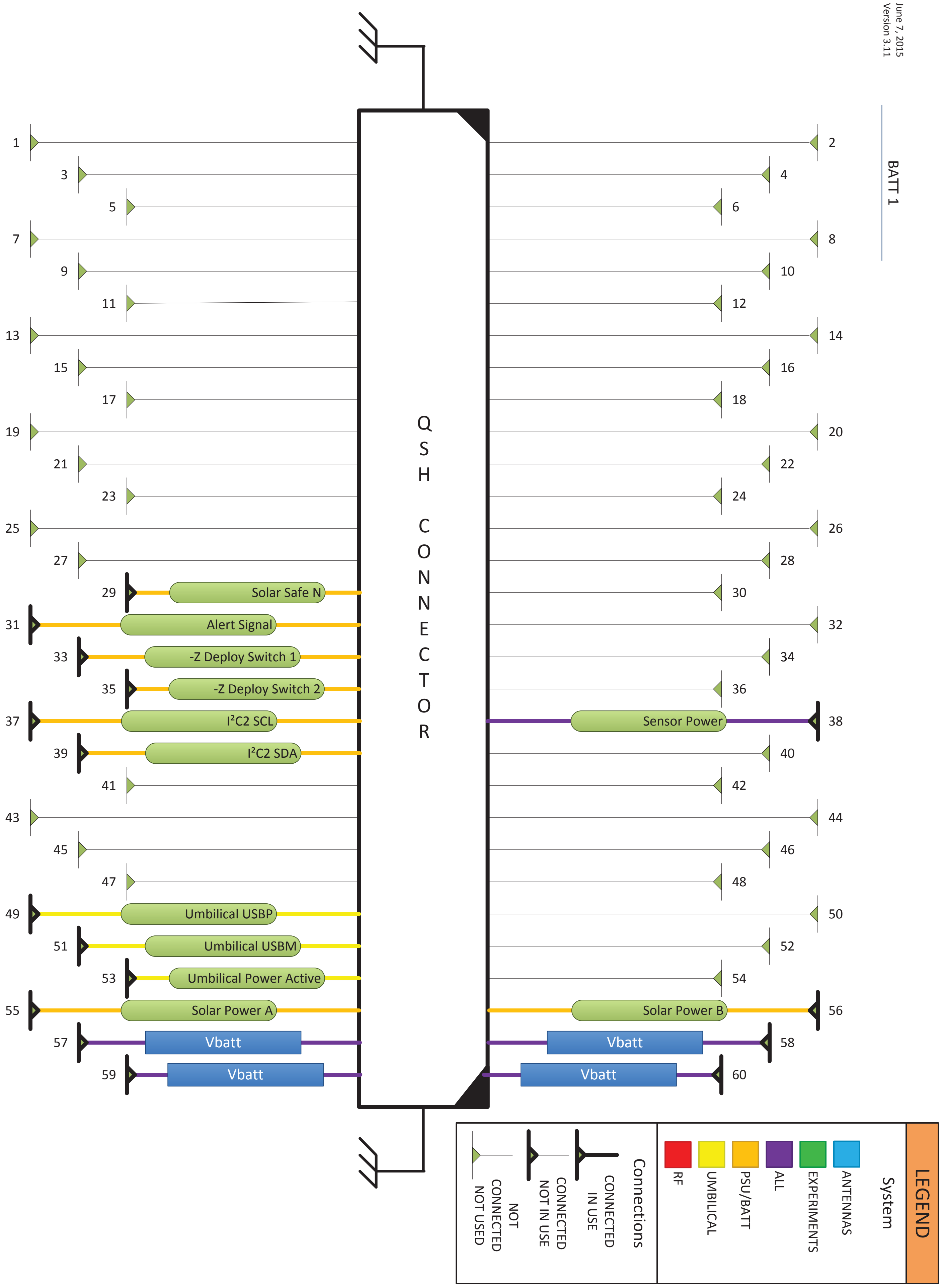
June 7, 2015
Version 3.11
BUS
Q S H C O N N E C T O R
1 SPI1 NSS
2 TX PA Current
3 SPI1 SCK
4 TX Temperature
5 SPI1 MISO
6 Experiment 4 Thermistor
7 SPI1 MOSI
8 RX Temperature
9 Serial2 RXD
10 RSSI
11 Serial2 TXD
12 IHU Audio Out
13 Experiment Enable 1
14
15 Experiment Enable 2
16 RX Command Data 0
17 Experiment Enable 3
18 RX Command Data 1
19 Experiment Enable 4
20 RX Command Data 2
21 Serial1 RXD
22 RX Command Data 3
23 I^2C1 SCL
24 RX Command Strobe
25 I^2C1 SDA
26 IHU RF Control
27 Serial1 TXD
28 IHU PTT
29 Solar Safe N
30 RF TX Active
31 Alert Signal
32 RX CD
33 -Z Deploy Switch 1
34 RX Audio
35 -Z Deploy Switch 2
36
37 I^2C2 SCL
38 Sensor Power
39 I^2C2 SDA
40 TX Frequency Control
41 +Z Thermistor
42 RX Frequency Control
43 -Z Thermistor
44 -Y Antenna Deploy
45 +Z CIC
46 -Y Antenna Sensor
47 -Z CIC
48 +Y Antenna Sensor
49 Umbilical USBP
50 +Y Antenna Deploy
51 Umbilical USBM
52
53 Umbilical Power Active
54
55 Solar Power A
56 Solar Power B
57 Vbatt
58 Vbatt
59 Vbatt
60 Vbatt
LEGEND
System
ANTENNAS
EXPERIMENTS
ALL
PSU/BATT
UMBILICAL
RF
Connections
CONNECTED IN USE
CONNECTED NOT IN USE
NOT CONNECTED NOT USED


June 7, 2015
Version 3.11
IHU
QSH CONNECTOR
1 SPI1 NSS
2 TX PA Current
3 SPI1 SCK
4 TX Temperature
5 SPI1 MISO
6 Experiment 4 Thermistor
7 SPI1 MOSI
8 RX Temperature
9 Serial2 RXD
10 RSSI
11 Serial2 TXD
12 IHU Audio Out
13 Experiment Enable 1
14
15 Experiment Enable 2
16 RX Command Data 0
17 Experiment Enable 3
18 RX Command Data 1
19 Experiment Enable 4
20 RX Command Data 2
21 Serial1 RXD
22 RX Command Data 3
23 I²C1 SCL
24 RX Command Strobe
25 I²C1 SDA
26 IHU RF Control
27 Serial1 TXD
28 IHU PTT
29
30 RF TX Active
31 Alert Signal
32 RX CD
33
34 RX Audio
35
36
37 I²C2 SCL
38 Sensor Power
39 I²C2 SDA
40 TX Frequency Control
41
42 RX Frequency Control
43
44 -Y Antenna Deploy
45
46 -Y Antenna Sensor
47
48 +Y Antenna Sensor
49 Umbilical USBP
50 +Y Antenna Deploy
51 Umbilical USBM
52
53 Umbilical Power Active
54
55
56
57 Vbatt
58 Vbatt
59 Vbatt
60 Vbatt
LEGEND
System
ANTENNAS
EXPERIMENTS
ALL
PSU/BATT
UMBILICAL
RF
Connections
CONNECTED IN USE
CONNECTED NOT IN USE
NOT CONNECTED NOT USED



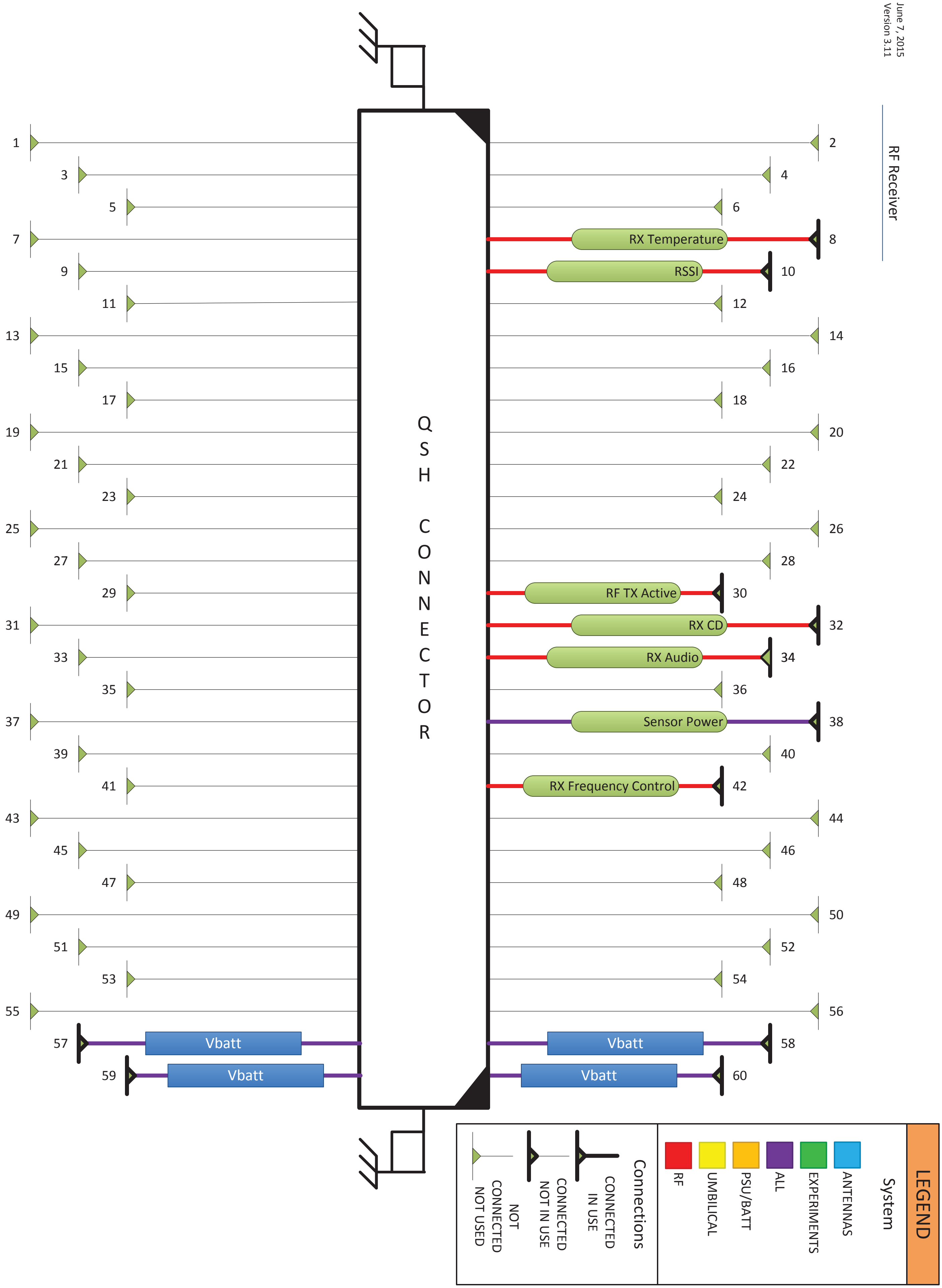
June 7, 2015
Version 3.11

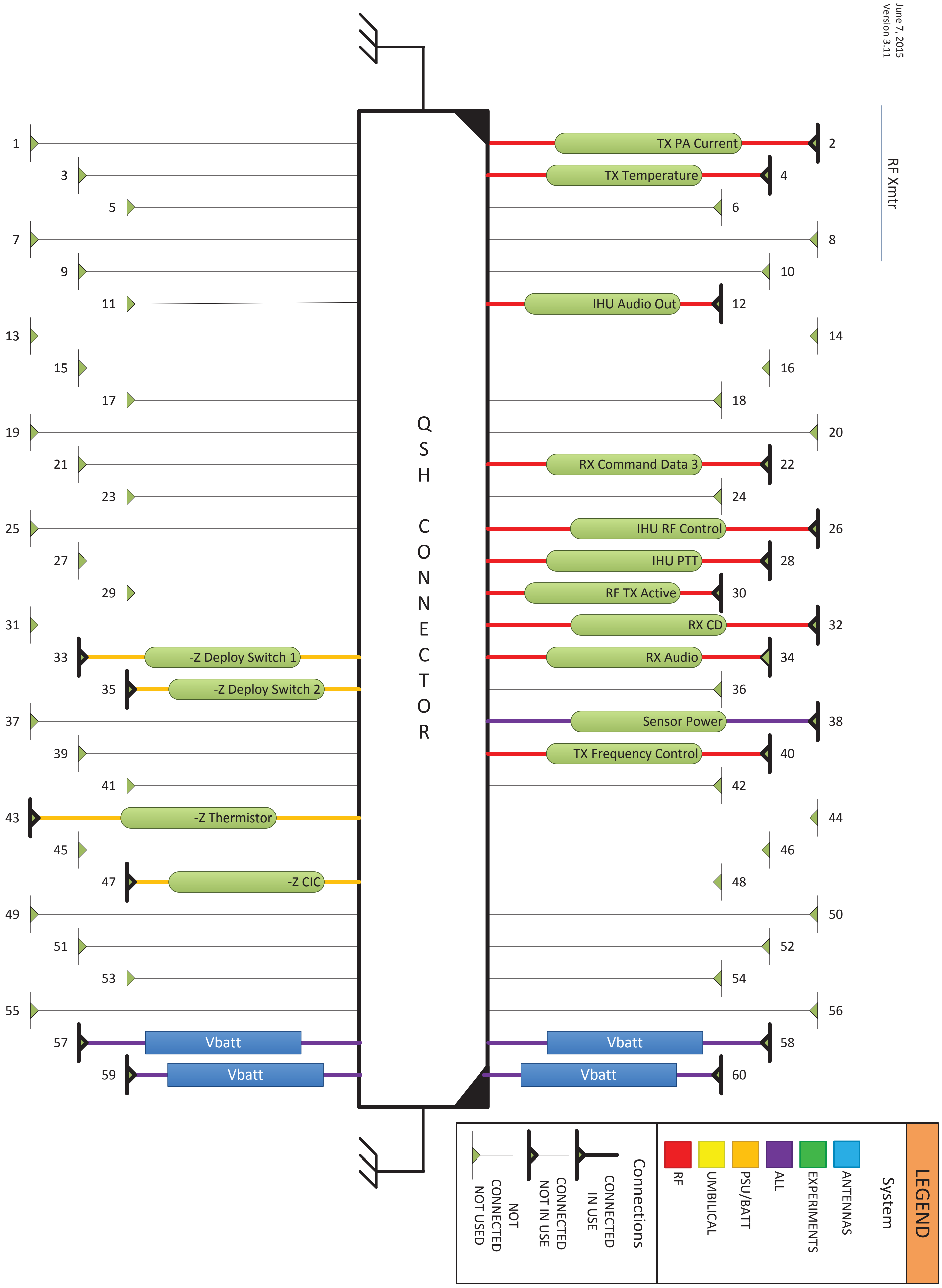
June 7, 2015
Version 3.11



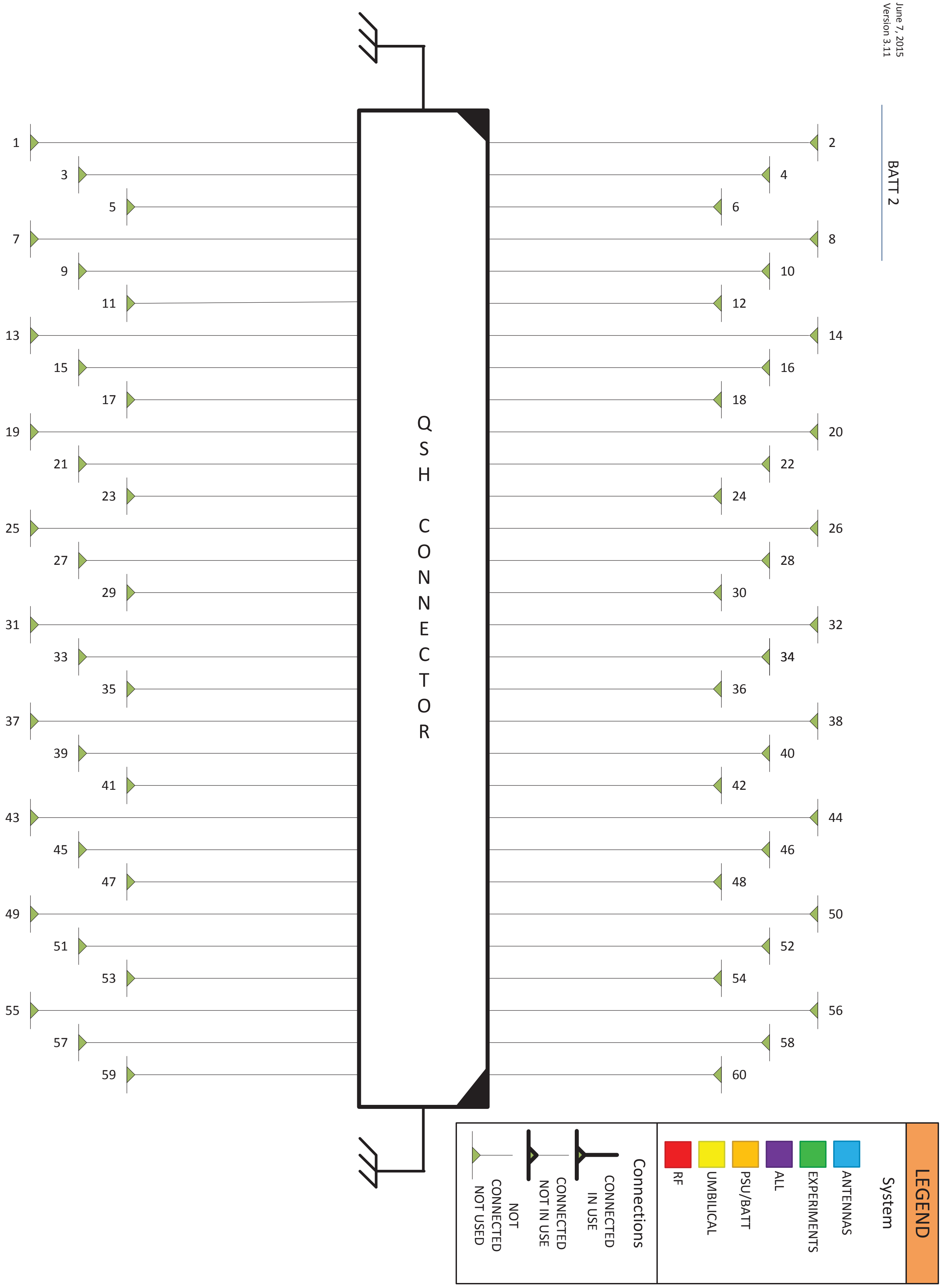
RF Receiver

June 7, 2015
Version 3.11



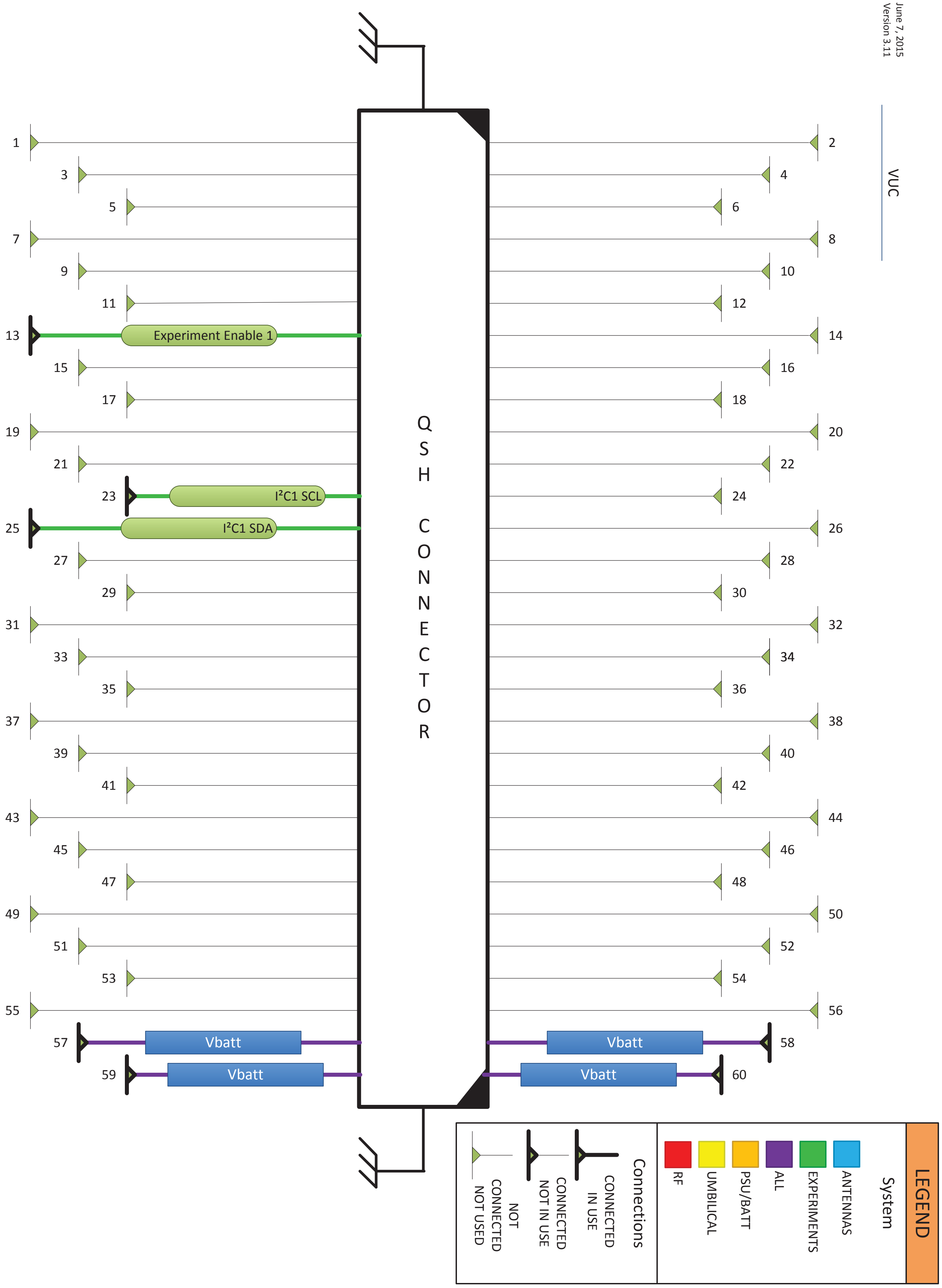

June 7, 2015
Version 3.11
RF Xmtr
QSH CONNECTOR
TX PA Current 2
TX Temperature 4
IHU Audio Out 12
RX Command Data 3 22
IHU RF Control 26
IHU PTT 28
RF TX Active 30
RX CD 32
RX Audio 34
Sensor Power 38
TX Frequency Control 40
33 -Z Deploy Switch 1
35 -Z Deploy Switch 2
43 -Z Thermistor
47 -Z CIC
57 Vbatt
59 Vbatt
Vbatt 58
Vbatt 60
1
3
5
6
7
8
9
10
11
13
14
15
16
17
18
19
20
21
23
24
25
27
29
31
36
37
39
41
42
44
45
46
48
49
50
51
52
53
54
55
56
LEGEND
System
ANTENNAS
EXPERIMENTS
ALL
PSU/BATT
UMBILICAL
RF
Connections
CONNECTED IN USE
CONNECTED NOT IN USE
NOT CONNECTED NOT USED

June 7, 2015
Version 3.11



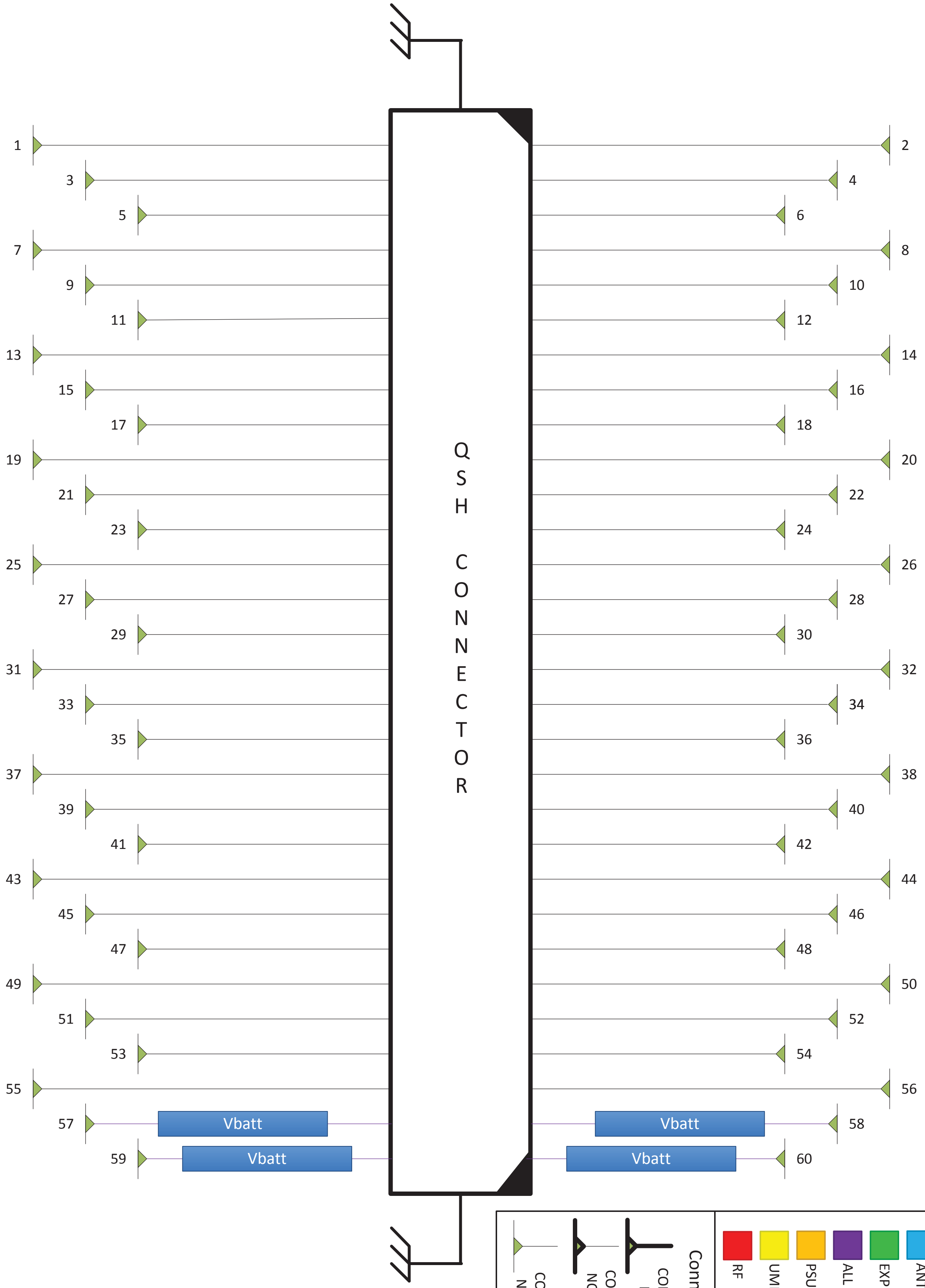
June 7, 2015
Version 3.11

VUC



EXP 2

June 7, 2015
Version 3.11



LEGEND

System

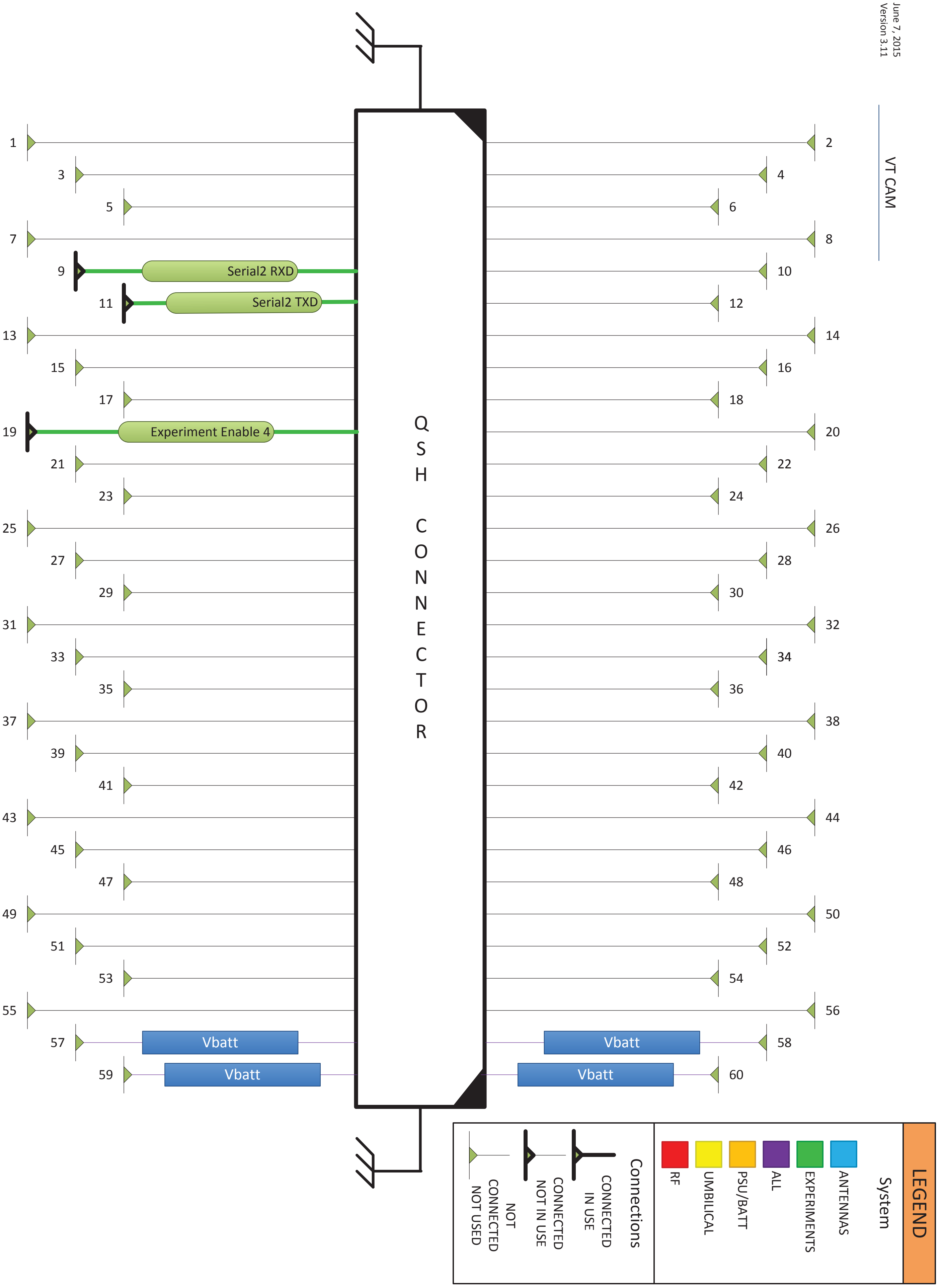
- 🟦 ANTENNAS
- 🟩 EXPERIMENTS
- 🟪 ALL
- 🟧 PSU/BATT
- 🟨 UMBILICAL
- 🟥 RF

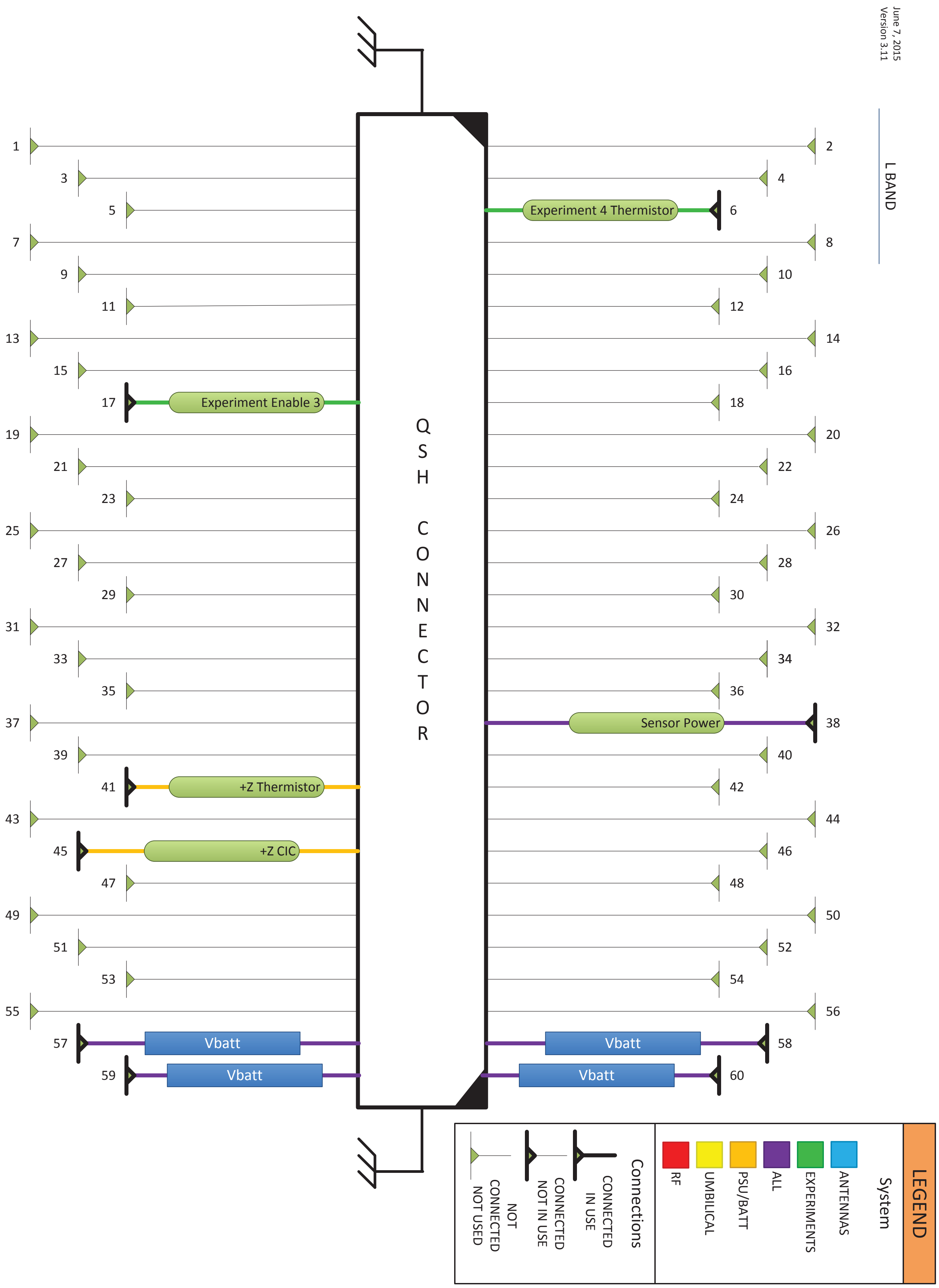
Connections

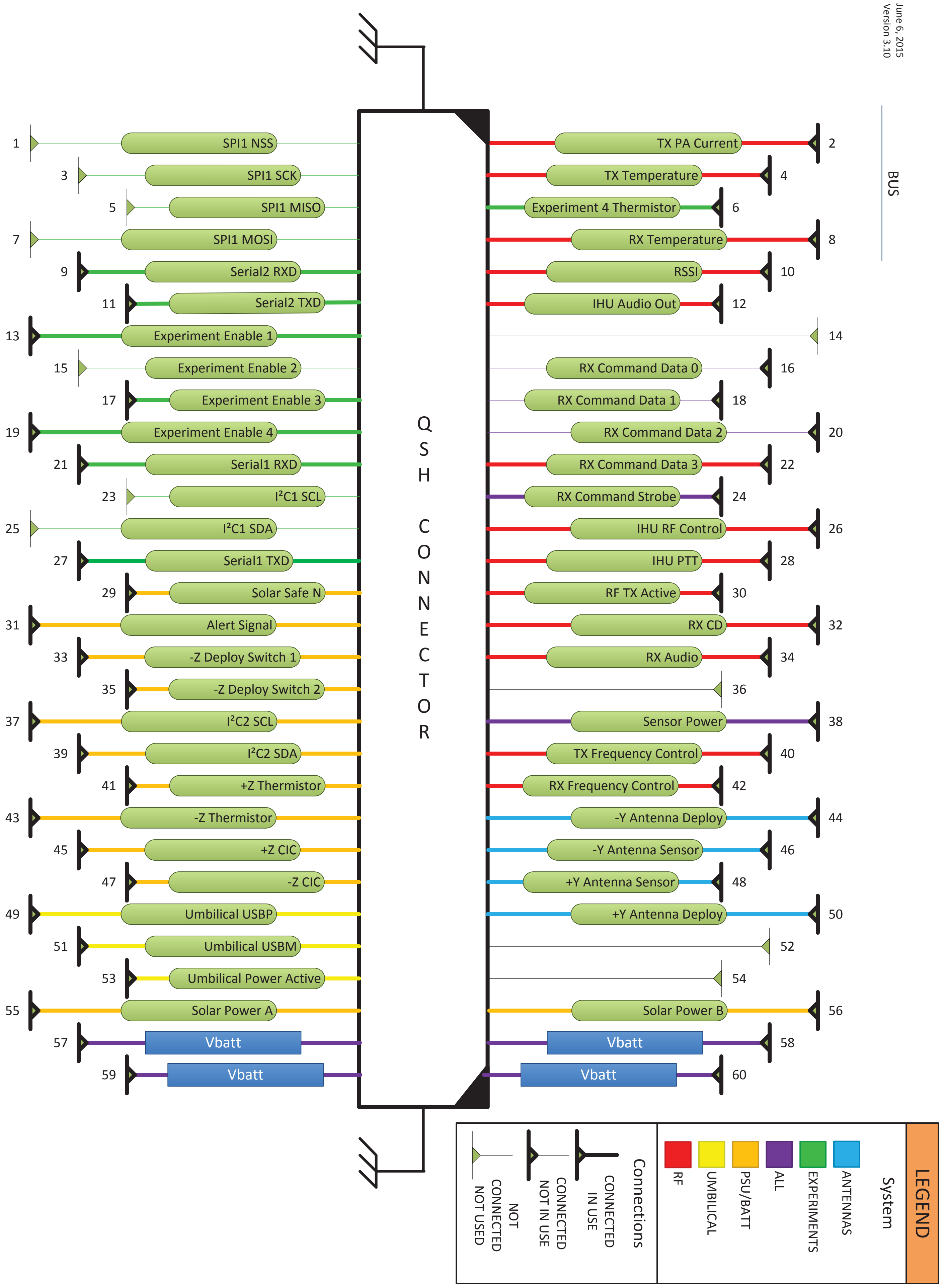
- CONNECTED IN USE
- CONNECTED NOT IN USE
- NOT CONNECTED NOT USED

June 7, 2015
Version 3.11

VT CAM

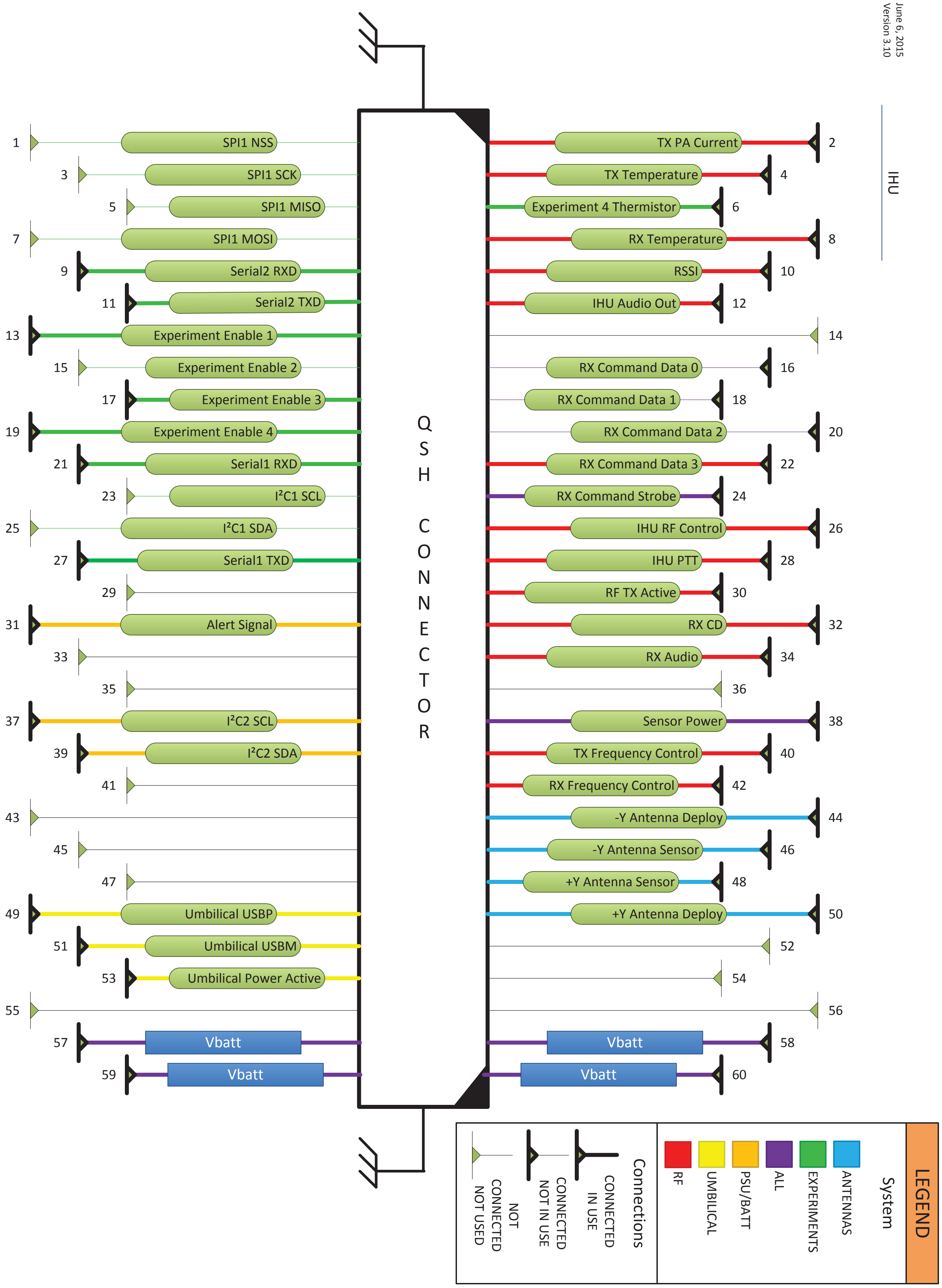


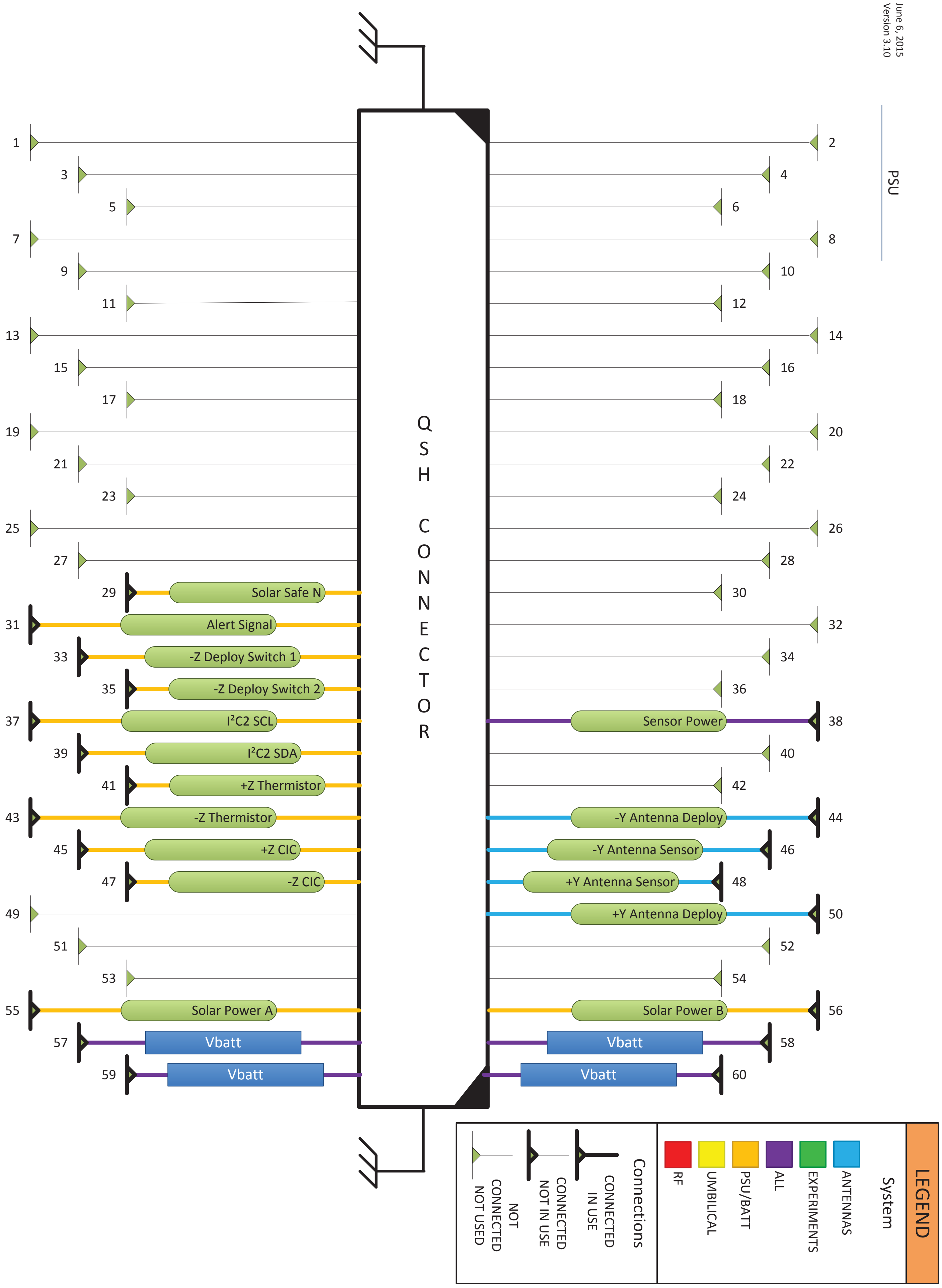

June 7, 2015
Version 3.11
L BAND
Q S H C O N N E C T O R
1
2
3
4
5
6
Experiment 4 Thermistor
7
8
9
10
11
12
13
14
15
16
17
Experiment Enable 3
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
Sensor Power
39
40
41
+Z Thermistor
42
43
44
45
+Z CIC
46
47
48
49
50
51
52
53
54
55
56
57
Vbatt
58
Vbatt
59
Vbatt
60
Vbatt
LEGEND
System
ANTENNAS
EXPERIMENTS
ALL
PSU/BATT
UMBILICAL
RF
Connections
CONNECTED IN USE
CONNECTED NOT IN USE
NOT CONNECTED NOT USED

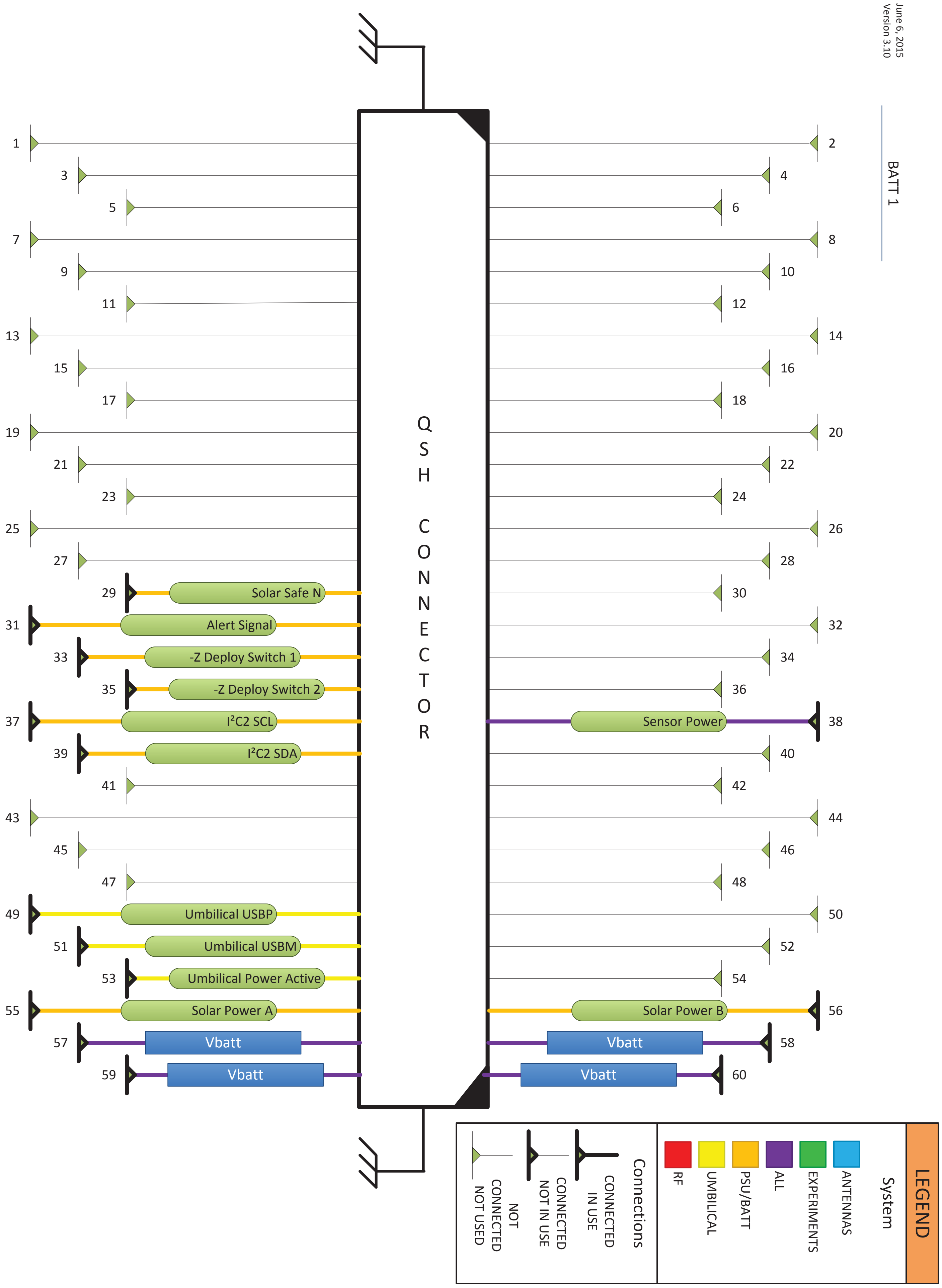

June 6, 2015
Version 3.10
BUS
Q S H CONNECTOR
1 SPI1 NSS
3 SPI1 SCK
5 SPI1 MISO
7 SPI1 MOSI
9 Serial2 RXD
11 Serial2 TXD
13 Experiment Enable 1
15 Experiment Enable 2
17 Experiment Enable 3
19 Experiment Enable 4
21 Serial1 RXD
23 I²C1 SCL
25 I²C1 SDA
27 Serial1 TXD
29 Solar Safe N
31 Alert Signal
33 -Z Deploy Switch 1
35 -Z Deploy Switch 2
37 I²C2 SCL
39 I²C2 SDA
41 +Z Thermistor
43 -Z Thermistor
45 +Z CIC
47 -Z CIC
49 Umbilical USBP
51 Umbilical USBM
53 Umbilical Power Active
55 Solar Power A
57 Vbatt
59 Vbatt
2 TX PA Current
4 TX Temperature
6 Experiment 4 Thermistor
8 RX Temperature
10 RSSI
12 IHU Audio Out
14
16 RX Command Data 0
18 RX Command Data 1
20 RX Command Data 2
22 RX Command Data 3
24 RX Command Strobe
26 IHU RF Control
28 IHU PTT
30 RF TX Active
32 RX CD
34 RX Audio
36
38 Sensor Power
40 TX Frequency Control
42 RX Frequency Control
44 -Y Antenna Deploy
46 -Y Antenna Sensor
48 +Y Antenna Sensor
50 +Y Antenna Deploy
52
54
56 Solar Power B
58 Vbatt
60 Vbatt
LEGEND
System
ANTENNAS
EXPERIMENTS
ALL
PSU/BATT
UMBILICAL
RF
Connections
CONNECTED IN USE
CONNECTED NOT IN USE
NOT CONNECTED NOT USED

June 6, 2015
Version 3.10

IHU

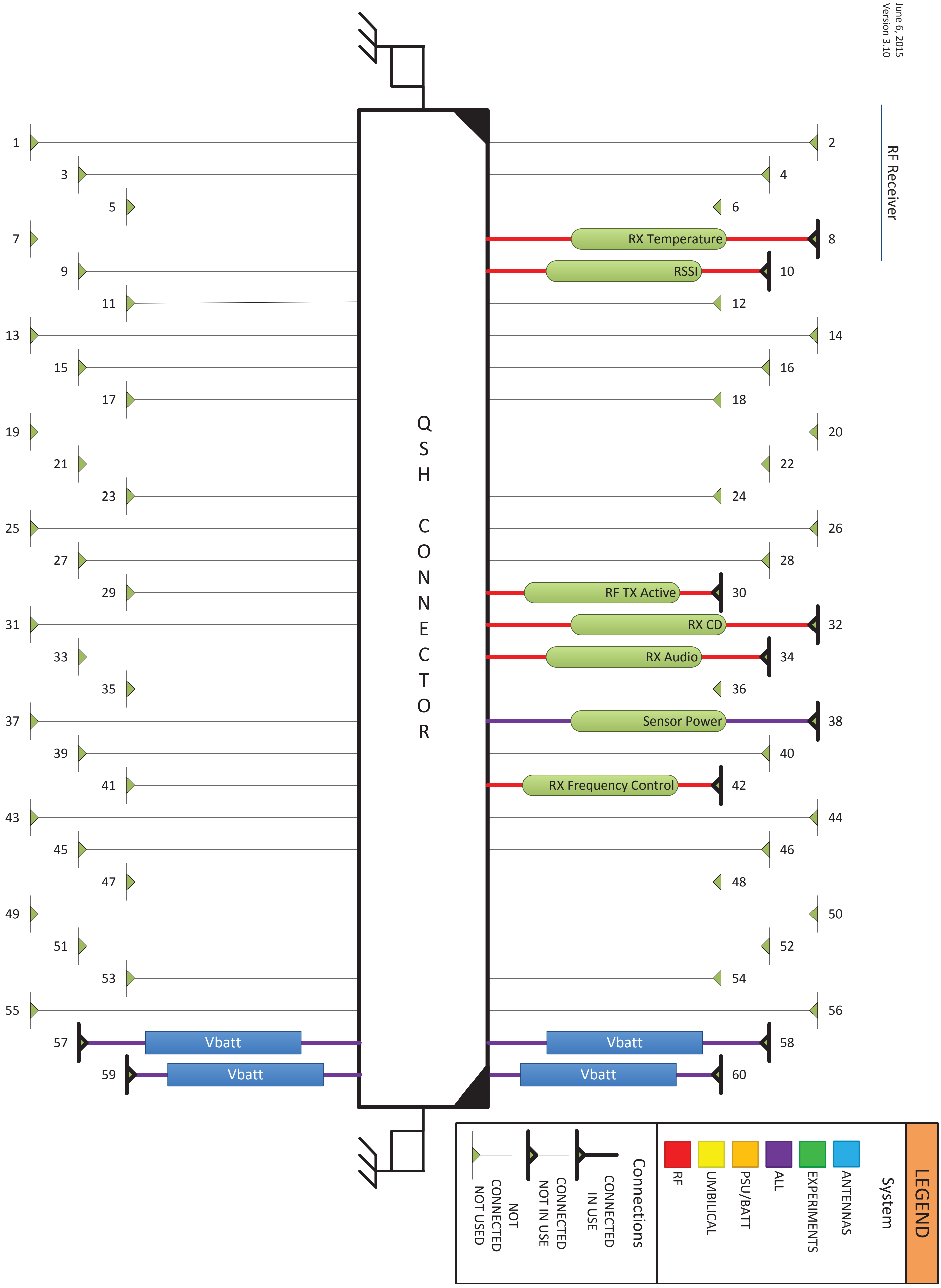


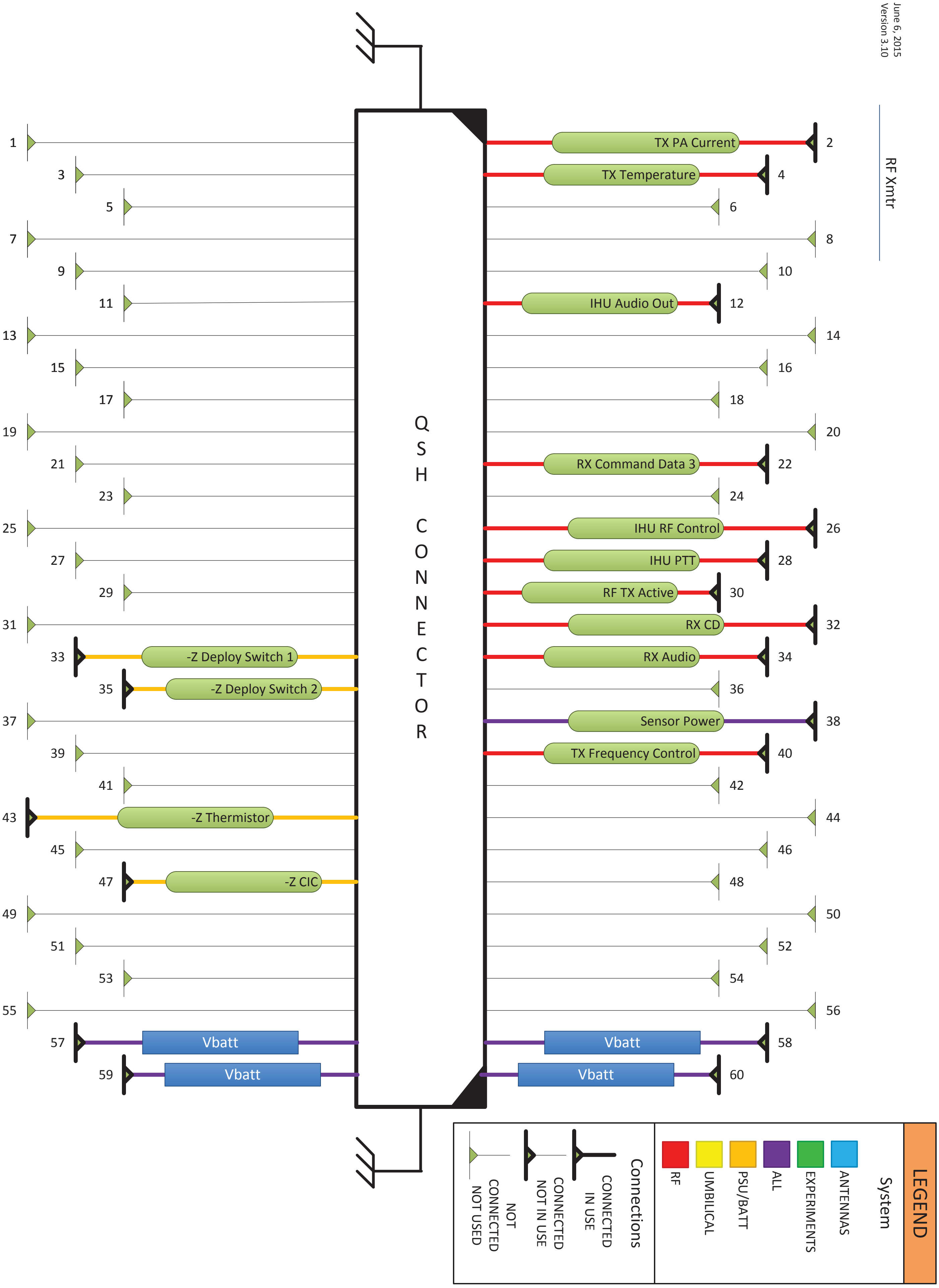

June 6, 2015
Version 3.10
PSU
Q S H C O N N E C T O R
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29 Solar Safe N
30
31 Alert Signal
32
33 -Z Deploy Switch 1
34
35 -Z Deploy Switch 2
36
37 I²C2 SCL
38 Sensor Power
39 I²C2 SDA
40
41 +Z Thermistor
42
43 -Z Thermistor
44 -Y Antenna Deploy
45 +Z CIC
46 -Y Antenna Sensor
47 -Z CIC
48 +Y Antenna Sensor
49
50 +Y Antenna Deploy
51
52
53
54
55 Solar Power A
56 Solar Power B
57 Vbatt
58 Vbatt
59 Vbatt
60 Vbatt
LEGEND
System
ANTENNAS
EXPERIMENTS
ALL
PSU/BATT
UMBILICAL
RF
Connections
CONNECTED IN USE
CONNECTED NOT IN USE
NOT CONNECTED NOT USED


June 6, 2015
Version 3.10
BATT 1
QSH CONNECTOR
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
Solar Safe N
30
31
Alert Signal
32
33
-Z Deploy Switch 1
34
35
-Z Deploy Switch 2
36
37
I²C2 SCL
38
Sensor Power
39
I²C2 SDA
40
41
42
43
44
45
46
47
48
49
Umbilical USBP
50
51
Umbilical USBM
52
53
Umbilical Power Active
54
55
Solar Power A
56
Solar Power B
57
Vbatt
58
Vbatt
59
Vbatt
60
Vbatt
LEGEND
System
ANTENNAS
EXPERIMENTS
ALL
PSU/BATT
UMBILICAL
RF
Connections
CONNECTED IN USE
CONNECTED NOT IN USE
NOT CONNECTED NOT USED

June 6, 2015
Version 3.10

RF Receiver



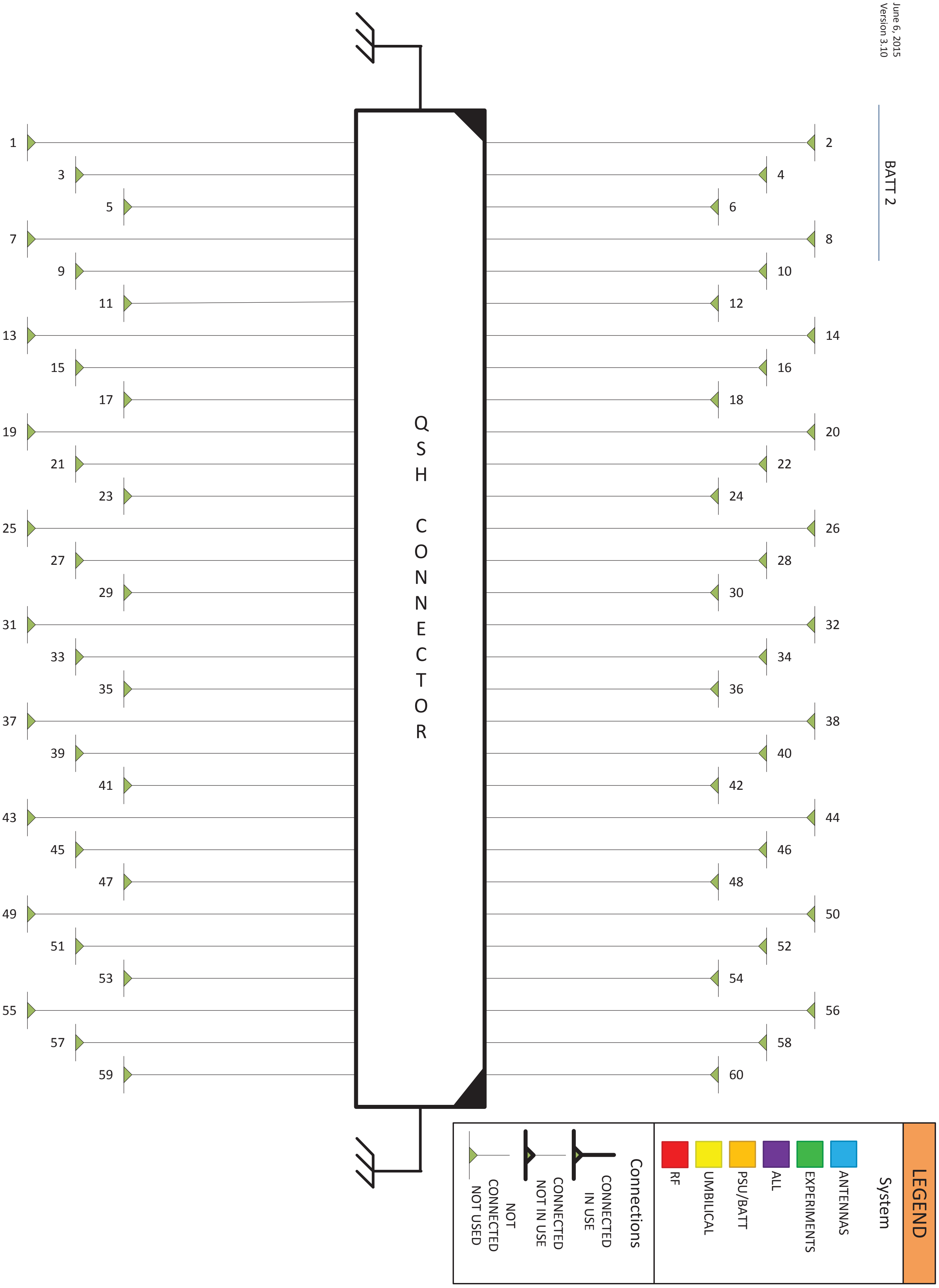


June 6, 2015
Version 3.10

RF Xmtr

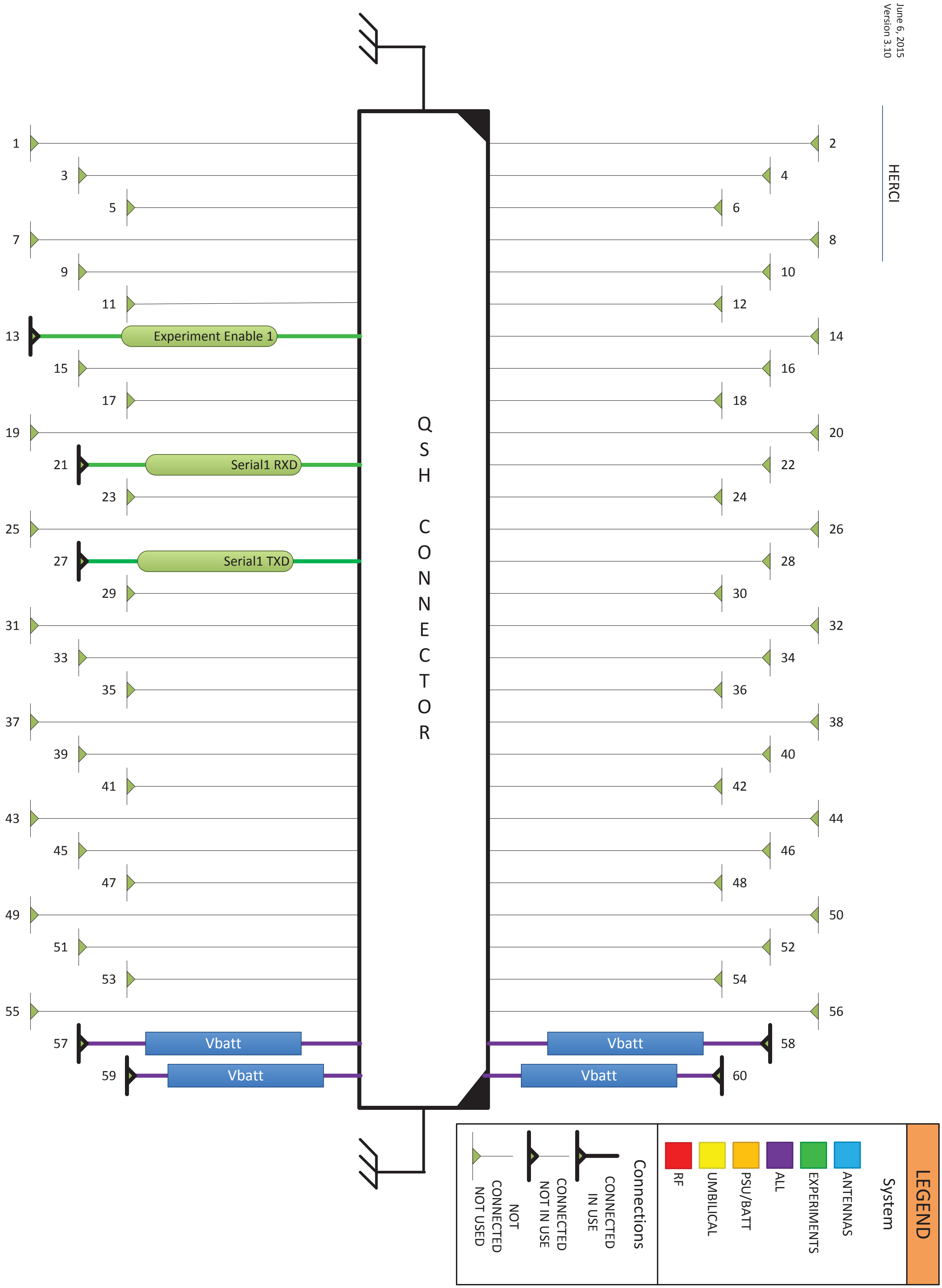
June 6, 2015
Version 3.10

BATT 2



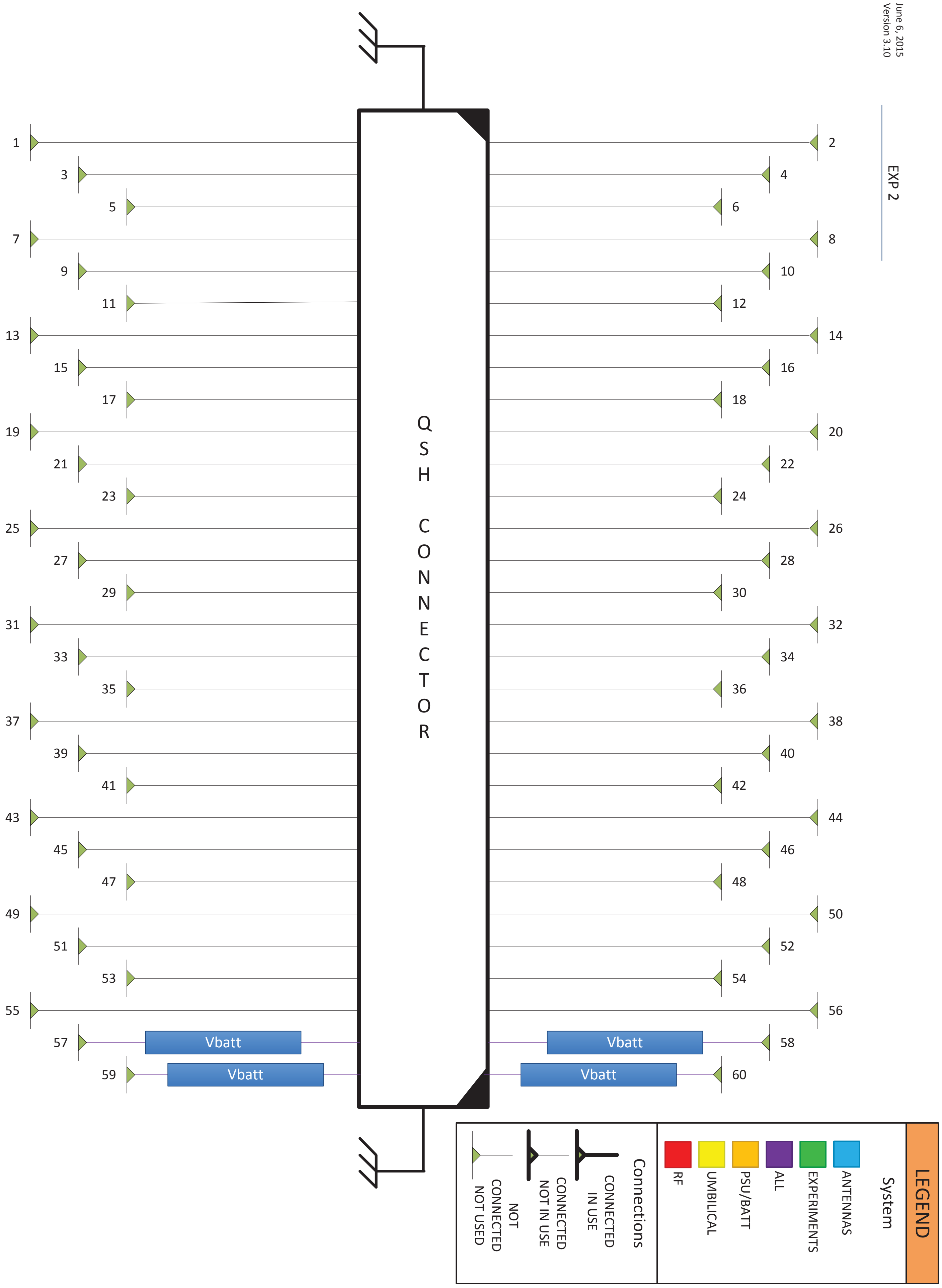
HERCI

June 6, 2015
Version 3.10



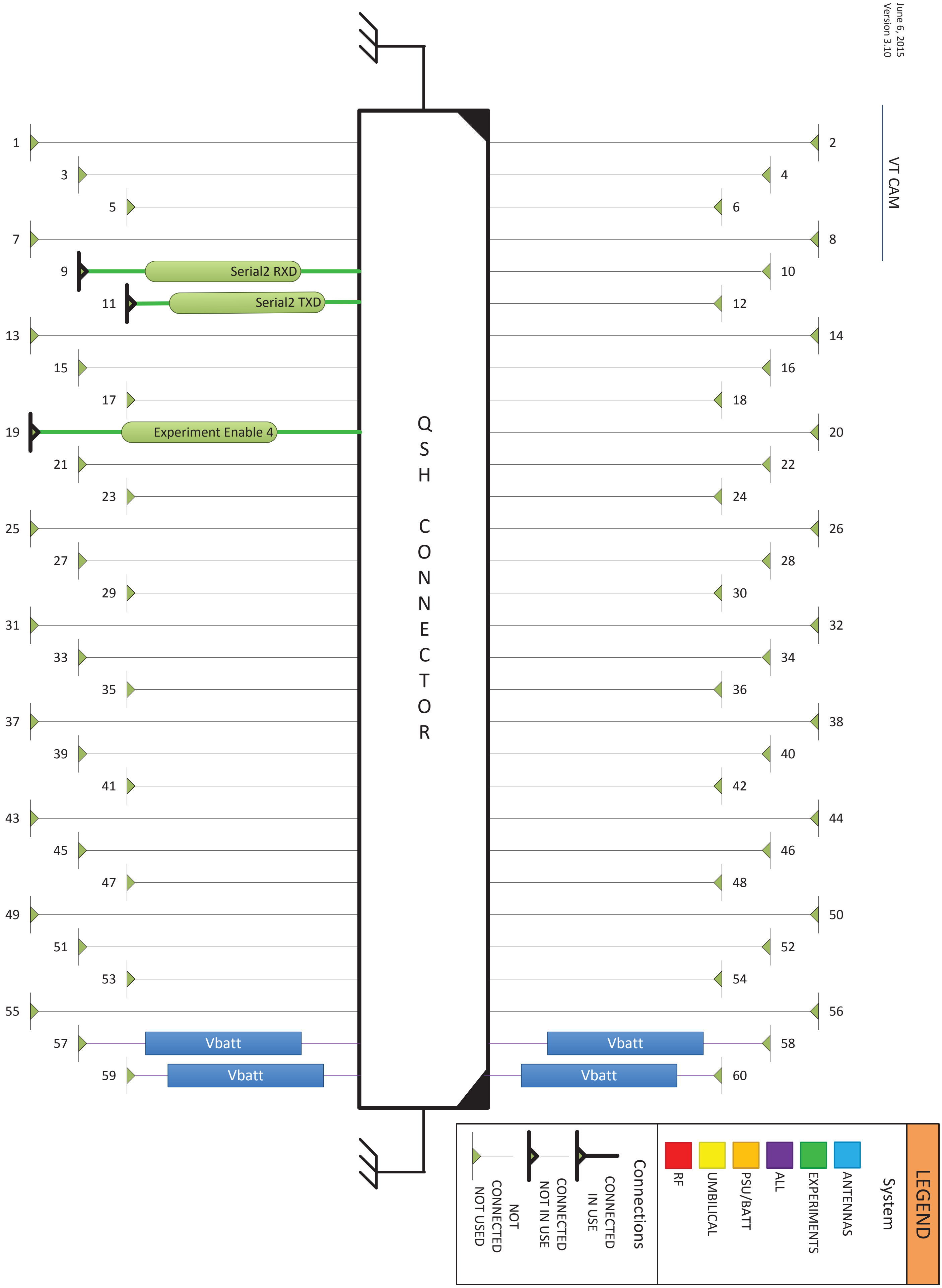
June 6, 2015
Version 3.10

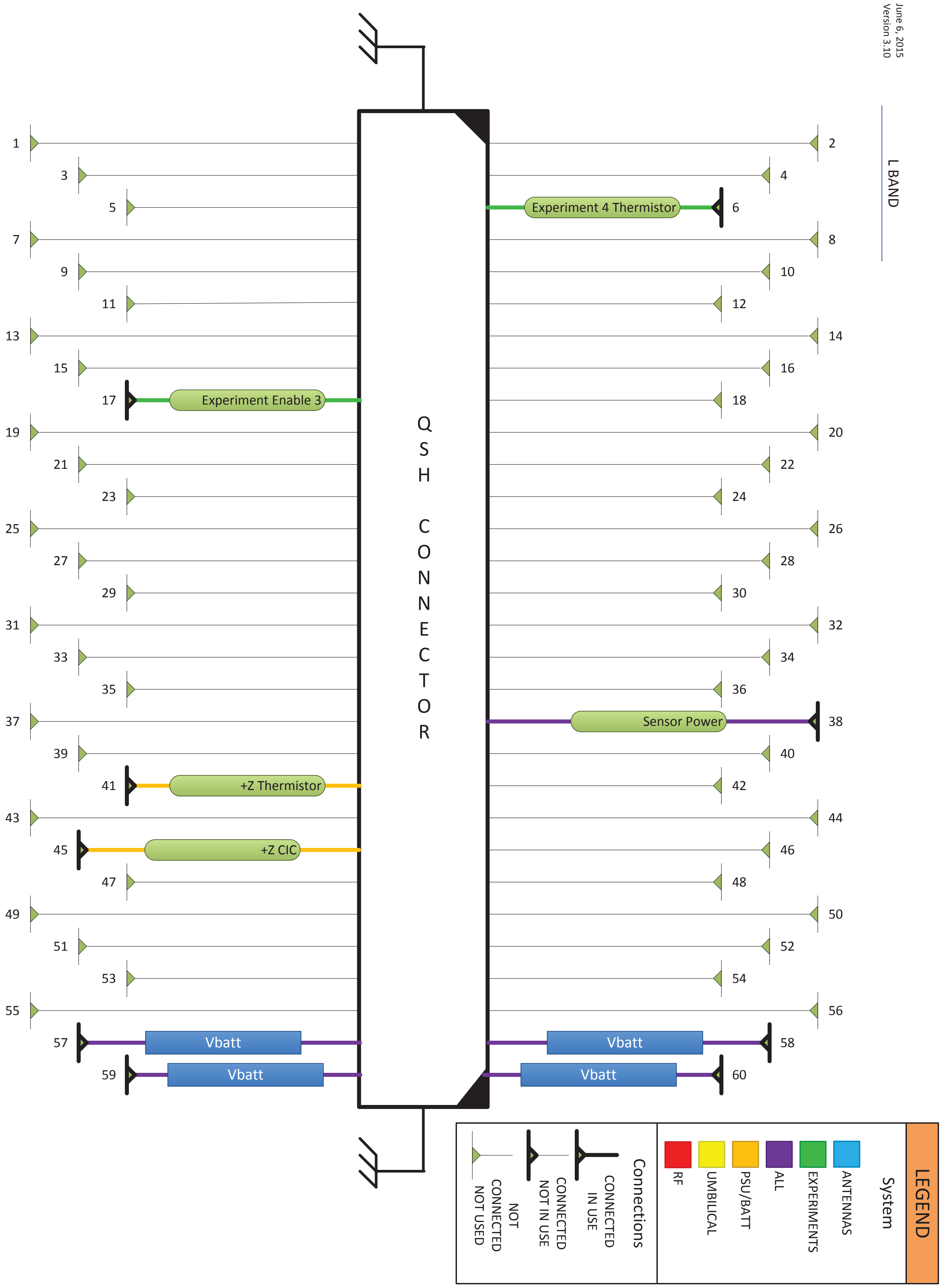
EXP 2

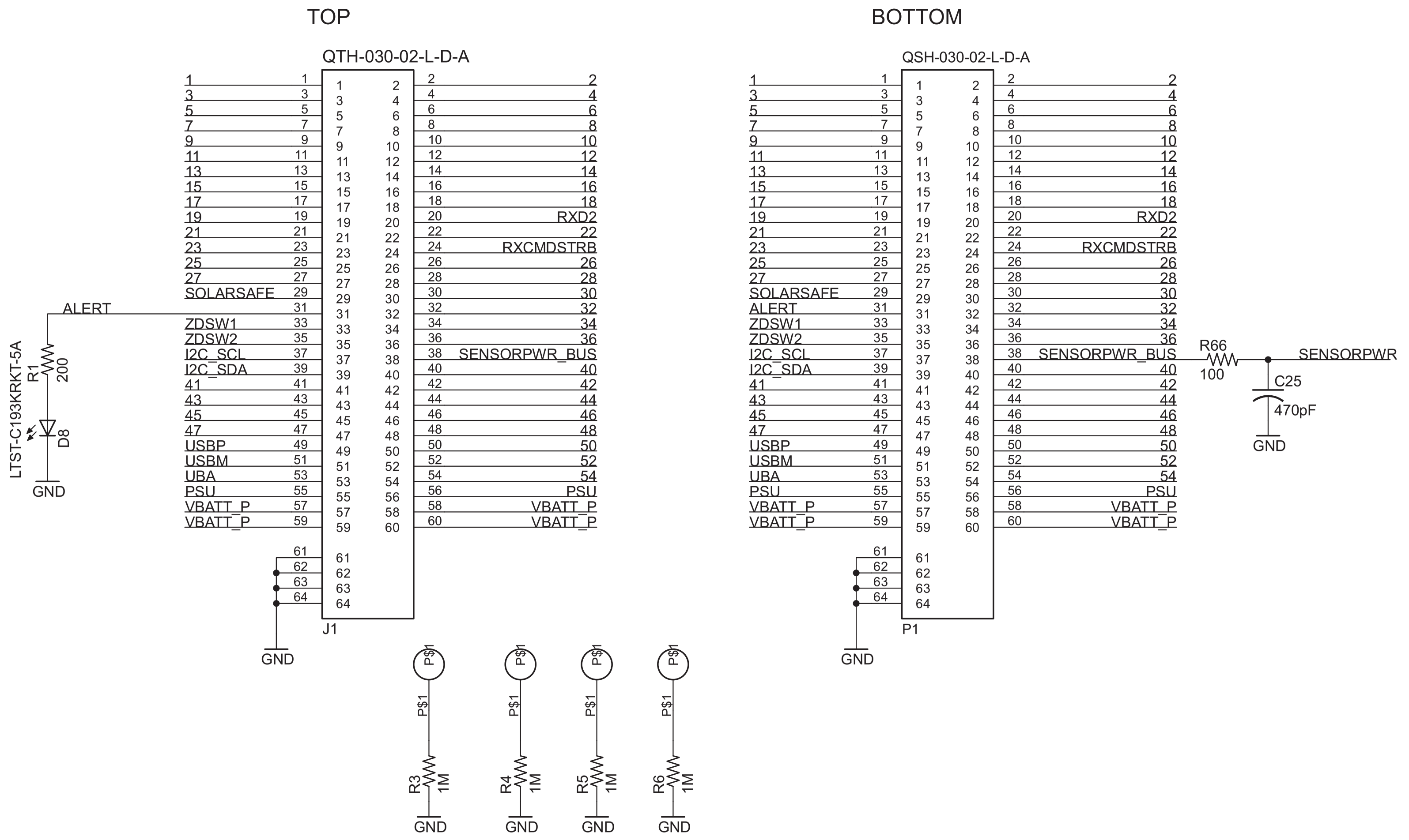


VT CAM

June 6, 2015
Version 3.10




June 6, 2015
Version 3.10
L BAND
Q S H CONNECTOR
1
2
3
4
5
Experiment 4 Thermistor
6
7
8
9
10
11
12
13
14
15
16
Experiment Enable 3
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
Sensor Power
38
39
40
+Z Thermistor
41
42
43
44
+Z CIC
45
46
47
48
49
50
51
52
53
54
55
56
Vbatt
57
Vbatt
58
Vbatt
59
Vbatt
60
LEGEND
System
ANTENNAS
EXPERIMENTS
ALL
PSU/BATT
UMBILICAL
RF
Connections
CONNECTED IN USE
CONNECTED NOT IN USE
NOT CONNECTED NOT USED



