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(54) COMMUNICATION WITH AN IMPLANTED WIRELESS SENSOR

KOMMUNIKATION MIT EINEM IMPLANTIERTEN DRAHTLOSEN SENSOR

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Description

TECHNICAL FIELD

[0001] The present invention is directed in general to communicating with a wireless sensor, and in particular to communicating with a wireless sensor implanted within the body to measure a physical condition.

BACKGROUND

[0002] Wireless sensors can be implanted within the body and used to monitor physical conditions, such as pressure or temperature. For example, U.S. Patent No. 6,111,520, U.S. Patent No. 6,855,115 and U.S. Publication No. 2003/0136417, all describe wireless sensors that can be implanted within the body. These sensors can be used to monitor physical conditions within the heart or an abdominal aneurysm. An abdominal aortic aneurysm (AAA) is a dilatation and weakening of the abdominal aorta that can lead to aortic rupture and sudden death. In the case of a repaired abdominal aneurysm, a sensor can be used to monitor pressure within the aneurysm sac to determine whether the intervention is leaking. The standard treatment for AAAs employs the use of stent-grafts that are implanted via endovascular techniques. However, a significant problem that has emerged with these stent-grafts for AAAs is acute and late leaks of blood into the aneurysms sac. Currently, following stent-graft implantation, patients are subjected to periodic evaluation via abdominal CT (Computed Tomography) with IV contrast to identify the potential presence of stent-graft leaks. This is an expensive, risky procedure that lacks appropriate sensitivity to detect small leaks.

[0003] Typically, the sensors utilize an inductive-capacitive ("LC") resonant circuit with a variable capacitor. The capacitance of the circuit varies with the pressure of the environment in which the sensor is located and thus, the resonant frequency of the circuit varies as the pressure varies. Thus, the resonant frequency of the circuit can be used to calculate pressure.

[0004] Ideally, the resonant frequency is determined using a non-invasive procedure. Several examples of procedures for determining the resonant frequency of an implanted sensor are discussed in U.S. Patent No. 6,111,520. Some of the procedures described in the patent require the transmission of a signal having multiple frequencies. A drawback of using a transmission signal having multiple frequencies is that the energy in the frequency bands outside the resonant frequency is wasted. This excess energy requires more power which results in an increase in cost, size, and thermal requirements, as well as an increase in electromagnetic interference with other signals. Thus, there is a need for an optimized method that is more energy efficient and requires less power.

[0005] There are unique requirements for communicating with an implanted sensor. For example, the system must operate in a low power environment and must be capable of handling a signal from the sensor with certain characteristics. For example, the signal from the sensor is relatively weak and must be detected quickly because the signal dissipates quickly. These requirements also impact the way that common problems are handled by the system. For example, the problems of switching transients and false locking need to be handled in a manner that accommodates the sensor signal characteristics. Thus, there is a need for a method for communicating with a wireless sensor that operates in a low power environment and that efficiently determines the resonant frequency of the sensor.

[0006] EP-0072003-A2 describes a system that samples a signal received from a sensor to measure the decay rate and determine the Q of the sensor circuit. This document does not measure the resonant frequency.

[0007] The resonant frequency of the sensor is a measured parameter that is correlated with the physical parameter of interest. To be clinically useful there must be means to ensure that variations in measurement environment do not affect the accuracy of the sensor. Thus, there is a need for a system and method for communicating with a wireless sensor that considers variations in the measurement environment.

SUMMARY OF THE INVENTION

[0008] The invention is as set out in the appended claims and in its broadest aspect comprises a method for determining a physical parameter of interest from a wireless sensor, in which the physical parameter of interest is correlated with a resonant frequency of the wireless sensor characterized in that the resonant frequency is determined by:

during a calibration cycle for system and environmental phase calibration:-

- generating an energizing signal;
- receiving a calibration signal comprising an energizing leakage signal;
- comparing the calibration signal with a local oscillator to determine a phase difference; and
- adjusting the phase of the energizing signal to drive the phase difference to a reference phase

and

adjusting the frequency of the energizing signal during a measurement cycle which includes:-

- energizing the wireless sensor (120);
- receiving a sensor signal from the wireless sensor (120);
- determining a characteristic of the sensor signal; and
- using the characteristic to determine the resonant frequency of the wireless sensor (120).

[0009] Determining a characteristic of the sensor signal may comprise comparing the sensor signal and a reference signal to determine a second phase difference; and using the second phase difference to determine the resonant frequency of the wireless sensor.

[0010] The reference signal may comprise the energizing signal, as mentioned in the claims.

[0011] The primary goal of aneurysm treatment is to depressurize the sac and to prevent rupture. Endoleaks, whether occurring intraoperatively or postoperatively, can allow the aneurysmal sac to remain pressurized and therefore, increase the chance of aneurysm rupture. The current imaging modalities angiography and CT scan are not always sensitive enough to detect endoleaks or stent graft failure. Intrasac pressure measurements provide a direct assessment of sac exclusion from circulation and may therefore offer intraoperative and post operative surveillance advantages that indirect imaging studies do not.

[0012] In one application of the present invention, an AAA pressure sensor is placed into the aneurysm sac at the time of stent-graft insertion. The pressure readings are read out by the physician by holding an electronic instrument, which allows an immediate assessment of the success of the stent-graft at time of the procedure and outpatient follow-up visits, by reading the resonant frequency of the wireless sensor and correlating the frequency reading to pressure.

[0013] The present invention meets the needs described above by providing a system and method for communicating with a wireless sensor to determine the resonant frequency of the sensor. The system energizes the sensor with a low duty cycle, gated burst of RF energy having a predetermined frequency or set of frequencies and a predetermined amplitude. The energizing signal is coupled to the sensor via a magnetic loop. The sensor may be an inductive-capacitive ("LC") resonant circuit with a variable capacitor that is implanted within the body and used to measure physical parameters, such as pressure or temperature. The energizing signal induces a current in the sensor which is maximized when the energizing frequency is the same as the resonant frequency of the sensor. The system receives the ring down response of the sensor via magnetic coupling and determines the resonant frequency of the sensor, which is used to calculate the measured physical parameter.

[0014] In one aspect of the invention a pair of phase locked loops ("PLLs") is used to adjust the phase and the frequency of the energizing signal until its frequency locks to the resonant frequency of the sensor. In one embodiment, one PLL samples during the calibration cycle and the other PLL samples during the measurement cycle. These cycles alternate every 10 microseconds synchronized with the pulse repetition period. The calibration cycle adjusts the phase of the energizing signal to a fixed reference phase to compensate for system delay or varying environmental conditions. The environmental conditions that can affect the accuracy of the sensor reading include, but are not limited to, proximity of reflecting or magnetically absorbative objects, variation of reflecting objects located within transmission distance, variation of temperature or humidity which can change parameters of internal components, and aging of internal components.

[0015] One of the PLLs is used to adjust the phase of the energizing signal and is referred to herein as the fast PLL. The other PLL is used to adjust the frequency of the energizing signal and is referred to herein as the slow PLL. During the time that the energizing signal is active, a portion of the signal enters the receiver and is referred to herein as a calibration signal. The calibration signal is processed and sampled to determine the phase difference between its phase and the phase of a local oscillator (referred to herein as the local oscillator 2). The cycle in which the calibration signal is sampled is referred to as the calibration cycle. The system adjusts the phase of the energizing signal to drive the phase difference to zero or another reference phase.

[0016] During the measurement cycle, the signal coupled from the sensor (referred to herein as the coupled signal or the sensor signal) is processed and sampled to determine the phase difference between the coupled signal and the energizing signal. The system then adjusts the frequency of the energizing signal to drive the phase difference to zero or other reference phase. Once the slow PLL is locked, the frequency of the energizing signal is deemed to match the resonant frequency of the sensor. The operation of the slow PLL is qualified based on signal strength so that the slow PLL does not lock unless the strength of the coupled signal meets a predetermined signal strength threshold.

[0017] The system also handles false locking and switching transients. A false lock occurs if the system locks on a frequency that does not correspond to the resonant frequency of the sensor. In one aspect of the invention, the system avoids false locks by examining how the phase difference signal goes to zero. If the slope of the phase difference signal relative to time meets a predetermined direction, e.g. positive, then the PLL is allowed to lock. However, if the slope of the phase difference signal relative to time does not meet the predetermined direction, e.g. it is negative, then the signal strength is suppressed to prevent a false lock.

[0018] Another aspect of the invention uses frequency dithering to avoid a false lock. A constant pulse repetition frequency can add spectral components to the sensor signal and cause a false lock. By randomly varying the pulse repetition frequency of the energizing signal, the sidebands move back and forth so that the average of the sidebands is reduced. Thus, the system locks on the center frequency rather than the sidebands.

[0019] In another aspect of the invention, phase dithering can be used to reduce switching transients. The phase of the energizing signal and a local oscillator (referred to herein as local oscillator 1) are randomly changed. Varying the phase of the energizing signal varies the phase of the coupled signal, but does not affect the phase of the transient signal. Thus, the average of the transient signal is reduced. Changing the resonant frequency of the coil as it is switched from energizing mode to coupling mode also reduces switching transients. The capacitors that are connected to the coil are switched between different modes to slightly change the resonant frequency in order to reduce switching transients.

[0020] These and other aspects, features and advantages of the present invention may be more clearly understood and appreciated from a review of the following detailed description of the disclosed embodiments and by reference to the appended drawings and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021]

Figure 1 is a block diagram of an exemplary system for communicating with a wireless sensor in accordance with an embodiment of the invention.

Figure 2(a) is a graph illustrating an exemplary energizing signal in accordance with an embodiment of the invention.

Figures 2(b), 2(c) and 2(d) are graphs illustrating exemplary coupled signals in accordance with an embodiment of the invention.

Figure 3 is a block diagram of an exemplary base unit in accordance with an embodiment of the invention.

Figures 4(a) and 4(b) are graphs illustrating exemplary phase difference signals in accordance with an embodiment of the invention.

Figure 5 illustrates frequency dithering in accordance with an embodiment of the invention.

Figure 6 illustrates phase dithering in accordance with an embodiment of the invention.

Figure 7 illustrates a coupling loop in accordance with an embodiment of the invention.

Figure 8 is a graph illustrating an exemplary charging response of an LC circuit in accordance with an embodiment of the invention.

DETAILED DESCRIPTION

[0022] The present invention is directed towards a system and method for communicating with a wireless sensor. Briefly described, the present invention determines the resonant frequency of the sensor by adjusting the phase and frequency of an energizing signal until the frequency of this signal locks to the resonant frequency of the sensor. The system energizes the sensor with a low duty cycle, gated burst of RF energy of a predetermined frequency or set of frequencies and predetermined amplitude. This signal induces a current in the sensor that can be used to track the resonant frequency of the sensor. The system receives the ring down response of the sensor and determines the resonant frequency of the sensor, which is used to calculate the measured physical parameter. The system uses a pair of phase locked loops ("PLL"s) to adjust the phase and the frequency of the energizing signal to track the resonant frequency of the sensor.

<u>Exemplary System</u>

[0023] Figure 1 illustrates an exemplary system for communicating with a wireless sensor implanted within a body. The system includes a coupling loop 100, a base unit 102, a display device 104 and an input device 106, such as a keyboard.

[0024] The coupling loop is formed from a band of copper. In one embodiment, the loop is eight inches in diameter. The coupling loop includes switching and filtering circuitry that is enclosed within a shielded box 101. The loop charges the sensor and then couples signals from the sensor into the receiver. The antenna can be shielded to attenuate in-band noise and electromagnetic emissions.

[0025] Another possible embodiment for a coupling loop is shown in Figure 7, which shows separate loops for energizing 702 and for receiving 704, although a single loop can be used for both functions. PIN diode switching inside the loop assembly is used to provide isolation between the energizing phase and the receive phase by opening the RX path pin diodes during the energizing period, and opening the energizing path pin diodes during the coupling period. Multiple energizing loops can be staggered tuned to achieve a wider bandwidth of matching between the transmit coils and the transmit circuitry.

