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**Schmidt et al.**

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[54] **PROGRAMMABLE WIRELESS DATA ACQUISITION SYSTEM**

[75] Inventors: **Robert N. Schmidt**; **Donald C. Ferencz**, both of Cleveland; **Steven P. Hendrix**, Sagamore Hills, all of Ohio

[73] Assignee: **Cleveland Medical Devices Inc.**, Cleveland, Ohio

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[51] **Int. Cl.**[7] ..... **H04M 3/00**; H04M 11/00; H04Q 7/20; G08L 19/16

[52] **U.S. Cl.** ..... **455/419**; 455/418; 455/423; 340/870.01; 379/106.01

[58] **Field of Search** ..... 600/301, 300; 340/870.01, 500, 573, 573.1; 128/903; 455/423, 419, 418, 420, 35.1, 68, 69, 70, 71, 72, 88; 379/106.01, 106.02, 106.03

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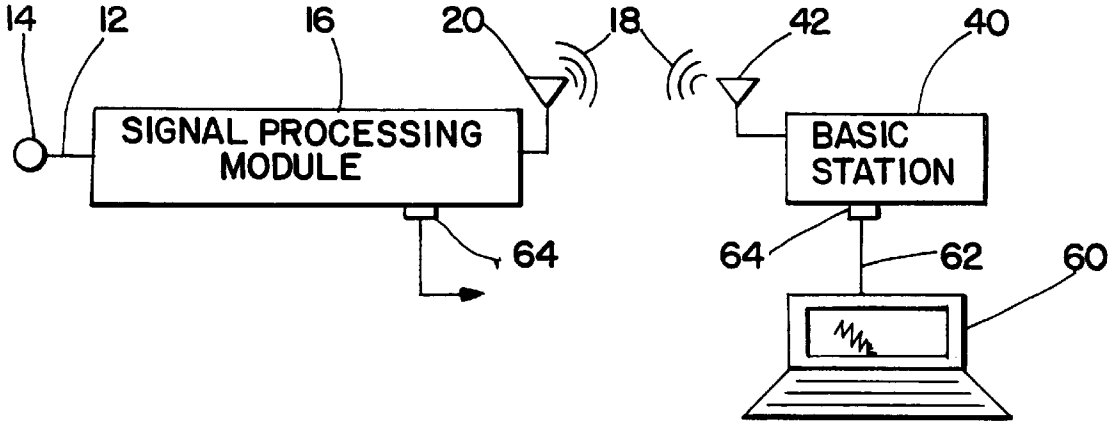
*Primary Examiner*—Nay Maung
*Assistant Examiner*—Raymond B. Persino

[57] **ABSTRACT**

A programmable wireless data acquisition system, comprising a transmitting device and a receiving device. The transmitting device is capable of receiving multiple external inputs and generating and transmitting a radio frequency signal encoded with data corresponding to the inputs. The transmitting device is variably configurable to enable it to accept inputs having different characteristics and ranges and to enable it to provide variable sampling rate, gain and filtering of the inputs. The transmitting device having a microprocessor such that the microprocessor controls the operation thereof. The receiving device is capable of receiving the radio frequency signal, demodulating it and decoding the data. The receiving device has a microprocessor such that the microprocessor controls the operation thereof. External programming device programs the transmitting device and the receiving device by wired connection or through radio frequency signal.