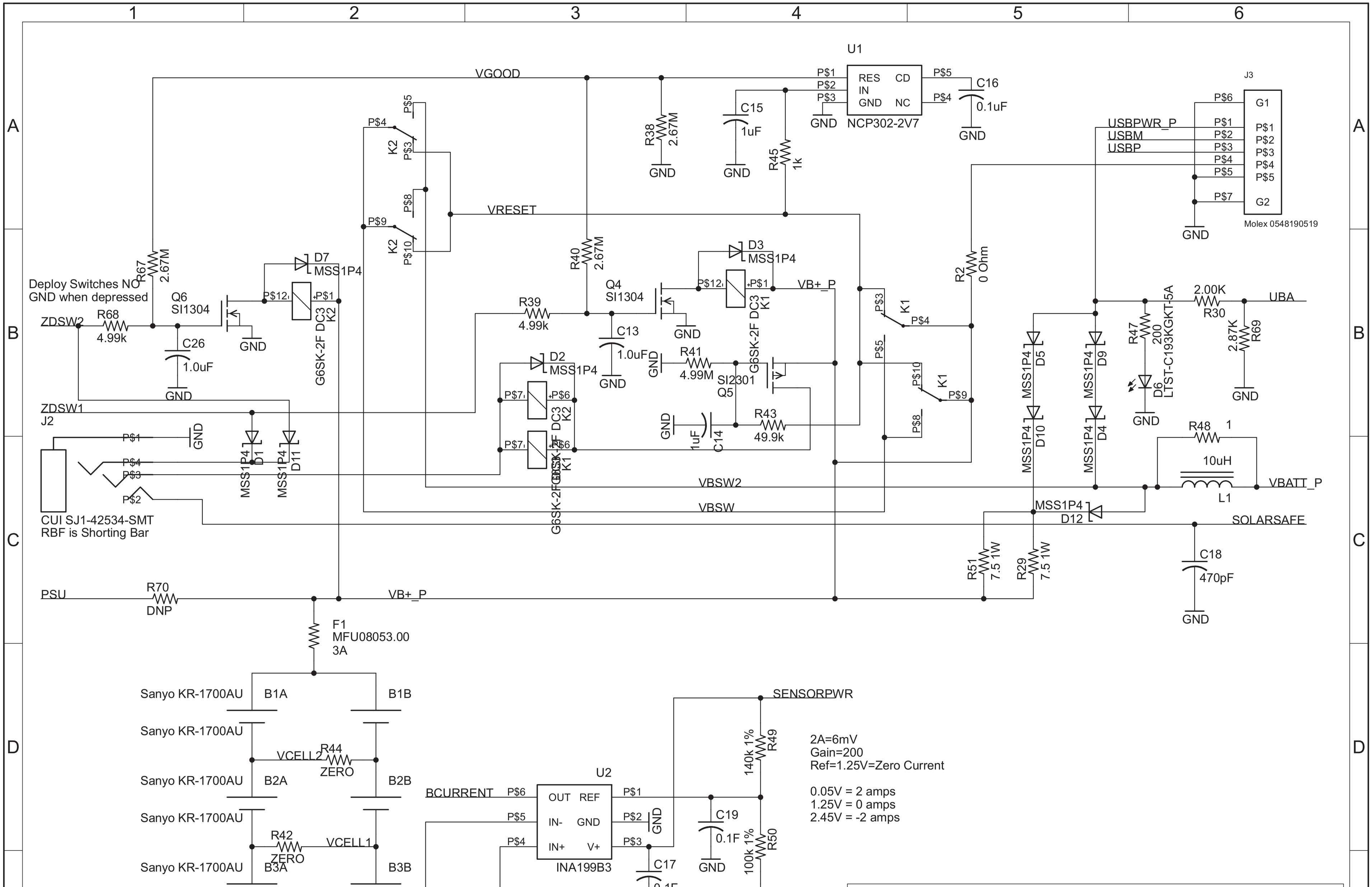
TITLE: battery

Document Number:
AMSAT-NA BATTERY CARD

REV:
3.1

Date: 8/31/2014 6:01:25 PM

Sheet: 1/5



2A=6mV
Gain=200
Ref=1.25V=Zero Current

0.05V = 2 amps
1.25V = 0 amps
2.45V = -2 amps

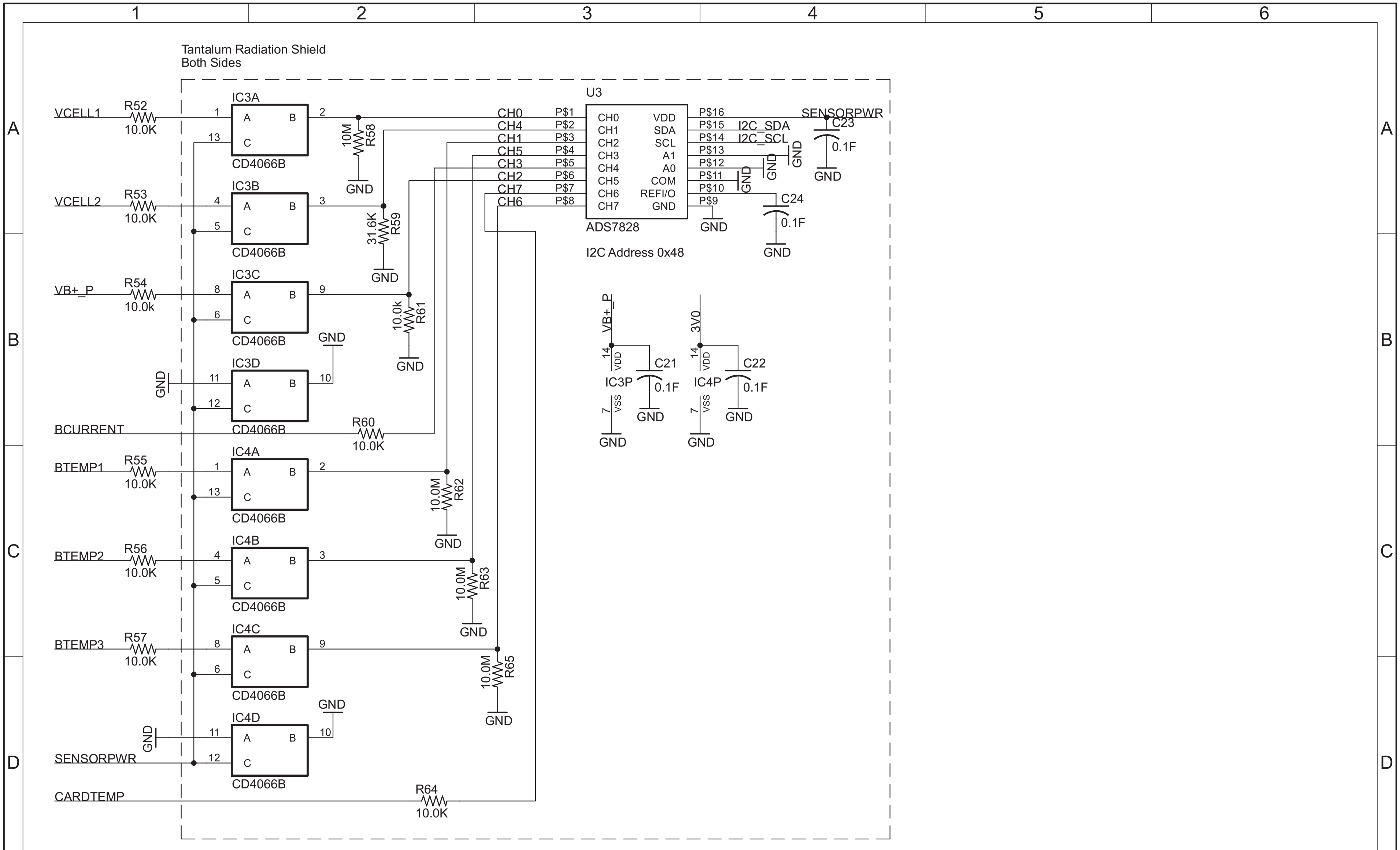
TITLE: battery

Document Number:
AMSAT-NA BATTERY CARD

REV:
3.1

Date: 8/31/2014 6:01:25 PM

Sheet: 2/5



TITLE: battery

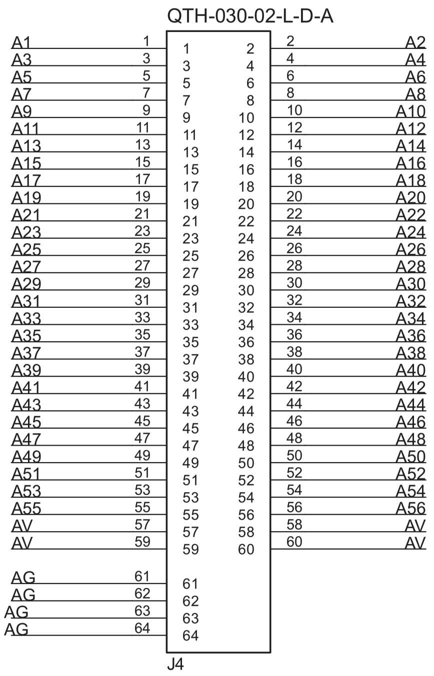
Document Number:
AMSAT-NA BATTERY CARD

REV:
3.1

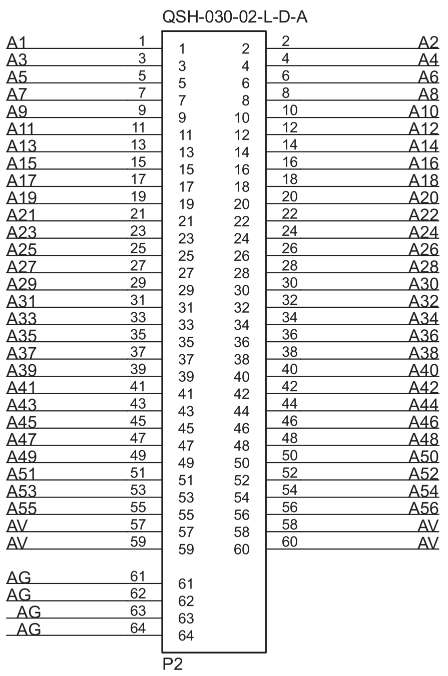
Date: 8/31/2014 6:01:25 PM

Sheet: 3/5

TOP



BOTTOM



Battery 2 Connector PCA

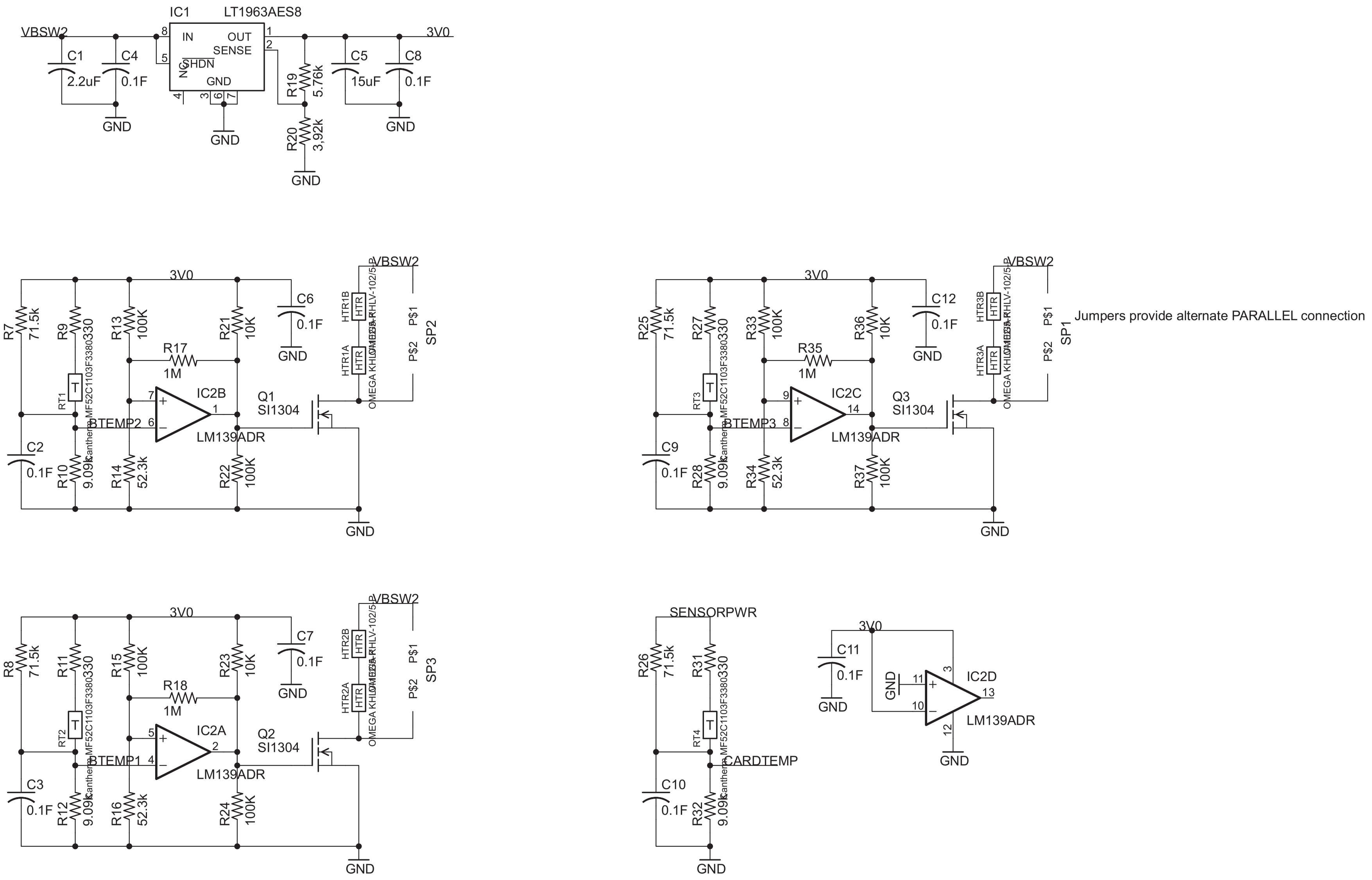
TITLE: battery

Document Number:
AMSAT-NA BATTERY CARD

REV:
3.1

Date: 8/31/2014 6:01:25 PM

Sheet: 4/5



TITLE: battery

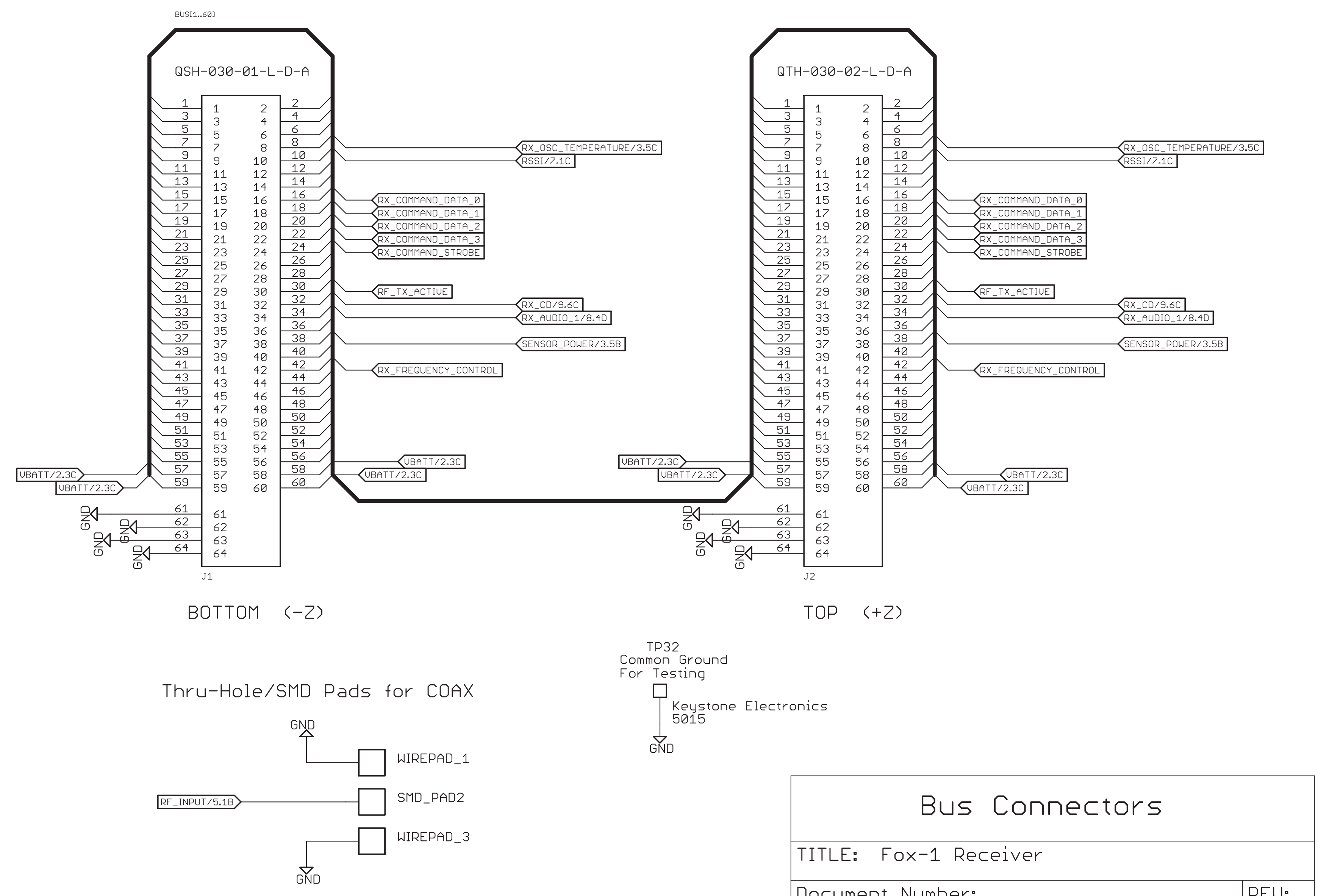
Document Number:
AMSAT-NA
BATTERY CARD

REV:
3.1

Date: 8/31/2014 6:01:25 PM

Sheet: 5/5

RF Receiver Bus Pin Assignments Version 2.95



Bus Connectors

TITLE: Fox-1 Receiver

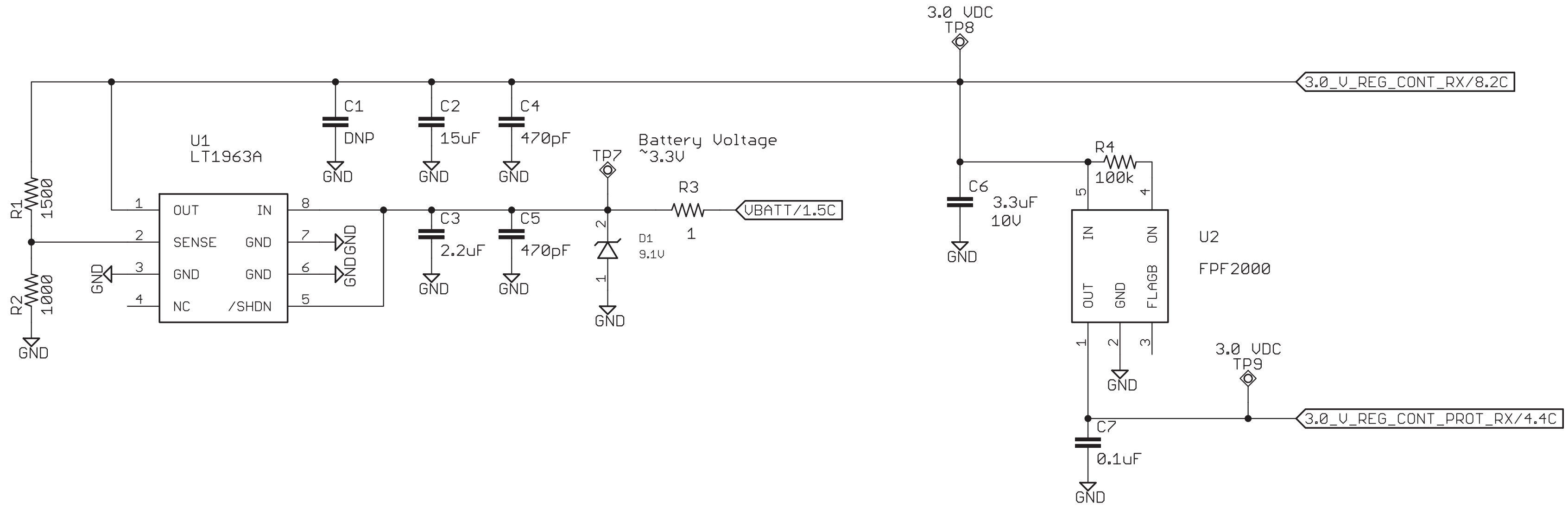
Document Number:
AMSAT-NA FOX-1 RX

REV: 2.00

Date: 9/13/2014 1:11:19 AM

Sheet: 1/9

DWG: K4OZS



Receiver Power Conditioning

TITLE: Fox-1 Receiver

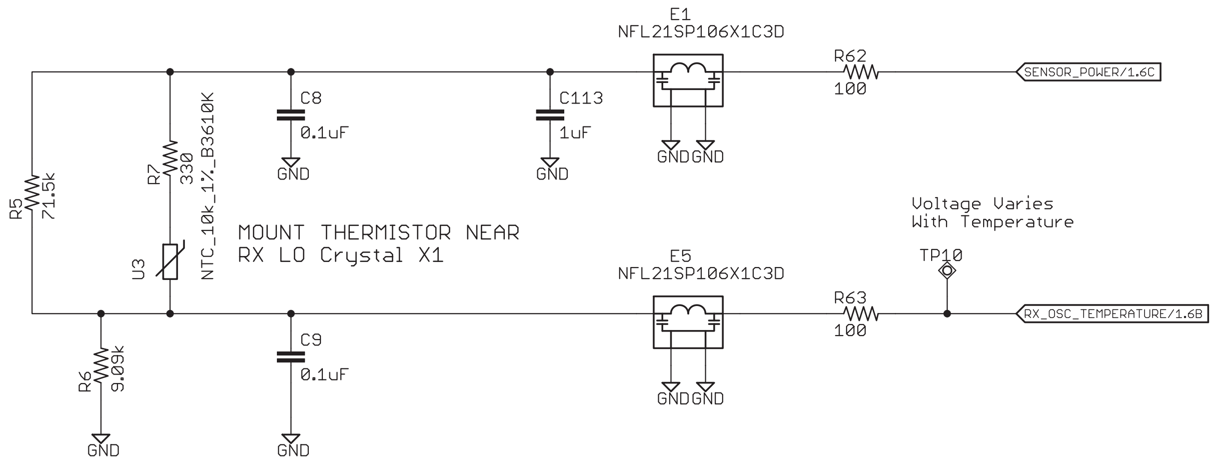
Document Number:
AMSAT-NA FOX-1 RX

REV:
2.00

Date: 9/13/2014 1:11:19 AM

Sheet: 2/9

DWG: K4OZS



RX Temperature Sensor

TITLE: Fox-1 Receiver

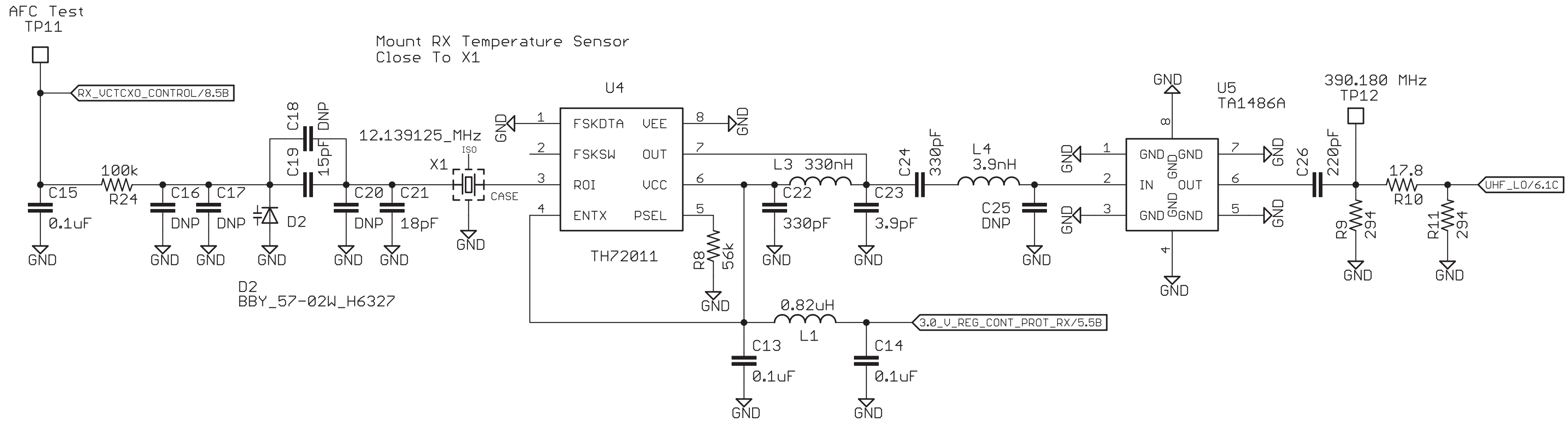
Document Number:
AMSAT-NA FOX-1 RX

REV:
2.00

Date: 9/13/2014 1:11:19 AM

Sheet: 3/9

DWG: K4OZS



UHF Local Oscillator

TITLE: Fox-1 Receiver

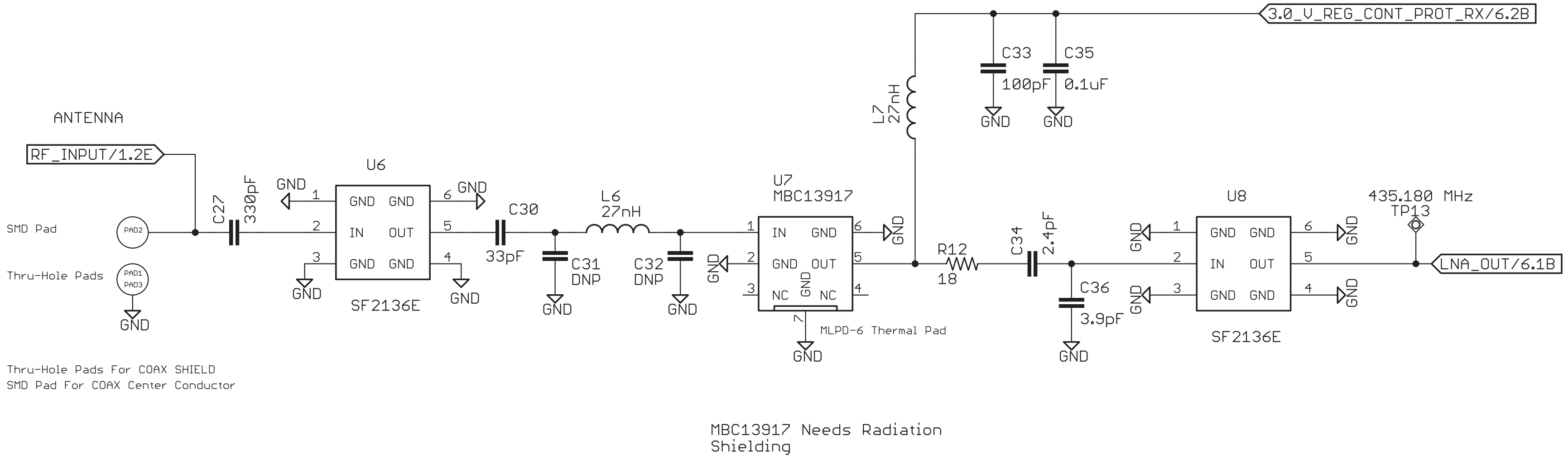
Document Number:
AMSAT-NA FOX-1 RX

REV:
2.00

Date: 9/13/2014 1:11:19 AM

Sheet: 4/9

DWG: K4OZS



Low-Noise Amplifier

TITLE: Fox-1 Receiver

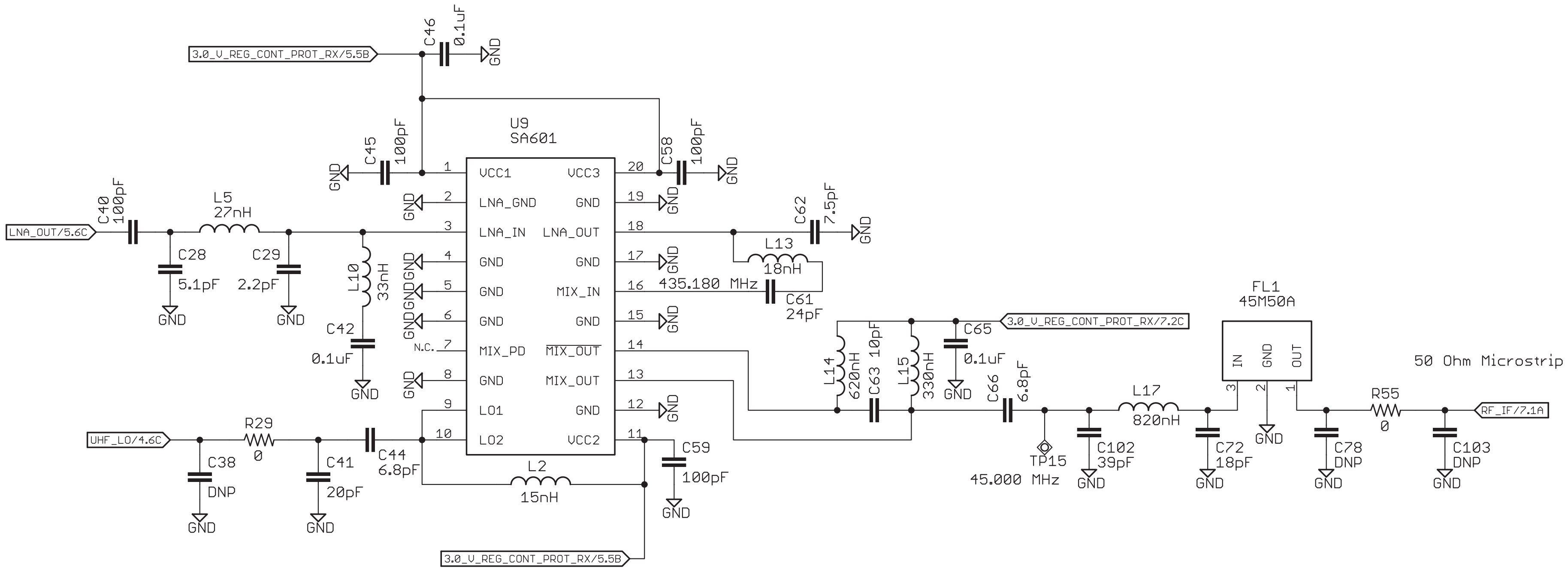
Document Number:
AMSAT-NA FOX-1 RX

REV:
2.00

Date: 9/13/2014 1:11:19 AM

Sheet: 5/9

DWG: K4OZS



SA601
Needs Radiation Shielding

Receiver LNA, First IF

TITLE: Fox-1 Receiver

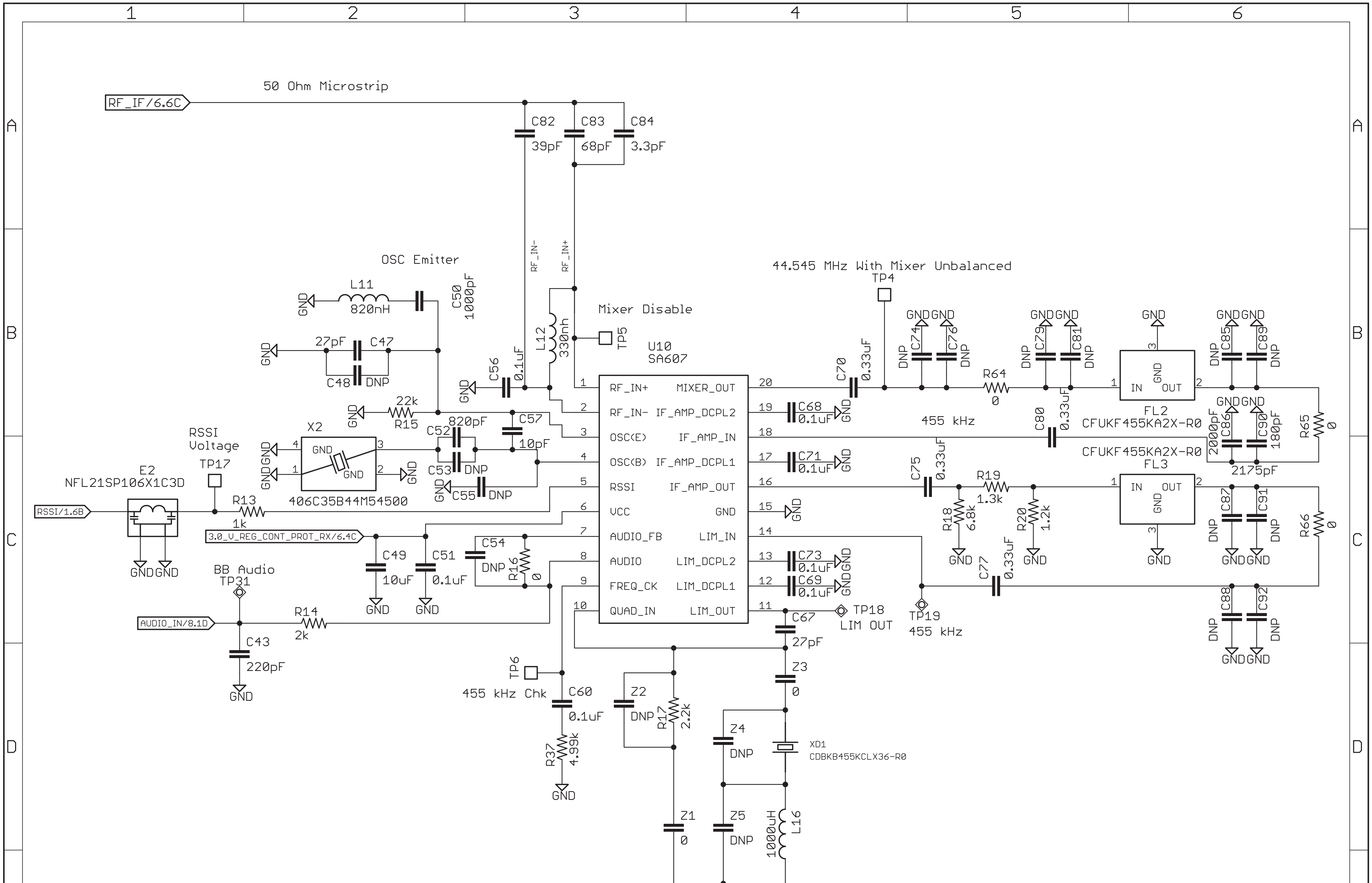
Document Number:
AMSAT-NA FOX-1 RX

REV:
2.00

Date: 9/13/2014 1:11:19 AM

Sheet: 6/9

DWG: K4OZS



Receiver Second IF, FM System

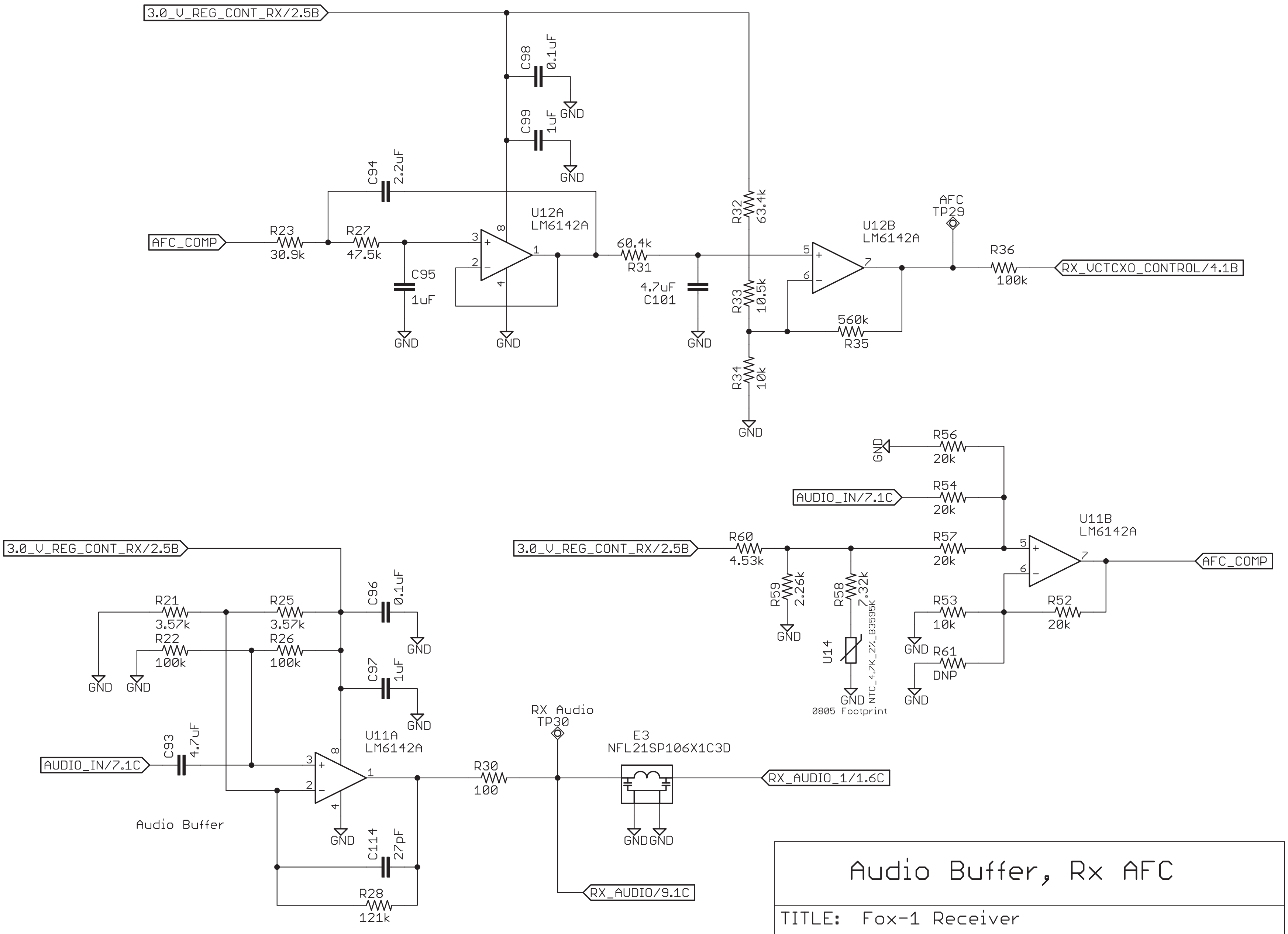
TITLE: Fox-1 Receiver

Document Number:
AMSAT-NA FOX-1 RX

REV:
2.00

Date: 9/13/2014 1:11:19 AM

Sheet: 7/9



Audio Buffer, Rx AFC

TITLE: Fox-1 Receiver

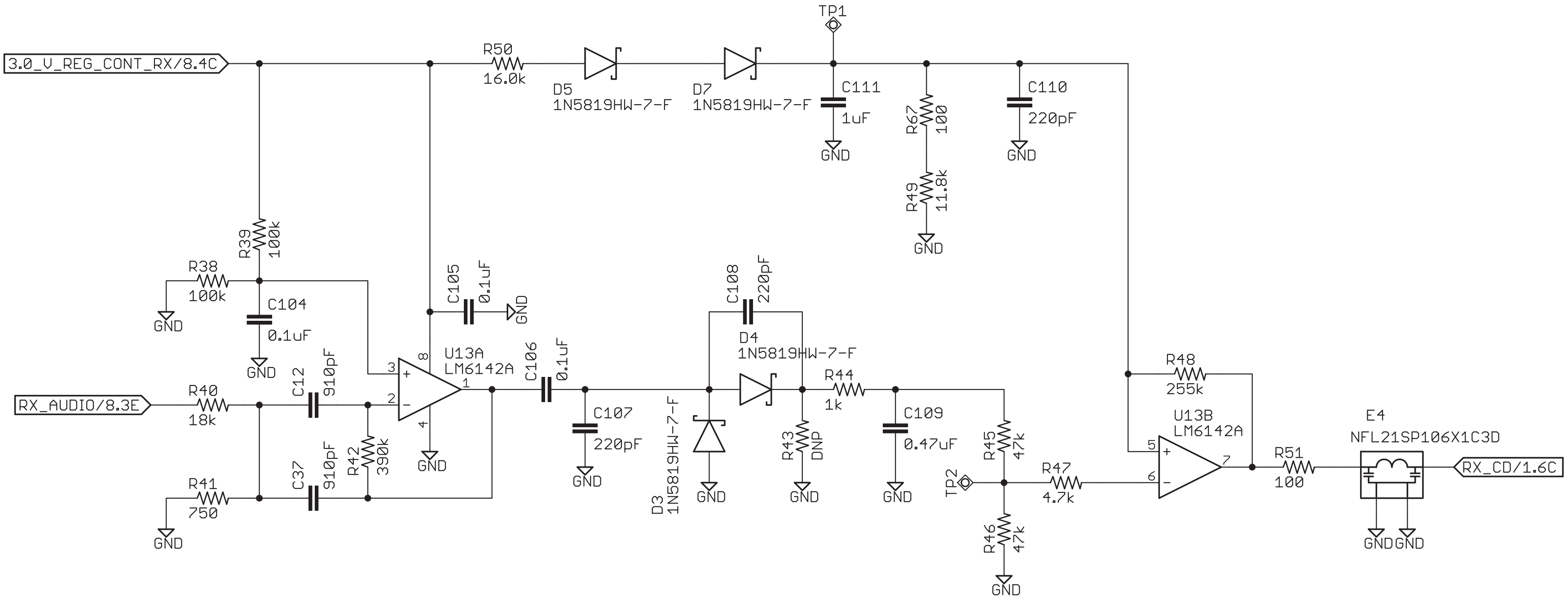
Document Number:
AMSAT-NA FOX-1 RX

REV:
2.00

Date: 9/13/2014 1:11:19 AM

Sheet: 8/9

DWG: K4OZS



Noise Squelch, COR

TITLE: Fox-1 Receiver

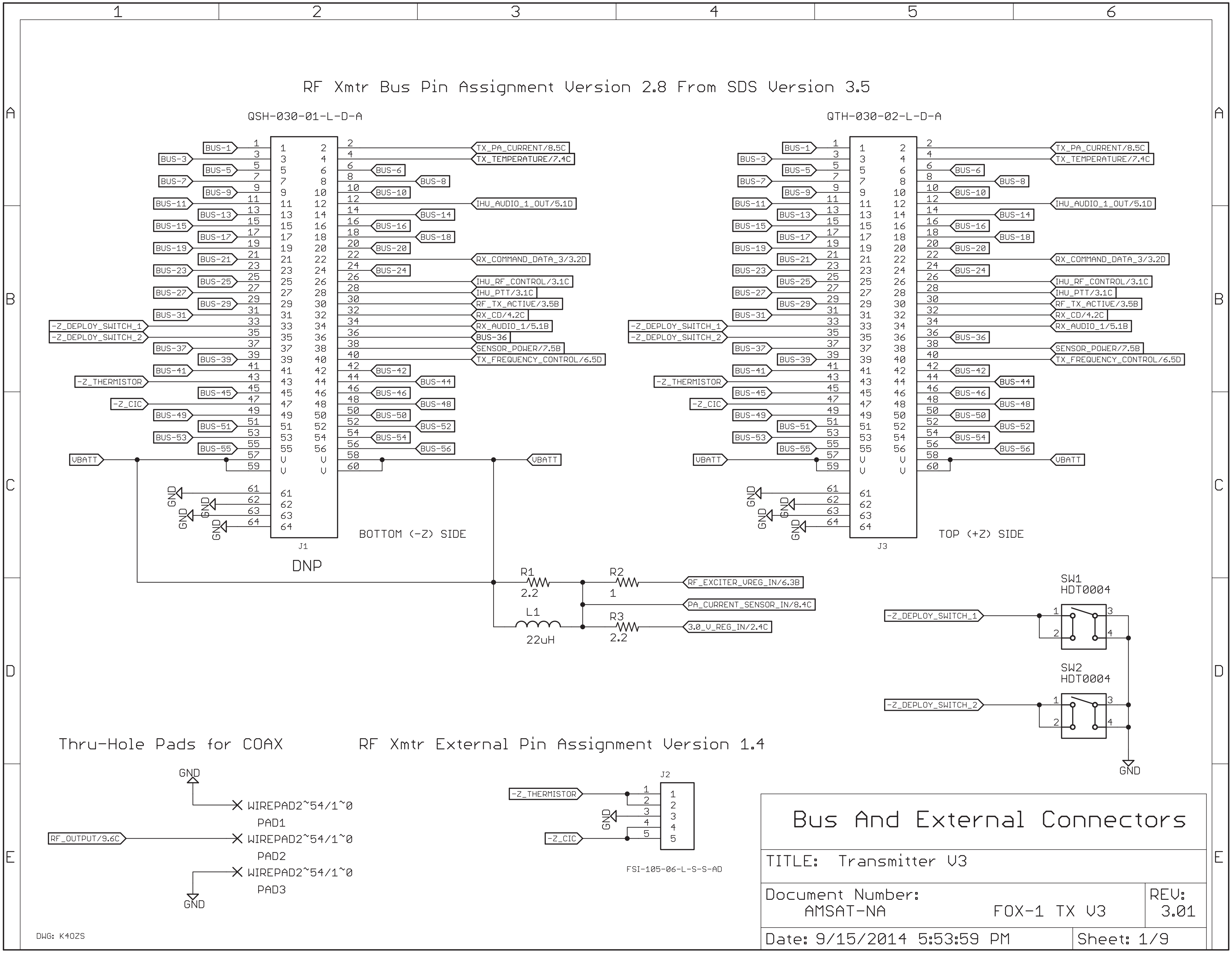
Document Number:
AMSAT-NA FOX-1 RX

REV:
2.00

Date: 9/13/2014 1:11:19 AM

Sheet: 9/9

DWG: K4OZS



Bus And External Connectors

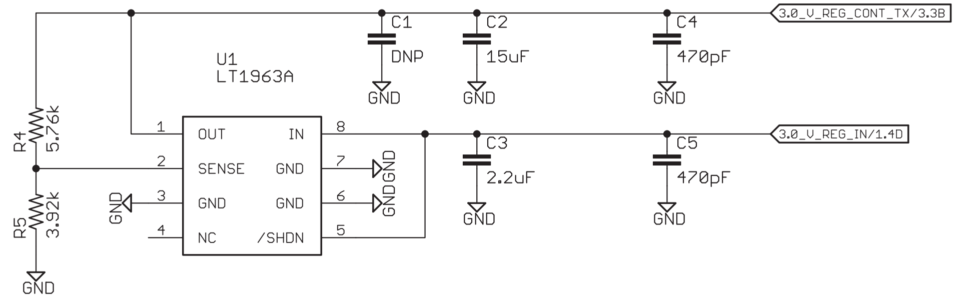
TITLE: Transmitter V3

Document Number:
AMSAT-NA FOX-1 TX V3

REV:
3.01

Date: 9/15/2014 5:53:59 PM

Sheet: 1/9



TX Power Supply

TITLE: Transmitter V3

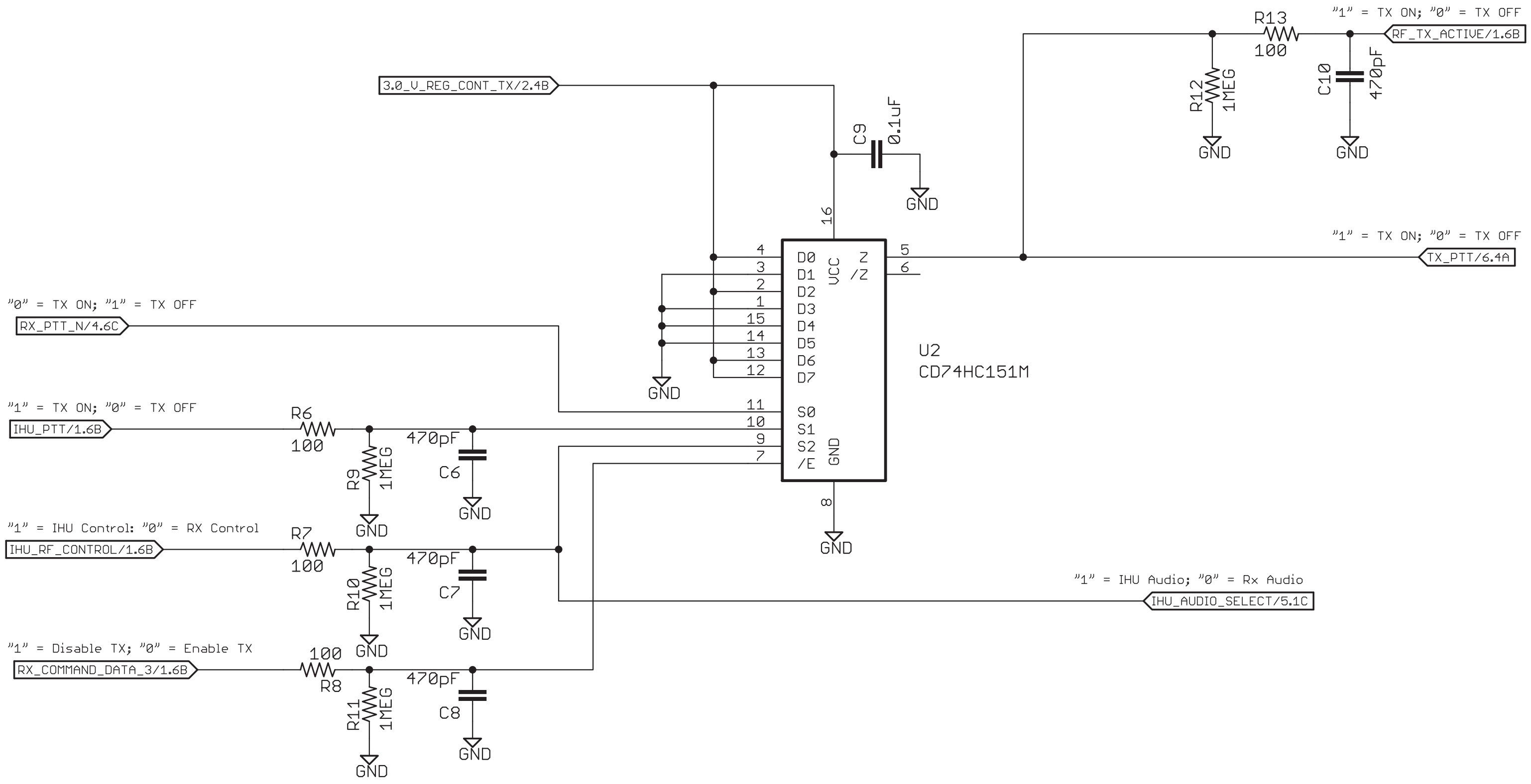
Document Number:
AMSAT-NA FOX-1 TX V3

REV:
3.01

Date: 9/15/2014 5:53:59 PM

Sheet: 2/9

DWG: K4OZS



TX Keying Logic

TITLE: Transmitter V3

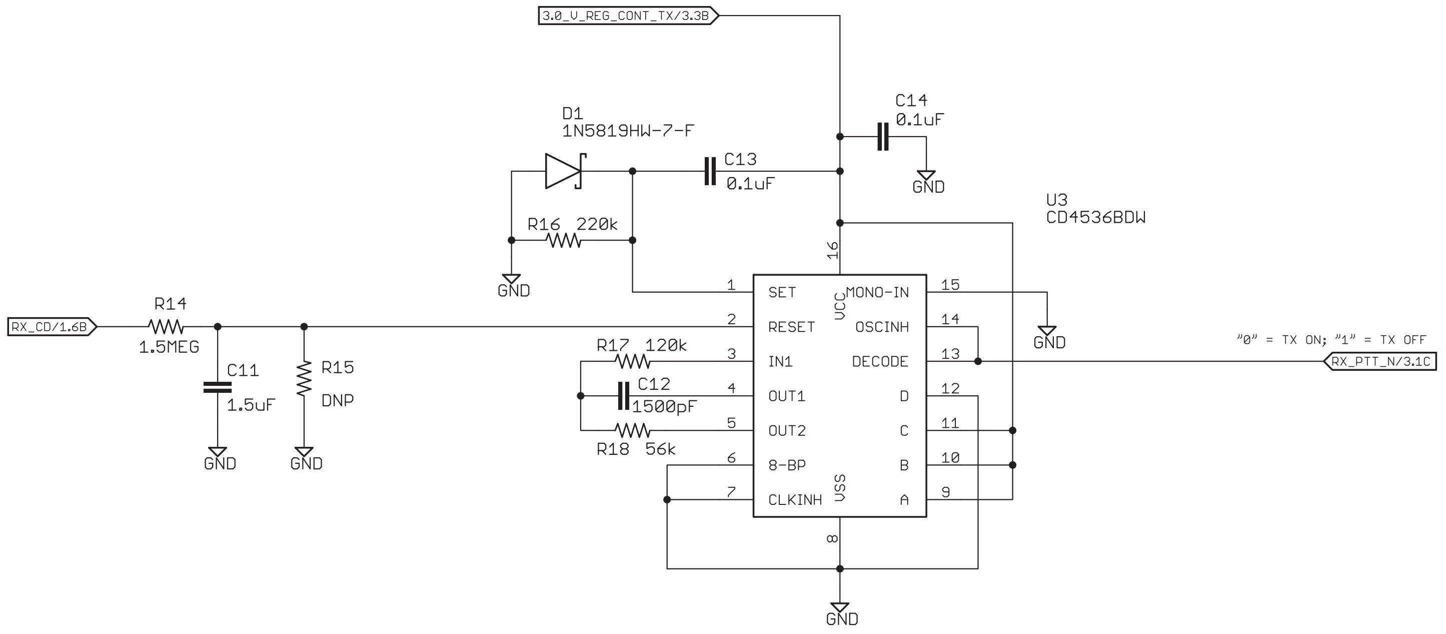
Document Number:
AMSAT-NA FOX-1 TX V3

REV:
3.01

Date: 9/15/2014 5:53:59 PM

Sheet: 3/9

DWG: K4OZS



C12:
Select By Test
For Hang Timer Duration

TX Hang Timer

TITLE: Transmitter V3

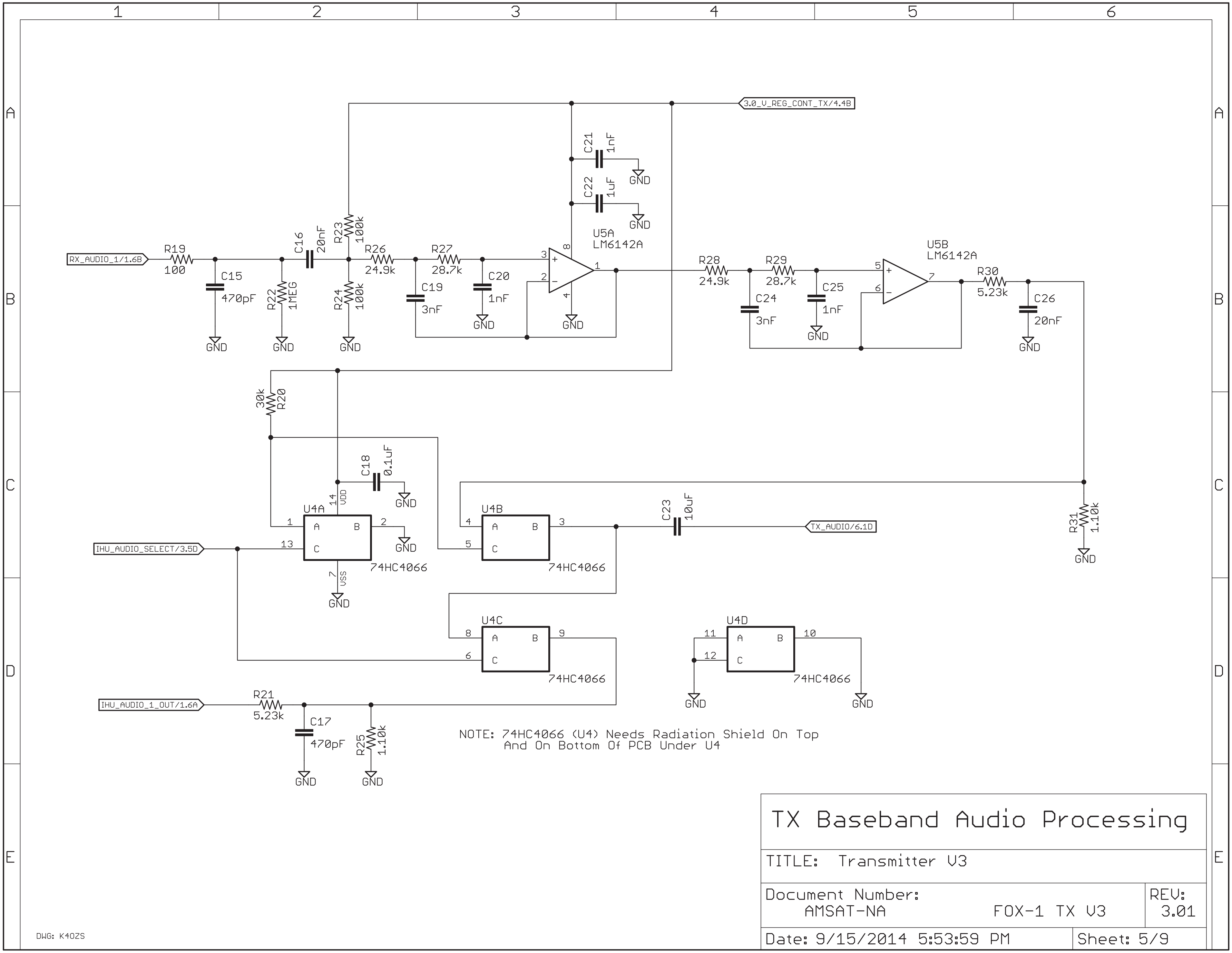
Document Number:
AMSAT-NA FOX-1 TX V3

REV:
3.01

Date: 9/15/2014 5:53:59 PM

Sheet: 4/9

DWG: K4OZS



NOTE: 74HC4066 (U4) Needs Radiation Shield On Top
And On Bottom Of PCB Under U4

TX Baseband Audio Processing

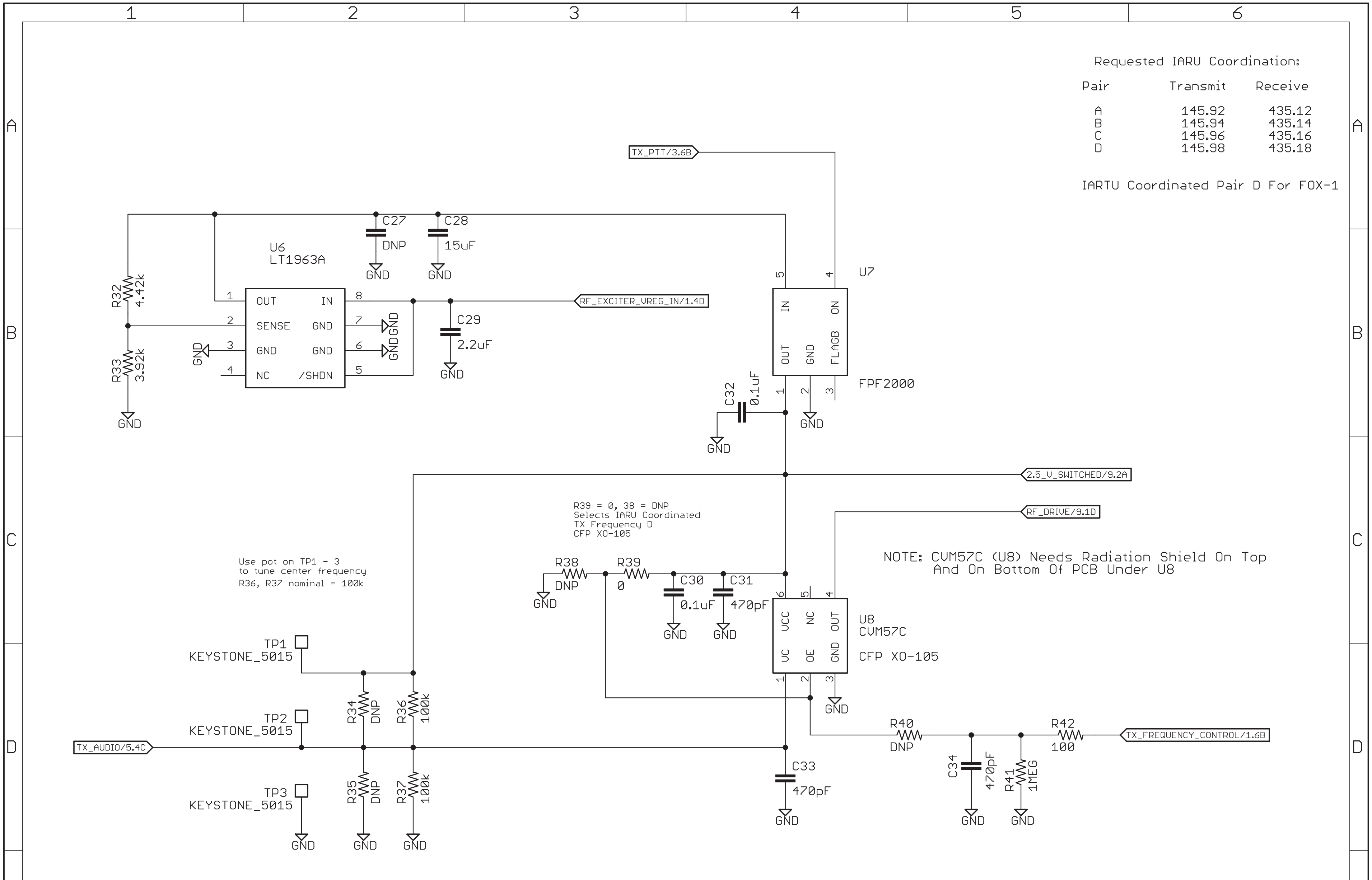
TITLE: Transmitter V3

Document Number:
AMSAT-NA FOX-1 TX V3

REV:
3.01

Date: 9/15/2014 5:53:59 PM

Sheet: 5/9



Requested IARU Coordination:

Pair	Transmit	Receive
A	145.92	435.12
B	145.94	435.14
C	145.96	435.16
D	145.98	435.18

IARTU Coordinated Pair D For FOX-1

R39 = 0, 38 = DNP
Selects IARU Coordinated
TX Frequency D
CFP XO-105

Use pot on TP1 - 3
to tune center frequency
R36, R37 nominal = 100k

NOTE: CVM57C (U8) Needs Radiation Shield On Top
And On Bottom Of PCB Under U8

R38 = 0, R39 = DNP
Selects IARU Coordinated
TX Frequency C
CFP XO-105

DWG: K4OZS

TX RF Exciter

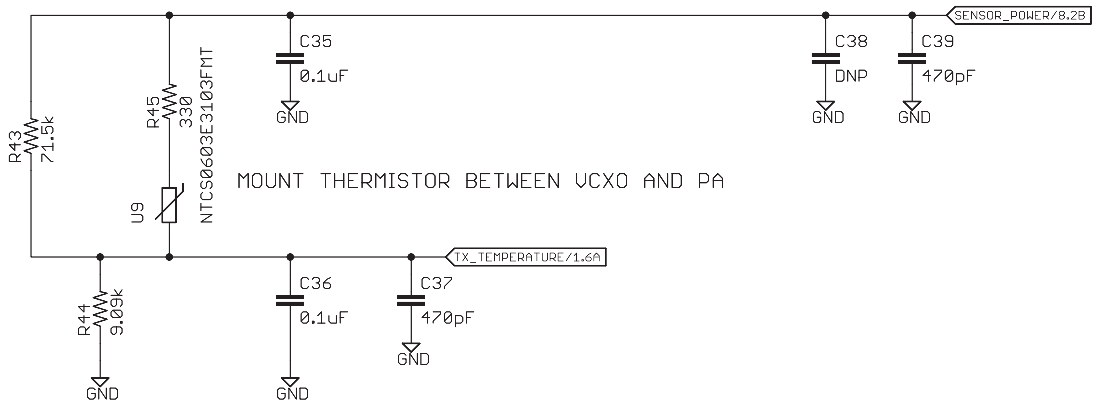
TITLE: Transmitter V3

Document Number:
AMSAT-NA FOX-1 TX V3

REV:
3.01

Date: 9/15/2014 5:53:59 PM

Sheet: 6/9



DWG: K4OZS

TX Temperature Sensor

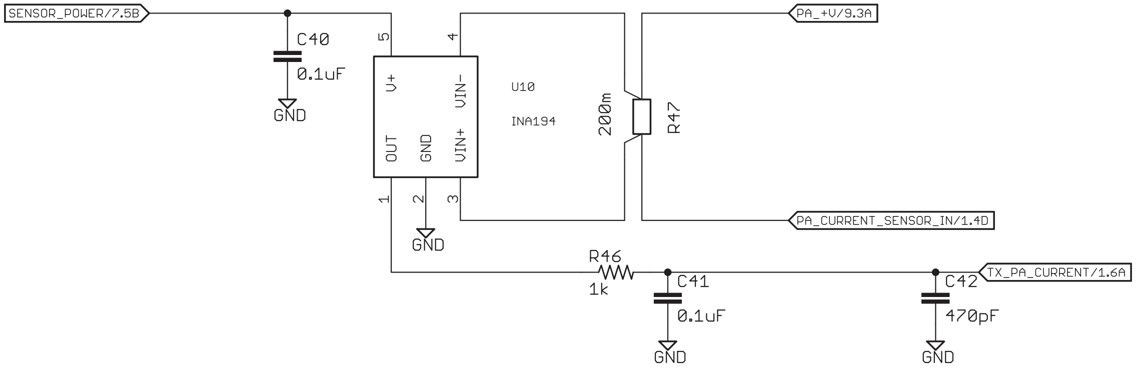
TITLE: Transmitter V3

Document Number:
AMSAT-NA FOX-1 TX V3

REV:
3.01

Date: 9/15/2014 5:53:59 PM

Sheet: 7/9



PA Current Sensor

TITLE: Transmitter V3

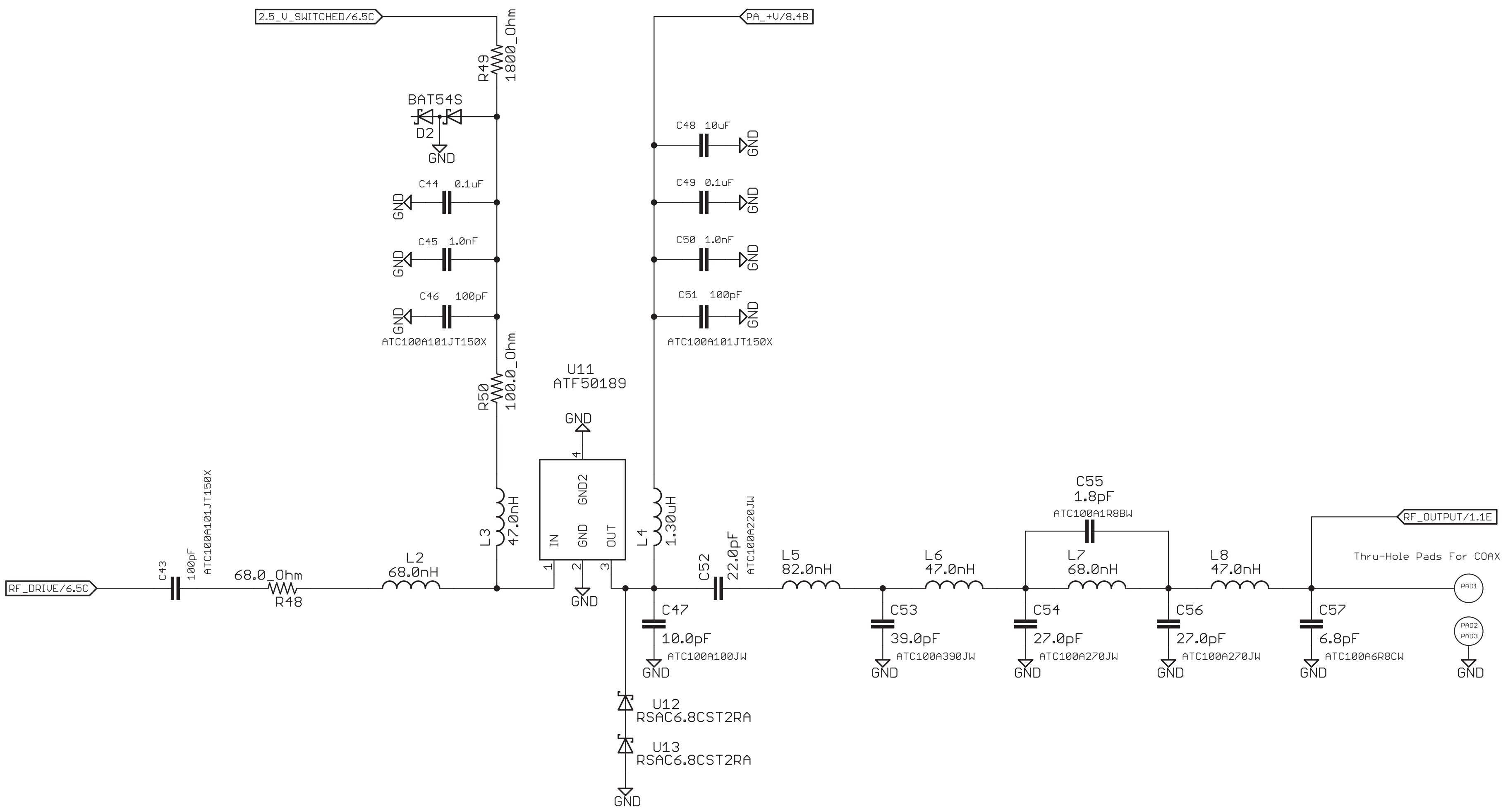
Document Number:
AMSAT-NA FOX-1 TX V3

REV:
3.01

Date: 9/15/2014 5:53:59 PM

Sheet: 8/9

DWG: K4OZS



DWG: K4OZS

TX Power Amplifier

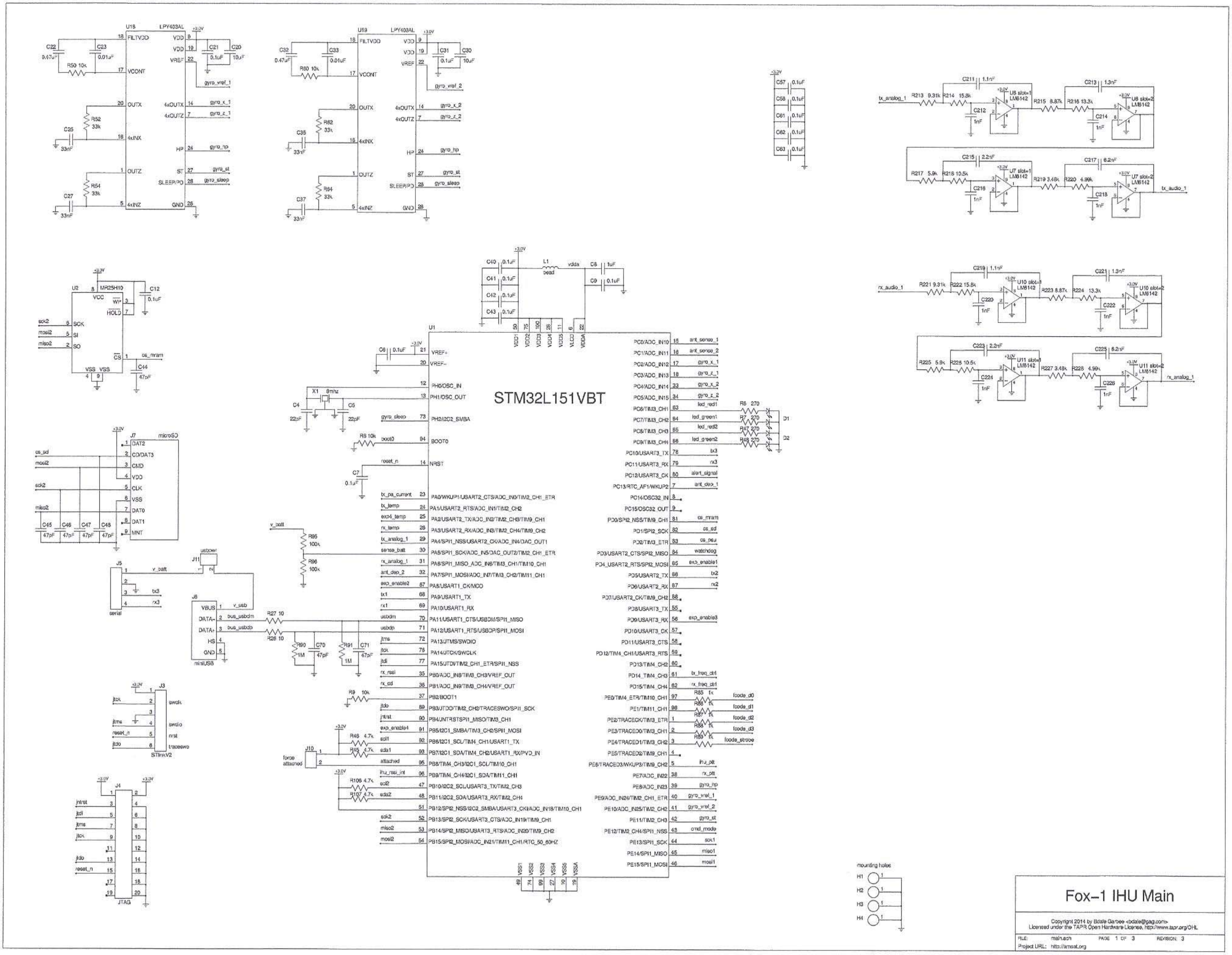
TITLE: Transmitter V3

Document Number:
AMSAT-NA FOX-1 TX V3

REV: 3.01

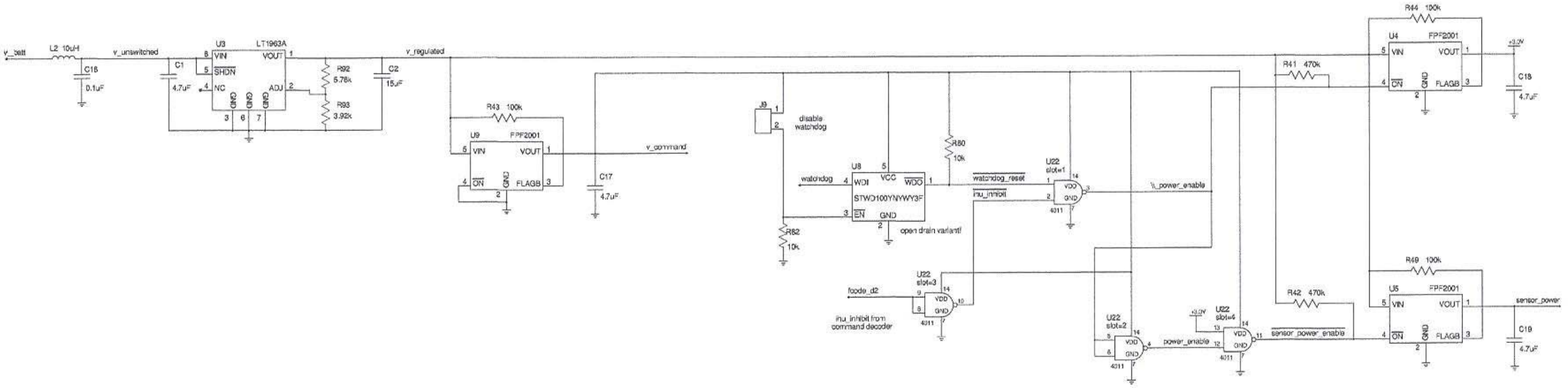
Date: 9/15/2014 5:53:59 PM

Sheet: 9/9



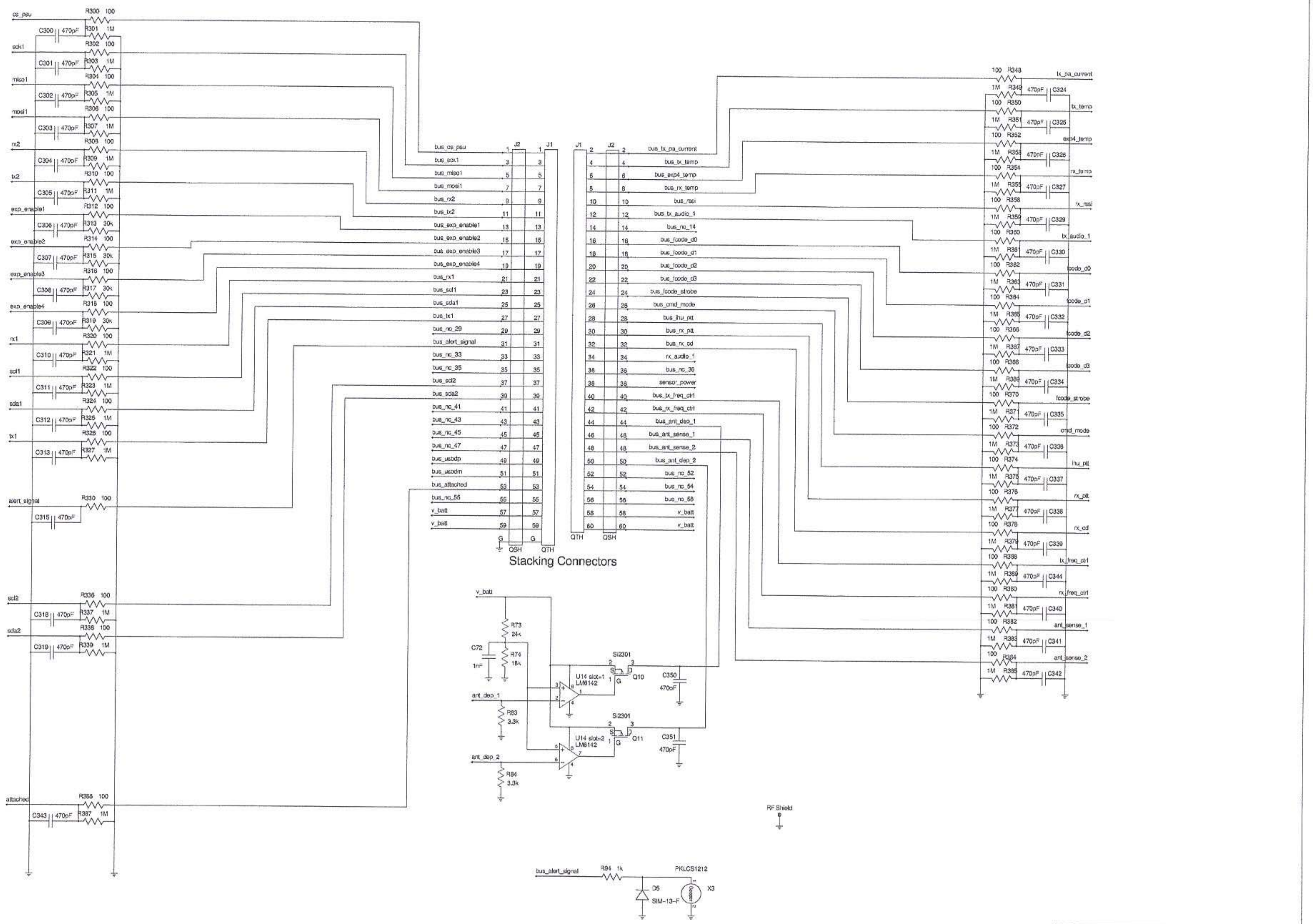
Fox–1 IHU Main

FILE: main.sch PAGE 1 OF 3 REVISION: 3
Project URL: http://amsat.org



Fox–1 IHU Power

FILE: power.sch PAGE 2 OF 3 REVISION: 3
Project URL: http://amsat.org



Fox–1 IHU Stacking Bus

FILE: bus.sch PAGE 3 OF 3 REVISION: 3
Project URL: http://amsat.org

Date: October 2, 2015
Version: 1.1
Author: Bryce Salmi, KB1LQC

AMSAT Fox-1 Maximum Power Point Tracker

Introduction

The Radio Amateur Satellite Corporation, *AMSAT*, has designed and built a series of 1U Cubesats referred to as Fox-1. Starting with these 1U Cubesats, AMSAT will build up intellectual property to leverage onto future satellite designs. A requirement for the Fox-1 satellites is an efficient way to maximize power generation from solar cells with a scalable Maximum Power Point Tracker, *MPPT*. Based on the Fox-2 design originally conceived by the P13271 senior design team[1] at the Rochester Institute of Technology AMSAT has developed a radiation tolerant analog MPPT for use on the Fox-1 satellites. Lessons learned building the Fox-1 MPPT detailed in this document can also be rolled into any future Fox-2 MPPT design.