[0026] The base unit includes an RF amplifier, a receiver, and signal processing circuitry. Additional details of the circuitry are described below in connection with Figure 3.

[0027] The display 104 and the input device 106 are used in connection with the user interface for the system. In the embodiment illustrated in Figure 1 the display device and the input device are connected to the base unit. In this embodiment, the base unit also provides conventional computing functions. In other embodiments, the base unit can be connected to a conventional computer, such as a laptop, via a communications link, such as an RS-232 link. If a separate computer is used, then the display device and the input devices associated with the computer can be used to provide the user interface. In one embodiment, LAB VIEW software is used to provide the user interface, as well as to provide graphics, store and organize data and perform calculations for calibration and normalization. The user interface records and displays patient data and guides the user through surgical and follow-up procedures.

[0028] An optional printer 108 is connected to the base unit and can be used to print out patient data or other types of information. As will be apparent to those skilled in the art other configurations of the system, as well as additional or fewer components can be utilized with the invention.

[0029] Patient and system information can be stored within a removable data storage unit, such as a portable USB storage device, floppy disk, smart card, or any other similar device. The patient information can be transferred to the physician's personal computer for analysis, review, or storage. An optional network connection can be provided to automate storage or data transfer. Once the data is retrieved from the system, a custom or third party source can be employed to assist the physician with data analysis or storage.

[0030] Figure 1 illustrates the system communicating with a sensor 120 implanted in a patient. The system is used in two environments: 1) the operating room during implant and 2) the doctor's office during follow-up examinations. During implant the system is used to record at least two measurements. The first measurement is taken during introduction of the sensor for calibration and the second measurement is taken after placement for functional verification. The measurements can be taken by placing the coupling loop either on or adjacent to the patient's back or the patient's stomach for a sensor that measures properties associated with an abdominal aneurysm. For other types of measurements, the coupling loop may be placed in other locations. For example, to measure properties associated with the heart, the coupling loop can be placed on the patient's back or the patient's chest.

[0031] The system communicates with the implanted sensor to determine the resonant frequency of the sensor. As described in more detail in the patent documents referenced in the Background section, a sensor typically includes an inductive-capacitive ("LC") resonant circuit having a variable capacitor. The distance between the plates of the variable capacitor varies as the surrounding pressure varies. Thus, the resonant frequency of the circuit can be used to determine the pressure.

[0032] The system energizes the sensor with an RF burst. The energizing signal is a low duty cycle, gated burst of RF energy of a predetermined frequency or set of frequencies and a predetermined amplitude. Typically, the duty cycle of the energizing signal ranges from 0.1 % to 50%. In one embodiment, the system energizes the sensor with a 30-37 MHz fundamental signal at a pulse repetition rate of 100 kHz with a duty cycle of 20%. The energizing signal is coupled to the sensor via a magnetic loop. This signal induces a current in the sensor which has maximum amplitude at the resonant frequency of the sensor. During this time, the sensor charges exponentially to a steady-state amplitude that is proportional to the coupling efficiency, distance between the sensor and loop, and the RF power. Figure 8 shows the charging response of a typical LC circuit to a burst of RF energy at its resonant frequency. The speed at which the sensor charges is directly related to the Q (quality factor) of the sensor. Therefore, the "on time" of the pulse repetition duty cycle is optimized for the Q of the sensor. The system receives the ring down response of the sensor via magnetic coupling and determines the resonant frequency of the sensor. Figure 2(a) illustrates a typical energizing signal and Figures 2(b), 2(c) and 2(d) illustrate typical coupled signals for various values of Q (quality factor) for the sensor. When the main unit is coupling energy at or near the resonant frequency of the sensor, the amplitude of the sensor return is maximized, and the phase of the sensor return will be close to zero degrees with respect to the energizing phase. The sensor return signal is processed via phase-locked-loops to steer the frequency and phase of the next energizing pulse.

<u>Operation of the Base Unit</u>

[0033] Figure 3 is a block diagram of the signal processing components within an exemplary base unit. The base unit determines the resonant frequency of the sensor by adjusting the energizing signal so that the frequency of the energizing signal matches the resonant frequency of the sensor. In the embodiment illustrated by Figure 3, two separate processors 302, 322 and two separate coupling loops 340, 342 are shown. In one embodiment, processor 302 is associated with the base unit and processor 322 is associated with a computer connected to the base unit. In other embodiments, a single processor is used that provides the same functions as the two separate processors. In other embodiments a single loop is used for both energizing and for coupling the sensor energy back to the receiver. As will be apparent to those skilled in the art, other configurations of the base unit are possible that use different components.

[0034] The embodiment illustrated by Figure 3 includes a pair of phase lock loops ("PLL"). One of the PLLs is used to adjust the phase of the energizing signal and is referred to herein as the fast PLL. The other PLL is used to adjust the frequency of the energizing signal and is referred to herein as the slow PLL. The base unit provides two cycles: the calibration cycle and the measurement cycle. In one embodiment, the first cycle is a 10 microsecond energizing period for calibration of the system, which is referred to herein as the calibration cycle, and the second cycle is a 10 microsecond energizing/coupling period for energizing the sensor and coupling a return signal from the sensor, which is referred to herein as the measurement cycle. During the calibration cycle, the system generates a calibration signal for system and environmental phase calibration and during the measurement cycle the system both sends and listens for a return signal, *i.e.* the sensor ring down. Alternatively, as those skilled in the art will appreciate, the calibration cycle and the measurement cycle can be implemented in the same pulse repetition period.

[0035] The phase of the energizing signal is adjusted during the calibration cycle by the fast PLL and the frequency of the energizing signal is adjusted during the measurement cycle by the slow PLL. The following description of the operation of the PLLs is presented sequentially for simplicity. However, as those skilled in the art will appreciate, the PLLs actually operate simultaneously.

[0036] Initially the frequency of the energizing signal is set to a default value determined by the calibration parameters of the sensor. Each sensor is associated with a number of calibration parameters, such as frequency, offset, and slope. An operator of the system enters the sensor calibration parameters into the system via the user interface and the system determines an initial frequency for the energizing signal based on the particular sensor. Alternatively, the sensor calibration information could be stored on portable storage devices, bar codes, or incorporated within a signal returned from the sensor. The initial phase of the energizing signal is arbitrary.

[0037] The initial frequency and the initial phase are communicated from the processor 302 to the DDSs (direct digital synthesizers) 304, 306. The output of DDS1 304 is set to the initial frequency and initial phase and the output of DDS2 306 (also referred to as local oscillator 1) is set to the initial frequency plus the frequency of the local oscillator 2. The phase of DDS2 is a fixed constant. In one embodiment, the frequency of local oscillator 2 is 4.725 MHz. The output of DDS1 is gated by the field programmable gate array (FPGA) 308 to create a pulsed transmit signal having a pulse repetition frequency ("PRF"). The FPGA provides precise gating so that the base unit can sample the receive signal during specific intervals relative to the beginning or end of the calibration cycle.

[0038] During the calibration cycle, the calibration signal which enters the receiver 310 is processed through the receive section 311 and the IF section 312, and is sampled. In one embodiment, the calibration signal is the portion of the energizing signal that leaks into the receiver (referred to herein as the energizing leakage signal). The signal is sampled during the on time of the energizing signal by a sample and hold circuit 314 to determine the phase difference between the signal and local oscillator 2. In the embodiment where the calibration signal is the portion of the energizing signal that leaks into the receiver, the signal is sampled approximately 100 ns after the beginning of the energizing signal pulse. Since the energizing signal is several orders of magnitude greater than the coupled signal, it is assumed that the phase information associated with the leaked signal is due to the energizing signal and the phase delay is due to the circuit elements in the coupling loop, circuit elements in the receiver, and environmental conditions, such as proximity of reflecting objects.

[0039] The phase difference is sent to a loop filter 316. The loop filter is set for the dynamic response of the fast PLL. In one embodiment, the PLL bandwidth is 1000 Hz and the damping ratio is 0.7. A DC offset is added to allow for positive and negative changes. The processor 302 reads its analog to digital converter (A/D) port to receive the phase difference information and adjusts the phase sent to direct digital synthesizer 1 (DDS1) to drive the phase difference to zero. This process is repeated alternatively until the phase difference is zero or another reference phase.

[0040] The phase adjustment made during the energizing period acts to zero the phase of the energizing signal with respect to local oscillator 2. Changes in the environment of the antenna or the receive chain impedance, as well as the phase delay within the circuitry prior to sampling affect the phase difference reading and are accommodated by the phase adjustment.

[0041] During the measurement cycle, the energizing signal may be blocked from the receiver during the on time of the energizing signal. During the off time of the energizing signal, the receiver is unblocked and the coupled signal from the sensor (referred to herein as the coupled signal or the sensor signal) is received. The coupled signal is amplified and filtered through the receive section 311. The signal is down converted and additional amplification and filtering takes place in the IF section 312. In one embodiment, the signal is down converted to 4.725 MHz. After being processed through the IF section, the signal is mixed with local oscillator 2 and sampled by sample and hold circuits 315 to determine the phase difference between the coupled signal and the energizing signal. In one embodiment, the sampling occurs approximately 30ns after the energizing signal is turned off.

[0042] In other embodiments, group delay or signal amplitude is used to determine the resonant frequency of the sensor. The phase curve of a second order system passes through zero at the resonant frequency. Since the group delay *i.e.* derivative of the phase curve reaches a maximum at the resonant frequency, the group delay can be used to determine the resonant frequency. Alternatively, the amplitude of the sensor signal can be used to determine the resonant frequency. The sensor acts like a bandpass filter so that the sensor signal reaches a maximum at the resonant frequency.

[0043] The sampled signal is accumulated within a loop filter 320. The loop filter is set for the dynamic response of the slow PLL to aid in the acquisition of a lock by the slow PLL. The PLLs are implemented with op-amp low pass filters that feed A/D inputs on microcontrollers, 302 and 322, which in turn talk to the DDSs, 304 and 306, which provide the energizing signal and local oscillator 1. The microcontroller that controls the energizing DDS 304 also handles communication with the display. The response of the slow PLL depends upon whether the loop is locked or not. If the loop is unlocked, then the bandwidth is increased so that the loop will lock quickly. In one embodiment, the slow PLL has a damping ratio of 0.7 and a bandwidth of 120 Hz when locked (the Nyquist frequency of the blood pressure waveform), which is approximately ten times slower than the fast PLL.

[0044] A DC offset is also added to the signal to allow both a positive and a negative swing. The output of the loop filter is input to an A/D input of processor 322. The processor determines a new frequency and sends the new frequency to the DSSs. The processor offsets the current frequency value of the energizing signal by an amount that is proportional to the amount needed to drive the output of the slow PLL loop filter to a preset value. In one embodiment the preset value is 2.5V and zero in phase. The proportional amount is determined by the PLL's overall transfer function.

[0045] The frequency of the energizing signal is deemed to match the resonant frequency of the sensor when the slow PLL is locked. Once the resonant frequency is determined, the physical parameter, such as pressure, is calculated using the calibration parameters associated with the sensor, which results in a difference frequency that is proportional to the measured pressure.

[0046] The operation of the slow PLL is qualified based on signal strength. The base unit includes signal strength detection circuitry. If the received signal does not meet a predetermined signal strength threshold, then the slow PLL is not allowed to lock and the bandwidth and search window for the PLL are expanded. Once the received signal meets the predetermined signal strength threshold, then the bandwidth and search window of the slow PLL is narrowed and the PLL can lock. In the preferred embodiment, phase detection and signal strength determination are provided via the "I" (in phase) and "Q" (quadrature) channels of a quadrature mixer circuit. The "I" channel is lowpass filtered and sampled to provide signal strength information to the processing circuitry. The "Q" channel is lowpass filtered and sampled to provide phase error information to the slow PLL.

