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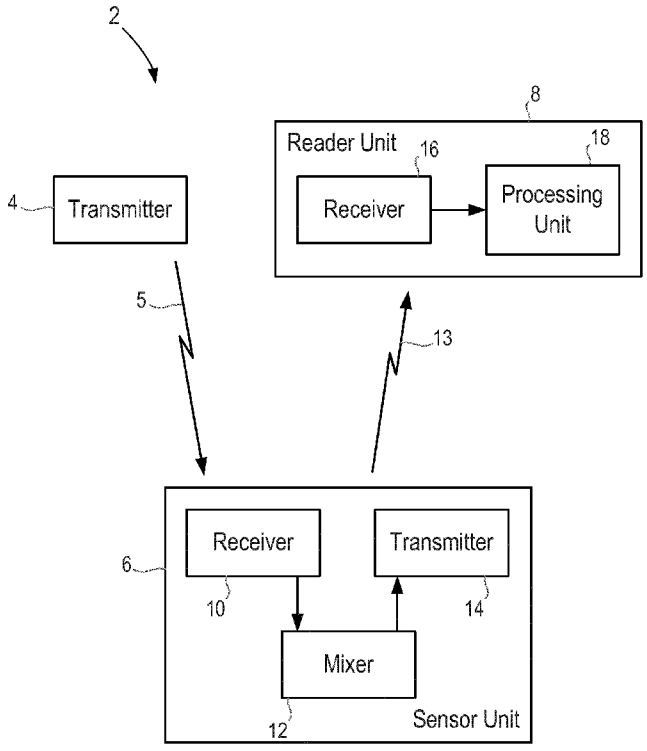

Figure 1

(57) Abstract: There is provided a system for measuring a physiological characteristic of a subject, the system comprising a first transmitter configured to transmit a first signal that has a first frequency; a sensor unit that is for use on or near a part of the body of the subject; and a reader unit; wherein the sensor unit comprises a first receiver configured to receive the first signal; a mixer configured to mix the first signal with a second signal that has a second frequency to form a third signal that has a third frequency, the third frequency corresponding to the difference between the first frequency and the second frequency; and a second transmitter configured to transmit the third signal; wherein the reader unit comprises a second receiver configured to receive the third signal; and a processing unit configured to measure changes in the signal strength and/or the phase of the received third signal over time, and to determine a measurement of the physiological characteristic from the measured changes in the signal strength and/or the phase.

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A METHOD, SYSTEM AND APPARATUS FOR MEASURING A PHYSIOLOGICAL CHARACTERISTIC OF A SUBJECT

TECHNICAL FIELD OF THE INVENTION

The invention relates to a method, system and apparatus for measuring a physiological characteristic of a subject.

BACKGROUND TO THE INVENTION

Unobtrusive continuous vital sign (physiological characteristic) monitoring is highly desired for ambulatory patients at hospital or for people at home. One way to measure vital signs such as heart rate and breathing rate in an unobtrusive way is to measure magnetic induction impedance modulations in the subject's chest. This can be done using an excitation magnetic field that covers the volume of the lung and/or heart of the subject. The magnetic induction (i.e. the generation of eddy currents in the tissue due to the application of an external alternating magnetic field) will be modulated by intra-thoracic fluid movements due to heart beats and breathing. These modulations can be measured and used to determine physiological characteristics of the subject, such as breathing rate, breathing depth, heart rate and/or other physiological characteristics.

Lower frequency signals (e.g. signals in the megahertz (MHz) range) penetrate more easily (i.e. further) into the body of the subject than higher frequency signals (e.g. signals in the gigahertz (GHz) range) but are less affected by tissue and fluid variations than higher frequency signals. Therefore there is a trade-off in measurement depth and measurement quality to be made when selecting the frequency of the excitation signal.

Another problem is in detecting the relatively weak dynamic response from the body in the presence of a very strong excitation field in the same bandwidth. This requires a high dynamic range in the detection electronics and limits the sensitivity and signal to noise ratio (SNR) of the measurement.

There is therefore a need for an improved method, system and apparatus for measuring a physiological characteristic of a subject.

SUMMARY OF THE INVENTION

According to the improved physiological characteristic measurement technique described herein, a physiological characteristic is measured by transmitting a signal at a high (e.g. GHz) frequency into a part of the body of the subject so that the signal is modulated by the fluid movement inside the part of the body. A sensor unit near to the part of the body of the subject (for instance in vicinity, or close vicinity thereof) receives the modulated signal and generates a signal at a low (e.g. MHz) frequency from the received modulated signal and transmits the low frequency signal to a reader unit. The reader unit analyses the signal strength (e.g. received signal strength indication (RSSI)) and/or phase changes of the signal to determine a physiological characteristic relating to the fluid movement in the part of the body (e.g. heart rate, or breathing rate, or breathing depth, or pulmonary edema). According to this technique, the high (e.g. GHz) frequency signal is used as an interrogating signal since it is more sensitive to the fluid movements in the body, and the fluid movement measurements are carried to the reader unit by a signal at a much lower frequency (e.g. MHz) signal to avoid using the same bandwidth as the interrogating signal. This also limits the dynamic range and cross-talk between the interrogating signal and the received low frequency signal in the reader unit, and thus improves the signal to noise ratio of dynamic measurements of a physiological characteristic. Since the cross-talk between the interrogating signal and the received low frequency signal is reduced, the probing depth of the interrogating signal can be improved.

In some embodiments a second high frequency signal is transmitted into the part of the body of the subject along with the first high frequency signal so that it is also modulated by the fluid movement, and the sensor unit receives both high frequency signals, and generates the lower frequency signal by mixing the two received signals. In other embodiments, the sensor unit generates a second signal at a fixed (high) frequency and mixes this signal with the received high frequency signal to generate the lower frequency signal.

According to a first aspect, there is provided a system for measuring a physiological characteristic of a subject, the system comprising a first transmitter configured to transmit a first signal that has a first frequency; a sensor unit that is for use on or near a part of the body of the subject; and a reader unit; wherein the sensor unit comprises a first receiver configured to receive the first signal; a mixer configured to mix the first signal with a second signal that has a second frequency to form a third signal that has a third frequency, the third frequency corresponding to the difference between the first frequency and the

second frequency; and a second transmitter configured to transmit the third signal; wherein the reader unit comprises a second receiver configured to receive the third signal; and a processing unit configured to measure changes in the signal strength and/or the phase of the received third signal over time, and to determine a measurement of the physiological characteristic from the measured changes in the signal strength and/or the phase.

