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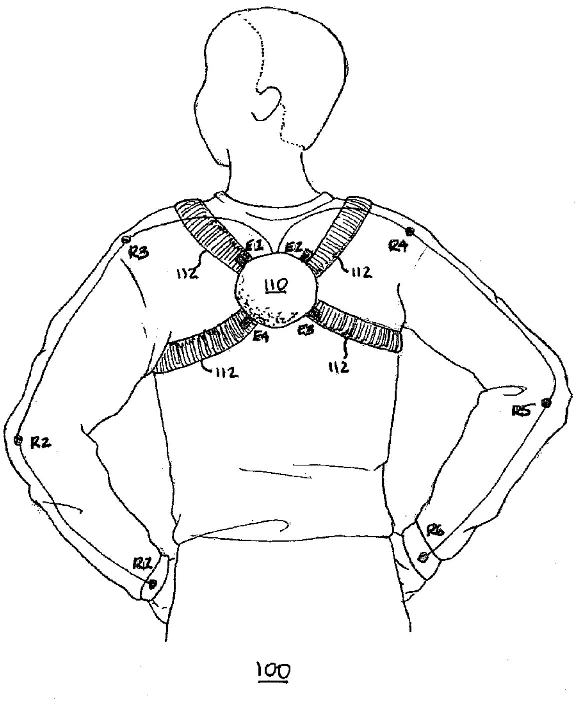

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FIG.7

(57) Abstract: A system, apparatus and method are provided for transforming a change in spatial relationship and/or velocity between a first and a second spatially distinct locations into machine discernible information, particularly for use with computer modeling applications. Embodiments of the apparatus associate at least one unique and/or shared transmitter-receiver pair with the spatial locations and use Spatial Determination Means (SDM) to establish an approximate change in spatial relationship between the first location and the second location, with or without reference to a time domain. The apparatus comprises emitting a first electromagnetic transmission, receiving the first electromagnetic transmission, emitting a second electromagnetic transmission and receiving the second electromagnetic transmission.

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METHODS, APPARATUS AND SYSTEMS FOR WIRELESS DETERMINATION OF RELATIVE SPATIAL RELATIONSHIP BETWEEN TWO LOCATIONS

BACKGROUND OF THE INVENTION

Motion capture is the process of recording movement and translating that movement into digital data for later use by graphic and analytical software. Motion capture has traditionally been a studio and laboratory based technology with studio installations costing US $50,000 or more, with the very least expensive single unit starting at US $3,000. Due to this high cost the marketplace of motion capture has traditionally been limited to universities, motion picture and animation studios, hospitals, professional sports, and the military. With this limited marketplace there are relatively few, dozens not hundreds, of companies producing motion capture hardware. There are also a very limited range of expensive specialized applications.

There are currently six fundamental types of motion capture systems. Optical, Mechanical, Inertial, Magnetic, Ultrasonic and RF positioning, with optical being adapted for some 80% of all applications.

Optical Motion Capture: This form of motion capture technology includes the use of tracking technology using passive markers, the golf-ball like markers usually coated with a reflective covering, and using active markers, usually LEDs that flash in specific patterns in order to identify the location tracked. In addition, a relatively new technology using face and pattern recognition software to locate and track features on a subject without markers has been developed.

Optical motion capture is limited by its use of cameras to record activity. Since most motion capture is used for the generation of 3D models, this means that multiple cameras are needed, usually 8. Since the cameras must surround the action, this also restricts optical motion capture to studios or specially constructed stages. This also means, with a couple exceptions, that this form of motion capture can't be used for real-time 3D since the images from multiple cameras have to be integrated to get the 3D image. And, while 2D motion capture from a single camera is adequate for most console gaming, it isn't sufficient for most VR applications. Finally, optical capture is generally adequate for animation and gait analysis, but tends to lack the precision necessary for more detailed medical and sports performance applications.

Inertial: Inertial motion tracking uses what are essentially gyroscopes and reads the movement through inertial forces. Due to it's inherent poor resolution this technology is most appropriate for full body motion and not for digital gloves. Since it tracks by essentially dead-reckoning, it suffers eventual drift. Body suits incorporating this technology generally cost from US $25,000 to $80,000 with the low-end product in the US $3-5,000 range, as of the filing date of this patent.

Mechanical and Laser Optical: Mechanical motion capture systems directly track the movement of body joint angles. An articulated skeletal-like structure is attached to the body or hand, and as it moves so do the articulated mechanical parts of the structure, measuring any changes in joint angle. Mechanical motion capture systems are real-time, relatively low-cost, free-of-occlusion, and can be untethered. Typically, they are rigid structures of jointed, straight metal or plastic rods linked together with potentiometers that articulate at the joints of the body. Thus, mechanical motion capture apparatus/systems are awkward, cumbersome and must usually be fitted to the wearer, but nevertheless give the highest precision and can be used in medical and sports applications, which require millimeter levels of accuracy. These suits tend to be in the US $25,000 to $75,000 range not including any external absolute positioning system.

Laser Optical Diffraction: For shorter distances over well known geometries such as the hand, loops of fiber optic cable are used to interment data gloves. The joint movement is measured by variations in a laser beam induced by the bending of the fiber optic cable.

Magnetic: Magnetic systems calculate position and orientation by the relative magnetic flux of three orthogonal coils on both the transmitter and each receiver. The relative intensity of the voltage or current of the three coils allows these systems to calculate both range and orientation by meticulously mapping the tracking volume. The capture volumes for magnetic systems are dramatically smaller than they are for optical systems. Magnetic and magnetic resonance systems are custom built and primarily used in a laboratory setting. They are very precise through the use of magnetic triangulation. They are also very expensive.

SUMMARY OF THE INVENTION

The invention is directed to apparatus, systems, software and methods for transforming a change in spatial relationship and/or velocity between first and second spatially distinct locations into machine discernible information, particularly for use with computer modeling applications. Embodiments of the invention associate at least one unique and/or shared transmitter-receiver pair with the spatial locations and use Spatial Determination Means (SDM) to establish an approximate change in spatial relationship between the first location and the second location, with or without reference to a time domain. The change in spatial relationship can be further refined by application of known algorithms to derive distance information that correlates with the change. In one series of embodiments of the invention, intrinsic constraints in functional movement between the spatial locations is identified and exploited to reduce hardware complexity and/or computational overhead, thus enabling efficient and rapid acquisition of datasets corresponding to the position(s) and/or velocity(ies) of interest. In another series of embodiments of the invention, at least two unique and/or shared transmitter-receiver pairs are associated with the spatial locations, and triangulation algorithms are used to determine an approximate change in spatial relationship between the first location and the second location.

Unlike systems and apparatus of the prior art, many system embodiments of the invention can be assembled from readily available parts and for under several hundred U.S. dollars (as of the actual filing date of this patent) with positional accuracy of about 1mm and a positional polling frequency in the range of about 10 to 20 polls/milliseconds. More robust system embodiments of the invention can achieve sub-millimeter positional accuracy and higher polling frequencies.

Method, apparatus and system embodiments of the invention comprise use of SDM for establishing an approximate change in spatial relationship between a first location associated with a structure and a second location associated with the same or different structure, with or without reference to a time domain. Once the approximate change in spatial relationship between the first and second locations has been identified and assigned a delta value (δ), the delta value (δ) may be transformed into a distance value (x_n) that approximates the general change in distance between the first and second locations (the value of "n" is an integer from 1 to infinity where each value identifies a unique distance value from a potential plurality of possible distance values that may result from use of certain SDM methodologies). Because the distance value (x_n) is a scalar value in rudimentary embodiments, *e.g.*, where triangulation or other means for resolving directional movement is not used, spatial certainty does not exist even if the spatial position between one of the locations is known; a plurality of valid spatial positions of the two locations may exist, which must be meaningfully resolved as described below.

In rudimentary embodiments according to the invention, the SDM comprise a wireless transmitter and receiver pair for transmitting and receiving at least two electromagnetic transmissions (EMTs). The received waveforms are then applied to Phase Comparison Means (PCM) and/or Power Differential Means (PDM) for determining a change in spatial relationship between the pair, as embodied by a delta value (δ). The delta value (δ), however, corresponds to a plurality of possible relative spatial arrangements between the pair; it is necessary to resolve these possible relative positions by introducing a constraint, which in many embodiments intrinsically occurs when finding the distance values (x_n). As will be described further below, however, other forms of constraints exist such as relative velocity limitations, range and/or direction of motion limitations, and the like.

PCM/PDM according to invention embodiments comprise discrete or integrated electrical and/or optical components that directly or indirectly generate a delta value (δ) by establishing a first initial value comprising data encoding a first spatial relationship between the transmitter and the receiver in the pair wherein the first initial value comprises an analog or digitized signal received from the receiver, transformation of such signal through mathematical algorithm, or other analog/digital transformation; establishing a second initial value of similar characteristics to the first initial value, comprising data encoding a second spatial relationship between the transmitter and the receiver in the pair; and comparing the first initial value with second initial value to establish the delta value (δ), which encodes information comprising the spatial difference(s) between the transmitter and the receiver in the pair.