**7 Claims, 4 Drawing Sheets**



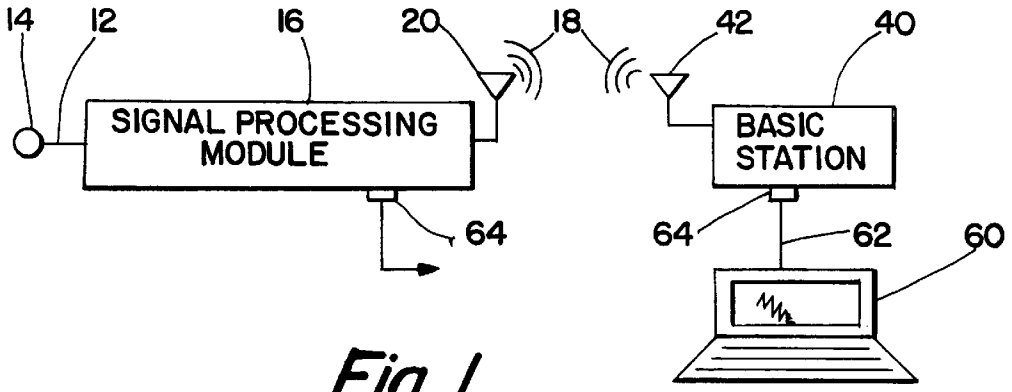



Fig. 1

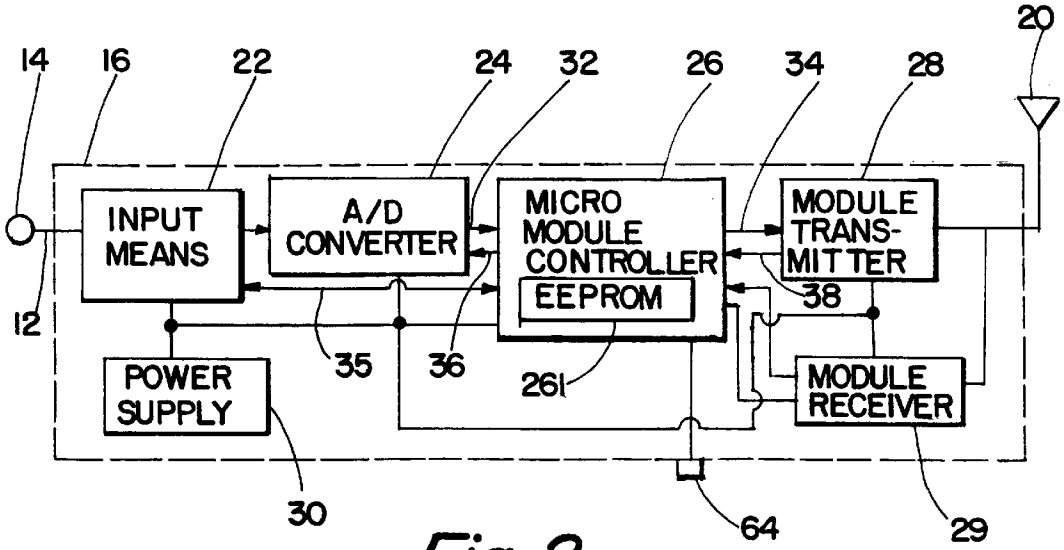



Fig. 2

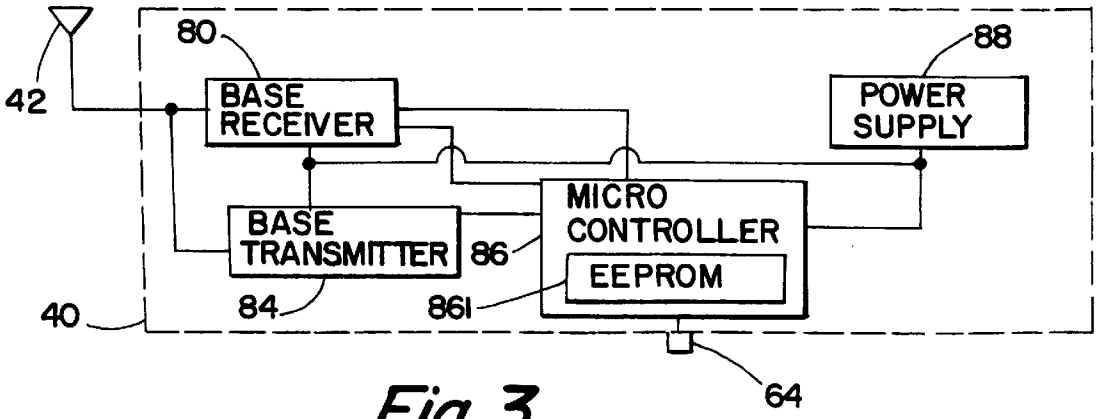



Fig. 3

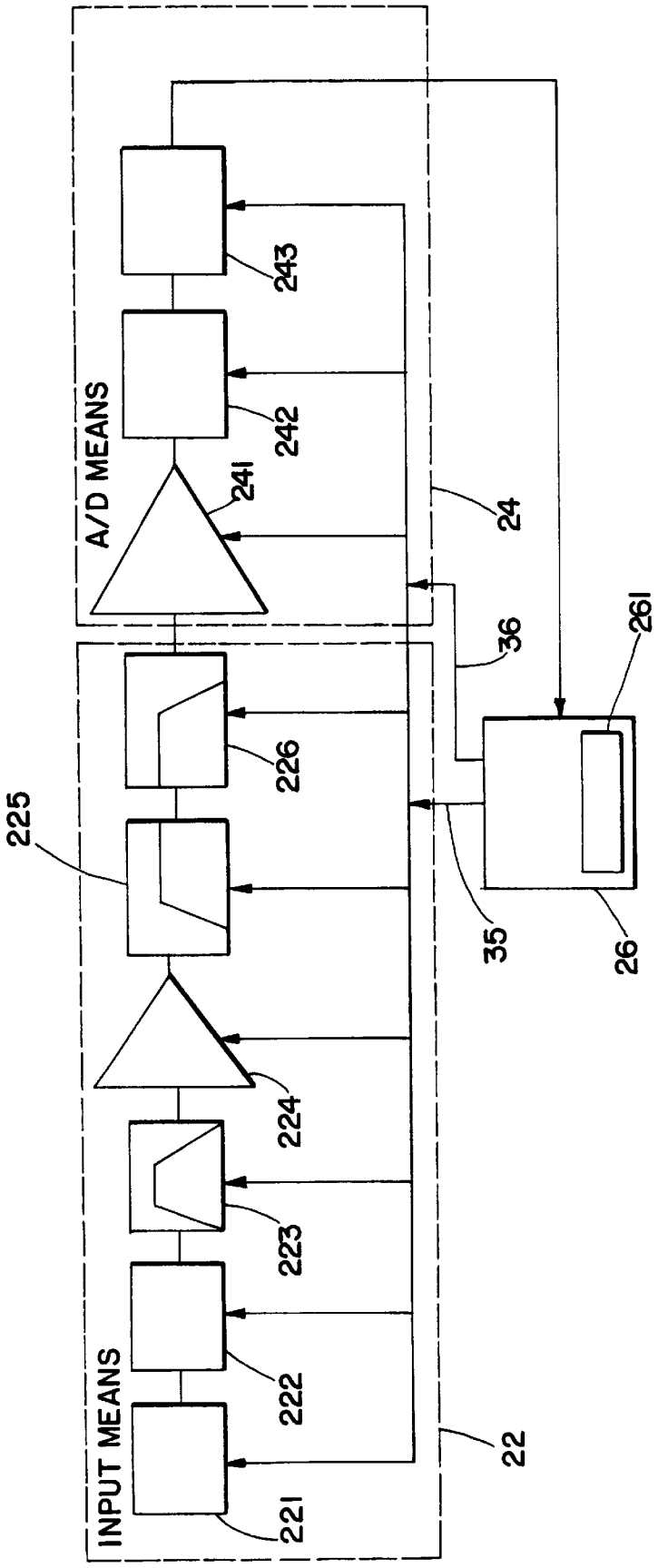

A/D MEANS
INPUT MEANS
221
222
223
224
225
226
241
242
243
22
24
26
261
35
36

Fig. 4

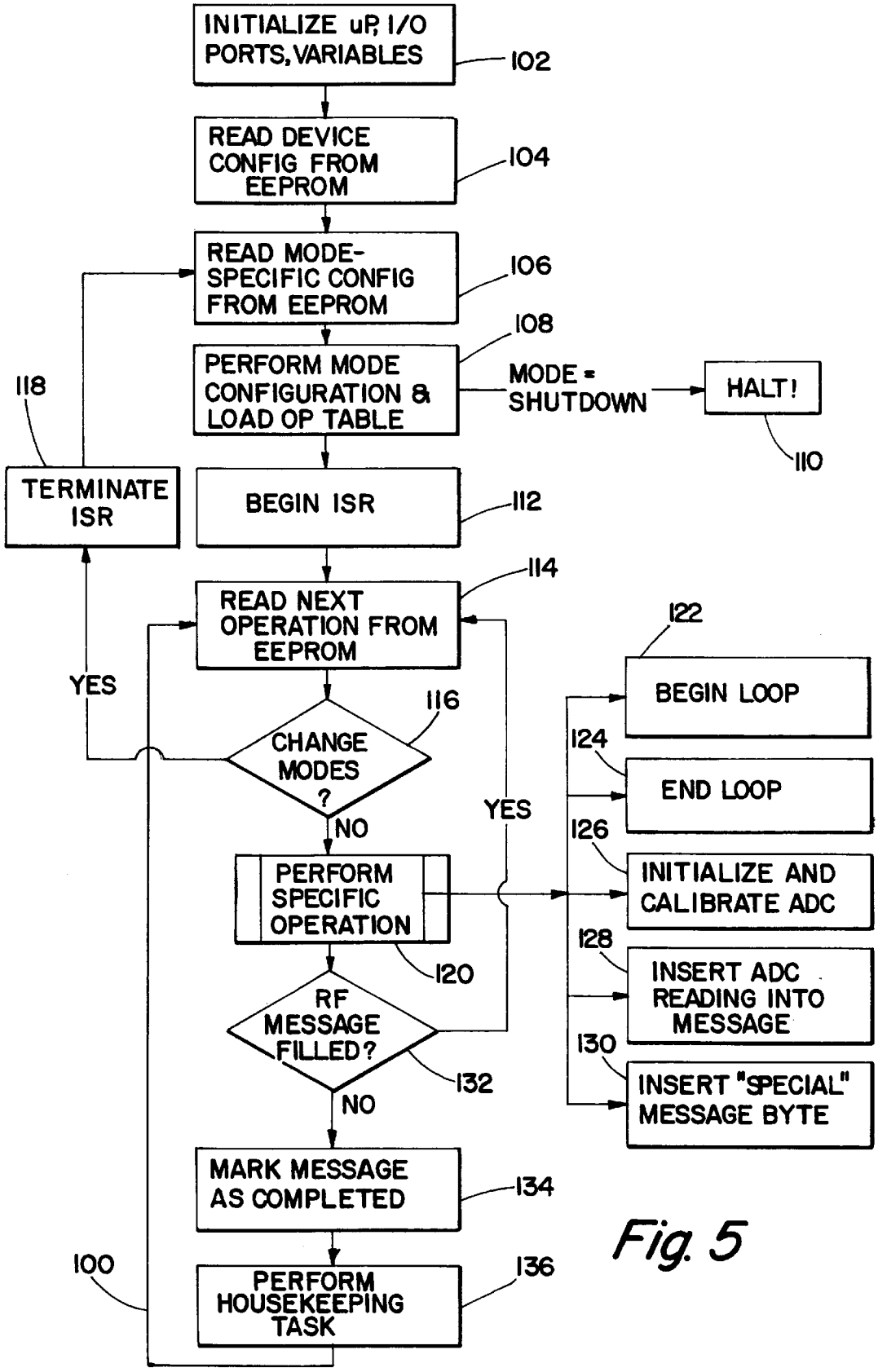

INITIALIZE uP, I/O PORTS, VARIABLES
102
READ DEVICE CONFIG FROM EEPROM
104
READ MODE-SPECIFIC CONFIG FROM EEPROM
106
108
PERFORM MODE CONFIGURATION & LOAD OP TABLE
MODE = SHUTDOWN
HALT!
110
118
TERMINATE ISR
BEGIN ISR
112
114
READ NEXT OPERATION FROM EEPROM
122
BEGIN LOOP
YES
116
CHANGE MODES ?
124
END LOOP
YES
NO
126
PERFORM SPECIFIC OPERATION
INITIALIZE AND CALIBRATE ADC
128
120
INSERT ADC READING INTO MESSAGE
RF MESSAGE FILLED?
130
132
INSERT "SPECIAL" MESSAGE BYTE
NO
MARK MESSAGE AS COMPLETED
134
100
PERFORM HOUSEKEEPING TASK
136