In some embodiments, the physiological characteristic is one or more of heart rate, breathing rate, breathing depth, pulmonary edema, or any other physiological characteristic that can be measured by fluid (liquid (such as blood, plasma) and/or gas (such as breathing air)) movement(s) within the body, for instance intra-thoracic fluid shift.

In some embodiments, the first signal and the second signal have higher (e.g. substantially higher) frequencies than the third signal. In some embodiments, the first frequency and the second frequency are in the range of 1 GHz to 100 GHz. In some embodiments, the third frequency is in the range of 1 MHz to 100 MHz.

In some embodiments, the first transmitter is configured to operate with a Wi-Fi network and the second receiver is a Near Field Communication (NFC) receiver or a Frequency Modulation (FM) radio receiver.

In some embodiments, the sensor unit further comprises a third receiver configured to receive a fourth signal, wherein the fourth signal provides power for operating the sensor unit.

In some embodiments, the mixer is a diode and the sensor unit further comprises a third receiver configured to receive a fourth signal, wherein the fourth signal provides power for providing a DC bias for the diode.

In some embodiments, the system further comprises a reflector that is to be placed on an opposite side of the part of the body of the subject to the sensor unit and the first transmitter, wherein the reflector is configured to reflect the transmitted first signal to the sensor unit.

In some embodiments, the first transmitter is further configured to transmit the second signal to the sensor unit. In some embodiments, the mixer is a non-linear mixer. In some embodiments, the mixer is a diode.

In alternative embodiments, the sensor unit further comprises an oscillator for generating the second signal. In some embodiments, the mixer is an active mixer.

According to a second aspect, there is provided a method for measuring a physiological characteristic of a subject, the method comprising transmitting a first signal that has a first frequency from a first transmitter to a part of the body of the subject; receiving

the first signal at a sensor unit that is on or near the part of the body of the subject; mixing the first signal with a second signal that has a second frequency to form a third signal that has a third frequency, the third frequency corresponding to the difference between the first frequency and the second frequency; transmitting the third signal from the sensor unit to a reader unit using a second transmitter; receiving the third signal using a second receiver in the reader unit; measuring changes in the signal strength and/or the phase of the received third signal over time; and determining a measurement of the physiological characteristic from the measured changes in the signal strength and/or the phase.

In some embodiments, the physiological characteristic is one or more of heart rate, breathing rate, breathing depth, pulmonary edema, or any other physiological characteristic that can be measured by fluid (liquid (such as blood, plasma) and/or gas (such as breathing air)) movement(s) within the body, for instance intra-thoracic fluid shift.

In some embodiments, the first signal and the second signal have higher (e.g. substantially higher) frequencies than the third signal. In some embodiments, the first frequency and the second frequency are in the range of 1 GHz to 100 GHz. In some embodiments, the third frequency is in the range of 1 MHz to 100 MHz.

In some embodiments, the first transmitter operates with a Wi-Fi network and the second receiver is a Near Field Communication (NFC) receiver or a Frequency Modulation (FM) radio receiver.

In some embodiments, the method further comprises the step of receiving a fourth signal using a third receiver in the sensor unit, wherein the fourth signal provides power for operating the sensor unit.

In some embodiments, the mixing is performed using a diode and the method further comprises the step of receiving a fourth signal using a third receiver in the sensor unit, wherein the fourth signal provides power for providing a DC bias for the diode.

In some embodiments, the method comprises placing a reflector on an opposite side of the part of the body of the subject to the sensor unit and the first transmitter, so that the reflector reflects the transmitted first signal to the sensor unit.

In some embodiments, the method further comprises the step of the first transmitter transmitting the second signal to the sensor unit. In some embodiments, the step of mixing comprises non-linearly mixing the first signal with the second signal. In some embodiments, the mixing is performed using a diode.

In alternative embodiments, the method further comprises the step of generating the second signal using an oscillator in the sensor unit. In some embodiments, the step of mixing comprises using an active mixer to mix the first signal with the second signal.

According to a third aspect, there is provided a reader unit for measuring a physiological characteristic of a subject, the reader unit comprising a first transmitter configured to transmit a first signal and a second signal to a sensor unit, the first signal being transmitted at a first frequency and the second signal being transmitted at a second frequency; a receiver configured to receive a third signal from the sensor unit, the third signal being at a third frequency, the third frequency corresponding to the difference between the first frequency the second frequency; and a processing unit configured to measure the signal strength and/or phase of the received third signal and to determine a measurement of the physiological characteristic from variations in the signal strength and/or phase.

In some embodiments, the physiological characteristic is one or more of heart rate, breathing rate, breathing depth, pulmonary edema, or any other physiological characteristic that can be measured by fluid (liquid (such as blood, plasma) and/or gas (such as breathing air)) movement(s) within the body, for instance intra-thoracic fluid shift.

In some embodiments, the first signal and the second signal have higher (e.g. substantially higher) frequencies than the third signal. In some embodiments, the first frequency and the second frequency are in the range of 1 GHz to 100 GHz. In some embodiments, the third frequency is in the range of 1 MHz to 100 MHz.

In some embodiments, the first transmitter is configured to operate with a Wi-Fi network and the receiver is a Near Field Communication (NFC) receiver or a Frequency Modulation (FM) radio receiver.

In some embodiments, the reader unit further comprises a second transmitter configured to transmit a fourth signal, wherein the fourth signal provides power for operating the sensor unit.

According to a fourth aspect, there is provided a method for measuring a physiological characteristic of a subject, the method comprising: transmitting a first signal and a second signal from a first transmitter in a reader unit through a part of the body of the subject to a sensor unit, the first signal being transmitted at a first frequency and the second signal being transmitted at a second frequency; receiving a third signal from the sensor unit using a receiver in the reader unit, the third signal being at a third frequency, the third frequency corresponding to the difference between the first frequency the second frequency; measuring changes in the signal strength and/or the phase of the received third signal over

time; and determining a measurement of the physiological characteristic from the measured changes in the signal strength and/or the phase.