In PCM embodiments, a phase difference between the first initial value and the second initial value comprises the delta value (δ) while in PDM embodiments, a power difference between the first initial value and the second initial value comprises the delta value (δ). For PCM embodiments, presuming that the frequencies of the EMTs remain constant or at least known, a phase shift between the first and second initial values is indicative of a change in spatial relationship between the transmitter and the receiver in the pair. For PDM embodiments, presuming that the power output of the EMTs remain constant or at least known, a change in power between the first and second initial values is indicative of a change in spatial relationship between the transmitter and the receiver in the pair using, for example, the inverse cube law. In both cases, however, the delta value (δ) is undifferentiated along any given radius about one of the spatial positions that meets the delta value (*e.g.*, the spatial location associated with the transmitter). This is because in the case of PCM embodiments, the change in phase is scalar (moreover, the possible spatial changes include multiples of 2π, unless constrained as described below), as is in PDM embodiments.

Because the delta value (δ) encodes information regarding a change in relative spatial relationship between the transmitter and the receiver in the pair without information relating to a change in absolute spatial distances, it is desirable to constrain the possible spatial changes to the least number of possible value(s). This constraining action can comprise mathematical solutions and/or environmental/structural solutions. For PCM applications relying upon abstract mathematical solutions, the delta value (δ) is transformed into a distance value (x_n), which resolves into one of two possible spatial relationships: one representing an increase in relative separation and one representing a decrease in relative separation. Generation of a distance value is done in PCM embodiments by multiplying the percentage of phase change by the wavelength of the EMTs. In this manner, the change in phase correlates directly with a specific change in distance. It should be noted, however, if the change in spatial relationship between the transmitter and the receiver in the pair is greater than one wavelength of the EMTs, then resolving means must be used for eliminating this condition or means employed for counting the number of cycles between the first and the second EMT. Common means for resolving or removing this condition include decreasing the time between the first and second EMTs (i.e., increasing sampling rates) and using longer wavelength EMTs; common means for counting the number of cycles include uniquely identifying each wavelength cycle or sampling at a high enough rate to detect and count zero crossings.

An alternative or ancillary method for deriving the delta value (δ) involves assessing changes in energy density, such as used by the PDM wherein the difference between received EMT energy levels is determined, while taking into account any change in output power between the first and second EMT emissions. By knowing the energy level for a given frequency, changes in received power correlate with changes in distance. Again, however, there exist at least two solutions to the equation (but such solutions are not radially aligned as with PCM embodiments) so again, constraints must be used to reduce the number of possible distance changes.

In the previous paragraphs it was noted that directional ambiguity existed with respect to x_n; the value was not a vector but scalar in nature, and could not be mathematically resolved with certainty without additional data. In many invention embodiments, mechanical constraints regarding the possible movement paths between the transmitter and the receiver in the pair are exploited to assign direction to x_n. The mechanical constraints may be inherent in the structure to which the transmitter and the receiver in the pair are associated, and/or inherent in the environment in which the structure to which the transmitter and the receiver in the pair are associated exists. Thus, if an initial spatial relationship between the transmitter and the receiver in the pair is such that a decrease distance between the two is not possible, then it can be presumed that any change in spatial position represents an increase of distance. As will be seen below, integration of environmental and/or structural constraints is considered an element of many invention embodiments.

While the disclosure herein references a transmitter and a functional or paired receiver, the terms "transmitter" and "receiver" as well as their plurals and equivalents are used for convention purposes unless otherwise stated, and should not be construed as limiting or exclusive. By way of specific example, elements of radio frequency identification devices (e.g., RFIDs) function as both receiver and transmitter, and furthermore are passive by design and do not include an integrated power source as would be the case with conventional transmitters and most receivers. However, because such devices receive radio frequency energy and convert the same into power for subsequent data transmission and such signal is then subject to phase assessment according to embodiments of the invention, such devices may be considered transmitters and/or receivers for the purpose of this patent, based upon functionality as opposed to simple naming conventions. Additionally, and depending upon context, the terms "transmitter" and "receiver" may also refer to any portion or all portions of a transmitting and/or receiving arrangement, e.g., a transmitter and/or receiver may refer to the antenna component of a transmitting/receiving system, the antenna functioning as an emitter and/or a detector; a transmitter may refer to a RF generator component of a transmission system. Thus, if reference is made to a paired transmitter/receiver, for example, the pairing may refer to the function of the referenced systems at the time of identification, the systems themselves and/or may be limited to components

Based upon the foregoing, it is therefore not necessary to have a one to one (1:1) ratio between transmitters and receivers (generally referred to as unique pairs). For example, it is within boundaries of the invention to have multiple transmitters, each transmitting preferably on a discrete and unique frequency or as a function of time (such as in time division transmission/reception where temporal differentiation is used to establish unique identity), functionally linked to a single receiver capable of discriminating between the various transmitters, or vice versa (generally referred to as shared pairs where one of a unique transmitter or receiver is common to each pair). Moreover, a single antenna can be coupled to suitable electronics so that it operates alternatively as a transmitting antenna and a receiving antenna as previously described. As a consequence of this arrangement, greater flexibility and adaptability can be achieved.

As used herein, the term "emitter" refers to any structure from which an intended EMT may emanate, and includes by way of example only, RF antennas, wave guides, radiators, lens, etc.; the term "generator" refers to any structure from which an intended EMT may be generated, and includes by way of example only, oscillators, analog to digital outputs, fluorescing devices, light emitting diodes (inorganic and organic), etc.. The term "sensor" refers to any structure by which an intended EMT may be received, and includes by way of example only, RF antennas, wave guides, photo detectors, photon/electron cascade devices, etc.; the term "receptor" refers to any structure by which an intended EMT may be transformed from its native state to another state (preferably but not necessarily a state useful to the cycle and/or phase discrimination means), and includes by way of example only, hardware or algorithmic transformations into analog or digital representations of the wave and phase information.

In invention embodiments wherein wireless transmitter and receiver pair(s) is/are used in conjunction with PCM, the transmitter (integrated package or emitter) is placed at one location (arbitrarily labeled as a first point) and the receiver (integrated package or sensor) is placed at the other location (arbitrarily labeled as a second point). After initialization where a baseline waveform (or facsimile thereof) is obtained that is associated with a current spatial relationship between the transmitter and the receiver (emission, reception and processing of the first EMT), subsequent changes in spatial relationship between the transmitter and the receiver (emission, reception and processing of the subsequent EMTs) will result in waveforms (or facsimiles thereof) having comparative phase shifts with respect to the baseline waveform or any prior waveform. Comparison with a baseline waveform prevents spatial drift, which is a consequence of error compounding if comparisons with an immediately preceding waveform are undertaken. However, if the absolute range of possible spatial distance between the transmitter and the receiver is greater than one wavelength of the EMT, and if other means for accounting for zero crossing are not employed, then such comparisons may be appropriate, preferably in limited numbers, *e.g.*, periodic resetting of the baseline waveform.

To determine the degree of phase shift within a sample period, which is embodied in a delta value (δ), one series of PCM embodiments uses a signal comparator, which may be physically distinct from any other component or may be associated with existing components such as the receiver and/or transmitter. The comparator (also considered a signal processor) compares an initially acquired baseline signal derived from a transmitter/receiver pair to a subsequently obtained signal from the same pair to obtain a phase difference there between. During the next comparison cycle, the most recently acquired signal is preferably compared to the baseline signal, but may also be compared to any previous signal, and so on. At least one position value can be ascribed from each comparison cycle once a distance value x_n is determined, and such values can be mathematically exploited as required by any suitable receiving electronics, such as a computer.

The signal derived from the EMT received by the receiver must be delivered to the PCM in such embodiments. The mode of delivery can be either through wireless or wired (electrical or optical) means. Preferably, the derived signal is delivered via wired means so that the only variable introduced into the received signal derives from the spatial separation between the transmitter and receiver during the EMT transmission; if the delivery mode were wireless, one would need to account for a second variable introduced during such retransmission. Moreover, a wired return requires no additional power amplification and virtually eliminates issues pertaining to noise. As an incidental benefit, should the receiver have power requirements, a wired delivery means will provide a convenient opportunity for such delivery.

In many embodiments, a reference signal from the transmitter is delivered to the phase comparator through a wired interface (*e.g.*, copper wire or optical cable), where after the comparator combines its received wireless signal with the reference signal to generate either an analog signal representing the addition of the two waveforms, or a value derived from the comparison (the value may be derived via digital or analog means). This signal combining serves to normalize the comparable waveforms and remove signal artifacts that may otherwise negatively affect the resolution of phase comparisons.