Document History

DATE	VERSION	SUMMARY
January 21, 2015	1.0	Initial creation of document
October 2, 2015	1.1	Updated with flight design

Document Scope

The purpose of this document is to clearly explain how the Fox-1 MPPT has been designed, how it operates, and to how any known failure modes or risks affect the spacecraft. Only PCB Revision 1.1 of the Fox-1 MPPT is detailed in this document. It also assumes a basic level of electrical knowledge and leaves some calculations up to the reader with reference material noted.

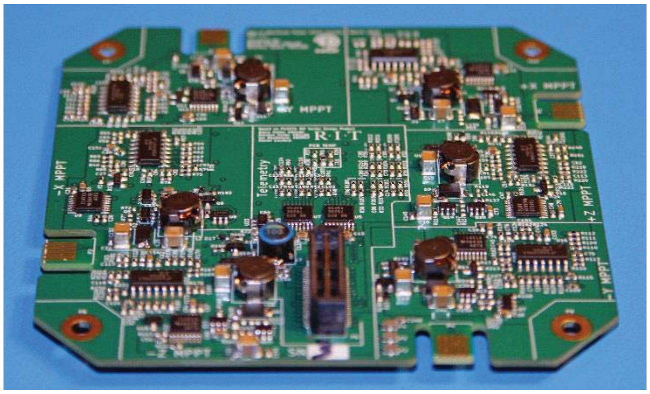


Figure 1: Fox-1 MPPT Rev 1.1

---

[1] Bryce Salmi (KB1LQC), Brenton Salmi (KB1LQD), Ian MacKenzie (KB3OCF), Dan Corriero

Contents

Overview

The Fox-1 MPPT PCB contains six set-point constant voltage MPPT circuits[2] with a single MPPT dedicated to each side of the spacecraft. Every side of Fox-1 contains two Spectrolab UTJ solar cells connected in series. All six MPPTs are combined through ideal diodes which allows for power sharing as the satellite rotates in orbit. The common diode OR'd output node then delivers the combined power of all sufficiently illuminated solar panels to the spacecraft main voltage bus. The Fox-1 MPPT also contains a telemetry circuit able to communicate with the Internal Housekeeping Unit, *IHU*, via I^{2}C communications. It's important to note that each of the six MPPTs is a zero fault tolerant design.

Specifications

Parameter	Value	Units
Maximum Input Voltage	50	*Volts*
Minimum Input Voltage	3.6	*Volts*
Maximum Input Current (Per MPPT)	0.443	*Amperes*
Maximum Input Power (Per MPPT)	2.57	*Watts*
Maximum Output Current (Per MPPT)	0.780	*Amps @ 3.3V Vout*
Maximum Output Voltage	4.33V	*Volts*
Maximum Switching Efficiency	~88	*%*
Maximum Tracking Error	+-5	*%*
Temperature Range of Components	-40° to +125°	*Celsius*
Solar Cell Operating Temperature Range	-60° to +60°	*Celsius*

Table 1: Overall Fox-1 MPPT Specifications

Careful use of radiation tested components, shielding, and a stateless design in the critical MPPT feedback loops on Fox-1 has been implemented in order to promote a 5 year mission timeline and an estimated 30kRad TID exposure. The stateless design hardens the MPPT to Single Event Upsets, *SEU,* and Single Event Latch-ups, SEL, which are expected during the mission. Table 1 documents the general specifications achieved as supported by engineering bring-up data.

---

[2] http://cdn.intechopen.com/pdfs-wm/37984.pdf

Spectrolab UTJ Solar Cells

Fox-1 was designed for use with two SpectroLab UTJ solar cells in series on each solar panel with each cell having 27 cm^2 of area as shown in Figure 2. Table 11 in the Appendix shows the calculations of the maximum power point thermal drift. This information was used to design the MPPT as well as predict the amount of power available to Fox-1 at any panel temperature expected in orbit. The RTD measuring panel temperature is mounted to the back side of the solar panels out of direct sunlight.

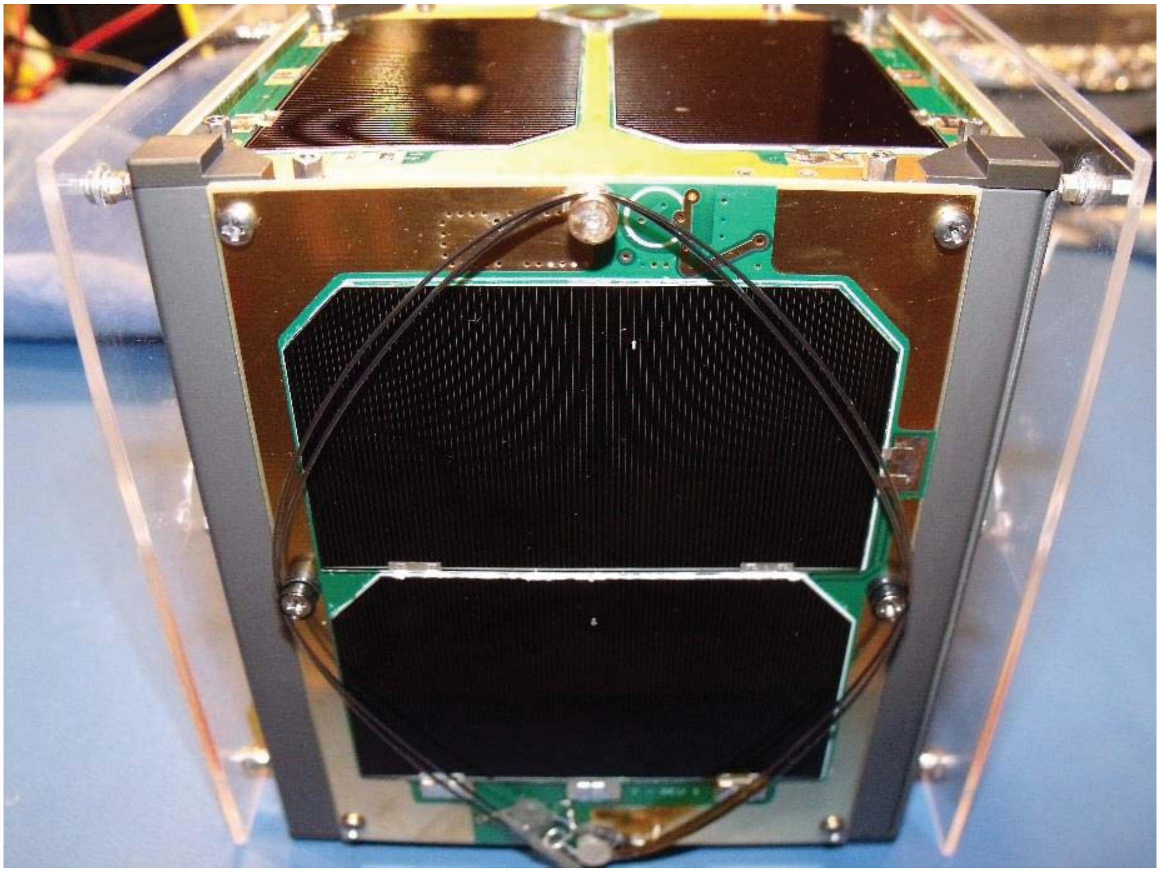


Figure 2: Solar panels on Fox-1, a stowed antenna is shown on the closest facing solar panel

MPPT PCB Configuration

PCB Block Diagram

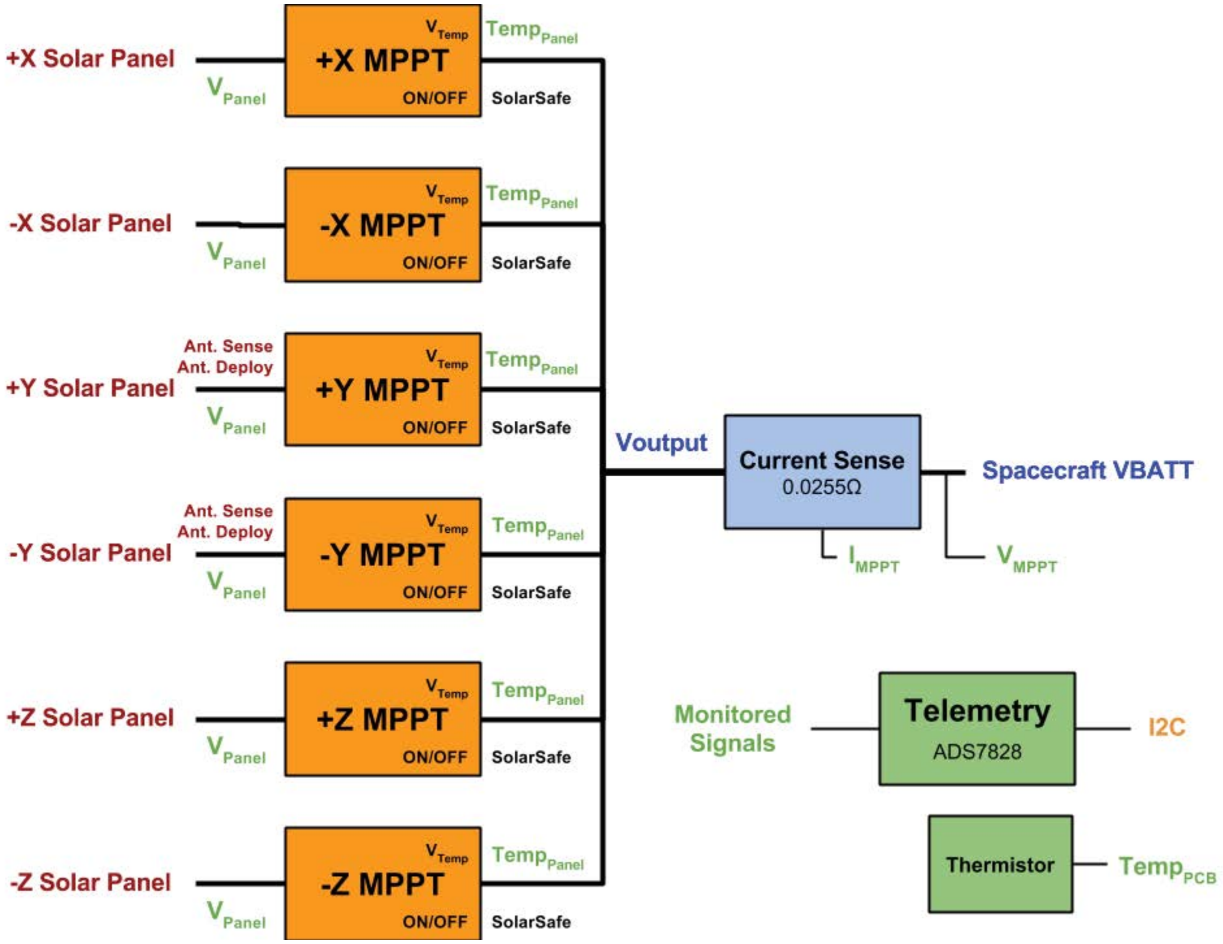


Figure 3: Fox-1 MPPT PCB block diagram containing six individual MPPT circuits combined together

Six Individual Maximum Power Point Trackers obtain power from their respective solar panels and if sufficient power is available then combine the generated power onto a common output node through ideal diodes. The combined power is then fed through a current sense circuit before being sent to the Fox-1 “VBATT” node to power the satellite and charge the batteries. A telemetry system comprised of voltage dividers, RC low pass filters, and ADC’s gather engineering data for transmission to the IHU via I^2C communications.

The design of the Fox-1 MPPT does not require a battery on the output of the PCB for proper operation. In the event of a battery failure where a properly designed circuit will disconnect the battery from the satellite power bus, the MPPT is fully capable of operation. The requirement for this operation however is that no more than maximum power available from the MPPT can be requested from the payload. This means that if the satellite can operate by never drawing more power than the lowest power available from solar panels then indefinite operation without a battery is possible.

Power is obtained from the X and Y axis panels through PCB edge connectors (Samtec *MEC1-105-02-L-D-NP-A*) and through the board-to-board connectors (Samtec *QSH-030-01-L-D-A* and *QTH-030-02-L-D-A*). Besides solar power, signals passing through these PCB edge connectors are the RTD connections (ground referenced) for measurement of each solar panel temperature as well as two antenna deploy and sense channels on the Y panels. The antenna deploy and sense connections are not thoroughly covered in this document, please refer to the schematic. All copper planes have been pulled back from the connector and a maximum of 20 mil traces were used to the connectors themselves to prevent heat loss to space from the MPPT PCB which is necessary for proper operation

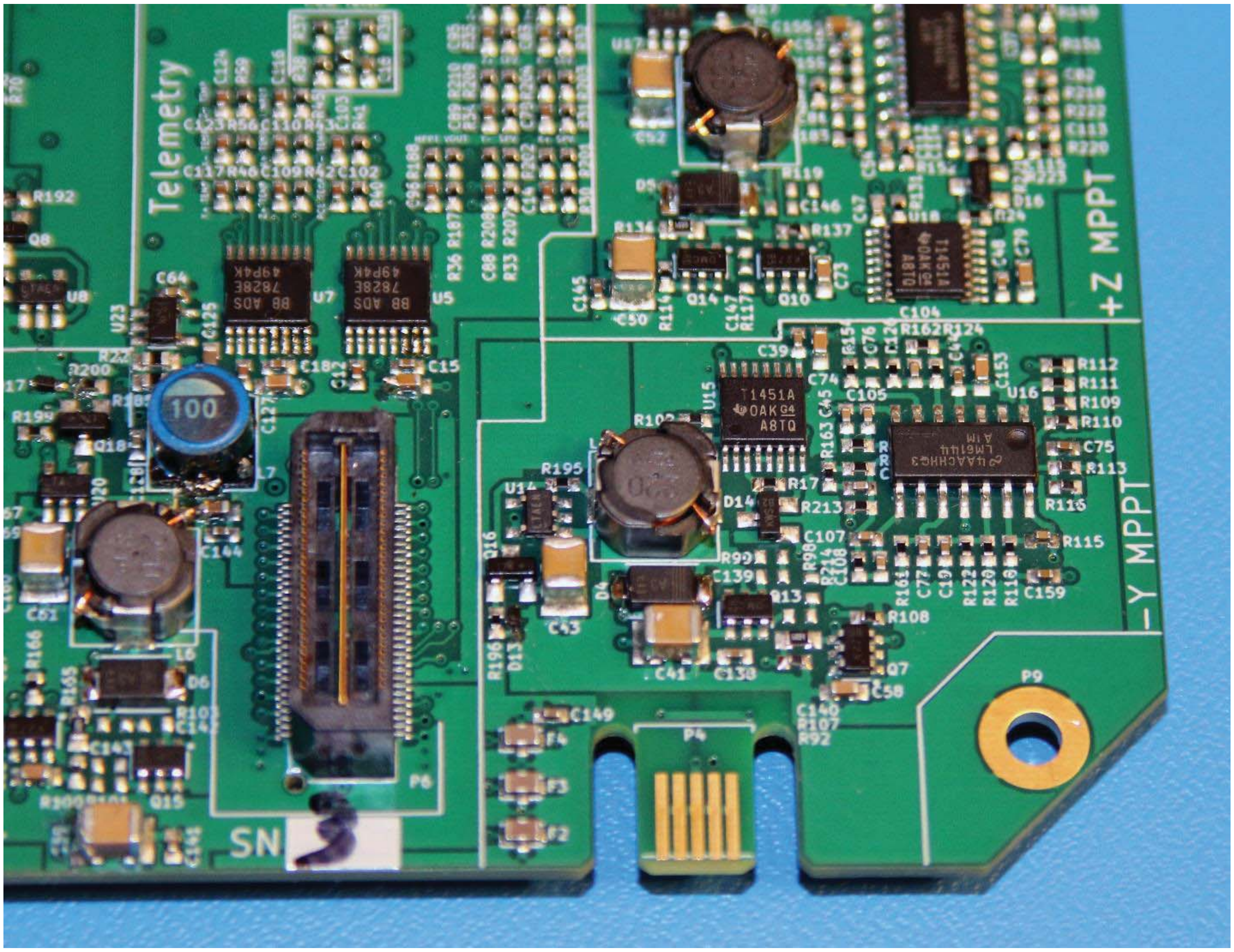
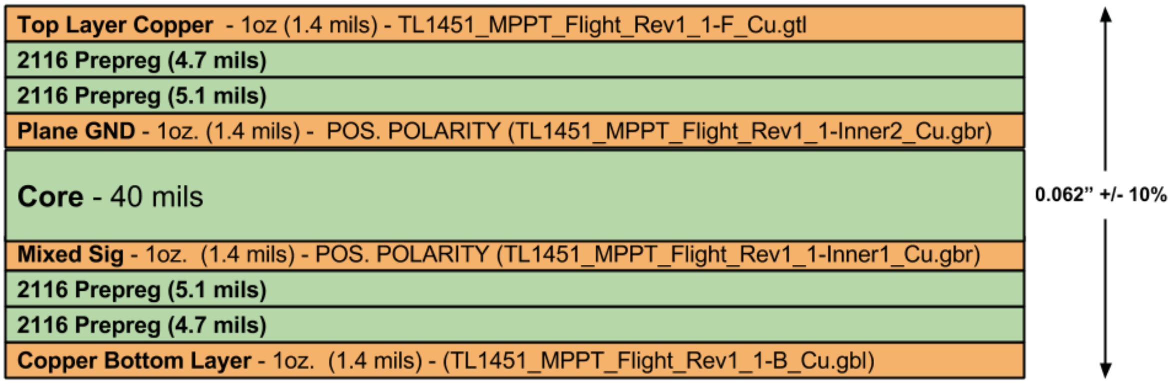


Figure 4: Samtec QTH-030-02-L-D-A board to board connector shown on left side of image, Samtec MEC1-105-02-L-D-NP-A edge connector shown near middle of image with male portion of connector made of PCB material

PCB Design

Each PCB is a four layer board developed in the open source KiCad EDA (Build: 2013-07-07 BZR 4022)-stable on Windows. Gerber files were exported and sent to Advanced Circuits for fabrication. Since Gerbers are very portable file formats, AMSAT has the ability to use almost any manufacturer they choose. All relevant PCB processes have been documented in the “Drawings” Layer of the Gerbers.

PCB Stackup



Top Layer Copper - 1oz (1.4 mils) - TL1451_MPPT_Flight_Rev1_1-F_Cu.gtl

2116 Prepreg (4.7 mils)

2116 Prepreg (5.1 mils)

Plane GND - 1oz. (1.4 mils) - POS. POLARITY (TL1451_MPPT_Flight_Rev1_1-Inner2_Cu.gbr)

Core - 40 mils

Mixed Sig - 1oz. (1.4 mils) - POS. POLARITY (TL1451_MPPT_Flight_Rev1_1-Inner1_Cu.gbr)

2116 Prepreg (5.1 mils)

2116 Prepreg (4.7 mils)

Copper Bottom Layer - 1oz. (1.4 mils) - (TL1451_MPPT_Flight_Rev1_1-B_Cu.gbl)

Figure 5: Four layer PCB stackup used on the Fox-1 MPPT Rev 1.1 PCB

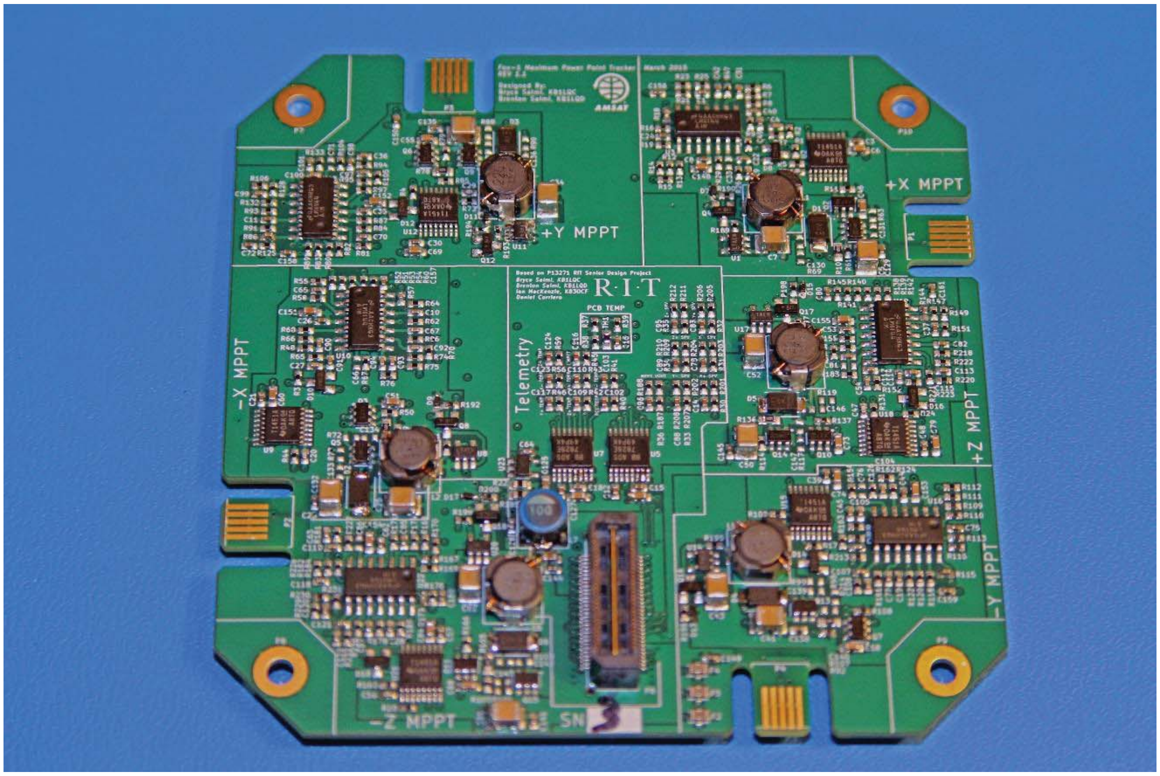


Figure 6: Fox-1 MPPT Rev 1.1 PCB with top layer visible, all components other than stacking connector located on top layer

Maximum Power Point Tracker Design

MPPT Overview

The Fox-1 MPPT is designed as a temperature based set-point constant voltage MPPT and is implemented with analog circuitry to mitigate radiation events associated with holding state. There are two discrete feedback loops implemented in the design, the MPPT feedback loop and an output voltage regulation feedback loop. Both MPPT feedback loop and MPPT as a PCB will be referred to in this document and the context will determine the subject. The output voltage regulation circuitry limits the MPPT channel output voltage to 4.33V prior to the ideal diodes in order to protect the Fox-1 payload and batteries from overvoltage conditions. Using temperature based MPPT allowed power to be maximized without computational resources such as a microcontroller which requires state.

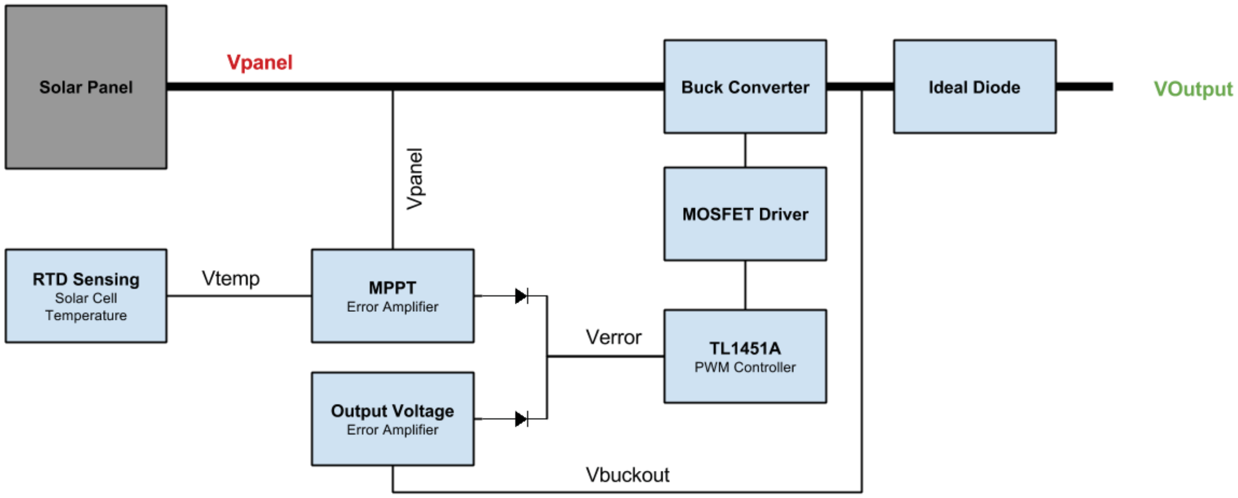


Figure 7: Fox-1 MPPT & voltage regulation feedback block diagram

As shown in Figure 7, there are two feedback loops used to control the TL1451A PWM controller. The internal TL1451A error amplifier is used as a unity gain buffer to directly pass the combined V_{error} signal from the external error amplifiers into the internal comparator used to generate the PWM signal. The inversions from the TL1451A open collector PWM output and PMOS gate create the following V_{error} to duty cycle relationship shown in Table 2.

V_{error} Change	**PWM Duty Cycle**
Increasing	Decreasing
Decreasing	Increasing

Table 2: Error voltage effect on the PWM duty cycle

Therefore, a simple diode-OR is used to combine both the MPPT error amplifier and output voltage regulation error amplifier signals. *This results in the highest voltage error signal applied to the TL1451A winning control of the buck converter and forcing the lowest duty cycle of the two feedback loops to be implemented*. This is extremely advantageous as shown later in this document.

MPPT Schematics

The latest version of the schematics for the Fox-1 MPPT are located in the AMSAT SVN MPPT folder. Using KiCad to open “*TL1451_MPPT_Flight_Rev1.pro*” one has access to the schematics and PCB files within the KiCad EDA. An important note is that the libraries and footprints used for KiCad live in the SVN Power KiCad folder so those must be checked out too and Kicad may need to be told where they are on your computer to display properly. An annotated PDF version of the schematics is provided with this document.

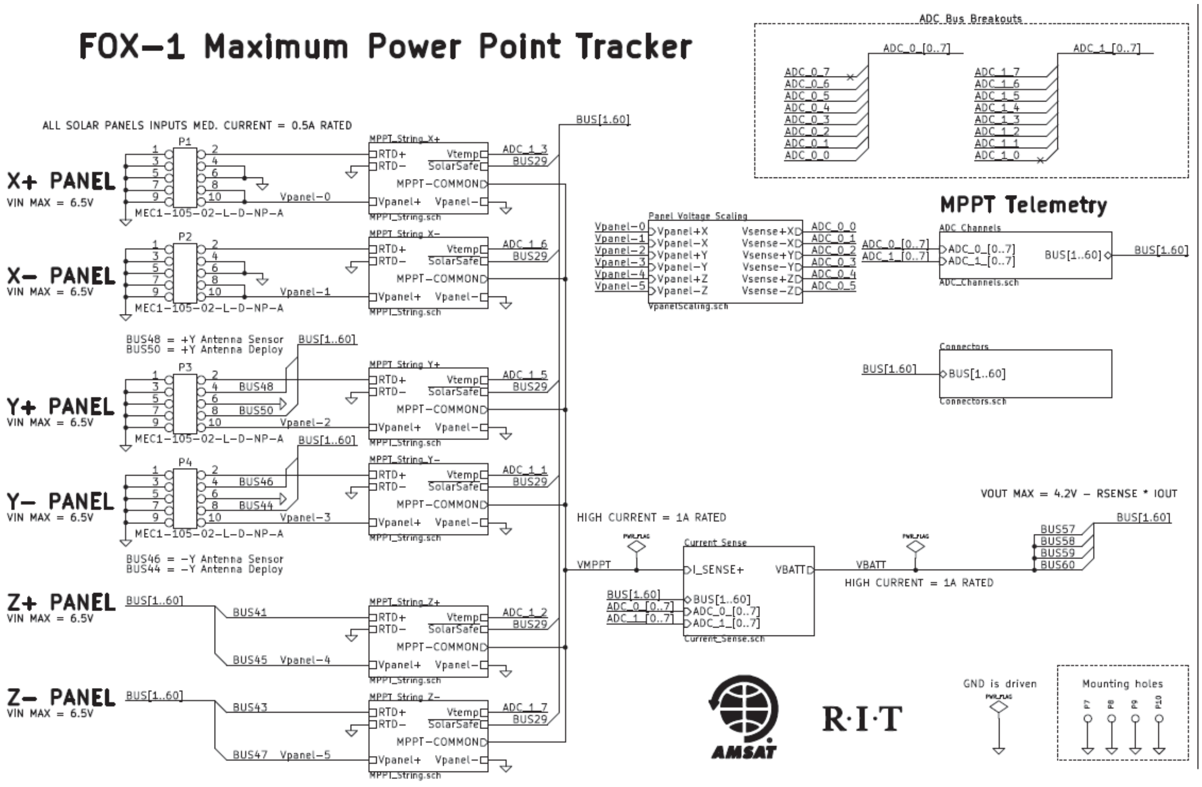


Figure 8: Main schematic page of the Fox-1 MPPT closely resembling the block diagram in Figure 3

The schematics are built up in a hierarchical arrangement as shown in Figure 8 much like block diagrams that contain sub-circuits within individual blocks. This makes understanding signal flows much easier and is very different from how EAGLE presents schematics. The main schematic page looks a lot like the overview block diagram shown in Figure 3. Hierarchical design results in a large number of schematics sheets due to channelization of the design. An annotated schematic included with this document at the 2015 AMSAT Symposium details all unique MPPT PCB circuits without duplication.

Resistive Temperature Detector Circuitry

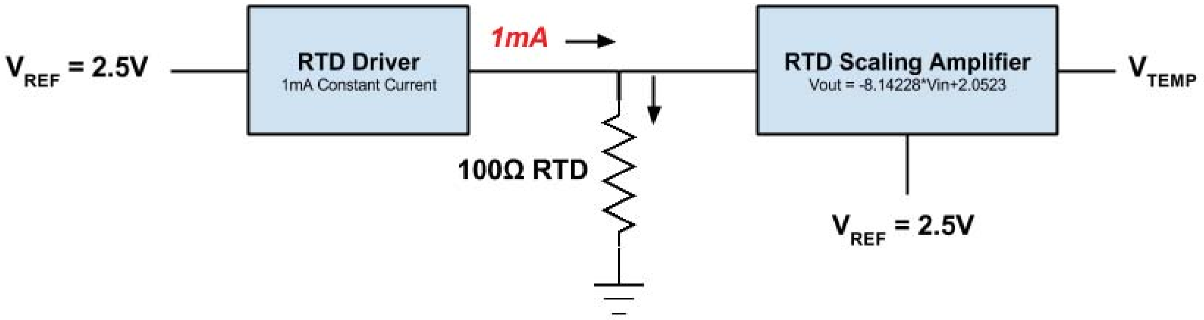


Figure 9: RTD drive and sensing block diagram

The AMSAT MPPT uses resistive temperature detectors, *RTDs*, to accurately measure solar panel temperature which is then used to predict the Maximum Power Point Voltage, *MPPV*. A constant current source forces exactly 1 mA into the RTD leaving only voltage to change with varying resistance as the RTD changes temperature. Both voltage and resistance are directly correlated as governed by Ohms law when using a constant current source. The measured voltage developed across the RTD is conditioned and amplified using a simultaneous equation based op-amp circuit implementing analog mathematics. This produces a voltage mimicking the solar panel voltage at MPPV and can be referenced by the MPPT error amplifier as it compares real panel voltage against this predicted reference voltage. This scaled voltage produced by the amplifier is referred to as V_{temp}. The RTD used for each panel is a PT100 type device, nominally 100Ω at 0°C (PTS080501B100RP100). RTDs are not thermistors, they use a pure metal such as nickel or platinum which have very accurate and predictable changes in resistance over temperature and nearly linear responses over the temperature ranges used.

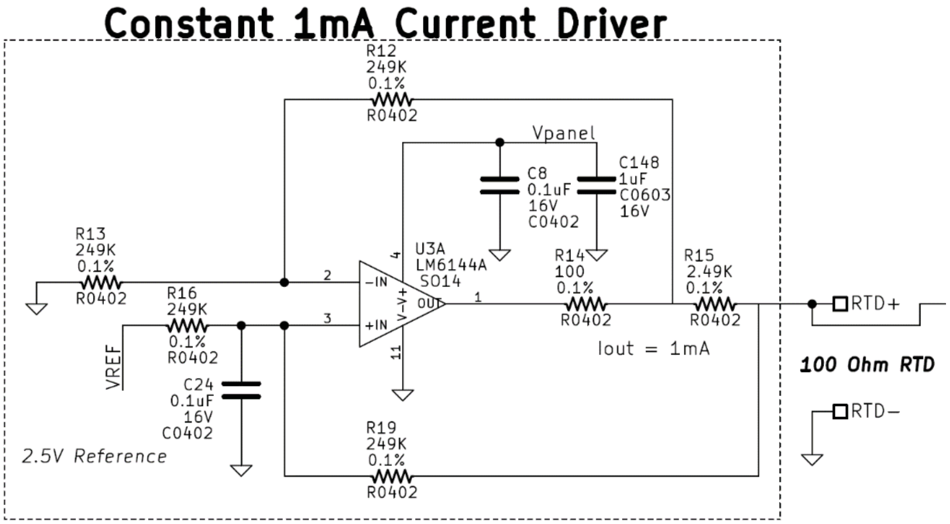


Figure 10: Fox-1 MPPT RTD constant current driver

U3A of Figure 10 is a LM6144A op-amp configured as a constant 1 mA source. Its sole purpose is to force exactly 1 mA of current through the RTD. Figure 11 shows a LTSpice schematic of the 1 mA RTD driver and is used to describe the RTD circuit for the remainder of this description. The following equation determines the output voltage of the op-amp U1:

$$Vout = V_2\left(\frac{R_4}{R_3 + R_4}\right) \times \left(\frac{R_2 + R_1}{R_2}\right) - V_1 \times \frac{R_1}{R_2}$$

Where V_2 is the reference voltage and V_1 is the grounded pad of R_1. However, since R_1, R_2, R_3, and R_4 are all 249KΩ we simplify the equation down to:

$$V_{OUT} = V_2 - V_1 = 2.5\text{V}$$

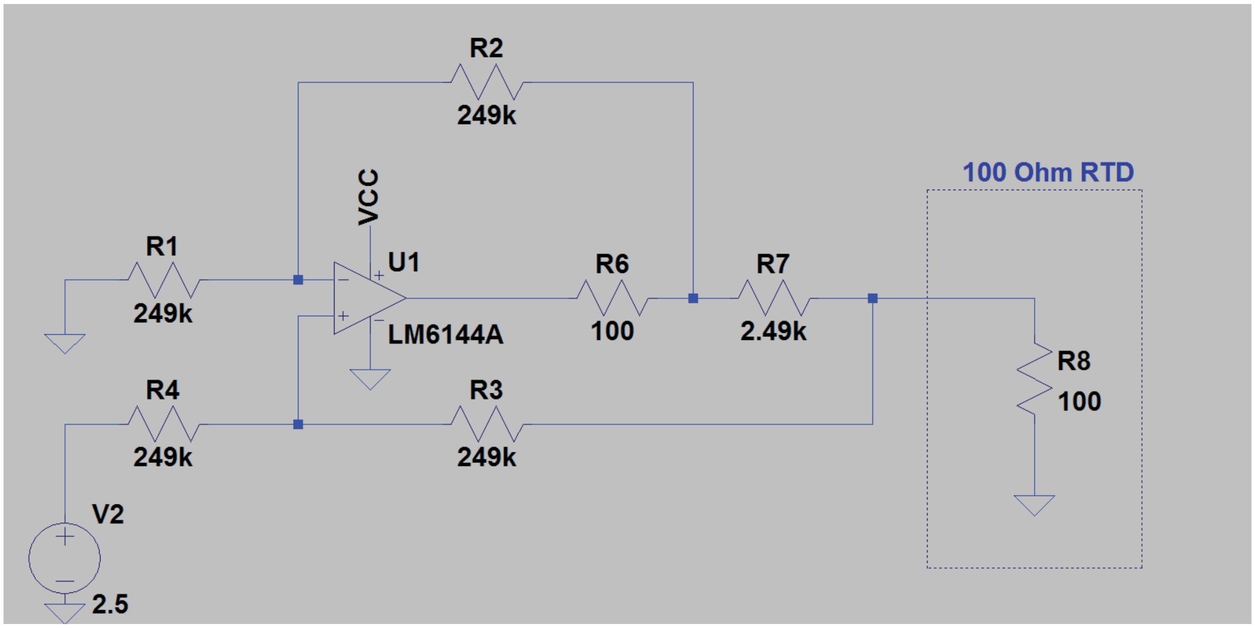


Figure 11: LTSpice 1mA RTD drive simulation schematic, capacitors not simulated.

Knowing we have 2.5V across R7 due to op-amp laws the following relationship for drive current is made.

$$R_7 = \frac{V_2}{I_{Drive}} = \frac{2.5V}{1mA} = 2.5K\Omega$$

With 1 mA of drive current being forced into R8 (a 100Ω RTD) the voltage across it is predictable thanks to Ohms Law. 1 mA of drive current will dissipate about 100uW of power in the RTD and therefore cause minimal internal self-heating of the device and allows for accurate measurements. Table 3 shows several data points along the operating conditions expected in orbit for the solar panels and the respective RTD circuit voltage.

RTD Temperature	Voltage Across RTD
-60°C	0.076V
0°C	0.100V
28°C	0.111V
+60°C	0.124V

Table 3: Expected RTD voltages at 1mA drive current

The voltage across the RTD is very small (between 76mV and 124mV) and exhibits a positive thermal coefficient. This means the voltage increases as the temperature increases. However, the solar cells exhibit a negative temperature coefficient since the MPPT voltage decreases with a temperature increase. An op-amp configured to follow a polynomial equation is used to amplify the measured RTD voltage and flip the RTD voltage thermal coefficient. Essentially the op-amp performs the function $y = -mX + b$ as covered in SLOA076 from Texas Instruments. The flight conditioning circuit implementing analog mathematics is shown in Figure 12. Note that the feedback capacitor C162 is not accounted for in the PCB layout and on MPPT Rev 1.1 was soldered in parallel across the feedback resistor by physically stacking the capacitor onto of R18.

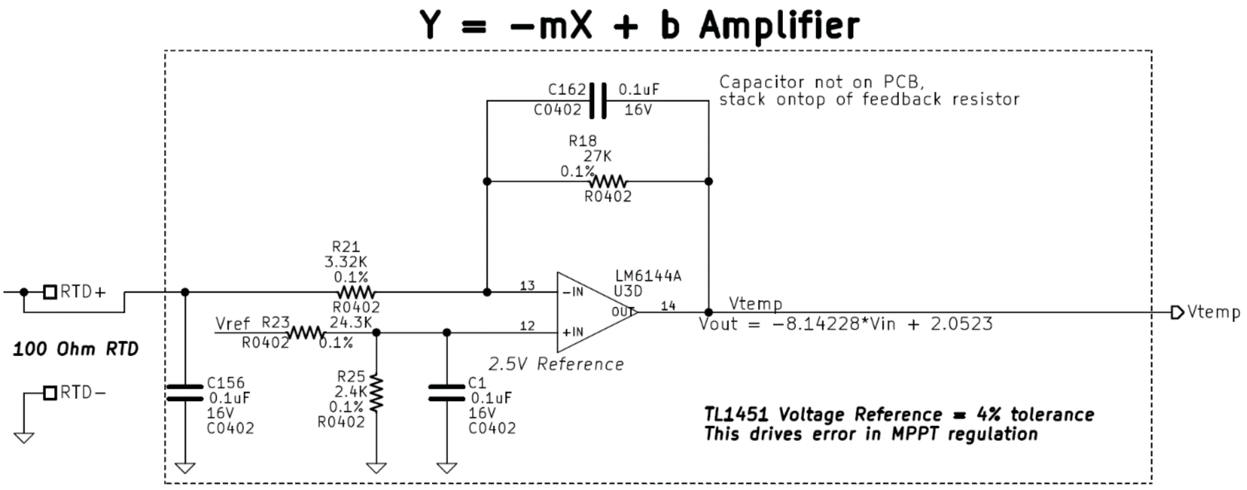


Figure 12: Scaling amplifier implemented on the Fox-1 MPPT panel temperature circuit which mimics solar panel MPPV

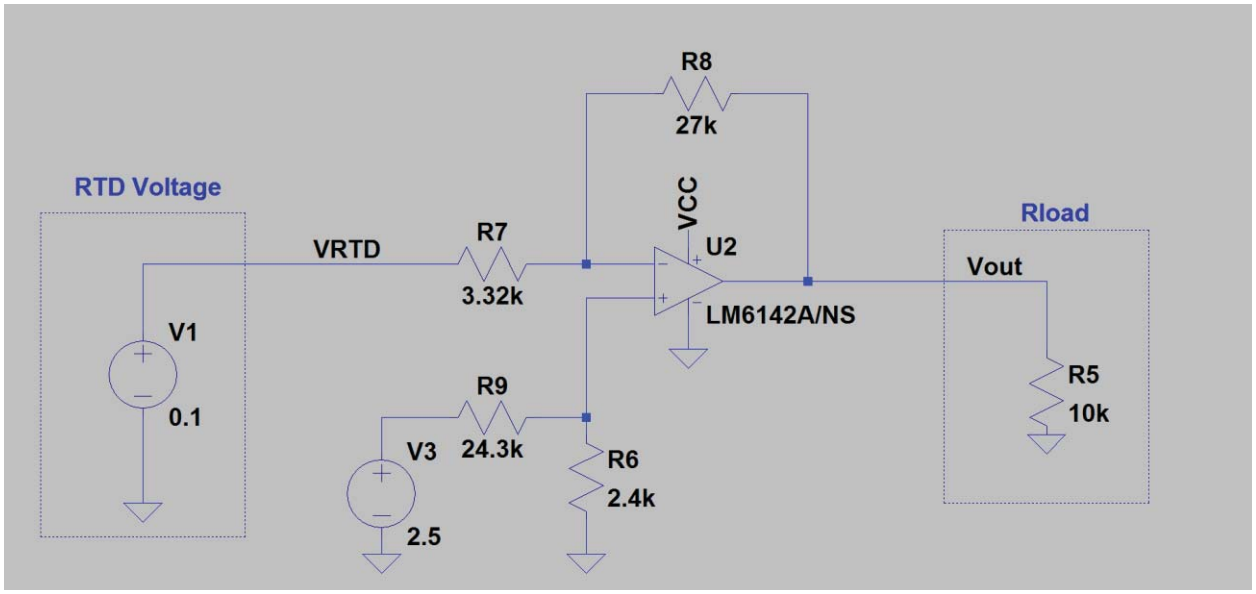


Figure 13: An LTSpice simulation of the RTD scaling amplifier, capacitors not simulated

Figure 13 shows the LTSpice simulation of the RTD conditioning amplifier referenced in the following description. Voltage source V1 represents the RTD voltage being measured and V3 represents the 2.5V reference from the TL1451A. A capacitor is added in the flight circuit across R6 to ground to low pass filter the voltage reference as shown in Figure 12. Another capacitor has been placed across R8 in the flight circuit to reduce the bandwidth of the circuit for stability also shown in Figure 12. A differential amplifier was not used to buffer the RTD since the solar panel PCBs have already been produced and were designed for thermistors which have one of the pins grounded and therefore the RTDs have a grounded pin too, rendering a differential amplifier not effective.

The TL1451A recommended error amplifier input voltage range is 1.05V to 1.45V so the panel voltage has been scaled by 0.245 using voltage dividers before being measured. The RTD predicted panel voltage must mimic this scaled voltage. The voltages in the Fox-1 Solar Panel Calculations in the Appendix show that minimum MPPV is obtained when high temperature panels are tracked at 4.28V and the maximum MPPV is 5.84V when the panels are tracked at low temperatures. This results in a MPPV voltage range of 1.048V to 1.430V present at the MPPT error amplifier during nominal power point tracking. These voltages are used as part of the simultaneous equations solved in SLOA076 and are given in Table 4 which are used to translate RTD measured voltages into the predicted MPPV reference voltage V_{temp}. The predicted voltage is also telemetered to sense panel temperature remotely from Earth via RF telemetry. With some basic mathematics described in the ADC section of this document the panel temperature can be resolved back from this voltage as measured by the ADC.

RTD Temperature	RTD Voltage	Vout Desired
60°C	0.124V	1.048V
-60°C	0.076V	1.430V

Table 4: Voltages used to solve for the scaling amplifiers component values

The values used for the output voltage of the scaling amplifier were chosen based on obtainable resistor values resulting in the following equation relating V_{out} of Figure 13 to RTD voltage:

$$V_{OUT} = -8.14228 \cdot V_{IN} + 2.0523$$

Figure 14 shows the RTD voltage versus scaling amplifier output voltage (predicted MPPV). The amplifier clearly amplifies the voltage as well as flips the temperature coefficient to match the Spectrolab solar cell based panel temperature coefficient.

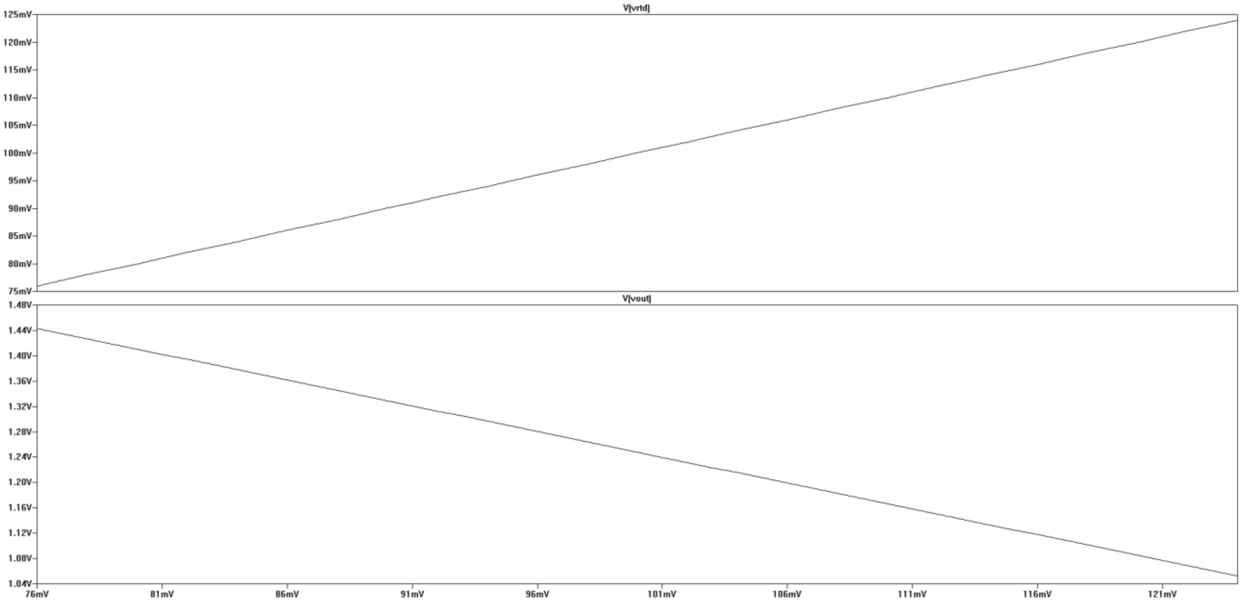


Figure 14: Simulated RTD voltage input to the amplifier and output voltage representing the scaled panel voltage desired. The top graph shows the RTD voltage over the expected operating range while the bottom graph shows the resulting op-amp output voltage for the

Totem Pole MOSFET Driver

The PWM output from the TL1451A is an open collector circuit and cannot provide a low impedance drive signal into the switching MOSFET gate. A low impedance drive signal is necessary to quickly turn the MOSFET on and off. A pull-up resistor, R11 in Figure 15, is connected to the open collector pin of the TL1451A where the PWM signal is output. More information can be found regarding MOSFET drivers in SLUP169 from TI.

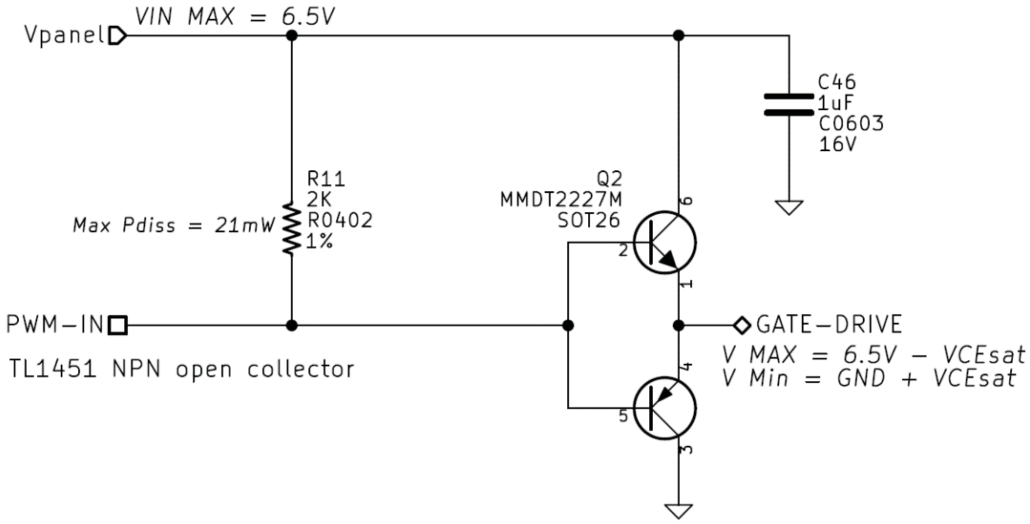


Figure 15: Open collector PWM output and totem pole MOSFET driver

The TL1451A output open collector stage inverts the signal produced by the PWM generator which is then fed into the totem pole driver (Q2 in Figure 15) which is a non-inverting circuit. The totem pole operates by pulling the MOSFET gate close to ground or close to the solar panel voltage, well into saturation or cutoff of the switching MOSFET. When the TL1451A open collector output pulls towards ground this will cause the PNP transistor base of Q2 (pin 5) to be a lower voltage than its emitter (pin 4 assumed at Vpanel) forcing the device into conduction and draining the MOSFET gate (GATE-DRIVE) into ground. Panel voltage from the open collector when it is open circuit will cause the PNP of Q2 to go into cutoff (base is higher voltage than emitter near ground) and then drive the NPN base (pin 2) to a higher voltage than the NPN emitter (pin 1) also near ground. This puts the NPN device into conduction and connects the solar panel voltage to the gate of the MOSFET. The voltage of the MOSFET gate will always be around a V_{BE} below panel voltage or above ground during cutoff and saturation respectively.

Buck Converter

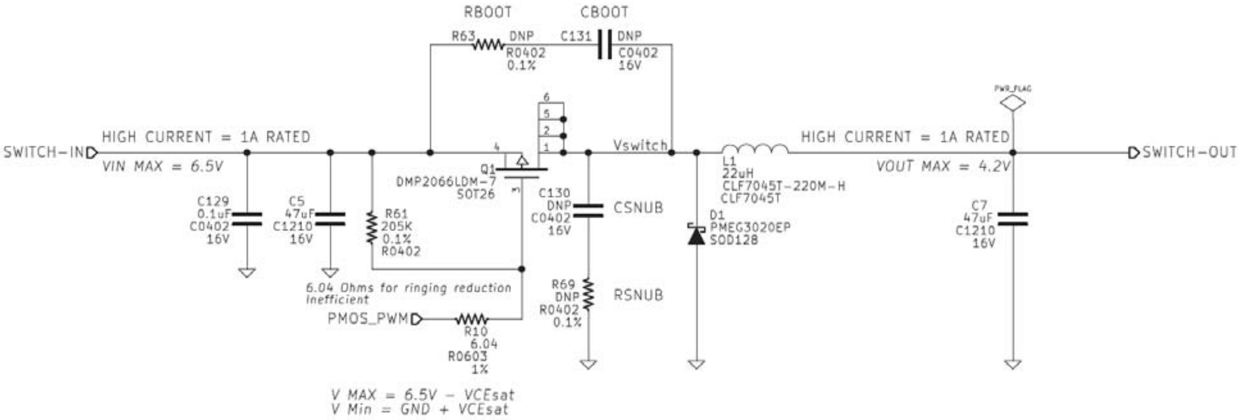


Figure 16: Fox-1 MPPT buck converter switching circuitry

A standard buck converter has been implemented on the Fox-1 MPPT as shown in Figure 16. The output of the totem pole MOSFET driver (GATE-DRIVE) is fed into PMOS_PWM which drives the gate of the P-channel device (PMOS) through a 6.04Ω resistor to dampen ringing. Standard buck converter design techniques were followed (SLVA477) to derive initial component values. The values in Table 5 show the parameters used to initially design the buck converter stage, these are assumptions about operating conditions prior to actually building the converter.

50mA was assumed to be the lowest current the buck converter would see when operating to guarantee continuous conduction mode and 780mA is the amount of current the coldest solar panel operating at MPPT would dump into a fully discharged battery at 3.3V. These are bounds which create a design capable of operating at all times in Fox-1. The design is non-synchronous and uses a catch diode as shown in Figure 16**Error! Reference source not found.**. Increased efficiency could be realized with a synchronous design in the future. Additionally, snubbing and boot RC circuits have been added to allow the control of ringing and edge rise time if necessary from the switching node to ground and the source to drain of the switching MOSFET. In the event that the series resistance to the gate is disconnected, a pullup resistor R61 has been implemented to provide fault tolerance by forcing the MOSFET off in that failure mode.

Parameter	Value	Unit
Minimum Input Voltage	4.284	Volts
Maximum Input Voltage	6.464	Volts
Minimum Output Voltage	3.3	Volts
Maximum Output Voltage	4.33	Volts
Minimum Current	0.050	A
Maximum Current	0.780	A
Assumed Efficiency	90	%
Minimum Duty Cycle	0.5	Ratio
Maximum Duty Cycle	0.98	Ratio

Table 5: Basic buck converter parameters used for the Fox-1 MPPT design

MPPT Feedback

Maximum Power Point Tracking on Fox-1 is achieved by predicting the expected MPPV determined by the measured solar panel temperature using an RTD as previously described. The solar panel voltage, V_{panel}, and predicted MPPV, V_{temp}, are fed into a dedicated MPPT error amplifier built using an LM6144A op-amp as shown in Figure 17.

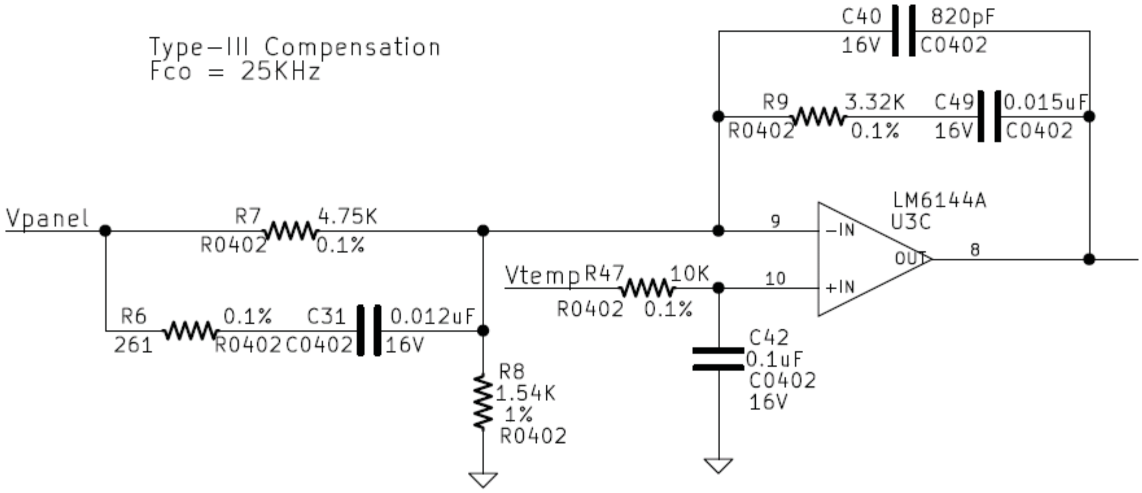


Figure 17: Maximum Power Point Tracking error amplifier

In Figure 17 the solar panel voltage is applied to the voltage divider created by R7 and R8 scaling the panel voltage by 0.245 and driving the inverting input of the op-amp U3C while the RTD measured

V_{Temp} signal is applied to the non-inverting input as the reference voltage for the error amplifier. The op-amp output voltage, V_{error}, is determined by the following equation

$$V_{OUT} = A \cdot (V_{IN+} - V_{IN-}) = A \cdot (V_{Temp} - V_{panel} \cdot 0.245)$$

This means that given a large gain A from U3C, the output of of the error amplifier will decrease towards ground whenever the panel voltage is greater than the predicted V_{Temp}. Likewise, when V_{Panel} is lower than V_{Temp} the output voltage increases towards the VCC voltage rail (panel voltage). The following relationship can be determined:

V_{error} Change	PWM Duty Cycle Change	Panel Voltage	Output Voltage
Increasing	Decreasing	Increasing Voltage	Decreasing Voltage
Decreasing	Increasing	Decreasing Voltage	Increasing Voltage

Table 6: MPPT error amplifier output effect on solar panel and MPPT output voltage

Type-III compensation has been implemented due to the use of ceramic capacitors which exhibit a high frequency resonance with the buck converter and cause a near 180° phase-lag at the crossover frequency: a recipe for switch-mode converter instability. More information about compensating buck converters can be found in SLVA301 from TI and specifically for Type-III in AN-1162 from International Rectifier.

A crossover frequency of 25 KHz was chosen after building the MPPT and performing engineering tests. It was discovered that the TL1451A could not change the output voltage quick enough at its switching frequency when the bandwidth of the error amplifier was set much higher. Therefore, 25KHz was empirically chosen but cannot be drastically increased without instability. This bandwidth is faster than necessary to respond to a spinning Cubesat and provides adequate transient performance.

Output Voltage Regulation Feedback

The purpose of the output voltage regulation error amplifier is to limit the maximum output voltage allowed to 4.33V at all times to protect the payload. A maximum of 4.33V accounts for some voltage drop from the ideal diode resulting in about 4.2V maximum at the battery. When this error amplifier is in control of the buck converter the maximum power of the solar panel is disregarded. This means the operating point is indeterminate but also unnecessary to know since full power is not needed. This occurs when the output voltage is close to 4.33V due to a fully charged battery and enough power from the panels is available to not discharge the batteries. Moving away from the maximum power point causes the extra power to dissipate as heat in the solar cells, radiating into space.

Much like the MPPT feedback error amplifier, the output voltage regulation error amplifier is implemented with a discrete LM6144A op-amp and compensated with a Type-III compensator. A 25KHz crossover frequency of the compensation network was also chosen to play nice with the TL1451A PWM controller. Refer to Figure 18 for the schematic of the voltage regulation error amplifier.

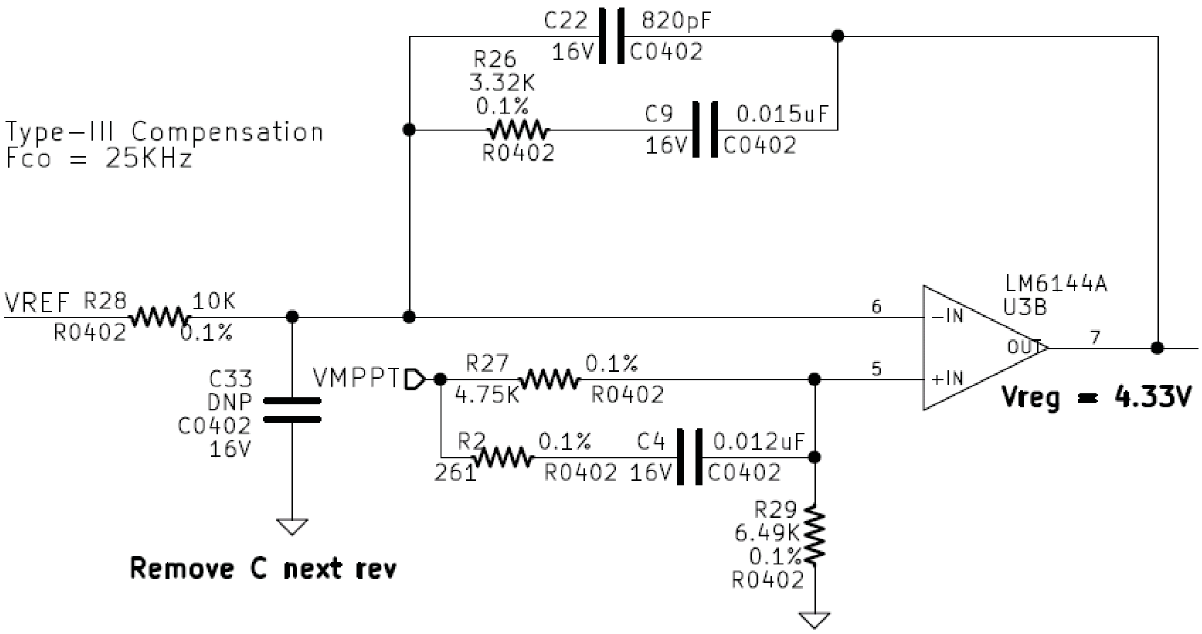


Figure 18: Output voltage regulation error amplifier

The output voltage regulation error amplifier is configured such that the 2.5V voltage reference (from the TL1451A) is applied to the inverting error amplifier input and the buck converter output voltage, V_{Output} (VMPPT), is applied to the non-inverting input. This is a classic voltage regulation error amplifier scheme. Notice that in Figure 18 C33 is DNP'd and a note to remove it is present. During engineering bring-up testing it was determined that C33 caused a low frequency oscillation of the converter and should be removed (along with respective capacitors in other MPPT channels).

The op-amp output voltage is determined by the following equation where A is the open loop gain and the output voltage is scaled to regulate to 4.33V. The resulting duty cycle characteristics can be observed in Table 7. Notice how the effects of the voltage regulation error amplifier signal are exactly the same as the MPPT error signal. The schematic in Figure 18 shows the Type-III compensation modified slightly to invert the output of the LM6144A used as a voltage regulator and match the necessary V_{error} polarity for implementation of the overall circuit characteristics detailed in Table 2.

$$V_{error} = A \cdot (V_{IN+} - V_{IN-}) = A \cdot (0.577 \cdot \ V_{Output} - V_{ref})$$

Whenever the output voltage V_{Output} is larger than the 2.5V reference, the error amplifier increases its output voltage and PWM duty cycle will trend towards 0% in an effort to reduce V_{Output}. Consequently, whenever V_{Output} is lower than the 2.5V reference, the error amplifier signal will trend towards ground and the duty cycle will trend up towards 100% in an effort to increase the output voltage.

V_{error} Change	PWM Duty Cycle Change	Panel Voltage	Output Voltage
Increasing	Decreasing	Increasing Voltage	Decreasing Voltage
Decreasing	Increasing	Decreasing Voltage	Increasing Voltage

Table 7: Output voltage regulation duty cycle characteristics

TL1451A Pulse-Width Modulation Controller

Converting error signals into Pulse-Width Modulation, *PWM*, signals is the job of the Texas Instruments TL1451A PWM controller shown in Figure 19. This IC provides two synchronized PWM circuits but only one is used on Fox-1, coupling of failure modes of a single TL1451A removing two MPPTs from service was unwarranted. It was also the only PWM controller IC found to operate at the low voltages required and most ASIC MPPTs could not operate above panel voltage of 5V. The TL1451A obtains power directly from the panel it's controlling and therefore it turns on when the panel reaches 3.6V, well above the LM6144A op-amp providing the input error signals which turns on at 1.8V. Thus ensuring valid input signals when powered on. The *PWM* generator uses an RC oscillator comprised of C2 and R5 running the circuit at a nominal 500 KHz. Frequency stability is not critical but thermal stability is highly recommended. The internal error amplifier is setup in a unity-gain configuration and simply buffers the externally generated error signals coming from the MPPT and voltage regulation error amplifiers detailed earlier.

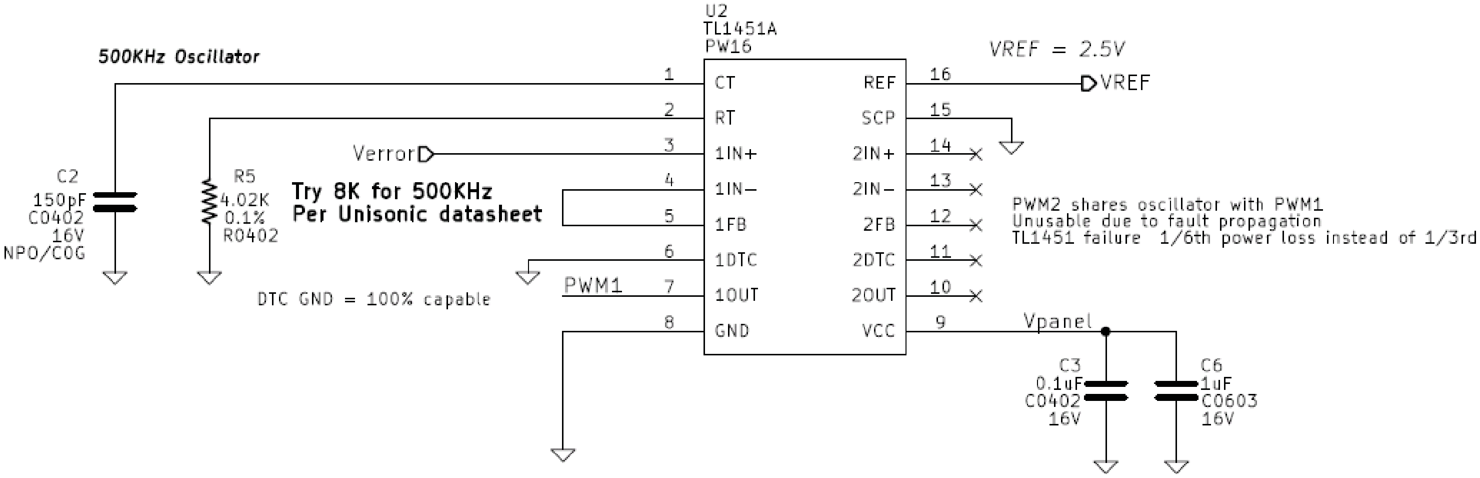


Figure 19: The TL1451 circuitry on Fox-1 used to convert error signals into PWM signals controlling the buck converter

As shown in Figure 20, the TL1451A uses the error signal from Error Amplifier 1 to compare with a triangle wave generated by the oscillator. The dead time control, *DTC*, pin is grounded in Figure 19 as it is disabled. Short-circuit protection, *SCP*, is also grounded and therefore disabled since solar panels effectively limit the short circuit current. The error signal from Error Amplifier 1 (unity gain) is sent into the PWM comparator and then into an AND gate (always passes due to *DTC* pin configuration) which drives an open-collector NPN output transistor. Figure 21 shows the error signal and corresponding waveforms related to the TL1451A.

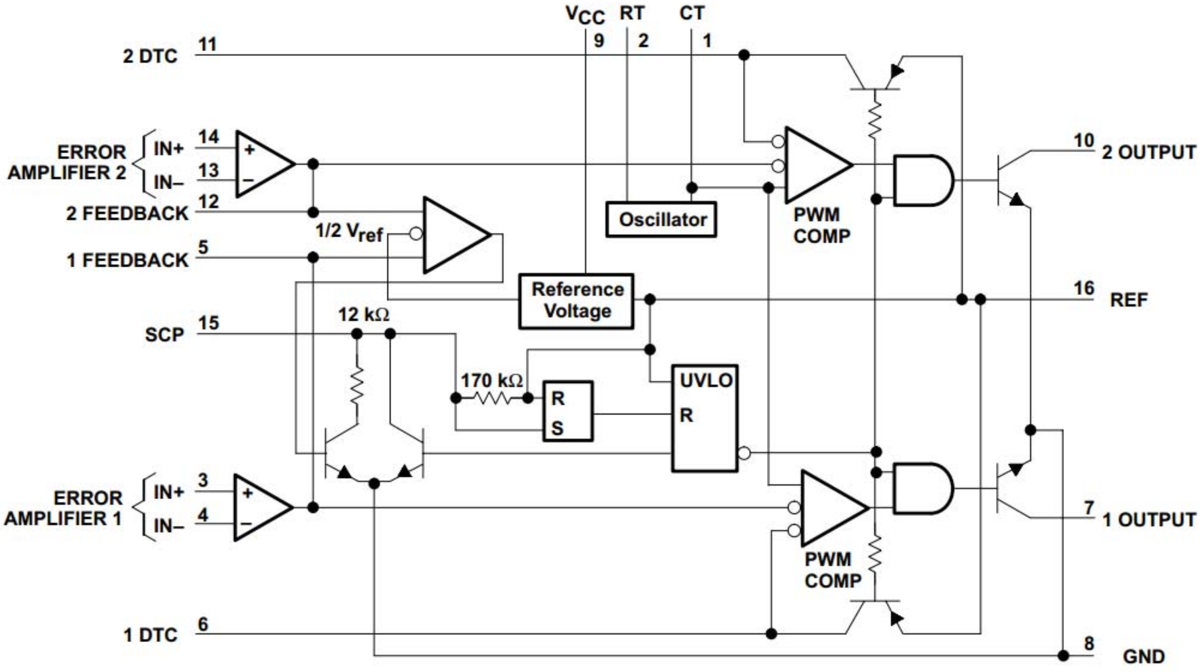


Figure 20: TL1451 block diagram from TI's datasheet SLVS024E

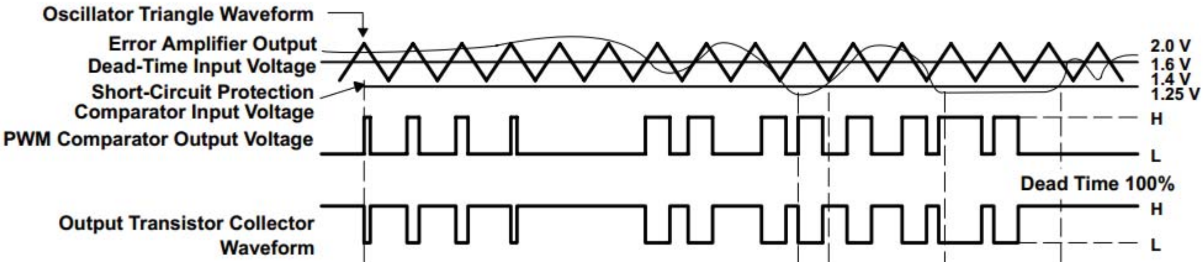


Figure 21: Example error amplifier to PWM open collector output signal path from TI's datasheet SLVS024E

The magic inside the Fox-1 MPPT happens at the output of the MPPT and voltage feedback error amplifiers shown in **Error! Reference source not found.**. Both error signals are combined in a diode-OR configuration with D8, a common cathode Schottky diode array. This combined error signal is sent directly into the TL1451A error amplifier. R1 is a pull down resistor necessary to allow proper operation by discharging the node slightly.

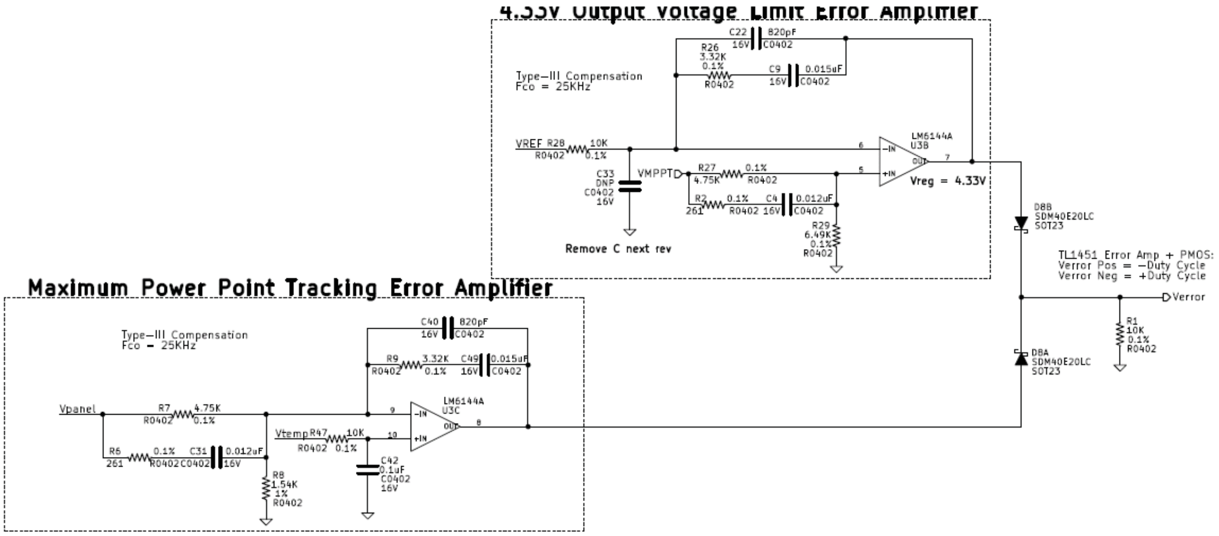


Figure 22: MPPT and output voltage regulation error amplifiers diode-OR connection into TL1451A error amplifier

The resulting effect of the diode-OR circuit combining the error signals in Figure 22 is that the highest voltage error amplifier always wins control of the TL1451A. As noted in Table 2, an increasing error signal demands a lower duty cycle which means this circuit properly interfaces with the PWM controller. Once an error amplifier voltage drops below the other, D8 will reverse bias for that amplifier. The voltage drop across D8 does not matter because the error amplifiers will force up to the solar panel voltage out in an effort to decrease duty cycle (4.28V "lowest" maximum voltage during operation) and automatically compensate for this loss as regulation is maintained.