Avoiding False Locks

[0047] The system provides unique solutions to the false lock problem. A false lock occurs if the system locks on a frequency that does not correspond to the resonant frequency of the sensor. There are several types of false locks. The first type of false lock arises due to the pulsed nature of the system. Since the energizing signal is a pulsed signal, it includes groups of frequencies. The frequency that corresponds to a false lock is influenced by the pulse repetition frequency, the Q of the sensor, and the duty cycle of the RF burst. For example, a constant pulse repetition frequency adds spectral components to the return signal at harmonic intervals around the resonant frequency of the sensor, which can cause a false lock. In one embodiment, false locks occur at approximately 600 kHz above and below the resonant frequency of the sensor. To determine a false lock, the characteristics of the signal are examined. For example, pulse repetition frequency dithering and/or observing the slope of the baseband signal are two possible ways of determine a false lock. In one embodiment where the system locks on a sideband frequency, the signal characteristics correspond to a heartbeat or a blood pressure waveform.

[0048] The second type of false lock arises due to a reflection or resonance of another object in the vicinity of the system. This type of false lock can be difficult to discern because it generally does not correspond to a heartbeat or blood pressure waveform. The lack of frequency modulation can be used to discriminate against this type of false lock. Changing the orientation of the magnetic loop also affects this type of false lock because the reflected false lock is sensitive to the angle of incidence.

[0049] The third type of false lock arises due to switching transients caused by switching the PIN diodes and analog switches in the RF path. These transients cause damped resonances in the filters in the receive chain, which can appear similar to the sensor signal. Typically, these types of false locks do not correspond to a heartbeat or blood pressure waveform because they are constant frequency. These types of false locks are also insensitive to orientation of the magnetic loop.

[0050] To avoid the first type of false lock, the present invention determines the slope of the baseband signal (the phase difference signal at point 330). In one embodiment, if the slope is positive, then the lock is deemed a true lock. However, if the slope is negative, then the lock is deemed a false lock. In another embodiment, a negative slope is deemed a true lock and a positive slope is deemed a false lock. The slope is determined by looking at points before and after the phase difference signal goes to zero. The slope can be determined in a number of different ways, including but not limited to, using an analog differentiator or multiple sampling. Figures 4(a) and 4(b) illustrate a true lock and a false lock respectively, when a positive slope indicates a true lock. In one embodiment, if a false lock is detected, then the signal strength is suppressed so that the signal strength appears to the processor 322 to be below the threshold and the system continues to search for the center frequency. In other embodiments, any non-zero slope can be interpreted as a false lock resulting in zero signal strength.

[0051] The system can also use frequency dithering to avoid the first type of false lock. Since the spectral components associated with a constant pulse repetition frequency can cause a false lock, dithering the pulse repetition frequency helps avoid a false lock. By dithering the pulse repetition frequency, the spectral energy at the potential false lock frequencies is reduced over the averaged sampling interval. As shown in Figure 5, the energizing signal includes an on time t1 and an off time t2. The system can vary the on time or the off time to vary the PRF (PRF = 1/(t1 + t2)). Figure 5 illustrates different on times (t1, t1') and different off times (t2, t2'). By varying the PRF, the sidebands move back and forth and the average of the sidebands is reduced. Thus, the system locks on the center frequency rather than the sidebands. The PRF can be varied between predetermined sequences of PRFs or can be varied randomly.

Reducing Switching Transients

[0052] The coupling loop switches between an energizing mode and a coupling mode. This switching creates transient signals, which can cause the third type of false lock. Phase dithering is one method used to reduce the switching transients. As shown in Figure 6, the system receives a switching transient 603 between the end of the energizing signal 602 and the beginning of the coupled signal 604. To minimize the transient, the phase of the energizing signal may be randomly changed. However, changing the phase of the energizing signal requires that the system redefine zero phase for the system. To redefine zero phase for the system, the phase of DDS2 is changed to match the change in phase of the energizing signal. Thus, the phase of the energizing signal 602' and the coupled signal 604' are changed, but the phase of the transient signal 603' is not. As the system changes phase, the average of the transient signal is reduced.

[0053] Changing the resonant frequency of the antenna as it is switched from energizing mode to coupling mode also helps to eliminate the switching transients. Eliminating the switching transients is especially important in the present invention because of the characteristics of the coupled signal. The coupled signal appears very quickly after the on period of the energizing signal and dissipates very quickly. In one embodiment, the invention operates in a low power environment with a passive sensor so that the magnitude of the coupled signal is small. However, the invention is not limited to working with a passive sensor.

[0054] The coupling loop is tuned to a resonant frequency that is based upon the sensor parameters. Changing the capacitors or capacitor network that is connected to the coupling loop changes the resonant frequency of the antenna. The resonant frequency typically is changed from approximately 1/10% to 2% between energizing mode and coupled mode. In some embodiments, the coupling loop is untuned.

[0055] Additional alternative embodiments will be apparent to those skilled in the art to which the present invention pertains without departing from its scope. For example, the system can operate with different types of sensors, such as non-linear sensors that transmit information at frequencies other than the transmit frequency or sensors that use backscatter modulations. Accordingly, the scope of the present invention is described by the appended claims and is supported by the foregoing description.

Claims

1. A method for determining a physical parameter of interest using a wireless sensor (120), in which the physical parameter of interest is correlated with the resonant frequency of the wireless sensor (120) **characterized in that**
the resonant frequency is determined by
during a calibration cycle for system and environmental phase calibration:-

    generating an energizing signal;
    receiving a calibration signal comprising an energizing leakage signal; comparing the calibration signal with a local oscillator to determine a phase difference ; and
    adjusting the phase of the energizing signal to drive the phase difference to a reference phase

   and
   adjusting the frequency of the energizing signal during a measurement cycle which includes:-

    energizing the wireless sensor (120);
    receiving a sensor signal from the wireless sensor (120);
    determining a characteristic of the sensor signal; and
    using the characteristic to determine the resonant frequency of the wireless sensor (120).

2. A method as claimed in Claim 1, wherein the characteristic is amplitude and wherein a maximum amplitude of the sensor signal is used to determine the resonant frequency of the wireless sensor (120).

3. A method as claimed in Claim 1, wherein the characteristic is sensor group delay and wherein a maximum sensor group delay of the sensor signal is used to determine the resonant frequency of the wireless sensor (120).

4. A method as claimed in Claim 1, wherein determining a characteristic of the sensor signal comprises comparing the sensor signal and a reference signal to determine a second phase difference; and using the second phase difference to determine the resonant frequency of the wireless sensor (120).

5. A method as claimed in Claim 1, wherein the calibration signal is a portion of the energizing signal that leaks into the receiver.

6. A method as claimed in Claim 4, wherein the reference signal is the energizing signal.

7. A method as claimed in Claim 4, wherein the calibration cycle further comprises adjusting a phase of the energizing signal until the phase difference is a predetermined value.

8. A method as claimed in Claim 4, wherein the measurement cycle further comprises adjusting a frequency of the energizing signal to reduce the second phase difference.

9. A method as claimed in Claim 8, wherein using the second phase difference to determine the frequency of the wireless sensor (120), comprises using the

frequency of the energizing signal to determine the frequency of the wireless sensor (120).

10. A method as claimed in Claim 8, wherein the measurement cycle is repeated until the second phase difference is a predetermined value.

11. A method as claimed in any one of Claims 1 to 10, wherein the calibration cycle is repeated until the phase difference is a predetermined value.

12. A method as claimed in Claim 1, comprising:

adjusting a phase of an energizing signal using a first phase lock loop (PLL) by:

generating the energizing signal with a first phase and a first frequency;
receiving the calibration signal via a receiver during a first period;
sampling the calibration signal;
determining a first phase difference between the sampled calibration signal and a reference signal; and
based on the first phase difference adjusting the phase of the energizing signal to reduce the first phase difference;

adjusting a frequency of the energizing signal using a second PLL by:

energizing the wireless sensor (120);
receiving a sensor signal from the wireless sensor (120) during a second period;
processing the sensor signal with a reference signal;
sampling the processed signal;
determining a second phase difference between the sampled signal and the energizing signal;
based on the second phase difference adjusting the frequency of the energizing signal to reduce the phase difference; and
determining the frequency of the energizing signal when the second PLL is locked; and

using the frequency of the energizing signal when the second PLL is locked to determine the resonant frequency of the sensor.

13. A method as claimed in Claim 12, wherein adjusting a phase of an energizing signal is repeated until the phase difference between the sampled calibration signal and the reference signal is a predetermined value.

14. A method as claimed in Claim 12, wherein adjusting a frequency of the energizing signal is repeated until the phase difference between the sampled signal and the energizing signal is a predetermined value.

15. A method as claimed in Claim 12, wherein the first frequency of the energizing signal is initially set to a default value determined by sensor calibration parameters.

16. A method as claimed in Claim 12, wherein the energizing signal is a pulsed signal having a pulse repetition frequency and wherein a pulse has a predetermined amplitude and a predefined frequency characteristic.

17. A method as claimed in Claim 16, wherein the predefined frequency characteristic is a single frequency.

18. A method as claimed in Claim 16, wherein the predefined frequency characteristic is a set of frequencies.

19. A method as claimed in Claim 16, further comprising: adjusting the pulse repetition frequency.

20. A method as claimed in Claim 16, further comprising:

adjusting the phase of the energizing signal; and
adjusting a phase of the reference signal to match the adjustment of the phase of the energizing signal.

21. A method as claimed in Claim 16, further comprising:

determining a signal strength of the sensor signal; and
if the signal strength of the sensor signal is below a predetermined threshold, then preventing the second PLL from locking.

22. A method as claimed in Claim 21, further comprising:

determining in a processor a relationship between the second phase difference and time; and
if the relationship does not satisfy a predetermined criteria, then suppressing the signal strength of the sensor signal to the processor.

23. A method as claimed in Claim 1, comprising:

providing a calibration cycle for determining a first relationship between an energizing signal and a calibration signal;
and
providing a measurement cycle for receiving a sensor signal, determining a second relationship between the sensor signal and the calibra-

tion signal and determining the resonant frequency of the wireless sensor (120) based on the first relationship and the second relationship.

24. A method as claimed in Claim 23, wherein the first relationship and/or the second relationship is a group delay.

25. A method as claimed in Claim 23, wherein a first phase locked loop (PLL) is used to provide the calibration cycle and a second PLL is used to provide the measurement cycle.

26. A method as claimed in Claim 25, wherein the first PLL is faster than the second PLL.

27. A method as claimed in Claim 1, in which means for preventing a false lock are provided comprising:

processing the sensor signal;
mixing the processed sensor signal with a reference signal;
determining a phase slope of a resulting baseband signal; and
if the phase slope does not satisfy a predetermined criteria, then preventing a phase lock loop (PLL) from locking.

28. A method as claimed in Claim 27, wherein the predetermined criteria corresponds to the phase difference increasing over time.

29. A method as claimed in Claim 27, wherein the predetermined criteria corresponds to the phase difference decreasing over time.

30. A method as claimed in Claim 27, wherein the predetermined criteria corresponds to an absolute magnitude of the phase difference being less than a predetermined threshold.

31. A method as claimed in Claim 27, further comprising if the slope does not satisfy a predetermined criteria, then suppressing a signal strength below a predetermined threshold.

32. A method as claimed in Claim 1
wherein the energizing signal has a predetermined frequency characteristic and a first pulse repetition frequency and , further comprising:

processing the sensor signal;
generating an adjusted energizing signal with a second pulse repetition frequency distinct from the first pulse repetition frequency;
receiving a second sensor signal, wherein the second sensor signal is based on the adjusted energizing signal;
processing the second sensor signal; and
averaging the processed sensor signal and the second processed sensor signal,
wherein the averaging reduces sidebands associated with the processed sensor signal and the second processed sensor signal.

33. A method as claimed in Claim 32, wherein the first pulse repetition frequency and the second pulse repetition frequency are predetermined.