The previously described embodiments have generally referenced only a single transmitter/receiver pair (whether unique or shared). Additional invention embodiments utilize a plurality of shared transmitter/receiver pairs to provide precise spatial position information in, for example, environmentally/structurally unconstrained systems. In such systems the acquisition and registration of multiple displacements between point/location pairs having a common point/location allows the determination of relative positions in trhee dimensions or full six degrees of freedom. An example of 3-D position determination is a digital glove with four transmitting antennas arranged radially around the wrist and a receiving antenna at a finger tip. The displacements (changes in distance) between the transmitting antennas around the wrist and the receiving antenna on the fingertip can then be geometrically integrated to determine the absolute Cartesian coordinate of the finger tip, preferably by a computing system receiving the generated data.Many invention embodiments find particular utility with respect to understanding and/or emulating position and/or movement of biologic joints. Applications include medical analysis, diagnostics and therapy; anatomic virtualization for medical and entertainment purposes; position/motion study in the field of Kinesthetics and Kinesiology; and similar fields of endeavor. As such, it is important to understand the environment in which the position and/or motion data is obtained.

Articulated joints in biologic structures comprise two fundamental types: linear and compound (also referred to herein as "complex"). Linear joints are generally constrained to intended movement in two dimensions (*e.g.*, planar gliding, hinged or pivoting) while compound joints rotary and ball-and-socket, for example, have the ability to undergo intended movement in all three dimensions. To determine an angle of a single linear joint or the position of a point of interest affected by the angle of the single linear joint, one need only know the joint's initial state (from which angular information can be obtained through geometric approximations) and establish a first reference location on a first extension from the joint and a second reference location, preferably but not necessarily, on a second extension from the joint to obtain first position data for the first reference location. With knowledge that the joint's range of motion is planar in nature, and of any subsequent spatial position of the first reference location, the angle of the joint can be determined. A similar approach can be used with respect to compound joints, but in three dimensions as opposed to two.

In many biologic structures, a structure of interest may have multiple joints operating concurrently for a single purpose. For example, in the human hand, a digit has a single knuckle joint (compound) and two phalange joints (linear), and each hand has four digits. In addition, a human hand has an opposable thumb, which has a single knuckle joint (compound) and a single phalange joint (linear). However, most movements of the hand are directed to grasping actions, wherein the movements of the phalanges generally follow a predictable range of motion (constrained movement) relative to the degree of adduction by the digit knuckles.

The reverse motions, abductions, are similarly predictable. Thus, an approximation of the complex (multiple) joint movements for each digit in simple grasping actions can be ascertained by assessing the degree of digit ab/adduction (angular change) at any joint, but preferably by assessing the degree of digit movement at joints that will undergo angular change during the entire range of motion.

In addition to the foregoing, a range of motion in a constrained linear multiple joint system can be exploited to acquire relative joint states by assessing the distance between a distal portion or location of the multiple joint system and a proximal portion or location of the system. The distal portion is a location along a joint extension preferably furthest from the proximal portion, and the proximal portion is a location along a joint extension preferably furthest from the distal portion. In such an arrangement, all joints in the system are between the distal and proximal locations, and a change in the distance between the distal and proximal locations during at least part of the range of constrained movements involves predictable articulation of the included joints. By assigning angular values to each joint in the constrained linear multiple joint system based on each discrete proximal-distal distance value (or establishing a suitable algorithm that yields similar information), an approximation of the joint system state at any given proximal-distal distance value can be established from a limited dataset. A similar approach can be used for constrained compound multiple joint systems, although several planes and iterations will need to be computed, as will be appreciated by the skilled practitioner.

In all invention embodiments, electrical power must be delivered to the transmitter. While embodiments of the invention contemplate the exploitation of a distributed energy delivery environment, such as by microwaves, conventional power sources are considered preferred for near-term implementation, and include traditional forms of portable energy storage devices such as chemical batteries, whether single use or rechargeable. Such storage devices may be co-located with the transmitter, the receiver, and/or the spatial determination means, or may be located physically remote there from, as design considerations dictate. In many embodiments, signal processing will be local with respect to one or a group of transmitters, which thereby minimizes the need for power distribution.

While centralizing power consuming components of system embodiments of the invention will enhance power consumption efficiency, additional efficiencies can be obtained through system optimizations. One such enhancement comprises the use of means for establishing directional signal gain to reduce noise and power consumption. If the range and/or degree of relative movement between a transmitter/receiver pair is known, for example when constrained by structure or environment, a directional signal (singular or plural) can be used without material concern over possible lost data. Cost effective implementations of such enhancements include the use of standardized directional emitters (if the EMT is not already directional in nature) intelligently positioned on the locations of interest. Alternatively or in conjunction there with, standardized directional detectors can similarly be intelligently positioned on the locations of interest.

Another means for enhancing efficiency of system embodiments comprises serial or sequential operation of transmitter/receiver pairs. In addition to decreasing maximum current requirements that would otherwise be encountered with parallel transmission/reception embodiments, such an arrangement and operation minimizes possible multipath and signal rejection requirements. Additionally, a serial architecture can be employed as opposed to a parallel processing architecture, further reducing manufacturing and operation costs and overhead.

Yet another means for enhancing efficiency of system embodiments as well as reducing multipath and noise issues comprises matching the output power for at least some transmitters to the least possible value while still retaining desired functionality. This feature can be hard coded into the invention embodiment or adaptive depending, for example, upon a feedback function. In addition to, or in the alternative, frequency selection can be made with this consideration in mind (*e.g.*, certain RF frequencies have tissue penetrating abilities, which would be considered undesirable unless all but the intended receiver were inactive). Spread spectrum applications can also significantly decrease noise while maximizing resolution.

While certain invention embodiments contemplate housing the SDM with one of the transmitter and/or receiver, other embodiments "outsource" such computational requirements. Thus, embodiments of the invention may comprise communication means for transmitting signal data wherein the signal data may comprise the analog and/or a digitized facsimile or approximation of the signal. These communication means may be wired and/or wireless embodiments, wherein the wired embodiments may comprise electrical or optical transmission mediums.

The various invention embodiments are particularly suited for use in the field of position and/or motion emulation in a virtual environment, and more particularly in the area of computer generated amusement gaming. In such an application environment, an embodiment for instrumenting a body suit or jacket comprises a thin disk, preferably having a diameter of about 7.5 to 10cm, with 4 opposing receiving antennas on its edge. The disk further comprises a transmitter, controller, battery, storage and other electronics disposed in the middle of the disk, and the disk mounted between a user's shoulders.

A glove embodiment incorporating the invention comprises a wristband portion having suitable controller, battery, storage and other electronics located there about and further comprising at least 3 and preferably 4 antennas positioned on either side, and top and bottom of the glove. Transmitting antennas are preferably located at each finger tip and the middle of the back of the hand. This configuration gives absolute positioning of the finger tips and hand position. Intermediate joint positions would be determined using standard kinematic inferences resulting from a constrained system, as noted earlier.

For purposes of this patent and where applicable, the terms "area", "boundary", "part", "portion", "surface", "zone", and their synonyms, equivalents and plural forms, as may be used herein and by way of example, are intended to provide descriptive references or landmarks with respect to the article and/or process being described. These and similar or equivalent terms are not intended, nor should be inferred, to delimit or define per se elements of the referenced article and/or process, unless specifically stated as such or facially clear from the several drawings and/or the context in which the term(s) is/are used.

Brief Description of the Drawings

Fig. 1 is a functional schematic illustrating the basic components of a system embodiment of the invention;

Fig. 2 is an illustrative schematic of the RF amplifier and splitter referenced in the functional schematic of Fig. 1;

Fig. 3 is an illustrative schematic of oscillator referenced in the functional schematic of Fig. 1;

Fig. 4 is an illustrative schematic of the RF amplifier limiter referenced in the functional schematic of Fig. 1;

Fig. 5 is an illustrative schematic of the RF amplifier1 referenced in the functional schematic of Fig. 1;

Fig. 6 is an illustrative schematic of the phase comparator referenced in the functional schematic of Fig. 1;

Fig. 7 illustrates a torso-adapted embodiment of the invention wherein a centralized SDM is collocated with four transmitters and operatively linked to six distributed receivers; and

Fig. 8 illustrates a hand-adapted embodiment of the invention wherein a centralized SDM is generally collocated with four transmitters and operatively linked to six distributed receivers.

