INSTRUCTION MANUAL

CS615

Water Content Reflectometer

version 8221-07

Revision: 10/96

Warranty and Assistance

The **CS615 WATER CONTENT REFLECTOMETER** is warranted by CAMPBELL SCIENTIFIC, INC. to be free from defects in materials and workmanship under normal use and service for twelve (12) months from date of shipment unless specified otherwise. Batteries have no warranty. CAMPBELL SCIENTIFIC, INC.'s obligation under this warranty is limited to repairing or replacing (at CAMPBELL SCIENTIFIC, INC.'s option) defective products. The customer shall assume all costs of removing, reinstalling, and shipping defective products to CAMPBELL SCIENTIFIC, INC. CAMPBELL SCIENTIFIC, INC. will return such products by surface carrier prepaid. This warranty shall not apply to any CAMPBELL SCIENTIFIC, INC. products which have been subjected to modification, misuse, neglect, accidents of nature, or shipping damage. This warranty is in lieu of all other warranties, expressed or implied, including warranties of merchantability or fitness for a particular purpose. CAMPBELL SCIENTIFIC, INC. is not liable for special, indirect, incidental, or consequential damages.

Products may not be returned without prior authorization. The following contact information is for US and International customers residing in countries served by Campbell Scientific, Inc. directly. Affiliate companies handle repairs for customers within their territories. Please visit www.campbellsci.com to determine which Campbell Scientific company serves your country. To obtain a Returned Materials Authorization (RMA), contact CAMPBELL SCIENTIFIC, INC., phone (435) 753-2342. After an applications engineer determines the nature of the problem, an RMA number will be issued. Please write this number clearly on the outside of the shipping container. CAMPBELL SCIENTIFIC's shipping address is:

CAMPBELL SCIENTIFIC, INC.
RMA#_____
815 West 1800 North
Logan, Utah 84321-1784

CAMPBELL SCIENTIFIC, INC. does not accept collect calls.

CS615 WATER CONTENT REFLECTOMETER
INSTRUCTION MANUAL
TABLE OF CONTENTS

PDF viewers note: These page numbers refer to the printed version of this document. Use the Adobe Acrobat® bookmarks tab for links to specific sections.

PAGE

CS615 WATER CONTENT REFLECTOMETER

1. INTRODUCTION

> **NOTE**: There is more than one version of the CS615. This manual is written for version 8221-07. The version number is listed on a cable label near the end of the probe cable. All CS615s are similar in measurement method but the calibration varies with version.

The CS615 Water Content Reflectometer provides a measure of the volumetric water content of porous media. The water content information is derived from the effect of changing dielectric constant on electromagnetic waves propagating along a wave guide.

The reflectometer output is a square wave and can be connected to Campbell Scientific dataloggers CR10X, CR10, CR500, 21X, or CR7. The measured period can be converted to volumetric water content using calibration values.

2. DESCRIPTION

The Water Content Reflectometer consists of two stainless steel rods connected to a printed circuit board. A shielded four-conductor cable is connected to the circuit board to supply power, enable the probe, and monitor the pulse output. The circuit board is encapsulated in epoxy.

High speed electronic components on the circuit board are configured as a bistable multivibrator. The output of the multivibrator is connected to the probe rods which act as a wave guide. The oscillation frequency of the multivibrator is dependent on the dielectric constant of the media being measured. The dielectric constant is predominantly dependent on the water content. Digital circuitry scales the multivibrator output to an appropriate frequency for measurement with a datalogger. The CS615 output is essentially a square wave with an amplitude swing of ±2.5VDC. The period of the square wave output ranges from 0.7 to 1.6 milliseconds and is used for the calibration to water content.