How MPPT and Voltage Regulation Coexist

It's important to remember the overall interaction of the MPPT and voltage regulation feedback loops must coexist with the input and output power scenarios presented to Fox-1. When the Fox-1 payload is not transmitting and has just finished charging its batteries in full sunlight the panels will be capable of delivering maximum power to the satellite which is no longer using all the power generated. At this point the MPPT feedback loop is in control. Since more power is delivered to the output than needed the output voltage rises and attempts to go above 4.33V. At this point the voltage regulation error amplifier output rises quickly and overtakes the MPPT voltage, reverse biasing D8 for the MPPT error signal, in an effort to reduce the duty cycle and maintain output regulation at 4.33V. This causes the solar panel voltage to rise towards open circuit voltage as less current is being pulled from it, delivering less power to the payload. Meanwhile, the MPPT feedback loop rails low in an effort to increase the duty cycle, trying to reduce the panel voltage towards MPPV but the output voltage regulation error signal will remain in control since highest error amplifier voltage wins control of the TL1451A. Saturation of the op-amps as they rail towards ground in any case is not really an issue since spacecraft rotation is on the order of a few rotations per minute which allows the op-amps ample time to desaturate.

When Fox-1 enters eclipse with fully charged batteries it will discharge them during the eclipse period. The MPPT is off during this time, however when Fox-1 just comes out of eclipse into sunlight the batteries will be discharged which forces the MPPT output voltage lower than 4.33V. The output voltage of the converter is governed by the battery voltage. The output voltage regulation error amplifier attempts to increase duty cycle to increase the output voltage and increases charging current into the batteries, pulling more current from the solar panels. This continues until the MPPT error amplifier senses that the solar panel voltage has decreased to the predicted MPPV. At this point the voltage regulation error signal has decreased in an effort to increase duty cycle as the panel voltage lowered; delivering more energy to the output in order to maintain 4.33V. However, the MPPT error signal has also started to increase and will eventually be higher than the voltage regulation error signal, forward biasing the D8 for the voltage regulation error signal, causing the maximum power point to be tracked. This remains true until the converter output voltage rises towards 4.33V when the batteries have fully charged and the voltage regulation loop regains control.

The end result is a feedback loop configuration on Fox-1 that only delivers maximum power to the satellite when the satellite demands it; otherwise the MPPT circuitry uses its voltage regulator feedback loop to protect the downstream electronics and moves the solar panels away from MPPT. The MPPT is not expected to properly charge the batteries, which is the job of the battery PCB and circuitry.

Ideal Diode

Each of the six MPPTs has an ideal diode immediately following the buck converter as shown in Figure 23. This provides an efficient power diode-OR function and permits power sharing between MPPTs. Each ideal diode connects to a common output node that is fed into a current sense amplifier before sending power to the Fox-1 payload. The LTC4411 (U1) provides the ideal diode function with only 140mΩ of resistance which equates to 85mW of loss at the maximum output current of 780 mA. The output status pin is not used and the control pin which is active low is pulled up to the solar panel voltage whenever the solar safe circuit is enabled (remove before flight pin inserted); disabling the MPPT from powering Fox-1 at all. This is a launch vehicle safety feature demanded by some launch providers.

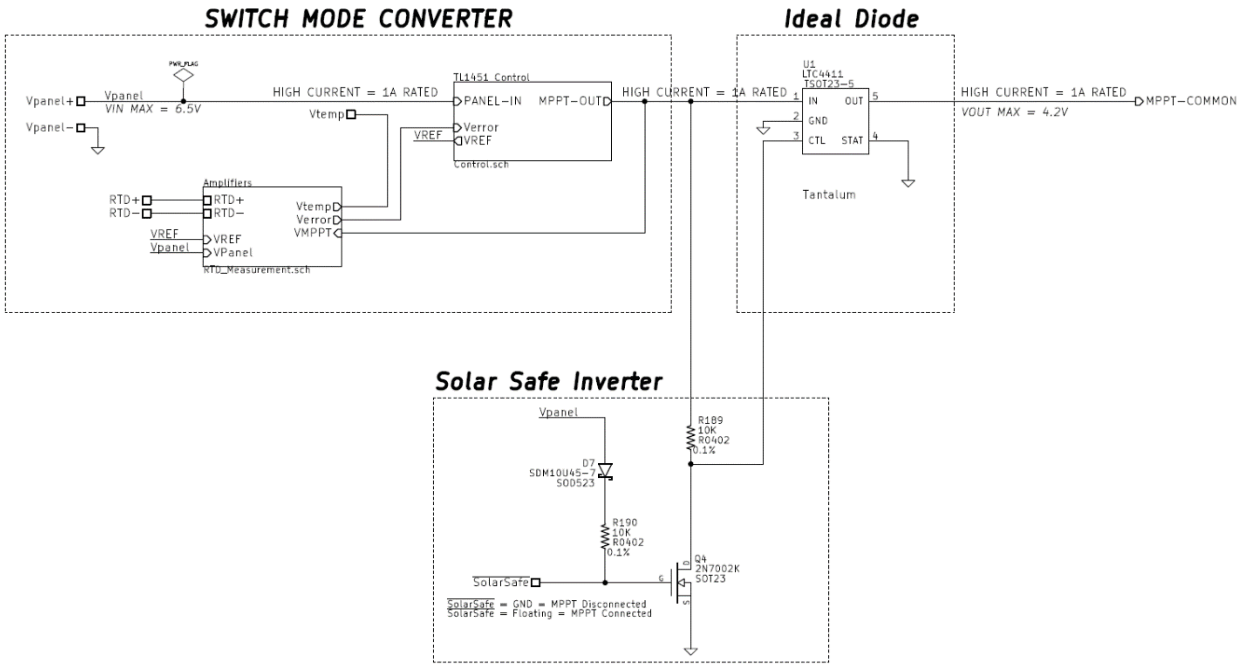


Figure 23: The LTC4411 ideal diode and accompanying solar safe circuitry shown with the MPPT converter circuitry

Solar Safe

In an effort to comply with PPOD and launch vehicle integration needs, the solar safe circuit is used to disconnect all MPPT circuits from the satellite, thus ensuring there is no way the satellite can obtain power while the remove before flight, *RBF*, pin is inserted. The solar safe signal is active low and is essentially a shorting bar to ground. Therefore while the RBF pin is inserted into its hole on Fox-1 the gate of Q4, is pulled to ground and turned off. This forces the ideal diode U1 in **Error! Reference source not found.** to turn off because the control pin is pulled high when the MPPT circuit turns on in sunlight.

Since the gate of Q4 is pulled up through R190 and D7, the shorting RBF pin will conduct through the respective devices to ground. R190 limits the current and D7 is used to prevent a reverse conduction path between each panel. When the RBF pin is the gate of Q4 is pulled up when the solar panel is in sunlight causing Q4 to conduct, pulling the LTC4411 control pin to ground and enabling the flow of current onto the satellite power bus from each MPPT.

Solar Safe is a common node among all six MPPT's of Fox-1. A single piece of Foreign Object Debris, FOD, or other fault pulling this node to ground in flight will completely disable all MPPT's. Disconnecting all MPPTs will cause the satellite to fail once the batteries have been depleted as they can no longer charge.

Telemetry Circuitry

The telemetry circuitry on the Fox-1 MPPT consists of analog voltage, current, and temperature sensing which are digitized by two 12-bit ADS7828 ADC’s. Power for all sensing circuitry is obtained from the IHU which is disabled when an IHU failure occurs. Sensor Power is provided from the PCB stack connector and is a regulated 3V. The idea for obtaining power from the IHU is that if/when the IHU gracefully fails it will go into a safe state which disconnects all telemetry power turning off the ADCs and support circuitry for them. This is largely a legacy requirement due to original Fox-1A circuitry designs.

PCB Temperature Thermistor Scaling

PCB temperature is measured by a thermistor powered by sensor power (3V) and attached to a linearizing circuit. The thermistor, TH1, is shown in Figure 24 and is linearize by R37, R38, and R39 while stabilized by C16. The resulting voltage is connected to Channel 0 of ADC 2. The linearizing circuit is based on the output from the Vishay Resistor/Thermistor Netsim Tool.

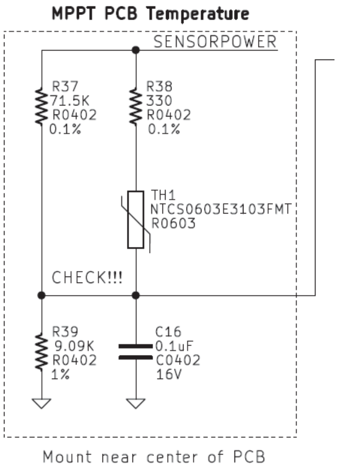


Figure 24: NTC thermistor linearizing circuit used to measure PCB temperature

Output Current Sense

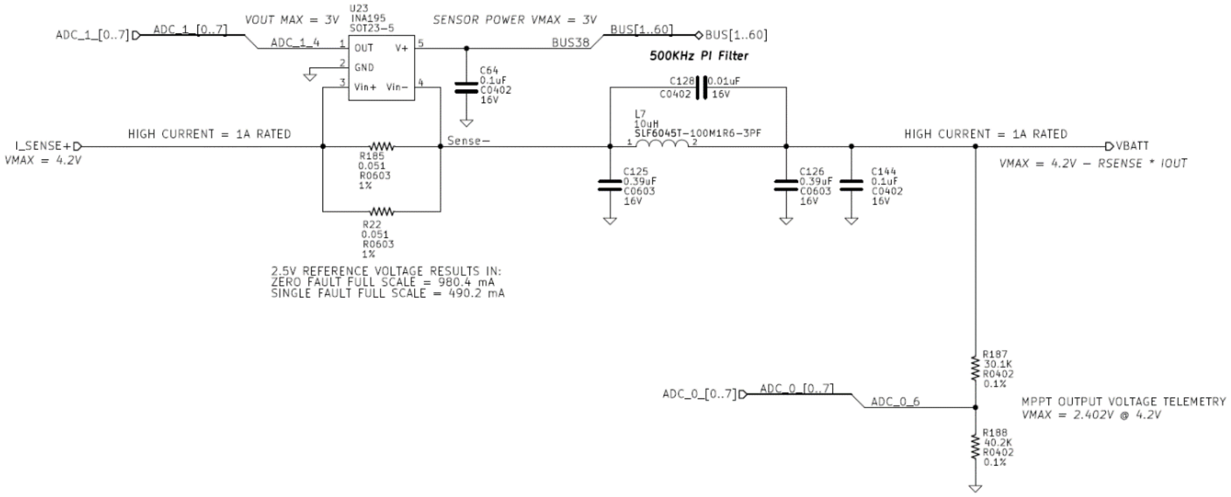


Figure 25: All MPPTs combine and feed through a current sense circuit for telemetry purposes

The common I_SENSE+ node is a combination of all six MPPT outputs following their respective ideal diodes. The INA195 from Texas Instruments is a 100V/V current shunt monitor measuring the voltage across a parallel combination of R22 and R185 shown in Figure 25. The shunt resistors are dual redundant to protect against a bad solder or vibration damage on one resistor causing complete current path loss and consequently mission failure.

In a parallel configuration the current shunt is nominally 0.0255Ω and will drop 19.9mV at the maximum output current of 780mA which is amplified by the INA195 to 1.989V. This dissipates about 15.5mW of power between both resistors at maximum current. In a fault case of either shunt resistor, a single 0.051Ω resistor will dissipate 31mW and the INA195 will attempt to amplify the signal up to 3.9V at maximum current but the output will be saturated at 3V from sensor power provided by the IHU. Table 8 shows the nominal and fault operation characteristics of the amplifier. Since the maximum output current from a single MPPT is 780mA, a failure of R22 or R185 will be observable as 980 mA whenever the current is expected to go over 490mA due to ground telemetry scaling coefficients. This should be obvious when compared to nominal operation data as full scale operation should not be common.

Shunt Resistance	ADC Full Scale Current	Mode
0.0255Ω	980mA	Nominal
0.051Ω	490mA	Fault

Table 8: Current shunt and amplifier values in nominal and fault modes of R22 and R185

Following the current sense amplifier is a capacitive input PI filter used to provide a low pass filter for MPPT voltage powering Fox-1. The parallel capacitor across L7 provides a deep null at the switching frequency.

Voltage Scaling Circuitry

The voltage dividers shown in Figure 26 scale all panel voltages by 0.428. This scaled voltage is then input into the low pass filters of the ADCs detailed next.

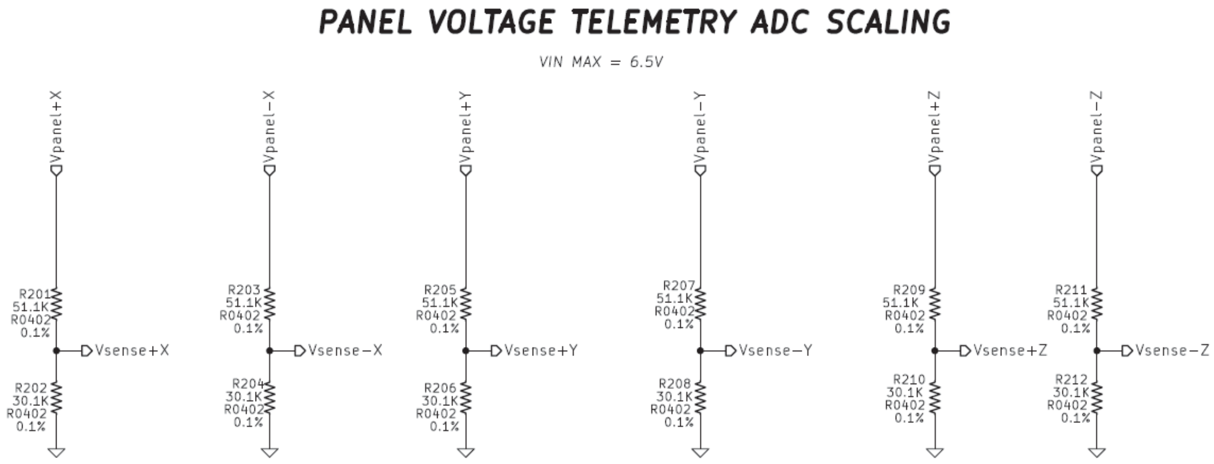


Figure 26: Voltage dividers used to scale solar panel voltages

Analog-to-Digital Converters

The ADS7828 ADCs communicate to the IHU via the I^2C protocol over the PCB stack connectors. These 12-bit ADCs are powered from 3V sensor power provided by the Fox-1 IHU card. The reasoning for this power configuration is to ensure that the ADC's are only turned ON/OFF when the microcontroller is operating correctly. Internal 2.5V references are used by the ADS7828 ADCs as commanded by the Fox-1 IHU via I^2C. This means each bit represents 610.4 uV on the ADC input, providing adequate resolution. Figure 27 and Figure 28 show the ADCs as implemented on the Fox-1 MPPT PCB.

16 Hz low pass filters are used to filter out high frequency content as telemetry is only sampled once every 15 seconds. This was deemed a suitable and realistic filter value. On-board IHU oversampling could be used to prevent aliasing but most signals of interest are so low frequency that avoiding aliasing is not a huge concern and that topic is outside the scope of this document. The filters also provide current limiting functionality for ADC protection. The series 10KΩ resistors limit current into the ADC to no more than about 320uA per channel when the ADC is on and about 650uA per channel when the ADC is off. It is important to remember that this only occurs during fault cases if signal conditioning circuits short panel voltage to the low pass filters. The limiting resistance works in conjunction with internal protection diodes inside the ADS7828 which conduct into the sensor power rail and ground.

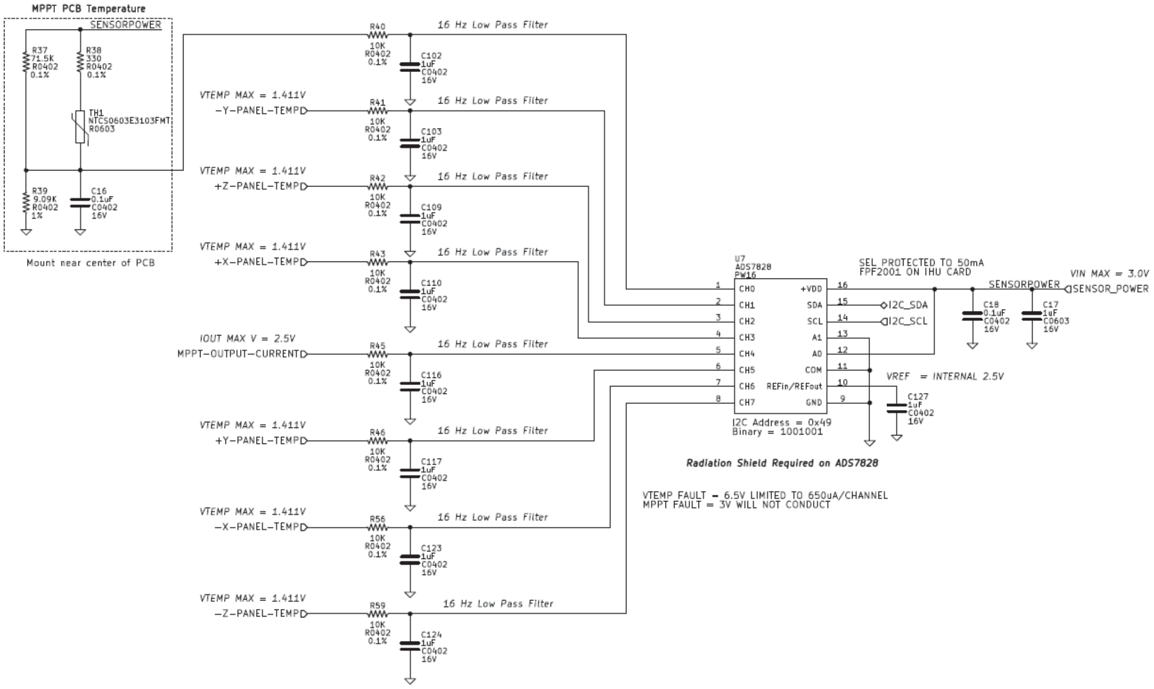


Figure 27: ADC 1 used to obtain PCB temperature, solar panel temperature, and output current telemetry.

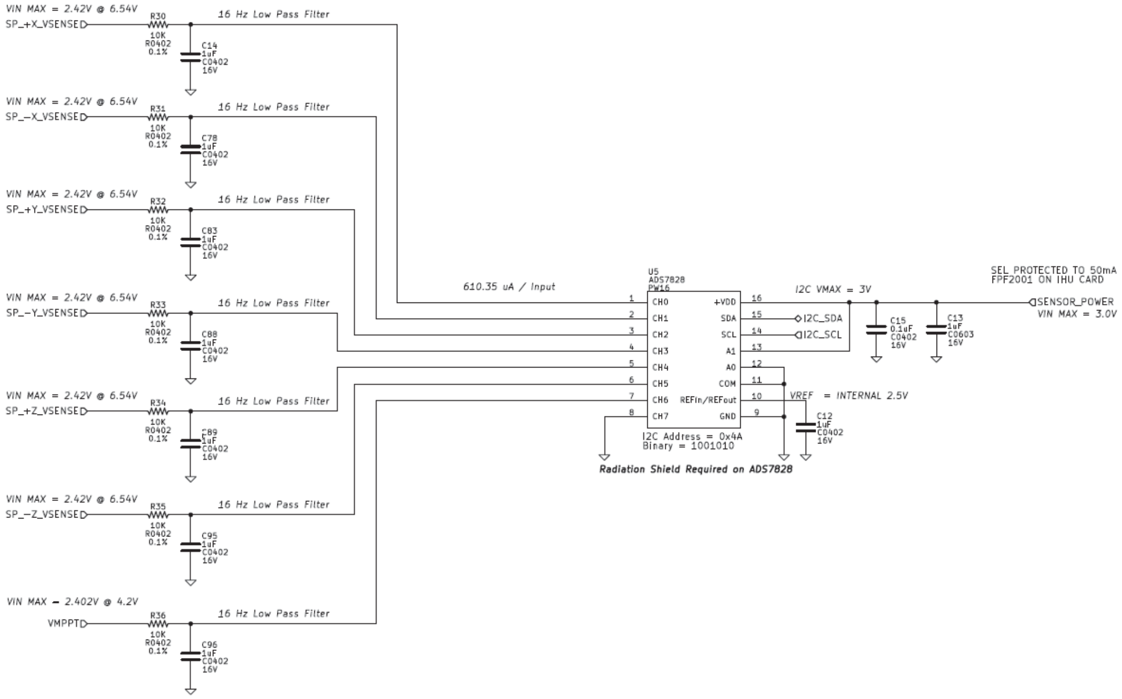


Figure 28: ADC 2 used to obtain solar panel and MPPT output voltage telemetry.

The I^{2}C communications defined in the AMSAT PSU to IHU ICD states that the IHU will be the I^{2}C master while the MPPT PCB ADCs will be slaves and that communications are established at 10 KHz. For more I^{2}C details please refer to the AMSAT PSU to IHU ICD.

ADC 1 (I^{2}C Address = 0x49)		
ADC Channel	**Telemetry Signal**	**Bit Scaling (Y = mX + b)**
0	PCB Temperature	Same as LDO PCB on Fox-1A
1	-Y Solar Panel RTD Resistance	m = -0.074961, b = 252.1
2	+Z Solar Panel RTD Resistance	m = -0.074961, b = 252.1
3	+X Solar Panel RTD Resistance	m = -0.074961, b = 252.1
4	MPPT Output Current	m = 2.3935E-4, b = 0
5	+Y Solar Panel RTD Resistance	m = -0.074961, b = 252.1
6	-X Solar Panel RTD Resistance	m = -0.074961, b = 252.1
7	-Z Solar Panel RTD Resistance	m = -0.074961, b = 252.1

Table 9: ADC 1 telemetry signals and scaling factors

ADC 2 (I^{2}C Address = 0x4A)		
ADC Channel	**Telemetry Signal**	**Bit Scaling (Y = mX + b)**
0	+X Solar Panel Voltage	m = 0.001647, b = 0
1	-X Solar Panel Voltage	m = 0.001647, b = 0
2	+Y Solar Panel Voltage	m = 0.001647, b = 0
3	-Y Solar Panel Voltage	m = 0.001647, b = 0
4	+Z Solar Panel Voltage	m = 0.001647, b = 0
5	-Z Solar Panel Voltage	m = 0.001647, b = 0
6	MPPT Output Voltage	m = 0.001647, b = 0
7	UNUSED (Grounded)	NONE

Table 10: ADC 2 telemetry signals and scaling factors

RTD Panel Temperature Scaling

Solar panel temperature is measured by a RTD on each solar panel and analog mathematics performed by op-amps condition this voltage to mimic the solar panel MPPV. These mathematics can be reversed to directly calculate RTD resistance. Table 9 contains the RTD scaling values which compute the resistance in Ohms from the bit value of the ADC. The ADC scaling values implement a simplified form of the equation below

$$R_{RTD}(\Omega) = \left[\frac{ADC\ Bits\ \times \left(\frac{2.5V}{4096}\right) - 2.0523}{-8.14228}\right] \times \left(\frac{1}{0.001A}\right)$$

All values used to determine the RTD scaling values were rounded to the 6th decimal place as this equation is pure mathematics and considered ideal. The TL1451A reference voltage has a pretty loose initial tolerance and essentially must be calibrated out to make the temperature sensing via ADCs very accurate. This is an MPPT specific process that results in six calibration values for each satellite and is outside the scope of this document. A cubic fit is used to convert RTD resistance into degrees Celsius. The basic formula for a cubic fit of a PT100 RTD is:

$$Temperature\ (C) = \ -247.29 + 2.3992 \times R + 0.00063962 \times R^2 + 1.0241E - 6\ \times R^3$$

Test Results

Testing was performed using a combination of digital multimeters, an active load, an Arduino™ with a current sense circuit and I^2C communications, and a digital oscilloscope. Various other tools were used but are not relevant to this document. Circuit operation as well as performance data will be showcased in an annotated form.

MPPT Operation

Operation of the MPPT is clearly shown in Figure 29. A 2.5 Farad super capacitor was used as a battery simulator to hold up the output voltage and allow plotting of a nice graph. As shown, the capacitor started fully charged at about 4.25V and was constant current discharged down to 3.3V where the load was removed. More power was demanded from the MPPT PCB than the maximum power the solar panel simulators could provide causing a slow but linear decrease in panel voltage. The super capacitor was then allowed to charge back up. It’s obvious to see that the panel voltage was near the open circuit voltage when the capacitor was fully charged but as the capacitor voltage decreased the MPPT feedback loop kicked in and forced the panel down to about 4.8V to operate at maximum power (+-5% error at 0C). When the capacitor charged back up the MPPT feedback loop lost control and the voltage regulation feedback loop took over limiting capacitor voltage but allowing panel voltage to rise.

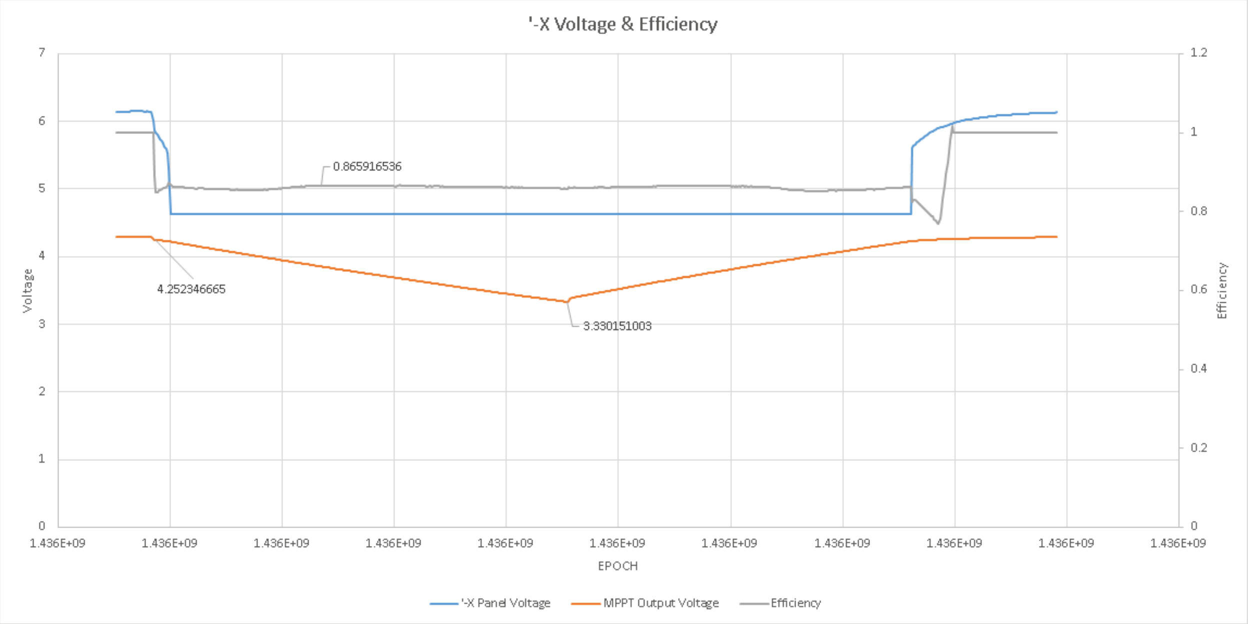


Figure 29: -X Panel operation as obtained by ADC telemetry through an Arduino™ test setup and an external current sense to computer input and output power for efficiency calculations

Figure 30 nicely plots the input and output power of the MPPT and the resulting efficiency. Numbers are only valid during the time the test is occurring. The output power has a linear decreasing slope which is caused by series resistance from the buck converter, ideal diode, and current sense circuits. Ohm's law! The power reaching the MPPT output drops as I^2R losses increase when output current increases as the capacitor voltage decreased and conservation of power must be maintained.

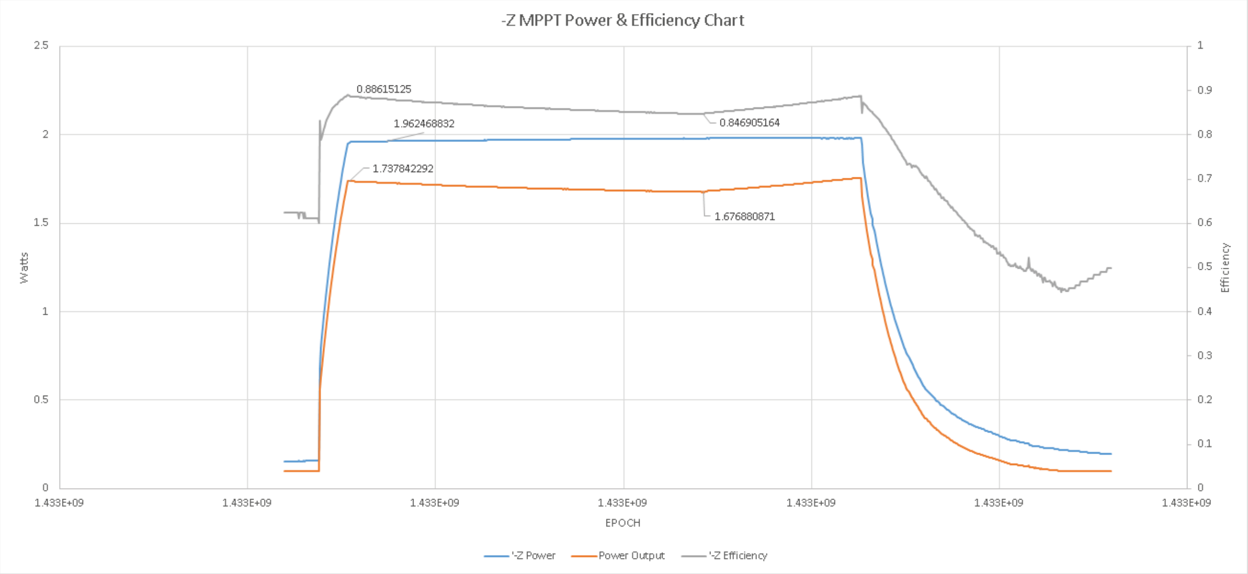


Figure 30: -Z panel operation showing solar panel power output, MPPT output power, and resulting efficiency over a super capacitor discharge test

Oscilloscope Captures

To showcase some of the MPPT operations Figure 31 is an oscilloscope capture of an MPPT load test. Channel 1 (top) is the simulated solar panel voltage, Channel 2 (middle) is the output voltage, and Channel 3 (bottom) is the switching node of the buck converter. A 50mA constant current load was the steady state operation condition the test started in. This means the MPPT was actually in voltage regulation mode to begin the test. A 1A constant current transient was immediately placed onto the output of the MPPT (super capacitor) as a large load causing the capacitor voltage to sag slightly as shown in channel 2 when the test occurred about 100us from the left edge of the screen. Please note this test is extremely unforgiving and unrealistic in orbit but a great example non-the-less.

Transitioning from voltage regulation mode into MPPT mode, the solar panel voltage dipped a bit below the maximum power point and then rose back up to maintain MPPT. Channel 3 clearly shows the duty cycle of the buck converter changing as the feedback loops maintain regulation. The switching node duty cycle is the important observation and absolute voltage of the switching node will track with the panel voltage as shown. Complete tradeoff of voltage regulation to MPPT regulation is observed in this oscilloscope capture. This event occurred in about 1ms from beginning to end which is more than sufficient for on-orbit performance since spacecraft rotation is much slower.

H 50.0us
250MSa/s
150k pts
D 150.000000us
T 2 5.59 V
Type: Edge
Source: CH2
Sweep: Single
Top=******
Base=******
Base=4.52 V
Top=6.45 V
Max=4.32 V
1 1.00 V
2 1.10 V
3 5.00 V
4 50.0mV

Figure 31: MPPT Operating with a charged super capacitor simulating a battery experiencing a load transient. Load was intense 50mA to 1A transient.

Appendix

Fox-1 Solar Panel Calculations

Fox-1 Solar Panel

PV Temp (C)	V_{OC} (V)	V_{MPP} (V)	I_{MPP} (A)	P_{MPP} (W)
-60	6.464	5.844	0.440	2.571
-55	6.399	5.779	0.440	2.543
-50	6.334	5.714	0.440	2.514
-45	6.269	5.649	0.440	2.486
-40	6.204	5.584	0.440	2.457
-35	6.139	5.519	0.440	2.428
-30	6.074	5.454	0.440	2.400
-25	6.009	5.389	0.440	2.371
-20	5.944	5.324	0.440	2.343
-15	5.879	5.259	0.440	2.314
-10	5.814	5.194	0.440	2.286
-5	5.749	5.129	0.440	2.257
0	5.684	5.064	0.440	2.228
5	5.619	4.999	0.440	2.200
10	5.554	4.934	0.440	2.171
15	5.489	4.869	0.440	2.143
20	5.424	4.804	0.440	2.114
25	5.359	4.739	0.440	2.086
28	5.320	4.700	0.440	2.068
30	5.294	4.674	0.440	2.057
35	5.229	4.609	0.440	2.028
40	5.164	4.544	0.440	2.000
45	5.099	4.479	0.440	1.971
50	5.034	4.414	0.440	1.943
55	4.969	4.349	0.440	1.914
60	4.904	4.284	0.440	1.886

Table 11: Estimated operating parameters of the Fox-1 solar panel using two Spectrolab UTJ cells in series

Maximum Power Point Tracking Theory

Solar Panels convert the Sun’s energy into electrical power for use by Fox-1. Due to the high impedance nature of solar cells, the payload can drastically affect the amount of power extracted from the cells by changing the voltage of panels with current draw from them. There is a specific voltage at which the maximum amount of power may be extracted which is called the Maximum Power Point Voltage, *MPPV*. This voltage varies with temperature and solar irradiance. An MPPT follows the maximum power point as it moves due to environmental disturbances.

The standard view of solar cell performance is by that of a current-voltage curve or IV curve as shown in Figure 32 from the Spectrolab UTJ solar cells used on Fox-1. To understand how to obtain information from the chart start with the two extremes. An open-circuit conducts no current and will operate the solar cell at the maximum voltage of about 2.66V on the bottom right of the IV curve. As current drawn from the solar cell is increased by the payload, the operating point of the solar cell moves from right to left along the plotted line. Under a short circuit condition the solar cell shows zero volts of potential and deliver about 17.05 mA/cm^2 of solar cell area to the load.

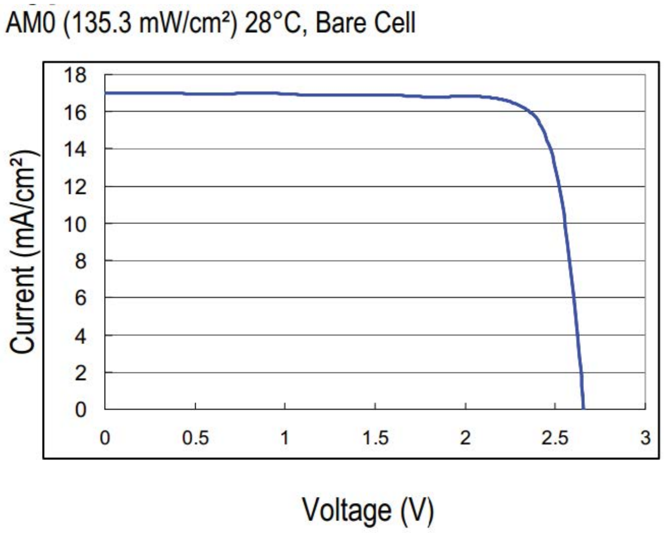


Figure 32: Spectrolab UTJ 28.3% efficiency solar cell IV curve

These two extremes both produce zero power in the ideal world.

$$Power = 2.66\,V \;\times 0\;A = 0\;Watts\;(open\;circuit)$$
$$Power = 0\;V \;\times 16.3\,{}^{mA}/_{cm^2} = 0\;Watts\;(short\;circuit)$$

The “knee” of the IV curve shown at about 2.35V on the x-axis is the maximum power point where the most energy can be extracted from the solar cell and delivered to the payload. Figure 33 shows example power curves and IV curves are as the values vary with temperature and irradiance of the solar cells. Notice how temperature is a huge contributor to changing the maximum power point.

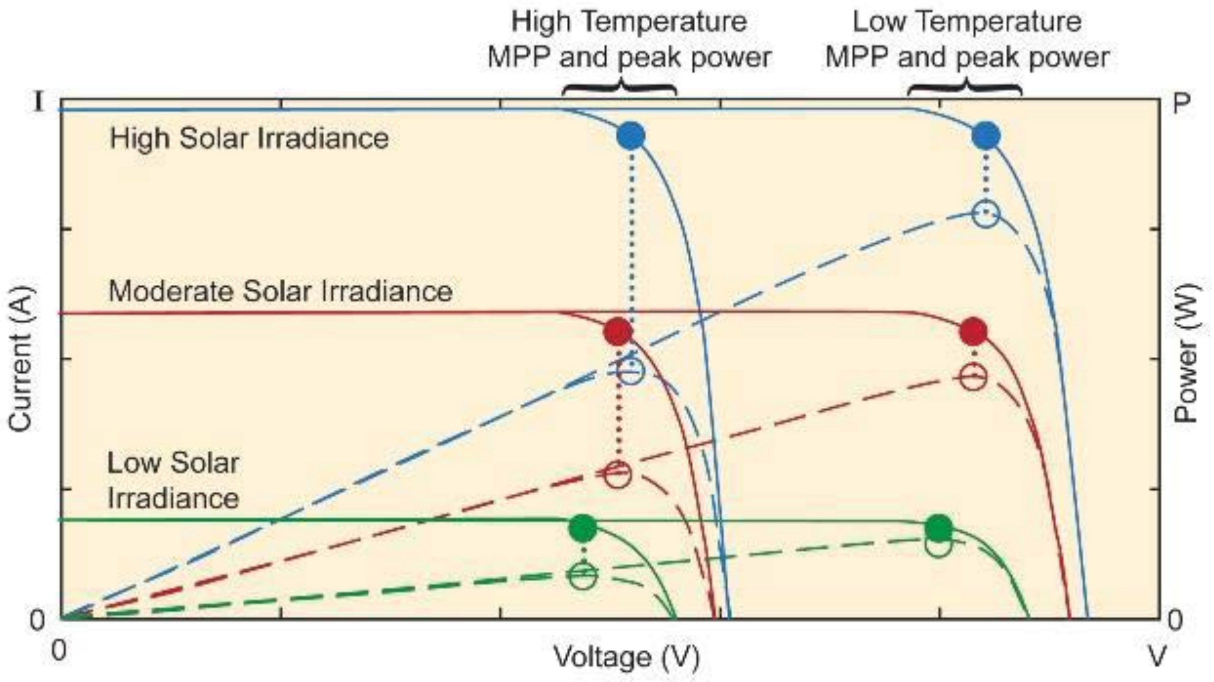
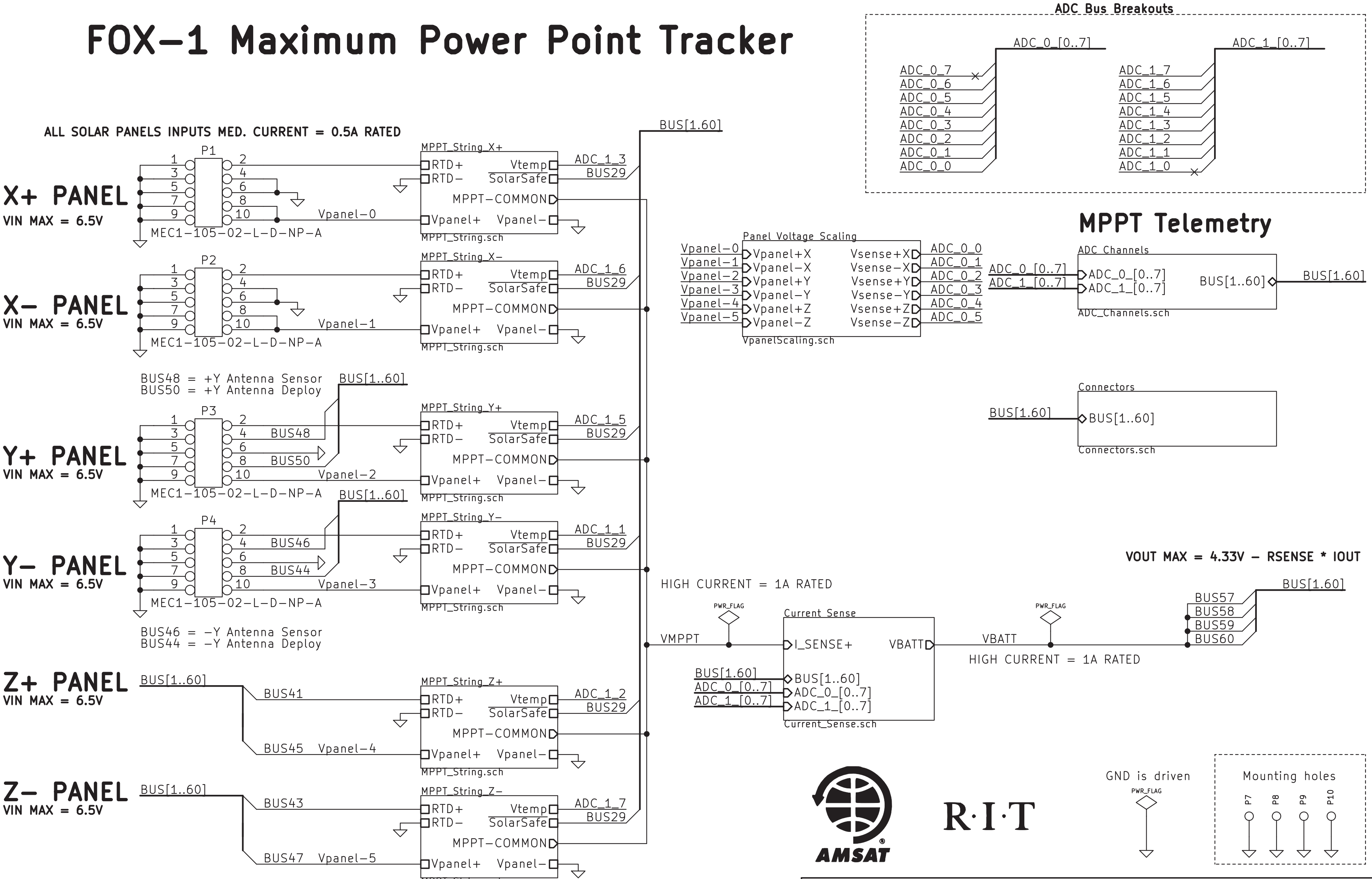


Figure 33: Solar panel MPPT versus temperature and irradiance changes. Image used from http://www.electronicproducts.com

A maximum Power Point Tracker is an intermediate circuit between the solar panels and the battery/satellite which isolates the source from the load in order to maintain the solar panel voltage at the MPPV. MPPTs are implemented with DC/DC converters and can be seen as impedance converters which match the high impedance of the solar panel (about 13Ω on Fox-1) to the payload which is usually much higher (low power needs) or much lower (high power needs) impedance. Used as an intermediate translator of impedances, the MPPT serves to decouple payload needs from solar panel operating point.

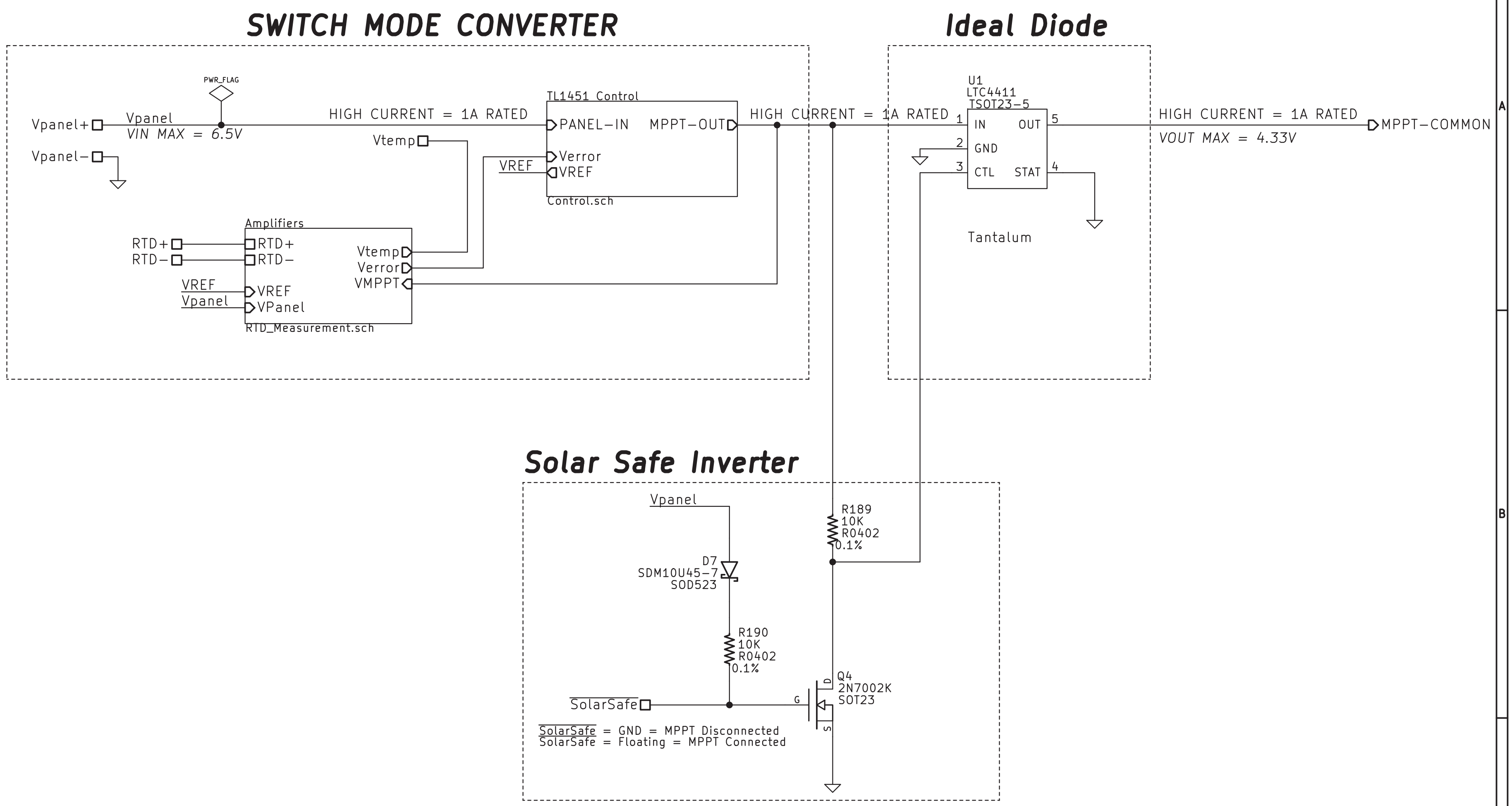
FOX-1 Maximum Power Point Tracker



NOTES

* This MPPT implements a set-point constant voltage tracking algorithm based on panel temperature.
* RIT MPPT Team: Brenton Salmi (KB1LQD), Bryce Salmi (KB1LQC), Ian MacKenzie (KB3OCF), Daniel Corriero.
* NASA derating taken into account, not gauranteed

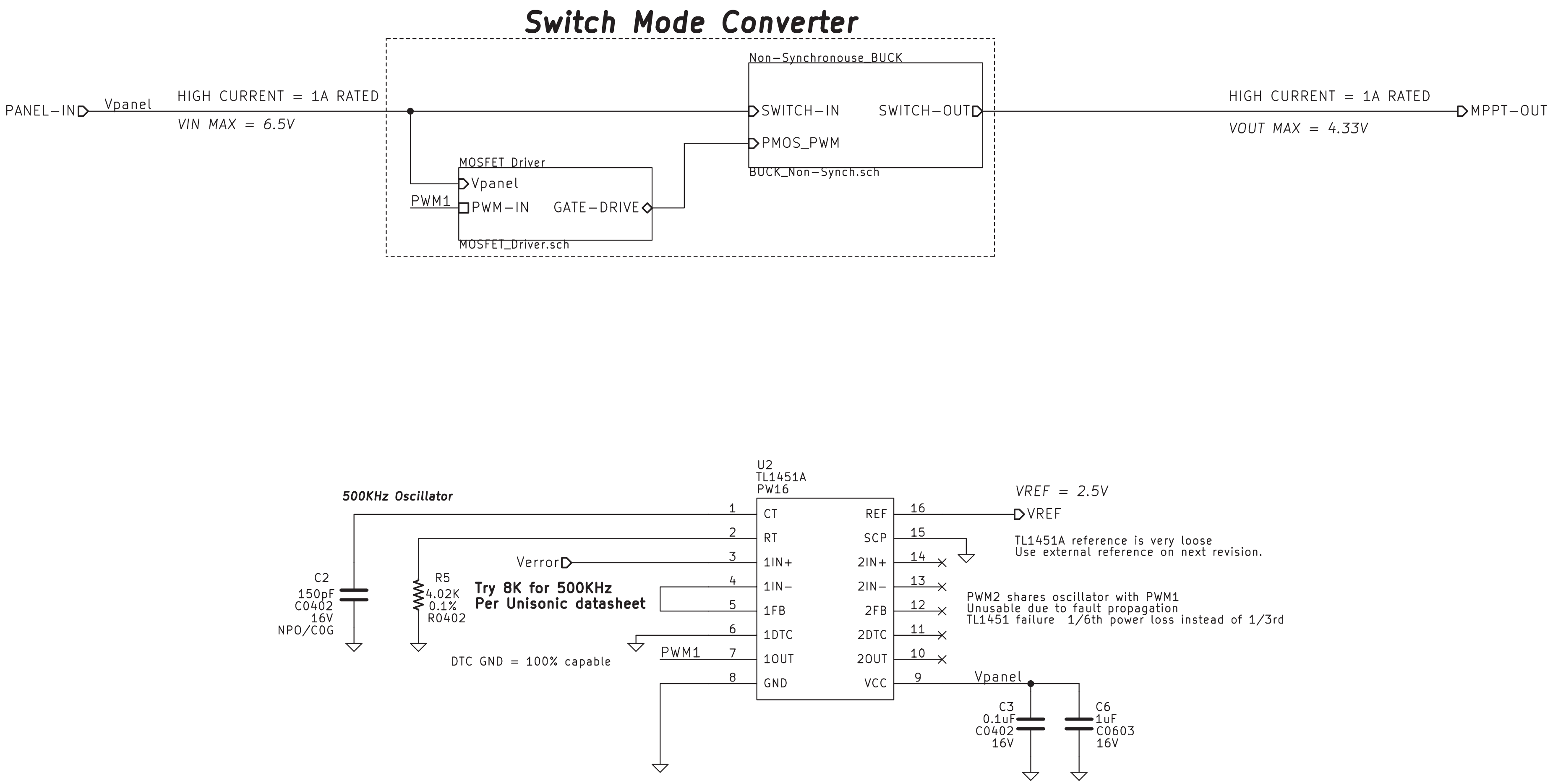
Based on Rochester Institute of Technology P13271 Design
Brent Salmi, KB1LQD
Bryce Salmi, KB1LQC
The Radio Amateur Satellite Corporation
File: TL1451_MPPT_Flight_Rev1.sch
Sheet: /
Title: Fox-1 Maximum Power Point Tracker
Size: USLetter *Date: 25 sep 2015* *Rev: 1.1*
KiCad E.D.A. Id: 1/37



NOTES

* This MPPT implements a set−point constant voltage tracking algorithm based on panel temperature.
* RIT MPPT Team: Brenton Salmi (KB1LQD), Bryce Salmi (KB1LQC), Ian MacKenzie (KB3OCF), Daniel Corriero.
* NASA derating taken into account, not gauranteed

Based on Rochester Institute of Technology P13271 Design
Brent Salmi, KB1LQD
Bryce Salmi, KB1LQC
The Radio Amateur Satellite Corporation
File: MPPT_String.sch
Sheet: /MPPT_String_X+/
Title: Fox−1 Maximum Power Point Tracker
Size: A | *Date: 25 sep 2015* | *Rev: 2*
KiCad E.D.A. | Id: 2/37

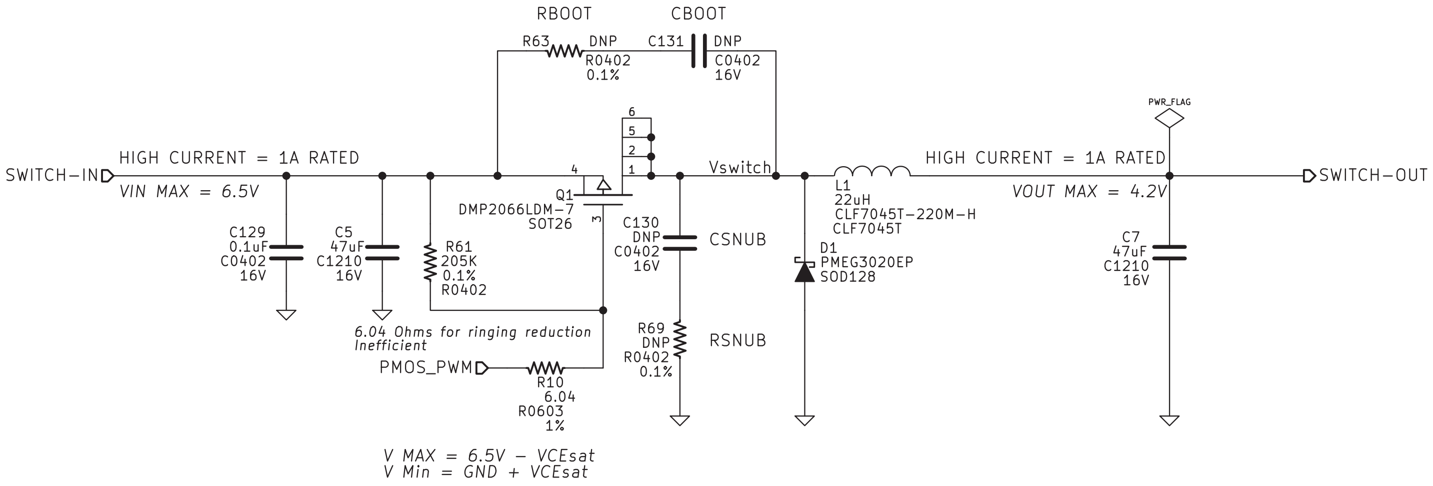


NOTES

* This MPPT implements a set−point constant voltage tracking algorithm based on panel temperature.
* RIT MPPT Team: Brenton Salmi (KB1LQD), Bryce Salmi (KB1LQC), Ian MacKenzie (KB3OCF), Daniel Corriero.
* NASA derating taken into account, not gauranteed

Based on Rochester Institute of Technology P13271 Design
Brent Salmi, KB1LQD
Bryce Salmi, KB1LQC
The Radio Amateur Satellite Corporation
File: Control.sch
Sheet: /MPPT_String_X+/TL1451 Control/
Title: Fox−1 Maximum Power Point Tracker
Size: A4 *Date: 25 sep 2015* *Rev: 2*
KiCad E.D.A. Id: 3/37

500 KHz Step–Down Buck Converter

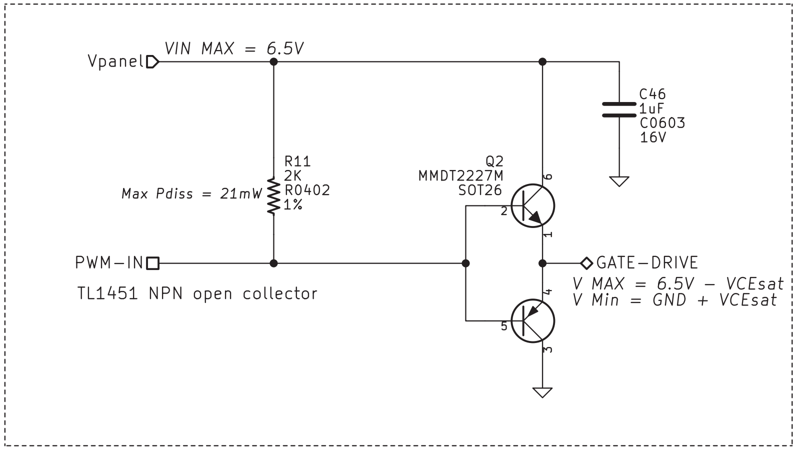


NOTES

* This MPPT implements a set–point constant voltage tracking algorithm based on panel temperature.
* RIT MPPT Team: Brenton Salmi (KB1LQD), Bryce Salmi (KB1LQC), Ian MacKenzie (KB3OCF), Daniel Corriero.
* Parts not yet NASA derated.

Based on Rochester Institute of Technology P13271 Design
Brent Salmi, KB1LQD
Bryce Salmi, KB1LQC
The Radio Amateur Satellite Corporation
File: BUCK_Non–Synch.sch
Sheet: /MPPT_String_X+/TL1451 Control/Non–Synchronouse_BUCK/
Title: Fox–1 Maximum Power Point Tracker
Size: A4 *Date: 25 sep 2015* *Rev: 2*
KiCad E.D.A. Id: 4/37

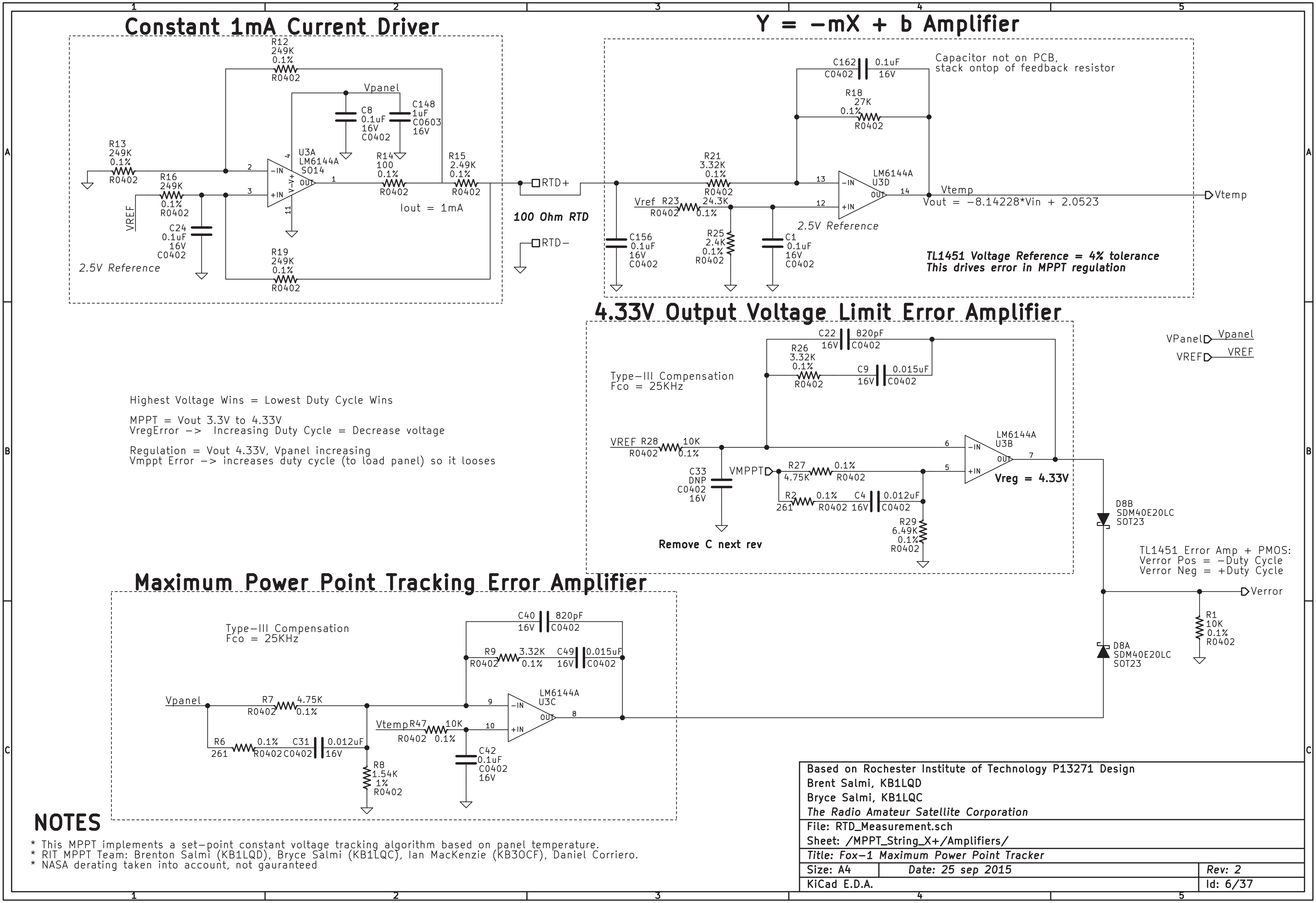
TOTEM POLE MOSFET DRIVER



NOTES

- * This MPPT implements a set-point constant voltage tracking algorithm based on panel temperature.
- * RIT MPPT Team: Brenton Salmi (KB1LQD), Bryce Salmi (KB1LQC), Ian MacKenzie (KB3OCF), Daniel Corriero.
- * Parts not yet NASA derated.

Based on Rochester Institute of Technology P13271 Design
Brent Salmi, KB1LQD
Bryce Salmi, KB1LQC
The Radio Amateur Satellite Corporation
File: MOSFET_Driver.sch
Sheet: /MPPT_String_X+/TL1451 Control/MOSFET Driver/
Title: Fox-1 Maximum Power Point Tracker
Size: A4 *Date: 25 sep 2015* *Rev: 2*
KiCad E.D.A. Id: 5/37



Highest Voltage Wins = Lowest Duty Cycle Wins

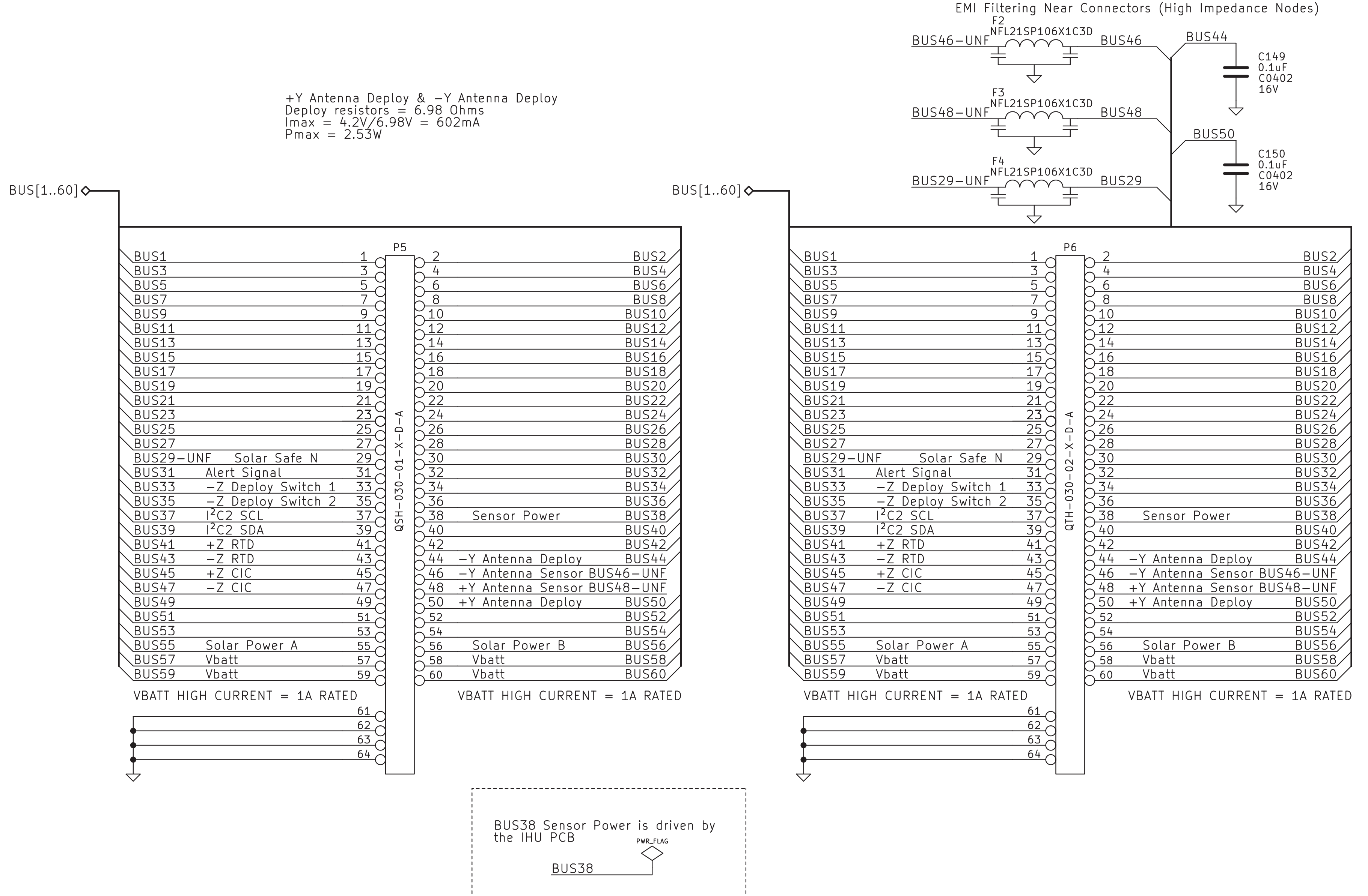
MPPT = Vout 3.3V to 4.33V
VregError -> Increasing Duty Cycle = Decrease voltage

Regulation = Vout 4.33V, Vpanel increasing
Vmppt Error -> increases duty cycle (to load panel) so it looses

NOTES

* This MPPT implements a set-point constant voltage tracking algorithm based on panel temperature.
* RIT MPPT Team: Brenton Salmi (KB1LQD), Bryce Salmi (KB1LQC), Ian MacKenzie (KB3OCF), Daniel Corriero.
* NASA derating taken into account, not gauranteed

Based on Rochester Institute of Technology P13271 Design
Brent Salmi, KB1LQD
Bryce Salmi, KB1LQC
The Radio Amateur Satellite Corporation
File: RTD_Measurement.sch
Sheet: /MPPT_String_X+/Amplifiers/
Title: Fox-1 Maximum Power Point Tracker
Size: A4 *Date: 25 sep 2015* *Rev: 2*
KiCad E.D.A. Id: 6/37

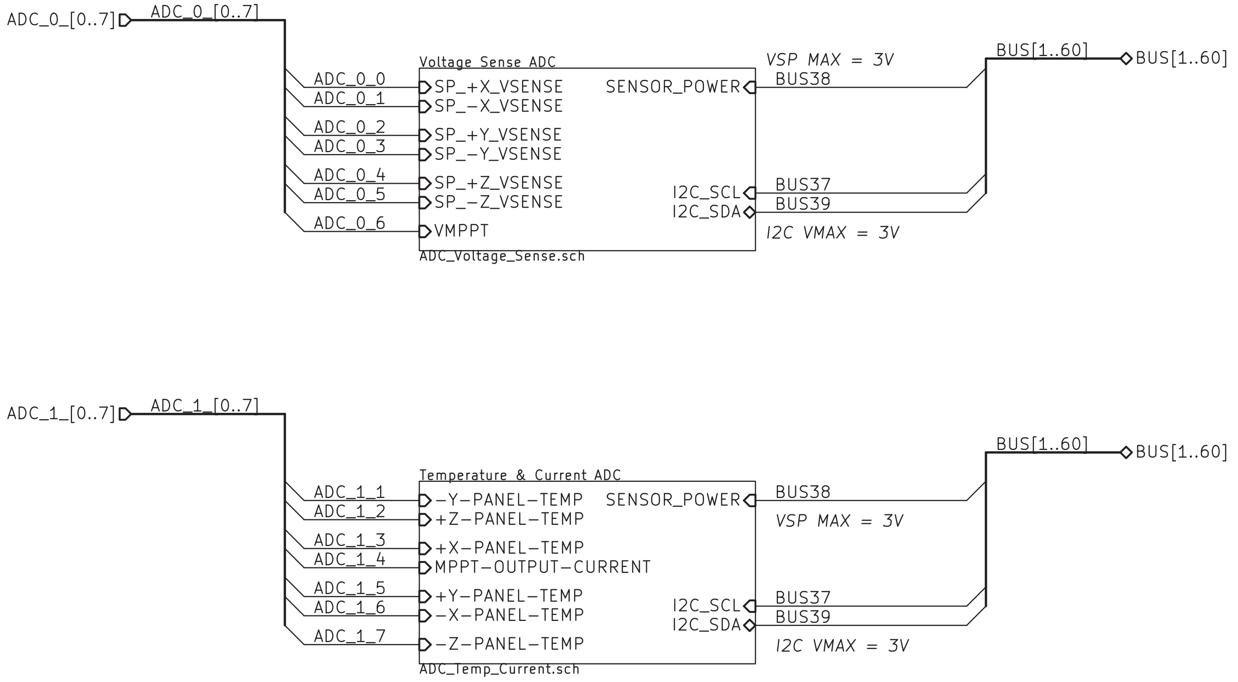


NOTES

- * This MPPT implements a set−point constant voltage tracking algorithm based on panel temperature.
- * RIT MPPT Team: Brenton Salmi (KB1LQD), Bryce Salmi (KB1LQC), Ian MacKenzie (KB3OCF), Daniel Corriero.
- * NASA derating taken into account, not gauranteed

Based on Rochester Institute of Technology P13271 Design
Brent Salmi, KB1LQD
Bryce Salmi, KB1LQC
The Radio Amateur Satellite Corporation

File: Connectors.sch
Sheet: /Connectors/
Title: Fox−1 Maximum Power Point Tracker
Size: A4 *Date: 25 sep 2015* *Rev: 2*
KiCad E.D.A. Id: 7/37

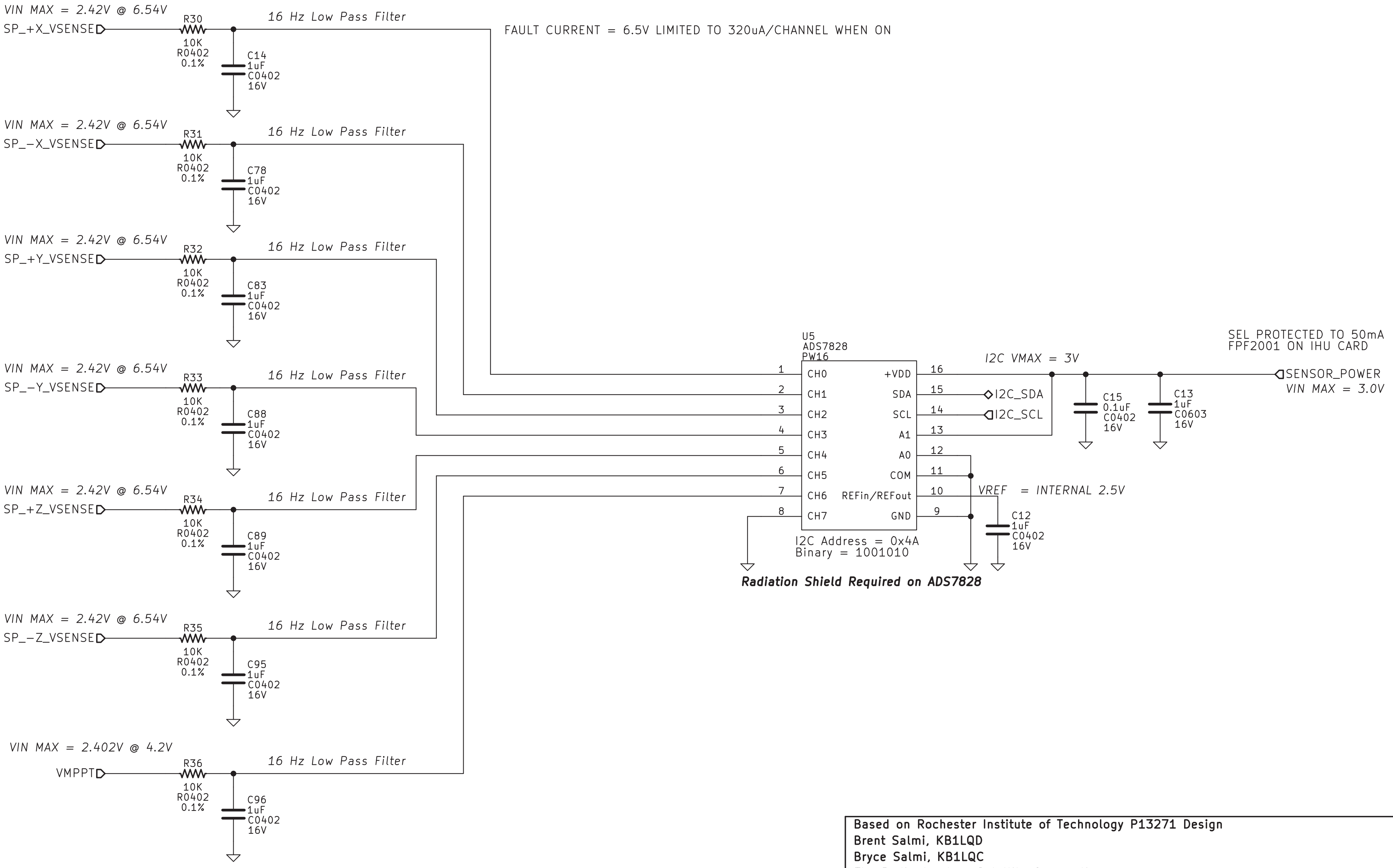


NOTES

* This MPPT implements a set–point constant voltage tracking algorithm based on panel temperature.
* RIT MPPT Team: Brenton Salmi (KB1LQD), Bryce Salmi (KB1LQC), Ian MacKenzie (KB3OCF), Daniel Corriero.
* NASA derating taken into account, not gauranteed

Based on Rochester Institute of Technology P13271 Design
Brent Salmi, KB1LQD
Bryce Salmi, KB1LQC
The Radio Amateur Satellite Corporation

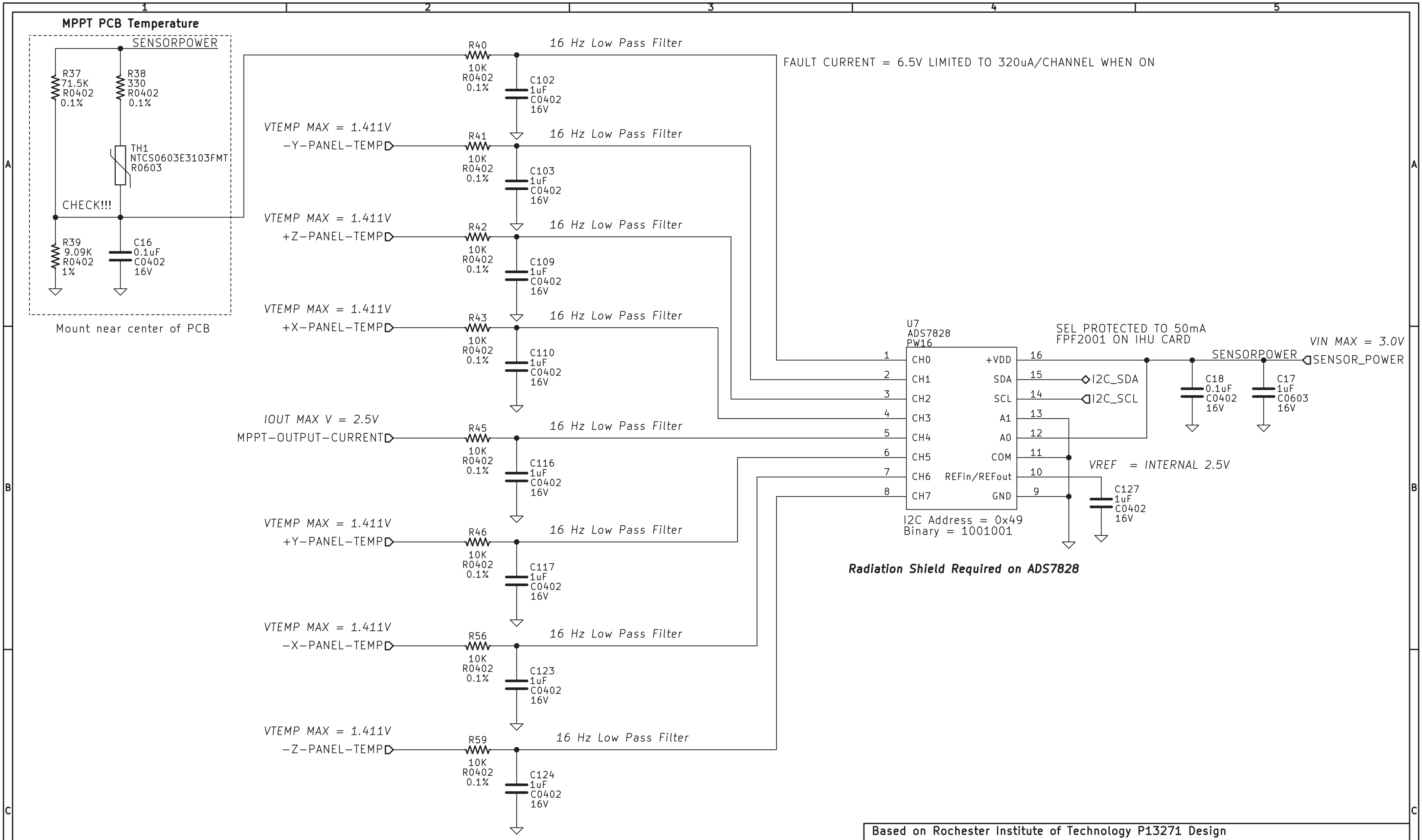
File: ADC_Channels.sch		
Sheet: /ADC Channels/		
Title: Fox–1 Maximum Power Point Tracker		
Size: A4	*Date: 25 sep 2015*	*Rev: 2*
KiCad E.D.A.		Id: 8/37



NOTES

- * This MPPT implements a set−point constant voltage tracking algorithm based on panel temperature.
- * RIT MPPT Team: Brenton Salmi (KB1LQD), Bryce Salmi (KB1LQC), Ian MacKenzie (KB3OCF), Daniel Corriero.
- * NASA derating taken into account, not gauranteed

Based on Rochester Institute of Technology P13271 Design
Brent Salmi, KB1LQD
Bryce Salmi, KB1LQC
The Radio Amateur Satellite Corporation
File: ADC_Voltage_Sense.sch
Sheet: /ADC Channels/Voltage Sense ADC/
Title: Fox−1 Maximum Power Point Tracker
Size: A4 *Date: 25 sep 2015* *Rev: 2*
KiCad E.D.A. Id: 9/37



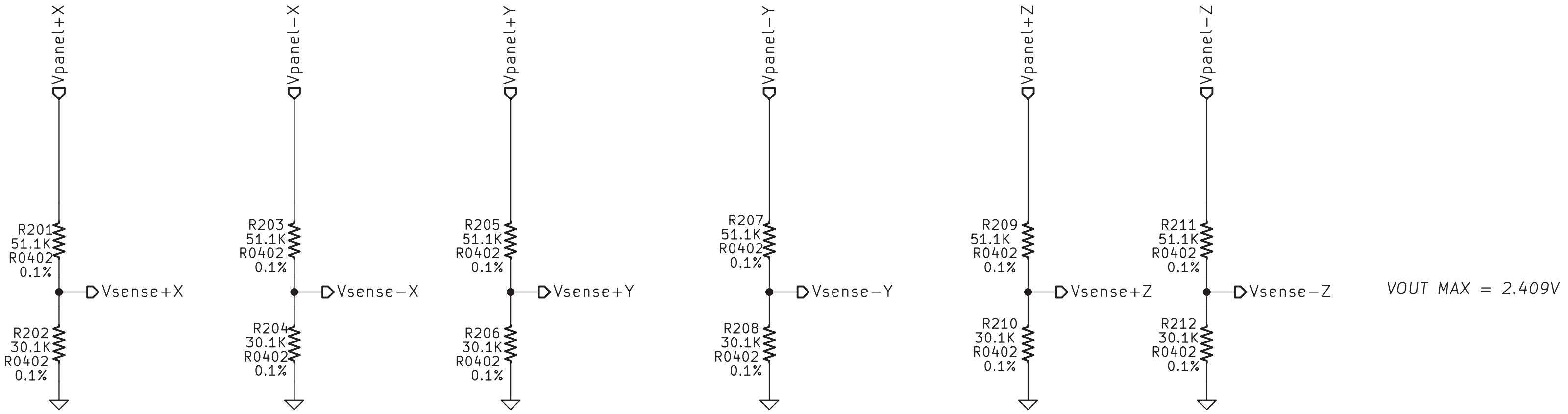
NOTES

* This MPPT implements a set-point constant voltage tracking algorithm based on panel temperature.
* RIT MPPT Team: Brenton Salmi (KB1LQD), Bryce Salmi (KB1LQC), Ian MacKenzie (KB3OCF), Daniel Corriero.
* NASA derating taken into account, not gauranteed