Description of Invention Embodiments

Preface: The terminal end of any numeric lead line in the several drawings, when associated with any structure or process, reference or landmark described in this section, is intended to representatively identify and associate such structure or process, reference or landmark with respect to the written description of such object or process. It is not intended, nor should be inferred, to delimit or define per se boundaries of the referenced object or process, unless specifically stated as such or facially clear from the drawings and the context in which the term(s) is/are used. Unless specifically stated as such or facially clear from the several drawings and the context in which the term(s) is/are used, all words and visual aids should be given their common commercial and/or scientific meaning consistent with the context of the disclosure herein.

With the foregoing in mind, the following description is presented to enable a person skilled in the art to make and use the claimed invention. Various modifications to the described embodiments will be readily apparent to those skilled in the art, and the generic principles disclosed herein may be applied to other embodiments and applications thereof without departing from the spirit and scope of the present invention, as defined by the appended claims. Thus, the claimed invention is not intended to nor should be limited to the disclosed and/or described embodiments, but is to be accorded the widest scope consistent with the principles and features disclosed herein.

The invention embodiments described below are generally adapted for use in motion capture environments such as might be encountered for input of data in a computer/console gaming application. First, generic system hardware and its operation will be described, and then the implementation of a hardware embodiment of the invention to an environment will be described.

The basic elements of a generic motion capture system 10, as illustrated in Fig. 1, comprise computer 20, controller 30, RF amplifier/splitter 40, oscillator 50, Tx antennas 60, RF limiter/amplifier 70, Rx antennas 80 and phase comparator 90. For simplicity, motion capture system is shown configured as a "black box" wherein all components thereof but computer 10, primary power supply 22, Tx antennas 60 and Rx antennas 80 are located therein. As noted in the Summary of the Invention section and elsewhere, the various components comprising system 10 can be grouped in various combinations depending upon both design considerations as well as environmental constraints.

All of the previously referenced components of motion capture system 10 are operatively coupled to each other as shown in Fig. 1, in a manner well understood by the skilled practitioner. And while the general description of each component should be sufficient for the skilled practitioner to make and use the presently disclosed invention, Figs. 2-6 are offered to further enable the invention. In particular, schematic detail for RF amplifier/splitter 40 is shown in Fig. 2, schematic detail for oscillator 50 is shown in Fig. 3, schematic detail for RF limiter/amplifier 70 is shown in Figs. 4 and 5, and schematic detail for phase comparator 90 is shown in Fig. 5.

The remaining illustrated components will now be described for completeness. Power supply 22 is preferably a self-contained, high power density rechargeable battery such as a lithium-ion battery, which delivers 12VDC current, with or without conditioning or regulation, to power distribution bus 36. From here, 12 VDC current is delivered to the various components: to transformer 38, which delivers regulated 8VDC current to controller 30; to amplifier/splitter 40, oscillator 50, limiter/amplifier 70, and phase comparator 90; and to switch 34, which is operatively controlled by controller 30. Controller 30 is, in turn, preferably a general purpose microcomputer, which is operatively linked with computer 20 having a suitable software application to enable operation of controller 30 as desired. Controller 30 also causes selective operation of RF relay drivers 64 and 84, which in turn selectively operate RF relays 62 for transmitting antennas 60 and RF relays 82 for receiving antennas 80. In addition to the aforementioned functions, controller 30 also receives analog signal phase information from phase comparator 90, and RSSI analog and state information from RF limiter/amplifier 70.

Turning then to Fig. 7, an exemplary implementation of the system illustrated in Figs. 1-6 is shown. In this implementation, system 100 comprises housing 110 attached to a person's torso by straps 112. Located in housing 110 is a suitable power source, memory and the electronic components identified in system 10 (note that six receiving antennas are shown as opposed to four as in Fig. 1). Extending from housing 110 are two electrically conductive wires 112a and 112b, which are operatively coupled to respective receiving antennas R1 – R6.

In operation, emitters E1, E2, E3, and E4 are arranged radially around housing 110. Receiving antennas R1, R2, R3, R4, R5, R6 are located at the points of articulation of the user, namely the wrists (R1 and R6), the elbows (R2 and R5) and the shoulder joints (R3 and R4). After energizing system 100, a known base pose is adopted, for example the pose shown in Fig. 7, and a start signal is sent to controller 30 (this may be as simple as a current emanating from a switch).

Controller 30 then selects a single receiving antenna, *e.g.*, R1, and activates an emitter, *e.g.*, E1. These actions create a first transmitter/receiver pair. The phase of the received signal is determined by phase comparator 90, time stamped and recorded to memory as the base value for the E1 - R1 pair. Emitter E1 is then disabled and emitter E2 is enabled. This creates a second transmitter/receiver pair, which is further characterized as a shared pair since receiving antenna R1 is common to both pairs. A base value is then recorded for the E2 - R1 pair in the same manner as for the E1 - R1 pair. This process continues until base values for En – R1 are obtained, where "n" is the total number of emitters in the shared pairs, *e.g.*, "n" = "4". Once the base values for each pair in the shared pairs for R1 are recorded, the same actions are preformed on each additional receiving antenna in turn, using the same four emitters. Once the base values are established for all viable transmitter/receiver pairs, spatial determination polling commences.

The same methodology for establishing base values for each pair applies to spatial determination polling. In this case, however, value comparisons between temporally distinct data sets takes place to ascertain changes in spatial separation; the phase of any subsequently received signal in a given pair may be compared against the stored base value phase for that pair, and a physical displacement, if any, may be calculated and stored.

The Cartesian coordinates of each receiving antenna Rn may be established by first determining a model space in which the positions of Rn and E1-4 are known for a given base pose. Then by integrating the displacements between a receiving antenna R and the four emitters E1-4 through a geometric formula such as the following, the absolute spatial position of the receiving antenna R within the model space can then be calculated or approximated.

$$z = -\frac{(x_B-x_C)((y_B-y_C)(x_C-x_D)-(y_C-y_D)(x_B-x_C))}{2\{(z_A-z_B)(x_B-x_C)((y_B-y_C)(x_C-x_D)-(y_C-y_D)(x_B-x_C))-(z_B-z_C)(x_A-x_B)((y_B-y_C)(x_C-x_D)-(y_C-y_D)(x_B-x_C))-(z_B-z_C)(x_C-x_D)((y_A-y_B)(x_B-x_C)-(y_B-y_C)(x_A-x_B))+(z_C-z_D)(x_B-x_C)((y_A-y_B)(x_B-x_C)-(y_B-y_C)(x_A-x_B))\}}\Big[D_A^2 - D_B^2 - \frac{(x_A-x_B)}{(x_B-x_C)}(D_B^2-D_C^2) - \frac{(x_C-x_D)((y_A-y_B)(x_B-x_C)-(y_B-y_C)(x_A-x_B))}{(x_B-x_C)((y_B-y_C)(x_C-x_D)-(y_C-y_D)(x_B-x_C))}\Big(D_B^2-D_C^2-\frac{(x_B-x_C)}{(x_C-x_D)}(D_C^2-D_D^2)\Big) - X_A^2 + X_B^2 - Y_A^2 + Y_B^2 - Z_A^2 + Z_B^2 + \frac{(x_A-x_B)}{(x_B-x_C)}(X_B^2-X_C^2+Y_B^2-Y_C^2+Z_B^2-Z_C^2) + \frac{(x_C-x_D)((y_A-y_B)(x_B-x_C)-(y_B-y_C)(x_A-x_B))}{(x_B-x_C)((y_B-y_C)(x_C-x_D)-(y_C-y_D)(x_B-x_C))}\Big(X_B^2-X_C^2+Y_B^2-Y_C^2+Z_B^2-Z_C^2-\frac{(x_B-x_C)}{(x_C-x_D)}(X_C^2-X_D^2+Y_C^2-Y_D^2+Z_C^2-Z_D^2)\Big)\Big]$$

In system 100, the base and polling data are preferably communicated to a remotely located computer for numerically intensive activity either wirelessly in approximate real time, or by physical transfer of memory. Examination of the timestamps of the positional data can be used to determine velocity and acceleration if so desired.

Figure 8 provides a similar system approach to the instrumenting of a human hand through the use of a glove. As can be seen, the only material difference between system 100 of Fig. 7 and system 200 of Fig. 8 concerns the nature of housing 210 and strap 212. All other components remain relatively unchanged, although due to issues pertaining to scale, battery size and other physically determined components may vary. As a consequence, economies of scale can be realized through reduced parts inventories and interchangeable componentry.

WHAT IS CLAIMED:

1. Method for wirelessly determining a change in relative spatial relationship between a first location and a second location using a paired transmitter/receiver comprising:

emitting a first electromagnetic transmission from the first location;

receiving the first electromagnetic transmission at the second location;

establishing a first value (value can be a signal (unprocessed), binary value or analog formula as in a sine wave with time domain knowledge (processed or unprocessed)) comprising data encoding a first spatial relationship between the first location and the second location;

emitting a second electromagnetic transmission from the first location;

receiving the second electromagnetic transmission at the second location;

establishing a second value comprising data encoding a second spatial relationship between the first location and the second location; and

comparing the first and second values to establish a delta value (δ) comprising information relating to a plurality of possible changes in the relative spatial relationship between the two locations.