In some embodiments, the physiological characteristic is one or more of heart rate, breathing rate, breathing depth, pulmonary edema, or any other physiological characteristic that can be measured by fluid (liquid (such as blood, plasma) and/or gas (such as breathing air)) movement(s) within the body, for instance intra-thoracic fluid shift.

In some embodiments, the first signal and the second signal have higher (e.g. substantially higher) frequencies than the third signal. In some embodiments, the first frequency and the second frequency are in the range of 1 GHz to 100 GHz. In some embodiments, the third frequency is in the range of 1 MHz to 100 MHz.

In some embodiments, the first transmitter is configured to operate with a Wi-Fi network and the receiver is a Near Field Communication (NFC) receiver or a Frequency Modulation (FM) radio receiver.

In some embodiments, the method further comprises the step of transmitting a fourth signal to the sensor unit, wherein the fourth signal provides power for operating the sensor unit.

According to a fifth aspect, there is provided a computer program product comprising a computer readable medium having computer readable code embodied therein, the computer readable code being configured such that, on execution by a suitable computer or processor, the computer or processor is caused to, i) control a transmitter in a reader unit to transmit a first signal and a second signal through a part of the body of the subject to a sensor unit, the first signal being transmitted at a first frequency and the second signal being transmitted at a second frequency, ii) control a receiver in the reader unit to receive a third signal from the sensor unit, the third signal being at a third frequency, the third frequency corresponding to the difference between the first frequency the second frequency, iii) measure changes in the signal strength and/or the phase of the received third signal over time, and iv) determine a measurement of a the physiological characteristic from the measured changes in the signal strength and/or the phase.

These and other aspects of the invention are apparent from and will be elucidated with reference to the embodiments described hereinafter.

It will be appreciated by those skilled in the art that two or more of the above-mentioned options, implementations, and/or aspects of the invention may be combined in any way deemed useful.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the invention, and to show more clearly how it may be carried into effect, reference will now be made, by way of example only, to the accompanying drawings, in which:

Figure 1 is a block diagram of a system according to an embodiment of the invention;

Figure 2 is a block diagram of a first specific embodiment of a system according to the invention;

Figure 3 is a circuit diagram of a sensor unit for use in the first specific embodiment;

Figure 4 is a block diagram of a second specific embodiment of a system according to the invention;

Figure 5 is a block diagram of a third specific embodiment of a system according to the invention;

Figure 6 is a block diagram of an exemplary arrangement of a transmitter, sensor unit and reader unit;

Figure 7 is a block diagram illustrating the operations of a receiver and processing unit in a reader unit according to an embodiment;

Figure 8 shows an exemplary amplitude signal;

Figure 9 shows an exemplary phase signal;

Figure 10 shows an exemplary frequency domain plot; and

Figure 11 is a flow chart illustrating a method of operating a system according to an embodiment of the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

A system 2 for measuring a physiological characteristic of a subject is shown in Figure 1. The physiological characteristic can be heart rate, breathing rate, breathing depth, pulmonary edema, or any other physiological characteristic that can be measured from changes or movements in the fluid in the body (or a body part) of a subject.

The system 2 comprises three main components. A transmitter 4 that transmits one or more interrogation signals, a sensor unit 6 that receives the one or more interrogation signals after they have been modulated by the fluid in the part of the body of the subject, and

that generates a signal from the received one or more interrogation signals and transmits the generated signal to a reader unit 8, and the reader unit 8. The reader unit 8 processes the signal to determine the value of a physiological characteristic. In some embodiments the transmitter 4 is part of (e.g. integral with) the reader unit 8, but in other embodiments the transmitter 4 is separate from the reader unit 8.

The transmitter 4, which is also referred to herein as the first transmitter 4, is configured to transmit a first (radio frequency (RF)) signal 5 that has a first frequency to the sensor unit 6. The first transmitter 4 may comprise a loop antenna (e.g. a coil) that has a resonant frequency corresponding to the first frequency. The first frequency can be a frequency in the GHz range or hundreds of MHz range, for example a frequency selected from the range of 1 GHz to 100 GHz. In some embodiments, the first frequency is, or is about, 2.4 GHz. In some embodiments the first transmitter 4 is configured to operate with a Wi-Fi network, and thus can transmit signals at frequencies that are used in Wi-Fi networks.

In use, the transmitter 4 and sensor unit 6 are arranged so the signal(s) 5 transmitted by the transmitter 4 enter a part of the body of a subject (e.g. the chest of the subject) so that the signal(s) are affected by the (time-varying) properties of tissue or fluid, e.g. heart beats, breathing, and fluid or blood movement.

The sensor unit 6 comprises a receiver 10 (which is also referred to herein as first receiver 10) that is configured to receive the first signal 5. The receiver 10 can comprise a loop antenna (e.g. a coil) that has a resonant frequency corresponding to the frequency of the first signal. The signal 5 received by the receiver 10 is provided to a mixer or mixing component 12 that mixes the received first signal 5 with a second signal having a second frequency to produce a third signal having a frequency that is equal to the difference between the first frequency and second frequency.

In some embodiments, the first transmitter 4 can transmit a second (RF) signal to the sensor unit 6 along with the first signal 5, and it is this second signal that is mixed with the first signal in mixer 12. The second signal has a second frequency that is different to the first frequency, but the second frequency is preferably similar to the first frequency. Thus, where the first frequency is in the GHz range, the second frequency is preferably also in the GHz range, for example selected from the range of 1 GHz to 100 GHz. Preferably, the first frequency and the second frequency are in the GHz range and differ by a few MHz, e.g. by 1 MHz to 100 MHz. In some embodiments, where the first frequency is, or is about, 2.4 GHz, the second frequency can also be about 2.4GHz. For example, in some embodiments the first frequency can be 2.4 GHz and the second frequency can be 2.41356 GHz, which means that

the frequency of the third signal is 13.56 MHz. More generally, the first frequency and the second frequency are substantially higher frequencies than the third frequency.