Fig. 5

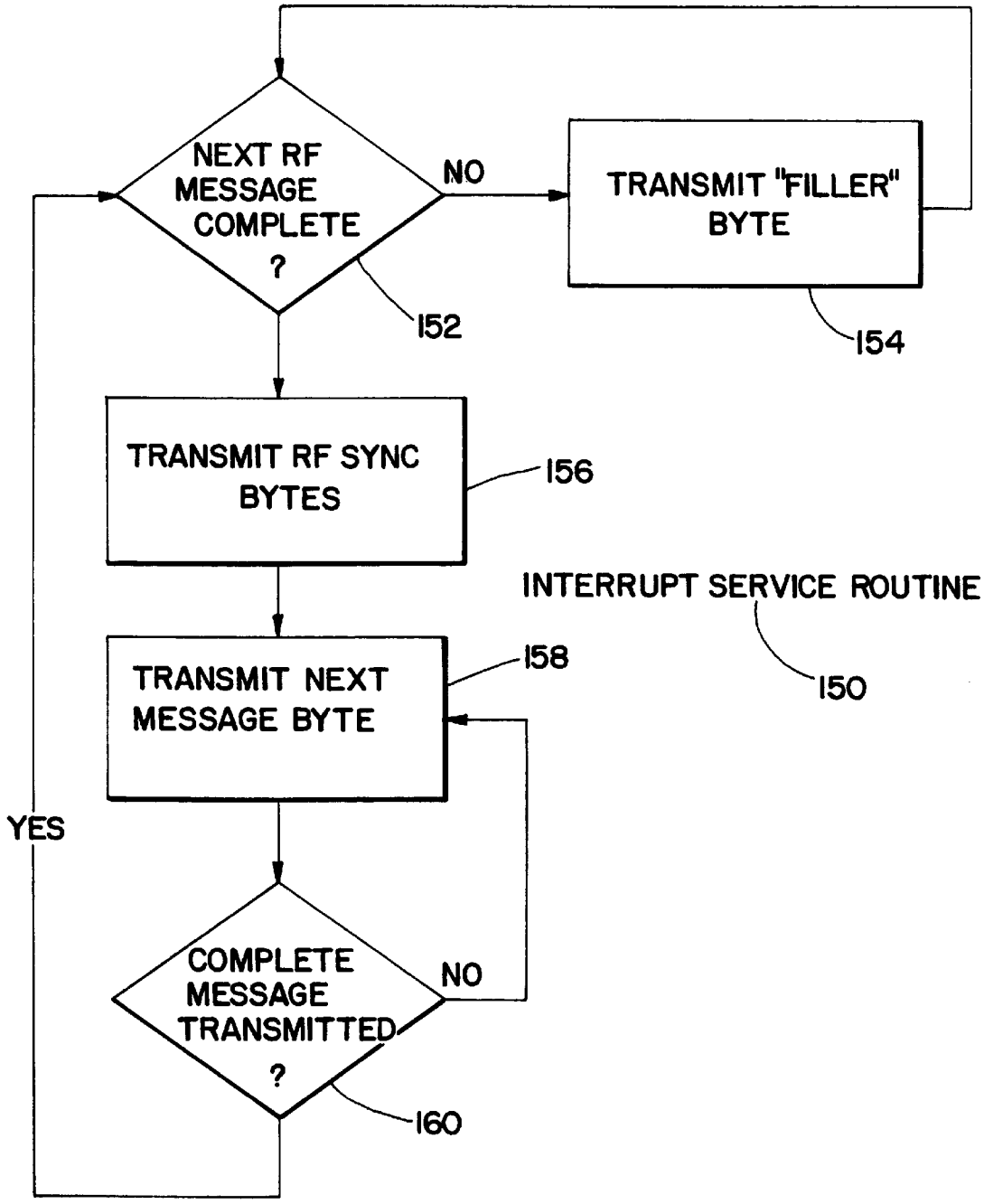

NEXT RF MESSAGE COMPLETE ?
NO
TRANSMIT "FILLER" BYTE
152
154
TRANSMIT RF SYNC BYTES
156
INTERRUPT SERVICE ROUTINE
150
TRANSMIT NEXT MESSAGE BYTE
158
YES
COMPLETE MESSAGE TRANSMITTED ?
NO
160

Fig. 6

# PROGRAMMABLE WIRELESS DATA ACQUISITION SYSTEM

## STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

This invention was made with Government support under Grant No.R44NS35413 awarded by the National Institute of Neurological Disorders and Stroke and Grant No. R44MH54949 awarded by the National Institute of Mental Health. The Government has certain rights in the invention.

## BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates, generally, to wireless data acquisition systems for data communications and, more particularly, to wireless data acquisition systems which employ small size, low power and low cost components and which may be adapted for different applications by software programming.

2. Description of the Related Art

All data acquisition systems generally operate in a similar fashion. They receive an external input from some type of sensing device, condition and/or convert the input to a format suitable for transmission, as necessary, and transmit it to another piece of equipment usually a monitor or controller, which may be a computer, and more specifically, a personal computer. The external input is generally an analog signal, although digital signals, frequently on-off switching, pulse-width modulation, or serial data protocols, are also involved. The inputs, though, come in many forms with many different characteristics, be they pneumatic, hydraulic or electronic, to list a few. Modern applications, control schemes and devices usually necessitate the use of electronic inputs in one form or another. For example, electronic analog inputs may have ranges of 4–20 mA, +/−5 volts, +/−15 volts, or microvolts to millivolts.

In the case of a wired system the analog input can be transmitted directly over interconnecting wiring with the major concern being that the interconnecting wires be suitably shielded to prevent interference by nearby electromagnetic sources. Signal conditioning becomes critically important for wireless systems, though. This is especially so when considering power consumption, size and cost factors. Because electronic inputs can have different characteristics (e.g.: high frequency or low frequency) and ranges (e.g.: microvolts to many volts), data acquisition systems are either application specific, i.e. designed to accept and condition a particular type of signal, i.e.: current, with a range of 4–20 mA for instance, or include separate discrete signal conditioning devices which consume a large amount of power and add considerable size.

Radio frequency (RF) wireless data acquisition systems can convert the input to a conditioned electronic signal which is used to modulate a carrier frequency which is then transmitted as a radio frequency signal to equipment in another location. The conditioned signal is encoded with data corresponding to the status of the input. The radio frequency signal is received, demodulated and decoded and the data is read, displayed, stored, and/or acted upon, i.e. monitored, analyzed, by equipment at the receiving point. In the United States the Federal Communications Commission (FCC) regulations govern RF transmissions, and similar agencies regulate RF transmissions in other countries, specifically as to the frequency band that can be utilized to transmit the signal and the strength of the signal. Other data



transmission means, such as infrared, optical, or any means which does not require a mechanical connection is understood to offer similar advantages as RF transmission.