2. The method of claim 1 further comprising selecting a single spatial change value using known environment or intrinsic constraints between the two locations.

3. The method of any previous claim further comprising finding a distance value (xn) from the delta value (δ) where "n" represents an integer corresponding to any one of the plurality of possible changes in the relative spatial relationship between the two locations.

4. The method of any previous claim further comprising finding a single distance value (x) from the delta value (δ) wherein the distance value (x) is selected using known environment or intrinsic constraints in movement between the two locations.

5. The method of any previous claim wherein the comparison of the first and second values comprises spatial determination means.

6. The method of claim 5 wherein the spatial determination means comprises phase comparison means, power differential means, or both phase comparison means and power differential means.

7. The method of claim 6 wherein the first electromagnetic transmission and the second electromagnetic transmission are at substantially the same frequency, and wherein the first value includes phase information of the first electromagnetic transmission and the second value includes phase information of the second electromagnetic transmission, and comparing the first and second values comprises determining a first difference in phase there between.

8. The method of claim 6 wherein the first electromagnetic transmission and the second electromagnetic transmission have substantially the same energy density, and wherein the first value includes energy density information of the first electromagnetic transmission and the second value includes energy density information of the second electromagnetic transmission, and comparing the first and second values comprises determining a first difference in energy density there between.

9. The method of claim 5 wherein the receiver is operatively coupled with the spatial determination means by a conductive wire, an optical fiber, or both a conductive wire and an optical fiber.

10. The method of any previous claim wherein the locations comprise biologic structures.

11. Method for wirelessly determining a change in relative spatial relationship between a first location and a second location, and the first location and a third location using two shared transmitter/receiver pairs comprising:

a) emitting a first electromagnetic transmission from the first location and receiving the first electromagnetic transmission at the second location;

b) establishing a first value (value can be a signal (unprocessed), binary value or analog formula as in a sine wave with time domain knowledge (processed or unprocessed)) comprising data encoding a first spatial relationship between the first location and the second location;

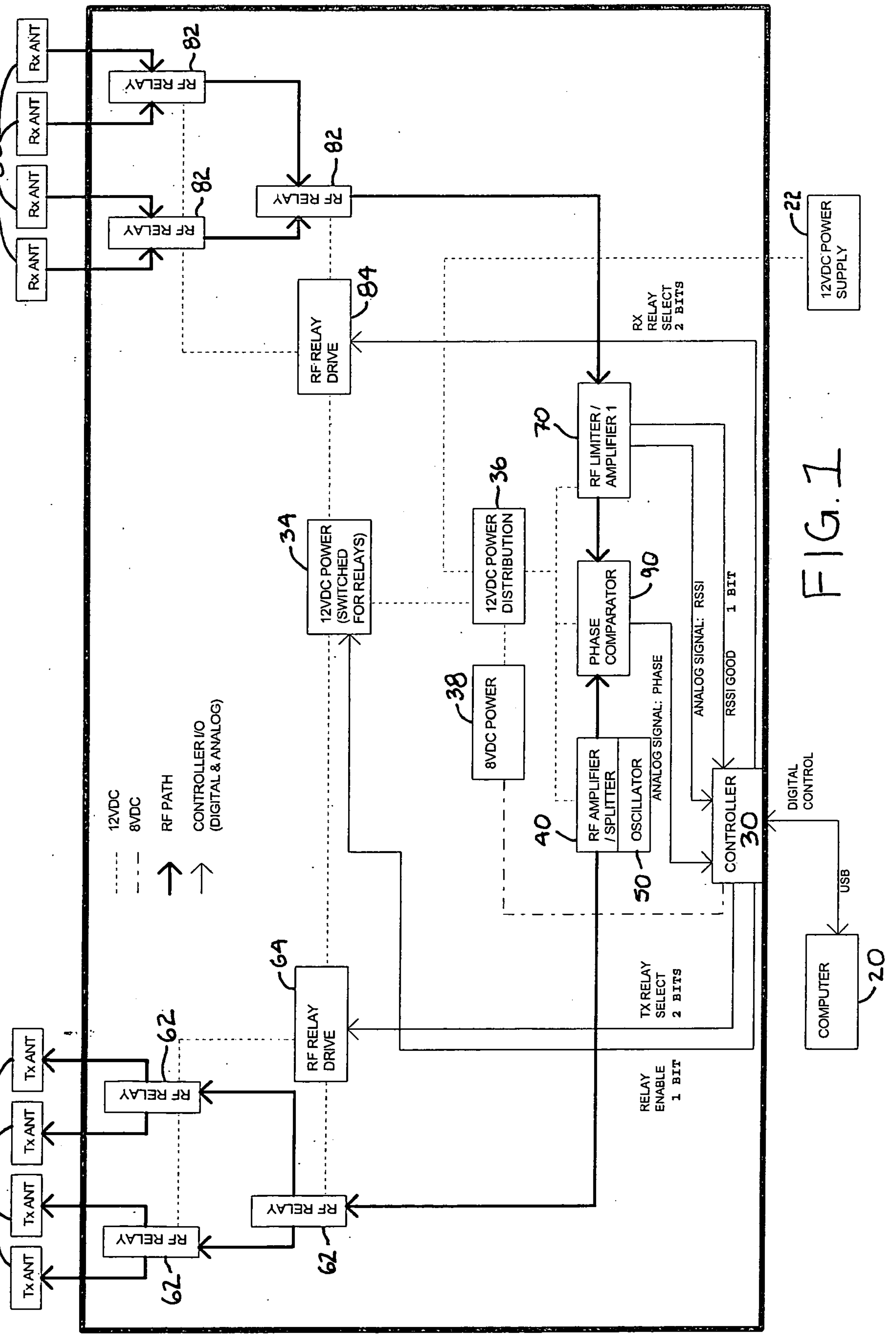
c) emitting a first electromagnetic transmission from the third location and receiving the first electromagnetic transmission at the second location prior to material movement of the second location relative to either the first or third location;

d) establishing a second value comprising data encoding a first spatial relationship between the second location and the third location;

e) repeating a) and b) with a second electromagnetic transmission and establishing a third value comprising data encoding a second spatial relationship between the first location and the second location;

f) repeating c) and d) with a second electromagnetic transmission and establishing a fourth value comprising data encoding a second spatial relationship between the second location and the third location; and

g) comparing the first and second values to establish a first delta value (δ) comprising information relating to a plurality of possible changes in the relative spatial relationship between the first and second locations, and comparing the third and fourth values to establish a second delta value (δ) comprising information relating to a plurality of possible changes in the relative spatial relationship between the second and third locations.


Rx ANT
Rx ANT
Rx ANT
Rx ANT
80
RF RELAY
82
RF RELAY
82
RF RELAY
82
RF RELAY DRIVE
84
12VDC POWER SUPPLY
22
RX RELAY SELECT 2 BITS
RF LIMITER / AMPLIFIER 1
70
12VDC POWER DISTRIBUTION
36
12VDC POWER (SWITCHED FOR RELAYS)
34
PHASE COMPARATOR
90
ANALOG SIGNAL: RSSI
RSSI GOOD 1 BIT
8VDC POWER
38
RF AMPLIFIER / SPLITTER
40
OSCILLATOR
50
ANALOG SIGNAL: PHASE
CONTROLLER
30
DIGITAL CONTROL
USB
COMPUTER
20
12VDC
8VDC
RF PATH
CONTROLLER I/O (DIGITAL & ANALOG)
RF RELAY DRIVE
64
TX RELAY SELECT 2 BITS
RELAY ENABLE 1 BIT
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62
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Tx ANT
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Tx ANT
Tx ANT
60