In alternative embodiments, rather than the first transmitter 4 transmitting the second signal to the sensor unit 6, the sensor unit 6 can comprise an oscillator that produces or generates the second signal having the second frequency, and this generated second signal is mixed with the received first signal 5.

The modulations of the strength and/or phase of the first signal 5 by the fluid movements in the part of the body are also found in the third signal, since it is generated from the first signal 5. Thus, the signal strength and/or phase modulations of the third signal 13 will be proportional to the signal strength and/or phase modulations of the first signal 5. The third signal 13 is transmitted from sensor unit 6 by transmitter 14 (which is also referred to herein as the second transmitter 14) to reader unit 8. The transmitter 14 may comprise a loop antenna (e.g. a coil) that has a resonant frequency corresponding to the frequency of the third signal (i.e. corresponding to the difference in frequencies of the first signal 5 and the second signal).

The third signal 13 is received by a receiver 16 in the reader unit 8 (which is also referred to herein as the second receiver 16), and the received third signal is provided to a processing unit 18 for processing and analysis. The receiver 16 may comprise a loop antenna (e.g. a coil) that has a resonant frequency corresponding to the frequency of the third signal. The receiver 16 may also comprise other components or circuitry in addition to the antenna, for example components or circuitry for demodulating the received third signal 13, in particular components or circuitry for performing amplitude demodulation and/or phase demodulation. In some embodiments, the receiver 16 may be configured to operate using Near Field Communication (NFC), and thus can be used to receive (and transmit) signals at frequencies that are used for NFC. In alternative embodiments, the receiver 16 may be a Frequency Modulation (FM) radio receiver.

The processing unit 18 determines or measures changes in the signal strength (e.g. received signal strength indication (RSSI)) and/or phase of the received third signal over time, and determines a measurement of a physiological characteristic (e.g. heart rate, or breathing rate, or breathing depth, or pulmonary edema) from the measured changes in signal strength (e.g. RSSI) and/or phase. Further details of the processing unit 18 are provided below with reference to Figure 7.

The processing unit 18 can be implemented in numerous ways, with software and/or hardware, to perform the various functions required. The processing unit 18 may

comprise one or more microprocessors that may be programmed using software to perform the required functions. The processing unit 18 may be implemented as a combination of dedicated hardware to perform some functions and a processor (e.g., one or more programmed microprocessors and associated circuitry) to perform other functions. Examples of controller components that may be employed in various embodiments of the present disclosure include, but are not limited to, conventional microprocessors, application specific integrated circuits (ASICs), and field-programmable gate arrays (FPGAs).

In various implementations, the processing unit 18 may be associated with one or more storage media (not shown in Figure 1) such as volatile and non-volatile computer memory such as RAM, PROM, EPROM, and EEPROM. The reader unit 8 can also comprise a memory unit that can be used for storing program code that can be executed by the processing unit 18 to perform the method described herein. The memory unit can also be used to store signals received by receiver 16, and/or measurements of physiological characteristics determined by the processing unit 18.

The third signal 13 can be processed by the processing unit 18 as the third signal is received (e.g. in real-time or near real-time), or the third signal 13 can be stored in the reader unit 8 and the processing unit 18 can retrieve the previously-received signals from the memory unit and process them at a later time.

It will be appreciated that Figure 1 only shows the components required to illustrate this aspect of the invention, and in a practical implementation the system 2 (or any of the first transmitter 4, sensor unit 6 and reader unit 8) may comprise additional components to those shown.

In some embodiments the sensor unit 6 comprises a battery or other type of power source for powering at least the mixer 12 and transmitter 14. In other embodiments the sensor unit 6 does not contain its own source of power, but instead the sensor unit 6 can be powered by an RF signal provided by an external source. In some embodiments the power for the sensor unit 6 is provided by the first signal 5, but in other embodiments the power for the sensor unit 6 is provided by another signal from the first transmitter 4 or a signal from the reader unit 8 or other device. Suitable power signals include NFC signals. In other embodiments the sensor unit 6 is a fully passive device, i.e. it does not receive a power signal or comprise a power source.

In embodiments where the sensor unit 6 is fully passive, the mixer 12 in the sensor unit 6 can comprise non-linear semiconductor devices like diodes, transistors and/or field effect transistors (FETs), as well or alternatively to non-linear devices like (saturated)

magnetic and polyvinylidene fluoride (PVDF)/piezoelectric materials. In embodiments where the sensor unit 6 comprises a power source or receives a power signal, the mixer 12 can be an active mixing implementation, which can provide an improved signal to noise ratio compared to passive implementations.

A high (e.g. GHz) frequency first signal 5 as suggested above is useful as an interrogating signal as it is sensitive to the fluid movements in the part of the body. Since the third signal 13 carrying the strength and/or phase changes due to fluid movements is transmitted at a much lower frequency (e.g. in the MHz range) to the reader unit 8, the first and third signals avoid using the same bandwidth and thus the dynamic range and cross-talk between the first signal and the third signal in the reader unit 8 is reduced, and thus the signal to noise ratio of dynamic measurements of a physiological characteristic is improved. Since the cross-talk between the first signal and the third signal is reduced, the probing depth of the first signal can be improved.

In some embodiments the reader unit 8 can be implemented as a smart phone or other wireless device having a receiver that can be used to receive a signal at the third frequency and a processing unit that can process the received signal to determine signal strength and/or phase changes due to fluid movements in the body of the subject. Thus, in some embodiments the reader unit 8 can comprise a smart phone that has an NFC antenna and/or a FM radio receiver. Where the reader unit 8 also comprises the first transmitter 4, the first transmitter 4 can correspond to the Wi-Fi antenna and transceiver circuitry in the smart phone.

In some embodiments the sensor unit 6 can be for use on or near the body of the subject (for example placed on the skin or on or in the clothing of the subject). In these embodiments the sensor unit 6 can be part of any type of on-body sensor, an electronic plaster, or any other type of wearable article (e.g. a chest band, shirt, etc.). In alternative embodiments, the sensor unit 6 can be for use inside the body of the subject, and thus the sensor unit 6 can be configured to be implanted into the body, e.g. subcutaneously, or as part of the tip of a catheter) or as an e-pill that can be swallowed by the subject. In other embodiments, the sensor unit 6 can be in the form of a hand held unit that can be held close to the body of the subject when a measurement of the physiological characteristic is required.