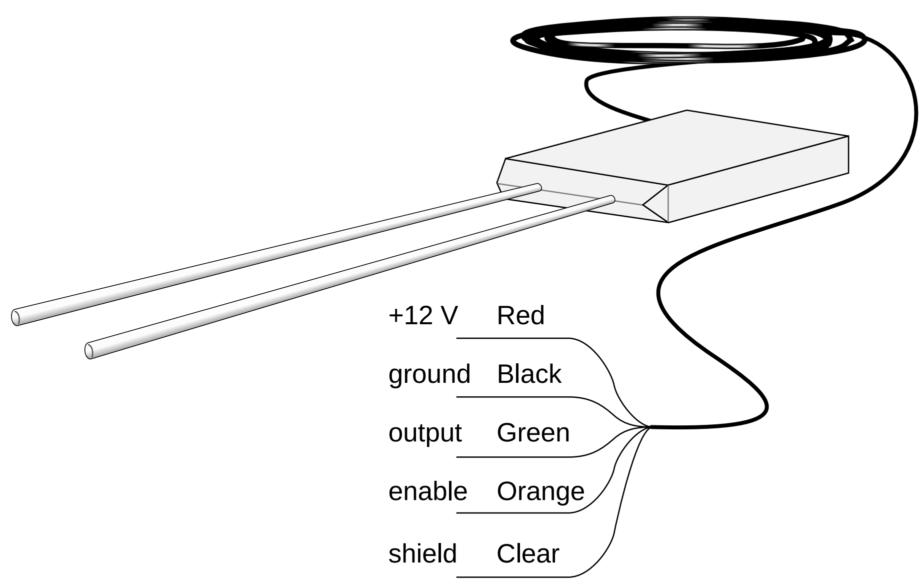

FIGURE 1. CS615 Water Content Reflectometer

3. SPECIFICATIONS

3.1 DIMENSIONS

Rods: 30.0 cm long
3.2 mm diameter
3.2 cm spacing
Head: 11.0 cm x 6.3 cm x 2.0 cm

3.2 WEIGHT

Probe: 280 g
Cable: 35 g m^{-1}

3.3 ELECTRICAL

Power

70 milliamps @ 12VDC when enabled
less than 10 microamps quiescent

Power Supply Voltage

9VDC minimum, 18VDC maximum

Enable Voltage

minimum voltage to enable probe is 1.3VDC

4. PERFORMANCE SPECIFICATIONS

4.1 ACCURACY

See the Calibration section for a discussion of accuracy. The accuracy is ±2% when using calibration for specific soil. The accuracy when using the general calibrations depends on soil texture and mineral composition.

4.2 RESOLUTION

The resolution of the volumetric water content measurement depends on which datalogger instruction is used. When the CR10X, CR10 or CR500 Instruction 27, Period Measurement, is used, the resolution is on the order of 10^{-6} m^3 m^{-3}. Period Measurement is not available on the CR7 or 21X.

When Instruction 3, Pulse Count, is used, the resolution with an execution interval of 1.0 second is 10^{-4} m^3 m^{-3} when pulse period is 1.3 milliseconds. The resolution improves as the water content decreases and as the execution interval increases. A shorter execution interval of 0.1 seconds yields a resolution of 10^{-2} m^3 m^{-3} at the same water content.

4.3 OPERATING RANGE

4.3.1 Soil Electrical Conductivity

The quality of soil moisture measurements which apply electromagnetic fields to wave guides is affected by soil electrical conductivity. The propagation of electromagnetic fields in the configuration of the CS615 is predominantly affected by changing dielectric constant due to changing water content, but it is also affected by electrical conductivity. Free ions in soil solution provide electrical conduction paths which result in attenuation of the signal applied to the waveguides. This attenuation both reduces the amplitude of the high-frequency signal on the probe rods and affects the shape of the oscillating signal. The attenuation reduces oscillation frequency at a given water content because it takes a longer time to reach the oscillator trip threshold.

Soil electrical conductivity can be described by (Rhoades et al., 1976)

$$\sigma_{bulk} = \sigma_{solution}\theta_V T + \sigma_{solid}$$

with σ the electrical conductivities of the bulk soil, the soil solution, and the solid constituents, θ_v the volumetric water content and T a soil-specific transmission coefficient intended to account for the tortuosity of the flow path as water content changes. See Rhoades et al., 1989 for a form of this equation which accounts for mobile and immobile water. The above equation is presented here the show the relationship between soil solution electrical conductivity and soil bulk electrical conductivity.

Soil solution electrical conductivity, $\sigma_{solution}$ can be determined in the laboratory using extraction methods. Soil bulk electrical conductivity can be measured using time domain reflectometry (TDR) methods. Most expressions of soil electrical conductivity are given in terms of solution conductivity. Discussion of the effects of soil electrical conductivity on CS615 performance will be on a soil solution basis unless stated otherwise.

When soil solution electrical conductivity values exceed 1 dS m^{-1}, the slope of the calibration begins to change. The slope decreases with increasing electrical conductivity. The probe will still respond to water content changes with good stability, but the calibration will have to be modified. (See the Calibration section.) At electrical conductivity values greater than 5 dS m^{-1} the probe output can become unstable.

4.3.2 Soil Organic Matter and Clay Content

The amount of organic matter and clay in a soil can alter the response of dielectric-dependent methods to changes in water content. This is apparent when mechanistic models are used to describe this measurement methodology.

The electromagnetic energy introduced by the probe acts to re-orientate or polarize the water molecules which are polar. If other forces are acting on the polar water molecules, the force exerted by the applied signal will be less likely to polarize it. This has the net effect of ‘hiding’ some of the water from the probe.

Organic matter and most clays are highly polar. Additionally, some clays sorb water interstitially and thus inhibit polarization by the applied field. It would be convenient if the calibration of water content to CS615 output period could be adjusted according to some parameter of the soil which reflects the affect of the intrinsic forces. However, identification of such a parameter has not been done, and it is likely that measurement of the correlation parameter would be more difficult than calibrating the CS615 for a given soil.