FIG. 1

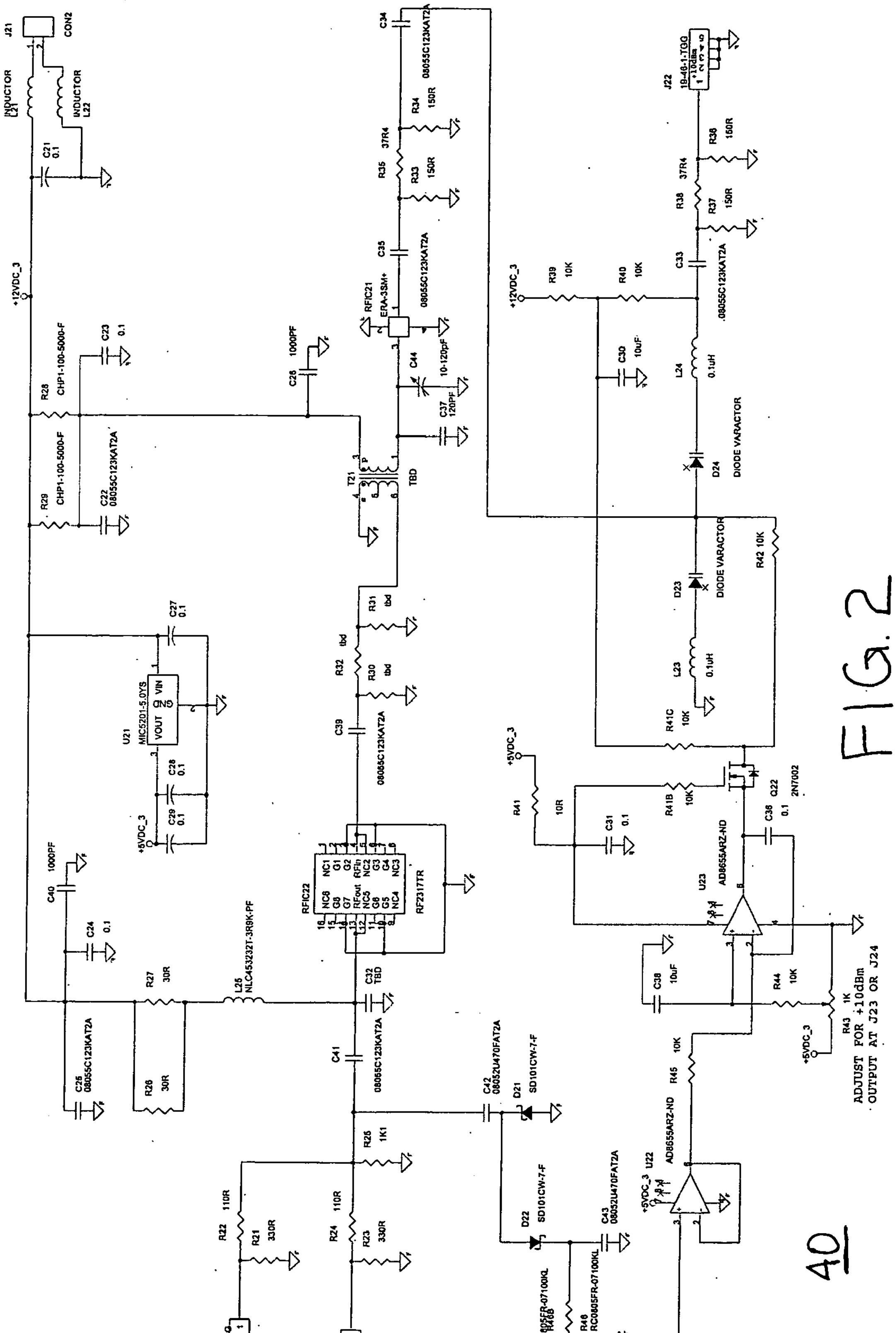


FIG. 2

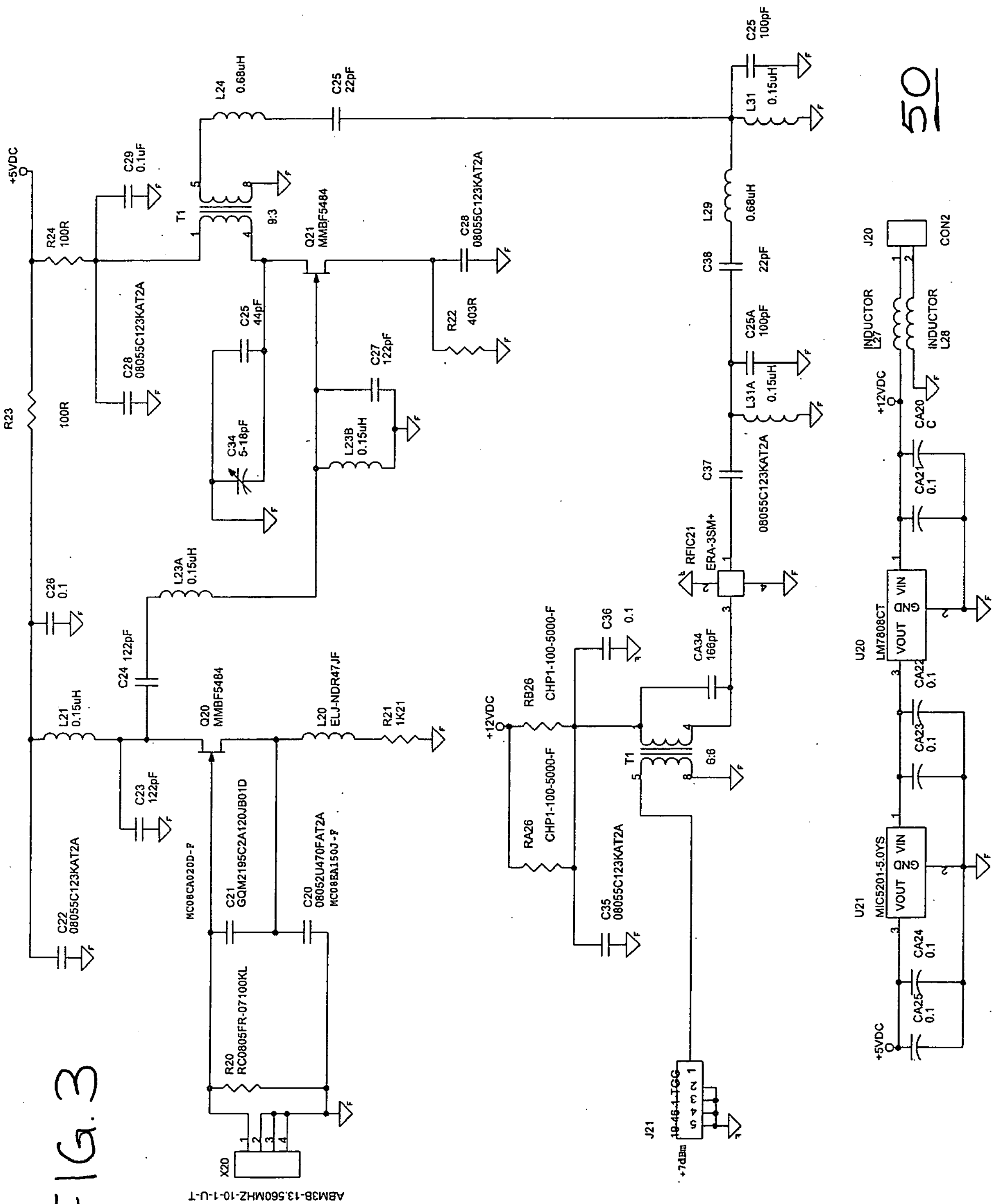

50
+5VDC
R24 100R
C29 0.1uF
T1
9:3
L24 0.68uH
C25 22pF
C25 100pF
L31 0.15uH
L29 0.68uH
C38 22pF
C25A 100pF
L31A 0.15uH
C37 08055C123KAT2A
RFIC21 ERA-3SM+
Q21 MMBF5484
C28 08055C123KAT2A
R22 403R
C25 44pF
C27 122pF
C34 5-18pF
L23B 0.15uH
L23A 0.15uH
R23 100R
C26 0.1
C24 122pF
L21 0.15uH
Q20 MMBF5484
L20 ELJ-NDR47JF
R21 1K21
C23 122pF
C22 08055C123KAT2A
C21 GQM2195C2A120JB01D
C20 08052U470FAT2A
MC08CA020D-P
MC08EA150J-P
R20 RC0805FR-07100KL
X20
ABM3B-13.560MHZ-10-1-U-T
+12VDC
RB26 CHP1-100-5000-F
RA26 CHP1-100-5000-F
C36 0.1
C35 08055C123KAT2A
CA34 166pF
6:6
J21
19-46-1-TGG
+7dBm
J20 CON2
INDUCTOR L27
INDUCTOR L28
+12VDC
CA20 C
CA21 0.1
U20 LM7808CT
VOUT GND VIN
CA22 0.1
CA23 0.1
U21 MIC5201-5.0YS
CA24 0.1
CA25 0.1
+5VDC