Wireless data acquisition systems are well known in the art. In the biomedical area, U.S. Pat. No. 5,704,351 to Mortara discloses a multiple channel biomedical digital telemetry transmitter. Mortara teaches an 8 channel biomedical transmitter specifically directed to electrocardiogram (EKG) signal transmission in the 902 to 928 MHz band. The Mortara device includes input circuitry and an analog-to-digital converter which receives the input signal from an EKG electrode and converts it to a digital signal which is inputted to a microprocessor. The microprocessor then converts the digital signal to a serial digital output signal which is used to frequency modulate the radio frequency carrier signal for telemetry transmission. The carrier frequency is adjustable within the 902 to 928 MHz band by two manual frequency setting switches. The use of these manual switches is the only adjustment available on the Mortara device and only to manually set the frequency within the 902 to 928 MHz band. The input circuitry and analog-to-digital converter are not adjustable nor adaptable to accept different input signal characteristics. In addition, the Mortara device cannot be adjusted, by programming or otherwise, to operate in any other frequency band. Finally, the Mortara device is just a transmitter and, therefore, is not able to receive RF or other signals to control its operation.

Similarly, U.S. Pat. No. 5,755,230 by Schmidt et al, discloses a device for monitoring a physiological signal, in this case EEG, and transmitting it by RF signal to a receiver. Like Mortara, the Schmidt device also cannot be modified or adjusted to receive inputs from different physiological sensors.

U.S. Pat. No. 5,579,775 to Dempsey, discloses a Dynamic Control of a Patient Monitoring System. Like Mortara and Schmidt, Dempsey '775 teaches a patient monitoring system with a telemetry subsystem which monitors and transmits an RF signal representing signals it receives from one or more physiological monitoring instruments. Unlike Mortara and Schmidt, Dempsey '775 teaches a receiving subsystem which can receive RF signals, in a backchannel arrangement to control the operation of the system. Dempsey '775, though, does not disclose or teach a system with the capabilities to adjust or modify input means, by software programming or otherwise, in response to different physiological signals. The device relies on separate monitoring sections in order to accommodate different physiological signals, i.e., EEG, ECG, $SpO_2$ etc.

U.S. Pat. No. 5,417,222, also to Dempsey, discloses a portable processor interfaceable with a telemetry monitor at its I/O port. The Dempsey '222 device includes a telemetry monitor comprising a physiological monitor which receives selected physiological signals indicating a specific physiological condition of a patient. The physiological monitor is a specific type of monitor, i.e. one that reads signals of a specific physiological function, EKG for example. In the event that a different physiological function is to be monitored, i.e. EEG, a different physiological monitor must be employed. The device taught in this patent is designed to operate with basic physiological monitors already utilized in patient diagnostic services. Actually, the Dempsey '222 patent really only teaches the interface of a programmable processor, an example of which is given as Hewlett Packard 100LX palmtop processor (Hewlett Packard being listed as assignee of the patent) with a physiological monitor. Like the device in Dempsey '775, the device is not able to adapt or change the physiological monitor, by software or otherwise, to accept different physiological signals.

Fluke Corporation markets a wireless data acquisition system entitled "Wireless Logger".

The system is an integration of Fluke's Hydra Data Logger, a portable instrument monitor/analyzer, which accepts wired external inputs, with a RF modem. The Hydra Data Logger includes a universal input module which accepts and conditions the external inputs. The resulting signals are transmitted by the modem to another modem wired to a personal computer. The separate modem and universal input module are relatively large and consume up to 10 watts of power. In addition, the operation of the system is not software programmable. RF Neulink markets a similar system utilizing the VHF (136–280 MHz) and UHF (403–512 MHz) bands.

Accordingly, a need exists for a programmable wireless data acquisition system having a signal processing module which is capable of accepting multiple external inputs having different characteristics and ranges, and is able, through software programming, to convert and condition these external inputs, generate a radio frequency signal encoded with data corresponding to the external inputs, be frequency agile and adaptable, and transmit said radio frequency signal to a base station. In addition, a need exists for such a programmable wireless data acquisition system employing small size, low power consumptive and low cost components. Finally, a need exists for such a system which can accurately and dependably transmit data.

## BRIEF SUMMARY OF THE INVENTION

The present invention provides a method and apparatus to satisfy the aforementioned need.

Accordingly, an object of the present invention is to provide a programmable wireless data acquisition system which is capable of accepting multiple external inputs having different characteristics and ranges.

Another object of the present invention is to provide a programmable wireless data acquisition system which is small, has low power consumption and contains low cost components.

Still another object of the present invention is to provide a programmable wireless data acquisition system which can adapt to any changes in the character, type or range of external inputs while the system is operating without affecting or discontinuing its operation.

Still another object of the present invention is to provide a programmable wireless data acquisition system which can be reconfigured easily by minor component changes.

Accordingly, the present invention relates to a programmable wireless data acquisition system comprising a signal processing module containing a module microcontroller having a memory. The signal processing module operation includes inputting, conditioning and processing at least one external input having a certain range, character and type, and transmitting by wireless means a signal encoded with data corresponding to said external input. The module microcontroller adapts the signal processing module in response to variation in the range, character and type of the external input such that the adaptation occurs during signal processing module operation.

In another aspect, the present invention relates to a programmable wireless data acquisition system, comprising a signal processing module having certain components populated therein and having a module microcontroller having a memory. The signal processing module operation includes inputting, conditioning and processing at least one external input and transmitting by wireless means a signal encoded with data corresponding to the external input. The signal processing module being adaptable to varying characteristics and ranges of different of the external inputs by reconfiguring the component population of the signal processing module.

In yet another aspect, the present invention relates to a programmable wireless data acquisition system, comprising a signal processing module comprising a module microcontroller having a memory. The signal processing module operation includes inputting, conditioning and processing at least one external input and transmitting by wireless means a signal encoded with data corresponding to the external input. The at least one external input comprising at least one physiological signal wherein the physiological signal is from the group of physiological signals consisting of EEG, EKG, EOG, $SpO_2$, $PO_2$, $PCO_2$ EMG, blood pressure, heart rate, pulse, body temperature, air flow and respiration. The module microcontroller adapts the signal processing module in response to variation in the range, character and type of the physiological signal such that the adaptation occurs during signal processing module operation.

In still yet another aspect, the present invention relates to a programmable wireless data acquisition system, comprising a signal processing module containing a module microcontroller having a memory, a module transmitter and a module receiver. The signal processing module operation includes inputting, conditioning and processing at least one external input having a certain range, character and type, and transmitting a radio frequency signal encoded with data corresponding to the external input. The module microcontroller through the module receiver receives a radio frequency signal with instructions for adapting the signal processing module in response to variation in the range, character and type of the external input such that the adaptation occurs during signal processing module operation.

## BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

Further features of the present invention will become apparent to those skilled in the art to which the present invention relates from reading the following specification with reference to the accompanying drawings in which:

FIG. **1** is a block diagram of the present invention.

FIG. **2** is a block diagram of the signal processing module of the present invention.

FIG. **3** is a block diagram of the base station of the present invention.

FIG. **4** is a block diagram showing the data acquisition function of the present invention in the signal processing module.

FIG. **5** is a block diagram of the programming of the firmware in the signal processing module.

FIG. **6** is a block diagram of the programming of the interrupt service routine in the firmware of the signal processing module.