Figure 2 shows a block diagram of a first specific embodiment of a system according to the invention. In this embodiment, the sensor unit 6 is a fully passive device (i.e. it does not comprise a power source or receive a dedicated power signal from another device). Also in this illustrated embodiment, the first transmitter 4 is comprised in the reader

unit 8, although it will be appreciated that this is not required in all implementations of this embodiment. The sensor unit 6 and reader unit 8 are arranged with a part of the body 20 of a subject (for example the chest of the subject) between them.

In this embodiment, the mixer 12 is a diode that is a non-linear element, such as a diode, and the first transmitter 4 transmits the first signal 5 and the second signal 21 to the sensor unit 6. The first signal 5 is shown as having frequency F1, and the second signal 21 is shown as having frequency F2. The first transmitter 4 therefore provides a twin-tone excitation field in this embodiment.

Both the first and second signals 5, 21 are modulated by movement of fluid in the part of the body 20 due to heart beats, breathing, and fluid or blood flow. The modulated first and second signals 5, 21 are received by receiver 10 (e.g. a resonating antenna structure, such as a coil) and provided to mixer 12. The mixer 12 generates a third signal having the frequency F3 = |F1-F2| from the first and second signals 5, 21. The generated third signal 13 is optionally low-pass filtered by low-pass filter 22, and the filtered signal 13 is transmitted by transmitter 14 (which is, e.g., a resonating antenna structure, such as a coil). After mixing in mixer 12 many frequency products exist, and most are not of any interest, only the lowest mixing product F1-F2. The low pass filter 22 can be used to select the frequency of interest (F1-F2) from the output of the mixer 12. However, in the case of a resonating antenna structure for transmitter 14, which is configured to resonate at a frequency at or around F1-F2, then the low pass filter is not required. It will be noted that two signal paths are shown the third signal 13, one passing through the body 20 to the reader unit 8, and the other to the reader unit 8 that does not pass through the part of the body 20. The path taken by the third signal 13 will depend on the relative positions of the reader unit 8, transmitter 14 and the part of the body 20. Preferably F1 and F2 are in the GHz frequency range, and they differ by a few MHz (i.e. F3 is a few MHz).

Figure 3 is a circuit diagram of a sensor unit 6 that can be used in the first specific embodiment. This sensor unit 6 can be formed on a small printed circuit board (PCB) that contains two resonating antenna structures 10, 14. The first antenna 10 (the receiver 10) is configured to resonate in response to the GHz-frequency excitation field (first signal 5 and second signal 21) and the second antenna 14 (second transmitter 14) is configured to resonate at a much lower frequency, in the MHz range, corresponding to the difference in frequency of the first signal 5 and the second signal 21. The sensor unit 6 comprises a diode 24 that acts as the mixing component 12, and the diode 24 is connected in parallel with a capacitor 26 and second antenna 14. The non-linear behavior of the diode 24 generates frequencies in the MHz

range from the received first and second signals 5, 21, which are emitted/transmitted by the second antenna 14 and can be received by the reader unit 8. As noted above, the strength and/or phase of this MHz signal 13 depends on the local strength and/or phase of the two GHz signals 5, 21, which are modulated by fluid shifts in the body 30 due to heartbeats and breathing.

The first antenna 10 and second antenna 14 can be loop antennas (e.g. coils). The coils can be wound around a core to create a specific form factor for the sensor unit 6 that is required for certain applications (e.g. an e-pill). Alternatively, the circuit shown in Figure 3 can be implemented on a flex foil PCB which can be bent easily. It will be appreciated that the higher the frequencies used (F1, F2 and F3), the smaller the sensor unit 6 can be.

Figure 4 shows a block diagram of a second specific embodiment of a system according to the invention. In this embodiment, the sensor unit 6 is an active device (i.e. it comprises a power source or receives a power signal from another device). This embodiment has the advantage that the sensitivity and SNR of the physiological characteristic measurement can be improved compared to the embodiment in Figure 2. As in the embodiment shown in Figure 2, in this illustrated embodiment the first transmitter 4 is comprised in the reader unit 8, although it will be appreciated that this is not required in all implementations of this embodiment. The sensor unit 6 and reader unit 8 are arranged with the body 20 of a subject between them.

In this embodiment, the mixer 12 can comprise a diode, and/or active electronics (e.g. that require power to operate), such as an amplifier, frequency mixer, etc. that can generate the third signal 13 from the received first signal 5 and second signal 21. The sensor unit 6 is shown as comprising a power source 28 such as a battery. However, in alternative implementations the power 28 can be provided by a power signal from another device. For example, the power 28 can be provided by an NFC signal from the reader unit 8 or first transmitter 4. In this case, the sensor unit 6 can comprise a receiver (e.g. loop antenna or coil) for receiving the power signal 28 and for providing the power signal to the components of the sensor unit 6, such as the mixer 12. In yet further implementations, the sensor unit 6 can comprise a power source 28 that powers the sensor unit 6 and that can be recharged by a power signal sent from the first transmitter 4 or reader unit 8.

In some embodiments, the received power signal (e.g. NFC signal) may be used to generate an additional DC bias for the diode mixer 12. This can be used to optimize the sensitivity of the measurement by adaptively tuning the DC bias (i.e. by tuning the

conductive threshold of the diode 12). In other words, the diode 12 is biased such that the mixing efficiency – and thus the overall sensitivity and SNR – is maximized. This will improve the sensitivity even if the power provided by the first signal 5 is not sufficient to cause the diode 12 to switch to conduction.

In embodiments where the power signal and the third signal are the same frequency (e.g. 13.5 MHz) the receiver 16 in the reader unit 8 can be switched between a transmit mode in which a power (e.g. NFC) signal is transmitted to the sensor unit 6 and a receive mode in which the third signal 13 is received and the physiological characteristic measured.