FIG. 3

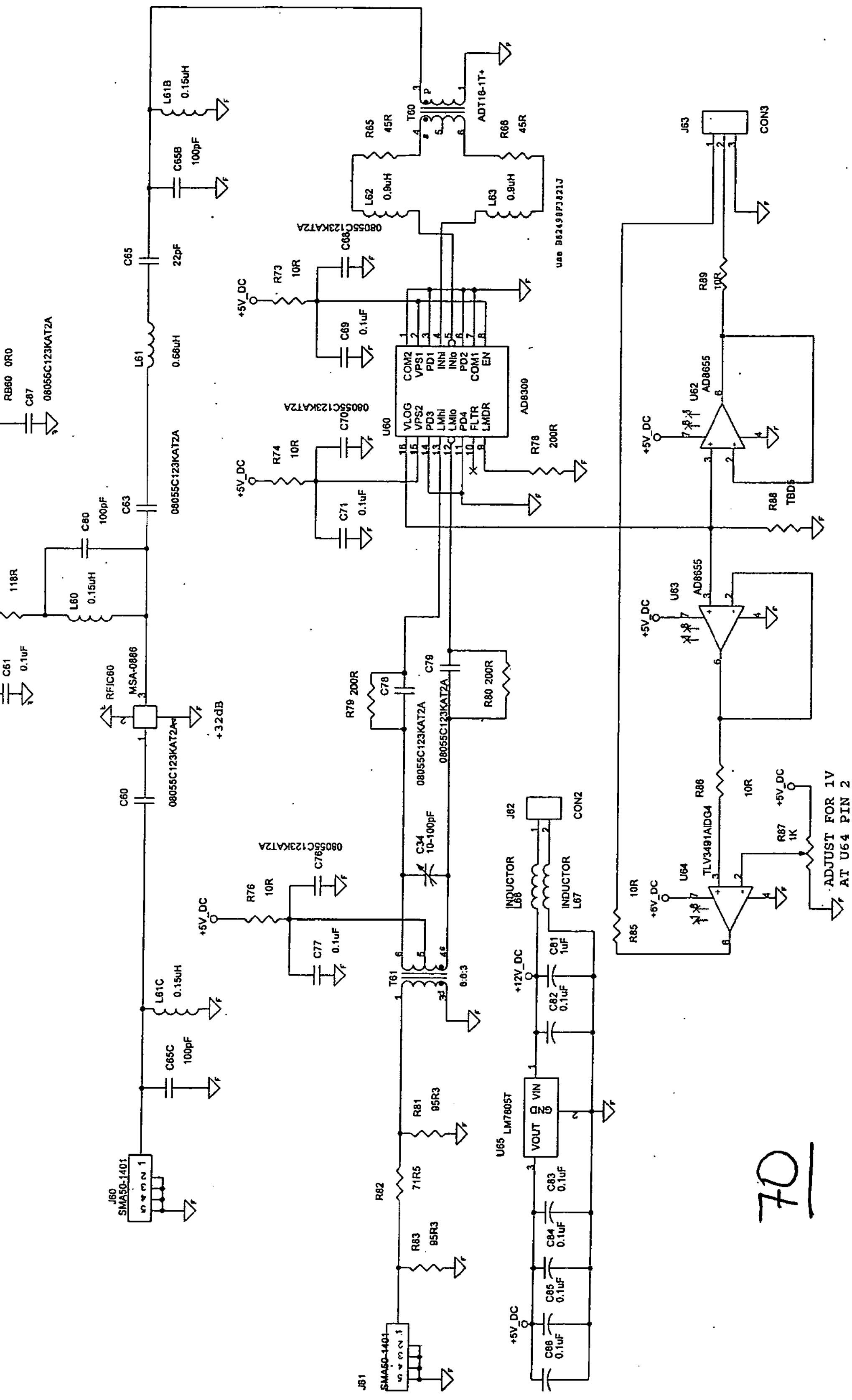

+12V_DC
RB60 0R0
C87 0805SC123KAT2A
RA60 118R
C61 0.1uF
L60 0.15uH
C80 100pF
C63 0805SC123KAT2A
L61 0.68uH
C65 22pF
C65B 100pF
L61B 0.15uH
RFIC60 MSA-0886
+32dB
C60 0805SC123KAT2A
L61C 0.15uH
C65C 100pF
J60 SMA50-1401
+5V_DC
R73 10R
C68 0805SC123KAT2A
C69 0.1uF
R74 10R
C70 0805SC123KAT2A
C71 0.1uF
U60 AD8309
COM2 VPS1 PD1 INHI INLO PD2 COM1 EN
VLOG VPS2 PD3 LMHI LMLO PD4 FLTR LMDR
R78 200R
R65 45R
R66 45R
L62 0.9uH
L63 0.9uH
T60 ADT16-1T+
R79 200R
C78
C79
R80 200R
C34 10-100pF
R76 10R
C76 0805SC123KAT2A
C77 0.1uF
T61 6:6:3
R81 95R3
R82 71R5
R83 95R3
J61 SMA50-1401
J63 CON3
R89 10R
U62 AD8655
R88 TBD
U63 AD8655
R86 10R
U64 TLV3491AIDG4
R87 1K
ADJUST FOR 1V AT U64 PIN 2
R85 10R
J62 CON2
INDUCTOR L68
INDUCTOR L67
C81 1uF
C82 0.1uF
U65 LM7805T
VIN GND VOUT
C83 0.1uF
C84 0.1uF
C85 0.1uF
C86 0.1uF

FIG. 4

7D

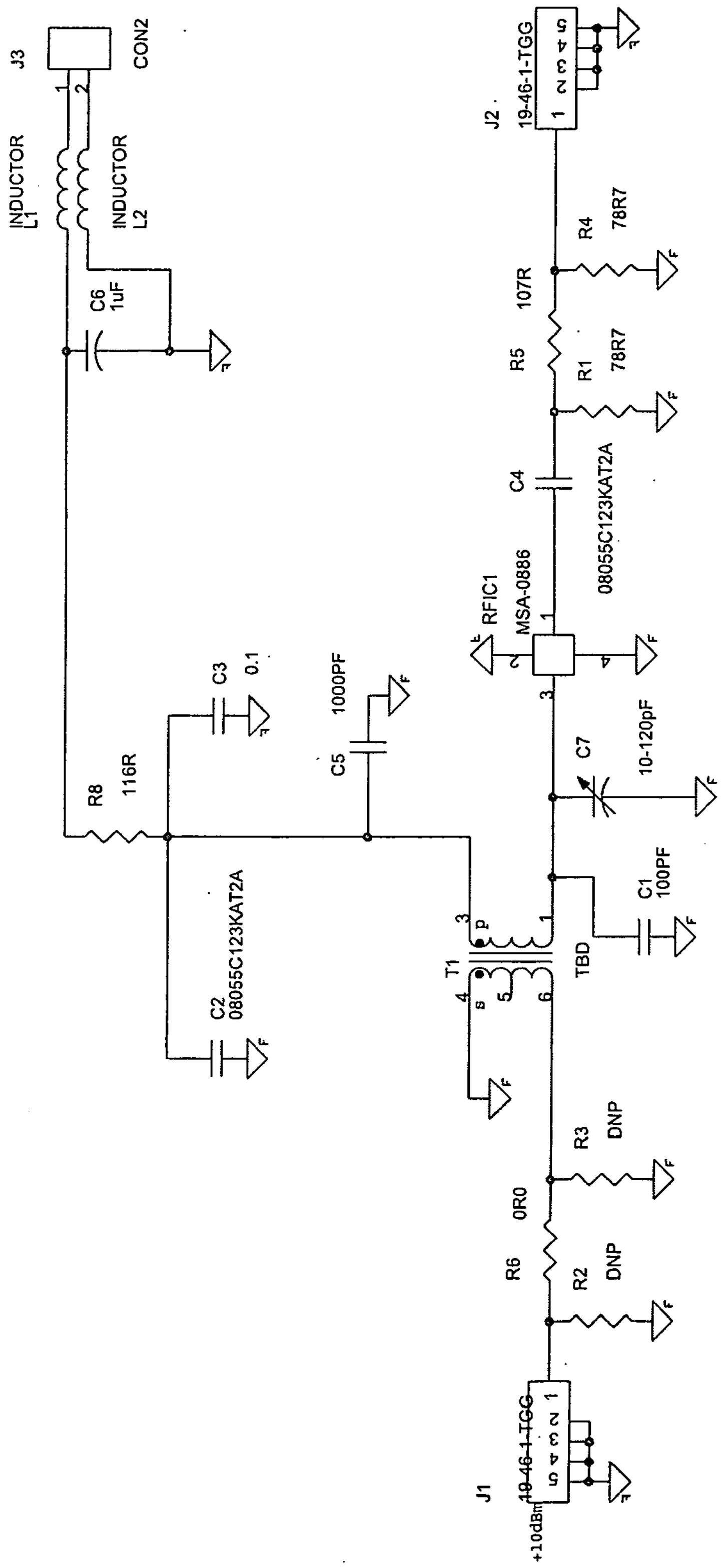
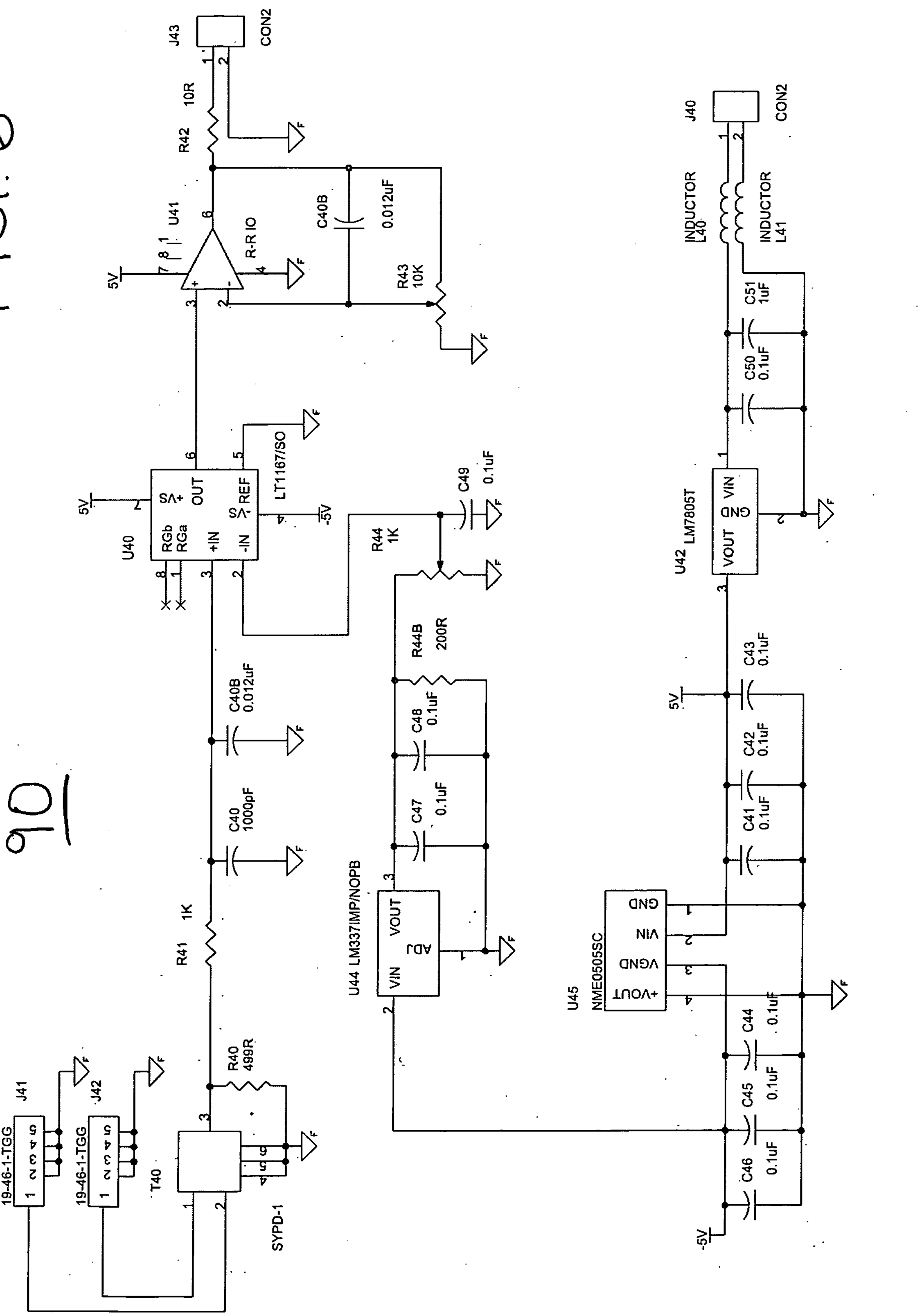