4.3.3 Cable Length

Probe cable length is not a limitation under typical applications. Laboratory measurements show no degradation in measurement quality with cable lengths up to 100 meters. Cable lengths greater than 50 m may increase the potential for damage from electrostatic discharge (lightning). The performance may be degraded if a cable type other than that provided with the probe is used.

4.3.4 Temperature Dependence

The CS615 output is sensitive to temperature, and compensation can be applied to enhance accuracy. The magnitude of the temperature coefficient varies with water content. Laboratory measurements were performed at various water contents and over the temperature range from 10°C to 30°C. The calibration information presented in Section 9 is for a temperature of 20°C. The following equation can be used to interpolate the temperature coefficient for a range of volumetric water content (θ_v) values.

$$\mathrm{Coef}_{\mathrm{temperature}} = -3.46 * 10^{-4} + 0.019\theta_v - 0.045\theta_v^2$$

To apply this correction, the following equation can be used.

$$\theta_{\mathrm{vcorrected}} = \theta_{\mathrm{vuncorrected}} - (T - 20) * \mathrm{Coef}_{\mathrm{temperature}}$$

Application of this correction yields a maximum difference between corrected and uncorrected water content of approximately 1.6%. Considering the accuracy of the measurement and the potential spatial variability of soil temperature along the length of the probe rods, the correction is not necessary in most cases.

An example for using the temperature correction is a measurement taken on a soil at a water content of about 0.23 and a temperature of 25°C. The temperature coefficient value is 0.00164 $m^3\ m^{-3}\ {}^\circ C^{-1}$ which means that the measured water content is 5°C *(0.00164 $m^3\ m^{-3}\ {}^\circ C^{-1}$) or 0.8% high.

5. INSTALLATION

5.1 ORIENTATION

The probe rods can be inserted vertically into the soil surface or buried at any orientation to the surface. A probe inserted vertically into a soil surface will give an indication of the water content in the upper 30 cm of soil. The probe can be installed horizontal to the surface to detect the passing of wetting fronts or other vertical water fluxes. A probe installed at an angle of 30 degrees with the surface will give an indication of the water content of the upper 15 cm of soil.

5.2 POTENTIAL PROBLEMS WITH IMPROPER INSERTION

The method used for probe installation can affect the accuracy of the measurement. The probe rods should be kept as close to parallel as possible when installed to maintain the design wave guide geometry. The sensitivity of this measurement is greater in the regions closest to the rod surface than at distances away from the surface. Probes inserted in a manner which generates air voids around the rods will reduce the measurement accuracy. In some applications, installation can be improved by using insertion guides or a pilot tool. Campbell Scientific offers the CS615G and CS615P insertion tools. The CS615G is a probe insertion guide which holds the rods parallel during rod insertion. The CS615P pilot tool is essentially the CS615 rods which are inserted into the soil then removed. This makes proper installation of the CS615 easier in soils which are difficult to insert probes into.

6. WIRING

color	function	CR10(X)	21X/CR7
red	+12 V	+12 V	+12 V
green	output	SE analog channel	pulse channel
orange	enable	control port	control port
black	ground	G	⏚
clear	shield (ground)	G	⏚

> **NOTE:** CS615s manufactured before 12/95 have the green and black leads reversed. Consult the wiring label near the end of the cable.

The enable line is set high to put the probe in the measuring mode.

7. DATALOGGER INSTRUCTIONS

7.1 INTRODUCTION

The output of the CS615 is essentially a square wave with amplitude ±2.5 volts and a frequency which is dependent on the dielectric constant of the material surrounding the probe rods. The frequency range is approximately 600 to 1500 Hz. The period (0.7 to 1.6 milliseconds) is used in the calibration for water content.

The Pulse Count instruction of a CR10, CR500, 21X or CR7 dataloggers can be used with the CS615 output connected to a pulse count channel. The Period Measurement instruction of the CR10 or CR500 can be used with the CS615 output connected to a single-ended analog channel.

7.2 PULSE COUNT

It is important to understand the event sequence during the Instruction 3 Pulse Count Measurement when using it with the CS615. See the Instructions section of the datalogger manual for a detailed explanation of the Pulse Count instruction.

A brief explanation of pulse count use in a CS615 application is presented here. The LOW LEVEL AC option for the configuration code is used, and the output is selected for frequency (Hz). Period (msec) is easily obtained with the Inverse instruction (42).