## DETAILED DESCRIPTION OF THE INVENTION

Referring now to the drawings and, in particular to FIG. **1**, there is shown a block diagram of the present invention. An external input **12** from sensor **14** is inputted to signal processing module **16**. Although, one sensor **14** and one external input **12** are shown, the signal processing module

16 is capable of accepting multiple external inputs 12 from multiple sensors 14. The signal processing module 16 generates a signal 18 encoded with data corresponding to the external input 12. The signal processing module 16 transmits the signal 18 by wireless means. to base station 40 In FIG. 1, the wireless means is shown as radio frequency (RF). In this case, the signal processing module generates a radio frequency signal 18 by frequency modulating a frequency carrier and transmits the radio frequency signal through module antenna 20. The base station 40 receives the radio frequency signal 18 through base antenna 42, demodulates the radio frequency signal 18, and decodes the data. It is understood that other wireless means can be utilized with the present invention, such as infrared and optical, for example. Although one module antenna 20 and one base antenna 42 is shown in this embodiment, it is understood that two or more diversity antennas can be used and are included in the present invention. An external programming means 60, shown in FIG. 1 as a personal computer, contains software which is used to program the signal processing module 16 and the base station 40 through data interface cable 62. The data interface cable 62 is connected to the base station 40 and signal processing module 16 by respective connectors 64. The same data interface cable 62 or two different interface cables 62 can be used, one for the base station 40 and one for the signal processing module 16. The signal processing module 16 and the base station 40 can be programmed by connecting a data interface cable 62 between it and an external programming means 60 or by radio frequency (or other type) of signals transmitted between a base station 40 to the signal processing module 16 or to another base station 40. RF signals, therefore, can be both transmitted and received by both signal processing module 16 and base station 40. In this event the signal processing module 16 also includes a module receiver 29 while the base station 40 also includes a base transmitter 84, in effect making both the signal processing module 16 and the base station 40 into transceivers. In addition, the data interface cable 62 also can be used to convey data from the base station 40 to the external programming means 60. If a personal computer is the external programming means 60, it can monitor, analyze and display the data in addition to its programming functions. The base receiver 80 and module receiver 29 can be any appropriate receivers, such as direct or single conversion types., The base receiver 80 preferably is a double conversion superheterodyne receiver while the module receiver 29 preferably is a single conversion receiver. Advantageously, the receiver employed will have automatic frequency control to facilitate accurate and consistent tuning of the radio frequency signal 18 received thereby.

Referring now to FIG. 2, there is shown a block diagram of the signal processing module 16 with the sensor 14 and the module antenna 20. The signal processing module 16 comprises input means 22, analog-to-digital (A/D) means 24, a module microcontroller 26 with a nonvolatile memory, advantageously, an EEPROM 261, a module transmitter 28, a module receiver 29 and a module power supply 30. Although the module antenna 20 is shown externally located from the signal processing module 16, it can also be incorporated therein. The module antenna 20 may be a printed spiral antenna printed on a circuit board or on the case of the signal processing module 16 or other type of antenna. A module power supply 30 provides electrical power to the signal processing module 16 which includes the input means 22, A/D means 24, module microcontroller 26 module transmitter 28 and module receiver 29.

The input means 22 is adjustable either under control of the module microcontroller 26 or by means of individually populatable components based upon the specific external input 12 characteristics and range enabling the input means 22 to accept that specific external input 12. For example, if the input is a 4–20 mA analog signal, the input means 22 is programmed by the module microcontroller 26 and/or populated with the components needed to accept that range and characteristic of signals. If the input characteristics change the programming and/or components change accordingly but the same platform circuit board design is utilized. In other words, the same platform design is utilized notwithstanding the character, range, or quantity (number of external inputs 12) [up to a predetermined limit] of the input. For example, bioelectric signals such as EEG, EMG, EKG, and EOG have typical amplitudes of a few microvolts up to a few tens of millivolts. For a given application, a specific frequency band of interest might be from 0.1 Hz to 100 Hz, whereas another application may require measurement of signals from 20 Hz to 10 KHz. Alternatively, measurement of vital signs such as body temperature and respiration rate may deal with signals in a range of +5 volts, with a frequency content from DC (0 Hz) to 20 Hz. For other applications such as industrial process monitoring, the information of interest may be contained in the signal as a current, such as a 4 to 20 mA current loop sensor, or it may take the form of resistance, impedance, capacitance, inductance, conductivity, or some other parameter, The present invention provides a single device for measuring such widely disparate signal types and presents distinct economic advantages, especially to small enterprises such as a medical clinic located in a rural area, which would be empowered by this invention to conduct tests which would otherwise have required patient travel to a large medical center, with all the attendant cost thereof.

This is possible due to the selectively adaptable input means 22 and A/D means 24, the frequency agile module transmitter 28 and base transmitter 84, and the programmability of the module microcontroller 26 and EEPROM 261. One universal platform design then can be utilized for all applications. In addition, the signal processing module can comprise multiple copies of the input means 22 and the A/D means 24. Cost savings can be achieved by multiplexing at several different points in the input means 22 and the A/D means 24 allowing hardware to be shared among external inputs 12.

After receipt by the input means 22, the external input 12 is inputted to the A/D means 24. The A/D means 24 converts the input to a digital signal 32 and conditions it. The A/D means 24 utilizes at least one programmable A/D converter. This programmable A/D converter may be an AD7714 as manufactured by Analog Devices or similar. Depending upon the application, the input means 22 may also include at least one low noise differential preamp. This preamp may be an INA126 as manufactured by Burr-Brown or similar. The module microcontroller 26 can be programmed to control the input means 22 and the A/D means 24 to provide specific number of external inputs 12, sampling rate, filtering and gain. These parameters are initially configured by programming the module microcontroller 26 to control the input means 22 and the A/D means 24 via input communications line 35 and A/D communications line 36 based upon the input characteristics and the particular application. If the application changes, the A/D converter is reconfigured by reprogramming the module microcontroller 26. In this manner, the input means 22 and the A/D means 24 can be configured to accept analog inputs of 4–20 mA, +/−5 volts,

+/−15 volts or a range from +/−microvolts to millivolts. They also can be configured to accept digital inputs, for detection of contact closure, for example.

The module microcontroller **26** controls the operation of the signal processing module **16**. In the present invention, the module microcontroller **26** includes a a serial EEPROM **261** but any nonvolatile memory (or volatile memory if the signal processing module remains powered) can be used. The EEPROM **261** can also be a separate component external to the module microcontroller **26**. Advantageously, the module microcontroller **26** may be PIC16C74A PIC16C74B or a PIC16C77 both manufactured by MicroChip, or an Amtel AT90S8515 or similar. The module microcontroller **26** is programmed by the external programming means **60** through the connector **64** or through radio frequency signal from the base station **40**. The same module microcontroller **26**, therefore, can be utilized for all applications and inputs by programming it for those applications and inputs. If the application or inputs change, the module microcontroller **26** is modified by merely reprogramming. The digital signal **32** is inputted to the module microcontroller **26**. The module microcontroller **26** formats the digital signal **32** into a digital data stream **34** encoded with the data from the digital signal **32**. The digital data stream **34** is composed of data bytes corresponding to the encoded data and additional data bytes to provide error correction and housekeeping functions. Advantageously, the digital data stream **34** is organized in data packets with the appropriate error correction data bytes coordinated on a per data packet basis. These packets can incorporate data from a single input channel or from several input channels in a single packet, or for some applications may advantageously include several temporally differing measurements of one or a plurality of input channels in a single packet. The digital data stream **34** is used to modulate the carrier frequency generated by the transmitter **28**.