34. A method as claimed in Claim 32, wherein the first pulse repetition frequency and the second pulse repetition frequency are randomly determined.

35. A method as claimed in Claim 1
wherein the energizing signal has a predetermined frequency characteristic and a first phase further comprising means for eliminating transient signals, comprising:

receiving a first transient signal;
processing the sensor signal;
generating an adjusted energizing signal with a second phase distinct from the first phase;
adjusting a phase of a reference signal so that the phase of the reference signal corresponds to the second phase;
receiving a second transient signal;
receiving a second sensor signal, wherein the second sensor signal is based on the adjusted energizing signal;
processing the second sensor signal; and
identifying the sensor signal and the second sensor signal based on a comparison of a phase of the sensor signal to the phase of the energizing signal and a comparison of a phase of the second sensor signal to the second phase.

36. A method as claimed in Claim 35, wherein the first phase and the second phase are predetermined.

37. A method as claimed in Claim 35, wherein the first phase and the second phase are randomly determined.

38. A method as claimed in Claim 1, further comprising using a coupling loop (100) for energizing and coupling signals, the method comprising:

using an energizing mode of the coupling loop (100), sending an energizing signal, wherein the energizing signal has a predetermined frequency characteristic and a pulse repetition frequency and wherein the coupling loop (100) has a first resonant frequency in the energizing mode;
switching to a coupled mode of the coupling loop (100), wherein the coupling loop (100) has a sec-

ond resonant frequency in the coupled mode that is distinct from the first resonant frequency; and

using the coupled mode, receiving a coupled signal, wherein the coupled signal is generated in response to coupling the energizing signal to a signal generating circuit and wherein the coupled signal is a low power, quickly dissipating signal.

39. The method of Claim 38, wherein switching to a coupled mode of the loop, comprises switching from a first capacitor network to a second capacitor network.

40. A method as claimed in Claim 38, 35 or 32, wherein the predetermined frequency characteristic is a single frequency.

41. A method as claimed in Claim 38, 35 or 32, wherein the predetermined frequency characteristic is a set of frequencies.

42. Apparatus for use in the method of any preceding claim, comprising:-

- means to provide an energizing signal;
- means to receive a calibration signal comprising an energizing leakage signal;
- means to compare the calibration signal with a local oscillator to determine a phase difference;
- means to adjust the phase of the energizing signal to drive the phase difference to a reference phase during a calibration cycle;
- means to adjust the frequency of the energizing signal during a measurement cycle;
- means to receive a signal from a sensor energized by said energizing signal;
- means to determine a characteristic of the sensor signal; and
- means to use the characteristic to determine the resonant frequency of the sensor.

43. Apparatus as claimed in Claim 42 comprising a coupling loop (100) for energizing and coupling signals, comprising:

a first capacitor network used to set a first resonant frequency for the coupling loop (100) in an energizing mode, wherein the coupling loop (100) couples an energizing signal in the energizing mode that has a predetermined frequency characteristic and a pulse repetition frequency;

a second capacitor network used to set a second resonant frequency for the coupling loop (100) in a coupled mode, wherein the coupling loop (100) receives a coupled signal in the coupled mode that is generated in response to coupling the energizing signal to a signal generating circuit and wherein the coupled signal is a low power, quickly dissipating signal; and

a switch for selecting between the first capacitor network and the second capacitor network.

Patentansprüche

1. Ein Verfahren zur Bestimmung eines physikalischen Parameters von Interesse unter Verwendung eines drahtlosen Sensors (120), wobei der physikalische Parameter von Interesse mit der Resonanzfrequenz des drahtlosen Sensors (120) korreliert, **dadurch gekennzeichnet, dass** die Resonanzfrequenz bestimmt wird durch

während eines Kalibrierungszyklus zur Phasenkalibrierung bezüglich des Systems und der Umweltbedingungen:

Erzeugen eines Anregungssignals;
Empfangen eines Kalibrierungssignals enthaltend ein Anregungsverlustsignal;
Vergleichen des Kalibrierungssignals mit einem Lokaloszillator, um eine Phasendifferenz zu bestimmen;
und
Anpassen der Phase des Anregungssignals bis die Phasendifferenz einer Referenzphase entspricht;

und

Anpassen der Frequenz des Anregungssignals während eines Messzyklus enthaltend:

Anregen des drahtlosen Sensors (120);
Empfangen eines Sensorsignals von dem drahtlosen Sensor (120);
Bestimmen einer Charakteristik des Sensorsignals; und
Verwenden der Charakteristik, um die Resonanzfrequenz des drahtlosen Sensors (120) zu bestimmen.

2. Ein Verfahren gemäß Anspruch 1, wobei die Charakteristik die Amplitude ist, und wobei eine maximale Amplitude des Sensorsignals verwendet wird, um die Resonanzfrequenz des drahtlosen Sensors (120) zu bestimmen.

3. Ein Verfahren gemäß Anspruch 1, wobei die Charakteristik die Sensorgruppenverzögerung ist, und wobei eine maximale Sensorgruppenverzögerung des Sensorsignals verwendet wird, um die Resonanzfrequenz des drahtlosen Sensors (120) zu bestimmen.

4. Ein Verfahren gemäß Anspruch 1, wobei die Bestimmung einer Charakteristik des Sensorsignals den Vergleich des Sensorsignals und eines Referenzsignals umfasst, um eine zweite Phasendifferenz zu bestimmen; und die Verwendung der zweiten Phasendifferenz, um die Resonanzfrequenz des drahtlosen Sensors (120) zu bestimmen.

5. Ein Verfahren gemäß Anspruch 1, wobei das Kalibrierungssignal ein Teil des Anregungssignals ist, das in den Empfänger leckt.

6. Ein Verfahren gemäß Anspruch 4, wobei das Referenzsignal das Anregungssignal ist.

7. Ein Verfahren gemäß Anspruch 4, wobei der Kalibrierungszyklus weiterhin das Einstellen einer Phase des Anregungssignals umfasst bis die Phasendifferenz einen vorbestimmten Wert erreicht.

8. Ein Verfahren gemäß Anspruch 4, wobei der Messzyklus weiterhin das Einstellen einer Frequenz des Anregungssignals umfasst, um die zweite Phasendifferenz zu verringern.

9. Ein Verfahren gemäß Anspruch 8, wobei die Verwendung der zweiten Phasendifferenz zur Bestimmung der Frequenz des drahtlosen Sensors (120) die Verwendung der Frequenz des Anregungssignals umfasst, zur Bestimmung der Frequenz des drahtlosen Sensors (120).

10. Ein Verfahren gemäß Anspruch 8, wobei der Messzyklus wiederholt wird bis die zweite Phasendifferenz einen vorbestimmten Wert erreicht.

11. Ein Verfahren gemäß irgendeinem der Ansprüche 1 bis 10, wobei der Kalibrierungszyklus wiederholt wird bis die Phasendifferenz einen vorbestimmten Wert erreicht.

12. Ein Verfahren gemäß Anspruch 1, umfassend Einstellen einer Phase eines Anregungssignals unter Verwendung einer ersten Phasenregelschleife (PLL) durch:

> Erzeugen des Anregungssignals mit einer ersten Phase und einer ersten Frequenz; Empfangen eines Kalibrierungssignals über einen Empfänger während einer ersten Periode;
> Abtasten des Kalibrierungssignals;
> Bestimmen einer ersten Phasendifferenz zwischen dem abgetasteten Kalibrierungssignal und einem Referenzsignal; und
> basierend auf der ersten Phasendifferenz Einstellen der Phase des Anregungssignals, um die erste Phasendifferenz zu verringern;
> Einstellen einer Frequenz des Anregungssignals unter Verwendung einer zweiten PLL durch:
>
> > Anregen des drahtlosen Sensors (120);
> > Empfangen eines Sensorsignals von dem drahtlosen Sensor (120) während einer zweiten Periode;
> > Verarbeiten des Sensorsignals mit einem Referenzsignal;
> > Abtasten des verarbeiteten Signals;
> > Bestimmen einer zweiten Phasendifferenz zwischen dem abgetasteten Signal und dem Anregungssignal;
> > basierend auf der zweiten Phasendifferenz Einstellen der Frequenz des Anregungssignals, um die Phasendifferenz zu verringern; und
> > Bestimmen der Frequenz des Anregungssignals, wenn die zweite PLL eingerastet ist; und
>
> Verwendung der Frequenz des Anregungssignals, wenn die zweite PLL eingerastet ist, um die Resonanzfrequenz des Sensors zu bestimmen.

13. Ein Verfahren gemäß Anspruch 12, wobei das Einstellen einer Phase eines Anregungssignals wiederholt wird bis die Phasendifferenz zwischen dem abgetasteten Kalibrierungssignal und dem Referenzsignal einen vorbestimmten Wert erreicht.

14. Ein Verfahren gemäß Anspruch 12, wobei das Anpassen einer Frequenz des Anregungssignals wiederholt wird bis die Phasendifferenz zwischen dem abgetasteten Signal und dem Anregungssignal einen vorbestimmten Wert erreicht.

15. Ein Verfahren gemäß Anspruch 12, wobei die erste Frequenz des Anregungssignals anfänglich auf einen Standardwert gesetzt wird, der durch Sensorkalibrierungsparameter bestimmt wird.

16. Ein Verfahren gemäß Anspruch 12, wobei das Anregungssignal ein gepulstes Signal mit einer Impulsfolgefrequenz ist, und wobei ein Impuls eine vorgegebene Amplitude und eine vorgegebene Frequenzcharakteristik aufweist.

17. Ein Verfahren gemäß Anspruch 16, wobei die vordefinierte Frequenzcharakteristik eine Gleichwelle ist.

18. Ein Verfahren gemäß Anspruch 16, wobei die vordefinierte Frequenzcharakteristik ein Satz von Frequenzen ist.

19. Ein Verfahren gemäß Anspruch 16, weiterhin umfassend: Einstellen der Impulsfolgefrequenz.

20. Ein Verfahren gemäß Anspruch 16, weiterhin umfassend:

Einstellen der Phase des Anregungssignals; und
Einstellen einer Phase des Referenzsignals, um der Einstellung der Phase des Anregungssignals zu entsprechen.

21. Ein Verfahren gemäß Anspruch 16, weiterhin umfassend:

Bestimmen einer Signalstärke des Sensorsignals; und
wenn die Signalstärke des Sensorsignals unter einem vorgegebenen Schwellenwert ist, Verhindern des Einrastens der zweiten PLL.

22. Ein Verfahren gemäß Anspruch 21, weiterhin umfassend:

in einem Prozessor Bestimmen einer Beziehung zwischen der zweiten Phasendifferenz und der Zeit; und
wenn die Beziehung ein vorgegebenes Kriterium nicht erfüllt, Unterdrückung der Signalstärke des an den Prozessor gerichteten Sensorsignals.

23. Ein Verfahren gemäß Anspruch 1, enthaltend:

Bereitstellen eines Kalibrierungszyklus zur Bestimmung einer ersten Beziehung zwischen einen Anregungssignal und einem Kalibrierungssignal;
und
Bereitstellen eines Messzyklus zum Erhalten eines Sensorsignals, Bestimmen einer zweiten Beziehung zwischen dem Sensorsignal und dem Kalibrierungssignal und Bestimmen den Resonanzfrequenz des drahtlosen Sensors (120) auf der Grundlage der ersten Beziehung und der zweiten Beziehung.

24. Ein Verfahren gemäß Anspruch 23, wobei die erste Beziehung und/oder die zweite Beziehung eine Gruppenverzögerung ist.

25. Ein Verfahren gemäß Anspruch 23, wobei eine erste Phasenregelschleife (PLL) verwendet wird, um den Kalibrierungszyklus bereitzustellen und eine zweite PLL verwendet wird, um den Messzyklus bereitzustellen.