TABLE 1. Instruction 3 Pulse Count Measurement Sample Program

```
;{21X}
;Simple program to demonstrate use of
;pulse count instruction with CS615
;
*Table 1 Program
  01:        2.0        Execution Interval (seconds)

1:  If time is (P92)
  1:      0000          Minutes into a
  2:        15          Minute Interval
  3:        30          Then Do

2:  Do (P86) ;set CS615 enable high
  1:        41          Set Port 1 High

3:  Beginning of Loop (P87)
  1:         1          Delay
  2:         2          Loop Count

4:  End (P95)

5:  Pulse (P3)
  1:         1          Reps
  2:         1          Pulse Input Channel
  3:        21          Low Level AC, Output Hz
  4:         1          Loc [ kHz      ]
  5:          .001      Mult ;convert Hz to kHz
  6:         0.0        Offset

6:  Do (P86) ;set CS615 enable low
  1:        51          Set Port 1 Low

7:  End (P95)

End Program
```

The Pulse Count instruction uses accumulators to monitor pulses on the datalogger Pulse Count Channels. At the beginning of each execution interval for the table containing the Pulse Count instruction, the accumulator count is dumped to a section in datalogger RAM, the accumulator is then reset to zero and begins accumulating counts again. When the Pulse Count instruction is reached, the value in RAM is modified by the multiplier and offset in the Pulse Count instruction and the result written to input storage. The RAM is then reset to zero.

Consider the simple 21X program in Table 1. Additional instructions which might be needed for multiplexer control or other functions have been omitted for simplicity. This program is written to obtain a CS615 reading every 15 minutes. When the program is compiled by the datalogger, the accumulators begin monitoring the Pulse Count Channels. Immediately following compilation by the datalogger, there is no signal on the input channels because the CS615 is not enabled until the 15 minute interval specified in the Instruction 92 is reached. When the 15 minute interval is reached, Instruction 86 is executed which sets the enable of the CS615 high and the probe outputs a signal which is detected by the pulse counters.

The Loop Instruction in this application uses a Delay of 1 and a Loop Count of 2. Program execution pauses during the first loop count until the execution interval of 2 seconds is complete. This delay is necessary because the probe has not been enabled for the entire execution interval which means a complete count is not obtained. More complex programs will contain additional instructions prior to the instruction to enable the CS615, and these instructions can take a significant amount of time to execute. During the second time through the Loop Instruction the pulse counters see the CS615 output for the full execution interval. At the end of this interval the accumulators transfer to RAM and are reset. When the program execution then moves to the Pulse Count Instruction (P3) the value in RAM is converted to kHz and written to input storage.

7.3 PERIOD MEASUREMENT

Instruction 27, Period Measurement is available only on the CR10, CR10X, or CR500. For convenience, the following tables from the datalogger manual are presented here. See the datalogger manual for detailed description of the instruction and the example programs for typical values.

8. MAINTENANCE

The CS615 does not require periodic maintenance.

9. CALIBRATION

9.1 GENERAL

The information in this calibration section applies only to CS615 version 8221-07. The version number is listed on a cable label near the end of the probe cable.

The CS615 provides an indirect measurement of soil water content by using the effect of changing dielectric constant on applied electromagnetic waves. The probe rods act as a wave guide and the material surrounding the rods (soil) varies in dielectric constant with the amount of water in the material.

The dielectric constant of the soil is a weighted summation of the dielectric constants of the soil constituents. The dielectric constant for water is significantly higher than that of other constituents. Changes in the dielectric constant of the soil system can be attributed to changes in water content. This is the basis for the measurement technique.

There are two soil properties which affect the response of the CS615 to changes in water content. High clay contents (greater than 30%) or high electrical conductivity (greater than 1 dS m^{-1}) may require that the calibration be adjusted or generated for the specific soil.