Figure 5 shows a block diagram of a third specific embodiment of a system according to the invention. In this embodiment, the first transmitter 4 transmits the first signal 5 to the sensor unit 6, and the sensor unit 6 comprises an oscillator 30 for generating the second signal 21 at a fixed (second) frequency. Thus in this embodiment only a single interrogation signal is transmitted into the part of the body 20 of the subject. In this embodiment, the sensor unit 6 is an active device as in Figure 4 (i.e. it comprises a power source or receives a power signal from another device). As in the embodiments shown in Figures 2 and 4, in this illustrated embodiment the first transmitter 4 is comprised in the reader unit 8, although it will be appreciated that this is not required in all implementations of this embodiment. The sensor unit 6 and reader unit 8 are arranged with the part of the body 20 of a subject between them.

Thus, the sensor unit 6 receives the modulated first signal 5 using antenna 10 and mixer 12 mixes the first signal 5 with the second signal from the oscillator 30 to form the third signal 13.

As shown in Figures 2, 4 and 5, the first transmitter 4 and the sensor unit 6 can be arranged on different sides of the part of the body 20. For example one of the first transmitter 4 and the sensor unit 6 can be placed on the front of the chest and the other one of the first transmitter 4 and the sensor unit 6 can be placed on the subject's back. Alternatively they can be placed on the left and right sides of the subject's chest. However, in other embodiments, as shown in Figure 6, the first transmitter 4 and the sensor unit 6 can be arranged on the same side of the part of the body 20 (e.g. both on the chest), and a reflector 32 provided on the opposite of the part of the body (e.g. on the subject's back) for reflecting the first signal 5 (and second signal 21, if also transmitted by the first transmitter 4) after it has passed through the part of the body 20 back towards the sensor unit 6. The reflector 32 can be in any suitable form, for example a metal plate. In this embodiment, the sensor unit 6

can be co-located with the first transmitter 4 and/or reader unit 8. For example, the first transmitter 4 and the reader unit 8 can be implemented in a smart phone, and the sensor unit 6 can be located on the housing of the smart phone.

It will be appreciated that, in some embodiments, the frequencies of the first signal 5, second signal 21 and third signal 13 can be selected to optimize the sensing of the desired physiological characteristic, and/or to enable a reader unit 8 to distinguish between or identify sensors and/or subjects. For example, a reader unit 8 may use a first set of frequencies (F1, F2 and F3) for a first sensor unit 6 in a first subject, and a second set of frequencies (different F1, F2 and F3) for a second sensor unit 6 in a second subject. As another example, specific frequencies can be chosen for a specific physiological characteristic, e.g. one set of frequencies can be used for measuring heart rate, breathing rate, etc., and another set of frequencies can be used for measuring, e.g., obesity, fat content, which requires the first signal 5 to penetrate deeper into the part of the body of the subject.

Although in the above embodiments two signals are mixed together to form the third signal, in some embodiments more complex spectra can be used. In particular, the first transmitter 4 may transmit signals at a number of different frequencies (e.g. three or more signals) through the part of the body 20, and the sensor unit 6 can receive these signals and mix them together to create a number of lower frequency (third) signals, each with known frequencies. These signals can then be transmitted to the reader unit 8. The signals can, for example, be received with a Software Defined Radio (SDR). Signal strength and/or phase variation caused by movements of the fluid in the tissue can be determined, and the most sensitive frequencies for sensing movements in different types of tissue, or at different locations on the body 20, can be determined. In some embodiments, analysis of multiple signals at different frequencies can be used to determine measurements of other physiological characteristics (in addition to heart rate and breathing rate), such as those that affect the conductivity of the body, such as fat content, blood content, etc.

Figure 7 is a block diagram illustrating the components and operations of a receiver 16 and processing unit 18 in a reader unit 8 according to an embodiment. The receiver 16 comprises a loop antenna (e.g. coil) 34 that is configured to resonate at or close to the frequency of the third signal 13. The receiver 16 also comprises an amplitude demodulator 36 and a phase demodulator 38 that receive the third signal 13 from the coil 34 and that perform amplitude demodulation and phase demodulation of the third signal 13 respectively. The amplitude demodulator 36 demodulates the received third signal 13 to produce an amplitude (e.g. signal strength) signal. An exemplary amplitude signal is shown

in Figure 8. The phase demodulator 38 demodulates the received third signal to produce a signal proportional to the phase variation over time. An exemplary phase signal is shown in Figure 9. It will be appreciated that in some embodiments the amplitude demodulator 36 and the phase demodulator 38 can be implemented in the processing unit 18 rather than the receiver 16.

The amplitude signal is provided to a signal analysis block 40 in the processing unit 18. The signal analysis block 40 analyses the amplitude (signal strength, e.g. RSSI) signal to determine a measurement of the physiological characteristic (e.g. heart rate and/or breathing rate and/or breathing depth and/or pulmonary edema). Typically, the breathing rate is determined from the amplitude signal, and it can be seen in Figure 8 that the amplitude is generally periodic. The heart rate is typically determined from the phase signal.

The phase signal from the phase demodulator 38 is provided to a time integrator 42 and a subtraction block 44. The time integrator 42 integrates the phase signal over time to determine an average phase (e.g. mean phase) for the signal. The average (e.g. mean) phase is used as a reference signal and is provided to the subtraction block 44. The reference signal (i.e. average phase) is subtracted from the phase signal from the phase demodulator 38 to give a signal showing the deviation in phase of the third signal 13 from the average phase.

The phase deviation signal is provided to the signal analysis block 40. The signal analysis block 40 analyses the phase deviation signal to determine a measurement of the physiological characteristic (e.g. heart rate and/or breathing rate and/or breathing depth and/or pulmonary edema).

In some embodiments, the signal analysis block 40 can combine the amplitude and phase signals into a vector vs time signal. This time domain signal can be converted to a frequency domain plot with a Fourier transform. An exemplary frequency domain plot is shown in Figure 10. It can be seen that there are two peaks in the plot, one at 0.1 Hz and the other at about 1.2 Hz. Since the rate of breathing is typically much less than the heart rate, the breathing rate corresponds to the lower peak and the heart rate corresponds to the higher peak. In this example, the breathing rate has a frequency around 0.1 Hz and is therefore around 6 breaths per minute, and the heart rate is about 1.2 Hz (around 72 beats per minute).