Based on Rochester Institute of Technology P13271 Design
Brent Salmi, KB1LQD
Bryce Salmi, KB1LQC
The Radio Amateur Satellite Corporation
File: ADC_Temp_Current.sch
Sheet: /ADC Channels/Temperature & Current ADC/
Title: Fox-1 Maximum Power Point Tracker
Size: A4 *Date: 25 sep 2015* *Rev: 2*
KiCad E.D.A. Id: 10/37

PANEL VOLTAGE TELEMETRY ADC SCALING

VIN MAX = 6.5V

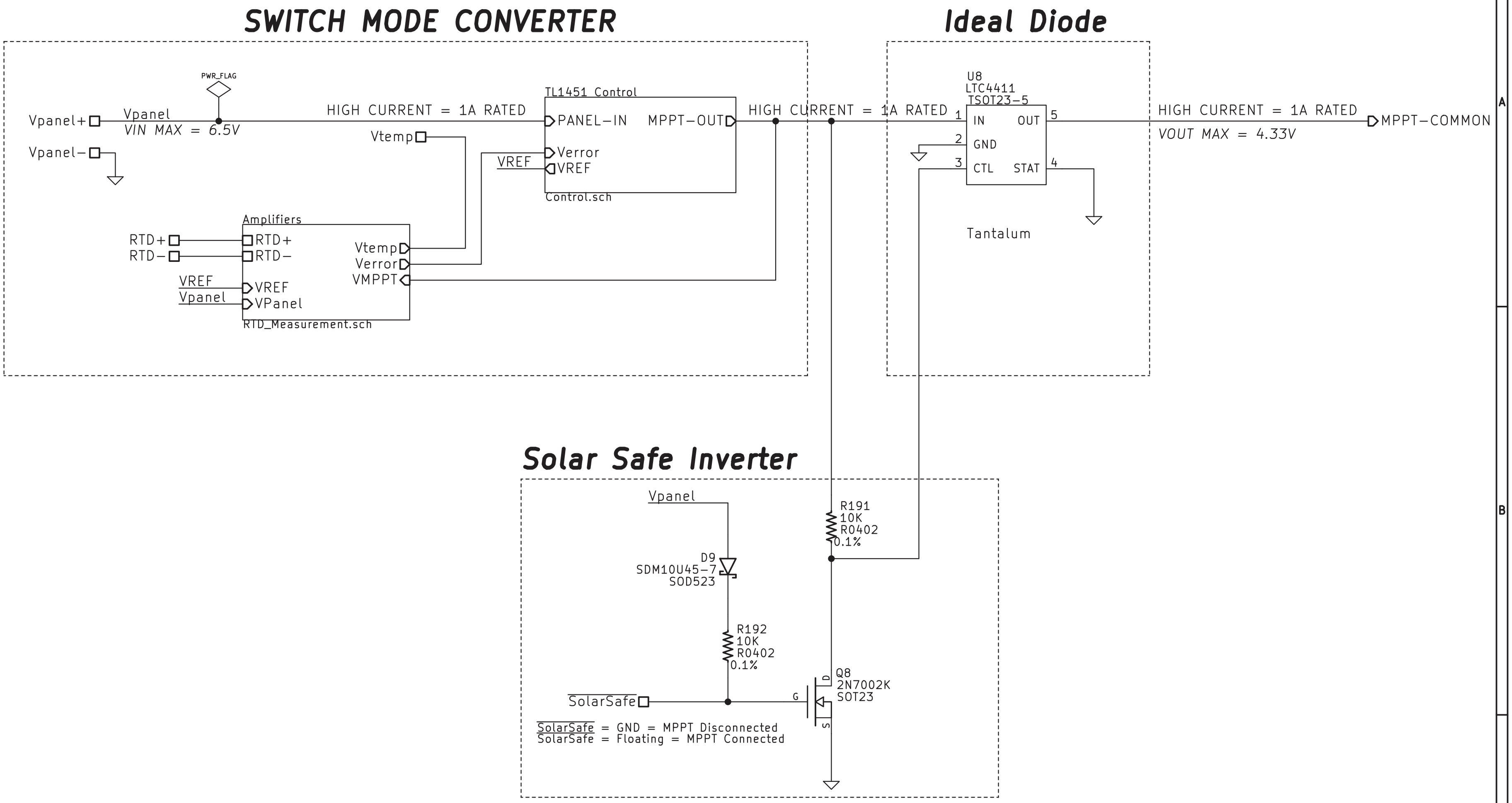


VOUT MAX = 2.409V

NOTES

* This MPPT implements a set−point constant voltage tracking algorithm based on panel temperature.
* RIT MPPT Team: Brenton Salmi (KB1LQD), Bryce Salmi (KB1LQC), Ian MacKenzie (KB3OCF), Daniel Corriero.
* NASA derating taken into account, not gauranteed

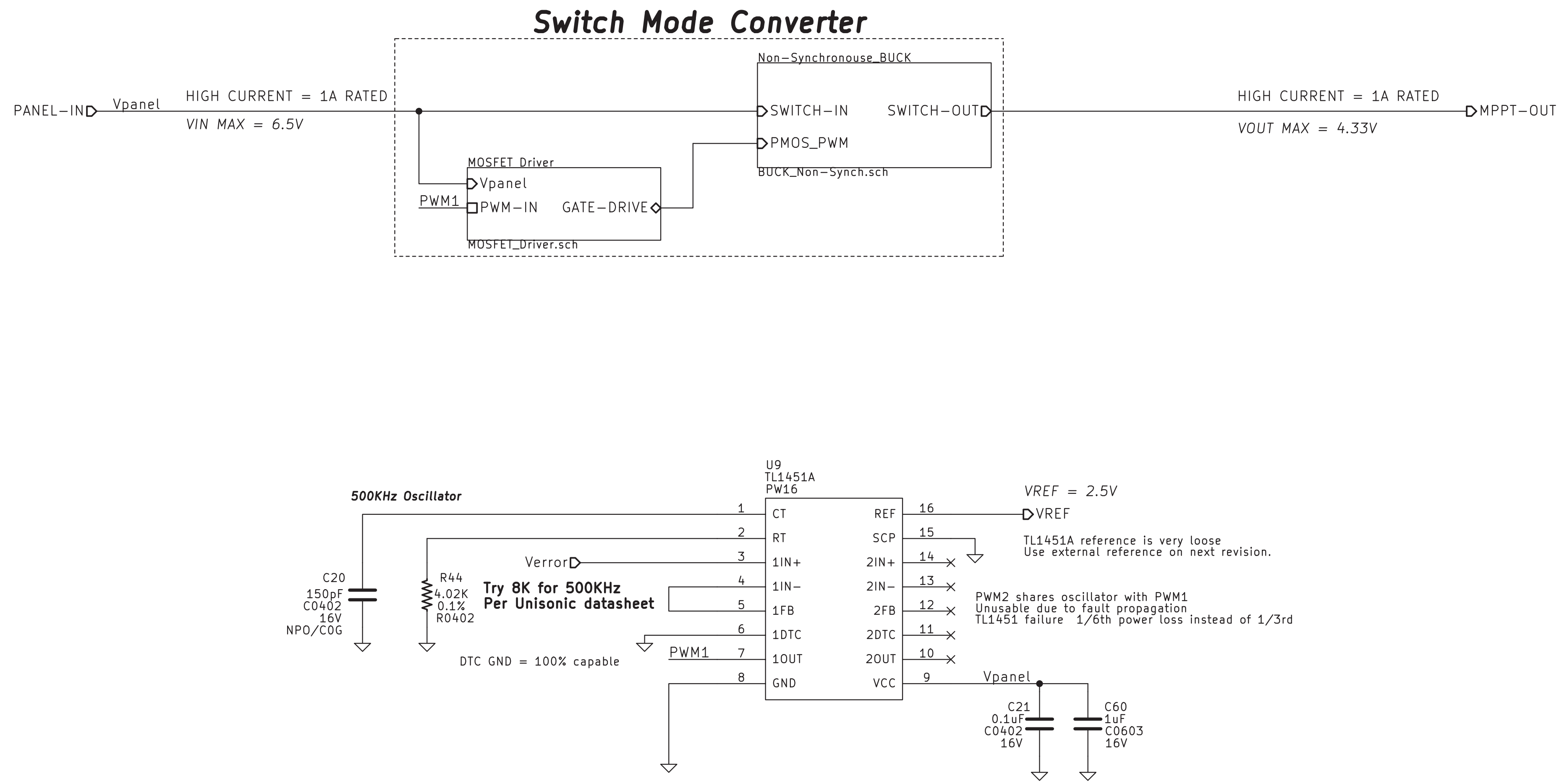
Based on Rochester Institute of Technology P13271 Design
Brent Salmi, KB1LQD
Bryce Salmi, KB1LQC
The Radio Amateur Satellite Corporation
File: VpanelScaling.sch
Sheet: /Panel Voltage Scaling/
Title:
Size: A4 *Date: 25 sep 2015* *Rev: 2*
KiCad E.D.A. Id: 11/37



NOTES

* This MPPT implements a set−point constant voltage tracking algorithm based on panel temperature.
* RIT MPPT Team: Brenton Salmi (KB1LQD), Bryce Salmi (KB1LQC), Ian MacKenzie (KB3OCF), Daniel Corriero.
* NASA derating taken into account, not gauranteed

Based on Rochester Institute of Technology P13271 Design
Brent Salmi, KB1LQD
Bryce Salmi, KB1LQC
The Radio Amateur Satellite Corporation
File: MPPT_String.sch
Sheet: /MPPT_String_X−/
Title: Fox−1 Maximum Power Point Tracker
Size: A *Date: 25 sep 2015* *Rev: 2*
KiCad E.D.A. Id: 12/37

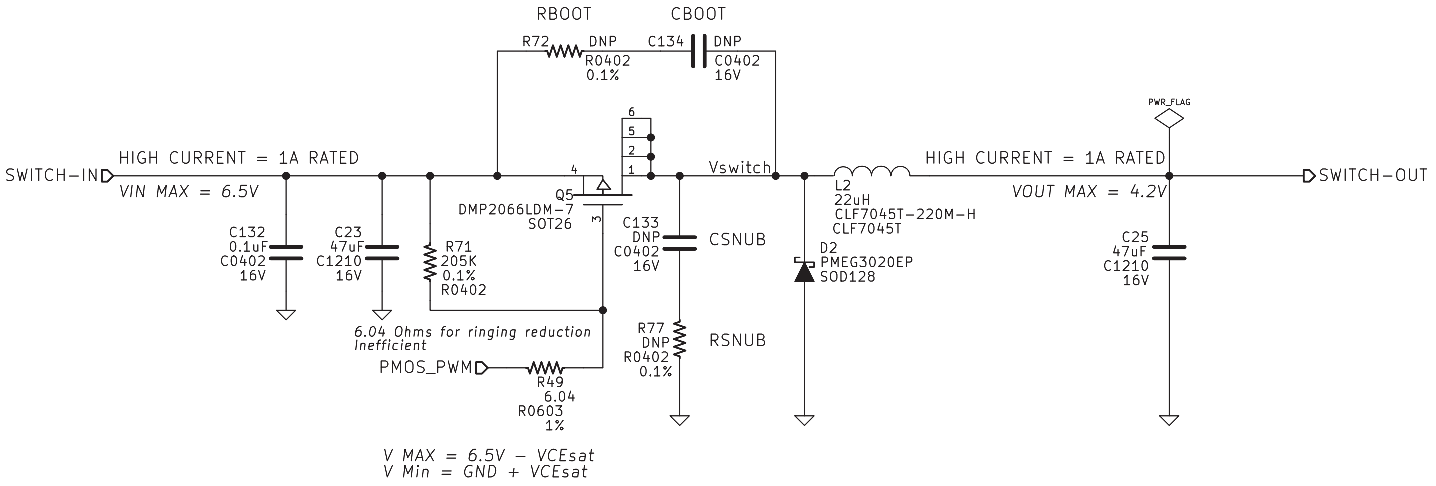


NOTES

* This MPPT implements a set−point constant voltage tracking algorithm based on panel temperature.
* RIT MPPT Team: Brenton Salmi (KB1LQD), Bryce Salmi (KB1LQC), Ian MacKenzie (KB3OCF), Daniel Corriero.
* NASA derating taken into account, not gauranteed

Based on Rochester Institute of Technology P13271 Design
Brent Salmi, KB1LQD
Bryce Salmi, KB1LQC
The Radio Amateur Satellite Corporation
File: Control.sch
Sheet: /MPPT_String_X−/TL1451 Control/
Title: Fox−1 Maximum Power Point Tracker
Size: A4 *Date: 25 sep 2015* *Rev: 2*
KiCad E.D.A. Id: 13/37

500 KHz Step-Down Buck Converter

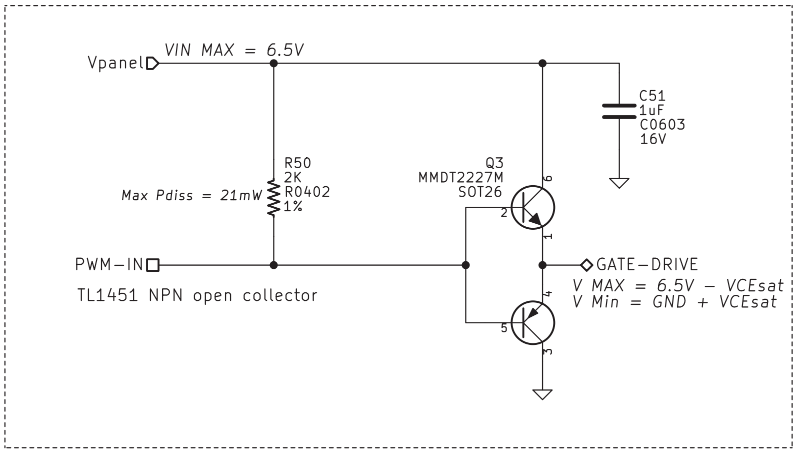


NOTES

* This MPPT implements a set−point constant voltage tracking algorithm based on panel temperature.
* RIT MPPT Team: Brenton Salmi (KB1LQD), Bryce Salmi (KB1LQC), Ian MacKenzie (KB3OCF), Daniel Corriero.
* Parts not yet NASA derated.

Based on Rochester Institute of Technology P13271 Design
Brent Salmi, KB1LQD
Bryce Salmi, KB1LQC
The Radio Amateur Satellite Corporation
File: BUCK_Non−Synch.sch
Sheet: /MPPT_String_X−/TL1451 Control/Non−Synchronouse_BUCK/
Title: Fox−1 Maximum Power Point Tracker
Size: A4 *Date: 25 sep 2015* *Rev: 2*
KiCad E.D.A. Id: 14/37

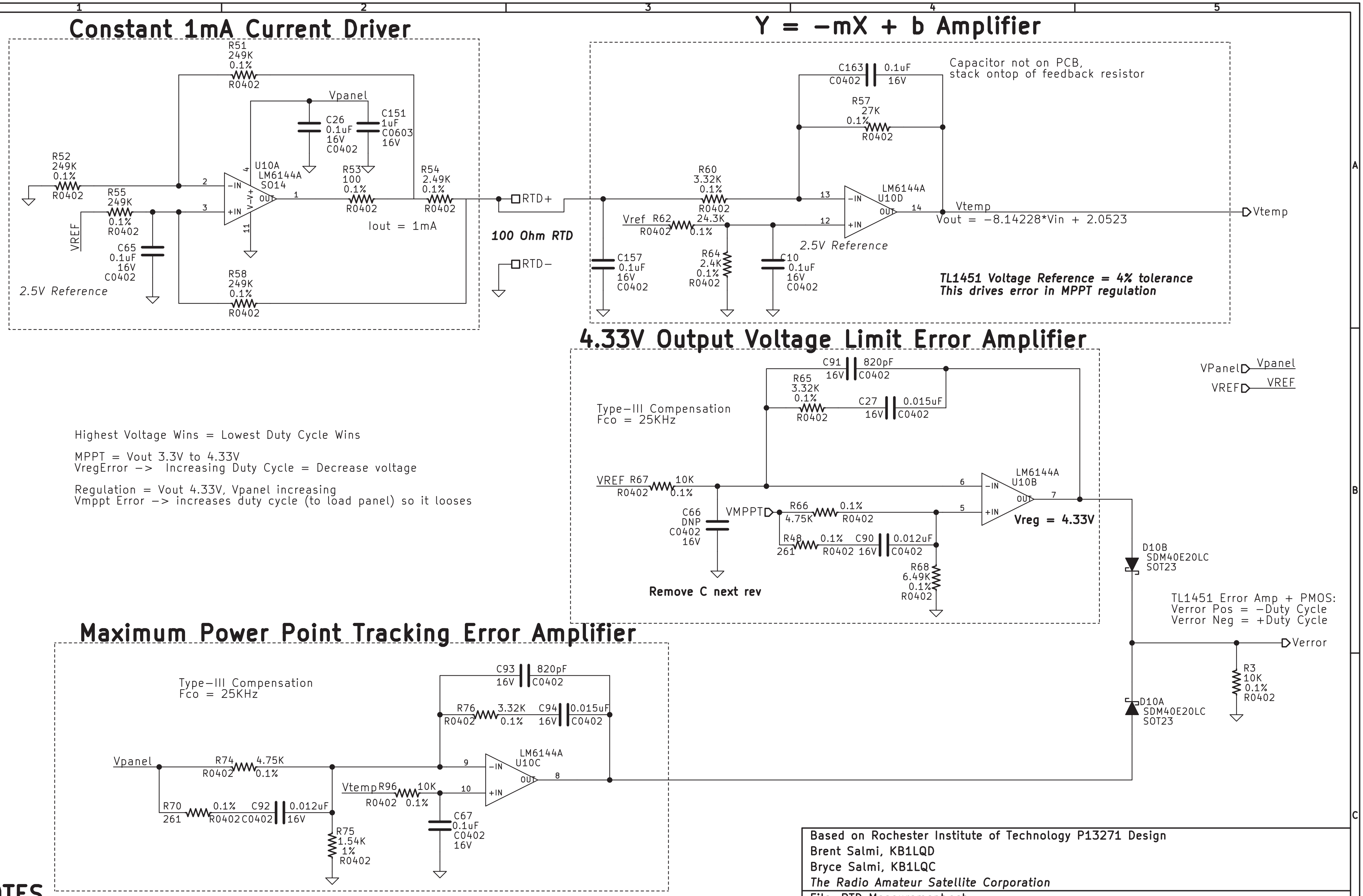
TOTEM POLE MOSFET DRIVER



NOTES

* This MPPT implements a set−point constant voltage tracking algorithm based on panel temperature.
* RIT MPPT Team: Brenton Salmi (KB1LQD), Bryce Salmi (KB1LQC), Ian MacKenzie (KB3OCF), Daniel Corriero.
* Parts not yet NASA derated.

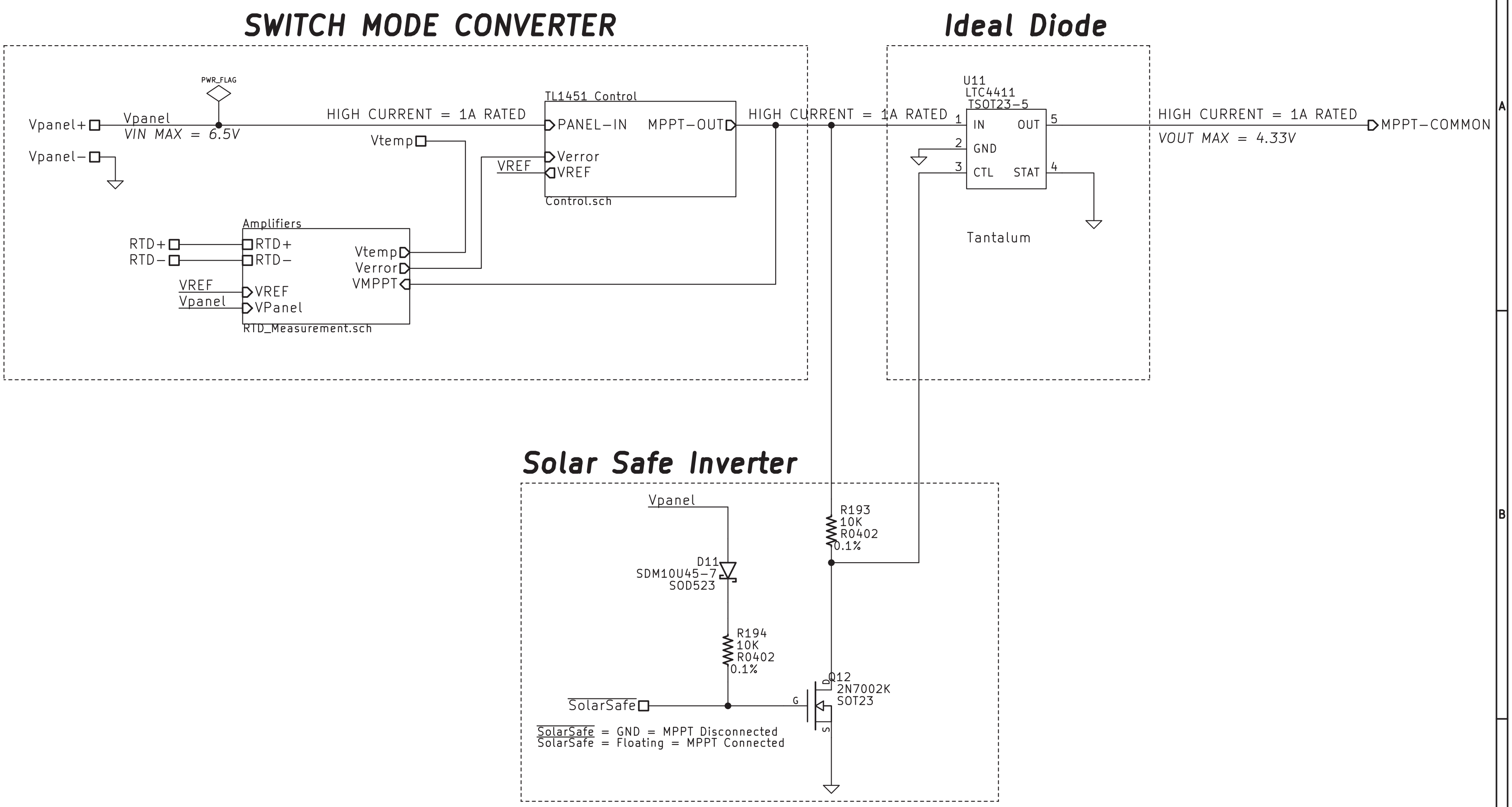
Based on Rochester Institute of Technology P13271 Design
Brent Salmi, KB1LQD
Bryce Salmi, KB1LQC
The Radio Amateur Satellite Corporation
File: MOSFET_Driver.sch
Sheet: /MPPT_String_X−/TL1451 Control/MOSFET Driver/
Title: Fox−1 Maximum Power Point Tracker
Size: A4 *Date: 25 sep 2015* *Rev: 2*
KiCad E.D.A. Id: 15/37



NOTES

* This MPPT implements a set−point constant voltage tracking algorithm based on panel temperature.
* RIT MPPT Team: Brenton Salmi (KB1LQD), Bryce Salmi (KB1LQC), Ian MacKenzie (KB3OCF), Daniel Corriero.
* NASA derating taken into account, not gauranteed

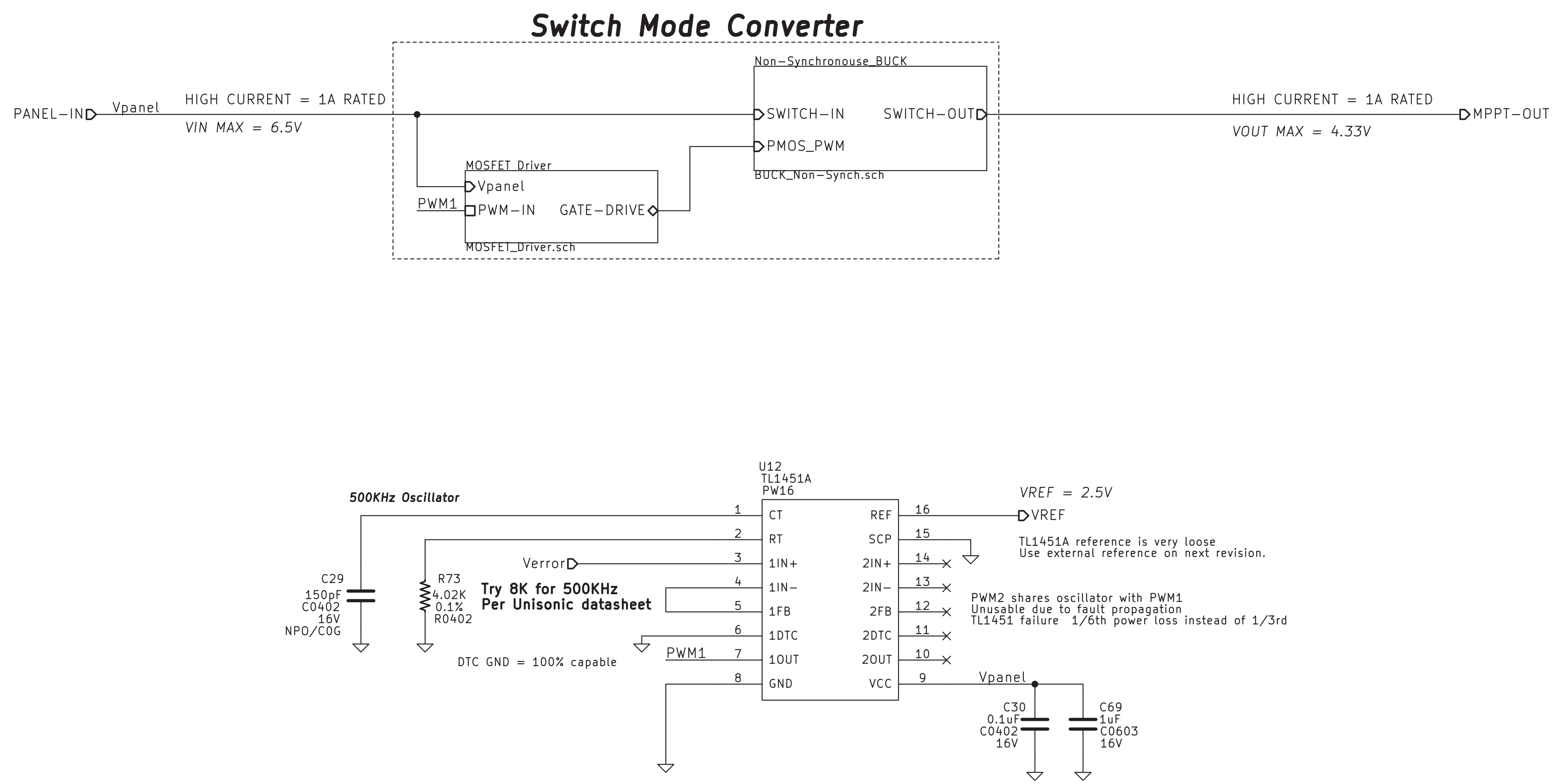
Based on Rochester Institute of Technology P13271 Design
Brent Salmi, KB1LQD
Bryce Salmi, KB1LQC
The Radio Amateur Satellite Corporation
File: RTD_Measurement.sch
Sheet: /MPPT_String_X−/Amplifiers/
Title: Fox−1 Maximum Power Point Tracker
Size: A4 *Date: 25 sep 2015* *Rev: 2*
KiCad E.D.A. Id: 16/37



NOTES

* This MPPT implements a set−point constant voltage tracking algorithm based on panel temperature.
* RIT MPPT Team: Brenton Salmi (KB1LQD), Bryce Salmi (KB1LQC), Ian MacKenzie (KB3OCF), Daniel Corriero.
* NASA derating taken into account, not gauranteed

Based on Rochester Institute of Technology P13271 Design
Brent Salmi, KB1LQD
Bryce Salmi, KB1LQC
The Radio Amateur Satellite Corporation
File: MPPT_String.sch
Sheet: /MPPT_String_Y+/
Title: Fox−1 Maximum Power Point Tracker
Size: A *Date: 25 sep 2015* *Rev: 2*
KiCad E.D.A. Id: 17/37

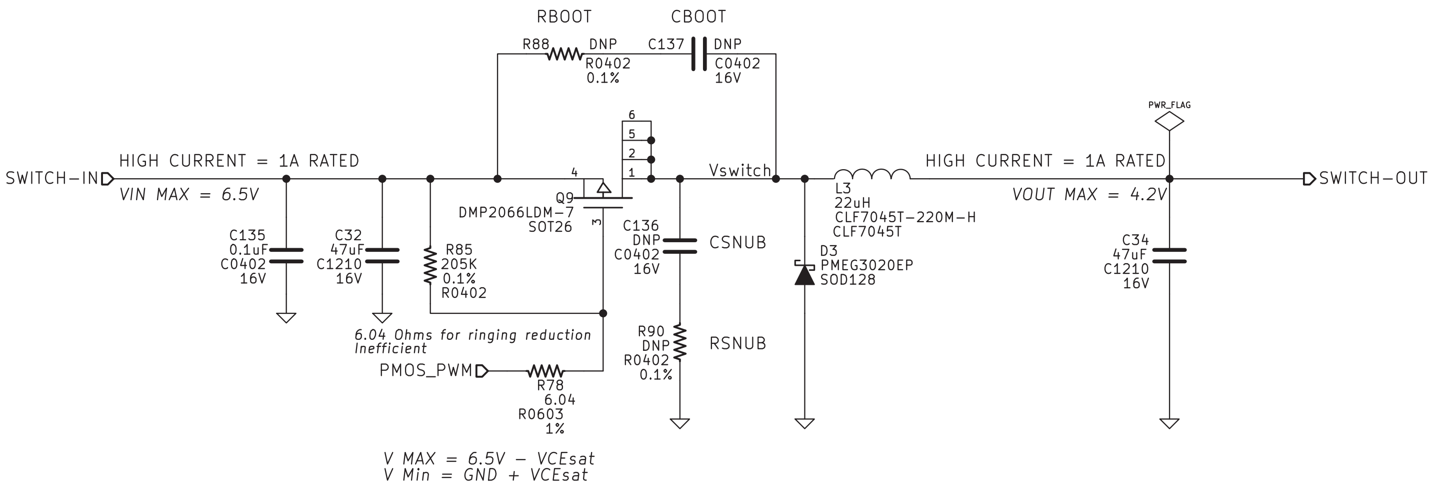


NOTES

* This MPPT implements a set-point constant voltage tracking algorithm based on panel temperature.
* RIT MPPT Team: Brenton Salmi (KB1LQD), Bryce Salmi (KB1LQC), Ian MacKenzie (KB3OCF), Daniel Corriero.
* NASA derating taken into account, not gauranteed

Based on Rochester Institute of Technology P13271 Design
Brent Salmi, KB1LQD
Bryce Salmi, KB1LQC
The Radio Amateur Satellite Corporation
File: Control.sch
Sheet: /MPPT_String_Y+/TL1451 Control/
Title: Fox-1 Maximum Power Point Tracker
Size: A4 *Date: 25 sep 2015* *Rev: 2*
KiCad E.D.A. Id: 18/37

500 KHz Step–Down Buck Converter

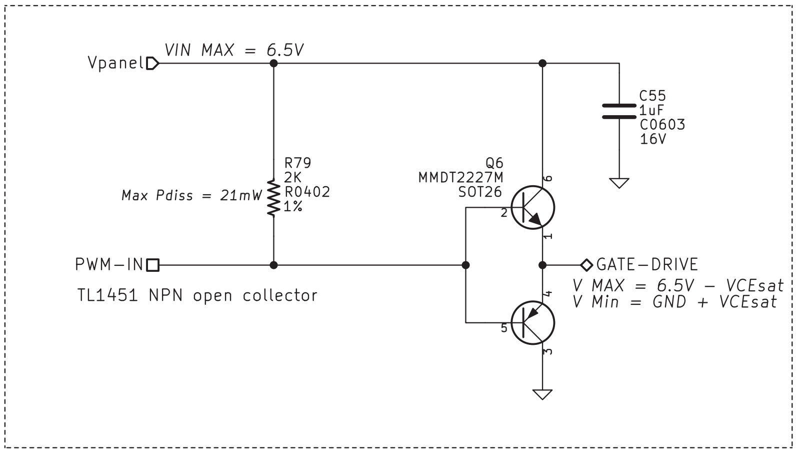


NOTES

* This MPPT implements a set–point constant voltage tracking algorithm based on panel temperature.
* RIT MPPT Team: Brenton Salmi (KB1LQD), Bryce Salmi (KB1LQC), Ian MacKenzie (KB3OCF), Daniel Corriero.
* Parts not yet NASA derated.

Based on Rochester Institute of Technology P13271 Design
Brent Salmi, KB1LQD
Bryce Salmi, KB1LQC
The Radio Amateur Satellite Corporation
File: BUCK_Non–Synch.sch
Sheet: /MPPT_String_Y+/TL1451 Control/Non–Synchronouse_BUCK/
Title: Fox–1 Maximum Power Point Tracker
Size: A4 *Date: 25 sep 2015* *Rev: 2*
KiCad E.D.A. Id: 19/37

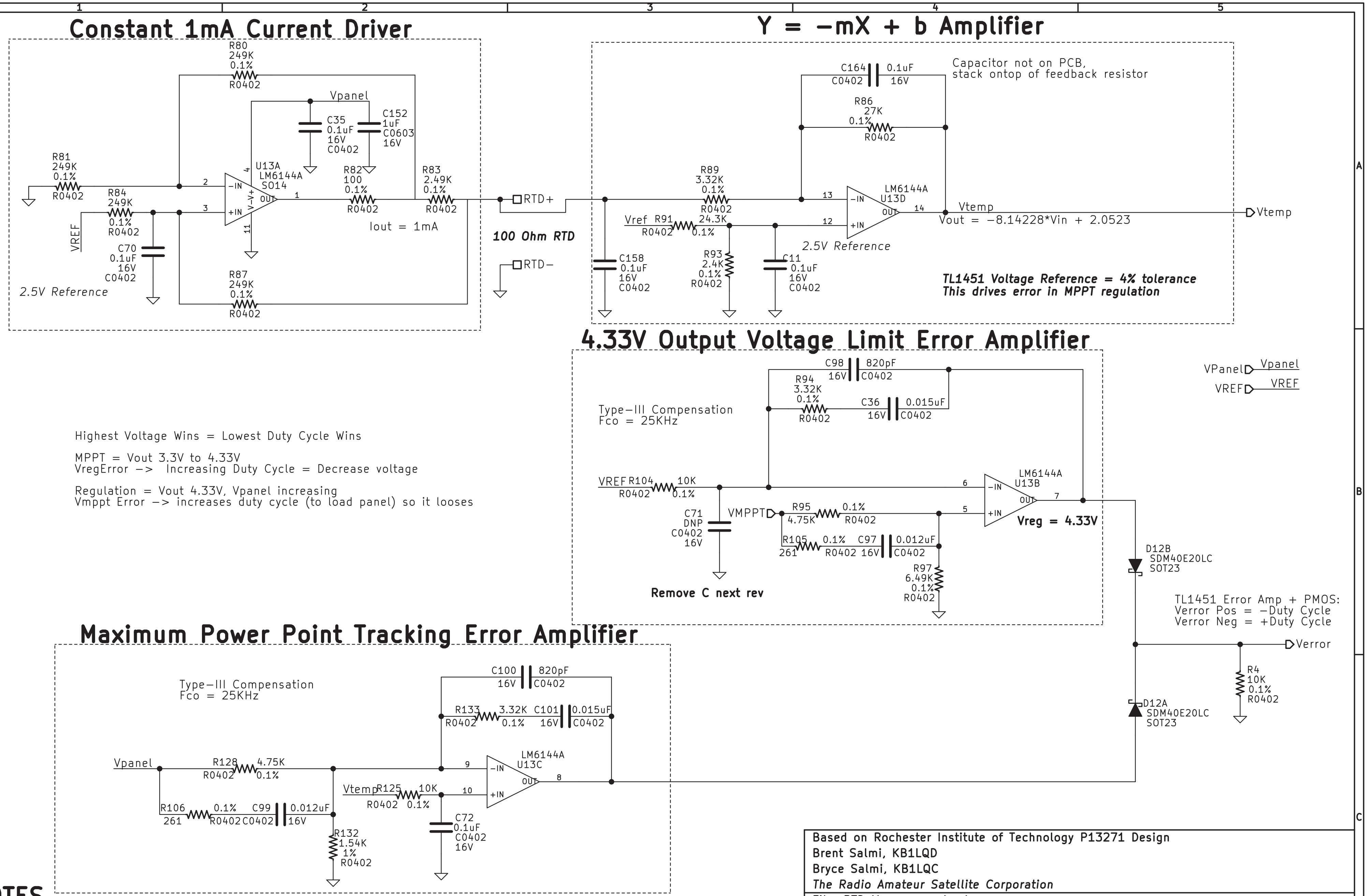
TOTEM POLE MOSFET DRIVER



NOTES

* This MPPT implements a set−point constant voltage tracking algorithm based on panel temperature.
* RIT MPPT Team: Brenton Salmi (KB1LQD), Bryce Salmi (KB1LQC), Ian MacKenzie (KB3OCF), Daniel Corriero.
* Parts not yet NASA derated.

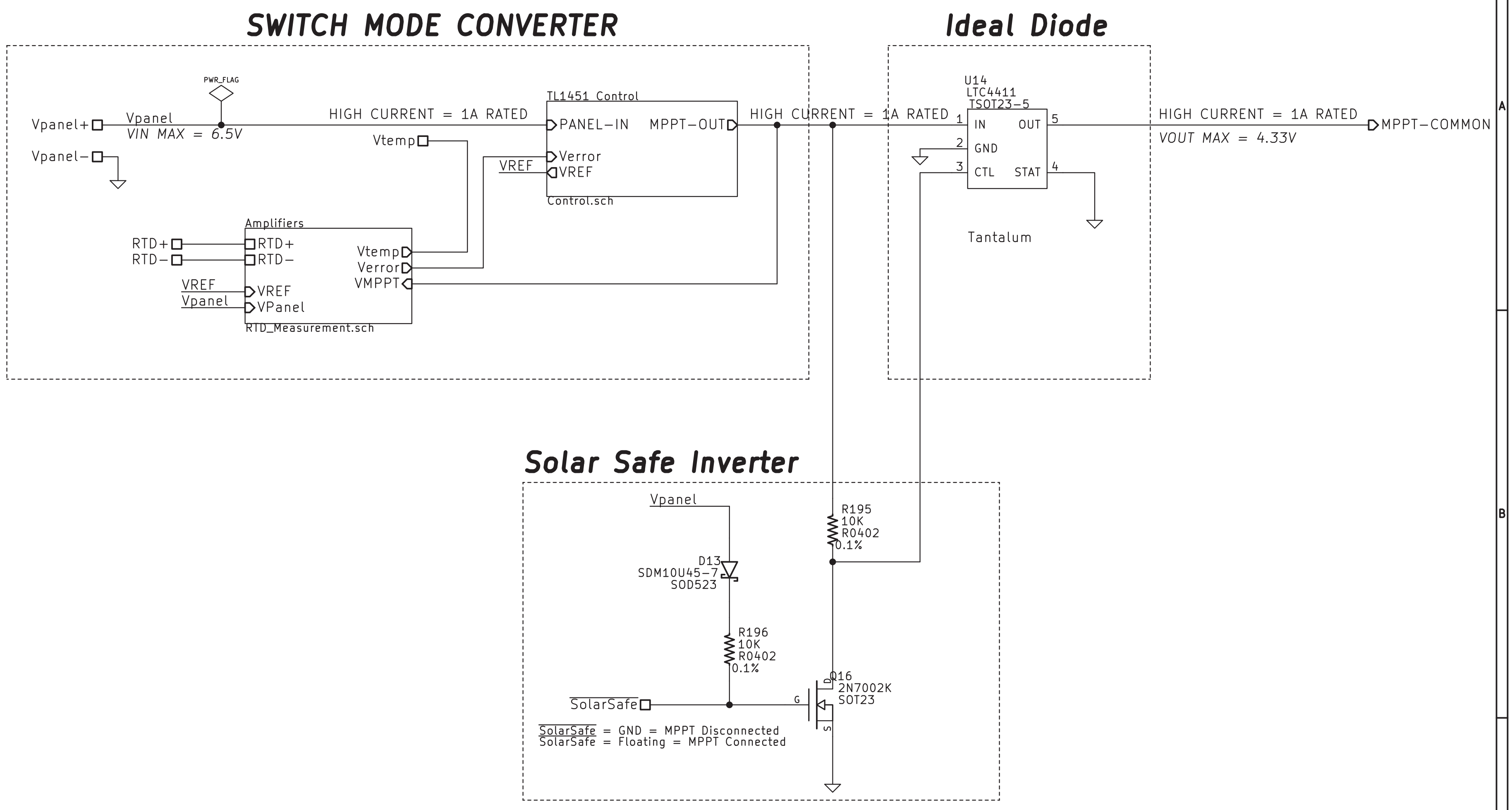
Based on Rochester Institute of Technology P13271 Design
Brent Salmi, KB1LQD
Bryce Salmi, KB1LQC
The Radio Amateur Satellite Corporation
File: MOSFET_Driver.sch
Sheet: /MPPT_String_Y+/TL1451 Control/MOSFET Driver/
Title: Fox−1 Maximum Power Point Tracker
Size: A4
Date: 25 sep 2015
Rev: 2
KiCad E.D.A.
Id: 20/37



NOTES

* This MPPT implements a set−point constant voltage tracking algorithm based on panel temperature.
* RIT MPPT Team: Brenton Salmi (KB1LQD), Bryce Salmi (KB1LQC), Ian MacKenzie (KB3OCF), Daniel Corriero.
* NASA derating taken into account, not gauranteed

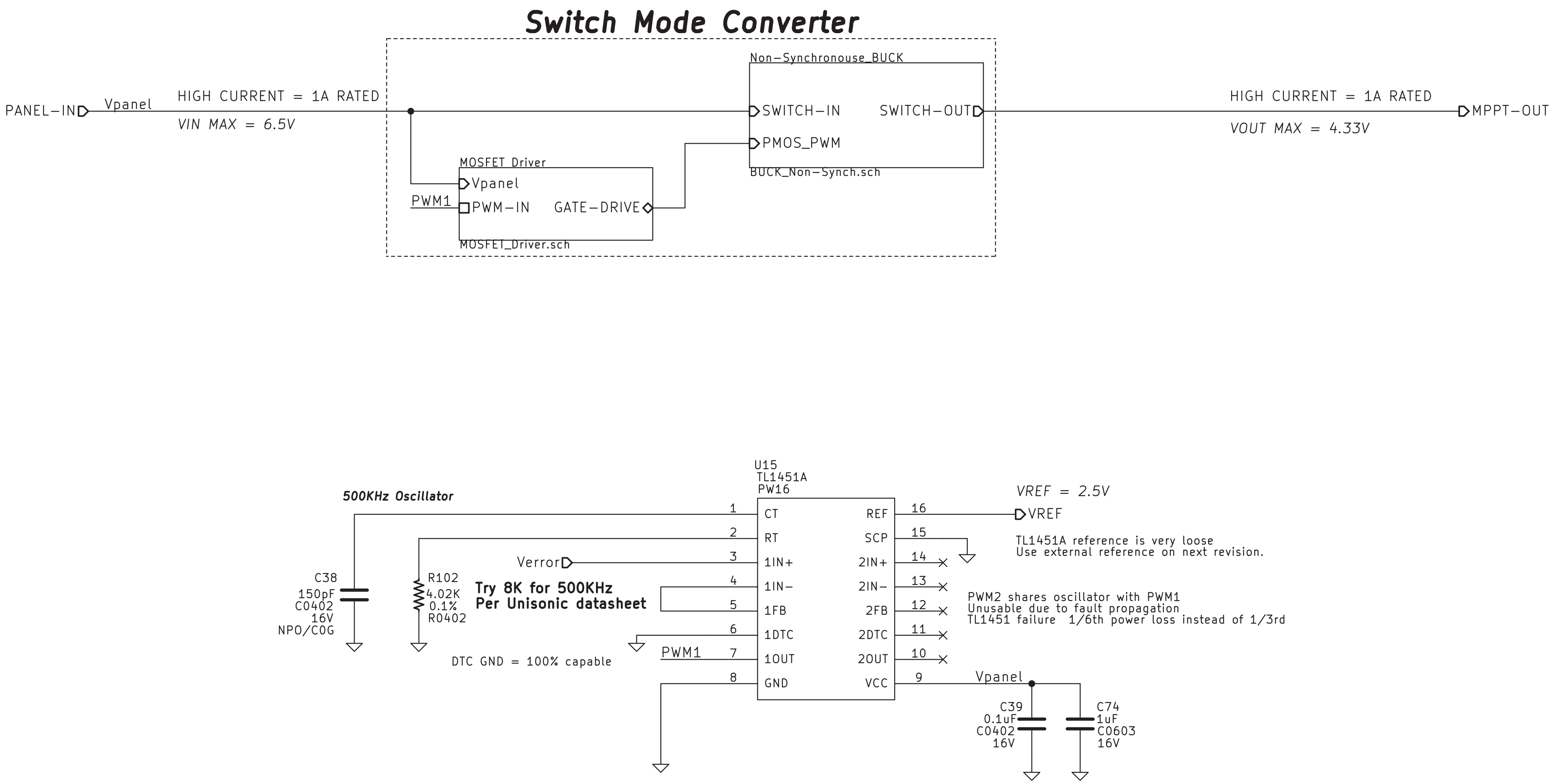
Based on Rochester Institute of Technology P13271 Design
Brent Salmi, KB1LQD
Bryce Salmi, KB1LQC
The Radio Amateur Satellite Corporation
File: RTD_Measurement.sch
Sheet: /MPPT_String_Y+/Amplifiers/
Title: Fox−1 Maximum Power Point Tracker
Size: A4 *Date: 25 sep 2015* Rev: 2
KiCad E.D.A. Id: 21/37



NOTES

* This MPPT implements a set−point constant voltage tracking algorithm based on panel temperature.
* RIT MPPT Team: Brenton Salmi (KB1LQD), Bryce Salmi (KB1LQC), Ian MacKenzie (KB3OCF), Daniel Corriero.
* NASA derating taken into account, not gauranteed

Based on Rochester Institute of Technology P13271 Design
Brent Salmi, KB1LQD
Bryce Salmi, KB1LQC
The Radio Amateur Satellite Corporation
File: MPPT_String.sch
Sheet: /MPPT_String_Y−/
Title: Fox−1 Maximum Power Point Tracker
Size: A *Date: 25 sep 2015* *Rev: 2*
KiCad E.D.A. Id: 22/37

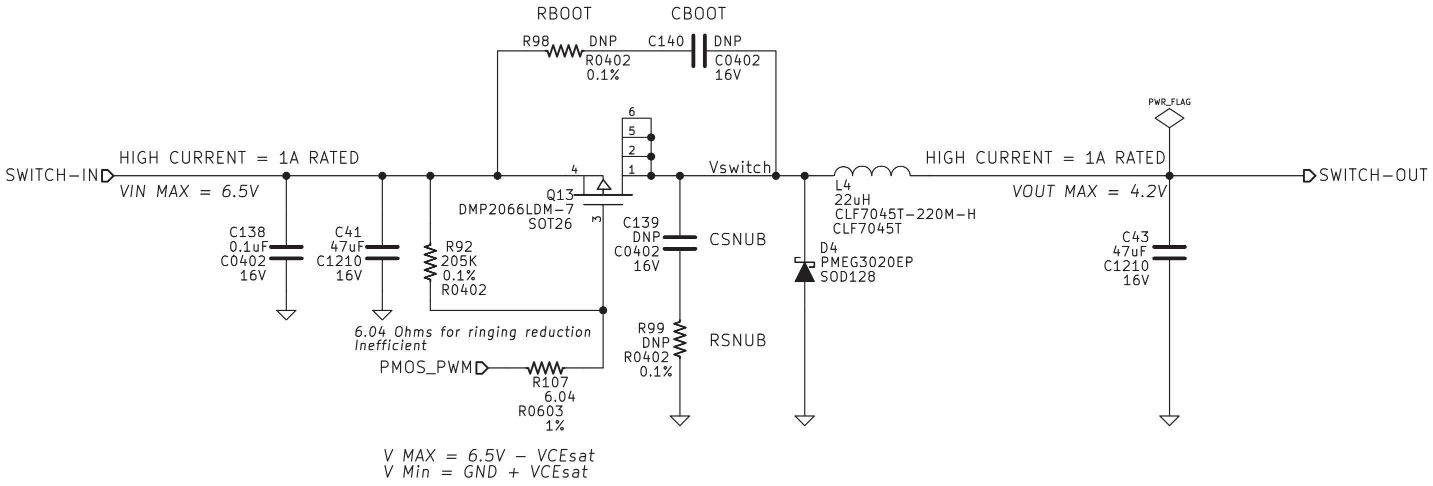


NOTES

* This MPPT implements a set-point constant voltage tracking algorithm based on panel temperature.
* RIT MPPT Team: Brenton Salmi (KB1LQD), Bryce Salmi (KB1LQC), Ian MacKenzie (KB3OCF), Daniel Corriero.
* NASA derating taken into account, not gauranteed

Based on Rochester Institute of Technology P13271 Design
Brent Salmi, KB1LQD
Bryce Salmi, KB1LQC
The Radio Amateur Satellite Corporation
File: Control.sch
Sheet: /MPPT_String_Y-/TL1451 Control/
Title: Fox-1 Maximum Power Point Tracker
Size: A4 *Date: 25 sep 2015* *Rev: 2*
KiCad E.D.A. Id: 23/37

500 KHz Step–Down Buck Converter

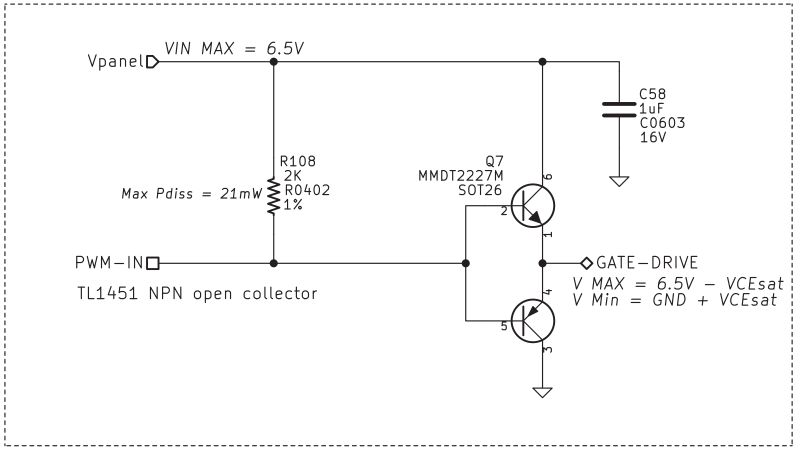


NOTES

* This MPPT implements a set–point constant voltage tracking algorithm based on panel temperature.
* RIT MPPT Team: Brenton Salmi (KB1LQD), Bryce Salmi (KB1LQC), Ian MacKenzie (KB3OCF), Daniel Corriero.
* Parts not yet NASA derated.

Based on Rochester Institute of Technology P13271 Design
Brent Salmi, KB1LQD
Bryce Salmi, KB1LQC
The Radio Amateur Satellite Corporation
File: BUCK_Non–Synch.sch
Sheet: /MPPT_String_Y–/TL1451 Control/Non–Synchronouse_BUCK/
Title: Fox–1 Maximum Power Point Tracker
Size: A4 *Date: 25 sep 2015* *Rev: 2*
KiCad E.D.A. Id: 24/37

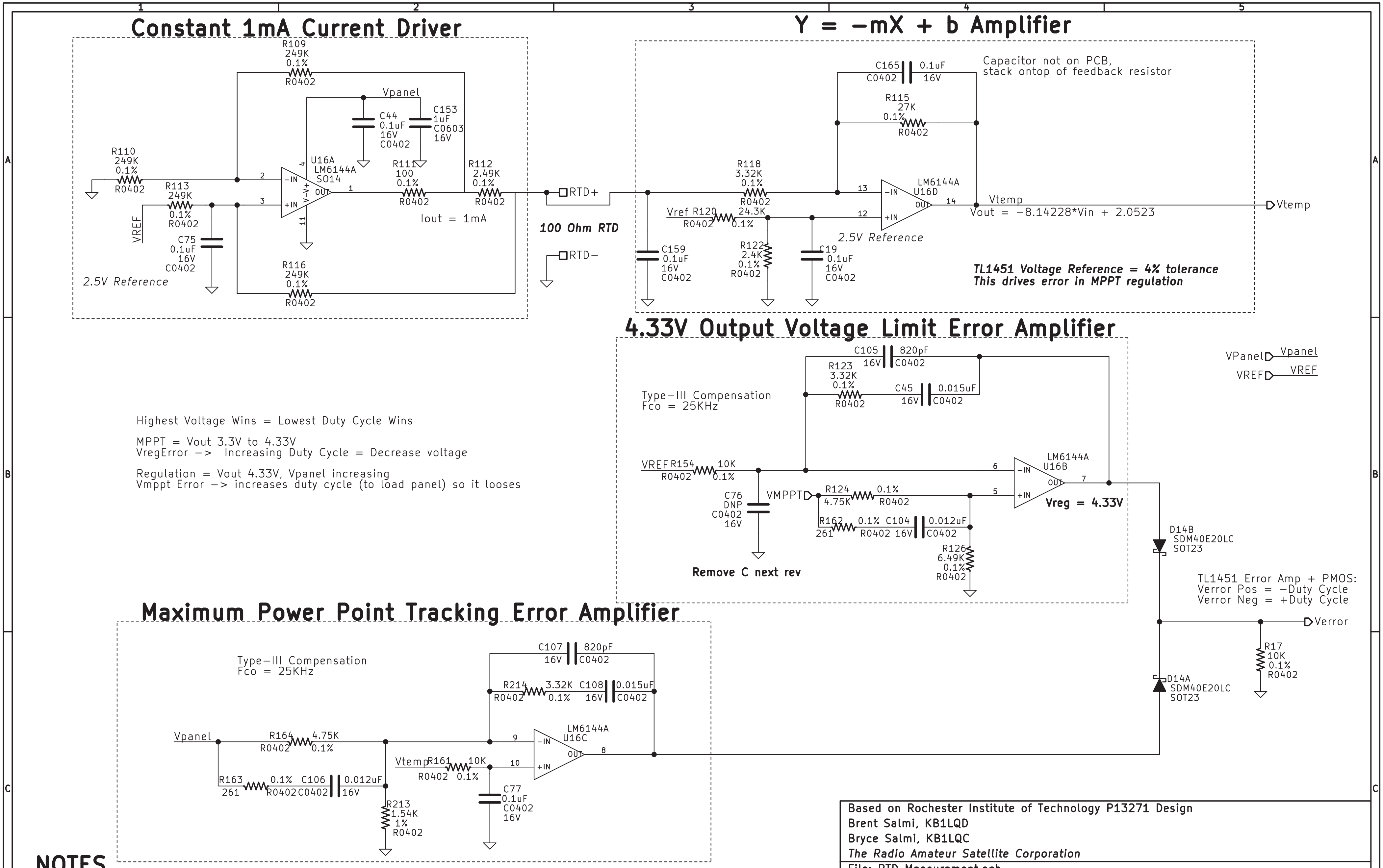
TOTEM POLE MOSFET DRIVER



NOTES

* This MPPT implements a set−point constant voltage tracking algorithm based on panel temperature.
* RIT MPPT Team: Brenton Salmi (KB1LQD), Bryce Salmi (KB1LQC), Ian MacKenzie (KB3OCF), Daniel Corriero.
* Parts not yet NASA derated.

Based on Rochester Institute of Technology P13271 Design
Brent Salmi, KB1LQD
Bryce Salmi, KB1LQC
The Radio Amateur Satellite Corporation
File: MOSFET_Driver.sch
Sheet: /MPPT_String_Y−/TL1451 Control/MOSFET Driver/
Title: Fox−1 Maximum Power Point Tracker
Size: A4 *Date: 25 sep 2015* *Rev: 2*
KiCad E.D.A. Id: 25/37



Capacitor not on PCB,
stack ontop of feedback resistor

TL1451 Voltage Reference = 4% tolerance
This drives error in MPPT regulation

Highest Voltage Wins = Lowest Duty Cycle Wins

MPPT = Vout 3.3V to 4.33V
VregError -> Increasing Duty Cycle = Decrease voltage

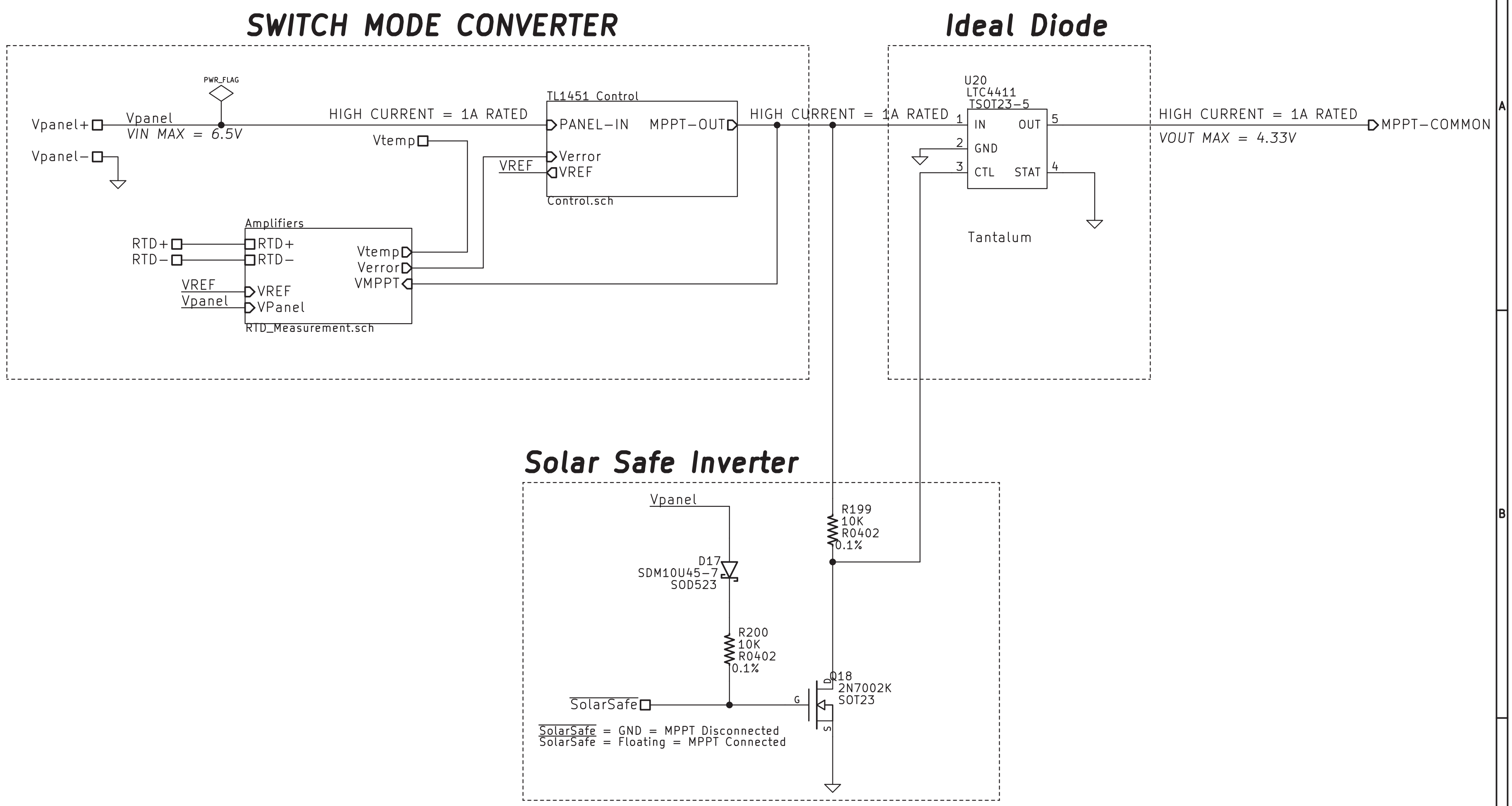
Regulation = Vout 4.33V, Vpanel increasing
Vmppt Error -> increases duty cycle (to load panel) so it looses

TL1451 Error Amp + PMOS:
Verror Pos = −Duty Cycle
Verror Neg = +Duty Cycle

NOTES

* This MPPT implements a set−point constant voltage tracking algorithm based on panel temperature.
* RIT MPPT Team: Brenton Salmi (KB1LQD), Bryce Salmi (KB1LQC), Ian MacKenzie (KB3OCF), Daniel Corriero.
* NASA derating taken into account, not gauranteed

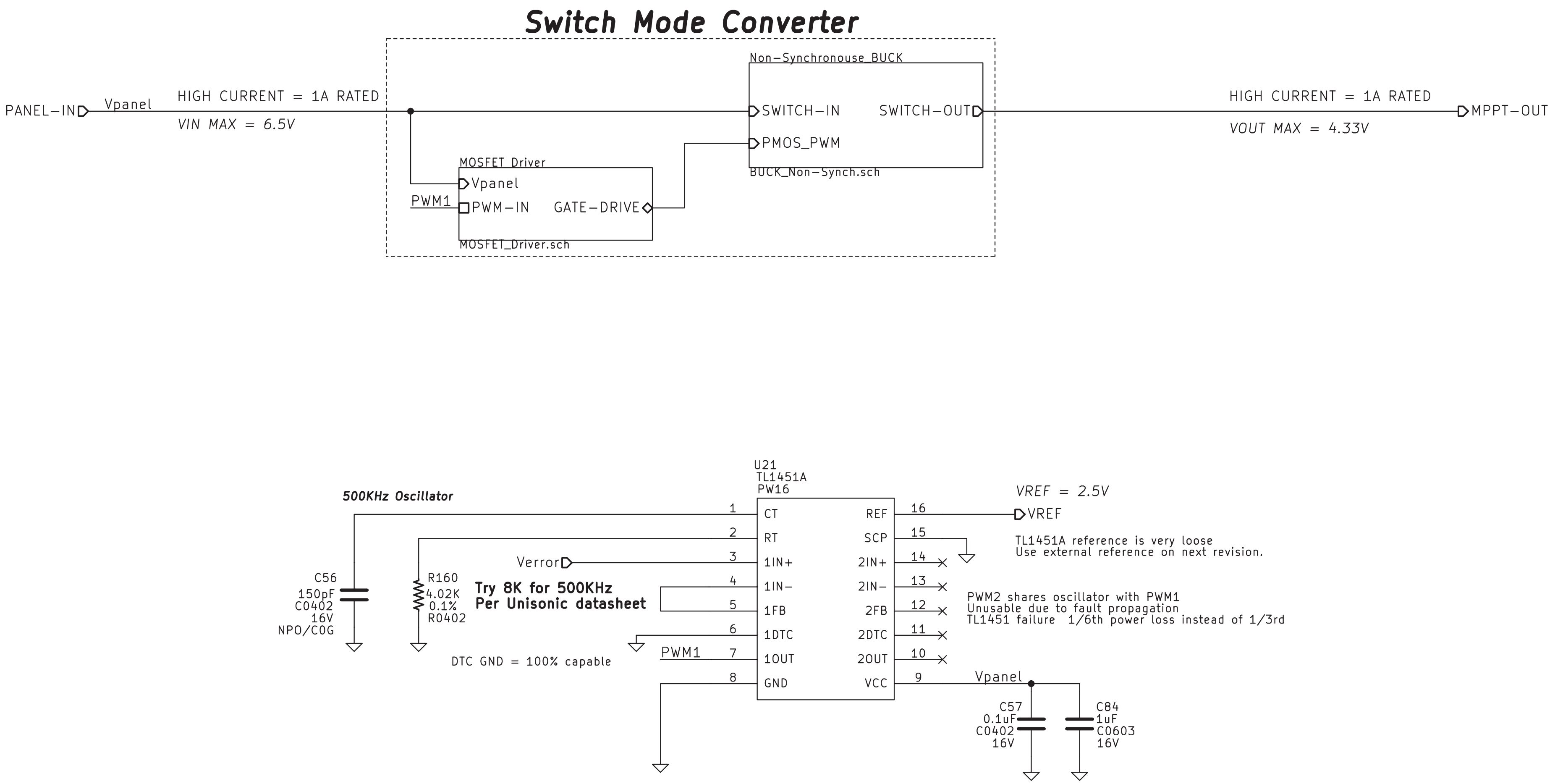
Based on Rochester Institute of Technology P13271 Design
Brent Salmi, KB1LQD
Bryce Salmi, KB1LQC
The Radio Amateur Satellite Corporation
File: RTD_Measurement.sch
Sheet: /MPPT_String_Y−/Amplifiers/
Title: Fox−1 Maximum Power Point Tracker
Size: A4 Date: 25 sep 2015 Rev: 2
KiCad E.D.A. Id: 26/37



NOTES

* This MPPT implements a set−point constant voltage tracking algorithm based on panel temperature.
* RIT MPPT Team: Brenton Salmi (KB1LQD), Bryce Salmi (KB1LQC), Ian MacKenzie (KB3OCF), Daniel Corriero.
* NASA derating taken into account, not gauranteed

Based on Rochester Institute of Technology P13271 Design
Brent Salmi, KB1LQD
Bryce Salmi, KB1LQC
The Radio Amateur Satellite Corporation
File: MPPT_String.sch
Sheet: /MPPT_String_Z−/
Title: Fox−1 Maximum Power Point Tracker
Size: A *Date: 25 sep 2015* *Rev: 2*
KiCad E.D.A. Id: 27/37

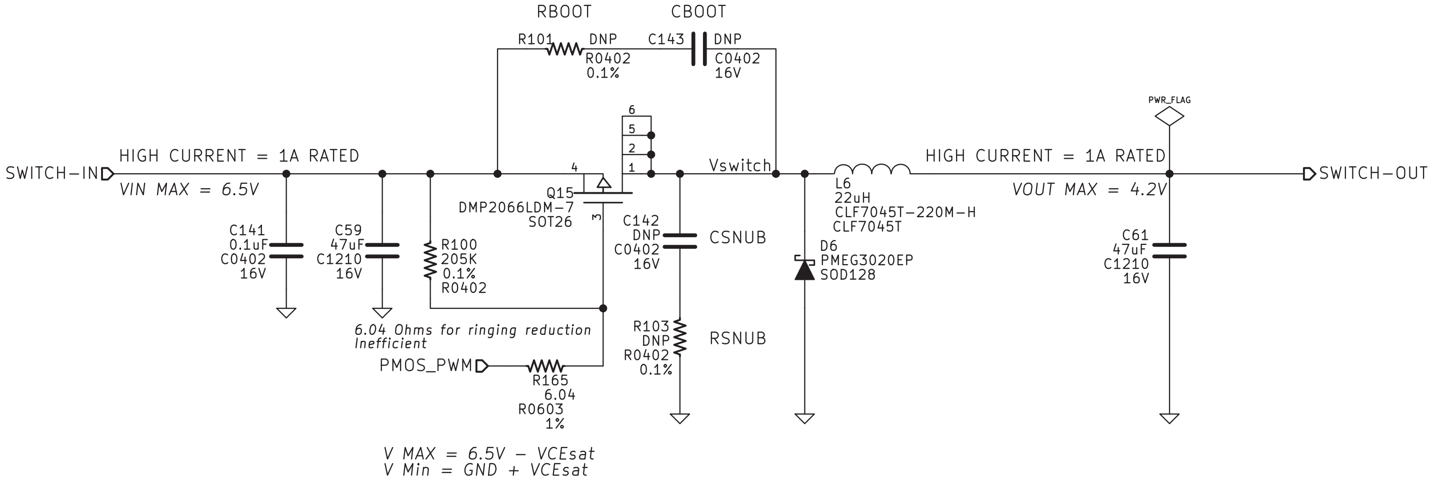


Based on Rochester Institute of Technology P13271 Design
Brent Salmi, KB1LQD
Bryce Salmi, KB1LQC
The Radio Amateur Satellite Corporation
File: Control.sch
Sheet: /MPPT_String_Z−/TL1451 Control/
Title: Fox−1 Maximum Power Point Tracker
Size: A4 *Date: 25 sep 2015* *Rev: 2*
KiCad E.D.A. Id: 28/37

NOTES

- * This MPPT implements a set−point constant voltage tracking algorithm based on panel temperature.
- * RIT MPPT Team: Brenton Salmi (KB1LQD), Bryce Salmi (KB1LQC), Ian MacKenzie (KB3OCF), Daniel Corriero.
- * NASA derating taken into account, not gauranteed

500 KHz Step–Down Buck Converter

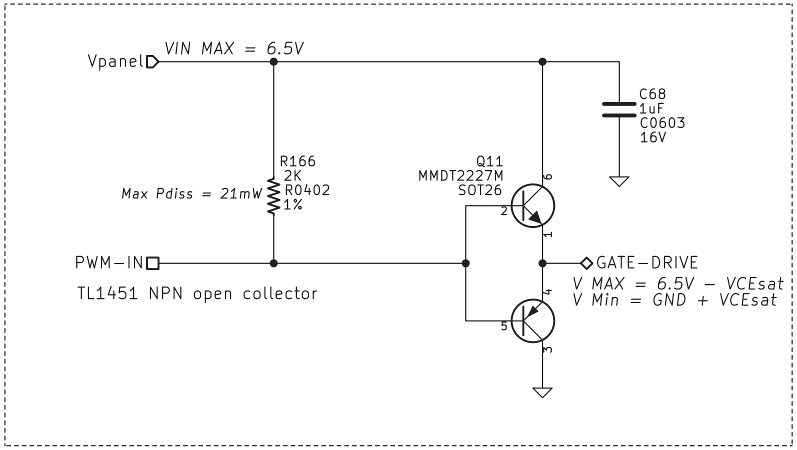


NOTES

* This MPPT implements a set–point constant voltage tracking algorithm based on panel temperature.
* RIT MPPT Team: Brenton Salmi (KB1LQD), Bryce Salmi (KB1LQC), Ian MacKenzie (KB3OCF), Daniel Corriero.
* Parts not yet NASA derated.

Based on Rochester Institute of Technology P13271 Design
Brent Salmi, KB1LQD
Bryce Salmi, KB1LQC
The Radio Amateur Satellite Corporation
File: BUCK_Non–Synch.sch
Sheet: /MPPT_String_Z–/TL1451 Control/Non–Synchronouse_BUCK/
Title: Fox–1 Maximum Power Point Tracker
Size: A4 *Date: 25 sep 2015* *Rev: 2*
KiCad E.D.A. Id: 29/37

TOTEM POLE MOSFET DRIVER



NOTES

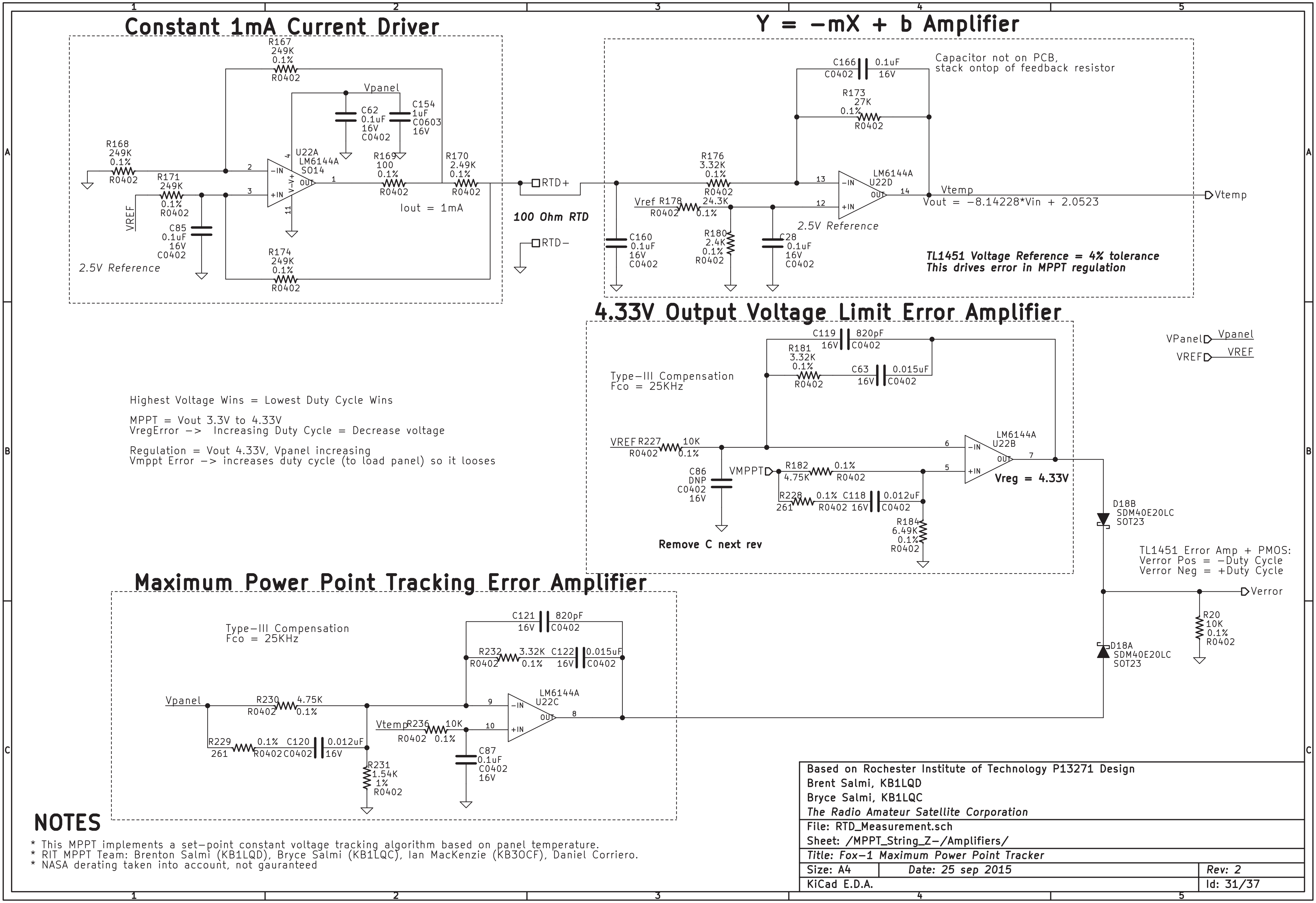
* This MPPT implements a set−point constant voltage tracking algorithm based on panel temperature.
* RIT MPPT Team: Brenton Salmi (KB1LQD), Bryce Salmi (KB1LQC), Ian MacKenzie (KB3OCF), Daniel Corriero.
* Parts not yet NASA derated.