26. Ein Verfahren gemäß Anspruch 25, wobei die erste PLL schneller als die zweite PLL ist.

27. Ein Verfahren gemäß Anspruch 1, wobei Mittel zur Verhinderung eines Einrastfehlers bereitgestellt werden, umfassend:

Verarbeiten des Sensorsignals;
Mischen des verarbeiteten Sensorsignals mit einem Referenzsignal;
Bestimmen einer Phasensteigung eines resultierenden Basisbandsignals; und
wenn die Phasensteigung ein vorbestimmtes Kriterium nicht erfüllt, Verhindern des Einrastens einer Phasenregelschleife (PLL).

28. Ein Verfahren gemäß Anspruch 27, wobei die vorbestimmten Kriterien der im Verlauf der Zeit sich vergrößernden Phasendifferenz entsprechen.

29. Ein Verfahren gemäß Anspruch 27, wobei die vorbestimmten Kriterien der im Verlauf der Zeit abnehmenden Phasendifferenz entsprechen.

30. Ein Verfahren gemäß Anspruch 27, wobei die vorbestimmten Kriterien einer absoluten Größe der Phasendifferenz entsprechen, die kleiner ist als ein vorbestimmter Schwellenwert.

31. Ein Verfahren gemäß Anspruch 27, weiterhin umfassend, wenn die Steigung ein vorbestimmtes Kriterium nicht erfüllt, Unterdrücken einer Signalstärke unter einen vorbestimmten Schwellenwert.

32. Ein Verfahren gemäß Anspruch 1,
wobei das Anregungssignal eine vorbestimmte Frequenzcharakteristik und eine erste Impulsfolgefrequenz aufweist; weiterhin enthaltend:

Verarbeiten des Sensorsignals;
Erzeugen eines eingestellten Anregungssignals mit einer zweiten Impulsfolgefrequenz, die verschieden ist von der ersten Impulsfolgefrequenz;
Empfangen eines zweiten Sensorsignals, wobei das zweite Sensorsignal auf dem eingestellten Anregungssignal basiert;
Verarbeiten des zweiten Sensorsignals; und
Mittelwertbildung des verarbeiteten Sensorsignals und des zweiten verarbeiteten Sensorsignals, wobei die Mittelwertbildung Seitenbänder reduziert, die mit dem verarbeiteten Sensorsignal und dem zweiten verarbeiteten Sensorsignal assoziiert sind.

33. Ein Verfahren gemäß Anspruch 32, wobei die erste Impulsfolgefrequenz und die zweite Impulsfolgefrequenz vorbestimmt sind.

34. Ein Verfahren gemäß Anspruch 32, wobei die erste Impulsfolgefrequenz und die zweite Impulsfolgefrequenz zufällig bestimmt werden.

35. Ein Verfahren gemäß Anspruch 1,
wobei das Anregungssignal eine vorbestimmte Frequenzcharakteristik und eine erste Phase aufweist, weiterhin enthaltend Mittel zum Eliminieren von Übergangssignalen, umfassend:

Empfangen eines ersten Übergangssignals;
Verarbeiten des Sensorsignals;
Erzeugen eines eingestellten Anregungssignals mit einer zweiten Phase, die von der ersten Phase verschieden ist;
Einstellen einer Phase eines Referenzsignals, so dass die Phase des Referenzsignals der zweiten Phase entspricht;
Empfangen eines zweiten Übergangssignals;
Empfangen eines zweiten Sensorsignals, wobei das zweite Sensorsignal auf dem eingestellten Anregungssignal basiert;
Verarbeiten des zweiten Sensorsignals; und
Identifizieren des Sensorsignals und des zweiten Sensorsignals basierend auf einem Vergleich einer Phase des Sensorsignals mit der Phase des Anregungssignals und einem Vergleich der Phase des zweiten Sensorsignals mit der zweiten Phase.

36. Ein Verfahren gemäß Anspruch 35, wobei die erste Phase und die zweite Phase vorbestimmt sind.

37. Ein Verfahren gemäß Anspruch 35, wobei die erste Phase und die zweite Phase willkürlich festgelegt werden.

38. Ein Verfahren gemäß Anspruch 1, weiterhin enthaltend die Verwendung einer Kopplungsschleife (100) zum Anregen und Koppeln von Signalen, wobei das Verfahren umfasst:

Verwendung eines Anregungsmodus der Kopplungsschleife (100), Senden eines Anregungssignals, wobei das Anregungssignal eine vorbestimmte Frequenzcharakteristik und eine Impulsfolgefrequenz aufweist, und wobei die Kopplungsschleife (100) eine erste Resonanzfrequenz im Anregungsmodus aufweist;
Umschalten in einen gekoppelten Modus der Kopplungsschleife (100), wobei die Kopplungsschleife (100) eine zweite Resonanzfrequenz im gekoppelten Modus aufweist, die verschieden ist von der ersten Resonanzfrequenz; und
Verwendung des gekoppelten Modus, Empfangen eines gekoppelten Signals, wobei das gekoppelte Signal als Antwort erzeugt wird auf die Kopplung des Anregungssignals an einen Signalerzeugungsschaltkreis, und wobei das gekoppelte Signal ein Signal mit niedriger Energie ist und rasch abgeleitet wird.

39. Das Verfahren gemäß Anspruch 38, wobei der Wechsel zu einem gekoppelten Modus der Schleife das Umschalten von einem ersten Kondensatornetzwerk zu einem zweiten Kondensatornetzwerk umfasst.

40. Ein Verfahren gemäß Anspruch 38, 35 oder 32, wobei die vorbestimmte Frequenzcharakteristik eine Gleichwelle ist.

41. Ein Verfahren gemäß Anspruch 38, 35 oder 32, wobei die vorbestimmte Frequenzcharakteristik ein Satz von Frequenzen ist.

42. Ein Apparat zur Verwendung in dem Verfahren gemäß irgendeinem der vorherigen Ansprüche, enthaltend:

- Mittel zur Bereitstellung eines Anregungssignals;
- Mittel zum Empfangen eines Kalibrierungssignals enthaltend ein Anregungsverlustsignal;
- Mittel zum Vergleichen des Kalibrierungssignals mit einem Lokaloszillator zur Bestimmung einer Phasendifferenz;
- Mittel zum Einstellen der Phase des Anregungssignals, um die Phasendifferenz in eine Referenzphase während eines Kalibrierungszyklus zu bringen;
- Mittel zum Einstellen der Frequenz des Anregungssignals während eines Messzyklus;
- Mittel zum Empfangen eines Signals von einem Sensor, der durch das Anregungssignal angeregt ist;
- Mittel zur Bestimmung einer Charakteristik des Sensorsignals; und
- Mittel, um die Charakteristik zur Bestimmung der Resonanzfrequenz des Sensors zu verwenden.

43. Ein Apparat gemäß Anspruch 42 enthaltend eine Kopplungsschleife (100) zum Anregen und Koppeln von Signalen enthaltend:

ein erstes Kondensatornetzwerk, um eine erste Resonanzfrequenz für die Kopplungsschleife (100) in einen Anregungsmodus zu versetzen, wobei die Kopplungsschleife (100) ein Anregungssignal, das eine vorgegebene Frequenzcharakteristik und eine Pulsfolgefrequenz besitzt, im Anregungsmodus koppelt;
ein zweites Kondensatornetzwerk, um eine zweite Resonanzfrequenz für die Kopplungsschleife (100) in einen gekoppelten Modus zu versetzen, wobei die Kopplungsschleife (100) ein gekoppeltes Signal im gekoppelten Modus

empfängt, das als Antwort erzeugt wird auf die Kopplung des Anregungssignals an einen Signalerzeugungsschaltkreis, und wobei das gekoppelte Signal ein Signal mit niedriger Energie ist und rasch abgeleitet wird; und
einen Schalter zum Auswählen zwischen dem ersten Kondensatornetzwerk und dem zweiten Kondensatornetzwerk.

Revendications

1. Procédé destiné à déterminer un paramètre physique d'intérêt utilisant un capteur sans fil (120), dans lequel le paramètre physique d'intérêt est corrélé à la fréquence de résonance du capteur sans fil (120) **caractérisé en ce que**
la fréquence de résonance est déterminée par pendant un cycle d'étalonnage pour l'étalonnage de système et de phase environnementale :

génération d'un signal d'alimentation en énergie ;
réception d'un signal d'étalonnage comprenant un signal de fuite d'alimentation en énergie ;
comparaison du signal d'étalonnage avec un oscillateur local pour déterminer une différence de phase ; et
ajustement de la phase du signal d'alimentation en énergie pour entraîner la différence de phase vers une phase de référence ;

et
ajustement de la fréquence du signal d'alimentation en énergie pendant un cycle de mesure qui inclut :

l'alimentation en énergie du capteur sans fil (120) ;
la réception d'un signal de capteur du capteur sans fil (120) ;
la détermination d'une caractéristique du signal de capteur ; et
l'utilisation de la caractéristique pour déterminer la fréquence de résonance du capteur sans fil (120).

2. Procédé selon la revendication 1, dans lequel la caractéristique est une amplitude et dans lequel une amplitude maximale du signal de capteur est utilisée pour déterminer la fréquence de résonance du capteur sans fil (120).

3. Procédé selon la revendication 1, dans lequel la caractéristique est un retard de groupe de capteur et dans lequel un retard de groupe de capteur maximal du signal de capteur est utilisé pour déterminer la fréquence de résonance du capteur sans fil (120).

4. Procédé selon la revendication 1, dans lequel la détermination d'une caractéristique de signal de capteur comprend la comparaison du signal de capteur et d'un signal de référence pour déterminer une seconde différence de phase ; et l'utilisation de la seconde différence de phase pour déterminer la fréquence de résonance du capteur sans fil (120).

5. Procédé selon la revendication 1, dans lequel le signal d'étalonnage est une partie du signal d'alimentation en énergie qui fuit dans le récepteur.

6. Procédé selon la revendication 4, dans lequel le signal de référence est le signal d'alimentation en énergie.

7. Procédé selon la revendication 4, dans lequel le cycle d'étalonnage comprend en outre l'ajustement d'une phase du signal d'alimentation en énergie jusqu'à ce que la différence de phase soit une valeur prédéterminée.

8. Procédé selon la revendication 4, dans lequel le cycle de mesure comprend en outre l'ajustement d'une fréquence du signal d'alimentation en énergie pour réduire la seconde différence de phase.

9. Procédé selon la revendication 8, dans lequel l'utilisation de la seconde différence de phase pour déterminer la fréquence du capteur sans fil (120) comprend l'utilisation de la fréquence du signal d'alimentation en énergie pour déterminer la fréquence du capteur sans fil (120).

10. Procédé selon la revendication 8, dans lequel le cycle de mesure est répété jusqu'à ce que la seconde différence de phase soit une valeur prédéterminée.

11. Procédé selon l'une quelconque des revendications 1 à 10, dans lequel le cycle d'étalonnage est répété jusqu'à ce que la différence de phase soit une valeur prédéterminée.

12. Procédé selon la revendication 1, comprenant :

l'ajustement d'une phase d'un signal d'alimentation en énergie à l'aide d'une première boucle à verrouillage de phase (PLL) par :

génération du signal d'alimentation en énergie avec une première phase et une première fréquence ;
réception du signal d'étalonnage via un récepteur pendant une première période ;
prélèvement du signal d'étalonnage ;
détermination d'une première différence de phase entre le signal d'étalonnage prélevé et un signal de référence ; et

en se basant sur la première différence de phase, l'ajustement de la phase du signal d'alimentation en énergie pour réduire la première différence de phase ;

l'ajustement d'une fréquence du signal d'alimentation en énergie à l'aide d'une seconde PLL par :

alimentation en énergie du capteur sans fil (120) ;
réception d'un signal de capteur du capteur sans fil (120) pendant une seconde période ;
traitement du signal de capteur avec un signal de référence ;
prélèvement du signal traité ;
détermination d'une seconde différence de phase entre le signal prélevé et le signal d'alimentation en énergie ;
en se basant sur la seconde différence de phase, ajustement de la fréquence du signal d'alimentation en énergie pour réduire la différence de phase ; et
détermination de la fréquence du signal d'alimentation en énergie lorsque la seconde PLL est verrouillée ; et

utilisation de la fréquence du signal d'alimentation en énergie lorsque la seconde PLL est verrouillée pour déterminer la fréquence de résonnance du capteur.