It will be appreciated that in some embodiments, the physiological characteristic may be determined from just one of the amplitude changes of the third signal 13 and the phase changes of the third signal 13. In this case the receiver 16 may only comprise one of the amplitude demodulator 36 and the phase demodulator 38, and the

processing unit 18 will only include the components/functionality required for processing the appropriate one of the amplitude and phase.

It will also be appreciated that the components and functions of the processing unit 18 illustrated in Figure 7 can be implemented using hardware components in the processing unit 18, by software or firmware executing on the processing unit 18, or any combination thereof.

The flow chart in Figure 11 illustrates a method of measuring a physiological characteristic of a subject according to an embodiment of the invention. The method can be performed in or by the system shown in Figure 1. In a first step, step 101, a first signal 5 that has a first frequency (F1) is transmitted from a first transmitter 4 into the body 20 (or a part of the body 20, such as the chest) of a subject. The first frequency is preferably in the range of 1 GHz to 100 GHz. As noted above, the first transmitter 4 can be part of or integral with a reader unit 8.

After passing through a part of the body 20 of the subject and being modulated by the fluid content of the part of the body, the first signal 5 is received at a sensor unit 6 (step 103). In step 105, in the sensor unit 6 the first signal 5 is mixed with a second signal that has a second frequency (F2) to form a third signal 13 that has a third frequency (F3). As described above, the third frequency corresponds to the difference between the first frequency and the second frequency. The third frequency is preferably in the range of 1 MHz to 100 MHz. Also as described above, in some embodiments the second signal is transmitted to the sensor unit 6 by the first transmitter 4, whereas in other embodiments the sensor unit 6 generates the second signal using an oscillator 26.

The third signal 13 is then transmitted from the sensor unit 6 to a reader unit 8 using a transmitter 14 (step 107), and received by a receiver 16 in the reader unit 8 (step 109). The reader unit 8 (and for example a processing unit 18 in the reader unit 8) measures changes in the signal strength and/or the phase of the received third signal 13 over time (step 111) and determines a measurement of a physiological characteristic from the measured changes in the signal strength and/or the phase (step 113). In some embodiments, the physiological characteristic is heart rate, or breathing rate, or breathing depth, or pulmonary edema, or any other physiological characteristic that can be measured from changes or movements in the fluid in the part of the body of a subject.

There is therefore provided an improved method, system and apparatus for measuring a physiological characteristic of a subject.

Variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the disclosure and the appended claims. In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. A single processor or other unit may fulfil the functions of several items recited in the claims. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage. A computer program may be stored/distributed on a suitable medium, such as an optical storage medium or a solid-state medium supplied together with or as part of other hardware, but may also be distributed in other forms, such as via the Internet or other wired or wireless telecommunication systems. Any reference signs in the claims should not be construed as limiting the scope.

CLAIMS:

1. A system for measuring a physiological characteristic of a subject, the system comprising:

a first transmitter configured to transmit a first signal that has a first frequency into a part of a body of the subject so that the signal strength and/or phase of the first signal is modulated by fluid and/or tissue movement inside the part of the body;

a sensor unit that is for use on or near a part of the body of the subject; and

a reader unit;

wherein the sensor unit comprises:

a first receiver configured to receive the modulated first signal;

a mixer configured to mix the modulated first signal with a second signal that has a second frequency to form a third signal that has a third frequency, wherein signal strength and/or phase modulations of the third signal are proportional to the signal strength and/or phase modulations of the modulated first signal, the third frequency corresponding to the difference between the first frequency and the second frequency; and

a second transmitter configured to transmit the third signal;

wherein the reader unit comprises:

a second receiver configured to receive the third signal; and

a processing unit configured to measure changes in the signal strength and/or the phase of the received third signal over time, and to determine a measurement of the physiological characteristic from the measured changes in the signal strength and/or the phase.

2. A system as claimed in claim 1, wherein the physiological characteristic is one or more of heart rate, breathing rate, breathing depth and pulmonary edema.

3. A system as claimed in claim 1 or 2, wherein the first signal and the second signal have higher frequencies than the third signal.

4. A system as claimed in claim 1, 2 or 3, wherein the first frequency and the second frequency are in the range of 1 GHz to 100 GHz.

5. A system as claimed in any of claims 1-4, wherein the third frequency is in the range of 1 MHz to 100 MHz.

6. A system as claimed in any of claims 1-5, wherein the sensor unit further comprises a third receiver configured to receive a fourth signal, wherein the fourth signal provides power for operating the sensor unit.

7. A system as claimed in any of claims 1-5, wherein the mixer is a diode and wherein the sensor unit further comprises a third receiver configured to receive a fourth signal, wherein the fourth signal provides power for providing a DC bias for the diode.

8. A system as claimed in any of claims 1-7, wherein the system further comprises a reflector that is to be placed on an opposite side of the part of the body of the subject to the sensor unit and the first transmitter, wherein the reflector is configured to reflect the transmitted first signal to the sensor unit.

9. A system as claimed in any of claims 1-8, wherein the first transmitter is further configured to transmit the second signal to the sensor unit.

10. A system as claimed in any of claims 1-7, wherein the sensor unit further comprises an oscillator for generating the second signal.

11. A method for measuring a physiological characteristic of a subject, the method comprising:

transmitting a first signal that has a first frequency from a first transmitter to a part of the body of the subject so that the signal strength and/or phase of the first signal is modulated by fluid and/or tissue movement inside the part of the body;

receiving the modulated first signal at a sensor unit that is on or near the part of the body of the subject;

mixing the modulated first signal with a second signal that has a second frequency to form a third signal that has a third frequency, wherein signal strength and/or

phase modulations of the third signal are proportional to the signal strength and/or phase modulations of the modulated first signal, the third frequency corresponding to the difference between the first frequency and the second frequency;

transmitting the third signal from the sensor unit to a reader unit using a second transmitter;

receiving the third signal using a second receiver in the reader unit;

measuring changes in the signal strength and/or the phase of the received third signal over time; and

determining a measurement of the physiological characteristic from the measured changes in the signal strength and/or the phase.