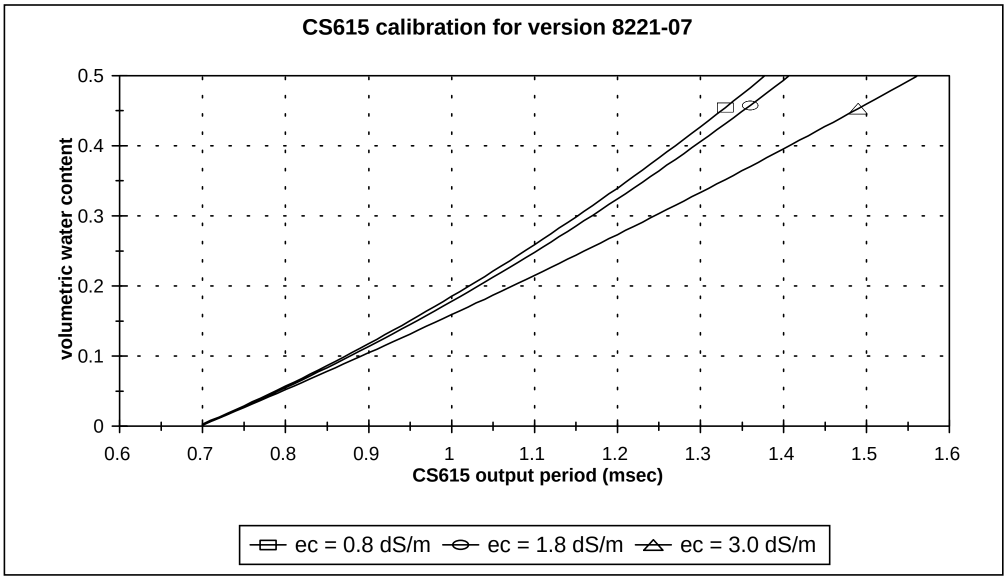

FIGURE 2. CS615 Calibration Curves

Figure 2 demonstrates the effect of electrical conductivity on the calibration. At electrical conductivity values of 1 dS m^{-1} and below, the calibration shown for 0.8 dS m^{-1} works well for a wide range of soil textures. The calibration curves for the higher electrical conductivities show that the slope decreases with increasing conductivity. The response of the CS615 to changes in water content at higher electrical conductivity values is well-behaved up to approximately 5 dS m^{-1}. The calibration can be approximated from figure 2 if the soil solution electrical conductivity is known or if soil measurements are made with the CS615 and the actual water content is independently determined. High clay content has a similar affect on the calibration but the magnitude is dependent on the clay type.

electrical conductivity (dS m^{-1})	**calibration**
≤1.0	$\theta_v(\tau) = -0.187 + 0.037 * \tau + 0.335 * \tau^2$
1.8	$\theta_v(\tau) = -0.207 + 0.097 * \tau + 0.288 * \tau^2$
3.0	$\theta_v(\tau) = -0.298 + 0.361 * \tau + 0.096 * \tau^2$

θ_v is the volumetric water content on a fraction basis i.e. 0.20 is 20% volumetric water content.
τ is the CS615 output period in milliseconds.

9.2 CALIBRATION FOR A SPECIFIC SOIL

The calibration relationship between volumetric water content and CS615 output period for a specific soil may need to be established if increased accuracy is needed or if the composition of the soil deviates from what might be considered typical. High electrical conductivity, high clay content, high quartz content and high organic matter content are conditions which will affect probe response.

10. SAMPLE PROGRAMS

Sample Program number	Description
1	Monitor 1 CS615 with CR10 datalogger using Period Averaging Instruction (P27)
2	Monitor 1 CS615 with 21X datalogger using Pulse Count Instruction (P3)
3	Monitor 48 CS615s with 21X datalogger and AM416 multiplexer using Pulse Count Instruction (P3)
4	Monitor 48 CS615s with CR10 datalogger and AM416 multiplexer using Period Averaging Instruction (P27)

The calibration coefficients in the example programs are demonstrative only. See Section 9 for information on calibration.

10.1 SAMPLE PROGRAM 1

Simple program using the Period Averaging Instruction (P27) of a CR10 datalogger to read a single CS615. The measurement is taken hourly and the period and water content are written to output storage.

CR10	CS615
Single-Ended Channel 1 (SE1)	green
Control Port 5 (C5)	orange

The red lead is connected to 12VDC and the black and shield are connected to ground.

```
;{CR10}
;
*Table 1 Program
  01:      5.0       Execution Interval (seconds)

1:  If time is (P92) ;take reading hourly
  1:    0000       Minutes (Seconds --) into a
  2:      60       Interval (same units as above)
  3:      30       Then Do

2:  Do (P86)
  1:      45       Set Port 5 High;enable CS615

3:  Period Average (SE) (P27)
  1:       1       Reps
  2:       4       2 V Peak to Peak/200 kHz
                   Max. Freq.
  3:       1       SE Channel
  4:      10       No. of Cycles
  5:       5       Timeout (units = 0.01 seconds)
  6:       1       Loc [ 615period ]
  7:       .001    Mult
  8:       0.0     Offset

4:  Do (P86) ;disable CS615
  1:      55       Set Port 5 Low

5:  Polynomial (P55) ;convert period to water content
  1:       1       Reps
  2:       1       X Loc [ 615period ]
  3:       2       F(X) Loc [ 615water  ]
  4:  -0.187       C0
  5:   0.037       C1
  6:   0.335       C2
  7:   0.0         C3
  8:   0.0         C4
  9:   0.0         C5
6:  Do (P86)
  1:      10       Set Output Flag High

7:  Real Time (P77)
  1:    0220       Day,Hour/Minute

8:  Sample (P70)
  1:       2       Reps
  2:       1       Loc [615period]

9:  End (P95)

End Program
```

10.2 SAMPLE PROGRAM 2

Simple program using the Pulse Count Instruction (P3) of a CR10, CR500 or 21X datalogger to read a single CS615. The Water Content Reflectometer is queried when Flag 1 is set high. The measurement is made and the period and water content values are written to output storage.