13. Procédé selon la revendication 12, dans lequel l'ajustement d'une phase d'un signal d'alimentation en énergie est répété jusqu'à ce que la différence de phase entre le signal d'étalonnage prélevé et le signal de référence soit une valeur prédéterminée.

14. Procédé selon la revendication 12, dans lequel l'ajustement d'une fréquence du signal d'alimentation en énergie est répété jusqu'à ce que la différence de phase entre le signal prélevé et le signal d'alimentation en énergie soit une valeur prédéterminée.

15. Procédé selon la revendication 12, dans lequel la première fréquence du signal d'alimentation en énergie est initialement fixée à une valeur par défaut déterminée par des paramètres d'étalonnage de capteur.

16. Procédé selon la revendication 12, dans lequel le signal d'alimentation en énergie est un signal pulsé ayant une fréquence de répétition d'impulsion et dans lequel une impulsion a une amplitude prédéterminée et une caractéristique de fréquence prédéfinie.

17. Procédé selon la revendication 16, dans lequel la caractéristique de fréquence prédéfinie est une fréquence unique.

18. Procédé selon la revendication 16, dans lequel la caractéristique de fréquence prédéfinie est un jeu de fréquences.

19. Procédé selon la revendication 16, comprenant en outre: l'ajustement de la fréquence de répétition d'impulsion.

20. Procédé selon la revendication 16, comprenant en outre :

l'ajustement de la phase du signal d'alimentation en énergie ; et
l'ajustement d'une phase du signal de référence pour concorder avec l'ajustement de la phase du signal d'alimentation en énergie.

21. Procédé selon la revendication 16, comprenant en outre :

la détermination d'une intensité de signal du signal de capteur ; et
si l'intensité de signal du signal de capteur est en dessous d'un seuil prédéterminé, alors
le fait d'empêcher la seconde PLL de se verrouiller.

22. Procédé selon la revendication 21, comprenant en outre :

la détermination dans un processeur d'une relation entre la seconde différence de phase et le temps ; et
si la relation ne satisfait pas un critère prédéterminé, alors la suppression de l'intensité de signal du signal de capteur sur le processeur.

23. Procédé selon la revendication 1, comprenant :

la fourniture d'un cycle d'étalonnage pour déterminer une première relation entre un signal d'alimentation en énergie et un signal d'étalonnage ; et
la fourniture d'un cycle de mesure pour recevoir un signal de capteur, la détermination d'une seconde relation entre le signal de capteur et le signal d'étalonnage et la détermination de la fréquence de résonnance du capteur sans fil (120) en se basant sur la première relation et la seconde relation.

24. Procédé selon la revendication 23, dans lequel la première relation et/ou la seconde relation sont un retard de groupe.

25. Procédé selon la revendication 23, dans lequel une première boucle à verrouillage de phase (PLL) est utilisée pour fournir le cycle d'étalonnage et une seconde PLL est utilisée pour fournir le cycle de mesure.

26. Procédé selon la revendication 25, dans lequel la première PLL est plus rapide que la seconde PLL.

27. Procédé selon la revendication 1, dans lequel des moyens permettant d'empêcher un faux verrouillage sont prévus comprenant :

le traitement du signal de capteur ;
le mélange du signal de capteur traité avec un signal de référence ;
la détermination d'une pente de phase d'un signal de bande de base résultant ; et
si la pente de phase ne satisfait pas un critère prédéterminé, alors le fait d'empêcher une boucle à verrouillage de phase (PLL) de se verrouiller.

28. Procédé selon la revendication 27, dans lequel le critère prédéterminé correspond à l'augmentation de la différence de phase au cours du temps.

29. Procédé selon la revendication 27, dans lequel le critère prédéterminé correspond à la diminution de la différence de phase au cours du temps.

30. Procédé selon la revendication 27, dans lequel le critère prédéterminé correspond au fait qu'une grandeur absolue de la différence de phase soit inférieure à un seuil prédéterminé.

31. Procédé selon la revendication 27, comprenant en outre, si la pente ne satisfait pas un critère prédéterminé, la suppression par voie de conséquence d'une intensité de signal en dessous d'un seuil prédéterminé.

32. Procédé selon la revendication 1
dans lequel le signal d'alimentation en énergie a une caractéristique de fréquence prédéterminée et une première fréquence de répétition d'impulsion et, comprenant en outre :

le traitement du signal de capteur ;
la génération d'un signal d'alimentation en énergie ajusté avec une seconde fréquence de répétition d'impulsion distincte de la première fréquence de répétition d'impulsion ;
la réception d'un second signal de capteur, dans lequel le second signal de capteur est basé sur le signal d'alimentation en énergie ajusté ;
le traitement du second signal de capteur ; et
le moyennage du signal de capteur traité et du second signal de capteur traité,
dans lequel le moyennage réduit des bandes latérales associées au signal de capteur traité et au second signal de capteur traité.

33. Procédé selon la revendication 32, dans lequel la première fréquence de répétition d'impulsion et la seconde fréquence de répétition d'impulsion sont prédéterminées.

34. Procédé selon la revendication 32, dans lequel la première fréquence de répétition d'impulsion et la seconde fréquence de répétition d'impulsion sont déterminées au hasard.

35. Procédé selon la revendication 1,
dans lequel le signal d'alimentation en énergie a une caractéristique de fréquence prédéterminée et une première phase comprenant en outre des moyens pour éliminer des signaux transitoires, comprenant :

la réception d'un premier signal transitoire ;
le traitement du signal de capteur ;
la génération d'un signal d'alimentation en énergie ajusté avec une seconde phase distincte de la première phase ;
l'ajustement d'une phase d'un signal de référence pour que la phase du signal de référence corresponde à la seconde phase ;
la réception d'un second signal transitoire ;
la réception d'un second signal de capteur, dans lequel le second signal de capteur est basé sur le signal d'alimentation en énergie ajusté ;
le traitement du second signal de capteur ; et
l'identification du signal de capteur et du second signal de capteur en se basant sur une comparaison d'une phase du signal de capteur à la phase du signal d'alimentation en énergie et une comparaison d'une phase du second signal de capteur à la seconde phase.

36. Procédé selon la revendication 35, dans lequel la première phase et la seconde phase sont prédéterminées.

37. Procédé selon la revendication 35, dans lequel la première phase et la seconde phase sont déterminées au hasard.

38. Procédé selon la revendication 1, comprenant en outre l'utilisation d'une boucle de couplage (100) pour alimenter en énergie et coupler des signaux, le procédé comprenant :

l'utilisation d'un mode d'alimentation en énergie de la boucle de couplage (100), l'envoi d'un signal d'alimentation en énergie, dans lequel le signal d'alimentation en énergie a une caracté-

ristique de fréquence prédéterminée et une fréquence de répétition d'impulsion et dans lequel la boucle de couplage (100) a une première fréquence de résonance dans le mode d'alimentation en énergie ;
la commutation à un mode couplé de la boucle de couplage (100), dans lequel la boucle de couplage (100) a une seconde fréquence de résonance dans le mode couplé qui est distincte de la première fréquence de résonance ; et
en utilisant le mode couplé, la réception d'un signal couplé, dans lequel le signal couplé étant généré en réponse au couplage du signal d'alimentation en énergie a un circuit de génération de signal et dans lequel le signal couplé est un signal de faible puissance se dissipant vite.

39. Procédé selon la revendication 38, dans lequel la commutation à un mode couplé de la boucle comprend la commutation d'un premier réseau de condensateurs à un second réseau de condensateurs.

40. Procédé selon la revendication 38, 35 ou 32, dans lequel la caractéristique de fréquence prédéterminée est une fréquence unique.

41. Procédé selon la revendication 38, 35 ou 32, dans lequel la caractéristique de fréquence prédéterminée est un jeu de fréquences.

42. Appareil à utiliser dans le procédé de l'une quelconque des revendications précédentes, comprenant :

- des moyens pour fournir un signal d'alimentation en énergie ;
- des moyens pour recevoir un signal d'étalonnage comprenant un signal de fuite d'alimentation en énergie ;
- des moyens pour comparer le signal d'étalonnage avec un oscillateur local pour déterminer une différence de phase ;
- des moyens pour ajuster la phase du signal d'alimentation en énergie pour entraîner la différence de phase vers une phase de référence pendant un cycle d'étalonnage ;
- des moyens pour ajuster la fréquence du signal d'alimentation en énergie durant un cycle de mesure ;
- des moyens pour recevoir un signal d'un capteur alimenté en énergie par ledit signal d'alimentation en énergie ;
- des moyens pour déterminer une caractéristique du signal de capteur ; et
- des moyens pour utiliser la caractéristique pour déterminer la fréquence de résonance du capteur.

43. Appareil selon la revendication 42, comprenant une boucle de couplage (100) pour alimenter en énergie et coupler des signaux, comprenant :

un premier réseau de condensateurs utilisé pour fixer une première fréquence de résonnance pour la boucle de couplage (100) dans un mode d'alimentation en énergie, dans lequel la boucle de couplage (100) couple un signal d'alimentation en énergie dans le mode d'alimentation en énergie qui a une caractéristique de fréquence prédéterminée et une fréquence de répétition d'impulsion ;
un second réseau de condensateurs utilisé pour fixer une seconde fréquence de résonance pour la boucle de couplage (100) dans un mode couplé, dans lequel la boucle de couplage (100) reçoit un signal couplé dans le mode couplé qui est généré en réponse au couplage du signal d'alimentation en énergie à un circuit de génération de signal et dans lequel le signal couplé est un signal de faible puissance se dissipant vite ; et
un commutateur pour effectuer une sélection entre le premier réseau de condensateurs et le second réseau de condensateurs.