The module transmitter **28** is under module microcontroller **26** control. The module transmitter **28** employs frequency synthesis to generate the carrier frequency. In the preferred embodiment, this frequency synthesis is accomplished by a voltage controlled crystal reference oscillator and a voltage controlled oscillator in a phase lock loop circuit. The digital data stream **34** is used to frequency modulate the carrier frequency resulting in the radio frequency signal **18** which is then transmitted through the module antenna **20**. The generation of the carrier frequency is controlled by the module microcontroller **26** through programming in the EEPROM **261**, making the module transmitter **28** frequency agile over a broad frequency spectrum. In the United States and Canada a preferred operating band for the carrier frequency is 902 to 928 MHz. The EEPROM **261** can be programmed such that the module microcontroller **26** can instruct the module transmitter **28** to generate a carrier frequency in increments between 902 to 928 MHz. as small as about 5 to 10 KHz. In the US and other countries of the world, the carrier frequency may be in the 2400 to 2483.5 MHz. band, 5.725 to 5.875 GHz. band, or the 24.0 to 24.25 GHz. band, or other authorized band. This allows the system to be usable in non-North American applications and provides additional flexibility.

The voltage controlled crystal oscillator (not shown) in the module transmitter **28**, not only provides the reference frequency for the module transmitter **28** but, advantageously also, provides the clock function **38** for the module microcontroller **26** and the A/D means **24** assuring that all components of the signal processing module **16** are synchronized. An alternate design can use a plurality of reference frequency sources where this arrangement can provide certain advantages such as size or power consumption in the implementation.

The module receiver **29** in the signal processing module **16** receives RF signals from the base station **40**. The signals from the base station **40** can be used to operate and control the signal processing module **16** by programming and reprogramming the module microprocessor **26** and EEPROM **261** therein.

The base station **40** has a base antenna **42** through which RF signals **18** are received. Base microcontroller **86** controls the operation of the base station **40** including base receiver **80**, base transmitter **82**, and base power supply **88**. Base receiver **80** receives the RF signal **18** from base antenna **42**. The base receiver **80** demodulates the RF signal **18** and the base microcontroller **86** removes any error correction and performs other housekeeping tasks. The data is then downloaded through connector **64** to the external programming means **60** or other personal computer (PC) or data storage/viewing device for viewing in real time, storage, or analysis.

Referring now to FIG. **4**, there is shown a block diagram of the input means **22** and A/D means **24** of the signal processing module **16**, which provides for the data acquisition function of the present invention. The signal processing module **16** is variably configurable through software programming initiated by the external programming means **60** to the EEPROM **261** of the microcontroller **26**. The variable configurability enables the signal processing module **16** to receive external inputs **12** having different characteristics and ranges and to provide variable sampling rate, filtering and gain of the external inputs **12** based upon such characteristics and range and/or the specific application. For example, if the present invention is utilized in a biomedical environment, EEG diagnosis and monitoring for instance, the sampling rate will need to be much higher than it would be for an industrial setting measuring thermocouple readings. The ability to reconfigure the system for varying signal characteristics arises at three separate levels in the present invention. For maximum flexibility, such reconfiguration can be carried out during a series of measurements by means of the wireless link, which is understood in this context to be bidirectional. Depending on the characteristics of the received signal **18**, the base station **40** can command the signal processing module **16** to reconfigure the input means **22** and/or A/D means **24** to accept an external input **12** of larger amplitude, or a different frequency range, where signal characteristics change significantly during the course of a series of measurements. Alternatively, for cost, size, and power advantages, this adjustment could be carried out prior to a series of measurements, with the configuration information stored in memory in the signal processing module **16**, where this memory is advantageously implemented in a nonvolatile form such as EEPROM **261**, allowing the configuration information to be retained, for instance, across power outages and obviating the need for module receiver **29** and base transmitter **84**, saving cost. A third alternative, which provides advantages in certain technical parameters, is to arrange the implementation of the signal processing module **16** such that minor changes in component values or parameters can reconfigure the same basic hardware to accept widely divergent external input **12** types. This reconfiguration could take place at the factory, providing cost and inventory advantages to the manufacturer, or it could be performed by the end user, providing similar cost advantages to the user in allowing one piece of equipment to perform multiple tasks.

A number of configurable components are shown in FIG. **4**. Any given component of this arrangement, though, may

be omitted, and, in some cases, the order of the components may be changed to gain certain advantages such as physical size, power consumption, or cost, without changing the basic spirit of the invention. Components in this FIG. **4** may be combined, either by having a single component carry out the function of two or more of the components shown or by combining functions within a single package such as an integrated circuit or hybrid module. Certain components may also operate with a fixed configuration, limiting the flexibility of certain parameters while retaining the advantages of configurability in other components.

The external input **12** inputs to the input protection network **221**, which protects the signal processing module **16** against damage caused by faults or unanticipated conditions encountered at the external inputs **12**. Depending on the rigors expected to be encountered in any given application and the tolerance to size and weight, the input protection network **221** may be omitted, may consist of a simple resistor network, or may include more elaborate protection such as diodes, zener diodes, transorbs, gas discharge tubes, and other components commonly known to those of ordinary skill in the art. Typically, the input protection network **221** is not configurable but its configurability in the present invention provides advantages in certain applications. Configuration options can include adjustable limits on input voltage and/or current as well as rates of change of those parameters, and other electrical parameters as well. These configuration changes can be achieved by changes to component values on a common platform for smallest size, or can be changed under processor control by means of various switches such as relays. A signal within normally expected ranges passes essentially unchanged to the measurement type means **222**.

The measurement type means **222** allows selection of the external input **12** configuration. The measurement type means **222** may be used to configure the input circuitry to accept external inputs **12** which are single-ended voltage (a voltage with respect to a common reference shared between several signals), differential voltage (voltage between two defined conductors), differential current (current flowing through a conductor), single-ended current (current flowing to a common reference), frequency, capacitance, inductance, resistance, impedance, conductivity, or any other electrical parameter. The measurement type means **222** converts the external input **12** to a common parameter such as voltage or current, which can be interpreted by the succeeding blocks regardless of the original type of external signal **12** measured. One input channel can be built with several different measurement type means, which can be selectively enabled by means of an analog switch, such as that found in the AD7714 chip in the present invention. It is understood that the AD7714 chip can provide many of the functions of the A/D means **24** and the input means **22** thus reducing the overall size of the signal processing module **16**. In the preferred embodiment, the output of the measurement type means **222** is a varying voltage carrrying the information which was present in the original signal, or in certain cases, a series of voltage measurements, which are then conveyed to the prefilter **223**.

The prefilter **223** allows rejection of external inputs **12** of large signals which are outside the frequency band of interest, so that such signals do not saturate the low-noise preamplifier **224**. The prefilter **223** can be advantageously arranged to be a relatively simple filter to provide cost, size, and power advantages, because it need only reject out of band signals to the extent necessary to protect the low-noise preamplifier **224**. A typical application might use a simple "R-C" filter to reject offset voltages in an AC-coupled application, or to reject extremely high frequencies which fall well beyond the frequency band of interest, or a combination of the two. Configurability of this section can be limited to simply enabling or bypassing the prefilter **223**, or may be more elaborate in allowing selection of cutoff frequencies. In the preferred embodiment this prefilter consists of a simple RC filter which can be bypassed under firmware control, to minimize noise injection; however, an alternate embodiment could incorporate electrically adjustable components such as electronic potentiometers or varactors to provide even more flexibility at the expense of size and noise injection. The prefiltered signal is then pased to the low-noise preamplifier **224**.

The low-noise preamplifier **224** is advantageous in certain applications to allow application of gain to the external input **12** early in the signal chain, before significant noise is introduced by the inherent characteristics of certain components, such as thermal noise. Configurability of the gain applied at this step provides an advantage in allowing the present invention to accept larger external inputs **12** using a low gain (unity gain or lower), or alternatively to accurately measure very small external inputs **12** with minimal noise by using higher gain. This gain can be selectively chosen to be either a fixed value or unity gain under processor control by means of the signal selector built into the AD7714 used in the preferred embodiment, or can be designed to allow a selection of one of several gains by means of analog switches combined with a plurality of gain setting resistors. Gain applied at this stage has the net effect of dividing any downstream noise by the gain factor applied here. This more robust signal output by the preamplifier **224** is then passed to the AC coupling filter **225**.