J3
CON2
INDUCTOR L1
INDUCTOR L2
C6 1uF
R8 116R
C3 0.1
C5 1000PF
C2 08055C123KAT2A
T1
TBD
C1 100PF
C7 10-120pF
RFIC1 MSA-0886
C4 08055C123KAT2A
R5 107R
R1 78R7
R4 78R7
J2 19-46-1-TGG
R6 0R0
R2 DNP
R3 DNP
J1 19-46-1-TGG
+10dBm

FIG. 5

70

FIG. 6


90
J43
CON2
R42
10R
U41
R-R IO
5V
C40B
0.012uF
R43
10K
U40
LT1167/SO
RGb
RGa
+IN
-IN
+VS
-VS
OUT
REF
-5V
C49
0.1uF
R44
1K
R44B
200R
C48
0.1uF
C47
0.1uF
U44 LM337IMP/NOPB
VIN
VOUT
ADJ
C40
1000pF
R41
1K
R40
499R
T40
SYPD-1
J41
J42
19-46-1-TGG
J40
INDUCTOR
L40
L41
C51
1uF
C50
0.1uF
U42
LM7805T
VIN
GND
VOUT
C43
0.1uF
C42
0.1uF
C41
0.1uF
U45
NME0505SC
GND
VIN
VGND
+VOUT
C44
0.1uF
C45
0.1uF
C46
0.1uF

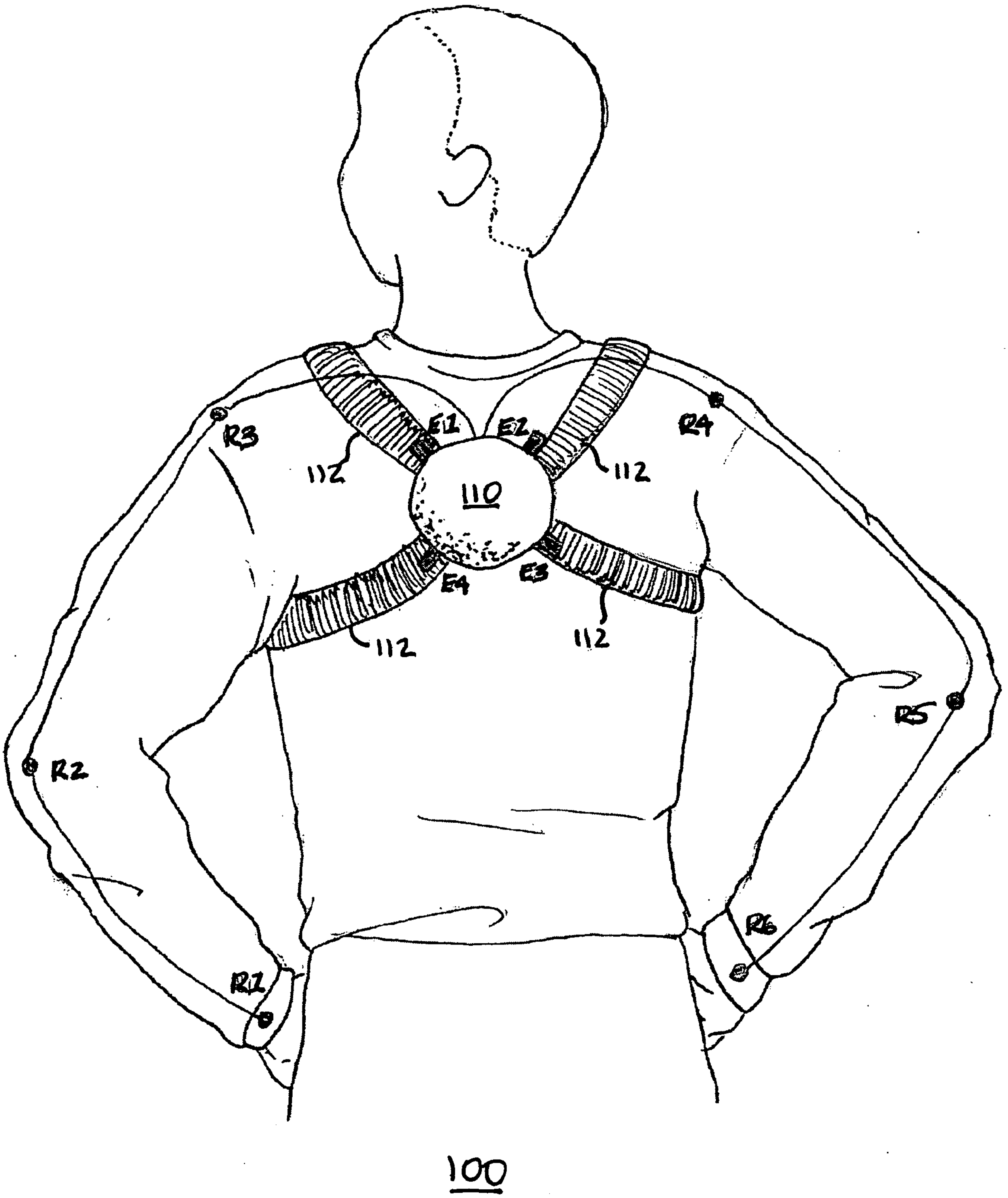


FIG. 7

FIG. 8