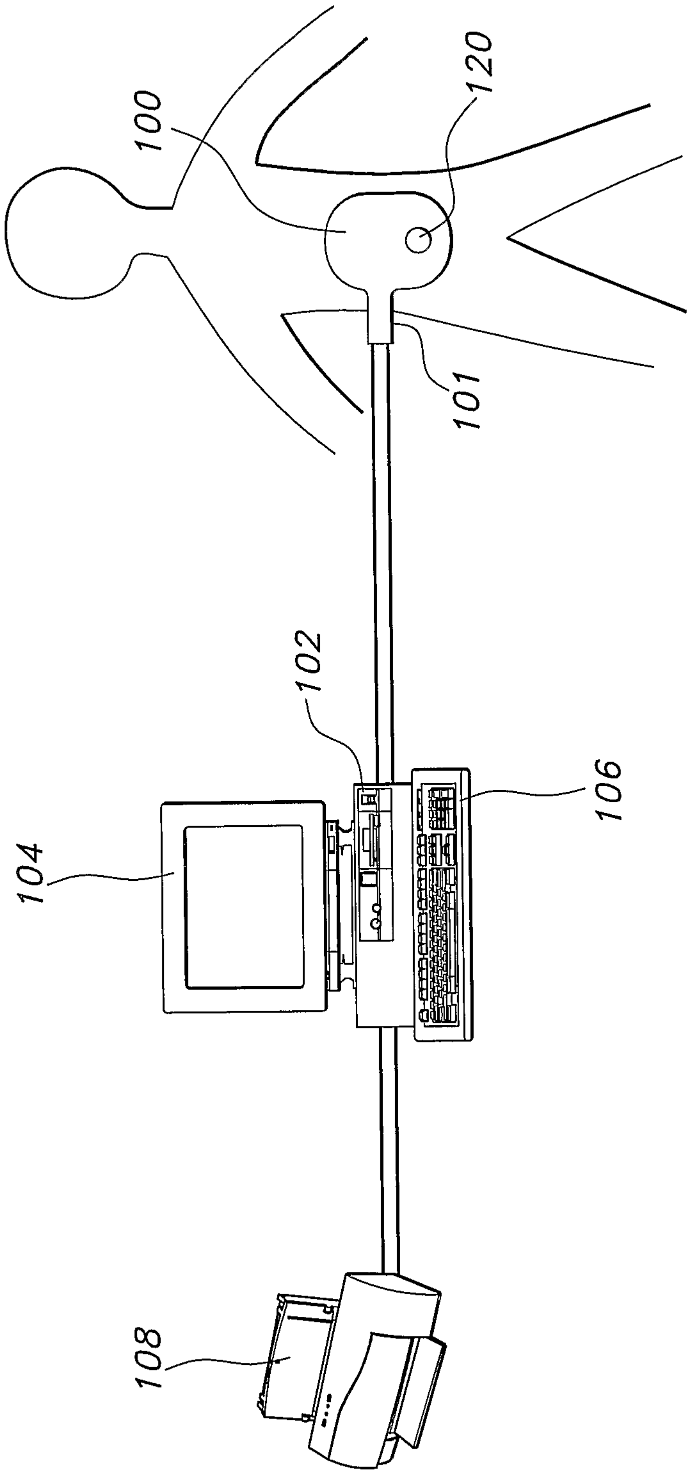


FIG. 1

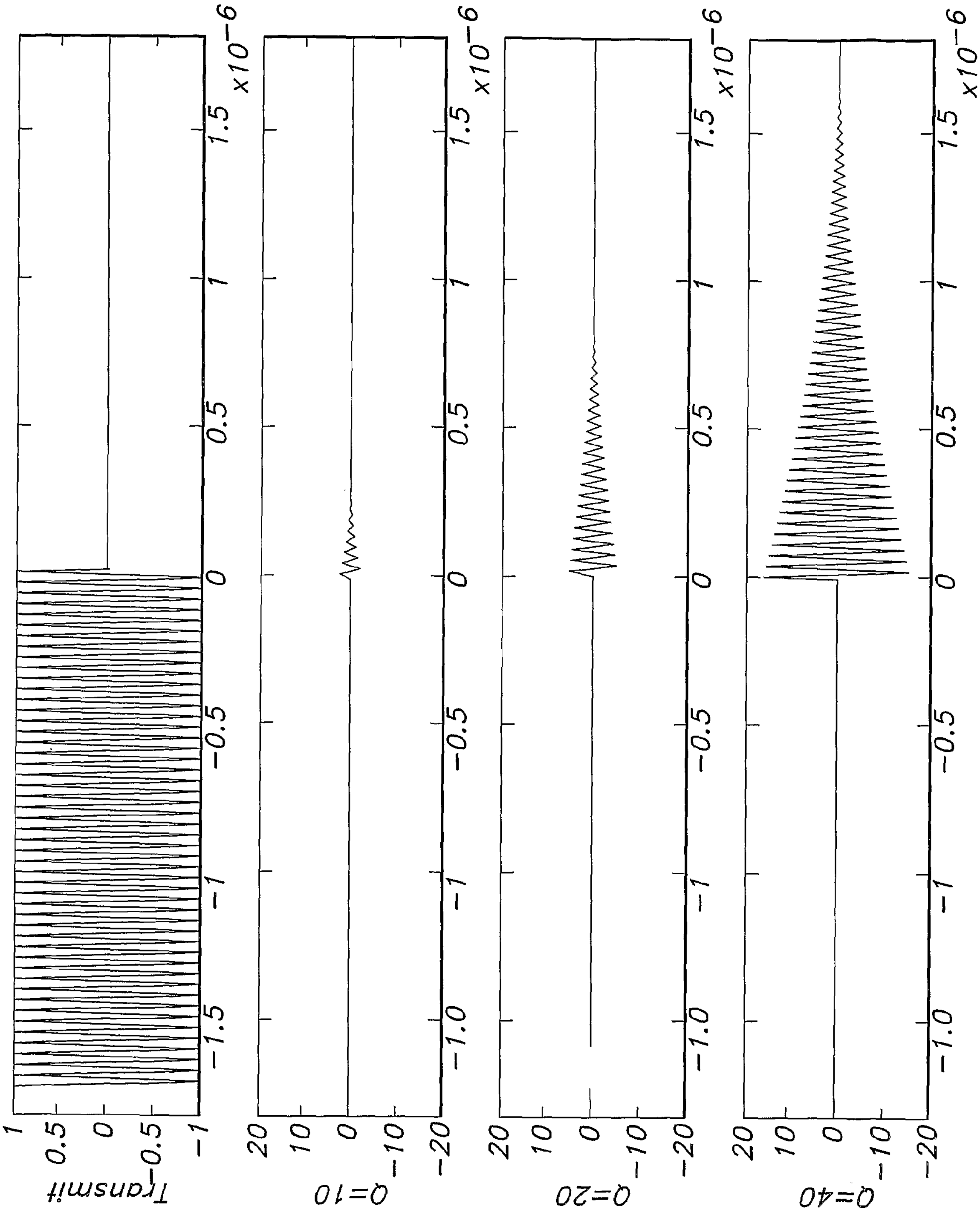
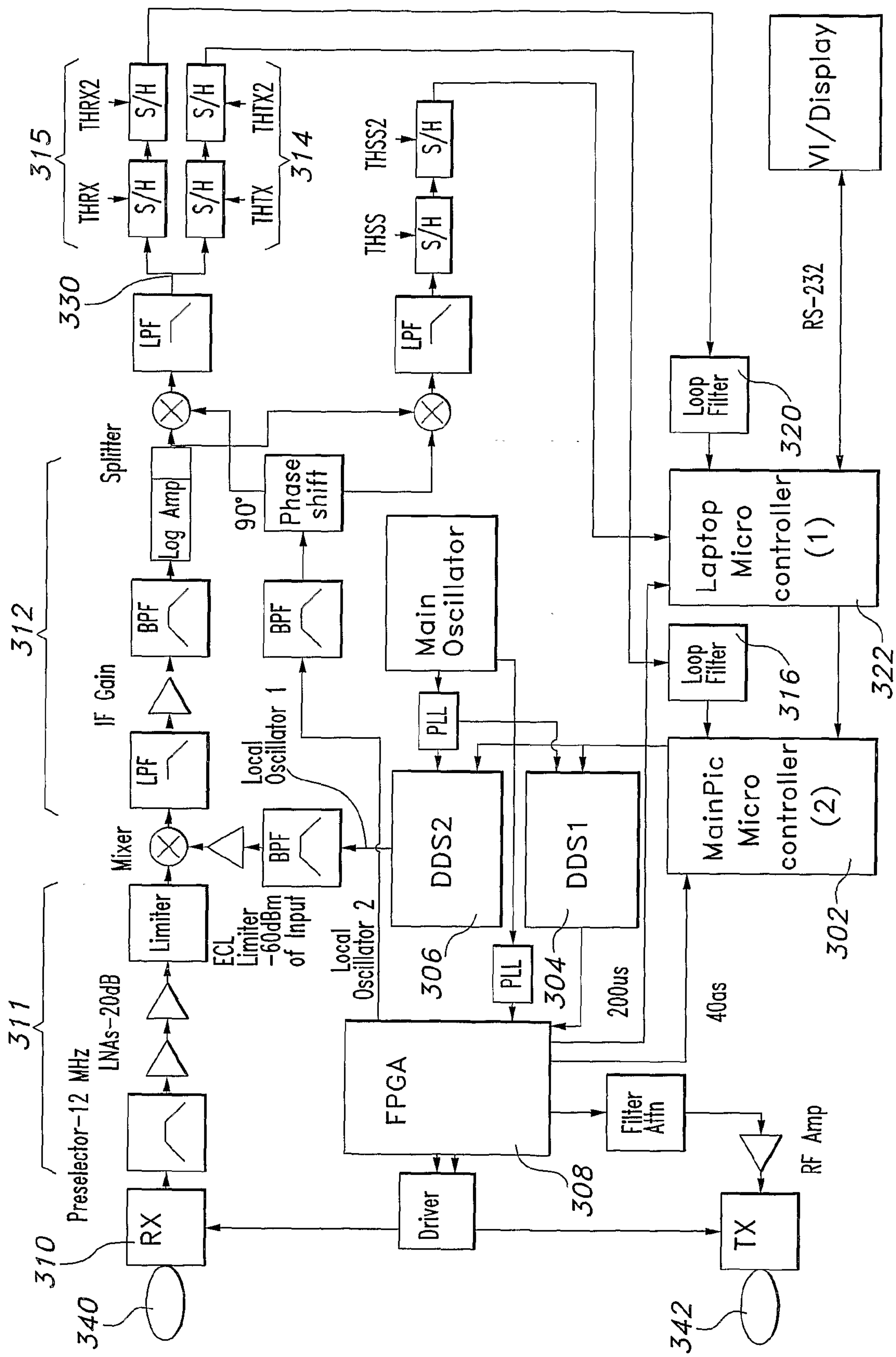


FIG. 2a

FIG. 2b

FIG. 2c

FIG. 2d



RX
TX
Preselector-12 MHz
LNAs-20dB
Limiter
ECL Limiter -60dBm of Input
Mixer
LPF
IF Gain
BPF
Log Amp
Splitter
Phase shift
90°
Local Oscillator 1
Local Oscillator 2
S/H
THRX
THRX2
THTX
THTX2
THSS
THSS2
Main Oscillator
PLL
DDS2
DDS1
FPGA
Driver
Filter Attn
RF Amp
Loop Filter
Laptop Micro controller (1)
MainPic Micro controller (2)
VI/Display
RS-232
200us
40as
310
311
312
314
315
316
320
322
330
302
304
306
308
340
342