The AC coupling filter **225** is a highpass filter used to allow the system to reject the DC offset or steady state value of an external input **12** wherein the offset is not of interest, allowing additional gain to be applied to the changes in the external input **12**. For instance, bioelectric signals such as EEG, EMG, or ECG are normally of interest only for the changes in those signals, and the absolute offset level is not of interest for diagnostic purposes. The cutoff frequency may be configured to allow adjustment of various parameters such as settling time, or may be adjusted to zero to effectively bypass the AC coupling filter **225**. In the preferred embodiment, the filter may be bypassed by use of the signal selector switch in the AD7714; however, the use of adjustable components such as electronic potentiometers or varactors would allow more flexibility in choosing the cutoff frequency, at the expense of size and power consumption. The resulting signal, now stripped of any interfering DC offset if so configured, is then passed to the antialias filter **226**.

The antialias filter **226** is a lowpass filter required to guard against false signals caused by aliasing between external input **12** content and sampling rate of downstream sampling functions such as multiplexing or analog-to-digital conversion. The Nyquist sampling theorem shows that any frequency content in the sampled signal which is higher than one-half the sampling rate of the sampling function will cause aliasing, which results in false signals. In practice the antialias filter **226** is more commonly set to a smaller fraction of the sampling rate, usually between ¼ and 1/10 the sampling rate. Regardless of the rate or ratio used, the cutoff frequency of the antialias filter **226** must change when the sampling rate changes significantly, to retain the most advantageous ratio of the sampling rate to the filter passband. The programmable cutoff frequency of the antialias

filter **226** is thus required to allow for variable sampling rates. In the preferred embodiment, the high sampling rate of the delta sigma modulator in the AD7714 permits the use of a simple fixed RC type filter, with the anitalias filtering begin provided as an inherent digital filter in the AD7714; however, an alternate embodiment might use a switched capacitor filter such as the MAX7409 or other filter with a programmable cutoff frequency. The resulting filtered signal is then conveyed to the programmable gain amplifier **241** in the A/D means **24**.

The programmable gain amplifier **241** adjusts the external input **12** amplitude to match the amplitude accepted by the A/D converter **242**. In the preferred embodiment this programmable gain amplifier is included in the AD7714 integrated circuit, but this function could also be provided with a dedicated programmable gain amplifier, or alternatively through the use of analog switches or adjustable components such as potentiometers or DACs. If too much gain is applied, the programmable gain amplifier **241** itself or downstream components will saturate, introducing severe distortion and usually rendering the external input **12** unmeasureable. If, on the other hand, insufficient gain is applied here, the quantization noise of the analog-to-digital conversion process comes to dominate the external input **12**, causing a severe degradation in the signal-to-noise ratio. For instance, a typical 16-bit A/D converter **242** can distinguish between $2^{16}$ or 65536 distinct levels. With an A/D converter **242** input range of ±3 volts, each level reperesents 92 $\mu$V. If insufficient gain is applied to the external input **12** such that the total signal swing is only 200 $\mu$V, the A/D converter **242** will convert at most three distinct levels, rendering fine features of the external input **12** totally illegible. The module microcontroller **26** therefore adjusts the gain applied in the programmable gain amplifier **241** such that the expected external input **12** as processed and filtered by the preceding elements as described above, is amplified to cover as much of the A/D converter **242** input range as practical, or some other gain which optimizes signal features of interest. Additionally, in some applications it is advantageous to have the module microcontroller **26** adjust this gain dynamically depending upon the actual measured external input **12**. For instance, the module microcontroller **26** might increase the programmable gain amplifier **241** gain when a measured external input **12** is very small, and then decrease the gain to avoid saturation when the external input **12** amplitude increases. This automatic gain control provides an increase in the total dynamic range achievable by the system without requiring expensive, large, and power-hungry components such as very high resolution A/D converters **242**. The signal resulting from application of the specified gain is then passed to the A/D converter **242**.

At least two parameters of a typical A/D converter **242** can be readily adjusted to achieve various goals as the situation dictates. First, the sampling rate may be adjusted to balance the conflicting goals of high fidelity measurements and low digital data rate. Where a signal has no high frequency content of interest, the sampling rate may be adjusted to a very low rate to minimize the demands on downstream processes such as digital filtering or telemetering of the data. On the other hand, sampling an external signal **12** with significant high-frequency content of interest demands a higher sampling rate. In the preferred embodiment, the sampling rate is programmable via the AD7714; in other implementations the sampling rate can be made adjustable by means of an externally applied sampling clock to an A/D converter. The adjustable sampling rate allows the controller to adapt the A/D converter **242** to best meet the system demands of the moment.

In a similar fashion, selection of the resolution provided by the A/D converter **242** must balance faithful reproduction of the external input **12** against total digital data rate. Depending on the particular A/D converter **242** used, there may also be a tradeoff of the maximum achievable sampling rate against the selected resolution, wherein selection of a higher resolution lowers the maximum attainable sampling rate. Again the module microcontroller **26** can adjust this parameter to best meet the system requirements, selecting higher resolution when smaller changes in the measured signal amplitude must be reported, and lower resolution when the lack of such a requirement allows advantages in the form of either a higher sampling rate or a lower digital data rate. In the preferred embodiment, the AD7714 can be programmed to either 16 bit or 24 bit resolution, and the firmware running in the microcontroller can selectively transmit 8, 12, 16, or 24 bits of the acquired data. The digital filter **243**, the module microcontroller **26**, or other downstream process can also reject certain portions of the digital data stream to provide an effective decrease in resolution where this decrease is advantageous, especially when the data must later cross a bandwidth-limited link such as a RF, IR or optical link. The A/D converter **242** passes the signal, now in the form of a succession of digital values, to the digital filter **243** for further processing.

The digital filter **243** extracts external input **12** parameters of interest while rejecting other signals, commonly referred to as noise. Implementation of the digital filter **243** could alternatively be in the form of analog filters applied anywhere in the signal chain prior to the A/D converter **242**, but implementation as a digital filter **243** provides advantages as to programmability, calibration, drift, and accuracy. The digital filter **243** could be implemented in many forms, depending upon the demands of the particular application. In the preferred embodiment, the digital filter is inherent in the analog to digital conversion process inside the AD7714, but it is understood that the digital filter **243** could be implemented as firmware inside the module microcontroller **26** itself, or as a digital signal processor, or as a specialized integrated circuit, or by some other means. Regardless of implementation, the programmability of the digital filter **243** allows the system to readily adapt to changing measurement requirements, whether those changes are brought about by changes in the environment, changes in the external input **12** itself, or changes in the focus of the overall system. The resulting output from the digital filter **243** is a stream of digital values, ready for further processing such as assembly into the desired format for transmission by the firmware.

Referring now to FIG. **5** there is shown a block diagram of the firmware of the present invention. The signal processing module **16** firmware defines several modes of operation **100**. There are several "test" modes which are used during factory calibration of the device. In addition, there are several operation modes which have mode-specific configuration. For example, the signal processing module **16** can be programmed to operate in a first operational mode in which it transmits calibration data (used to properly zero the analog inputs) for the first three seconds of operation (or for some other predetermined time), and then switches to a second operational mode which transmits analog signal information as collected from the A/D converters **242**. The configuration for each mode of operation is programmed in the non-volatile memory EEPROM **261**.