Based on Rochester Institute of Technology P13271 Design
Brent Salmi, KB1LQD
Bryce Salmi, KB1LQC
The Radio Amateur Satellite Corporation

File: MOSFET_Driver.sch
Sheet: /MPPT_String_Z−/TL1451 Control/MOSFET Driver/

Title: Fox−1 Maximum Power Point Tracker

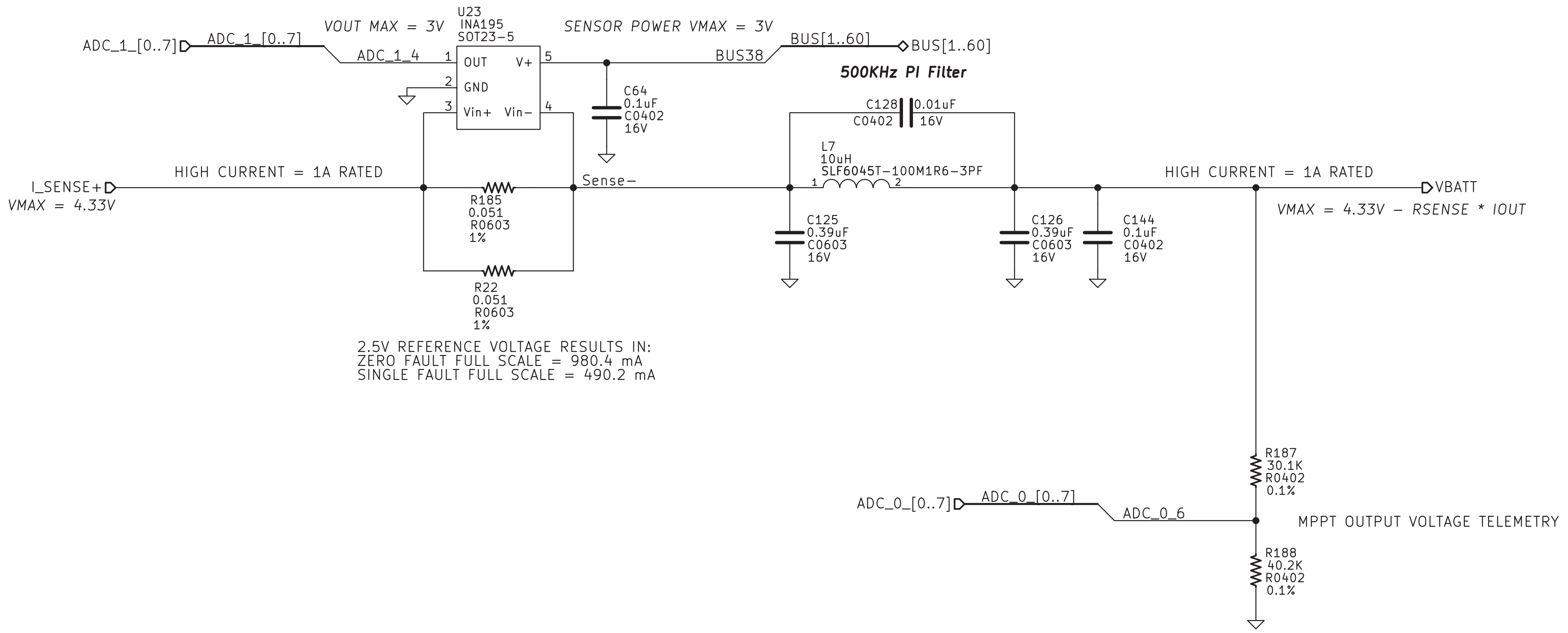
Size: A4
Date: 25 sep 2015
Rev: 2
KiCad E.D.A.
Id: 30/37



NOTES

* This MPPT implements a set−point constant voltage tracking algorithm based on panel temperature.
* RIT MPPT Team: Brenton Salmi (KB1LQD), Bryce Salmi (KB1LQC), Ian MacKenzie (KB3OCF), Daniel Corriero.
* NASA derating taken into account, not gauranteed

Based on Rochester Institute of Technology P13271 Design
Brent Salmi, KB1LQD
Bryce Salmi, KB1LQC
The Radio Amateur Satellite Corporation
File: RTD_Measurement.sch
Sheet: /MPPT_String_Z−/Amplifiers/
Title: Fox−1 Maximum Power Point Tracker
Size: A4 *Date: 25 sep 2015* *Rev: 2*
KiCad E.D.A. Id: 31/37

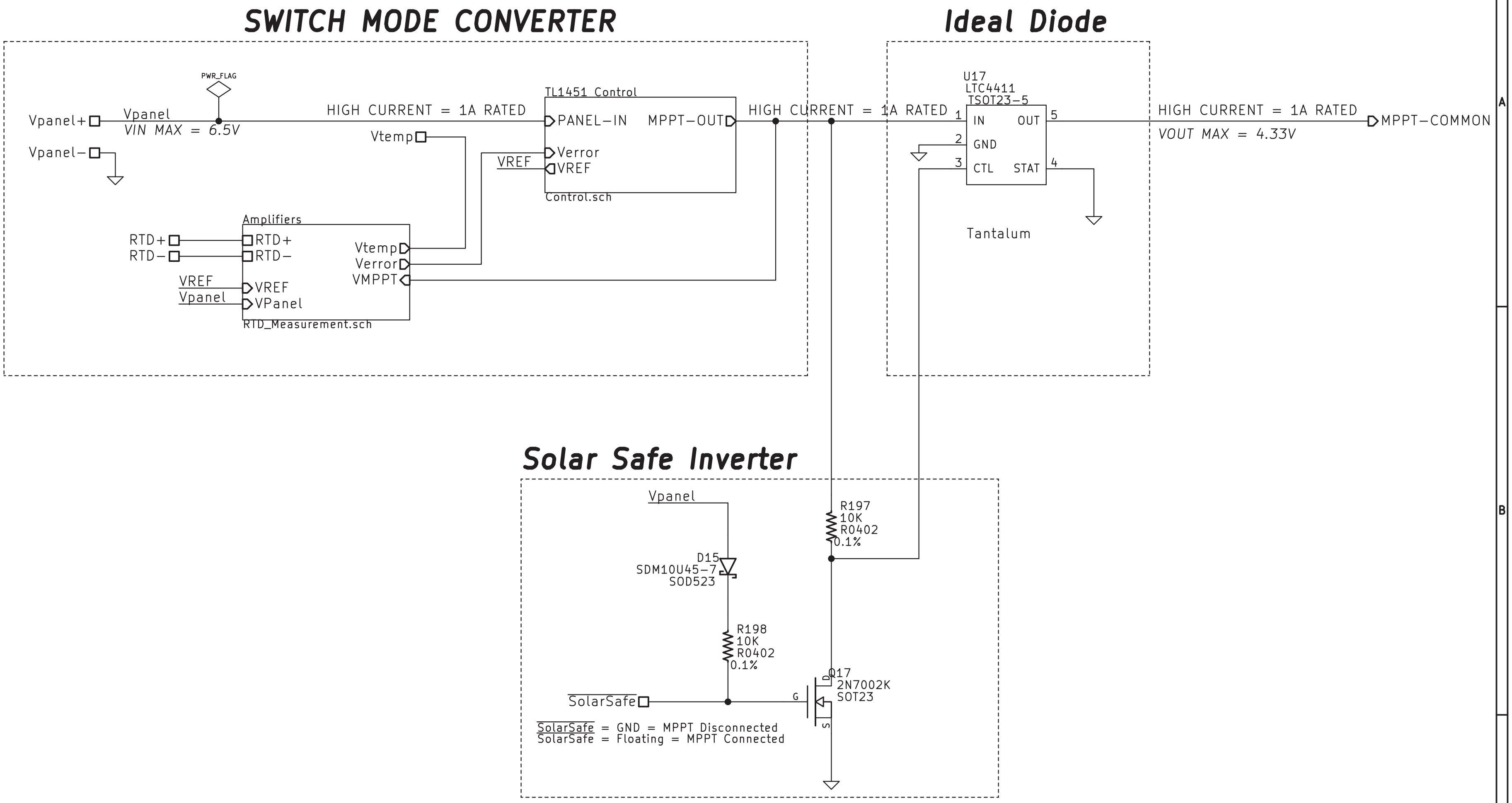


2.5V REFERENCE VOLTAGE RESULTS IN:
ZERO FAULT FULL SCALE = 980.4 mA
SINGLE FAULT FULL SCALE = 490.2 mA

NOTES

- * This MPPT implements a set-point constant voltage tracking algorithm based on panel temperature.
- * RIT MPPT Team: Brenton Salmi (KB1LQD), Bryce Salmi (KB1LQC), Ian MacKenzie (KB3OCF), Daniel Corriero.
- * NASA derating taken into account, not gauranteed

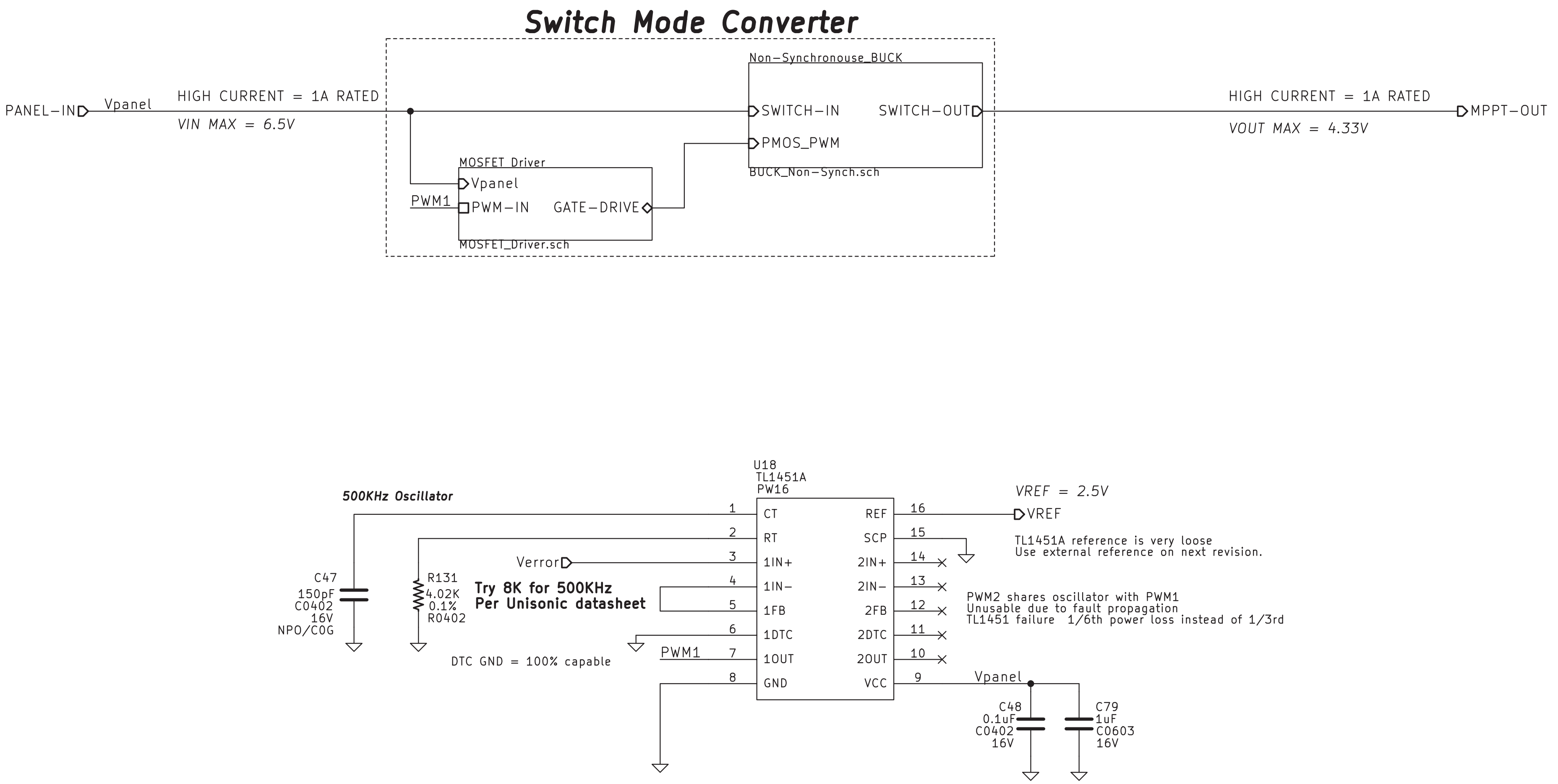
Based on Rochester Institute of Technology P13271 Design
Brent Salmi, KB1LQD
Bryce Salmi, KB1LQC
The Radio Amateur Satellite Corporation
File: Current_Sense.sch
Sheet: /Current Sense/
Title: Fox-1 Maximum Power Point Tracker
Size: A4 *Date: 25 sep 2015* *Rev: 2*
KiCad E.D.A. Id: 32/37



NOTES

* This MPPT implements a set−point constant voltage tracking algorithm based on panel temperature.
* RIT MPPT Team: Brenton Salmi (KB1LQD), Bryce Salmi (KB1LQC), Ian MacKenzie (KB3OCF), Daniel Corriero.
* NASA derating taken into account, not gauranteed

Based on Rochester Institute of Technology P13271 Design
Brent Salmi, KB1LQD
Bryce Salmi, KB1LQC
The Radio Amateur Satellite Corporation
File: MPPT_String.sch
Sheet: /MPPT_String_Z+/
Title: Fox−1 Maximum Power Point Tracker
Size: A
Date: 25 sep 2015
Rev: 2
KiCad E.D.A.
Id: 33/37



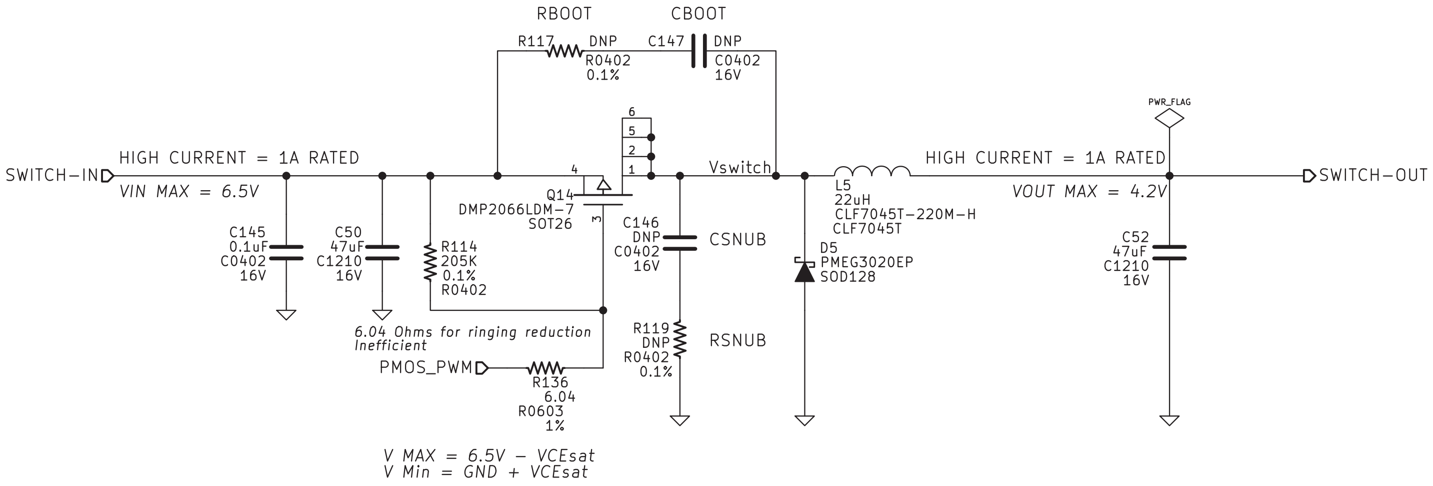
NOTES

* This MPPT implements a set−point constant voltage tracking algorithm based on panel temperature.
* RIT MPPT Team: Brenton Salmi (KB1LQD), Bryce Salmi (KB1LQC), Ian MacKenzie (KB3OCF), Daniel Corriero.
* NASA derating taken into account, not gauranteed

Based on Rochester Institute of Technology P13271 Design
Brent Salmi, KB1LQD
Bryce Salmi, KB1LQC
The Radio Amateur Satellite Corporation

File: Control.sch		
Sheet: /MPPT_String_Z+/TL1451 Control/		
Title: Fox−1 Maximum Power Point Tracker		
Size: A4	*Date: 25 sep 2015*	*Rev: 2*
KiCad E.D.A.		Id: 34/37

500 KHz Step-Down Buck Converter

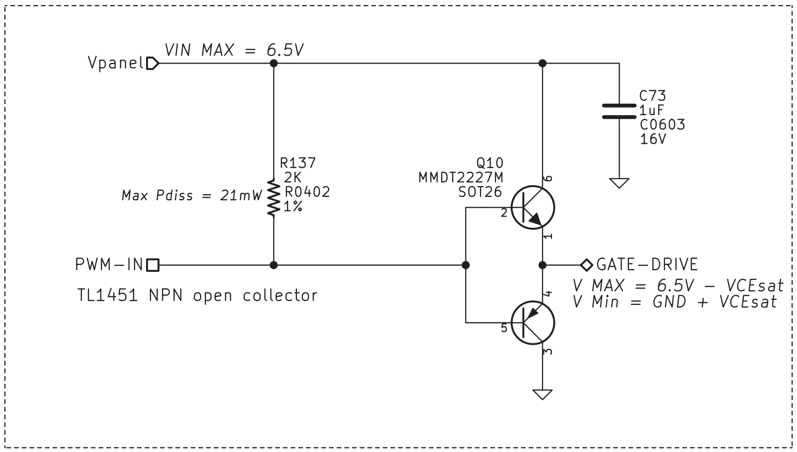


NOTES

* This MPPT implements a set–point constant voltage tracking algorithm based on panel temperature.
* RIT MPPT Team: Brenton Salmi (KB1LQD), Bryce Salmi (KB1LQC), Ian MacKenzie (KB3OCF), Daniel Corriero.
* Parts not yet NASA derated.

Based on Rochester Institute of Technology P13271 Design
Brent Salmi, KB1LQD
Bryce Salmi, KB1LQC
The Radio Amateur Satellite Corporation
File: BUCK_Non–Synch.sch
Sheet: /MPPT_String_Z+/TL1451 Control/Non–Synchronouse_BUCK/
Title: Fox–1 Maximum Power Point Tracker
Size: A4 *Date: 25 sep 2015* *Rev: 2*
KiCad E.D.A. Id: 35/37

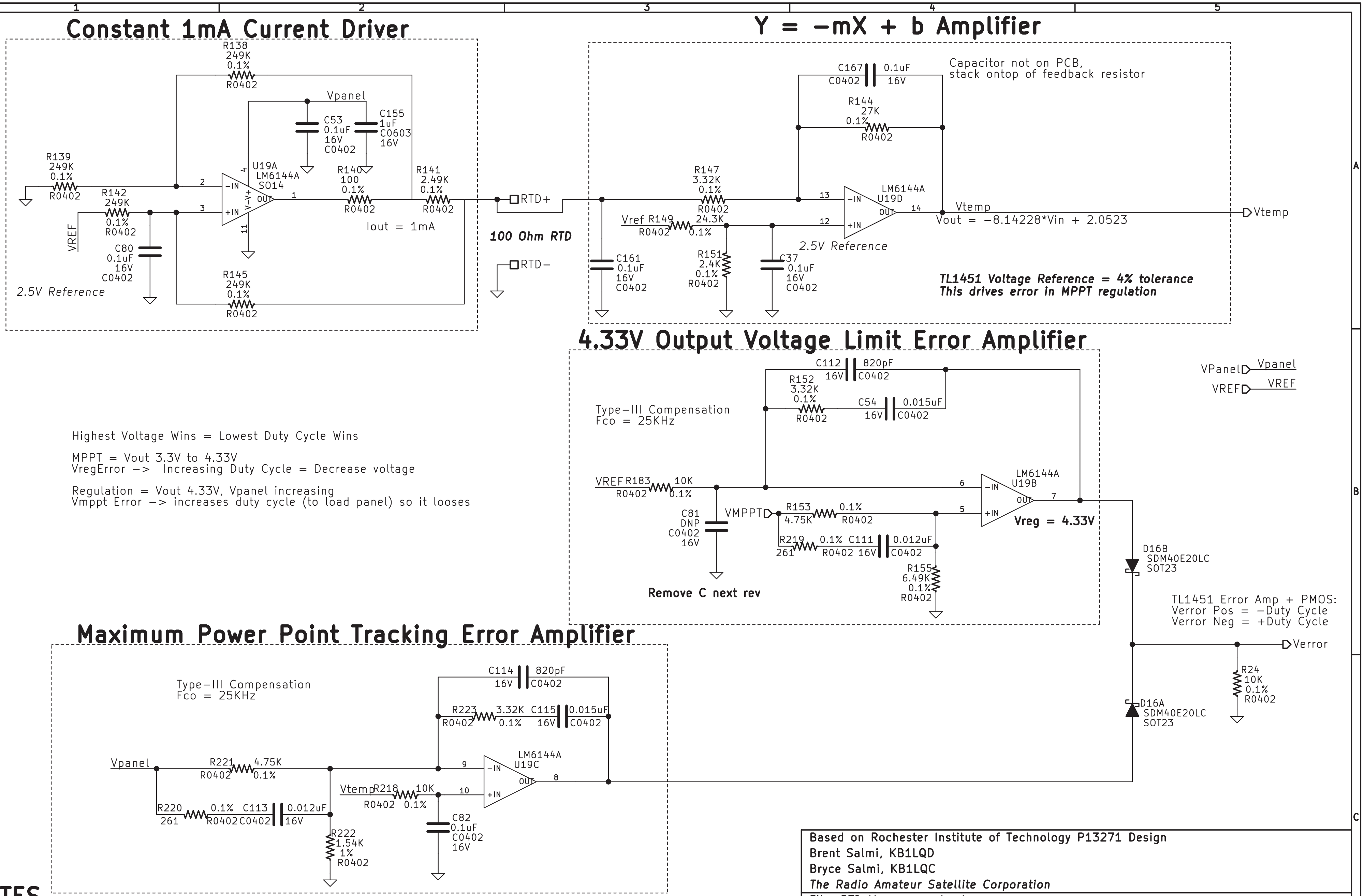
TOTEM POLE MOSFET DRIVER



NOTES

* This MPPT implements a set−point constant voltage tracking algorithm based on panel temperature.
* RIT MPPT Team: Brenton Salmi (KB1LQD), Bryce Salmi (KB1LQC), Ian MacKenzie (KB3OCF), Daniel Corriero.
* Parts not yet NASA derated.

Based on Rochester Institute of Technology P13271 Design
Brent Salmi, KB1LQD
Bryce Salmi, KB1LQC
The Radio Amateur Satellite Corporation
File: MOSFET_Driver.sch
Sheet: /MPPT_String_Z+/TL1451 Control/MOSFET Driver/
Title: Fox−1 Maximum Power Point Tracker
Size: A4 *Date: 25 sep 2015* *Rev: 2*
KiCad E.D.A. Id: 36/37



NOTES

* This MPPT implements a set−point constant voltage tracking algorithm based on panel temperature.
* RIT MPPT Team: Brenton Salmi (KB1LQD), Bryce Salmi (KB1LQC), Ian MacKenzie (KB3OCF), Daniel Corriero.
* NASA derating taken into account, not gauranteed

Based on Rochester Institute of Technology P13271 Design Brent Salmi, KB1LQD Bryce Salmi, KB1LQC *The Radio Amateur Satellite Corporation*		
File: RTD_Measurement.sch		
Sheet: /MPPT_String_Z+/Amplifiers/		
Title: Fox−1 Maximum Power Point Tracker		
Size: A4	*Date: 25 sep 2015*	*Rev: 2*
KiCad E.D.A.		Id: 37/37

AMSAT Engineering Documentation Update

Compiled by Jerry Buxton, N0JY
AMSAT Vice President - Engineering
n0jy@amsat.org

AMSAT, as an educational organization, would like to publicly release the majority of our design documentation to serve as a learning tool to anyone interested in satellite development. However, in order to avoid complications with ITAR and Export Administration Rules, the information must first be released via an openly available publication. We would also like to be able to discuss our satellite projects with our own members, some of whom are not "US-persons" per those regulations. These AMSAT Space Symposium proceedings provide a convenient mechanism for the needed publication in order to make this information public domain and allow us to communicate with our members.

While many of the Fox-1 documents were published in previous *Proceedings*, some of these documents have undergone changes as the satellite design has progressed and evolved therefore the updated versions will be reproduced in these 2016 Space Symposium proceedings. In addition, these proceedings also present new engineering documents that have been produced since the last publication which include some of the documentation for the RadFxSat (Fox-1B) and RadxSat-2 (Fox-1E) satellites. Also included are some of the documents from the development of the Heimdallr (Phase 5) lunar orbiting satellite.

Fox-1 Documents

This section contains the final RadFxSat (Fox-1B) ICD (Interface Control Document) for the Vanderbilt University ISDE experiment (**page 57**). The control of the RadFxSat experiment is essentially the same as that of the Fox-1A Vanderbilt experiment. Also included for RadFxSat are an updated avionics bus pin assignment (**page 73**), and a CAD drawing of the avionics stack (**page 85**).

One document is included for Fox-1Cliff and Fox-1D, which details the resolution calculations for the Virginia Tech camera experiments (**page 87**). These calculations were necessary in the application for the NOAA imaging licenses.

The Fox-1E documentation includes the draft System Requirements (**page 95**), Downlink Specification for the telemetry being sent (**page 105**), a document describing the use of average power tracking for the Fox-1E linear transponder (**page 123**), a schematic of the mixers and IF for the Fox-1E transponder (**page 129**), and a document describing a 1200 bps BPSK modulator for the Fox-1E transponder (**page 131**).

Heimdallr (Phase 5 / CubeQuest Challenge) Documents

This section contains several link budget calculations used in the planning and design for the Heimdallr lunar orbiting satellite (Phase 5) (**page 137**).

Date: December 16, 2015
Version: Version 1.01

AMSAT *Fox-1B (RadFxSat)*

IHU to Experiment 1 Interface Control Document

1 Introduction

This document specifies the message interface between the Internal Housekeeping Unit (IHU) and the Experiment System in Position 1 of the satellite, known as the Vanderbilt University Phoenix Payload and abbreviated herein as EXP1.

1.1 Document History

DATE	VERSION	SUMMARY
December 15, 2015	1.00	Initial version
December 16, 2015	1.01	Change Vulcan to Phoenix

1.2 Document Scope

This document will specify the control of EXP1, the messaging format, and the I²C bus hardware operation for the communications between the IHU and the EXP1.

1.3 References

1. AMSAT *Fox-1,* System Requirements Specification
2. AMSAT *Fox-1*, System Design Specification
3. AMSAT *Fox-1*, IHU Software Architecture Specification
4. Vanderbilt University Phoenix Payload Interface Control Document

2 General Messaging Requirements

2.1 Link Protocol Requirements

2.1.1 The IHU shall initiate a command to the EXP1.

2.1.2 The EXP1 shall send a reply to each IHU request.

2.1.3 Message bit order shall be Big Endian.

2.1.4 The IHU shall determine the action to be taken in the event of an invalid, improper, or missing message from the EXP1.

2.1.5 The EXP1 shall take no action in the event of an invalid or improper message from the IHU.

2.1.6 Message byte order shall be Big Endian.

2.2 General Message Requirements

2.2.1 Each message shall contain a header block.

2.2.2 Each message shall contain a packet error check (PEC) in the form of CRC8.

2.2.2.1 The message address byte shall be included when calculating the CRC8.

2.3 I²C 1 Bus Hardware Interface Requirements

2.3.1 The I²C Vdd shall be 3.0V.

2.3.2 The bus speed shall be Fast (400kbit/s).

2.3.3 The EXP1 I²C 7 bit address shall be 0x2A.

3 Experiment Operation

3.1 Experiment Power Control

3.1.1 The IHU shall exert control over the power state of the EXP1 by the Experiment Enable 1 pin on the satellite bus as shown in Table 1.

Table 1

Pin State	Description
High	Power On Experiment
Low or high-impedance	Power Off Experiment

3.1.2 The IHU shall not power on the experiment if the power bus voltage (VBATT) is less than or equal to 3.3 Volts.

3.1.3 The IHU shall perform the Experiment Cease Operation Sequence and the Experiment Power Off Sequence if the power bus voltage (VBATT) falls to less than or equal to 3.3 Volts while the experiment is powered on.

3.2 Experiment Power On Sequence

3.2.1 The IHU shall set and hold the Experiment Enable 1 pin HIGH.

3.2.2 The IHU shall not send any message to the EXP1 for a minimum of 100 milliseconds.

3.2.3 The IHU shall send a Set Time command to the EXP1.

3.3 Experiment Begin Operation Sequence

3.3.1 Upon completion of the Power On sequence the IHU shall send a Set Run State Active command message to the EXP1.

3.4 Experiment Cease Operation Sequence

3.4.1 The IHU shall send a Set Run State Halt command message to the EXP1.

3.4.2 The IHU shall not send any message to the EXP1 for a minimum of 10000 milliseconds.

3.4.3 The IHU shall send a Set Run State Standby command message to the EXP1.

3.4.4 The IHU shall send the command message “0x05 0x00 0x00 0x01 0x00 0x01 (opcode=0x0500, arg1=0x0001, arg2=0x0001)” to the EXP1.

3.4.5 The IHU shall send the following series of command messages to the EXP1:

- “0x05 0x00 0x00 0x5C 0x00 0x00 (opcode=0x0500, arg1=0x005C, arg2=0x0000)”

- "0x05 0x00 0x00 0x5D 0x00 0x00 (opcode=0x0500, arg1=0x005D, arg2=0x0000)"
- "0x05 0x00 0x00 0x5E 0x00 0x00 (opcode=0x0500, arg1=0x005E, arg2=0x0000)"
- "0x05 0x00 0x00 0x5F 0x00 0x00 (opcode=0x0500, arg1=0x005F, arg2=0x0000)"
- "0x05 0x00 0x00 0x60 0x00 0x00 (opcode=0x0500, arg1=0x0060, arg2=0x0000)"
- "0x05 0x00 0x00 0x61 0x00 0x00 (opcode=0x0500, arg1=0x0061, arg2=0x0000)"
- "0x05 0x00 0x00 0x62 0x00 0x00 (opcode=0x0500, arg1=0x0062, arg2=0x0000)"
- "0x05 0x00 0x00 0x63 0x00 0x00 (opcode=0x0500, arg1=0x0063, arg2=0x0000)"

3.5 Experiment Power Off Sequence

3.5.1 The IHU shall set the Experiment Enable 1 pin LOW.

3.5.1.1 The absence of a HIGH state on the Experiment Enable 1 pin shall be construed as a LOW state whether the pin is actually LOW, or in a high-impedance state.

4 Message Content Requirements

4.1 Command Message

4.1.1 The message header block shall be constructed as shown in table 2.

4.1.2 The message header block shall be sent with each Command and Response block.

Table 2

Field	Size (Bytes)	Type	Min Value	Max Value	Description
Message Version	2	Unsigned	0x01	0xFFFF	Message ICD version
Software Build	2	Unsigned	0x01	0xFFFF	Software Build version

4.1.2.1 The Message Version shall be an integer representing the IHU to EXP1 ICD document version number from which the message format is derived, having the decimal point removed (e.g. version 1.03 would be 103 decimal or 0x67).

4.1.2.2 The Software Build shall be an integer representing the software build version number of the system originating the message, having any decimal points removed (e.g. version 1.03 would be 103 decimal or 0x67).

4.2 Command Message Block

4.2.1 The command message block shall be constructed as shown in Table 3.

Table 3

Field	Size (Bytes)	Type	Min Value	Max Value	Description
COMMAND	2	Unsigned	0x0000	0x0280	Hexadecimal Command
ARGUMENT	Variable	Unsigned	-	-	Optional Arguments As Required

The command message block shall contain one command in the COMMAND field as shown in Table 4.

Table 4

Command Name	Size (Bytes)	Type	Min Value	Max Value	Description
Nop	2	Unsigned	0x0000	0x0000	No effect; response undefined. Test for I²C acknowledgement only.
Echo	2	Unsigned	0x0001	0x0001	Echo this byte stream
Resend	2	Unsigned	0x0002	0x0002	Resend last result
Get UID	2	Unsigned	0x0003	0x0003	Controller 7 byte identifier
Get Status	2	Unsigned	0x0004	0x0004	Controller status indication
Get Diagnostics	2	Unsigned	0x0006	0x0006	Self-check Diagnostic
Get Telemetry	2	Unsigned	0x0010	0x0010	Send telemetry data
Set Run State	2	Unsigned	0x0080	0x0080	Enter specified Run State
Get Run State	2	Unsigned	0x0081	0x0081	Query current Run State
Set Time	2	Unsigned	0x0100	0x0100	Number of seconds since epoch
Get Time	2	Unsigned	0x0101	0x0101	Number of seconds since epoch
Get Data	2	Unsigned	0x0280	0x0280	Send (number of bytes) data

4.2.3 The command message shall contain arguments for the Echo command, as shown in Table 5.

Table 5

Field	Size (Bytes)	Type	Min Value	Max Value	Description
ARGUMENT	4	Unsigned	-	-	Data to be echoed

4.2.4 The command message shall contain one argument for the Set Run State command, as shown in Table 6.

Table 6

Run State	**Size (Bytes)**	**Type**	**Min Value**	**Max Value**	**Description**
STANDBY	2	Unsigned	0x0001	0x0001	Enter Standby State
ACTIVE	2	Unsigned	0x0003	0x0003	Activate Experiments
HALT	2	Unsigned	0x0005	0x0005	Terminate Experiments

4.2.5 The command message shall contain arguments for the Set Time command, as shown in Table 7.

Table 7

Argument	**Size (Bytes)**	**Type**	**Min Value**	**Max Value**	**Description**
IHU Reset Counter	16	Unsigned	0x00	-	Count of the number of IHU resets from non-volatile FRAM
MET Timestamp	32	Unsigned	-	-	MET timestamp (seconds since last IHU reset)

4.2.6 The command message shall contain arguments for the Get Data command, as shown in Table 8.

Table 8

Argument	**Size (Bytes)**	**Type**	**Min Value**	**Max Value**	**Description**
BYTES TO SEND	2	Unsigned	0x00	0x00FF	Number of bytes to send (1-256)

4.3 Response Message Block

4.3.1 The response message block shall be constructed as shown in Table 9.

Table 9

Field	Size (Bytes)	Type	Min Value	Max Value	Description
RESERVED	1	Unsigned	-	-	Reserved, ignore
ERROR CODE	1	Unsigned	0x0000	0x0006	Response to Command
LENGTH	2	Unsigned	0x00	0xFFFF	Length of Return Value in Bytes
RETURN VALUE	Variable	Variable	-	-	Return Value

4.3.2 The Error Code shall contain one code as shown in table 10.

Table 10

Name	Size (Bytes)	Type	Min Value	Max Value	Description
CMD_OK	1	Unsigned	0x0000	0x0000	Command invoked successfully
CMD_OP_ERR	1	Unsigned	0x0001	0x0001	Command not recognized
CMD_FORMAT_ERR	1	Unsigned	0x0002	0x0002	Incorrect command argument length
CMD_RANGE_ERR	1	Unsigned	0x0003	0x0003	Argument(s) out of bounds
CMD_PEC_ERR	1	Unsigned	0x0004	0x0004	Error check (CRC) mismatch
CMD_EXEC_ERR	1	Unsigned	0x0005	0x0005	Execution error
CMD_VERSION_ERR	1	Unsigned	0x0006	0X0006	Header Message Version mismatch

4.3.3 The Status Flags for a GET STATUS response message shall be represented as individual bit values of a 16 bit RETURN VALUE as shown in Table 11.

Table 11

Name	Bit Number	Description
REBOOTED	0	1 = Experiment has rebooted – **NOT USED**
DATA READY	1	1 = Experiment data available
TIME REQUEST	2	1 = Request SET TIME
FAILED RUN STATE	3	1 = Failed the run state – **NOT USED**
COMPLETED RUN STATE	4	1 = Completed the run state – **NOT USED**
RESERVED	5-15	Always 0

4.3.4 The response message to a Set Time command shall contain one of the values as shown in Table 12.

Table 12

Response Name	Size (Bytes)	Type	Min Value	Max Value	Description
SUCCESS	2	Signed	0x00	0x00	Time Set successfully
FAILURE	2	Signed	0xFFFF	0xFFFF	Time Set failed

5 Message Integrity

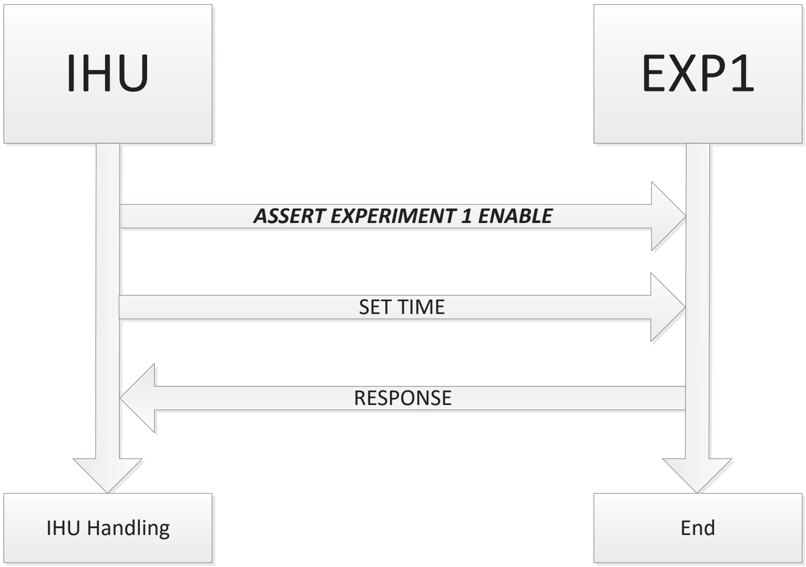
5.1 Invalid Messages

5.1.1 If the PEC (CRC8) fails, the message shall be considered invalid.

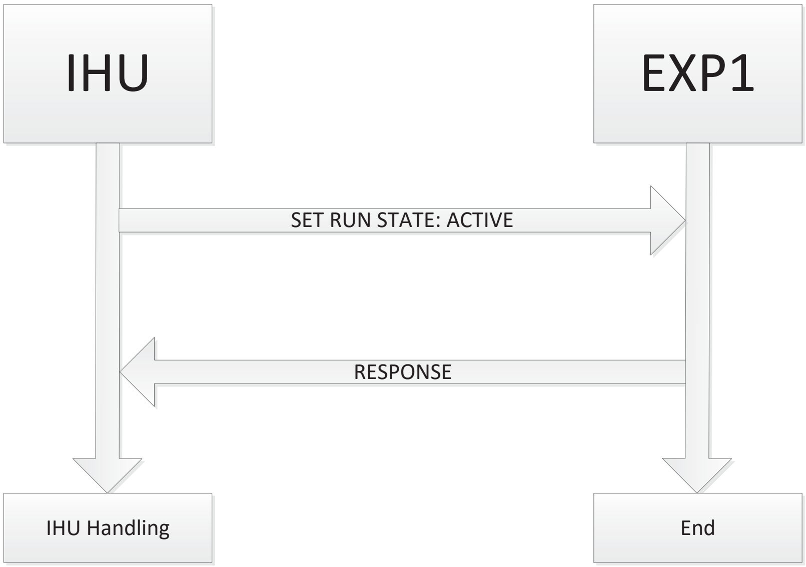
5.1.2 If the Message Version does not match the message version in use for the construction of messages on the receiving system, the message shall be considered invalid.

6 Message Flow Diagrams

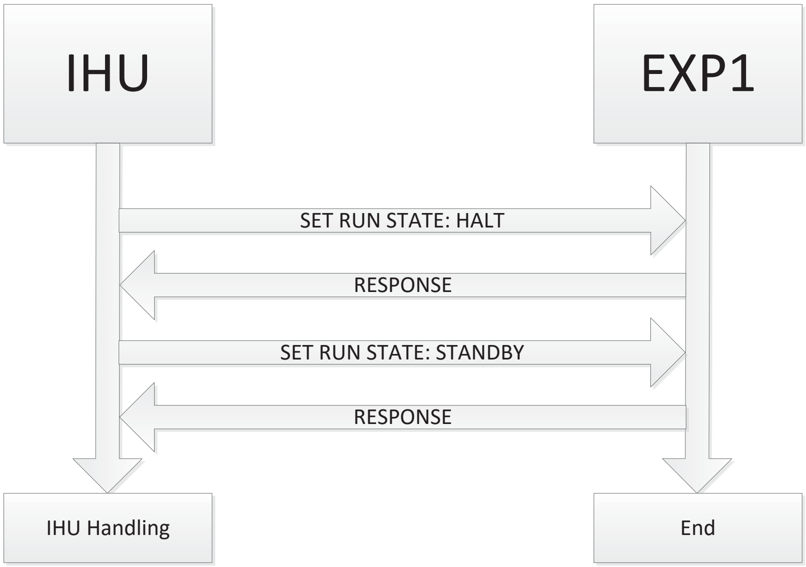
6.1 EXPERIMENT POWER ON SEQUENCE



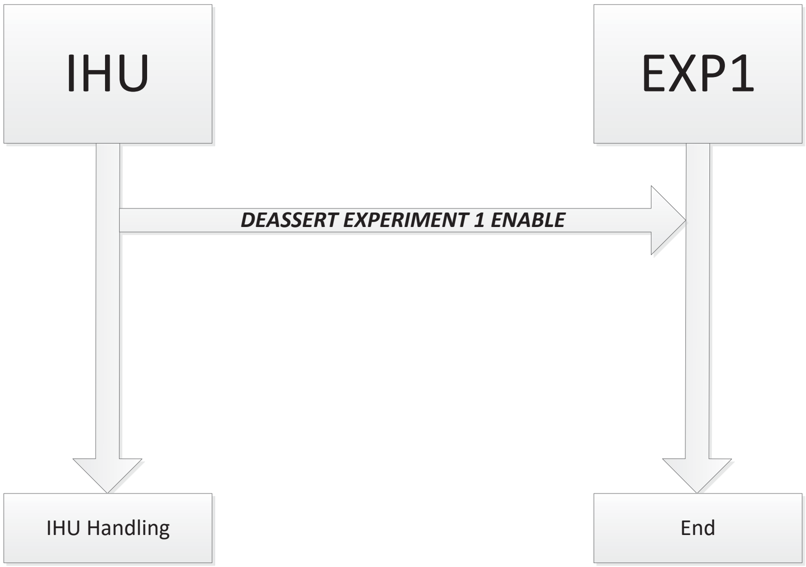
6.2 EXPERIMENT BEGIN OPERATION SEQUENCE



6.3 EXPERIMENT CEASE OPERATION SEQUENCE



6.4 EXPERIMENT POWER OFF SEQUENCE



6.5 SERVICING EXPERIMENT OPERATION

Figure 1

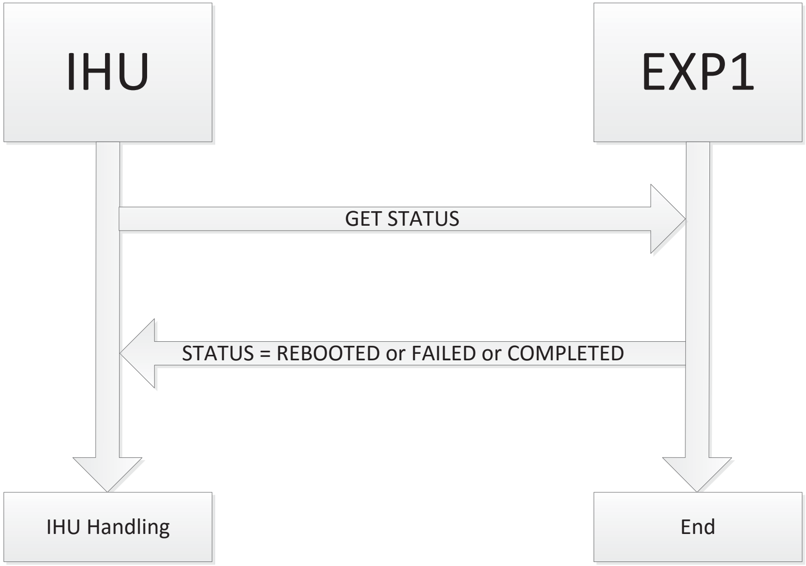


Figure 2

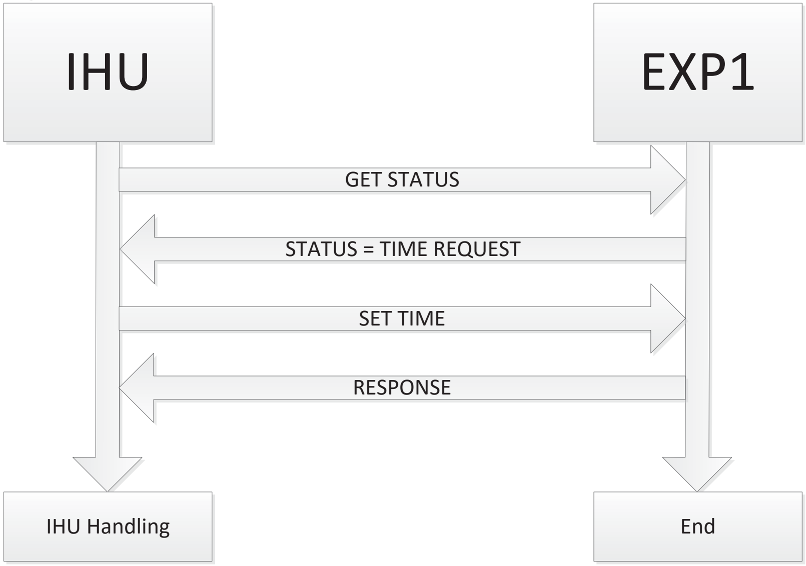
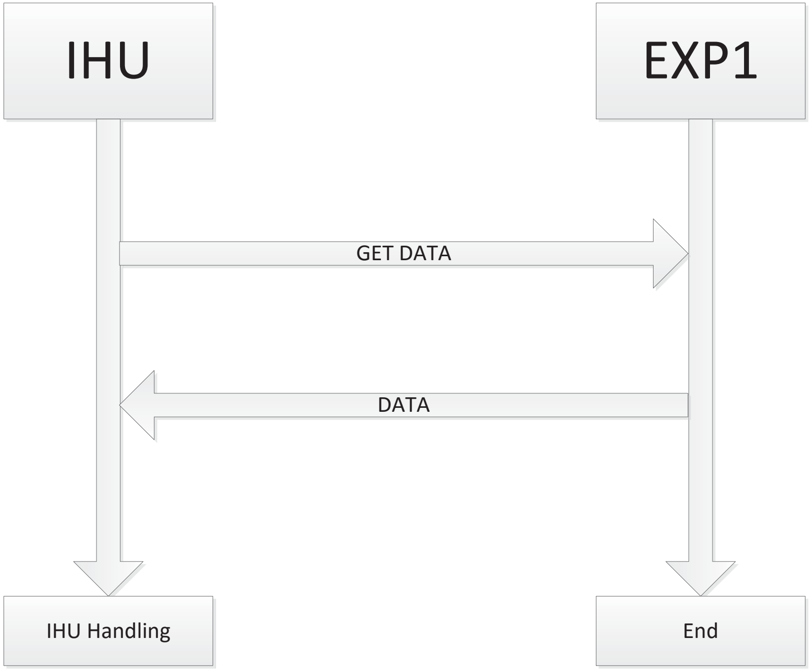
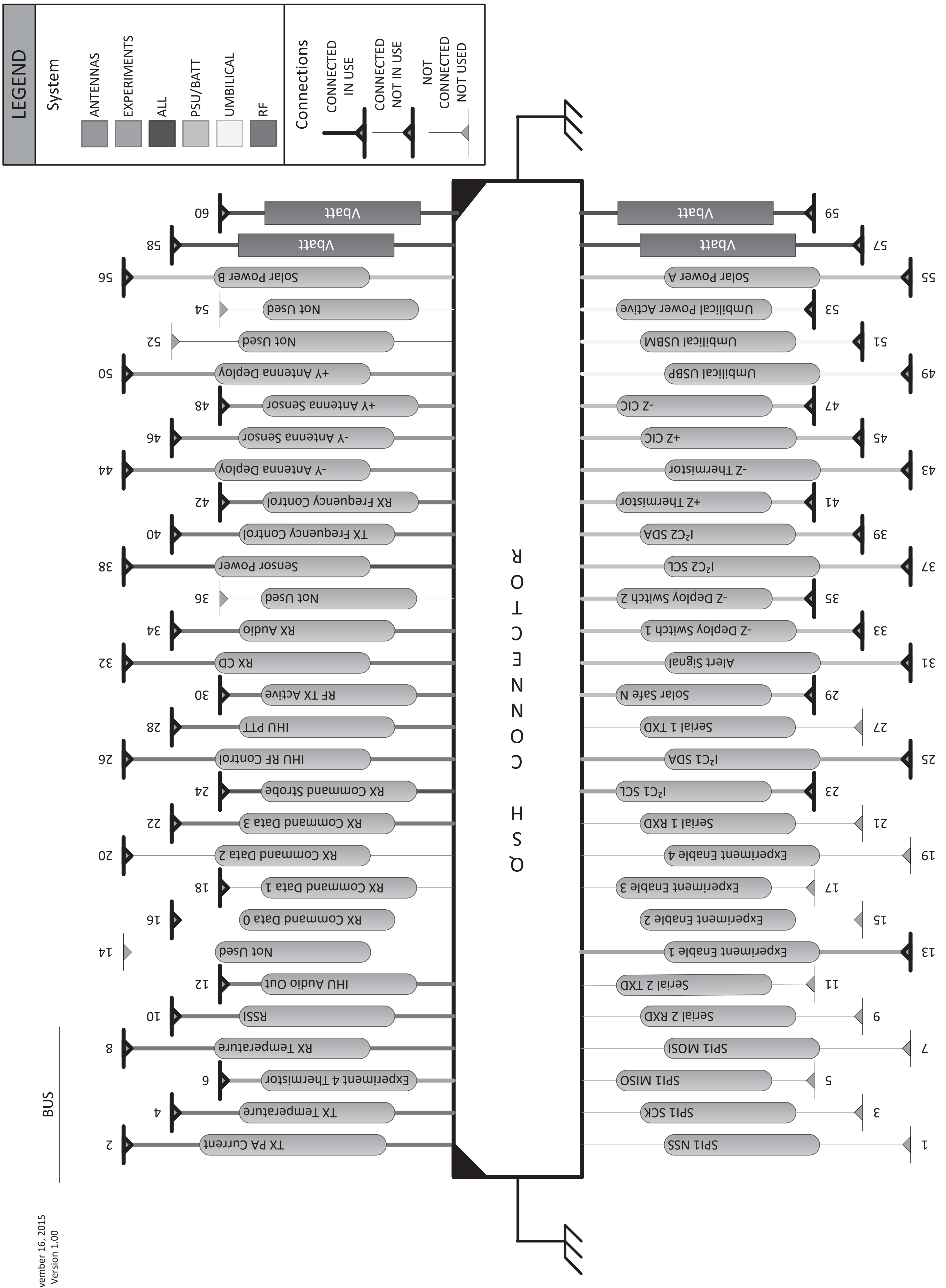
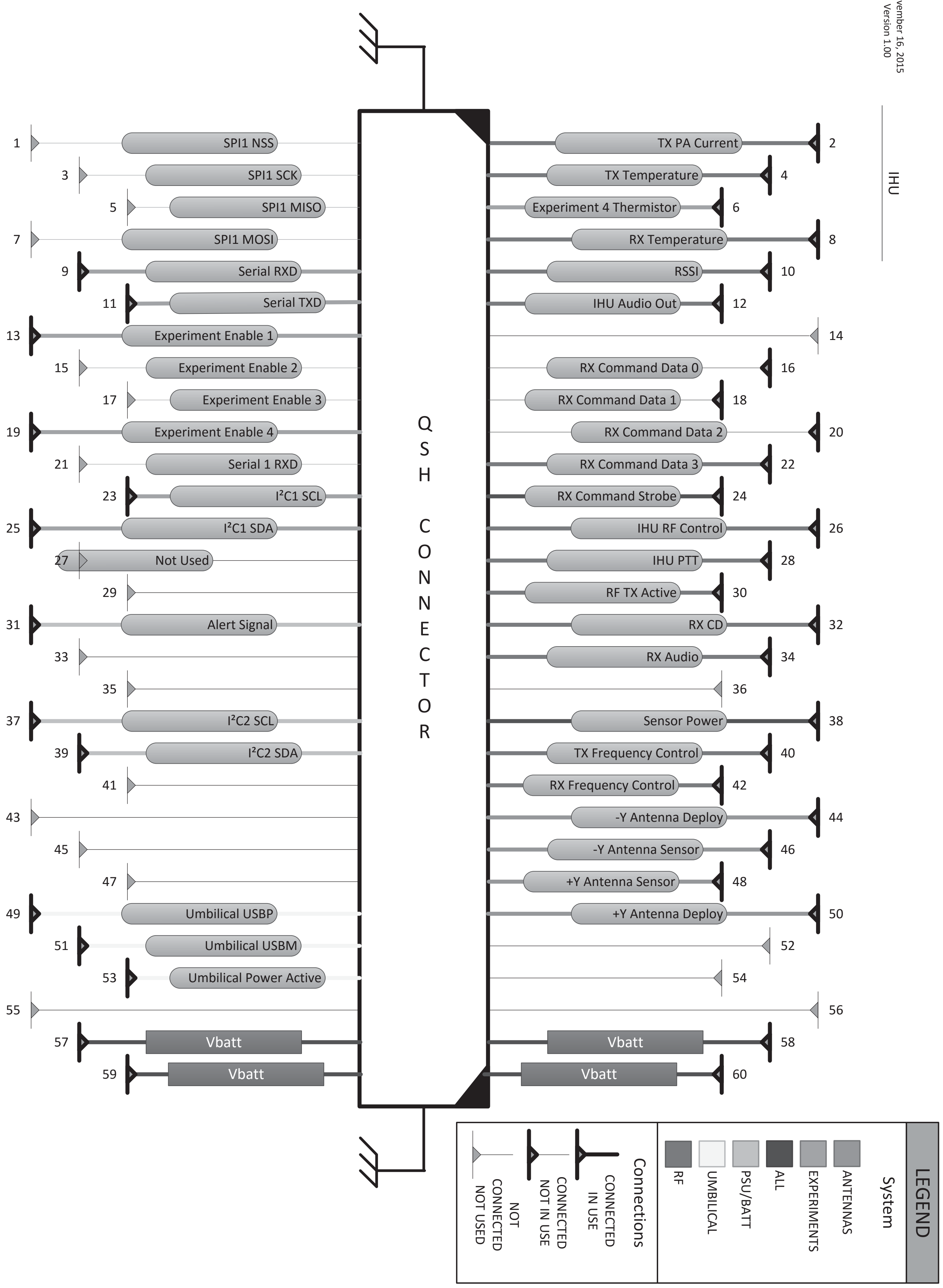


Figure 3

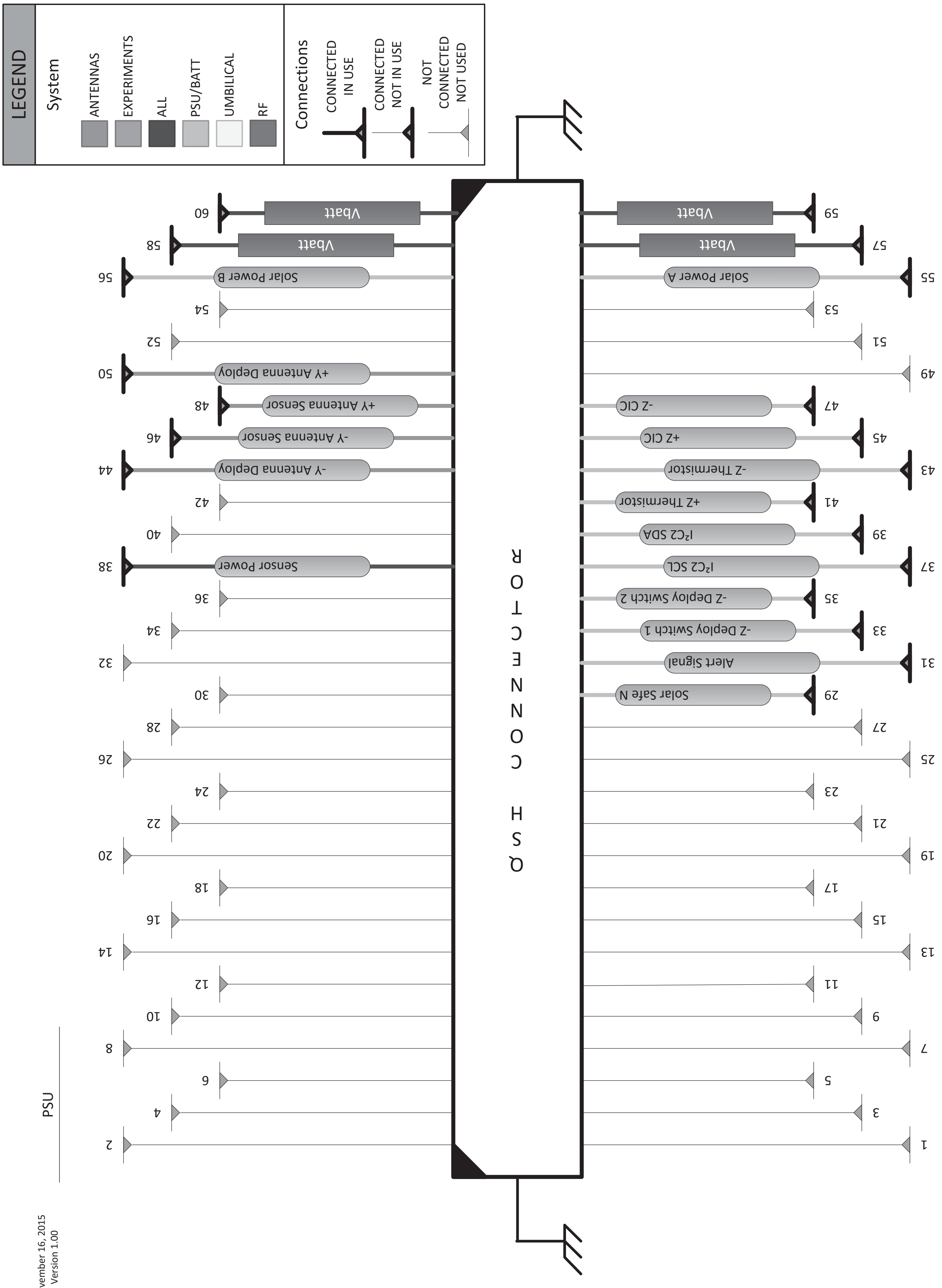




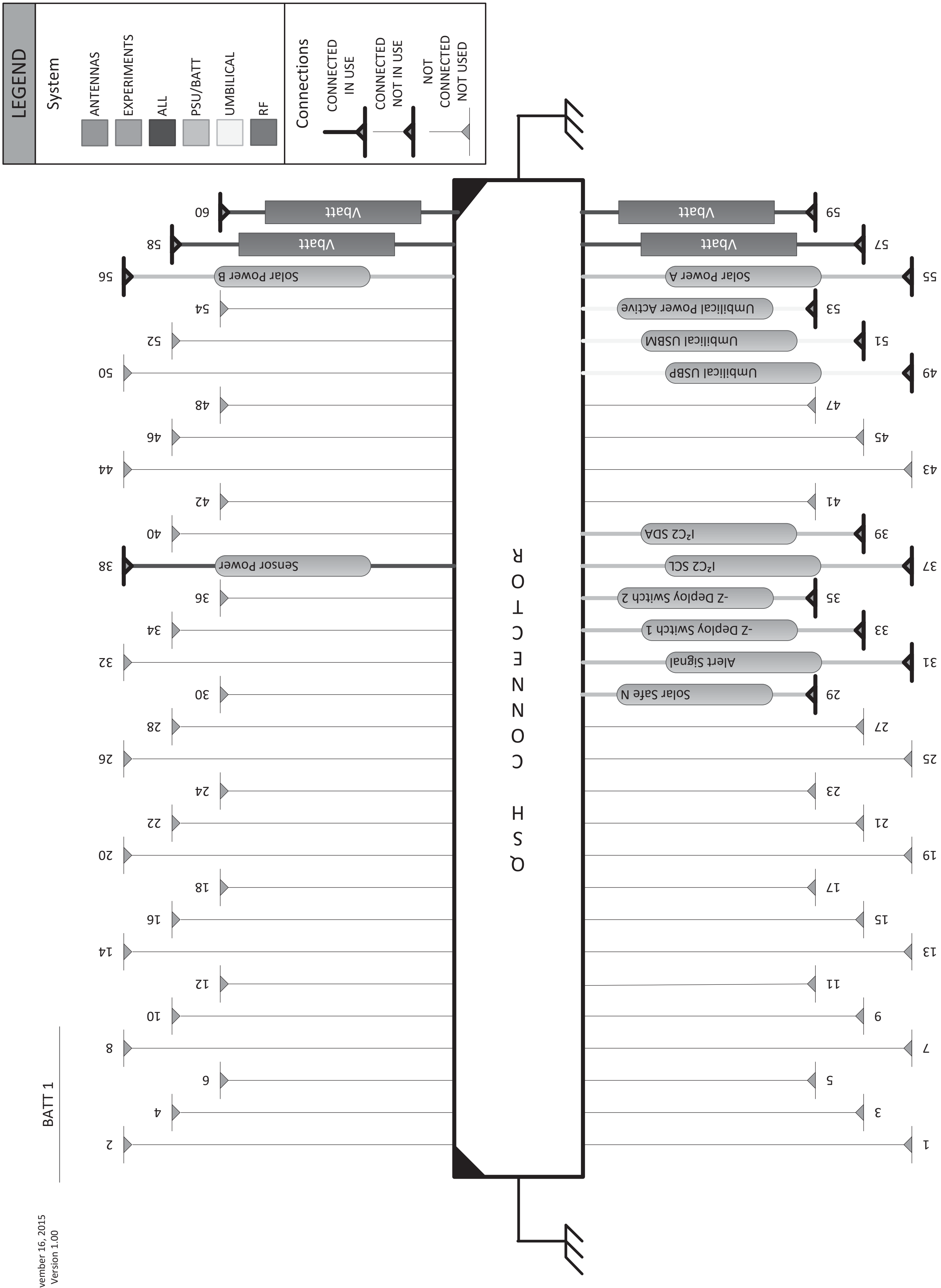
November 16, 2015
Version 1.00



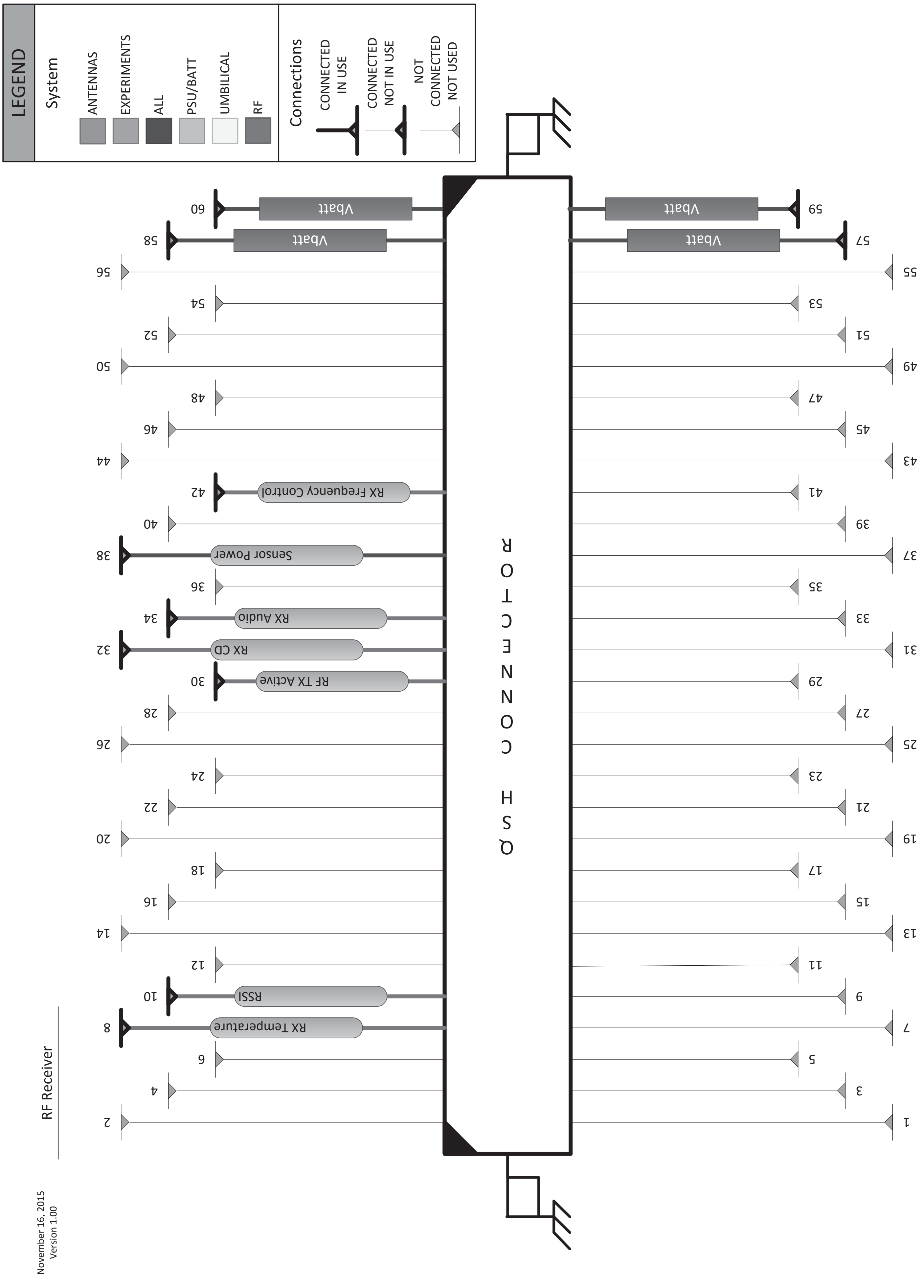
November 16, 2015
Version 1.00



November 16, 2015
Version 1.00



November 16, 2015
Version 1.00

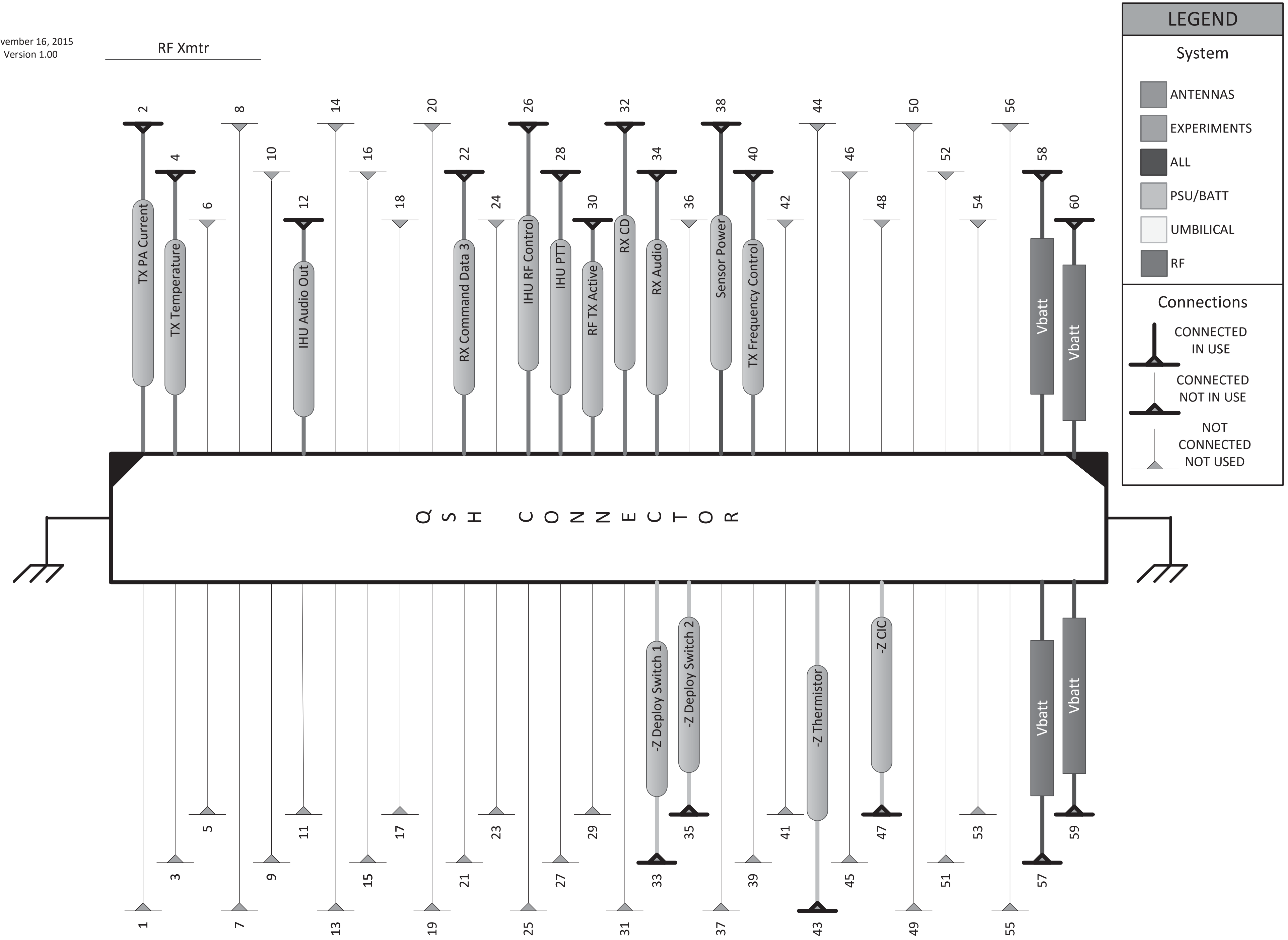


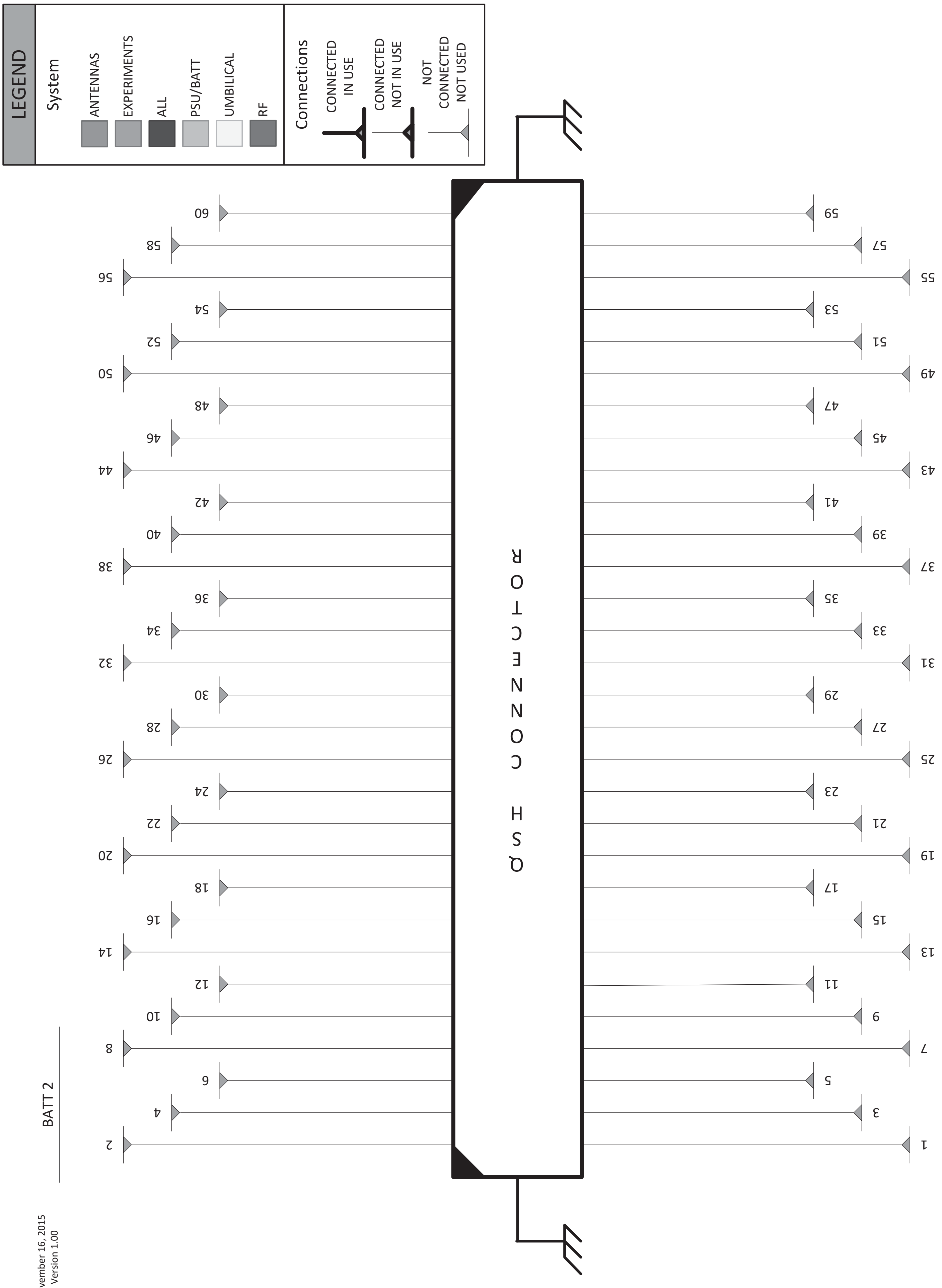
RF Receiver

November 16, 2015
Version 1.00

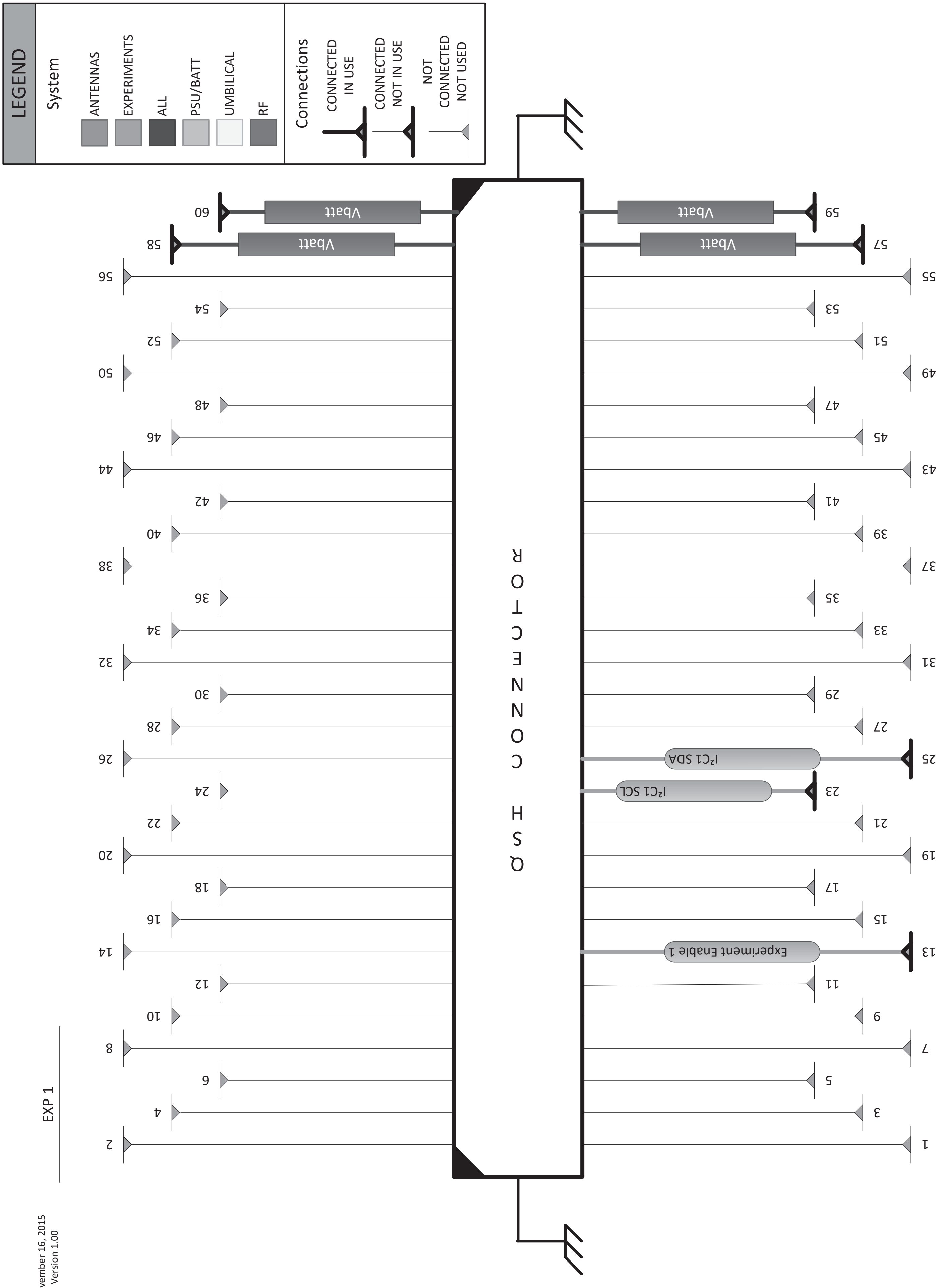
November 16, 2015
Version 1.00

RF Xmtr

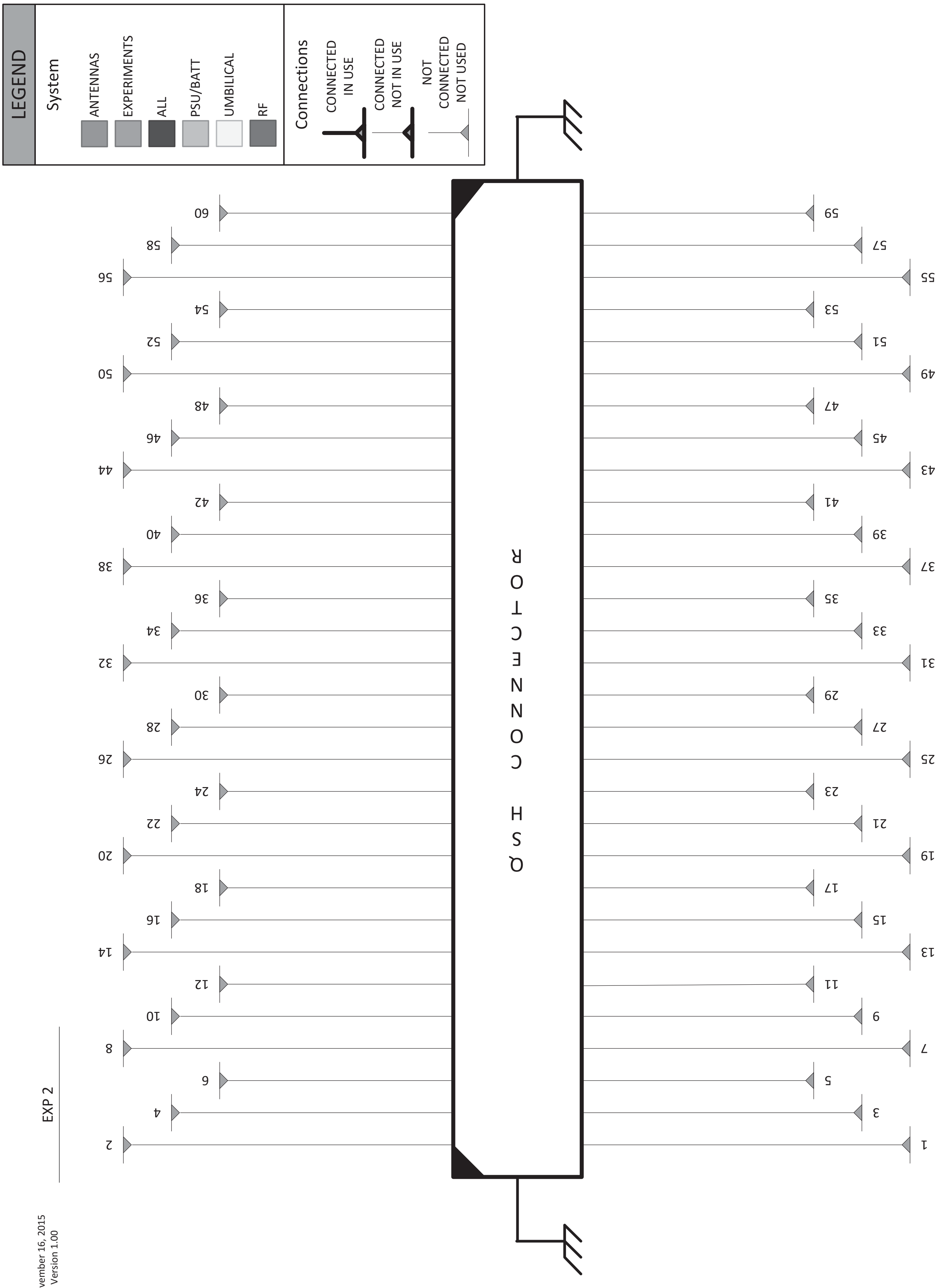




November 16, 2015
Version 1.00



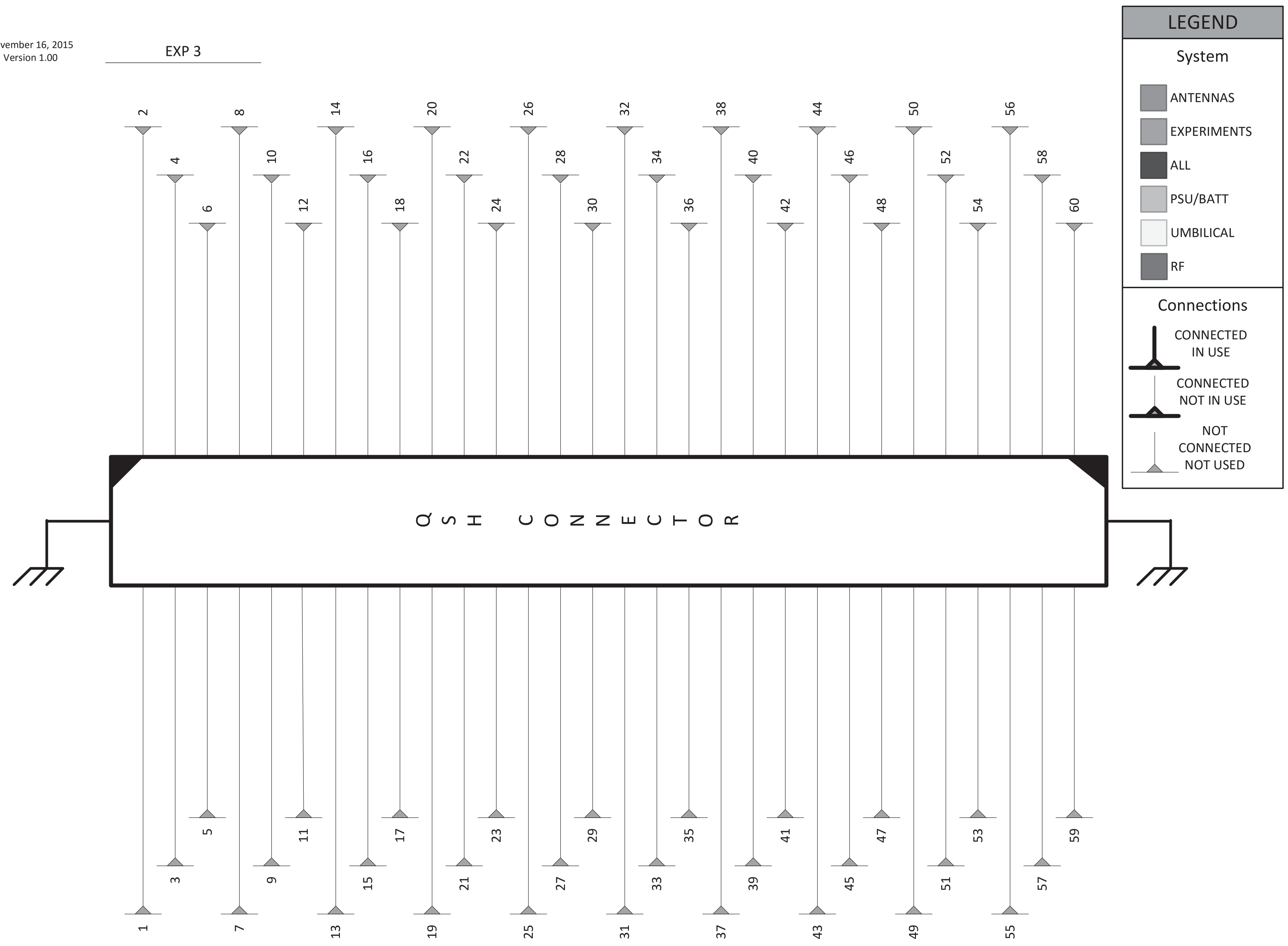
November 16, 2015
Version 1.00



November 16, 2015
Version 1.00

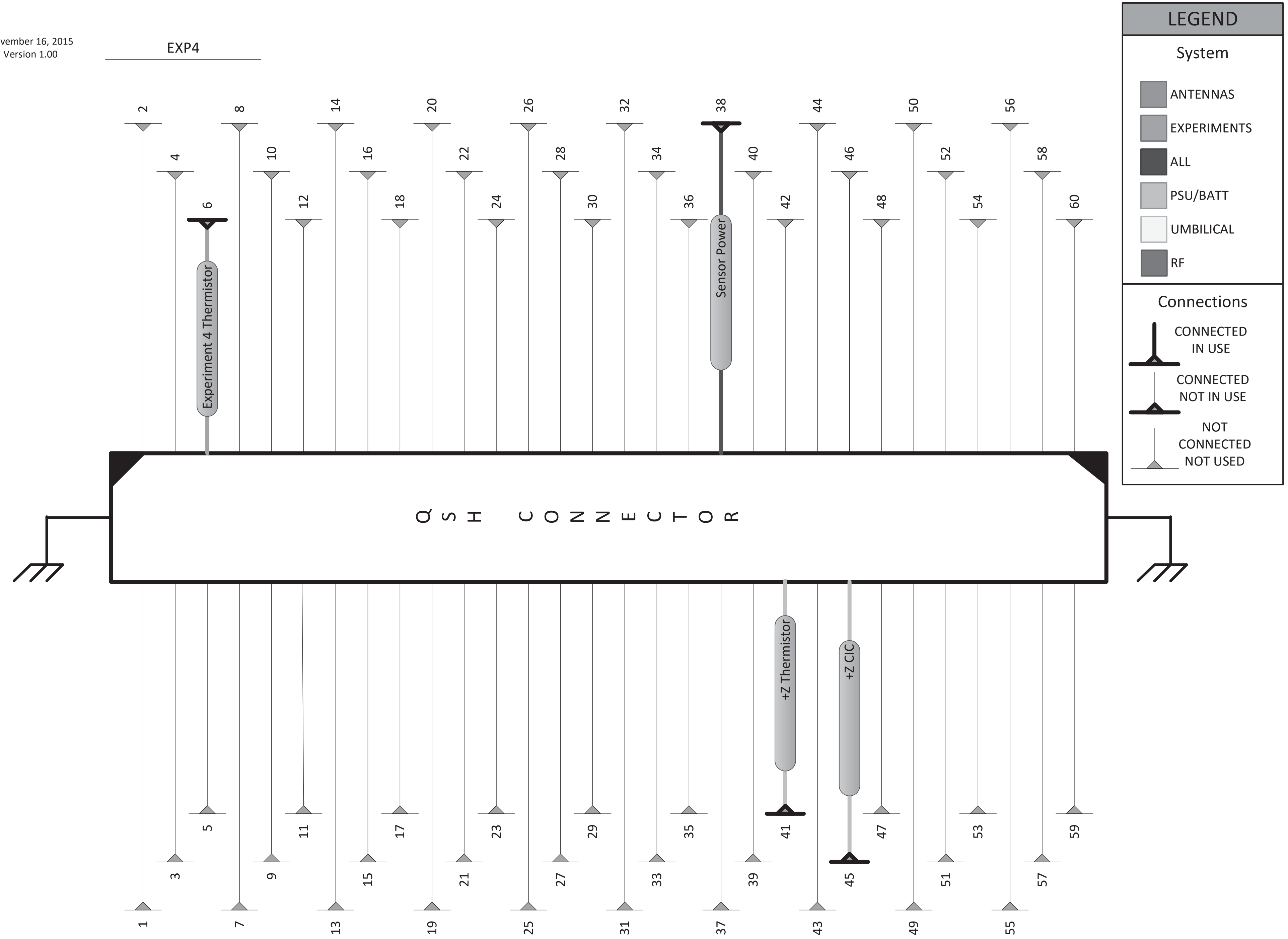
November 16, 2015
Version 1.00

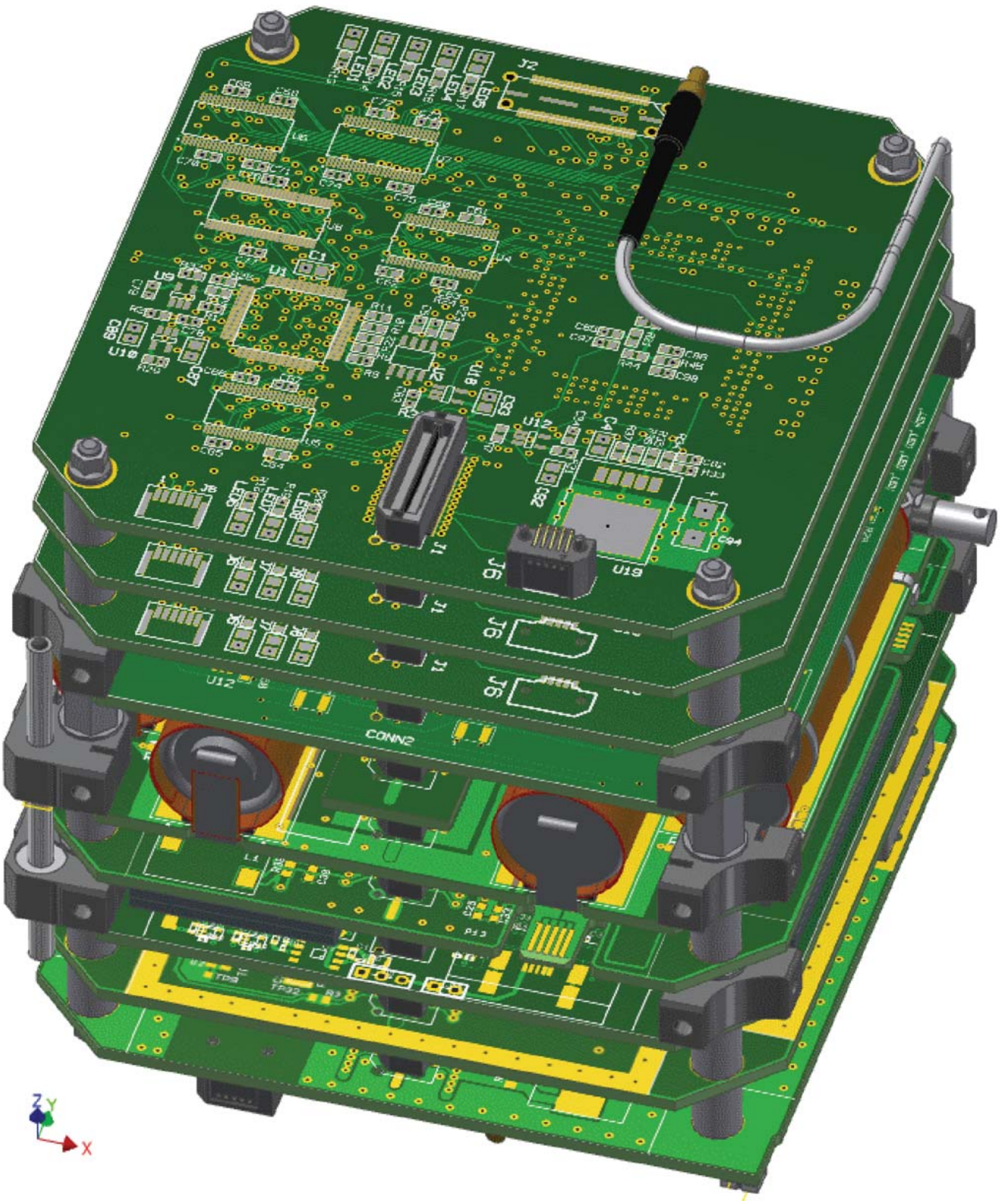
EXP 3



November 16, 2015
Version 1.00

EXP4





RadFxSat avionics stack

Given Data:

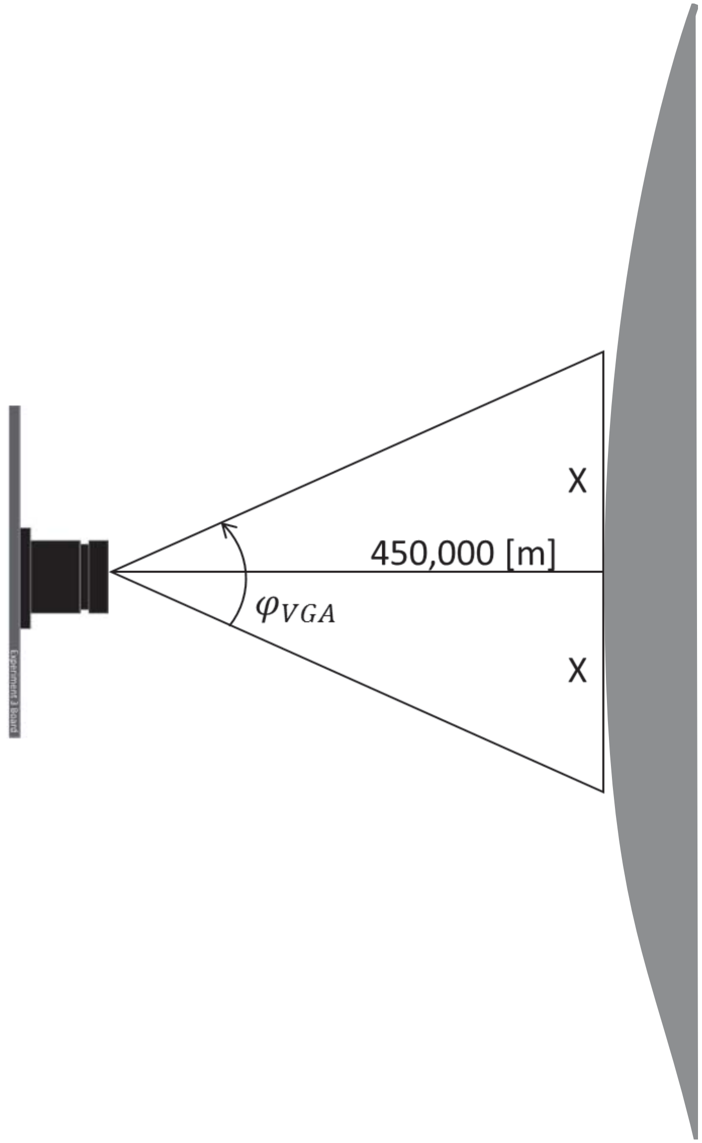
- Orbital Altitude = 450 km
- Calculation done for Perigee

Assumptions:

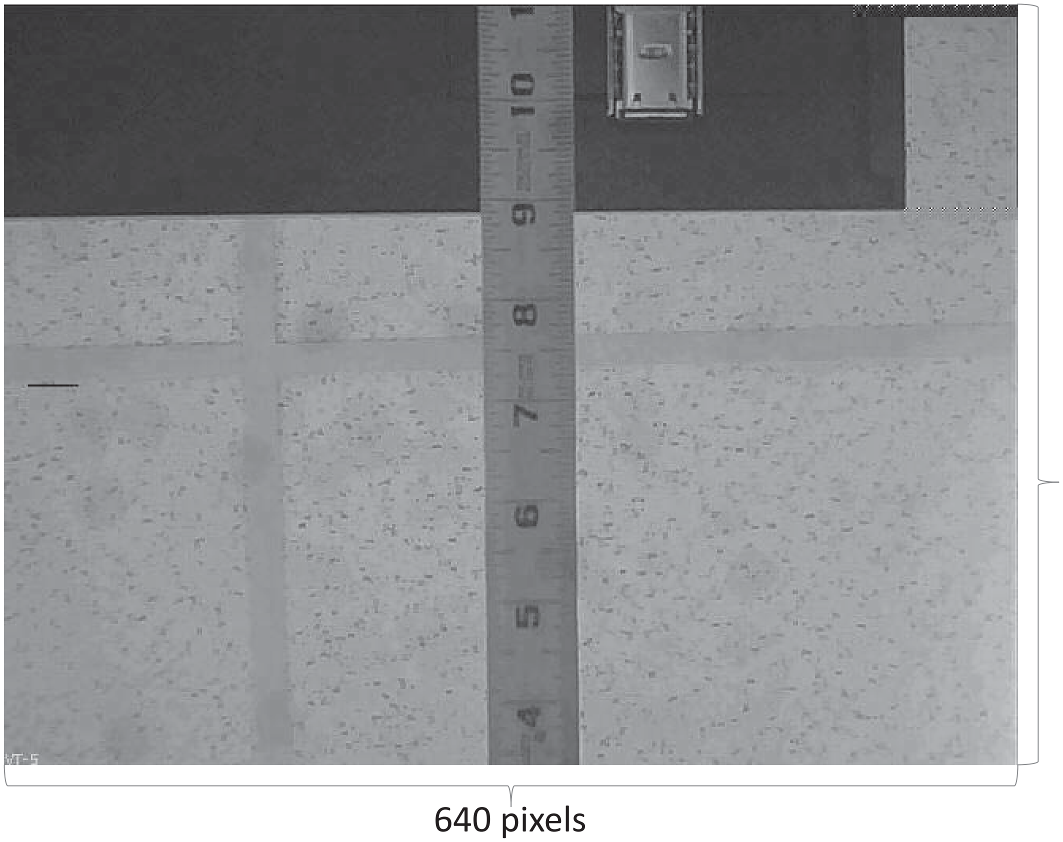
- Flat Earth: When accounting for curve of earth, resolution will decrease.

Goal:

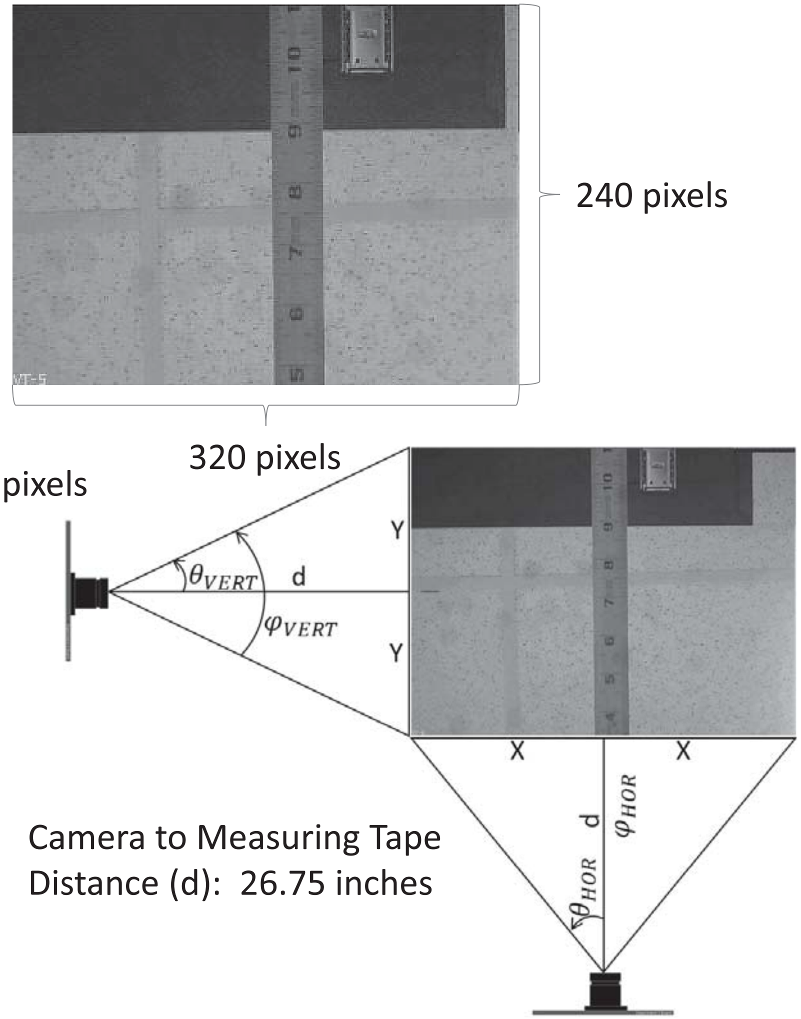
- Determine Resolution of Camera at Perigee in VGA (640x480 pixels) Mode.
- Determine Resolution of Camera at Perigee in QVGA (320x240 pixels) Mode.



VGA Image:

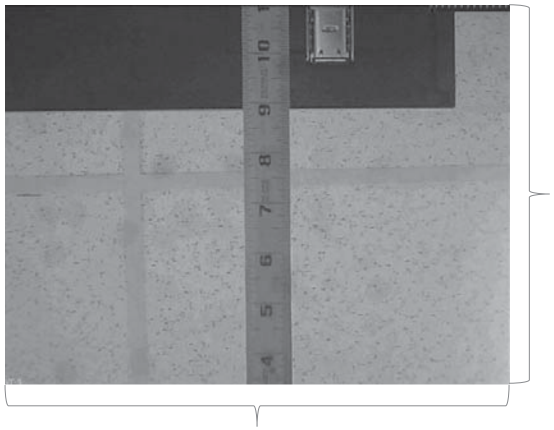


QVGA Image:



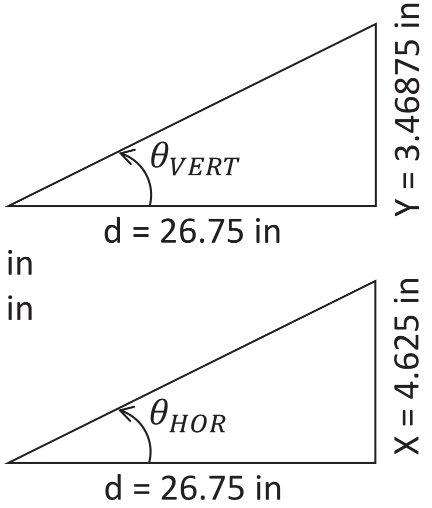
Camera to Measuring Tape Distance (d): 26.75 inches

VGA Image:



480 pixels
2Y = 6.9375 in
Y = 3.46875 in

640 pixels, 2X = 9.25 in, X = 4.625 in



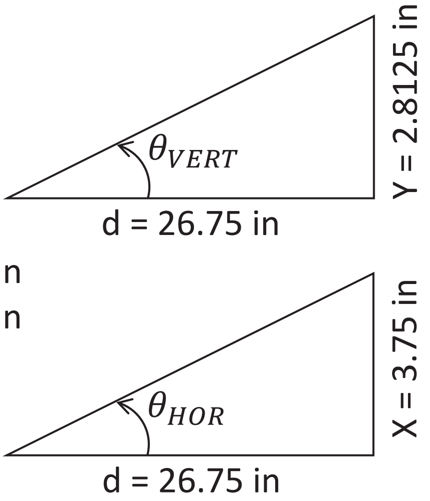
$$\theta_{VGA,VERT} = \tan^{-1}\left(\frac{3.46875}{26.75}\right)$$
$$\theta_{VGA,VERT} = 7.38848\ [deg]$$
$$\boldsymbol{\varphi_{VGA,VERT}} = \boldsymbol{2\theta_{VGA,VERT}} = \mathbf{14.777}[\boldsymbol{deg}]$$

$$\theta_{VGA,HOR} = \tan^{-1}\left(\frac{4.625}{26.75}\right)$$
$$\theta_{VGA,HOR} = 9.8093\ [deg]$$
$$\boldsymbol{\varphi_{VGA,HOR}} = \boldsymbol{2\theta_{VGA,HOR}} = \mathbf{19.619}[\boldsymbol{deg}]$$

QVGA Image:

240 pixels
2Y = 5.625 in
Y = 2.8125 in

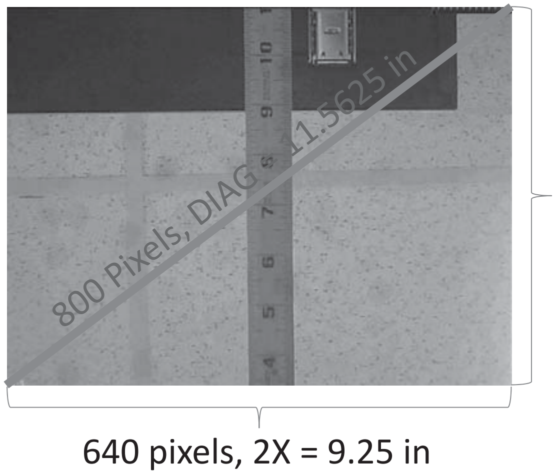
320pixels, 2X = 7.5 in, X = 3.75 in

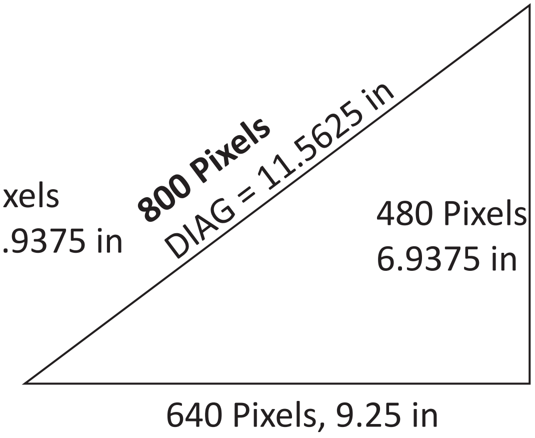


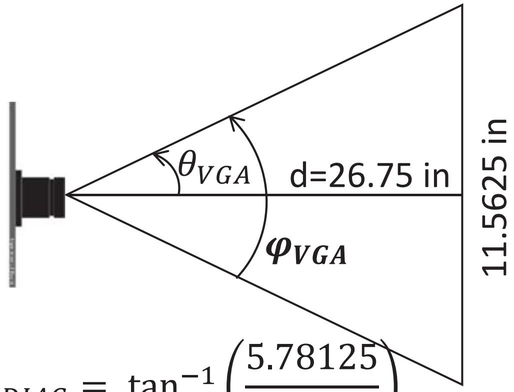
$$\theta_{QVGA,VERT} = \tan^{-1}\left(\frac{2.8125}{26.75}\right)$$
$$\theta_{QVGA,VERT} = 6.00204\ [deg]$$
$$\boldsymbol{\varphi_{QVGA,VERT}} = \boldsymbol{2\theta_{QVGA,VERT}} = \mathbf{12.004}[\boldsymbol{deg}]$$

$$\theta_{QVGA,HOR} = \tan^{-1}\left(\frac{3.75}{26.75}\right)$$
$$\theta_{QVGA,HOR} = 7.98011\ [deg]$$
$$\boldsymbol{\varphi_{QVGA,HOR}} = \boldsymbol{2\theta_{QVGA,HOR}} = \mathbf{15.960}[\boldsymbol{deg}]$$

VGA Image:





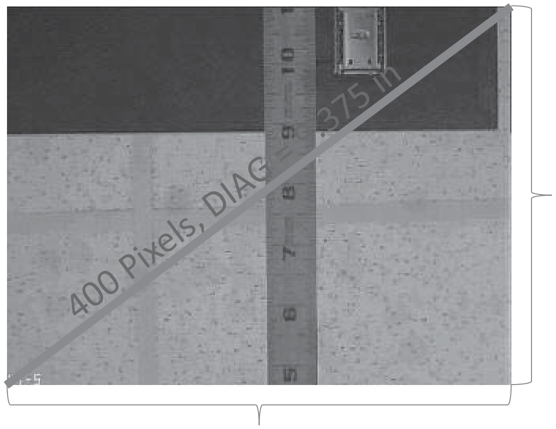


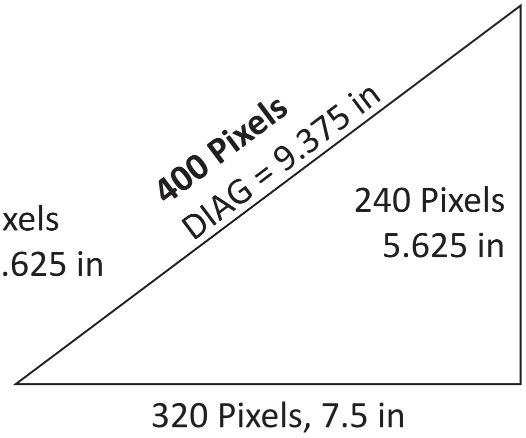
$$\theta_{VGA,DIAG} = \tan^{-1}\left(\frac{5.78125}{26.75}\right)$$

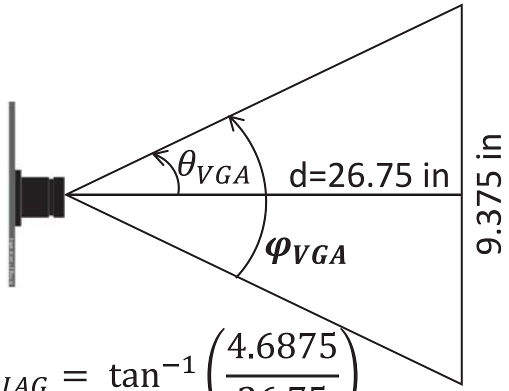
$$\theta_{VGA,DIAG} = 12.1953\ [deg]$$

$$\boldsymbol{\varphi_{VGA,DIAG} = 2\theta_{VGA,DIAG} = 24.391\ [deg]}$$

QVGA Image:





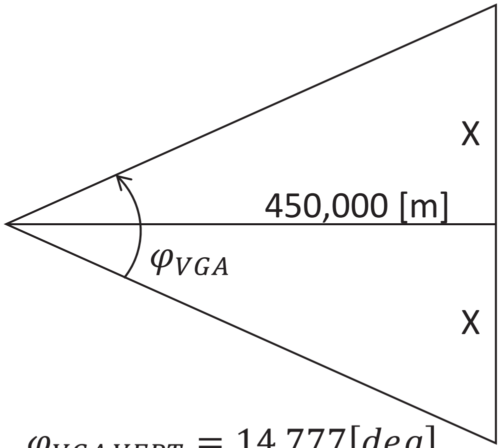


$$\theta_{QVGA,DIAG} = \tan^{-1}\left(\frac{4.6875}{26.75}\right)$$

$$\theta_{QVGA,DIAG} = 9.9392\ [deg]$$

$$\boldsymbol{\varphi_{QVGA.DIAG} = 2\theta_{QVGA,DIAG} = 19.879\ [deg]}$$

VGA Image:



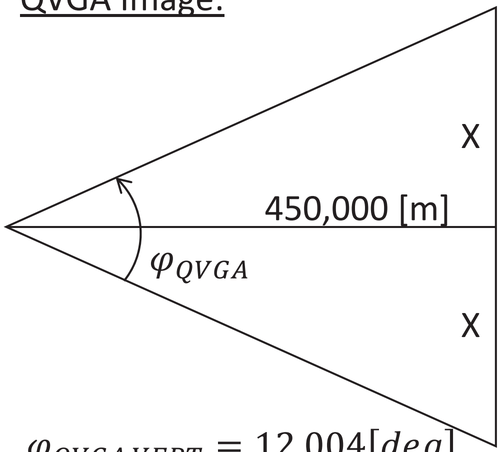
$\varphi_{VGA,VERT} = 14.777[deg]$

$$X = 450{,}000\ [m]\ * \tan\left({}^{\varphi_{VGA,VERT}}/_{2}\right)$$
$$= 58{,}353\ [m]$$
$$2X = \ 116{,}706[m]$$

CAM pixel res: 640 x 480 pixels
Vertical: 480 $[pixels]$
THUS:

$$\boxed{RESOLUTION_{VGA,VERT} = \frac{116{,}706[m]}{480[pixels]} \cong \mathbf{243.138}\left[{}^{\boldsymbol{m}}/_{\boldsymbol{pixel}}\right]}$$

QVGA Image:



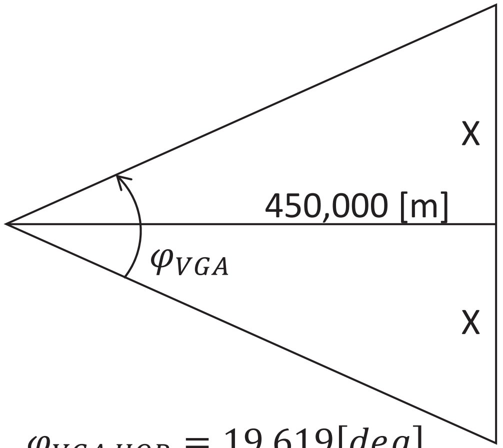
$\varphi_{QVGA,VERT} = 12.004[deg]$

$$X = 450{,}000\ [m]\ * \tan\left({}^{\varphi_{QVGA,VERT}}/_{2}\right)$$
$$= 47{,}312.8\ [m]$$
$$2X = \ 94{,}625.6\ [m]$$

CAM pixel res: 320 x 240 pixels
Vertical: 240$[pixels]$
THUS:

$$\boxed{RESOLUTION_{QVGA,VERT} = \frac{94{,}625.6\ [m]}{240[pixels]} \cong \mathbf{394.273}\ \left[{}^{\boldsymbol{m}}/_{\boldsymbol{pixel}}\right]}$$

VGA Image:



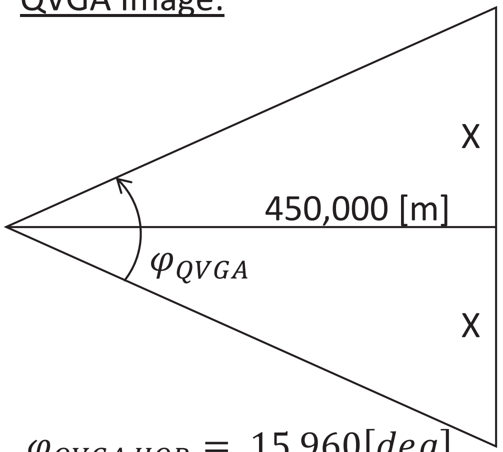
$\varphi_{VGA,HOR} = 19.619[deg]$

$$X = 450{,}000\ [m]\ * \tan\left({}^{\varphi_{VGA,DIAG}}/_{2}\right)$$
$$= 77{,}805.3\ [m]$$
$$2X = \ 155{,}611\ [m]$$

CAM pixel res: 640 x 480 pixels
Horizontal: 640 $[pixels]$
THUS:

$$\boxed{RESOLUTION_{VGA,HOR} = \frac{115{,}611[m]}{640[pixels]} \cong \mathbf{243.142}\left[{}^{\boldsymbol{m}}/_{\boldsymbol{pixel}}\right]}$$

QVGA Image:



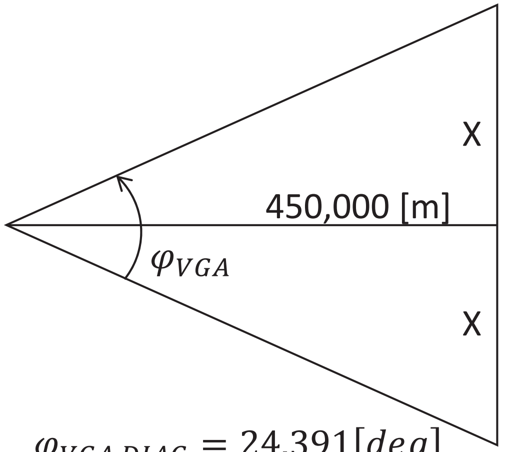
$\varphi_{QVGA,HOR} = \ 15.960[deg]$

$$X = 450{,}000\ [m]\ * \tan\left({}^{\varphi_{QVGA,DIAG}}/_{2}\right)$$
$$= 63{,}083.2\ [m]$$
$$2X = \ 126{,}166\ [m]$$

CAM pixel res: 320 x 240 pixels
Horizontal: 320 $[pixels]$
THUS:

$$\boxed{RESOLUTION_{QVGA,HOR} = \frac{126{,}166\ [m]}{320[pixels]} \cong \mathbf{394.270}\ \left[{}^{\boldsymbol{m}}/_{\boldsymbol{pixel}}\right]}$$

VGA Image:



$\varphi_{VGA,DIAG} = 24.391[deg]$

$$X = 450{,}000\ [m]\ * \tan\left({}^{\varphi_{VGA,DIAG}}/_{2}\right)$$
$$= 97{,}256.4\ [m]$$
$$2X = \ 194{,}513\ [m]$$

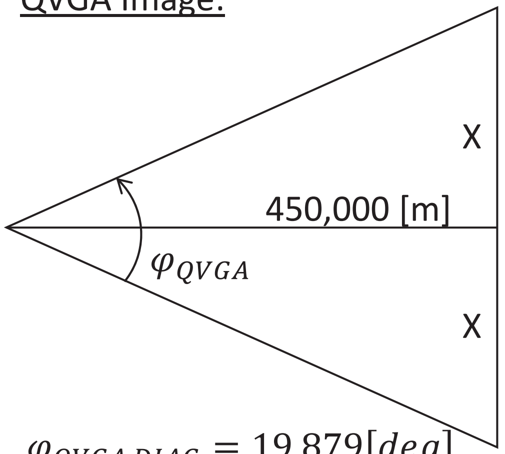
CAM pixel res: 640 x 480 pixels

Diagonal: $\sqrt{(640)^2 + (480)^2} = 800\ [pixels]$

THUS:

$$\boxed{RESOLUTION_{VGA,DIAG} = \frac{194{,}509[m]}{800\ [pixels]} \cong \mathbf{243.141}\left[{}^{\boldsymbol{m}}/_{\boldsymbol{pixel}}\right]}$$

QVGA Image:



$\varphi_{QVGA,DIAG} = 19.879[deg]$

$$X = 450{,}000\ [m]\ * \tan\left({}^{\varphi_{QVGA,DIAG}}/_{2}\right)$$
$$= 78{,}857.3\ [m]$$
$$2X = \ 157{,}715\ [m]$$

CAM pixel res: 320 x 240 pixels

Diagonal: $\sqrt{(320)^2 + (240)^2} = 400\ [pixels]$

THUS:

$$\boxed{RESOLUTION_{QVGA,DIAG} = \frac{157{,}715\ [m]}{400\ [pixels]} \cong \mathbf{394.286}\ \left[{}^{\boldsymbol{m}}/_{\boldsymbol{pixel}}\right]}$$

SUMMARY:

VGA

$$\boldsymbol{\varphi_{VGA,VERT} = 14.777[deg]}$$
$$\boldsymbol{\varphi_{VGA,HOR} = 19.619[deg]}$$
$$\boldsymbol{\varphi_{VGA,DIAG} = 24.391\,[deg]}$$

$$RESOLUTION_{VGA,VERT} \cong \mathbf{243.138}\left[\boldsymbol{{}^{m}/_{pixel}}\right]$$
$$RESOLUTION_{VGA,HOR} \cong \mathbf{243.142}\left[\boldsymbol{{}^{m}/_{pixel}}\right]$$
$$RESOLUTION_{VGA,DIAG} \cong \mathbf{243.141}\left[\boldsymbol{{}^{m}/_{pixel}}\right]$$

QVGA

$$\boldsymbol{\varphi_{QVGA,VERT} = 12.004[deg]}$$
$$\boldsymbol{\varphi_{QVGA,HOR} = 15.960[deg]}$$
$$\boldsymbol{\varphi_{QVGA.DIAG} = 19.879\,[deg]}$$

$$RESOLUTION_{QVGA,VERT} \cong \mathbf{394.273}\,\left[\boldsymbol{{}^{m}/_{pixel}}\right]$$
$$RESOLUTION_{QVGA,HOR} \cong \mathbf{394.270}\,\left[\boldsymbol{{}^{m}/_{pixel}}\right]$$
$$RESOLUTION_{QVGA,DIAG} \cong \mathbf{394.286}\,\left[\boldsymbol{{}^{m}/_{pixel}}\right]$$

Date: April 4, 2016
Version: Version 1.01 (DRAFT)

Fox-1E

(RadFxSat 2)

System Requirements Specification

1 Introduction

This document specifies the system level requirements for the AMSAT Fox-1E satellite project. This 1-Unit CubeSat is one part of the AMSAT Fox program and includes a subset of the capabilities to be realized in the overall program.

Fox-1E is intended as a follow-on and upgrade to the initial Fox-1 series CubeSat satellites. The first four Fox-1 satellites flew single channel FM repeaters as their bus-supporting communications system. Fox-1E will have essentially the same configuration and basic bus structure as the earlier Fox-1 satellites, but with their single channel FM repeater transmitter and receiver replaced with a new wideband linear transponder. This type of amateur radio communications system will provide more channels for multiple, simultaneous radio contacts, as well as a higher data rate, continuous telemetry downlink.

In addition to its mission as a communications satellite, Fox-1E will host an experiment payload. The satellite will reserve mass and volume for the experiment and will provide DC power and communications capability to support experiment data downlinking. The experiment will be provided by students at Vanderbilt University's Institute for Space and Defense Electronics (ISDE).

1.1 Document History

DATE	VERSION	AUTHOR	SUMMARY
November 4, 2015	1.0	J. Buxton (N0JY)	Original Fox-1 SRS
April 4, 2016	1.01	E. Skoog (K1TVV)	Update draft for review/comment

1.2 Document Scope

The purpose of this document is to specify the requirements of the satellite at the system (i.e., "black box") level. It is intended to be used by hardware, software and mechanical designers to develop architecture/high-level design specifications. It is also intended to be used for test planning and development.

1.3 Document Format

This document provides requirements in numbered format. Each requirement is assigned a unique number. Additional information such as comments or examples provided for guidance or clarity is *italicized* to distinguish it from specific requirements.

1.4 References

1. AMSAT Fox-1 Concept of Operations, Version 1.03, October 19, 2011
2. CubeSat Design Specification, Rev. 13, February 20, 2014, The CubeSat Program Cal Poly SLO
3. Launch Services Program, Program Level Dispenser and CubeSat Requirements Document, LSP-REQ-317.01 Revision B, January 30, 2014, National Aeronautics and Space Administration (NASA)
4. ITU Radio Regulations, Edition of 2012, available from http://www.itu.int/publ/R-REG-RR-2012/en

2 General Requirements

2.1 CubeSat Requirements

2.1.1 The satellite shall satisfy the requirements specified in the CubeSat Design Specification, Rev. 13.

2.1.2 The satellite shall satisfy the requirements specified in the NASA LSP-REQ-317.01 Revision B.

2.1.3 The satellite shall satisfy the requirements for a 1 Unit (single) CubeSat.

2.1.4 The satellite shall provide mass for an experiment payload up to 100 g.

2.1.5 The satellite shall provide volume for an experiment payload up to 95 x 95 x 31.4 mm. **<<equivalent to four (experiment slot) PCBs' volume, i.e., one VUC plus 3 REMs>>**

2.2 Environmental Requirements

2.2.1 The satellite avionics shall be designed for an operating temperature range of -40^{0}C to +70^{0}C.

2.2.2 The satellite shall be designed to operate in an approximate 500 to 700 km, sun-synchronous, circular orbit.

2.2.3 The satellite shall be designed to tolerate the radiation environment in orbit.

2.3 Reliability Requirements

2.3.1 The satellite shall be designed for a minimum 5-year, on-orbit lifetime.

2.4 Radio Frequency (RF) Regulatory Requirements

2.4.1 The satellite's RF transmitter shall meet or exceed the requirements specified in ITU Radio Regulations, Volume 1 Articles, Chapter 1 – Terminology and Technical Characteristics of Stations, Article 3.

2.4.2 All satellite uplinks shall be in the 2 meter band of the Amateur Satellite Service.

2.4.3 All satellite downlinks shall be in the 70 cm band of the Amateur Satellite Service.

2.4.4 All satellite transmitter and receiver generated frequencies shall deviate by no more than 5 parts-per-million from their specified values including initial accuracy and temperature variation.

2.4.5 All satellite frequencies shall be coordinated with the IARU.

2.4.6 The command uplink shall be a narrow band FM signal (+/- 5 kHz deviation) located outside of the user transponder passband.

The band plan with the actual coordinated frequencies will be specified in a separate document.

3 Functional Requirements

3.1 Antenna System

3.1.1 The satellite shall include a deployable antenna system.

3.2 Attitude Control

3.2.1 The satellite shall incorporate passive magnetic stabilization to align the deployed antennas with the magnetic field of the earth.

3.3 Access Ports

3.3.1 The satellite shall include a "Remove Before Flight" (RBF) pin as per the CubeSat Design Specification.

3.3.2 The satellite shall include an umbilical port as per the CubeSat Design Specification.

3.4 Pre-launch Features

3.4.1 The satellite battery and photovoltaic panels shall be electronically disconnected from the avionics when the "Remove Before Flight" pin is inserted, regardless of the state of the deployment switch(es).

3.4.2 The satellite shall provide a means to charge the battery via the umbilical port while integrated with the dispenser.

3.4.3 The satellite shall provide a means to run diagnostic tests via the umbilical port while integrated with the dispenser.

3.5 Power

3.5.1 The satellite shall produce electrical power from sunlight.

3.5.2 The satellite shall produce electrical power while in sunlight regardless of orientation and while tumbling or spinning.

3.5.3 The satellite shall produce sufficient average electrical power to operate continuously in the orbit of maximum eclipse.

3.5.4 The satellite shall provide sufficient battery capacity to operate continuously in the orbit of maximum eclipse.

3.5.5 The satellite shall not provide battery power to the main bus until approximately 90 seconds after activation of both deployment switches indicating successful launch vehicle dispenser separation.

<<Should McCann, Burns, et al provide additional (new) functional requirement statements, e.g., SSTV, Whole Orbit Data (WOD), etc.>>

3.6 Experiment

3.6.1 The satellite shall provide DC power for an experiment payload.

3.6.2 The satellite shall provide a means to activate and deactivate the experiment payload.

3.6.3 The satellite shall provide a means to telemeter data from the experiment payload.

The experiment payload details will be specified in a separate document.

3.7 RF Uplink

3.7.1 The satellite shall include a linear uplink receiver.

3.7.2 The uplink receiver shall process signals in a linear manner. The receiver will process SSB, CW, PSK, and FSK signals to its intermediate frequency with intermodulation distortion (IMD) products no higher than -40 dBc when the maximum intended level signals are applied to the spacecraft.

3.8 RF Downlink

3.8.1 The satellite shall include a linear downlink transmitter.

3.8.2 The downlink transmitter shall be a linear transmitter with intermodulation products no higher than -20 dBc when the highest level output signal is at maximum output power.

3.9 Transponder

3.9.1 The satellite shall provide linear transponder operation via the RF uplink and RF downlink.

3.9.2 The user transponder shall have a -3dB bandwidth of 30 kHz and a -20dB bandwidth of 50 kHz, referenced to the center of the passband.

3.9.3 The transponder shall be an inverting transponder.

3.9.4 The transponder shall have a means of sensing and adjusting gain so that the highest level throughput signal is not distorted with intermodulation products higher than -20 dBc with multiple signals in the passband.

3.9.5 The transponder gain adjustment shall have a time constant of <TBD> seconds, so that the highest level signal in the passband will not 'pump' other signals in the passband by its modulation.

3.9.6 The transponder shall have a mechanism for detecting the level of signals in the uplink passband. This aggregate level shall have a threshold switching mechanism for activating and deactivating the satellite transmitter when no signals exceed the threshold. The transmitter shall be activated when the threshold is exceeded for at least two seconds.

The threshold mechanism shall continue to keep the transmitter activated for 30 seconds after the threshold conditions are no longer satisfied.

3.9.7 The transponder shall have a linear gain such that a received CW signal of <TBD> dBm will result in a power output of +23 dBm. Any other signals amplified in the passband shall create IMD products not to exceed -20 dBc in the passband of the transponder.

3.10 Telemetry Data

3.10.1 The satellite shall collect telemetry data.

3.10.2 The telemetry data shall include at a minimum, the measured parameters shown in Table 1.

Table 1

PARAMETER NAME	DESCRIPTION
CELL V	Voltages of battery cells
PANEL V	Voltages of solar panels
TOTAL I	Total DC current out of power system
PA I	DC current into RF power amp
BATTERY T	Temperature of battery
PANEL T	Temperatures of solar panels
TX T	Temperature of RF transmitter card
RX T	Temperature of RF receiver card

3.10.3 The measured parameters shall be sampled at least every 15 seconds.

3.10.4 The minimum and maximum values of each of the measured parameters shall be saved in non-volatile memory.

3.10.5 The telemetry data shall also include at a minimum, the calculated parameters shown in Table 2.

Table 2

PARAMETER NAME	DESCRIPTION
UP TIME	Total seconds since avionics power-up or the last Reset
SPIN	Satellite spin rate and direction

3.10.6 A telemetry frame shall include the current measured values, the saved minimum and maximum values, and the current calculated values.

The detailed telemetry interface will be specified in a separate document.

3.11 Telemetry Transmission

3.11.1 The satellite shall send slow speed telemetry using BPSK on the RF downlink.

3.11.2 The downlink telemetry signal shall be a 1200 bps BPSK signal located outside the user transponder passband and shall be part of the frequency multiplexed downlink. The telemetry signal's peak power level shall be no greater than 40 dB below the maximum output power of the transponder.

3.11.3 Telemetry data shall be transmitted simultaneously with user transponder signals, and shall cease to be transmitted when the user transponder threshold signal "hang time' of 30 seconds has expired.

3.11.4 The telemetry transmission shall include telemetry frames.

3.11.5 The telemetry transmission shall also include experiment data.

3.12 Command Capability

3.12.1 The satellite shall provide a means to process commands sent via the RF uplink from authorized ground control stations.

3.12.2 The command receiver shall be on a frequency outside the transponder bandwidth.

3.12.3 A 1200 bps AFSK-FM via a NBFM channel demodulation capability shall be provided to the IHU for the purpose of transferring data and commands to the IHU. This AFSK-FM channel shall follow the FSK requirements of Bell 202 modems.

3.12.4 The uplink command receiver shall be capable of receiving and demodulating AFSK-FM signals at 1200 bps with an input signal level of 0.5 uV with a baseband Bit Error Rate (BER) of 1 x 10^{-4}.

3.12.5 The command uplink receiver will not be responsible for bit or byte synchronization, re-timing, or error correction.

3.12.6 The following commands shall be provided, as shown in Table 3, below.

Table 3

Command	Operation
SAFE MODE	Enter Safe Mode
INHIBIT TX	Inhibit RF transmission
ENABLE TX	Enable RF transmission
IHU OFF	Power off IHU
IHU ON	Power on IHU
CLEAR	Clear stored telemetry
TRANSPONDER MODE	Enter Transponder Mode
ENABLE AUTO-SAFE	Enable Auto-Safe Mode
DISABLE AUTO-SAFE	Disable Auto-Safe Mode

3.12.7 A SAFE MODE command shall cause the satellite to enter the Safe Mode.

3.12.8 An INHIBIT TX command shall disable the RF transmitter.

3.12.9 An ENABLE TX command shall enable the RF transmitter.

3.12.10 An IHU OFF command shall cause the IHU System to power off.

3.12.11 An IHU ON command shall cause the IHU System to power on.

3.12.12 A CLEAR command shall cause the satellite to clear the saved minimum and maximum telemetry parameter values.

3.12.13 A TRANSPONDER MODE command shall cause the satellite to enter the Transponder Mode.

3.12.14 An ENABLE AUTO-SAFE command shall enable the auto-safe mode state.

3.12.15 A DISABLE AUTO-SAFE command shall disable the auto-safe mode state.

The control interface details will be specified in a separate document.

3.13 On-Orbit Operating Modes

3.13.1 The satellite shall provide on-orbit operating modes as shown in Table 4.

Table 4

NAME	DESCRIPTION
Startup Mode	Wait 50 minutes and deploy antennas
Safe Mode	Wait 120 seconds then begin telemetry beacon sequencing; Experiment powered off
Auto-Safe Mode	If enabled, automatically detects a low battery condition and shuts down some major satellite activities
Transponder Mode	Linear transponder mode; telemetry channel and experiment active

3.13.2 The satellite shall transition between its on-orbit operational modes as shown in the State Transition Diagram in Figure 1.

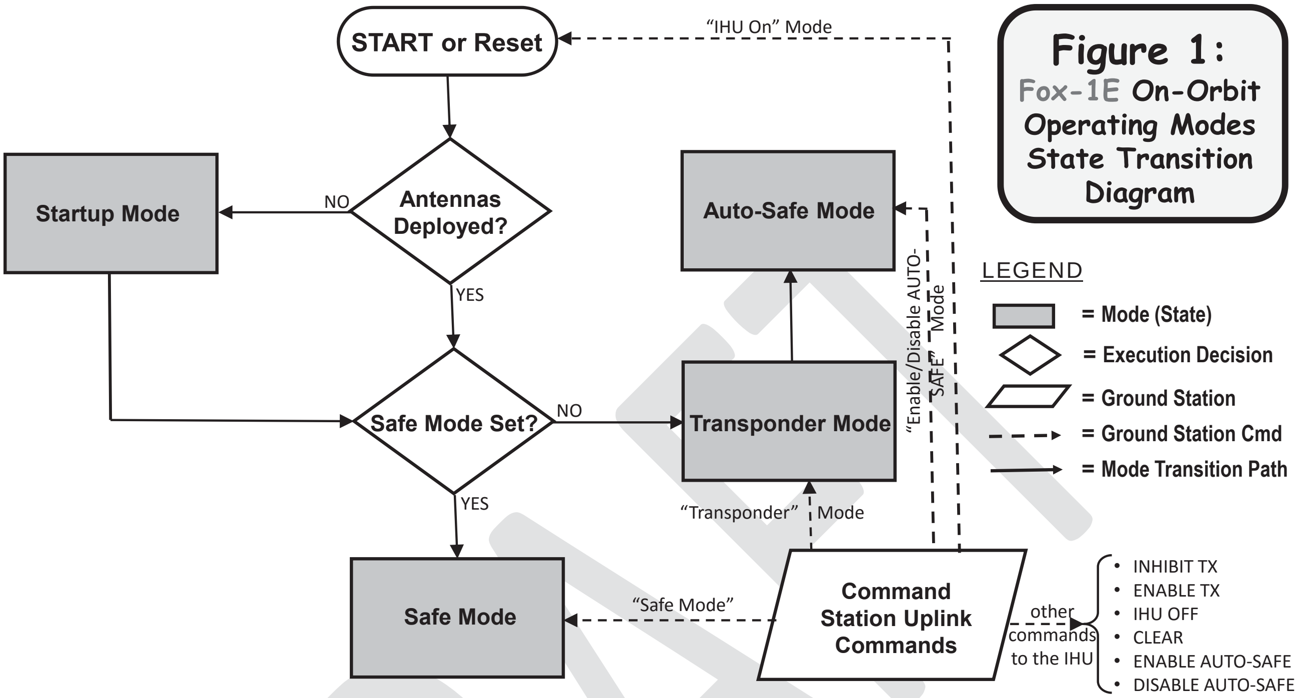


Figure 1:
Fox-1E On-Orbit Operating Modes State Transition Diagram

3.13.3 Upon launch, a power cycle of the avionics, or after a reset action, the satellite shall enter the "START" point as shown in Figure 1.

3.13.4 An IHU ON command shall also cause the satellite to begin operation from the "START" point as shown in Figure 1.

3.13.5 If the antennas have not been deployed, the satellite shall enter Startup Mode.

3.13.5.1 In Startup Mode, the satellite shall wait at least 50 minutes before commanding antenna deployment and initiating RF transmissions.

3.13.5.2 After the antennas have been successfully deployed upon initial orbit, the satellite shall enter Safe Mode.

3.13.6 After a Reset action and antennas successfully deployed check, the satellite shall determine whether its last state was SAFE MODE.

3.13.6.1 If the last state was SAFE MODE. the satellite shall (re)enter SAFE MODE.

3.13.6.2 1200 bps BPSK telemetry beacon downlink channel operation shall occur during SAFE MODE. There shall be NO CW beacon functionality implemented in the satellite

3.13.6.3 If the last state was not SAFE MODE, the satellite shall enter TRANSPONDER MODE.

3.13.6.4 In TRANSPONDER MODE, the transponder and the telemetry shall be active.

3.13.7 The command RF uplink shall be monitored for commands in all modes.

3.14 Operational Timing Requirements

3.14.1 The satellite shall satisfy the operational times shown in Table 5.

Table 5

FUNCTION	TIME (± 5%)	OPERATIIONAL CONDITIONS
Burn Resistor Activation	≈ 4 seconds	Time allotted for the (activated) burn resistors' initial melting of the deployable antenna restrainers
Burn Resistors RE-activation	≈ 20 seconds	Time allotted for the (RE-activated) burn resistors' subsequent melting of the deployable antenna restrainers
Deployment Switch Notification Delay	≈ 90 seconds	Delay time from deployment switch physical activation to electronic activation report.
IHU Boot-Up/POST	< 20 seconds	Time for the Internal Housekeeping Unit (IHU) to boot-up and run Power On System Tests (POST)
Antenna/RF Initiation Delay	≈ 50 minutes	Antenna deployment and transmission inhibit time after dispenser launch
Beacon (Safe Mode) Duty Cycle	≈ 2 minutes	Elapsed time from end of beacon telemetry transmission to start of next beacon transmission while in SAFE MODE
Hang Timer	≈ 30 seconds	RF transmit carrier time after the uplink passband (aggregate) signal(s) no longer satisfy the threshold criteria.
Telemetry Period	≈ 15 seconds	Sampling period for all telemetry parameters
ENABLE TX Confirm	≈ 3 minutes	Time after receipt of ENABLE TX command before transmitting a telemetry beacon
Watchdog Timer	≈ 10 seconds	If IHU-directed tasks do not report back within this time period, the satellite will reset.

4 External Interface Documents

To fully specify the satellite's technical requirements, the following documents should be consulted:

1. IARU Coordinated Frequency Plan
2. Downlink Specification
3. Control Interface Specification
4. Experiment Payload Specification

5 Summary

The *Fox-1E* satellite will be AMSAT's first linear transponder CubeSat. Its primary mission is to provide linear transponder communications capability. The secondary mission is to host a university-provided experiment payload.

Date: Sept 26, 2016
Version: Version 1.00

AMSAT *Fox-1E*

Downlink Specification

1 Introduction

This document specifies downlink frame formats for the Fox-1E telemetry and experiment telemetry.

Document History

DATE	VERSION	SUMMARY
Sept 26, 2016	1.00	Initial Version

DATE	VERSION	SUMMARY

1.1 Document Scope

The purpose of this document is to specify the downlink protocol on the AMSAT Fox-1E spacecraft.

1.2 References

1. Fox1 Downlink Specification
2. Fox-1E System Requirements

1.3 Definitions

1.3.1 BPSK Downlink – Data transmitted at approximately 1200 bits per second on a separate carrier outside the transponder passband.

1.3.2 Spacecraft Telemetry – Downlink data containing specific information about spacecraft systems and health as defined in the System Requirements and related documents.

1.3.3 Experiment Telemetry – Downlink data containing specific information about the various experiment platforms flown on the satellite.

1.3.4 Frame – A set of data to be transmitted to the ground with a specific overall size comprised of a header, a sync vector, payloads and FEC check bytes.

1.3.5 Payload – A set of data with a specific overall size containing fields of a specific bit or byte length.

1.3.6 FEC – Forward Error Correction provided by the Reed-Solomon 225,223 encoding scheme.

2 Protocol Structure

2.1 Physical Layer

2.1.1 DBPSK Telemetry operation uses differential binary phase shift keying.

2.1.2 The details of the physical layer are shown in Table 1.

Table 1

Bit Rate	1200 bps
Spectral efficiency	1 bps/Hz
Modulation type	Differential Binary Phase Shift Keying (DBPSK)
Signal bandwidth	10 Hz to 2400 Hz (-3 dB points)
Spectral Mask	-20 dB at 2400 Hz
RF Channel Bandwidth	2400 Hz

2.2 Link Layer

2.2.1 The link layer protocol provides a 32 bit sync vector

2.2.2 Link layer shall include a header and a trailer surrounding the applications layer payloads to form data packets as shown in Table 2.

Table 2

Header	Applications Payloads	Trailer

2.2.3 The applications payload layer shall include satellite telemetry, experiment telemetry, and debug frames.

2.2.4 Debug frames may be used during ground testing but shall not be transmitted for flight

2.2.5 Bits shall be transmitted in the order of most significant bit first.

2.2.6 Bytes shall be transmitted in Little Endian order.

2.2.7 The link layer header structure shall be as shown in Table 3.

Table 3

Field	Size (Bits)	Type	Min Value	Max Value	Description
Fox ID	3	Unsigned	0x01	0x01	0x05 specifies Fox-1E (each Fox satellite will have a unique ID)
Reset Count	16	Unsigned	0x00	0xFFFF	Total number of times IHU has reset since initial on-orbit startup
Uptime	25	Unsigned	0x00	0x1FFFFFF	This is the IHU uptime in seconds since the last reset

2.2.7.1 Each link layer structure shall contain the payload types shown in table 4.

Table 4

Payload Type	Size (Bytes)	Description
1	58	Real-Time Telemetry Payload
2	58	Telemetry Maximum Values Payload
3	58	Telemetry Minimum Values Payload
4	232	4 Radiation Experiment Payloads (58 bytes each)

2.2.7.2 Reset Count and Uptime shall reflect the time at which the payload data was collected.

2.2.7.3 Reset Count and Uptime shall not be changed if the payload data has not been updated

2.2.7.4 Real-Time Telemetry Payload, Telemetry Maximum Values Payload, and Telemetry Minimum Values Payload data shall be padded with zeros to equal 58 bytes length for each.

2.2.8 Forward error correction (FEC) bytes shall be sent in the link layer trailer. The FEC shall be a Reed Solomon RS 255,223 code. (This provides 32 parity bytes per code word allowing error detection and correction capability.) Two code words will be required. 30 bytes of zero padding (which will not be transmitted) are added to the 416 bytes of header/payload data to equal the 446 bytes needed for 2 code words.

3 Link Layer Transmission Scheduling

3.1 Safe Mode Beacons

3.1.1 During Safe mode the telemetry will be sent in beacon mode, designed to conserve power. The transponder will be off and two frame will be sent every 2 minutes.

3.2 Transponder Mode

3.2.1 While the transponder is on telemetry will be sent continuously.

4 Application Layer Payload Data

4.1 Payload Type 0 – Debug Frame (NOT TO BE TRANSMITTED FOR FLIGHT)

Table 5

Field	Size (Bits)	Type	Min Value	Max Value	Description
UNDEFINED	1 - 464	Undefined	-	-	Debug data for ground testing

4.2 Payload Type 1 - Real-Time Telemetry Frame (Size = 429 bits)

Table 6

Field	Size (Bits)	Type	Min Value	Max Value	Description	Bit Offset
BATT A V	12	Unsigned	0x00	0xFFF	Battery pair A voltage raw value (0-2.5V scale)	0
BATT B V	12	Unsigned	0x00	0xFFF	Battery pairs A+B voltage raw value (0-3.3V scale)	12
BATT C V	12	Unsigned	0x00	0xFFF	Battery pairs A+B+C voltage raw value (0-5.0V scale) This value also represents the power bus voltage (VBATT)	24
BATT A T	12	Unsigned	0x00	0xFFF	Battery pair A temperature raw value	36
BATT B T	12	Unsigned	0x00	0xFFF	Battery pair B temperature raw value	48
BATT C T	12	Unsigned	0x00	0xFFF	Battery pair C temperature raw value	60
TOTAL BATT I	12	Signed	0x00	0xFFF	Total Battery DC current raw value	72
BATT Board Temperature	12	Unsigned	0x00	0xFFF	PC Board Temperature of BATT raw value	84
+X PANEL V	12	Unsigned	0x00	0xFFF	+X solar panel voltage raw value	96
-X PANEL V	12	Unsigned	0x00	0xFFF	-X solar panel voltage raw value	108
+Y PANEL V	12	Unsigned	0x00	0xFFF	+Y solar panel voltage raw value	120
-Y PANEL V	12	Unsigned	0x00	0xFFF	-Y solar panel voltage raw value	132
+Z PANEL V	12	Unsigned	0x00	0xFFF	+Z solar panel voltage raw value	144
-Z PANEL V	12	Unsigned	0x00	0xFFF	-Z solar panel voltage raw value	156
+X PANEL T	12	Unsigned	0x00	0xFFF	+X solar panel temperature raw value	168
-X PANEL T	12	Unsigned	0x00	0xFFF	-X solar panel temperature raw value	180
+Y PANEL T	12	Unsigned	0x00	0xFFF	+Y solar panel temperature raw value	192
-Y PANEL T	12	Unsigned	0x00	0xFFF	-Y solar panel temperature raw value	204
+Z PANEL T	12	Unsigned	0x00	0xFFF	+Z solar panel temperature raw value	216

Field	Size (Bits)	Type	Min Value	Max Value	Description	Bit Offset
-Z PANEL T	12	Unsigned	0x00	0xFFF	-Z solar panel temperature raw value	228
PSU Temperature	12	Unsigned	0x00	0xFFF	PSU card temperature raw value	240
SPIN	12	Signed	0x00	0xFFF	Calculated spin rate RPM using solar cells Bit 11 = sign Bits 10 to 8 = integer Bits 7 to 0 = fraction	252
TX PA Current	12	Unsigned	0x00	0xFFF	Transmit power amplifier current raw value	264
TX Temperature	12	Unsigned	0x00	0xFFF	Transmitter card temperature raw value	276
RX Temperature	12	Unsigned	0x00	0xFFF	Receiver card temperature raw value	288
RSSI	12	Unsigned	0x00	0xFFF	Received Signal Strength Indication raw value	300
IHU CPU Temperature	12	Unsigned	0x00	0xFFF	CPU Temperature of IHU raw value	312
Satellite X Axis Angular Velocity	12	Unsigned	0x00	0xFFF	Raw Angle	324
Satellite Y Axis Angular Velocity	12	Unsigned	0x00	0xFFF	Raw Angle	336
Satellite Z Axis Angular Velocity	12	Unsigned	0x00	0xFFF	Raw Angle	348
EXP 4 Temperature	12	Unsigned	0x00	0xFFF	Experiment 4 card temperature raw value	360
PSU Current	12	Unsigned	0x00	0xFFF	PSU DC current	372
IHU Diagnostic Data	32	Unsigned	-	-	Diagnostic Data on IHU Performance	384
Experiment Failure Indication	4	Unsigned	0x00 0x08	0x01 0x09	Bit 0 is Experiment 1 Bit 1 is Experiment 2 (N/A on Fox-1A) Bit 2 is Experiment 3 (N/A on Fox-1A) Bit 3 is Experiment 4 State: 0 = Working, 1 = Failed	416

Field	Size (Bits)	Type	Min Value	Max Value	Description	Bit Offset
System I2C Failure Indications	3	Unsigned	0x00	0x07	Bit 0 is BATT Bit 1 is PSU Device 1 Bit 2 is PSU Device 2 State: 0 = Working, 1 = Failed	420
Number of Ground Commanded TLM Resets	4	Unsigned	0x00	0x0F	Number of times command stations reset stored telemetry	423
Antenna Deploy Sensors	2	Unsigned	0x00	0x03	Bit 0 is RCV Bit 1 is XMT State: 0 = stowed 1 = deployed	427

4.3 Payload Type 2 - Telemetry Maximum Values Frame (Size = 460 bits)

Table 7

Field	Size (Bits)	Type	Min Value	Max Value	Description	Bit Offset
BATT A V	12	Unsigned	0x00	0xFFF	Battery pair A high voltage raw value (0-2.5V scale)	0
BATT B V	12	Unsigned	0x00	0xFFF	Battery pairs A+B high voltage raw value (0-3.3V scale)	12
BATT C V	12	Unsigned	0x00	0xFFF	Battery pairs A+B+C high voltage raw value (0-5.0V scale) This value also represents the power bus voltage (VBATT)	24
BATT A T	12	Unsigned	0x00	0xFFF	Battery pair A high temperature raw value	36
BATT B T	12	Unsigned	0x00	0xFFF	Battery pair B high temperature raw value	48
BATT C T	12	Unsigned	0x00	0xFFF	Battery pair C high temperature raw value	60
TOTAL BATT I	12	Signed	0x00	0xFFF	Battery DC high current raw value	72
BATT Board Temperature	12	Unsigned	0x00	0xFFF	High PC Board Temperature of BATT raw value	84
+X PANEL V	12	Unsigned	0x00	0xFFF	+X solar panel high voltage raw value	96
-X PANEL V	12	Unsigned	0x00	0xFFF	-X solar panel high voltage raw value	108
+Y PANEL V	12	Unsigned	0x00	0xFFF	+Y solar panel high voltage raw value	120
-Y PANEL V	12	Unsigned	0x00	0xFFF	-Y solar panel high voltage raw value	132
+Z PANEL V	12	Unsigned	0x00	0xFFF	+Z solar panel high voltage raw value	144
-Z PANEL V	12	Unsigned	0x00	0xFFF	-Z solar panel high voltage raw value	156
+X PANEL T	12	Unsigned	0x00	0xFFF	+X solar panel high temperature raw value	168

Field	Size (Bits)	Type	Min Value	Max Value	Description	Bit Offset
-X PANEL T	12	Unsigned	0x00	0xFFF	-X solar panel high temperature raw value	180
+Y PANEL T	12	Unsigned	0x00	0xFFF	+Y solar panel high temperature raw value	192
-Y PANEL T	12	Unsigned	0x00	0xFFF	-Y solar panel high temperature raw value	204
+Z PANEL T	12	Unsigned	0x00	0xFFF	+Z solar panel high temperature raw value	216
-Z PANEL T	12	Unsigned	0x00	0xFFF	-Z solar panel high temperature raw value	228
PSU Temperature	12	Unsigned	0x00	0xFFF	PSU card high temperature raw value	240
SPIN	12	Signed	0x00	0xFFF	Highest calculated spin rate RPM using solar cells	252
TX PA Current	12	Unsigned	0x00	0xFFF	Transmit power amplifier high current raw value	264
TX Temperature	12	Unsigned	0x00	0xFFF	Transmitter card high temperature raw value	276
RX Temperature	12	Unsigned	0x00	0xFFF	Receiver card high temperature raw value	288
RSSI	12	Unsigned	0x00	0xFFF	High Received Signal Strength Indication raw value	300
IHU CPU Temperature	12	Unsigned	0x00	0xFFF	High CPU Temperature of IHU raw value	312
Satellite X Axis Angular Velocity	12	Unsigned	0x00	0xFFF	Highest Raw Angle	324
Satellite Y Axis Angular Velocity	12	Unsigned	0x00	0xFFF	Highest Raw Angle	336
Satellite Z Axis Angular Velocity	12	Unsigned	0x00	0xFFF	Highest Raw Angle	348

Field	Size (Bits)	Type	Min Value	Max Value	Description	Bit Offset
EXP 4 Temperature	12	Unsigned	0x00	0xFFF	Experiment 4 card high temperature raw value	360
PSU Current	12	Unsigned	0x00	0xFFF	PSU DC high current	372
IHU Hard Error Data	32	Unsigned	-	-	Diagnostic Data on IHU Hard Errors	384
MAX Timestamp Reset Count	16	Unsigned	0x00	0xFFFF	At last MAX, total number of times IHU has reset since initial on-orbit startup	416
MAX Timestamp Uptime	25	Unsigned	0x00	0x1FFFFFF	At last MAX, the IHU uptime in seconds since the last reset	432
Safe Mode Indication	1	Unsigned	0x00	0x01	State: 1 = Safe Mode Active	457
Auto-Safe Mode Indication	1	Unsigned	0x00	0x01	State: 1 = Safe Mode activated by Auto-Safe	458
Auto-Safe Enabled	1	Unsigned	0x00	0x01	State: 1 = Auto-Safe Mode enabled	459

4.4 Payload Type 3 - Telemetry Minimum Values Frame (Size = 460 bits)

Table 8

Field	Size (Bits)	Type	Min Value	Max Value	Description	Bit Offset
BATT A V	12	Unsigned	0x00	0xFFF	Battery pair A low voltage raw value (0-2.5V scale)	0
BATT B V	12	Unsigned	0x00	0xFFF	Battery pair A+B low voltage raw value (0-3.3V scale)	12
BATT C V	12	Unsigned	0x00	0xFFF	Battery pair A+B+C low voltage raw value (0-5.0V scale) This value also represents the power bus voltage (VBATT)	24
BATT A T	12	Unsigned	0x00	0xFFF	Battery pair A low temperature raw value	36
BATT B T	12	Unsigned	0x00	0xFFF	Battery pair B low temperature raw value	48
BATT C T	12	Unsigned	0x00	0xFFF	Battery pair C low temperature raw value	60
TOTAL BATT I	12	Signed	0x00	0xFFF	Battery DC low current raw value	72
BATT Board Temperature	12	Unsigned	0x00	0xFFF	Low PC Board Temperature of BATT raw value	84
+X PANEL V	12	Unsigned	0x00	0xFFF	+X solar panel low voltage raw value	96
-X PANEL V	12	Unsigned	0x00	0xFFF	-X solar panel low voltage raw value	108
+Y PANEL V	12	Unsigned	0x00	0xFFF	+Y solar panel low voltage raw value	120
-Y PANEL V	12	Unsigned	0x00	0xFFF	-Y solar panel low voltage raw value	132
+Z PANEL V	12	Unsigned	0x00	0xFFF	+Z solar panel low voltage raw value	144
-Z PANEL V	12	Unsigned	0x00	0xFFF	-Z solar panel low voltage raw value	156
+X PANEL T	12	Unsigned	0x00	0xFFF	+X solar panel low temperature raw value	168

Field	Size (Bits)	Type	Min Value	Max Value	Description	Bit Offset
-X PANEL T	12	Unsigned	0x00	0xFFF	-X solar panel low temperature raw value	180
+Y PANEL T	12	Unsigned	0x00	0xFFF	+Y solar panel low temperature raw value	192
-Y PANEL T	12	Unsigned	0x00	0xFFF	-Y solar panel low temperature raw value	204
+Z PANEL T	12	Unsigned	0x00	0xFFF	+Z solar panel low temperature raw value	216
-Z PANEL T	12	Unsigned	0x00	0xFFF	-Z solar panel low temperature raw value	228
PSU Temperature	12	Unsigned	0x00	0xFFF	PSU card low temperature raw value	240
SPIN	12	Signed	0x00	0xFFF	Lowest calculated spin rate RPM using solar cells	252
TX PA Current	12	Unsigned	0x00	0xFFF	Transmit power amplifier low current raw value	264
TX Temperature	12	Unsigned	0x00	0xFFF	Transmitter card low temperature raw value	276
RX Temperature	12	Unsigned	0x00	0xFFF	Receiver card low temperature raw value	288
RSSI	12	Unsigned	0x00	0xFFF	Low Received Signal Strength Indication raw value	300
IHU CPU Temperature	12	Unsigned	0x00	0xFFF	Low CPU Temperature of IHU raw value	312
Satellite X Axis Angular Velocity	12	Unsigned	0x00	0xFFF	Lowest Raw Angle	324
Satellite Y Axis Angular Velocity	12	Unsigned	0x00	0xFFF	Lowest Raw Angle	336
Satellite Z Axis Angular Velocity	12	Unsigned	0x00	0xFFF	Lowest Raw Angle	348

Field	Size (Bits)	Type	Min Value	Max Value	Description	Bit Offset
EXP 4 Temperature	12	Unsigned	0x00	0xFFF	Experiment 4 card low temperature raw value	360
PSU Current	12	Unsigned	0x00	0xFFF	PSU DC low current	372
IHU Soft Error Data	32	Unsigned	-	-	Diagnostic Data on IHU Soft Errors	384
MIN Timestamp Reset Count	16	Unsigned	0x00	0xFFFF	At last MIN, total number of times IHU has reset since initial on-orbit startup	416
MIN Timestamp Uptime	25	Unsigned	0x00	0x1FFFFFF	At last MIN, the IHU uptime in seconds since the last reset	432
Safe Mode Indication	1	Unsigned	0x00	0x01	State: 1 = Safe Mode Active	457
Auto-Safe Mode Indication	1	Unsigned	0x00	0x01	State: 1 = Safe Mode activated by Auto-Safe	458
Auto-Safe Enabled	1	Unsigned	0x00	0x01	State: 1 = Auto-Safe Mode enabled	459

4.5 Payload Type 4 - Radiation Experiment Data Frame (Size = 464 bits)

Table 9

Field	Size (Bytes)	Type	Min Value	Max Value	Description
Data	58	Unsigned	-	-	Experiment 1 Data

The following boards will be in the experiment slots:

- 1 VUC experiment controller board interfacing with AMSAT Fox-1 satellite bus in Position 1 (EXP1)
- 1 LEP in Position 2 (EXP2) (as flown on Fox-1A),
- 1 LEPF in Position 3 (EXP3) (new),
- 1 REM in Position 4 (EXP4) (as flown on Fox-1B)

The VUC will send the 58 byte chunks as per the ICD. This will contain a set of Telemetry data for the experiments that the VUC is controlling.

Id	FIELD	BITS	UNIT	CONVERSION	SHORT_NAME	DESCRIPTION
0	VUC_STATE	4	NONE	27	Status	Status of the Vanderbilt University Controller
1	VUC_RESTARTS	8	NONE	1	Restarts	Number of restarts by the Vanderbilt University Controller
2	VUC_UPTIME	20	s	25	Uptime	Uptime of the Vanderbilt University Controller
3	State1	4	NONE	27	State	Vulcan Experiment 1 State
4	State2	4	NONE	27	State	Vulcan Experiment 2 State
5	State3	4	NONE	27	State	Vulcan Experiment 3 State
6	State4	4	NONE	27	State	Vulcan Experiment 4 State
7	Power1	8	mW	0	Power	Vulcan Experiment 1 Power
8	Power2	8	mW	0	Power	Vulcan Experiment 2 Power
9	Power3	8	mW	0	Power	Vulcan Experiment 3 Power
10	Power4	8	mW	0	Power	Vulcan Experiment 4 Power
11	REM1	80	NONE	0	NONE	NONE
12	REM2_RESETS	8	NONE	1	Resets	Number of times the REM2 Experiment has reset
13	REM2_UPTIME	16	s	25	Uptime	Uptime of the REM2 Experiment
14	REM2_CORE_VOLTAGE	8	mV	25	Core Voltage	REM2 Core Voltage
15	REM2_SEU_LIVETIME	32	s	1	SEU Livetime	REM2 SEU Livetime
16	REM2_UPSETS	16	NONE	1	Memory	Cumulative number of

					Errors	memory upsets in REM2 Experiment
17	REM3_RESETS	8	NONE	1	Resets	Number of times the REM3 Experiment has reset
18	REM3_UPTIME	16	s	25	Uptime	Uptime of the REM3 Experiment
19	REM3_CORE_VOLTAGE	8	mV	25	Core Voltage	REM3 Core Voltage
20	REM3_SEU_LIVETIME	32	s	1	SEU Livetime	REM3 SEU Livetime
21	REM3_UPSETS	16	NONE	1	Memory Errors	Cumulative number of memory upsets in REM3 Experiment
22	REM4_RESETS	8	NONE	1	Resets	Number of times the REM4 Experiment has reset
23	REM4_UPTIME	16	s	25	Uptime	Uptime of the REM4 Experiment
24	REM4_CORE_VOLTAGE	8	mV	25	Core Voltage	REM4 Core Voltage
25	REM4_SEU_LIVETIME	32	s	1	SEU Livetime	REM4 SEU Livetime
26	REM4_UPSETS	16	NONE	1	Memory Errors	Cumulative number of memory upsets in REM4 Experiment

Fox 1-E Linear Transponder Average Power Tracking

Marc Franco, N2UO – Dan Habecker, W9EQ

May 2016

Fox 1-E is the first satellite of the Fox series to feature a linear transponder. The downlink will be on the 70 cm band. The preliminary design goals are as follows:

Frequency: 435.8 MHz (nominal).

Bandwidth: 30 KHz.

Output power: 250 mW.

IMD: -20 dBc.

Harmonics: meet FCC.

Supply voltage: satellite battery, nominal 3.6 V.

We have chosen the RFPA0133 integrated circuit made by Qorvo (formerly RFMD) using their GaAs HBT process. This power amplifier provides more than 30 dB of gain. The output match is external, allowing for the use of low loss components. The power added efficiency of the PA is greater than 60%.

Linear transponders can be reasonably efficient when operated as close to saturation as possible while maintaining the required linearity. However, when relaying weak signals or the satellite's beacon, their efficiency will be severely degraded. This is true for any linear amplifier; since the load resistance RL is related to the supply voltage Vcc and the output power Po by the following equation,

$$RL = \frac{Vcc^2}{2Po}$$

any decrease in output power will result in a load resistance that is higher than that for maximum power, where the amplifier operates efficiently. One approach to maintain the efficiency high is to adjust the Vcc according to the output power in order to maintain RL constant. This will minimize the amount of energy wasted in heat. Three methods to control the Vcc are shown in Fig. 1: fixed Vcc, envelope tracking, and average power tracking.

In the fixed Vcc case, the amount of wasted energy is very large. No matter what the output power is, the Vcc is adjusted to provide the maximum peak power, and it is not varied when the power is lowered. Envelope tracking (ET), on the other hand, does exactly the opposite: it adjusts the Vcc following the envelope of the signal, so the Vcc value is optimum at all times. This is similar to the HELAPS or Envelope Elimination and Restoration methods used in past satellites. The advantage of ET over EER is that it is simpler to implement and it is easier to achieve good linearity. However, it takes a significant amount of energy to implement ET; there is a minimum amount of current that needs to be drawn, no matter what the power amplifier power is, for the envelope processing. In the case of a large amplifier, let's say, above 5 W, the current needed to implement ET is negligible, but at much lower RF power levels, the complexity and current needed are hard to justify.

Another way to improve the efficiency of a power amplifier when operated at a significant back off level is to use Average Power Tracking (APT). In this case, the value of the Vcc does not follow the instantaneous amplitude of the envelope, but it follows its average value. The complexity required in the modulator is a fraction of what is needed for ET, since now the Vcc envelope frequency is much lower. Although the efficiency achieved with this method is not as high as with ET, it is very convenient for small power amplifiers since the overhead current needed is much lower than with ET.

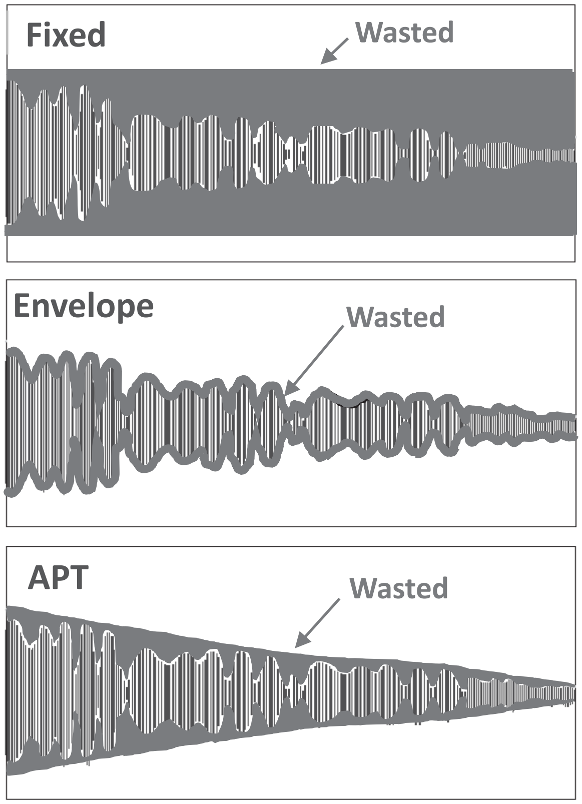


Fig. 1 – Time domain waveforms showing wasted power in fixed Vcc, average power tracking and envelope tracking

In APT, the output of the power amplifier is sampled and applied to a peak power detector. The output of the detector drives a high efficiency dc to dc converter that reduces the Vcc applied to the PA directly proportionally to the time average of the peak output power. Ideally, the peak detector should be placed at the input of the amplifier, but since the gain of this PA is not affected significantly by the change in Vcc value, the detector can be placed at the output without causing any instability.

Fig. 2 shows the schematic diagram of a practical implementation of the APT method. The detector is a Linear Technology LTC5533, and the dc to dc converter is a Linear Technology LTC1772. The Vcc of both stages in the RFPA0133 is controlled by the dc to dc converter.

The peak/hold function is implemented by adding some capacitance to ground after diode D1 (not shown in the schematic). The time constant should be found experimentally using real SSB and CW signals in the passband, but we have determined that between 1 to 2 seconds is satisfactory.

The current savings of the APT method can be seen in Fig. 3. Here, the current drawn by the amplifier is plotted both with the APT system on or by simply applying a fixed Vcc to the amplifier. The difference is quite significant at low power levels. In fact, if the satellite is to transmit only the beacon, the current needed will be minimized. Implementing a “squelch” type circuit for weak SSB and CW signals is not straightforward, as it is on FM.

The peak power detector used for the APT control can also be used for telemetry and to implement an automatic gain control in the transponder. The total current drawn by the amplifier biasing and power control circuit is 14 mA at 2.9 V.