FIG. 3

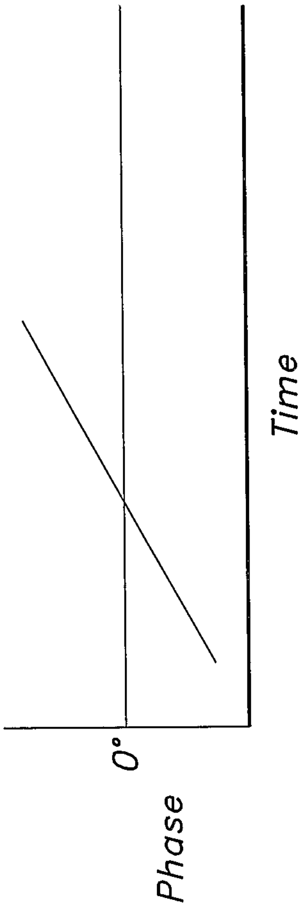


FIG. 4a

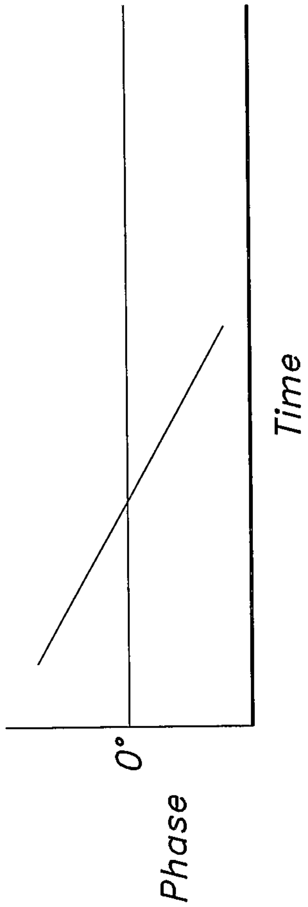


FIG. 4b

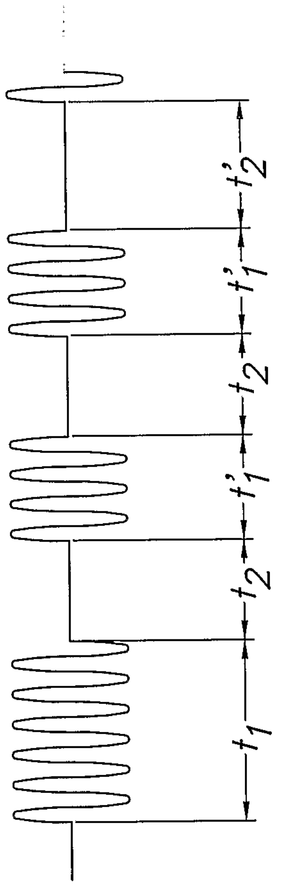


FIG. 5

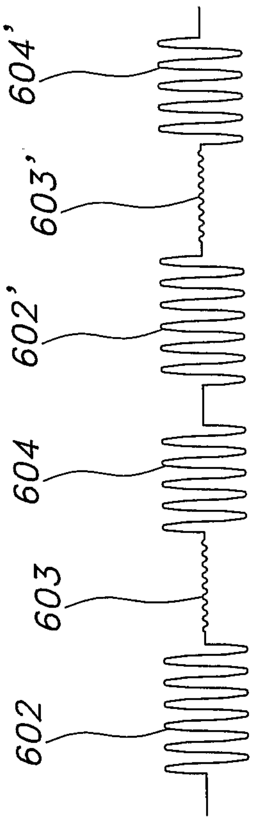


FIG. 6

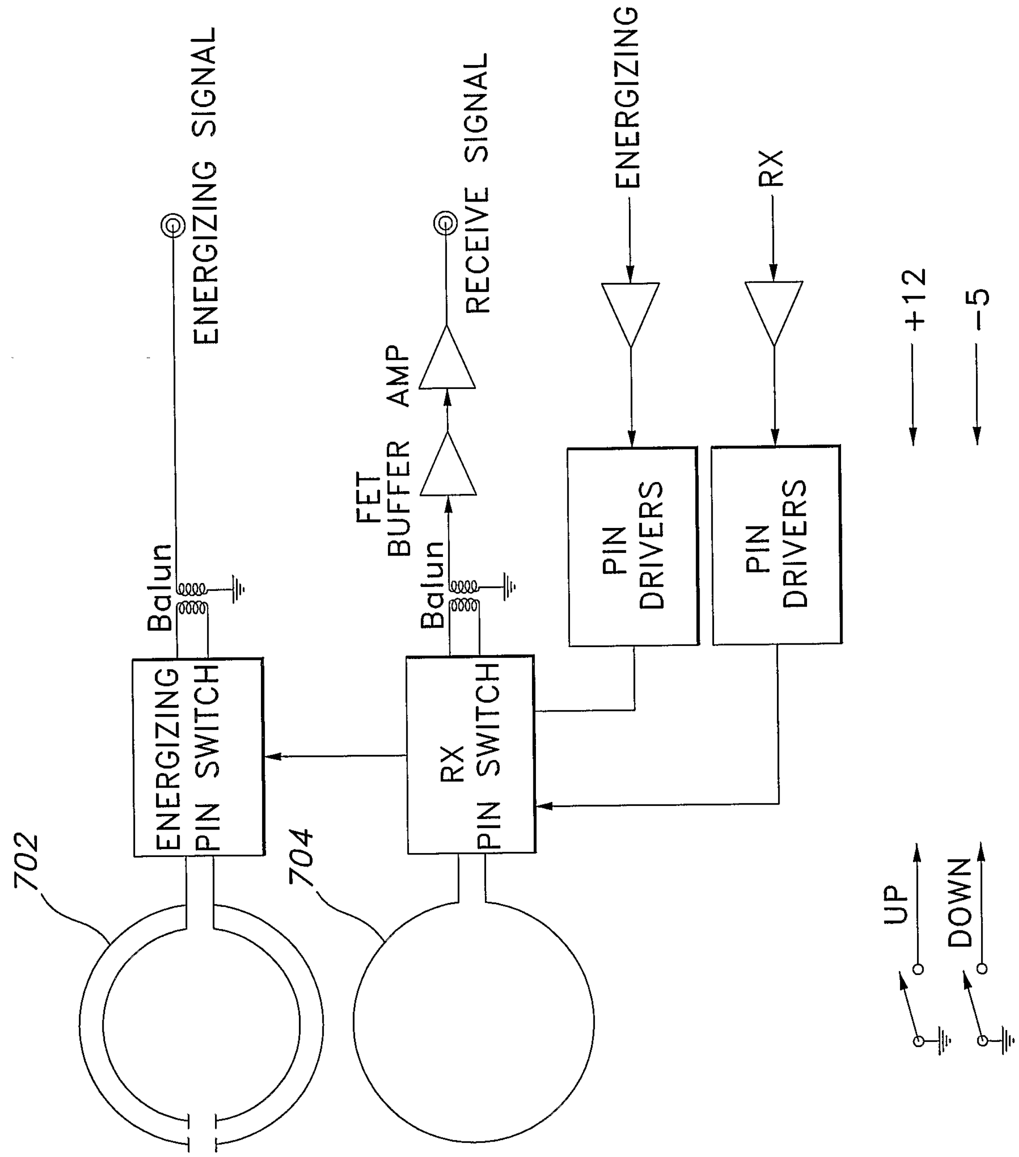

ENERGIZING SIGNAL
RECEIVE SIGNAL
FET BUFFER AMP
Balun
Balun
ENERGIZING
RX
PIN DRIVERS
PIN DRIVERS
ENERGIZING PIN SWITCH
RX PIN SWITCH
702
704
+12
−5
UP
DOWN

FIG. 7

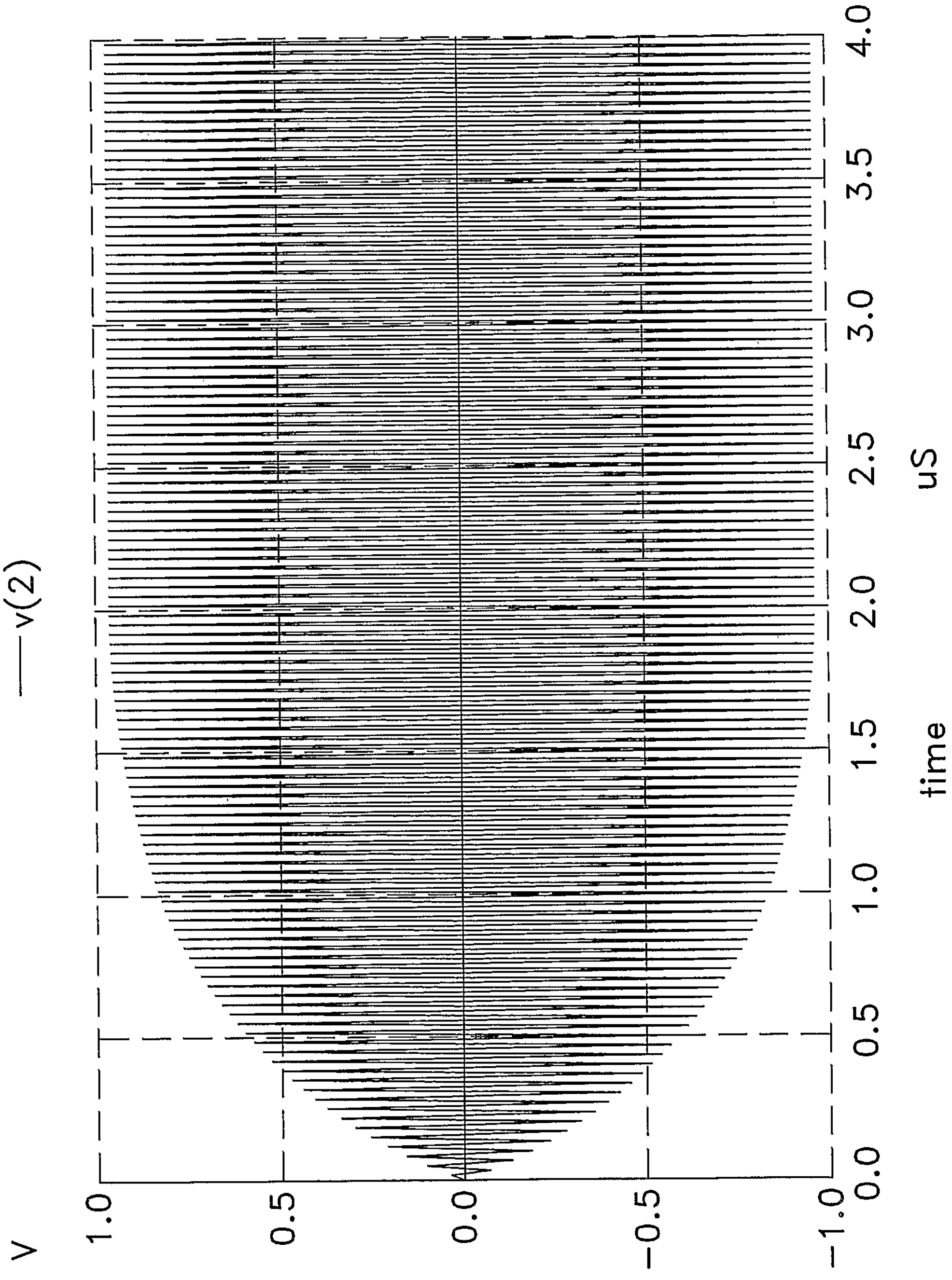


FIG. 8

REFERENCES CITED IN THE DESCRIPTION

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- EP 0072003 A2 **[0006]**

patsnap

专利名称(译)	与植入式无线传感器通信		
公开(公告)号	EP1817593B1	公开(公告)日	2015-12-23
申请号	EP2005805691	申请日	2005-10-04
[标]申请(专利权)人(译)	的CardioMEMS		
申请(专利权)人(译)	的CardioMEMS，INC.		
当前申请(专利权)人(译)	的CardioMEMS，INC.		
[标]发明人	JOY JAMES KROH JASON ELLIS MICHAEL ALLEN MARK PYLE WILTON		
发明人	JOY, JAMES KROH, JASON ELLIS, MICHAEL ALLEN, MARK PYLE, WILTON		
IPC分类号	G01R23/12 A61B5/00 G01D21/00 A61B5/05 A61B5/07 G01R23/14 G01F15/06		
CPC分类号	G01R23/12 A61B5/0002 A61B5/0031 A61B5/05 A61B5/076 A61B2560/0219 A61B2560/0223 G01D21/00 G01F15/066 G01R23/145		
代理机构(译)	B关，JAMES CHARLES		
优先权	60/623959 2004-11-01 US		
其他公开文献	EP1817593A2 EP1817593A4		
外部链接	Espacenet		

摘要(译)

本发明通过调节激励信号的相位和频率来确定传感器的谐振频率，直到激励信号的频率与传感器的谐振频率匹配。该系统以低占空比激励传感器，具有预定频率或频率组和预定幅度的RF能量的门控脉冲串。激励信号通过磁耦合耦合到传感器，并在传感器中感应出以传感器的谐振频率振荡的电流。系统通过磁耦合接收传感器的振铃响应，并确定传感器的谐振频率，用于计算测量的物理参数。系统使用一对锁相环来调节激励信号的相位和频率。

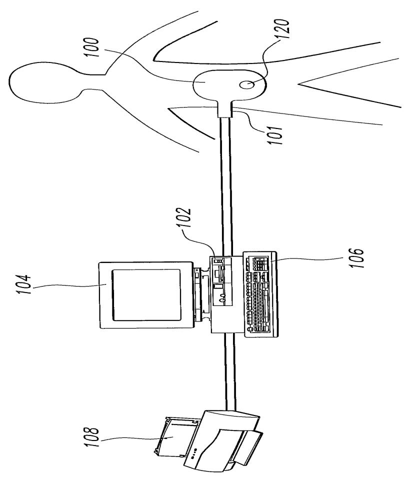

FIG. 1