Once power is first applied to the signal processing module **16**, the module microcontroller **26** performs the basic device initialization, including proper configuration of the I/O ports and internal variables **102**. Next, the module

microcontroller **26** reads the initial device configuration **104** from the EEPROM **261**. This configuration controls the input means **22** of the signal processing module **16**, including the number of external inputs (also herein referred to as channels), the resolution of the A/D converter **242**, and the sampling rate of each individual input channel. This configuration also controls the operation of the module transmitter **28** in the signal processing module **16**, including the carrier frequency, modulation type, output power control, and the length in bytes of each transmitted RF message packet. This configuration also describes the initial mode of operation for the signal processing module **16**.

Once the initial configuration has been read, the module microcontroller **26** enters the first mode of operation described in the configuration. It reads the mode-specific configuration **106**, which includes the state of the module transmitter **28** and the analog inputs as used in the mode. This configuration can reside in EEPROM **261** or in module microcontroller **26** memory. The module microcontroller **26** then initializes all the peripheral devices according to this mode configuration **108**. In the special case that this is the "shutdown" mode, the module microcontroller **26** will perform a software power-down **110**.

Once the mode has been initialized, the module microcontroller **26** begins execution of the interrupt service routine (ISR) **112**, which is responsible for transmitting the data in the form of messages along the modulated RF carrier. Operation of the interrupt service routine is asynchronous and distinct from the mainline code, and is described later.

The module microcontroller **26** begins execution of the mode-specific "opcodes" **114**, which are a sequence of instructions contained either in EEPROM **261** or in the module microcontroller **26** memory. These opcodes are performed for each operational mode. The module microcontroller **26** reads the first operational code from the EEPROM **261** and interprets the opcode, performing an appropriate action:

If the opcode instructs the module microcontroller **26** to change modes **116**, the module microcontroller **26** terminates the ISR **118** and returns to the mode initialization, and begins execution of a new operational mode;

If the opcode instructs the module microcontroller **26** to begin a loop construct **120**, the module microcontroller **26** begins the loop by initializing a loop counter variable **122**;

If the opcode instructs the module microcontroller **26** to end a loop construct, the module microcontroller **26** increments the loop counter variable and determines if the loop is complete **124**. If not, the module microcontroller **26** resets the index of current opcode to the beginning of the loop, otherwise it sets the index of the next opcode to after the loop;

If the opcode instructs the module microcontroller **26** to initialize a single A/D converter **242**, the module microcontroller **26** will perform the specified calibration **126**;

If the opcode instructs the module microcontroller **26** to the read a single A/D converter **242**, the module microcontroller **26** will take the reading and insert the data into the current message to be transmitted over the RF carrier **128**;

If the opcode instructs the module microcontroller **26** to insert a special byte of data into the RF message, the module microcontroller **26** will insert this data into the message **130**. This special message byte may include an identifier to uniquely identify the signal processing module **16**, an error check field such as a cyclic redundancy check, or some data representing the internal state of the signal processing module **16** such as the RF frequency, measured temperature, etc.

After each opcode has been read and interpreted, the module microcontroller **26** determines if the RF message has been completely filled and is ready to be transmitted over the RF carrier **132**. If it has, the module microcontroller **26** marks a flag variable for the interrupt service routine to begin transmitting the RF message **134**.

Next, the module microcontroller **26** performs any housekeeping tasks, such as updating the RF tuning parameters based on changes in temperature, updating timers, etc. **136** Finally, the module microcontroller **26** returns to execute the next opcode in the sequence **114**.

Referring now to FIG. **6** there is shown a block diagram of the software programming function of the ISR **150**. The ISR is responsible for transmitting the individual message bytes over the RF carrier. The ISR is executed by a hardware interrupt which occurs immediately before every byte to be transmitted over the RF carrier. The ISR detects whether an RF mesage is completely filled **152**. If the ISR detects (based on the flag variable) that an RF message is not yet completely filled by the main code, the ISR transmits a "filler" byte, or a byte with an even number of "1" and "0" bits **154**. This acts to maintain an even (50%) modulation duty cycle on the carrier frequency.

Once the ISR detects that the main code has filled an RF message to be transmitted, it transmits the RF sync bytes **156**. These are two unique bytes transmitted at the beginning of every RF message which are easily identified by the base station **40** as the start of a message.

Once the RF sync bytes have been transmitted, the ISR transmits each message byte of the RF message, in sequence **158**. Once the RF message has been completely transmitted **160**, the ISR resumes transmitting filler bytes until the next RF message is filled by the main code.

Because of the phase locked loop based frequency synthesizer used in the present invention, the module transmitter **28** and base transmitter **84** are frequency agile over the frequency range. Since the module receiver **29** and the base receiver **80** employ automatic frequency control, the present invention consumes relatively low power as the module transmitter **28** and base transmitter **84** can be intermittently powered down without loosing reception due to drift or sacrificing data transmission accuracy. The utilization of programmable firmware allows inexpensive and flexible operation for the inputting, conditioning and processing of any type, character and range of the external inputs. This also allows the module microcontroller **26**, in response to the variation of the external inputs **12** or, in response to instructions received by RF signal through the module receiver **29**, to adapt the signal processing module **16** based upon the variations allowing the signal processing means **16** to input, condition, process and transmit said external input notwithstanding said variation. The present invention performs this adaptation without the need to modify or alter hardware or select or use different hardware already present in the device. In other words all adaptation can be accomplished by software programming totally.

A particular embodiment of the invention has been described, but those skilled in the art will recognize that many modifications are possible that will achieve the same goals by substantially the same system, device or method, and where those systems, devices or methods still fall within the true spirit and scope of the invention disclosed. Therefore the invention should be considered to be limited in scope only in accordance with the following claims.

What is claimed is:

**1**. A programmable wireless physiological data acquisition system comprising a signal processing module including a microcontroller having a memory, means for remotely receiving system operating instructions, and physiological

input signal receiving means, said signal processing module processing at least one external physiological input signal received by said physiological input signal receiving means, said physiological input signal having specific characteristics, said signal processing module producing an output signal encoded with data identifying said specific physiological input signal characteristics and transmitting said output signal by wireless means, said microcontroller adapting the operation of said physiological input signal receiving means in response to instructions remotely received by said system operating instruction receiving means permitting said signal processing module to process external physiological input signals having different characteristics.

**2**. The programmable wireless physiological data acquisition system of claim **1** wherein said signal processing module includes means for accepting and processing simultaneously multiple various external physiological input signals from multiple physiological signal sources and transmitting by wireless means an output signal encoded with data identifying said physiological input signal characteristics.

**3**. The programmable wireless physiological data acquisition system of claim **2** wherein said microcontroller adapts the operation of said physiological input signal receiving means in response to instructions remotely received by said system operating instruction receiving means permitting said system processing module to process simultaneously a plurality of external physiological input signals having different characteristics.

**4**. The programmable wireless physiological data acquisition system of claim **1** wherein said wireless means is radio frequency.

**5**. The programmable wireless physiological data acquisition system of claim **1** wherein said wireless means is infrared.

**6**. A programmable wireless physiological data acquisition system comprising a signal processing module including a microcontroller having a memory, a module transmitter, and a module receiver, said signal processing module processing at least one external physiological input signal having specific characteristics and producing an output signal encoded with data identifying said specific physiological input signal characteristics, said signal processing module transmitting said output signal via said transmitter, said microcontroller adapting the operation of said signal processing module in response to instructions remotely received via said receiver permitting said signal processing module to process external physiological input signals having different characteristics.

**7**. The programmable wireless physiological data acquisition system of claim **6** wherein said signal processing module includes means for processing simultaneously multiple various external physiological input signals from multiple physiological signal sources and transmitting by wireless means an output signal encoded with data identifying said physiological input signal characteristics.

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