CR10 or 21X	CS615
Pulse Count Channel 1 (P1)	green
Control Port 5 (C5)	orange

The red lead is connected to 12VDC and the black and shield are connected to ground.

```
;{CR10, CR500 or 21X}
;
*Table 1 Program
  01:      1.0       Execution Interval (seconds)

1:  If Flag/Port (P91) ;set flag1 high to initiate
reading
  1:      11       Do if Flag 1 is High
  2:      30       Then Do

2:  Do (P86) ;enable CS615
  1:      45       Set Port 5 High

3:  Beginning of Loop (P87) ;delay for complete
count interval
  1:       1       Delay
  2:       2       Loop Count

4:  End (P95)

5:  Pulse (P3) ;determine CS615 output frequency
  1:       1       Reps
  2:       1       Pulse Input Channel
  3:      21       Low Level AC, Output Hz
  4:       1       Loc [ 615kHz    ]
  5:       .001    Mult ;convert to kHz
  6:     0.0       Offset
```

```
6:  Do (P86) ;disable CS615
  1:        55            Set Port 5 Low

7:  Z=1/X (P42) ;convert kHz to milliseconds
  1:         1            X Loc [ 615kHz    ]
  2:         2            Z Loc [ 615msec   ]

8:  Polynomial (P55) ;convert period to water content
  1:         1            Reps
  2:         2             X Loc [ 615msec   ]
  3:         3            F(X) Loc [ 615water  ]
  4:    -0.187            C0
  5:     0.037            C1
  6:     0.335            C2
  7:     0.0              C3
  8:     0.0              C4
  9:     0.0              C5

9:  Do (P86)
  1:        10            Set Output Flag High

10:  Real Time (P77)
  1:      0220            Day,Hour/Minute

11:  Sample (P70)
  1:         2            Reps
  2:         2            Loc [615msec]

9:  Do (P86)
  1:        21            Set Flag 1 low

12:  End (P95)

End Program
```

10.3 SAMPLE PROGRAM 3

Program using the Pulse Count Instruction (P3) of 21X datalogger and AM416 multiplexer to read 48 CS615 probes. *See the cautions listed below*.

This program is written to read 48 CS615s every hour and write the water content value to output storage. The AM416 multiplexer is a 16 channel multiplexer with 4 lines per channel. See figure 3 for wiring schematic. Three CS615 outputs and a common enable for all 3 probes are attached to each AM416 channel. Three CS615s connected to a AM416 channel are enabled simultaneously while the Pulse Count Instruction uses a repetition value of 3 to sequentially read the probe outputs. The frequency value of the Pulse Count Instruction is converted to period by the Z=1/X Instruction (P42) and the calibration to volumetric water content is invoked using the Polynomial Instruction. The water content values are written to output storage.

Attention to program structure when using the Pulse Count Instruction with sensors that are periodically enabled is necessary to ensure accurate results. See Section 7.2 for a detailed description of the Pulse Count Instruction.

CAUTION:

1. The probe rods of the CS615 are essentially antennae which transmit and receive radio waves. Interference can occur when enabled probes are in close proximity and electrical conductivity of the measured medium is high. Generally, interference is not a problem when the distance between enabled probes is greater than 20 cm. It may be necessary to configure probe placement and multiplexer connection to alleviate probe interaction.
2. Reading 48 CS615s using the Pulse Count Instruction will take approximately 32 seconds. This may conflict with other measurements.

```
;{21X}
;
*Table 1 Program
  01:        1.0          Execution Interval (seconds)

1:  If time is (P92) ;take CS615 readings hourly
  1:     0000             Minutes into a
  2:       60             Minute Interval
  3:       30             Then Do

2:  Do (P86) ;enable AM416
  1:       41             Set Port 1 High

3:  Do (P86) ;set CS615 enable high
  1:       43             Set Port 3 High

4:  Beginning of Loop (P87) ;multiplexing loop
  1:     0000             Delay
  2:       16             Loop Count

;loop index of 3 so 3 readings measured
;by pulse instruction are advanced 3
;locations each pass through measurement
loop.

5:  Step Loop Index (P90)
  1:        3             Step

6:  Do (P86) ;clock AM416
  1:       72             Pulse Port 2
```

```
;delay loop to wait remainder of execution
;interval once AM416 is clocked, and one
;complete execution interval for precise
;pulse count interval.

7:  Beginning of Loop (P87)
  1:        1        Delay
  2:        2        Loop Count

8:  End (P95) ;end of delay loop

9:  Pulse (P3) ;read CS615s
  1:        3        Reps
  2:        1        Pulse Input Channel
  3:       21        Low Level AC, Output Hz
  4:        1        Loc [ kHz#1     ]
  5:         .001    Mult
  6:        0.0      Offset

;convert frequencies to period.  0.001 multiplier
;converts kHz to milliseconds.

10:  Z=1/X (P42)
  1:        1        X Loc [ kHz#1     ]
  2:        4        Z Loc [ period#1  ]
11:  Z=1/X (P42)
  1:        2        X Loc [ kHz#2     ]
  2:        5        Z Loc [ period#2  ]

12:  Z=1/X (P42)
  1:        3        X Loc [ kHz#3     ]
  2:        6        Z Loc [ period#3  ]

13:  Polynomial (P55) ;apply calibration
  1:        3        Reps
  2:        4        X Loc [ period#1  ]
  3:        7--      F(X) Loc [ water#1   ]
  4:        -.187    C0
  5:         .037    C1
  6:         .335    C2
  7:        0.0      C3
  8:        0.0      C4
  9:        0.0      C5

14:  End (P95)

15:  Do (P86) ;set CS615 enable low
  1:       53        Set Port 3 Low

16:  Do (P86) ;set AM416 reset low
  1:       51        Set Port 1 Low

17:  Do (P86)
  1:       10        Set Output Flag High

18:  Sample (P70)
  1:       48        Reps
  2:        7        Loc [ water#1   ]

19:  End (P95)

End Program
```