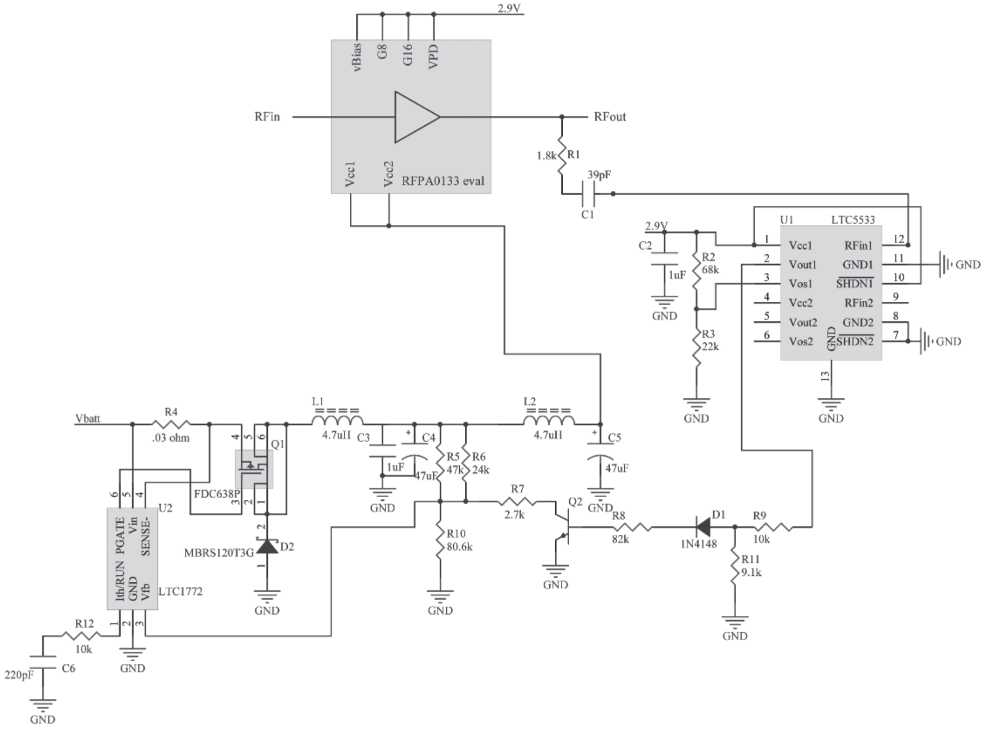


Fig. 2 – Schematic of the Average Power Tracking

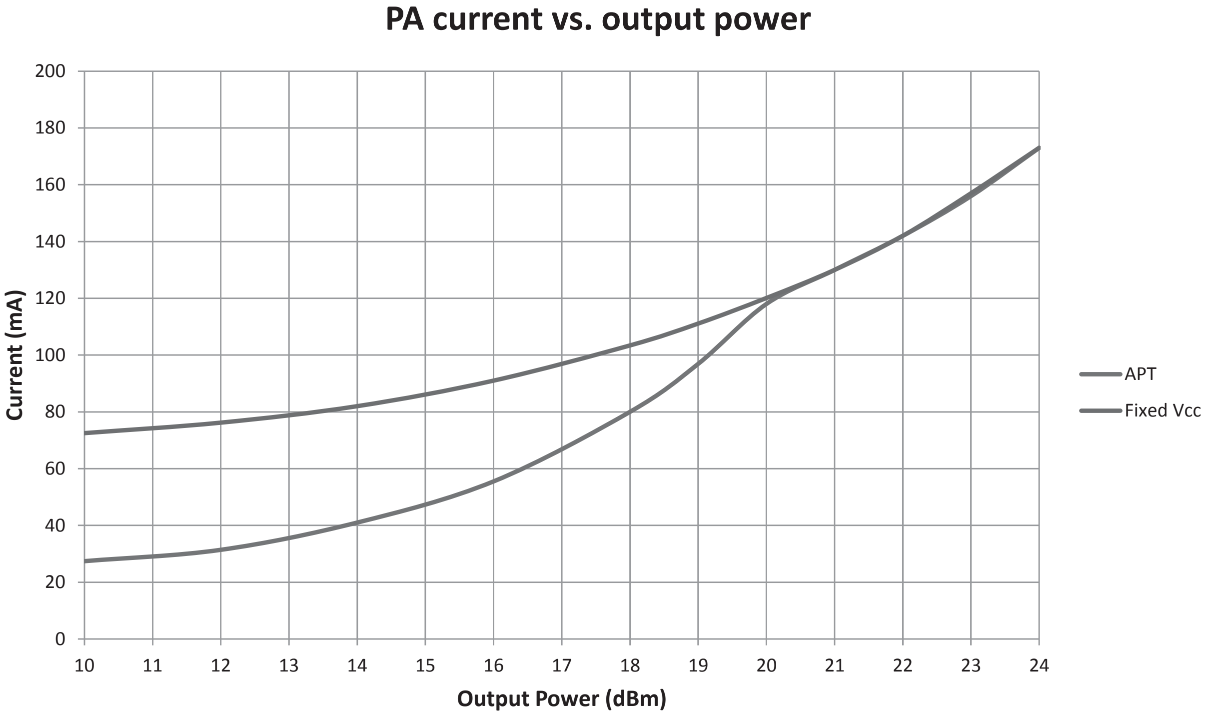
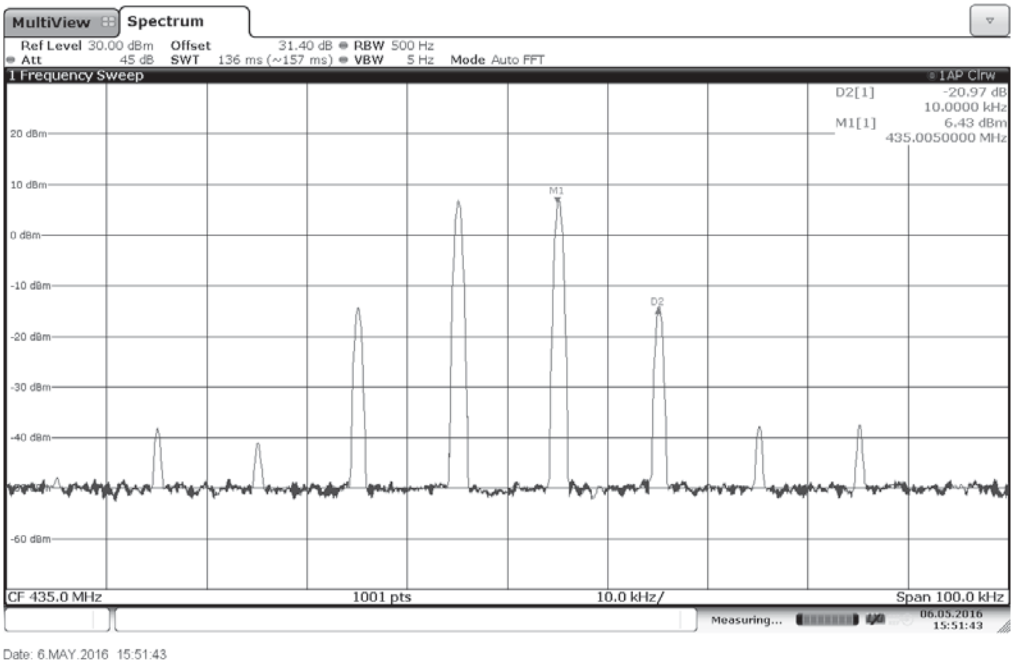


Fig. 3 – Measured current draw of the power amplifier using APT or a fixed Vcc

The linearity of the amplifier is maintained at all voltages. As an example, the measured two-tone spectrum at 10 dBm average power is shown in Fig. 4, whereas the two-tone spectrum at 23.7 dBm is shown in Fig. 5. Fig. 6 shows the 12-tone spectrum at 21.8 dBm total average power.



Ref Level 30.00 dBm Offset 31.40 dB RBW 500 Hz
Att 45 dB SWT 136 ms (~157 ms) VBW 5 Hz Mode Auto FFT

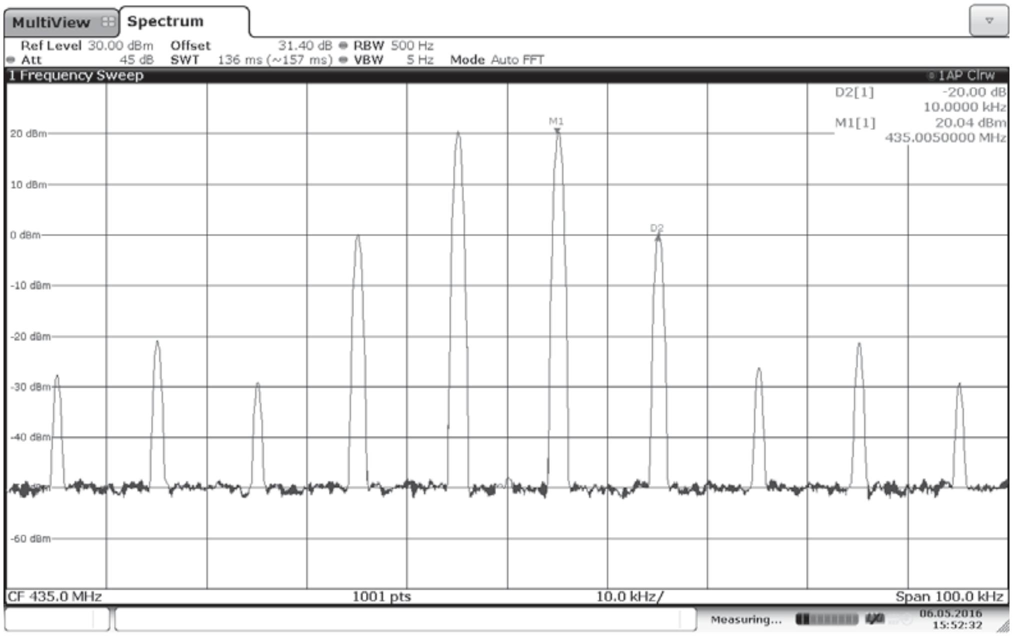
D2[1] -20.97 dB
10.0000 kHz
M1[1] 6.43 dBm
435.0050000 MHz

CF 435.0 MHz 1001 pts 10.0 kHz/ Span 100.0 kHz

06.05.2016
15:51:43

Date: 6.MAY.2016 15:51:43

Fig. 4 – Measured two-tone spectrum at 21.8 dBm using APT



Ref Level 30.00 dBm Offset 31.40 dB ● RBW 500 Hz
● Att 45 dB SWT 136 ms (~157 ms) ● VBW 5 Hz Mode Auto FFT

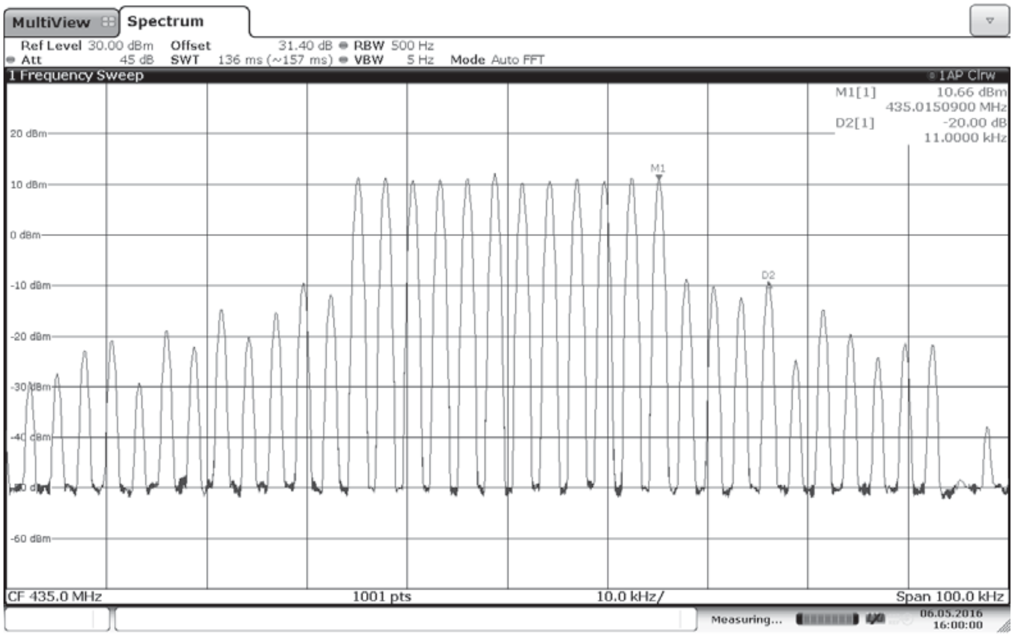
D2[1] -20.00 dB
10.0000 kHz
M1[1] 20.04 dBm
435.0050000 MHz

CF 435.0 MHz 1001 pts 10.0 kHz/ Span 100.0 kHz

06.05.2016
15:52:32

Date: 6.MAY.2016 15:52:32

Fig. 5 – Measured two-tone spectrum at 23.7 dBm using APT



Ref Level 30.00 dBm Offset 31.40 dB ● RBW 500 Hz
● Att 45 dB SWT 136 ms (~157 ms) ● VBW 5 Hz Mode Auto FFT

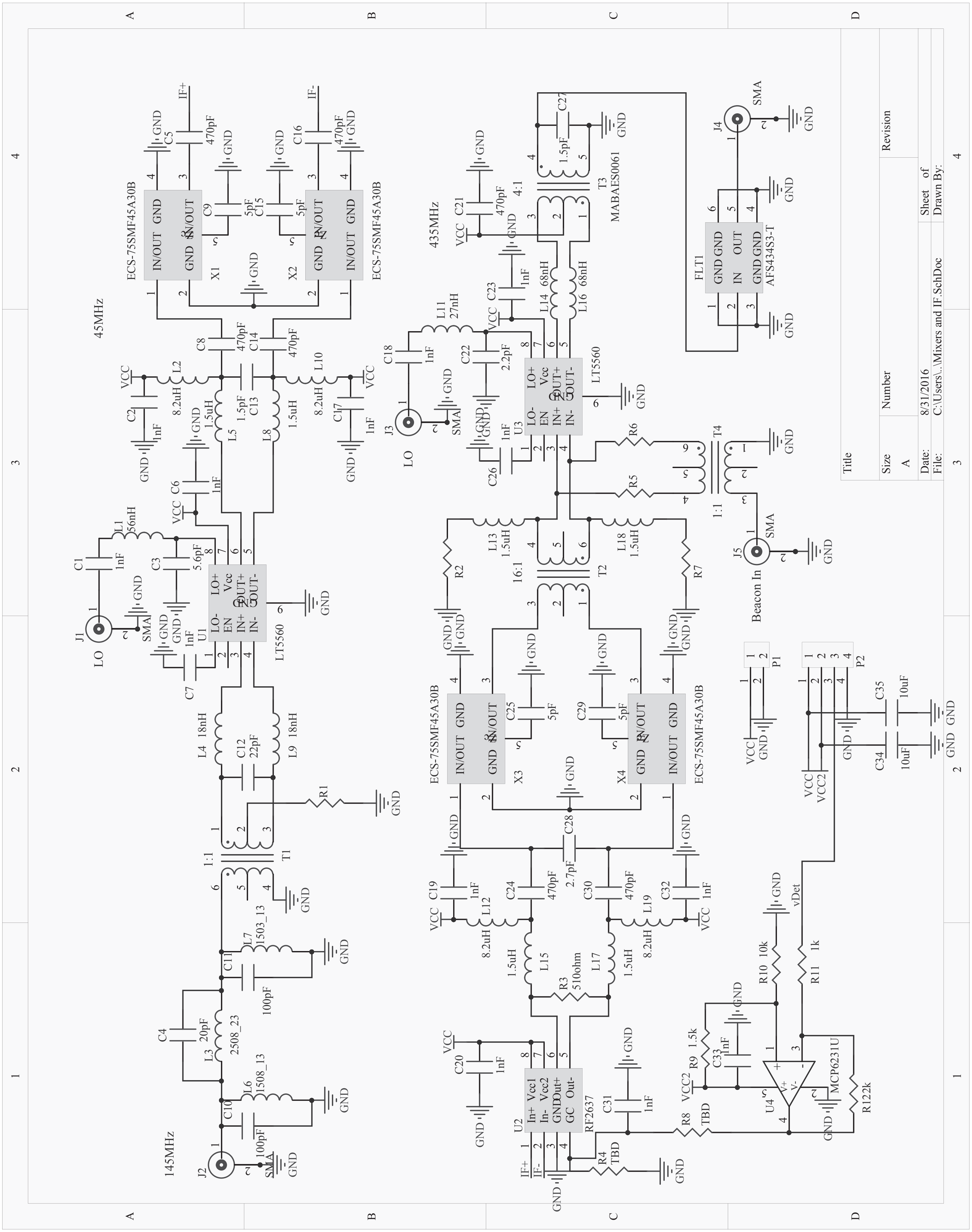
M1[1] 10.66 dBm
435.0150900 MHz
D2[1] -20.00 dB
11.0000 kHz

CF 435.0 MHz 1001 pts 10.0 kHz/ Span 100.0 kHz

06.05.2016
16:00:00

Date: 6.MAY.2016 16:00:00

Fig. 6 – Measured twelve-tone spectrum spread out 30 KHz at 21.8 dBm using APT


145MHz
45MHz
435MHz
LO
Beacon In
J1
J2
J3
J4
J5
SMA
U1
LT5560
U2
RF2637
U3
LT5560
U4
MCP6231U
X1
X2
X3
X4
ECS-75SMF45A30B
T1
1:1
T2
16:1
T3
MABAES0061
4:1
T4
1:1
FLT1
AFS434S3-T
L1 56nH
L2 8.2uH
L3 2508_23
L4 18nH
L5 1.5uH
L6 1508_13
L7 1503_13
L8 1.5uH
L9 18nH
L10 8.2uH
L11 27nH
L12 8.2uH
L13 1.5uH
L14 68nH
L15 1.5uH
L16 68nH
L17 1.5uH
L18 1.5uH
L19 8.2uH
C1 1nF
C2 1nF
C3 5.6pF
C4 20pF
C5 470pF
C6 1nF
C7 1nF
C8 470pF
C9 5pF
C10 100pF
C11 100pF
C12 22pF
C13 1.5pF
C14 470pF
C15 5pF
C16 470pF
C17 1nF
C18 1nF
C19 1nF
C20 1nF
C21 470pF
C22 2.2pF
C23 1nF
C24 470pF
C25 5pF
C26 1nF
C27 1.5pF
C28 2.7pF
C29 5pF
C30 470pF
C31 1nF
C32 1nF
C33 1nF
C34 10uF
C35 10uF
R1
R2
R3 510ohm
R4 TBD
R5
R6
R7
R8 TBD
R9 1.5k
R10 10k
R11 1k
R12 2k
P1
P2
VCC
VCC2
GND
IF+
IF-
vDet
Title
Size A
Number
Revision
Date: 8/31/2016
Sheet of
File: C:\Users\..\Mixers and IF.SchDoc
Drawn By:

FOX1E 1200 BPS BPSK modulator

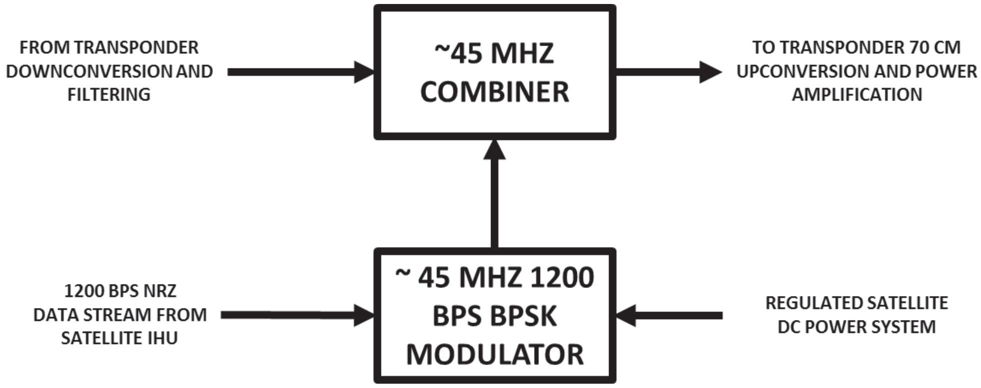
John Klingelhoeffer, WB4LNM

Current revision: 27 August 2016

Introduction: The AMSAT FOX1E has been discussed as providing a 1200 BPS BPSK downlink telemetry channel with a carrier outside of the user transponder bandwidth. This would increase the bandwidth of the telemetry downlink bandwidth compared with FOX1A-D, providing for a higher speed continuous scientific data downlink, and making the satellite compatible with legacy AMSAT telemetry downlink ground stations.

Discussion of the generation of this signal has previously been mentioned both as firmware-based in the IHU and hardware-based in the transponder transmitter. This document will address the later generation method *only*. This document proposes an approach to generate BPSK that requires significantly less system power, which is critical on small satellites. This is a concept document and is not a detailed design which is left to the AMSAT volunteer.

Requirements: The FOX1E transponder requires an approximately 45 MHz, low level, 1200 BPS BPSK signal that can be combined into the transponder after user bandwidth filtering and prior to up-conversion to 70 cm.



This document contains Technical Data whose export is restricted by the Arms Export Control Act (Title 22, U.S.C., Sec 2751, et seq.). Violations of these export laws are subject to severe criminal penalties.

Approach: The hardware modulator subsystem proposed consists of two main blocks, a carrier generator and the BPSK modulator itself.

The carrier generator would be a conventional, third-overtone, Colpitts crystal oscillator. The oscillator may or may not be temperature-compensated depending upon the desire to stabilize the frequency over long periods of time. In the short term, after mixing with the up-converter local oscillator and amplified, this signals frequency drift will be overwhelmingly dominated by short-term Doppler shift which will be many orders of magnitude more than the long-term temperature-induced drift. The continuous carrier wave output of this oscillator is at a frequency close to the 45 MHz center frequency of the linear transponder IF, but outside the user passband.

The second block of the BPSK function is the modulator itself. What is proposed herein is to use a quadruple analog switch instead of the more traditional double balanced mixer. This minimizes the interfacing drive needs from the NRZ data stream control input and therefore power. It allows the BPSK stream to be generated with much lower power levels than traditional methods.

Quad bilateral analog switches (QBS) have progressed in performance significantly since the days of the original CD4066, which was only functional to several megahertz at best. In this instance, the switch proposed for this application is the Texas Instruments TS112A44513DR:

http://www.ti.com/lit/ds/symlink/ts12a44514.pdf.

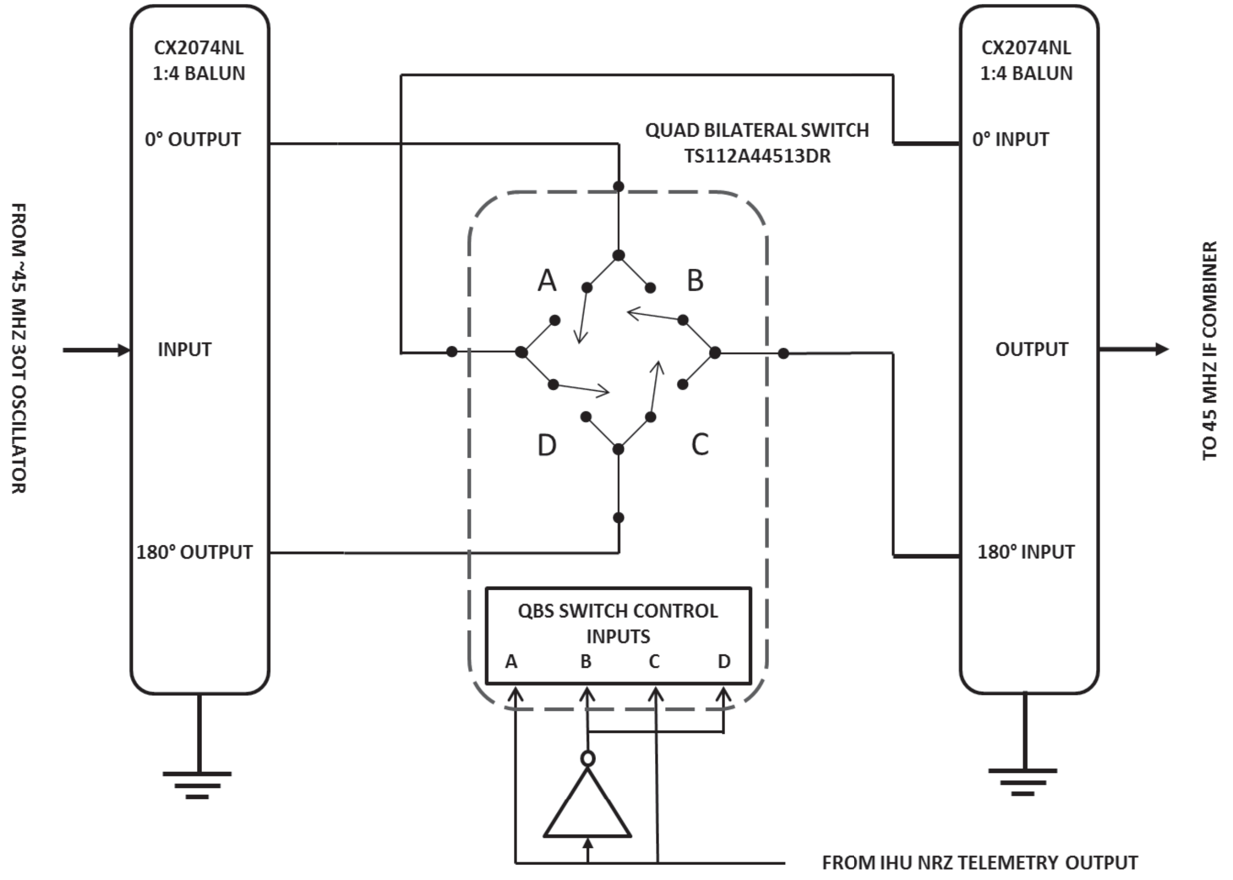
This IC has a 530 MHz high frequency cutoff at 5V operation, although it is operable down to 2.7 Volts. There may be better quad analog switches available for this specific application – no extensive survey was made. A more comprehensive search by the AMSAT detail designer is recommended during detail design.

The input and output signal processing to the quad bilateral analog switch by baluns allows the ~45 MHz signal to be split and combined in-phase and out of phase 180 degrees. One such balun is the Pulse Electronics CX2074NL unit, although as with the QBS, other devices are available.

http://www.digikey.com/product-detail/en/pulse-electronics-corporation/CX2074NL/553-1655-ND/2265447

This combination of parts is shown in the block diagrams on the following pages to help visualize the action of the modulator. For this discussion, the four switches of the QBS are designated as switches A,B,C and D.

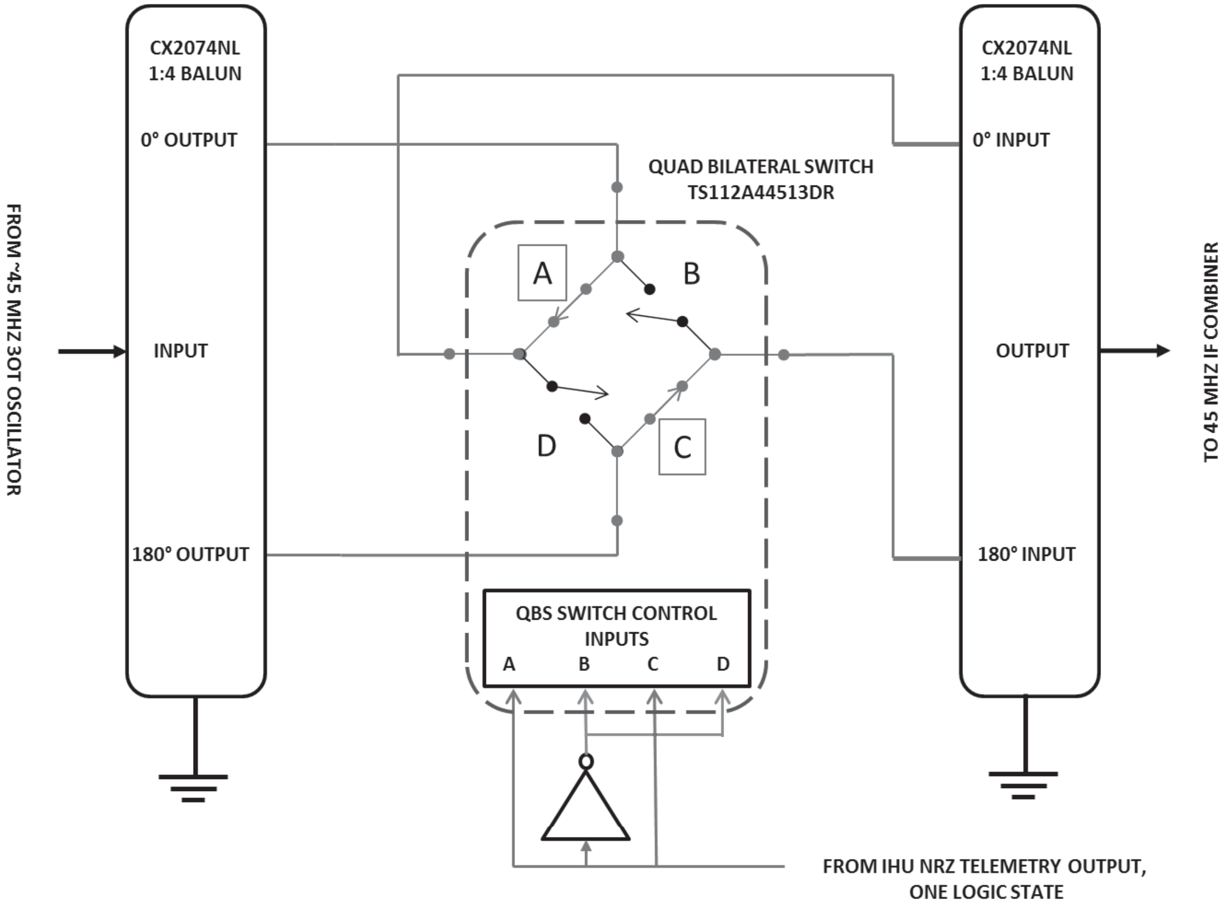
The control signal for the QBS is the 1200 BPS NRZ telemetry output stream of the IHU. This is a CMOS level digital signal. The non-inverted version of the control signal comes directly from the IHU, while an inverted version of the same signal is produced by the inverter shown in the diagram. The inverted and not-inverted signals each control two of the switches at a time, leaving the other two in the opposite state.



This page contains ITAR Restricted Data.

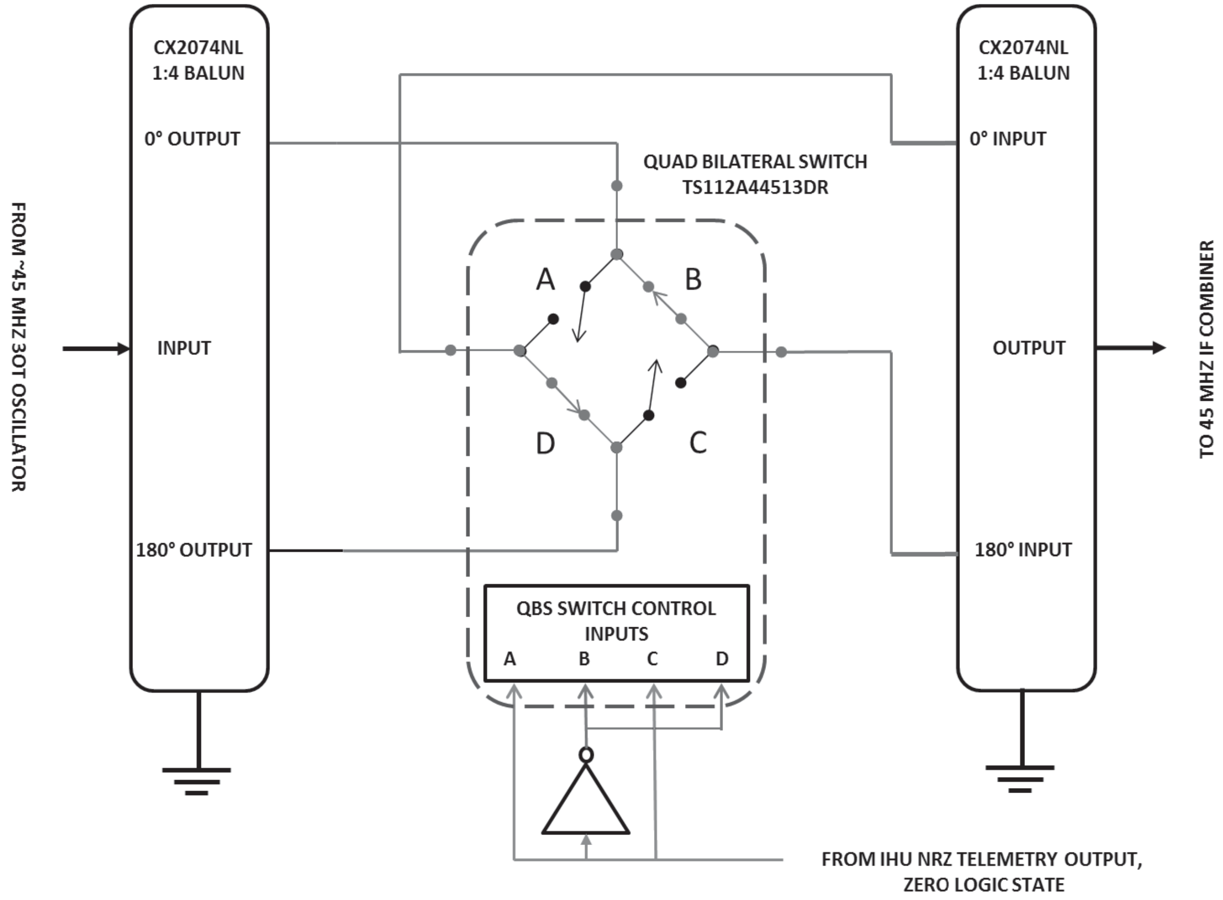
In the diagram shown, there are two states for the QBS IC; one is with the NRZ input signal in the logic zero state and one for the logic one state. In one state, switches A and C will be closed and B and D open, and in the other state A and C will be open and B and D will be closed.

As a visual aid, if the telemetry NRZ output of the IHU is in the “one” state, logic high, switches A and C close and B and D remain open:



This allows the zero phase output pin of the input balun to be connected to the zero degree phase input pin on the output balun via switch A. Simultaneously, it connects the 180 degree output pin of the input balun to be connected to the 180 degree input pin on the output balun. In this state, the output RF carrier is in phase with the input RF carrier.

If the NRZ telemetry output of the IHU changes to the zero logic state, then switches B and D close, and A and C open, resulting in the following signal path:



In this state, the zero phase output pin from the input balun is connected to the 180 degree input pin on the output balun via switch B. Simultaneously, the 180 degree output pin on the input balun is connected to the zero degree input pin on the output balun via switch D. In this state, the RF output signal is 180 degrees out of phase with the RF input signal.

The relative change in output phase relative to the input signal impresses the BPSK modulation on the input carrier. In the ‘ONE’ state, the output is in phase with the input, and in the ‘ZERO’ state, the output is 180 degrees out of phase with the input carrier. This resulting ~45 MHz BPSK modulated carrier can then be combined with the user transponder bandwidth, mixed up to 70 cm and further amplified by the power amplifier.

The output of this BPSK modulator would be united with the user signals with the aid of an RF combiner. The RF combiner could be in the form of a directional coupler or a 3 dB, zero degree hybrid, whichever is more appropriate to match other constraints on signal level and PCB real estate area.

The keying of the BPSK signal is not synchronous with the carrier in this approach. Synchronicity is not critical when the carrier frequency is several orders of magnitude higher than the keying rate, which it is in this case. The ratio of keyed to carrier frequency in this instance is approximately 37,500 to 1.

Summary: This approach is proposed because traditional high level double balanced diode mixers require significant power to operate due to high current level signals to make the diodes conduct to switch the RF signal. With the QBS, the signal drive levels can be quite low which is more desirable for low power satellite circuitry.

Downlink Budget

Produced by AB2S

Wednesday 15 June 2016

Service Name	lunar
Downlink earth station	Valparaiso, USA-IN
Satellite name	Heimdallr
Modcod	DVBS2,normal frame,4-PSK (1/5),pilots

Link Input Parameters	**Value**	**Units**
Site latitude	41.47N	degrees
Site longitude	87.07W	degrees
Site altitude	0.230	km
Frequency	10.5	GHz
Polarization	Vertical	
Rain model	ITU-R	
Rain zone or mm/h	42.3	
Availability (average year)	95.0000	%
Antenna aperture	2.4	metres
Antenna efficiency or gain (+ or - prefix)	65	% or dBi
Coupling loss	0	dB
Antenna mispoint loss	0	dB
Other path losses	0	dB
LNB noise figure or temp (+ prefix)	1	dB or K
Antenna noise	52.92	K
LNB gain	20	dB
LNB load impedance	75	Ohms
Csat/ACIo	140	dB/Hz
Csat/ASIo	140	dB/Hz
Csat/CCIo	140	dB/Hz
C/IM	20	dB

Satellite Input Parameters	**Value**	**Units**
EIRP (saturation)	25	dBW
Bandwidth	10	MHz
Range	405000	km
Elevation	10	degrees
Longitude Difference	10	degrees

Carrier/Link Input Parameters	**Value**	**Units**
Modulation	4-PSK	
Required Es/No	-0.30	dB
Information rate	.05	Mbps
Required Eb/No	-0.30	dB
Information rate	.05	Mbps
Overhead	0	%
FEC code rate	0.3853	
Spreading gain	0	dB
Implementation loss	0	dB
System margin	3	dB

General Calculations	**Value**	**Units**
XPD during rain	46.83	dB
Propagation time delay	1.350932	seconds
Antenna gain	46.56	dBi
EIRP density (satellite)	-23.12	dBW/Hz
EIRP density (flange)	-204.61	dBW/Hz
Availability (average year)	95.0000	%
Link downtime (average year)	438.300	hours
Availability (worst month)	88.4386	%
Link downtime (worst month)	84.456	hours
Maximum availability	95.1645	%
Minimum antenna size	2.3890	metres

Downlink Calculation	**Clear**	**Rain**	**Units**
Satellite EIRP per carrier	25.00	25.00	dBW
Antenna mispoint	0.00	0.00	dB
Free space loss	225.02	225.02	dB
Atmospheric absorption	0.32	0.47	dB
Tropospheric scintillation	0.00	0.42	dB
Cloud attenuation	0.00	0.47	dB
Rain attenuation	0.00	0.26	dB
Total attenuation (gas-rain-cloud-scintillation)	0.32	1.31	dB
Other path losses	0.00	0.00	dB
Noise increase due to precipitation	0.00	1.72	dB
Downlink degradation (DND)	0.00	2.72	dB
Total system noise	130.70	194.35	K
Figure of merit (G/T)	25.40	23.68	dB/K
Power flux density	-158.14	-160.86	dBW/m2
Carrier power at LNB output	-133.46	-136.17	dBW
Carrier level at LNB output (75 Ohm)	5.29	2.58	dBuV
Carrier level at LNB output (75 Ohm)	-54.71	-57.42	dBmV
C/No (thermal)	53.66	50.94	dB.Hz
C/N (thermal)	5.54	2.82	dB
C/ACI	91.88	91.88	dB
C/ASI	91.88	91.88	dB
C/CCI	91.88	91.88	dB
C/IM	20.00	20.00	dB
C/(N+I)	5.39	2.74	dB
Implementation loss	0.00	0.00	dB
System margin	3.00	3.00	dB
Net Es/(No+Io)	2.39	-0.26	dB
Required Es/(No+Io)	-0.30	-0.30	dB
Excess margin	**2.69**	**0.04**	**dB**

Space Segment Utilization	**Value**	**Units**
Information rate	0.0500	Mbps
Information rate (inc overhead)	0.0500	Mbps
Transmit rate	0.1298	Mbps
Symbol rate	0.0649	MBaud
Noise Bandwidth	48.12	dB.Hz
Occupied bandwidth	0.0779	MHz
Allocated bandwidth	0.0910	MHz

Downlink Budget

Produced by AB2S

Wednesday 8 June 2016

Service Name	lunar
Downlink earth station	Leesburg, USA-VA
Satellite name	Heimdallr
Modcod	DVBS2,short frame,BPSK-S (1/5) *,pilots

Link Input Parameters	Value	Units
Site latitude	39.12N	degrees
Site longitude	77.57W	degrees
Site altitude	0.104	km
Frequency	10.5	GHz
Polarization	Vertical	
Rain model	ITU-R	
Rain zone or mm/h	47.7	
Availability (average year)	95.0000	%
Antenna aperture	2.0	metres
Antenna efficiency or gain (+ or - prefix)	65	% or dBi
Coupling loss	0	dB
Antenna mispoint loss	0	dB
Other path losses	0	dB
LNB noise figure or temp (+ prefix)	1	dB or K
Antenna noise	44.31	K
LNB gain	20	dB
LNB load impedance	75	Ohms
Csat/ACIo	140	dB/Hz
Csat/ASIo	140	dB/Hz
Csat/CCIo	140	dB/Hz
C/IM	20	dB

Satellite Input Parameters	Value	Units
EIRP (saturation)	22	dBW
Bandwidth	7	MHz
Range	405000	km
Elevation	20	degrees
Longitude Difference	20	degrees

Carrier/Link Input Parameters	Value	Units
Modulation	2-PSK	
Required Es/No	-9.60	dB
Information rate	.005	Mbps
Required Eb/No	-9.60	dB
Information rate	.005	Mbps
Overhead	0	%
FEC code rate	0.0731	
Spreading gain	0	dB
Implementation loss	0	dB
System margin	9	dB

General Calculations	Value	Units
XPD during rain	50.21	dB
Propagation time delay	1.350932	seconds
Antenna gain	44.98	dBi
EIRP density (satellite)	-26.35	dBW/Hz
EIRP density (flange)	-208.46	dBW/Hz
Availability (average year)	95.0000	%
Link downtime (average year)	438.300	hours
Availability (worst month)	88.4386	%
Link downtime (worst month)	84.456	hours
Maximum availability	94.9999	%
Minimum antenna size	2.0000	metres

Downlink Calculation	Clear	Rain	Units
Satellite EIRP per carrier	22.00	22.00	dBW
Antenna mispoint	0.00	0.00	dB
Free space loss	225.02	225.02	dB
Atmospheric absorption	0.17	0.24	dB
Tropospheric scintillation	0.00	0.20	dB
Cloud attenuation	0.00	0.33	dB
Rain attenuation	0.00	0.18	dB
Total attenuation (gas-rain-cloud-scintillation)	0.17	0.79	dB
Other path losses	0.00	0.00	dB
Noise increase due to precipitation	0.00	1.29	dB
Downlink degradation (DND)	0.00	1.90	dB
Total system noise	122.10	164.15	K
Figure of merit (G/T)	24.11	22.83	dB/K
Power flux density	-161.14	-163.04	dBW/m2
Carrier power at LNB output	-138.04	-139.94	dBW
Carrier level at LNB output (75 Ohm)	0.71	-1.19	dBuV
Carrier level at LNB output (75 Ohm)	-59.29	-61.19	dBmV
C/No (thermal)	49.52	47.62	dB.Hz
C/N (thermal)	1.17	-0.73	dB
C/ACI	91.65	91.65	dB
C/ASI	91.65	91.65	dB
C/CCI	91.65	91.65	dB
C/IM	20.00	20.00	dB
C/(N+I)	1.12	-0.77	dB
Implementation loss	0.00	0.00	dB
System margin	9.00	9.00	dB
Net Es/(No+Io)	-7.88	-9.77	dB
Required Es/(No+Io)	-9.60	-9.60	dB
Excess margin	**1.72**	**-0.17**	**dB**

Space Segment Utilization	Value		Units
Information rate	0.0050		Mbps
Information rate (inc overhead)	0.0050		Mbps
Transmit rate	0.0684		Mbps
Symbol rate	0.0684		MBaud
Noise Bandwidth	48.35		dB.Hz
Occupied bandwidth	0.0821		MHz
Allocated bandwidth	0.1000		MHz

Downlink Budget

Produced by AB2S

Wednesday 8 June 2016

Service Name	lunar
Downlink earth station	Leesburg, USA-VA
Satellite name	Heimdallr
Modcod	DVBS2,medium frame,BPSK (1/5) *,no pilots

Link Input Parameters	Value	Units
Site latitude	39.12N	degrees
Site longitude	77.57W	degrees
Site altitude	0.104	km
Frequency	10.5	GHz
Polarization	Vertical	
Rain model	ITU-R	
Rain zone or mm/h	47.7	
Availability (average year)	95.0000	%
Antenna aperture	2.0	metres
Antenna efficiency or gain (+ or - prefix)	65	% or dBi
Coupling loss	0	dB
Antenna mispoint loss	0	dB
Other path losses	0	dB
LNB noise figure or temp (+ prefix)	1	dB or K
Antenna noise	44.31	K
LNB gain	20	dB
LNB load impedance	75	Ohms
Csat/ACIo	140	dB/Hz
Csat/ASIo	140	dB/Hz
Csat/CCIo	140	dB/Hz
C/IM	20	dB

Satellite Input Parameters	Value	Units
EIRP (saturation)	22	dBW
Bandwidth	7	MHz
Range	405000	km
Elevation	20	degrees
Longitude Difference	20	degrees

Carrier/Link Input Parameters	Value	Units
Modulation	2-PSK	
Required Es/No	-6.85	dB
Information rate	.005	Mbps
Required Eb/No	-6.85	dB
Information rate	.005	Mbps
Overhead	0	%
FEC code rate	0.1677	
Spreading gain	0	dB
Implementation loss	0	dB
System margin	9	dB

General Calculations	Value	Units
XPD during rain	50.21	dB
Propagation time delay	1.350932	seconds
Antenna gain	44.98	dBi
EIRP density (satellite)	-22.74	dBW/Hz
EIRP density (flange)	-204.86	dBW/Hz
Availability (average year)	95.0000	%
Link downtime (average year)	438.300	hours
Availability (worst month)	88.4386	%
Link downtime (worst month)	84.456	hours
Maximum availability	97.6040	%
Minimum antenna size	1.8550	metres

Downlink Calculation	Clear	Rain	Units
Satellite EIRP per carrier	22.00	22.00	dBW
Antenna mispoint	0.00	0.00	dB
Free space loss	225.02	225.02	dB
Atmospheric absorption	0.17	0.24	dB
Tropospheric scintillation	0.00	0.20	dB
Cloud attenuation	0.00	0.33	dB
Rain attenuation	0.00	0.18	dB
Total attenuation (gas-rain-cloud-scintillation)	0.17	0.79	dB
Other path losses	0.00	0.00	dB
Noise increase due to precipitation	0.00	1.29	dB
Downlink degradation (DND)	0.00	1.90	dB
Total system noise	122.10	164.15	K
Figure of merit (G/T)	24.11	22.83	dB/K
Power flux density	-161.14	-163.04	dBW/m2
Carrier power at LNB output	-138.04	-139.94	dBW
Carrier level at LNB output (75 Ohm)	0.71	-1.19	dBuV
Carrier level at LNB output (75 Ohm)	-59.29	-61.19	dBmV
C/No (thermal)	49.52	47.62	dB.Hz
C/N (thermal)	4.78	2.88	dB
C/ACI	95.26	95.26	dB
C/ASI	95.26	95.26	dB
C/CCI	95.26	95.26	dB
C/IM	20.00	20.00	dB
C/(N+I)	4.65	2.79	dB
Implementation loss	0.00	0.00	dB
System margin	9.00	9.00	dB
Net Es/(No+Io)	-4.35	-6.21	dB
Required Es/(No+Io)	-6.85	-6.85	dB
Excess margin	**2.50**	**0.64**	**dB**

Space Segment Utilization	Value		Units
Information rate	0.0050		Mbps
Information rate (inc overhead)	0.0050		Mbps
Transmit rate	0.0298		Mbps
Symbol rate	0.0298		MBaud
Noise Bandwidth	44.74		dB.Hz
Occupied bandwidth	0.0358		MHz
Allocated bandwidth	0.0500		MHz

Downlink Budget

Produced by AB2S

Wednesday 8 June 2016

Service Name	lunar
Downlink earth station	Leesburg, USA-VA
Satellite name	Heimdallr
Modcod	DVBS2,normal frame,4-PSK (1/4),no pilots

Link Input Parameters	Value	Units
Site latitude	39.12N	degrees
Site longitude	77.57W	degrees
Site altitude	0.104	km
Frequency	10.5	GHz
Polarization	Vertical	
Rain model	ITU-R	
Rain zone or mm/h	47.7	
Availability (average year)	95.0000	%
Antenna aperture	2.0	metres
Antenna efficiency or gain (+ or - prefix)	65	% or dBi
Coupling loss	0	dB
Antenna mispoint loss	0	dB
Other path losses	0	dB
LNB noise figure or temp (+ prefix)	1	dB or K
Antenna noise	44.31	K
LNB gain	20	dB
LNB load impedance	75	Ohms
Csat/ACIo	140	dB/Hz
Csat/ASIo	140	dB/Hz
Csat/CCIo	140	dB/Hz
C/IM	20	dB

Satellite Input Parameters	Value	Units
EIRP (saturation)	22	dBW
Bandwidth	7	MHz
Range	405000	km
Elevation	20	degrees
Longitude Difference	20	degrees

Carrier/Link Input Parameters	Value	Units
Modulation	4-PSK	
Required Es/No	-2.35	dB
Information rate	.005	Mbps
Required Eb/No	-2.35	dB
Information rate	.005	Mbps
Overhead	0	%
FEC code rate	0.2451	
Spreading gain	0	dB
Implementation loss	0	dB
System margin	9	dB

General Calculations	Value	Units
XPD during rain	50.21	dB
Propagation time delay	1.350932	seconds
Antenna gain	44.98	dBi
EIRP density (satellite)	-18.09	dBW/Hz
EIRP density (flange)	-200.20	dBW/Hz
Availability (average year)	95.0000	%
Link downtime (average year)	438.300	hours
Availability (worst month)	88.4386	%
Link downtime (worst month)	84.456	hours
Maximum availability	97.6654	%
Minimum antenna size	1.8500	metres

Downlink Calculation	Clear	Rain	Units
Satellite EIRP per carrier	22.00	22.00	dBW
Antenna mispoint	0.00	0.00	dB
Free space loss	225.02	225.02	dB
Atmospheric absorption	0.17	0.24	dB
Tropospheric scintillation	0.00	0.20	dB
Cloud attenuation	0.00	0.33	dB
Rain attenuation	0.00	0.18	dB
Total attenuation (gas-rain-cloud-scintillation)	0.17	0.79	dB
Other path losses	0.00	0.00	dB
Noise increase due to precipitation	0.00	1.29	dB
Downlink degradation (DND)	0.00	1.90	dB
Total system noise	122.10	164.15	K
Figure of merit (G/T)	24.11	22.83	dB/K
Power flux density	-161.14	-163.04	dBW/m2
Carrier power at LNB output	-138.04	-139.94	dBW
Carrier level at LNB output (75 Ohm)	0.71	-1.19	dBuV
Carrier level at LNB output (75 Ohm)	-59.29	-61.19	dBmV
C/No (thermal)	49.52	47.62	dB.Hz
C/N (thermal)	9.44	7.53	dB
C/ACI	99.91	99.91	dB
C/ASI	99.91	99.91	dB
C/CCI	99.91	99.91	dB
C/IM	20.00	20.00	dB
C/(N+I)	9.07	7.29	dB
Implementation loss	0.00	0.00	dB
System margin	9.00	9.00	dB
Net Es/(No+Io)	0.07	-1.71	dB
Required Es/(No+Io)	-2.35	-2.35	dB
Excess margin	**2.42**	**0.64**	**dB**

Space Segment Utilization	Value	Units
Information rate	0.0050	Mbps
Information rate (inc overhead)	0.0050	Mbps
Transmit rate	0.0204	Mbps
Symbol rate	0.0102	MBaud
Noise Bandwidth	40.09	dB.Hz
Occupied bandwidth	0.0122	MHz
Allocated bandwidth	0.0200	MHz

Downlink Budget

Produced by AB2S

Wednesday 15 June 2016

Service Name	lunar
Downlink earth station	Perth, Australia
Satellite name	Heimdallr
Modcod	DVBS2,normal frame,4-PSK (1/5),no pilots

Link Input Parameters	**Value**	**Units**
Site latitude	31.97S	degrees
Site longitude	115.82E	degrees
Site altitude	0.100	km
Frequency	10.5	GHz
Polarization	Vertical	
Rain model	ITU-R	
Rain zone or mm/h	39.8	
Availability (average year)	95.0000	%
Antenna aperture	7.6	metres
Antenna efficiency or gain (+ or - prefix)	65	% or dBi
Coupling loss	0	dB
Antenna mispoint loss	0	dB
Other path losses	0	dB
LNB noise figure or temp (+ prefix)	1	dB or K
Antenna noise	54.18	K
LNB gain	20	dB
LNB load impedance	75	Ohms
Csat/ACIo	140	dB/Hz
Csat/ASIo	140	dB/Hz
Csat/CCIo	140	dB/Hz
C/IM	20	dB

Satellite Input Parameters	**Value**	**Units**
EIRP (saturation)	25	dBW
Bandwidth	7	MHz
Range	405000	km
Elevation	10	degrees
Longitude Difference	10	degrees

Carrier/Link Input Parameters	**Value**	**Units**
Modulation	4-PSK	
Required Es/No	-0.30	dB
Information rate	.6	Mbps
Required Eb/No	-0.30	dB
Information rate	.6	Mbps
Overhead	0	%
FEC code rate	0.3947	
Spreading gain	0	dB
Implementation loss	0	dB
System margin	3	dB

General Calculations	**Value**	**Units**
XPD during rain	47.99	dB
Propagation time delay	1.350932	seconds
Antenna gain	56.58	dBi
EIRP density (satellite)	-33.81	dBW/Hz
EIRP density (flange)	-204.46	dBW/Hz
Availability (average year)	95.0000	%
Link downtime (average year)	438.300	hours
Availability (worst month)	88.4386	%
Link downtime (worst month)	84.456	hours
Maximum availability	95.7389	%
Minimum antenna size	7.4690	metres

Downlink Calculation	Clear	Rain	Units
Satellite EIRP per carrier	25.00	25.00	dBW
Antenna mispoint	0.00	0.00	dB
Free space loss	225.02	225.02	dB
Atmospheric absorption	0.33	0.39	dB
Tropospheric scintillation	0.00	0.44	dB
Cloud attenuation	0.00	0.15	dB
Rain attenuation	0.00	0.22	dB
Total attenuation (gas-rain-cloud-scintillation)	0.33	0.97	dB
Other path losses	0.00	0.00	dB
Noise increase due to precipitation	0.00	1.24	dB
Downlink degradation (DND)	0.00	1.87	dB
Total system noise	131.97	175.55	K
Figure of merit (G/T)	35.37	34.13	dB/K
Power flux density	-158.14	-160.01	dBW/m2
Carrier power at LNB output	-123.44	-125.32	dBW
Carrier level at LNB output (75 Ohm)	15.31	13.43	dBuV
Carrier level at LNB output (75 Ohm)	-44.69	-46.57	dBmV
C/No (thermal)	63.62	61.74	dB.Hz
C/N (thermal)	4.81	2.93	dB
C/ACI	81.19	81.19	dB
C/ASI	81.19	81.19	dB
C/CCI	81.19	81.19	dB
C/IM	20.00	20.00	dB
C/(N+I)	4.68	2.85	dB
Implementation loss	0.00	0.00	dB
System margin	3.00	3.00	dB
Net Es/(No+Io)	1.68	-0.15	dB
Required Es/(No+Io)	-0.30	-0.30	dB
Excess margin	**1.98**	**0.15**	**dB**

Space Segment Utilization	Value		Units
Information rate	0.6000		Mbps
Information rate (inc overhead)	0.6000		Mbps
Transmit rate	1.5201		Mbps
Symbol rate	0.7601		MBaud
Noise Bandwidth	58.81		dB.Hz
Occupied bandwidth	0.9121		MHz
Allocated bandwidth	1.0700		MHz

Downlink Budget

Produced by AB2S

Wednesday 15 June 2016

Service Name	lunar
Downlink earth station	Bochum, Germany
Satellite name	Heimdallr
Modcod	DVBS2,normal frame,4-PSK (1/5),no pilots

Link Input Parameters	Value	Units
Site latitude	51.47N	degrees
Site longitude	7.18E	degrees
Site altitude	0.122	km
Frequency	10.5	GHz
Polarization	Vertical	
Rain model	ITU-R	
Rain zone or mm/h	37.4	
Availability (average year)	95.0000	%
Antenna aperture	21	metres
Antenna efficiency or gain (+ or - prefix)	65	% or dBi
Coupling loss	0	dB
Antenna mispoint loss	0	dB
Other path losses	0	dB
LNB noise figure or temp (+ prefix)	1	dB or K
Antenna noise	53.53	K
LNB gain	20	dB
LNB load impedance	75	Ohms
Csat/ACIo	140	dB/Hz
Csat/ASIo	140	dB/Hz
Csat/CCIo	140	dB/Hz
C/IM	20	dB

Satellite Input Parameters	Value	Units
EIRP (saturation)	25	dBW
Bandwidth	10	MHz
Range	405000	km
Elevation	10	degrees
Longitude Difference	10	degrees

Carrier/Link Input Parameters	Value	Units
Modulation	4-PSK	
Required Es/No	-0.30	dB
Information rate	4.5	Mbps
Required Eb/No	-0.30	dB
Information rate	4.5	Mbps
Overhead	0	%
FEC code rate	0.3947	
Spreading gain	0	dB
Implementation loss	0	dB
System margin	3	dB

General Calculations	Value	Units
XPD during rain	49.45	dB
Propagation time delay	1.350932	seconds
Antenna gain	65.40	dBi
EIRP density (satellite)	-42.56	dBW/Hz
EIRP density (flange)	-204.68	dBW/Hz
Availability (average year)	95.0000	%
Link downtime (average year)	438.300	hours
Availability (worst month)	88.4386	%
Link downtime (worst month)	84.456	hours
Maximum availability	94.9999	%
Minimum antenna size	21.0000	metres

Downlink Calculation	Clear	Rain	Units
Satellite EIRP per carrier	25.00	25.00	dBW
Antenna mispoint	0.00	0.00	dB
Free space loss	225.02	225.02	dB
Atmospheric absorption	0.33	0.40	dB
Tropospheric scintillation	0.00	0.22	dB
Cloud attenuation	0.00	0.40	dB
Rain attenuation	0.00	0.18	dB
Total attenuation (gas-rain-cloud-scintillation)	0.33	1.03	dB
Other path losses	0.00	0.00	dB
Noise increase due to precipitation	0.00	1.48	dB
Downlink degradation (DND)	0.00	2.18	dB
Total system noise	131.32	184.76	K
Figure of merit (G/T)	44.22	42.74	dB/K
Power flux density	-158.14	-160.32	dBW/m2
Carrier power at LNB output	-114.62	-116.79	dBW
Carrier level at LNB output (75 Ohm)	24.13	21.96	dBuV
Carrier level at LNB output (75 Ohm)	-35.87	-38.04	dBmV
C/No (thermal)	72.47	70.29	dB.Hz
C/N (thermal)	4.91	2.73	dB
C/ACI	72.44	72.44	dB
C/ASI	72.44	72.44	dB
C/CCI	72.44	72.44	dB
C/IM	20.00	20.00	dB
C/(N+I)	4.78	2.65	dB
Implementation loss	0.00	0.00	dB
System margin	3.00	3.00	dB
Net Es/(No+Io)	1.78	-0.35	dB
Required Es/(No+Io)	-0.30	-0.30	dB
Excess margin	**2.08**	**-0.05**	**dB**

Space Segment Utilization	Value	Units
Information rate	4.5000	Mbps
Information rate (inc overhead)	4.5000	Mbps
Transmit rate	11.4011	Mbps
Symbol rate	5.7005	MBaud
Noise Bandwidth	67.56	dB.Hz
Occupied bandwidth	6.8406	MHz
Allocated bandwidth	7.9900	MHz

Downlink Budget

Produced by AB2S

Wednesday 15 June 2016

Service Name	lunar
Downlink earth station	Valparaiso, USA-IN
Satellite name	Heimdallr
Modcod	DVBS2,normal frame,4-PSK (1/3),pilots

Link Input Parameters	**Value**	**Units**
Site latitude	41.47N	degrees
Site longitude	87.07W	degrees
Site altitude	0.230	km
Frequency	10.5	GHz
Polarization	Vertical	
Rain model	ITU-R	
Rain zone or mm/h	42.3	
Availability (average year)	95.0000	%
Antenna aperture	4.2	metres
Antenna efficiency or gain (+ or - prefix)	65	% or dBi
Coupling loss	0	dB
Antenna mispoint loss	0	dB
Other path losses	0	dB
LNB noise figure or temp (+ prefix)	1	dB or K
Antenna noise	52.92	K
LNB gain	20	dB
LNB load impedance	75	Ohms
Csat/ACIo	140	dB/Hz
Csat/ASIo	140	dB/Hz
Csat/CCIo	140	dB/Hz
C/IM	20	dB

Satellite Input Parameters	**Value**	**Units**
EIRP (saturation)	25	dBW
Bandwidth	10	MHz
Range	405000	km
Elevation	10	degrees
Longitude Difference	10	degrees

Carrier/Link Input Parameters	**Value**	**Units**
Modulation	4-PSK	
Required Es/No	-1.24	dB
Information rate	.16	Mbps
Required Eb/No	-1.24	dB
Information rate	.16	Mbps
Overhead	0	%
FEC code rate	0.3204	
Spreading gain	0	dB
Implementation loss	0	dB
System margin	3	dB

General Calculations	**Value**	**Units**
XPD during rain	46.83	dB
Propagation time delay	1.350932	seconds
Antenna gain	51.42	dBi
EIRP density (satellite)	-28.97	dBW/Hz
EIRP density (flange)	-205.60	dBW/Hz
Availability (average year)	95.0000	%
Link downtime (average year)	438.300	hours
Availability (worst month)	88.4386	%
Link downtime (worst month)	84.456	hours
Maximum availability	95.0614	%
Minimum antenna size	4.1930	metres

Downlink Calculation	Clear	Rain	Units
Satellite EIRP per carrier	25.00	25.00	dBW
Antenna mispoint	0.00	0.00	dB
Free space loss	225.02	225.02	dB
Atmospheric absorption	0.32	0.47	dB
Tropospheric scintillation	0.00	0.40	dB
Cloud attenuation	0.00	0.47	dB
Rain attenuation	0.00	0.26	dB
Total attenuation (gas-rain-cloud-scintillation)	0.32	1.30	dB
Other path losses	0.00	0.00	dB
Noise increase due to precipitation	0.00	1.72	dB
Downlink degradation (DND)	0.00	2.71	dB
Total system noise	130.70	194.35	K
Figure of merit (G/T)	30.26	28.54	dB/K
Power flux density	-158.14	-160.85	dBW/m2
Carrier power at LNB output	-128.60	-131.30	dBW
Carrier level at LNB output (75 Ohm)	10.15	7.45	dBuV
Carrier level at LNB output (75 Ohm)	-49.85	-52.55	dBmV
C/No (thermal)	58.52	55.81	dB.Hz
C/N (thermal)	4.55	1.84	dB
C/ACI	86.03	86.03	dB
C/ASI	86.03	86.03	dB
C/CCI	86.03	86.03	dB
C/IM	20.00	20.00	dB
C/(N+I)	4.42	1.77	dB
Implementation loss	0.00	0.00	dB
System margin	3.00	3.00	dB
Net Es/(No+Io)	1.42	-1.23	dB
Required Es/(No+Io)	-1.24	-1.24	dB
Excess margin	**2.66**	**0.01**	**dB**

Space Segment Utilization	Value	Units
Information rate	0.1600	Mbps
Information rate (inc overhead)	0.1600	Mbps
Transmit rate	0.4994	Mbps
Symbol rate	0.2497	MBaud
Noise Bandwidth	53.97	dB.Hz
Occupied bandwidth	0.2996	MHz
Allocated bandwidth	0.3500	MHz

Downlink Budget

Produced by AB2S

Wednesday 15 June 2016

Service Name	lunar
Downlink earth station	Perth, Australia
Satellite name	Heimdallr
Modcod	DVBS2,normal frame,4-PSK (1/3),no pilots

Link Input Parameters	Value	Units
Site latitude	31.97S	degrees
Site longitude	115.82E	degrees
Site altitude	0.100	km
Frequency	10.5	GHz
Polarization	Vertical	
Rain model	ITU-R	
Rain zone or mm/h	39.8	
Availability (average year)	95.0000	%
Antenna aperture	7.6	metres
Antenna efficiency or gain (+ or - prefix)	65	% or dBi
Coupling loss	0	dB
Antenna mispoint loss	0	dB
Other path losses	0	dB
LNB noise figure or temp (+ prefix)	1	dB or K
Antenna noise	54.18	K
LNB gain	20	dB
LNB load impedance	75	Ohms
Csat/ACIo	140	dB/Hz
Csat/ASIo	140	dB/Hz
Csat/CCIo	140	dB/Hz
C/IM	20	dB

Satellite Input Parameters	Value	Units
EIRP (saturation)	25	dBW
Bandwidth	7	MHz
Range	405000	km
Elevation	10	degrees
Longitude Difference	10	degrees

Carrier/Link Input Parameters	Value	Units
Modulation	4-PSK	
Required Es/No	-1.24	dB
Information rate	.15	Mbps
Required Eb/No	-1.24	dB
Information rate	.15	Mbps
Overhead	0	%
FEC code rate	0.3282	
Spreading gain	0	dB
Implementation loss	0	dB
System margin	9	dB

General Calculations	Value	Units
XPD during rain	47.99	dB
Propagation time delay	1.350932	seconds
Antenna gain	56.58	dBi
EIRP density (satellite)	-28.59	dBW/Hz
EIRP density (flange)	-199.24	dBW/Hz
Availability (average year)	95.0000	%
Link downtime (average year)	438.300	hours
Availability (worst month)	88.4386	%
Link downtime (worst month)	84.456	hours
Maximum availability	95.6213	%
Minimum antenna size	7.4910	metres

Downlink Calculation	Clear	Rain	Units
Satellite EIRP per carrier	25.00	25.00	dBW
Antenna mispoint	0.00	0.00	dB
Free space loss	225.02	225.02	dB
Atmospheric absorption	0.33	0.39	dB
Tropospheric scintillation	0.00	0.44	dB
Cloud attenuation	0.00	0.15	dB
Rain attenuation	0.00	0.22	dB
Total attenuation (gas-rain-cloud-scintillation)	0.33	0.97	dB
Other path losses	0.00	0.00	dB
Noise increase due to precipitation	0.00	1.24	dB
Downlink degradation (DND)	0.00	1.87	dB
Total system noise	131.97	175.55	K
Figure of merit (G/T)	35.37	34.13	dB/K
Power flux density	-158.14	-160.01	dBW/m2
Carrier power at LNB output	-123.44	-125.32	dBW
Carrier level at LNB output (75 Ohm)	15.31	13.43	dBuV
Carrier level at LNB output (75 Ohm)	-44.69	-46.57	dBmV
C/No (thermal)	63.62	61.74	dB.Hz
C/N (thermal)	10.03	8.15	dB
C/ACI	86.41	86.41	dB
C/ASI	86.41	86.41	dB
C/CCI	86.41	86.41	dB
C/IM	20.00	20.00	dB
C/(N+I)	9.61	7.88	dB
Implementation loss	0.00	0.00	dB
System margin	9.00	9.00	dB
Net Es/(No+Io)	0.61	-1.12	dB
Required Es/(No+Io)	-1.24	-1.24	dB
Excess margin	**1.85**	**0.12**	**dB**

Space Segment Utilization	Value	Units
Information rate	0.1500	Mbps
Information rate (inc overhead)	0.1500	Mbps
Transmit rate	0.4570	Mbps
Symbol rate	0.2285	MBaud
Noise Bandwidth	53.59	dB.Hz
Occupied bandwidth	0.2742	MHz
Allocated bandwidth	0.3200	MHz

Downlink Budget

Produced by AB2S

Wednesday 15 June 2016

Service Name	lunar
Downlink earth station	Bochum, Germany
Satellite name	Heimdallr
Modcod	DVBS2,normal frame,4-PSK (1/3),no pilots

Link Input Parameters	Value	Units
Site latitude	51.47N	degrees
Site longitude	7.18E	degrees
Site altitude	0.122	km
Frequency	10.5	GHz
Polarization	Vertical	
Rain model	ITU-R	
Rain zone or mm/h	37.4	
Availability (average year)	95.0000	%
Antenna aperture	21	metres
Antenna efficiency or gain (+ or - prefix)	65	% or dBi
Coupling loss	0	dB
Antenna mispoint loss	0	dB
Other path losses	0	dB
LNB noise figure or temp (+ prefix)	1	dB or K
Antenna noise	53.53	K
LNB gain	20	dB
LNB load impedance	75	Ohms
Csat/ACIo	140	dB/Hz
Csat/ASIo	140	dB/Hz
Csat/CCIo	140	dB/Hz
C/IM	20	dB

Satellite Input Parameters	Value	Units
EIRP (saturation)	25	dBW
Bandwidth	7	MHz
Range	405000	km
Elevation	10	degrees
Longitude Difference	10	degrees

Carrier/Link Input Parameters	Value	Units
Modulation	4-PSK	
Required Es/No	-1.24	dB
Information rate	1.1	Mbps
Required Eb/No	-1.24	dB
Information rate	1.1	Mbps
Overhead	0	%
FEC code rate	0.3282	
Spreading gain	0	dB
Implementation loss	0	dB
System margin	9	dB

General Calculations	Value	Units
XPD during rain	49.45	dB
Propagation time delay	1.350932	seconds
Antenna gain	65.40	dBi
EIRP density (satellite)	-37.24	dBW/Hz
EIRP density (flange)	-199.37	dBW/Hz
Availability (average year)	95.0000	%
Link downtime (average year)	438.300	hours
Availability (worst month)	88.4386	%
Link downtime (worst month)	84.456	hours
Maximum availability	95.1267	%
Minimum antenna size	20.9490	metres

Downlink Calculation	Clear	Rain	Units
Satellite EIRP per carrier	25.00	25.00	dBW
Antenna mispoint	0.00	0.00	dB
Free space loss	225.02	225.02	dB
Atmospheric absorption	0.33	0.40	dB
Tropospheric scintillation	0.00	0.22	dB
Cloud attenuation	0.00	0.40	dB
Rain attenuation	0.00	0.18	dB
Total attenuation (gas-rain-cloud-scintillation)	0.33	1.03	dB
Other path losses	0.00	0.00	dB
Noise increase due to precipitation	0.00	1.48	dB
Downlink degradation (DND)	0.00	2.18	dB
Total system noise	131.32	184.76	K
Figure of merit (G/T)	44.22	42.74	dB/K
Power flux density	-158.14	-160.32	dBW/m2
Carrier power at LNB output	-114.62	-116.79	dBW
Carrier level at LNB output (75 Ohm)	24.13	21.96	dBuV
Carrier level at LNB output (75 Ohm)	-35.87	-38.04	dBmV
C/No (thermal)	72.47	70.29	dB.Hz
C/N (thermal)	10.22	8.05	dB
C/ACI	77.76	77.76	dB
C/ASI	77.76	77.76	dB
C/CCI	77.76	77.76	dB
C/IM	20.00	20.00	dB
C/(N+I)	9.79	7.78	dB
Implementation loss	0.00	0.00	dB
System margin	9.00	9.00	dB
Net Es/(No+Io)	0.79	-1.22	dB
Required Es/(No+Io)	-1.24	-1.24	dB
Excess margin	**2.03**	**0.02**	**dB**

Space Segment Utilization	Value	Units
Information rate	1.1000	Mbps
Information rate (inc overhead)	1.1000	Mbps
Transmit rate	3.3516	Mbps
Symbol rate	1.6758	MBaud
Noise Bandwidth	62.24	dB.Hz
Occupied bandwidth	2.0110	MHz
Allocated bandwidth	2.3500	MHz

Downlink Budget

Produced by AB2S

Wednesday 15 June 2016

Service Name	lunar
Downlink earth station	Valparaiso, USA-IN
Satellite name	Heimdallr
Modcod	DVBS2,normal frame,4-PSK (1/3),no pilots

Link Input Parameters	**Value**	**Units**
Site latitude	41.47N	degrees
Site longitude	87.07W	degrees
Site altitude	0.230	km
Frequency	10.5	GHz
Polarization	Vertical	
Rain model	ITU-R	
Rain zone or mm/h	42.3	
Availability (average year)	95.0000	%
Antenna aperture	4.2	metres
Antenna efficiency or gain (+ or - prefix)	65	% or dBi
Coupling loss	0	dB
Antenna mispoint loss	0	dB
Other path losses	0	dB
LNB noise figure or temp (+ prefix)	1	dB or K
Antenna noise	52.92	K
LNB gain	20	dB
LNB load impedance	75	Ohms
Csat/ACIo	140	dB/Hz
Csat/ASIo	140	dB/Hz
Csat/CCIo	140	dB/Hz
C/IM	20	dB

Satellite Input Parameters	**Value**	**Units**
EIRP (saturation)	25	dBW
Bandwidth	7	MHz
Range	405000	km
Elevation	10	degrees
Longitude Difference	10	degrees

Carrier/Link Input Parameters	**Value**	**Units**
Modulation	4-PSK	
Required Es/No	-1.24	dB
Information rate	.035	Mbps
Required Eb/No	-1.24	dB
Information rate	.035	Mbps
Overhead	0	%
FEC code rate	0.3282	
Spreading gain	0	dB
Implementation loss	0	dB
System margin	9	dB

General Calculations	**Value**	**Units**
XPD during rain	46.83	dB
Propagation time delay	1.350932	seconds
Antenna gain	51.42	dBi
EIRP density (satellite)	-22.27	dBW/Hz
EIRP density (flange)	-198.89	dBW/Hz
Availability (average year)	95.0000	%
Link downtime (average year)	438.300	hours
Availability (worst month)	88.4386	%
Link downtime (worst month)	84.456	hours
Maximum availability	96.6888	%
Minimum antenna size	3.9570	metres

Downlink Calculation	Clear	Rain	Units
Satellite EIRP per carrier	25.00	25.00	dBW
Antenna mispoint	0.00	0.00	dB
Free space loss	225.02	225.02	dB
Atmospheric absorption	0.32	0.47	dB
Tropospheric scintillation	0.00	0.40	dB
Cloud attenuation	0.00	0.47	dB
Rain attenuation	0.00	0.26	dB
Total attenuation (gas-rain-cloud-scintillation)	0.32	1.30	dB
Other path losses	0.00	0.00	dB
Noise increase due to precipitation	0.00	1.72	dB
Downlink degradation (DND)	0.00	2.71	dB
Total system noise	130.70	194.35	K
Figure of merit (G/T)	30.26	28.54	dB/K
Power flux density	-158.14	-160.85	dBW/m2
Carrier power at LNB output	-128.60	-131.30	dBW
Carrier level at LNB output (75 Ohm)	10.15	7.45	dBuV
Carrier level at LNB output (75 Ohm)	-49.85	-52.55	dBmV
C/No (thermal)	58.52	55.81	dB.Hz
C/N (thermal)	11.25	8.55	dB
C/ACI	92.73	92.73	dB
C/ASI	92.73	92.73	dB
C/CCI	92.73	92.73	dB
C/IM	20.00	20.00	dB
C/(N+I)	10.71	8.25	dB
Implementation loss	0.00	0.00	dB
System margin	9.00	9.00	dB
Net Es/(No+Io)	1.71	-0.75	dB
Required Es/(No+Io)	-1.24	-1.24	dB
Excess margin	**2.95**	**0.49**	**dB**

Space Segment Utilization	Value	Units
Information rate	0.0350	Mbps
Information rate (inc overhead)	0.0350	Mbps
Transmit rate	0.1066	Mbps
Symbol rate	0.0533	MBaud
Noise Bandwidth	47.27	dB.Hz
Occupied bandwidth	0.0640	MHz
Allocated bandwidth	0.0800	MHz

Downlink Budget

Produced by AB2S

Wednesday 8 June 2016

Service Name	lunar
Downlink earth station	Leesburg, USA-VA
Satellite name	Heimdallr
Modcod	Manual

Link Input Parameters	Value	Units
Site latitude	39.12N	degrees
Site longitude	77.57W	degrees
Site altitude	0.104	km
Frequency	10.5	GHz
Polarization	Vertical	
Rain model	ITU-R	
Rain zone or mm/h	47.7	
Availability (average year)	95.0000	%
Antenna aperture	1.0	metres
Antenna efficiency or gain (+ or - prefix)	65	% or dBi
Coupling loss	0	dB
Antenna mispoint loss	0	dB
Other path losses	0	dB
LNB noise figure or temp (+ prefix)	1	dB or K
Antenna noise	44.31	K
LNB gain	20	dB
LNB load impedance	75	Ohms
Csat/AClo	140	dB/Hz
Csat/ASIo	140	dB/Hz
Csat/CCIo	140	dB/Hz
C/IM	20	dB

Satellite Input Parameters	Value	Units
EIRP (saturation)	22	dBW
Bandwidth	7	MHz
Range	405000	km
Elevation	20	degrees
Longitude Difference	20	degrees

Carrier/Link Input Parameters	Value	Units
Modulation	1 bit/symbol	
Required Eb/No	10	dB
Information rate	.00001	Mbps
Required Eb/No	10	dB
Information rate	.00001	Mbps
Overhead	0	%
FEC code rate	0.2451	
Spreading gain	0	dB
Implementation loss	0	dB
System margin	9	dB

General Calculations	Value	Units
XPD during rain	50.21	dB
Propagation time delay	1.350932	seconds
Antenna gain	38.96	dBi
EIRP density (satellite)	5.89	dBW/Hz
EIRP density (flange)	-182.24	dBW/Hz
Availability (average year)	95.0000	%
Link downtime (average year)	438.300	hours
Availability (worst month)	88.4386	%
Link downtime (worst month)	84.456	hours
Maximum availability	99.9901	%
Minimum antenna size	0.2610	metres

Downlink Calculation	**Clear**	**Rain**	**Units**
Satellite EIRP per carrier	22.00	22.00	dBW
Antenna mispoint	0.00	0.00	dB
Free space loss	225.02	225.02	dB
Atmospheric absorption	0.17	0.24	dB
Tropospheric scintillation	0.00	0.20	dB
Cloud attenuation	0.00	0.33	dB
Rain attenuation	0.00	0.18	dB
Total attenuation (gas-rain-cloud-scintillation)	0.17	0.79	dB
Other path losses	0.00	0.00	dB
Noise increase due to precipitation	0.00	1.29	dB
Downlink degradation (DND)	0.00	1.90	dB
Total system noise	122.10	164.15	K
Figure of merit (G/T)	18.09	16.81	dB/K
Power flux density	-161.14	-163.05	dBW/m2
Carrier power at LNB output	-144.06	-145.97	dBW
Carrier level at LNB output (75 Ohm)	-5.31	-7.21	dBuV
Carrier level at LNB output (75 Ohm)	-65.31	-67.21	dBmV
C/No (thermal)	43.50	41.60	dB.Hz
C/N (thermal)	27.40	25.49	dB
C/ACI	123.89	123.89	dB
C/ASI	123.89	123.89	dB
C/CCI	123.89	123.89	dB
C/IM	20.00	20.00	dB
C/(N+I)	19.27	18.92	dB
Eb/(No+Io)	25.38	25.03	dB
Implementation loss	0.00	0.00	dB
System margin	9.00	9.00	dB
Net Eb/(No+Io)	16.38	16.03	dB
Required Eb/(No+Io)	10.00	10.00	dB
Excess margin	**6.38**	**6.03**	**dB**

Space Segment Utilization	**Value**	**Units**
Information rate	0.0000	Mbps
Information rate (inc overhead)	0.0000	Mbps
Transmit rate	0.0000	Mbps
Symbol rate	0.0000	MBaud
Noise Bandwidth	16.11	dB.Hz
Occupied bandwidth	0.0000	MHz
Allocated bandwidth	0.0100	MHz