10.4 SAMPLE PROGRAM 4

Program using the Period Averaging Instruction (P27) of CR10 datalogger and AM416 multiplexer to read 48 CS615 probes

> **CAUTION:**
>
> 1. The probe rods of the CS615 are essentially antennae which transmit and receive radio waves. Interference can occur when enabled probes are in close proximity and electrical conductivity of the measured medium is high. Generally, interference is not a problem when the distance between enabled probes is greater than 20 cm. It may be necessary to configure probe placement and multiplexer connection to alleviate probe interaction.

```
;{CR10}
;
*Table 1 Program
  01:       1.0       Execution Interval (seconds)

;Once an Hour, Read Probes

1:  If time is (P92)
  1:        0         Minutes into a
  2:       60         Minute Interval
  3:       30         Then Do

; enable multiplexer

2:  Do (P86)
  1:       41         Set Port 1 High

; turn on port that enables 615s

3:  Do (P86)
  1:       43         Set Port 3 High

;Multiplexer loop

4:  Beginning of Loop (P87)
  1:        0         Delay
  2:       16         Loop Count

; clock multiplexer

5:  Do (P86)
  1:       72         Pulse Port 2
```

```
; loop index multiplied by 3 so that 3 readings
measured by pulse
; instruction are advanced 3 locations each pass
through measurement loop

6:  Step Loop Index (P90)
   1:      3        Step

7:  Period Average (SE) (P27)
   1:      3        Reps
   2:      4        2 V Peak to Peak/200 kHz
                    Max. Freq.
   3:      1        SE Channel
   4:     10        No. of Cycles
   5:      5        Timeout (units = 0.01 seconds)
   6:      1--      Loc [ msec#1    ]
   7:       .001    Mult
   8:      0.0      Offset

8:  End (P95)

; set ports enabling mux and probes low

9:  Do (P86)
   1:     51        Set Port 1 Low

10:  Do (P86)
   1:     53        Set Port 3 Low

; apply calibration

11:  Polynomial (P55)
   1:     48        Reps
   2:      1        X Loc [ Period#1  ]
   3:     49        F(X) Loc [ WatCont#1 ]
   4:     -0.187    C0
   5:      0.037    C1
   6:      0.335    C2
   7:      0.0      C3
   8:      0.0      C4
   9:      0.0      C5

12:  Do (P86)
   1:     10        Set Output Flag High

13:  Real Time (P77)
   1:     10        Hour/Minute

14:  Sample (P70)
   1:     48        Reps
   2:     49        Loc [ WatCont#1 ]

15:  End (P95)

End Program
```

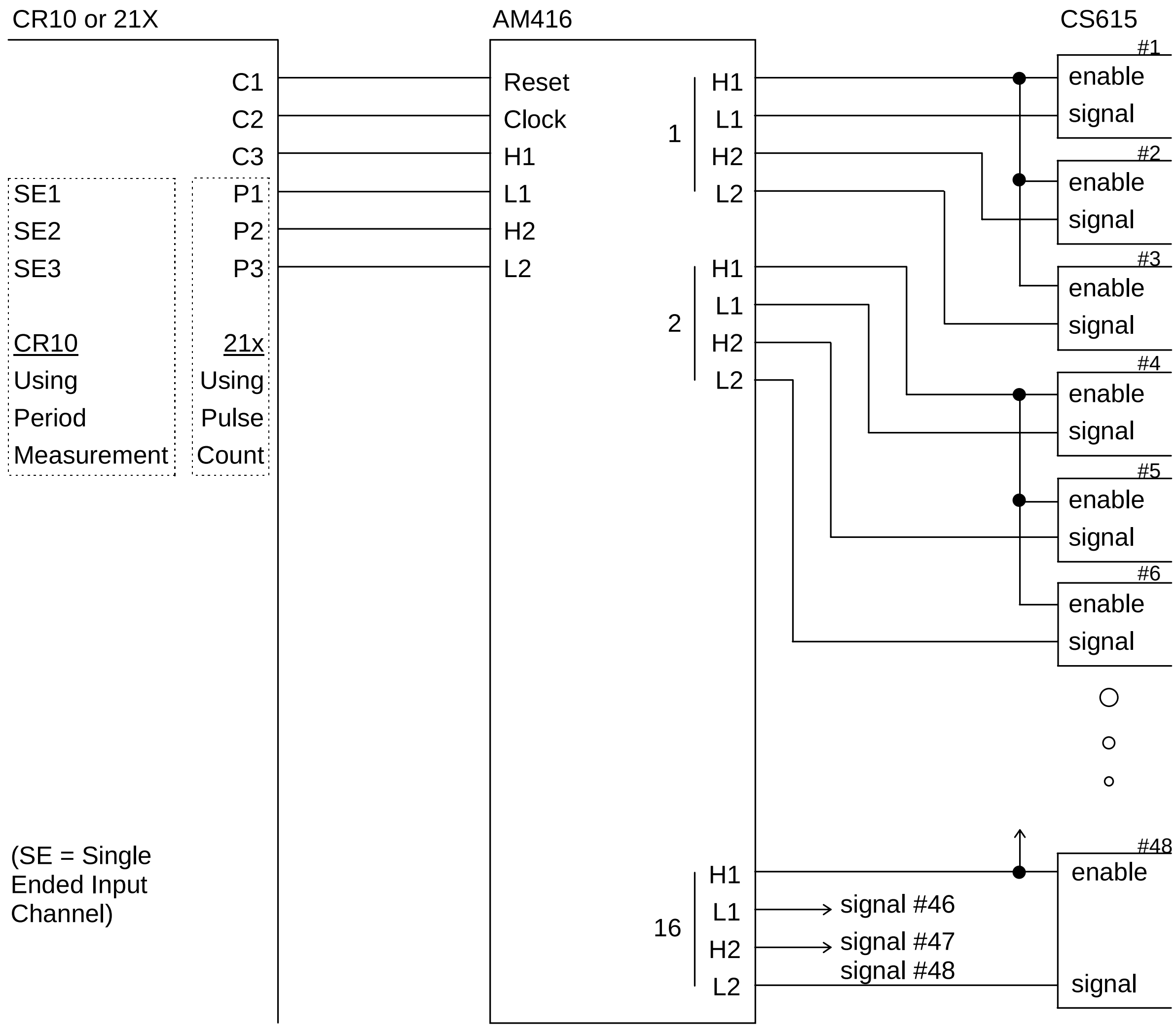

FIGURE 3. Wiring configuration for multiplexing 48 CS615s with AM416 and CR10 or 21X datalogger.

Campbell Scientific Companies

Campbell Scientific, Inc. (CSI)
815 West 1800 North
Logan, Utah 84321
UNITED STATES
www.campbellsci.com
info@campbellsci.com

Campbell Scientific Africa Pty. Ltd. (CSAf)
PO Box 2450
Somerset West 7129
SOUTH AFRICA
www.csafrica.co.za
sales@csafrica.co.za

Campbell Scientific Australia Pty. Ltd. (CSA)
PO Box 444
Thuringowa Central
QLD 4812 AUSTRALIA
www.campbellsci.com.au
info@campbellsci.com.au

Campbell Scientific do Brazil Ltda. (CSB)
Rua Luisa Crapsi Orsi, 15 Butantã
CEP: 005543-000 São Paulo SP BRAZIL
www.campbellsci.com.br
suporte@campbellsci.com.br

Campbell Scientific Canada Corp. (CSC)
11564 - 149th Street NW
Edmonton, Alberta T5M 1W7
CANADA
www.campbellsci.ca
dataloggers@campbellsci.ca

Campbell Scientific Ltd. (CSL)
Campbell Park
80 Hathern Road
Shepshed, Loughborough LE12 9GX
UNITED KINGDOM
www.campbellsci.co.uk
sales@campbellsci.co.uk

Campbell Scientific Ltd. (France)
Miniparc du Verger - Bat. H
1, rue de Terre Neuve - Les Ulis
91967 COURTABOEUF CEDEX
FRANCE
www.campbellsci.fr
campbell.scientific@wanadoo.fr

Campbell Scientific Spain, S. L.
Psg. Font 14, local 8
08013 Barcelona
SPAIN
www.campbellsci.es
info@campbellsci.es

Please visit www.campbellsci.com to obtain contact information for your local US or International representative.