12. A reader unit for measuring a physiological characteristic of a subject, the reader unit comprising:

a first transmitter configured to transmit a first signal and a second signal through a part of a body of the subject to a sensor unit so that the signal strength and/or phase of the first signal is modulated by fluid and/or tissue movement inside the part of the body, the first signal being transmitted at a first frequency and the second signal being transmitted at a second frequency;

a receiver configured to receive a third signal from the sensor unit, the third signal being at a third frequency, the third frequency corresponding to the difference between the first frequency and the second frequency; and

a processing unit configured to measure the signal strength and/or phase of the received third signal and to determine a measurement of the physiological characteristic from variations in the signal strength and/or phase.

13. A reader unit as claimed in claim 12, wherein the reader unit further comprises a second transmitter configured to transmit a fourth signal, wherein the fourth signal provides power for operating the sensor unit.

14. A method for measuring a physiological characteristic of a subject, the method comprising:

transmitting a first signal and a second signal from a first transmitter in a reader unit through a part of the body of the subject to a sensor unit so that the signal strength and/or phase of the first signal is modulated by fluid and/or tissue movement inside the part

of the body, the first signal being transmitted at a first frequency and the second signal being transmitted at a second frequency;

receiving a third signal from the sensor unit using a receiver in the reader unit, the third signal being at a third frequency, the third frequency corresponding to the difference between the first frequency and the second frequency;

measuring changes in the signal strength and/or the phase of the received third signal over time; and

determining a measurement of the physiological characteristic from the measured changes in the signal strength and/or the phase.

15. A computer program product comprising a computer readable medium having computer readable code embodied therein, the computer readable code being configured such that, on execution by a suitable computer or processor, the computer or processor is caused to:

control a transmitter in a reader unit to transmit a first signal and a second signal through a part of the body of the subject to a sensor unit so that the signal strength and/or phase of the first signal is modulated by fluid and/or tissue movement inside the part of the body, the first signal being transmitted at a first frequency and the second signal being transmitted at a second frequency;

control a receiver in the reader unit to receive a third signal from the sensor unit, the third signal being at a third frequency, the third frequency corresponding to the difference between the first frequency and the second frequency;

measure changes in the signal strength and/or the phase of the received third signal over time; and

determine a measurement of a the physiological characteristic from the measured changes in the signal strength and/or the phase.

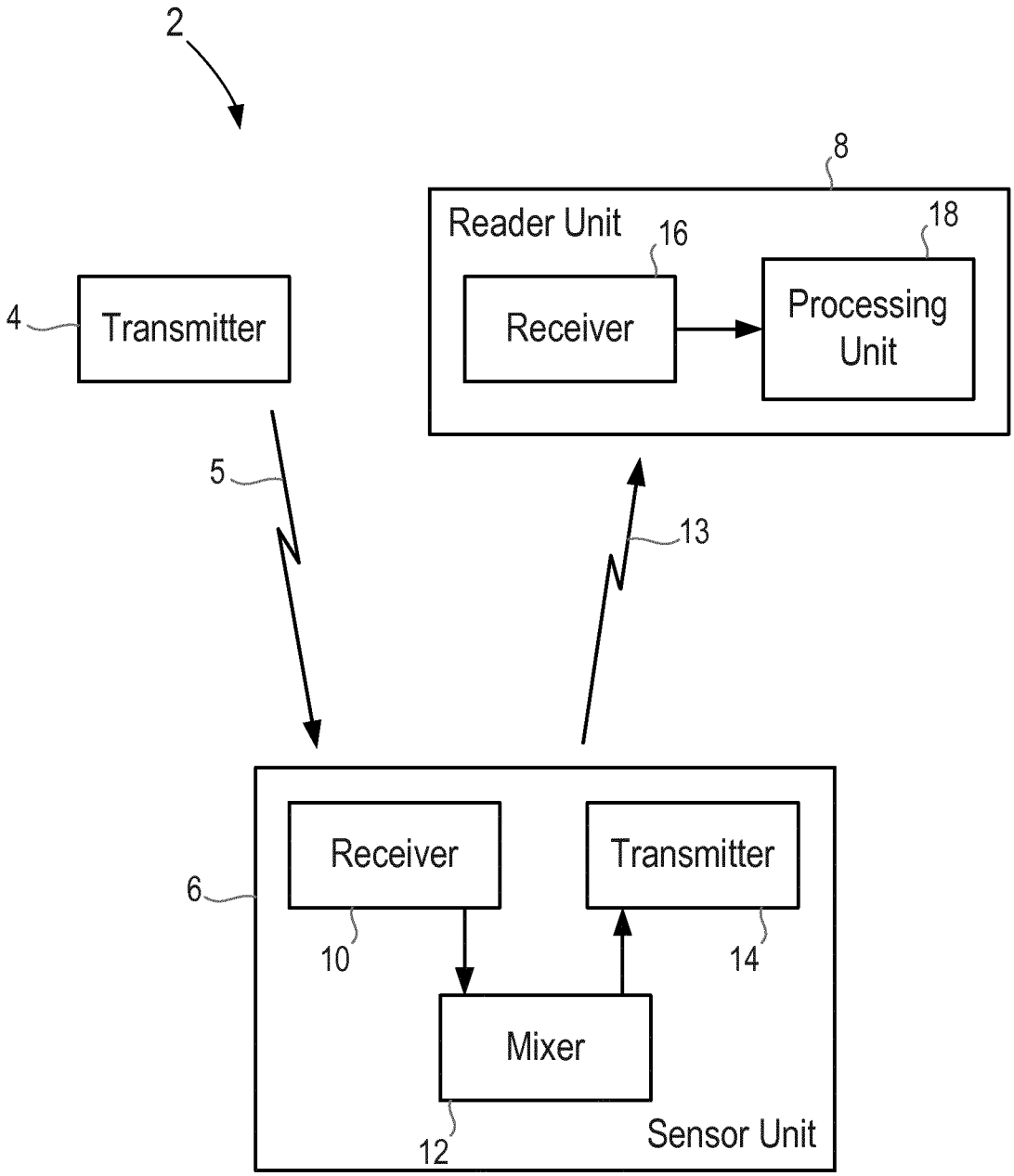
2
8
Reader Unit
16
18
Receiver
Processing Unit
4
Transmitter
5
13
6
Receiver
Transmitter
10
14
Mixer
12
Sensor Unit

Figure 1

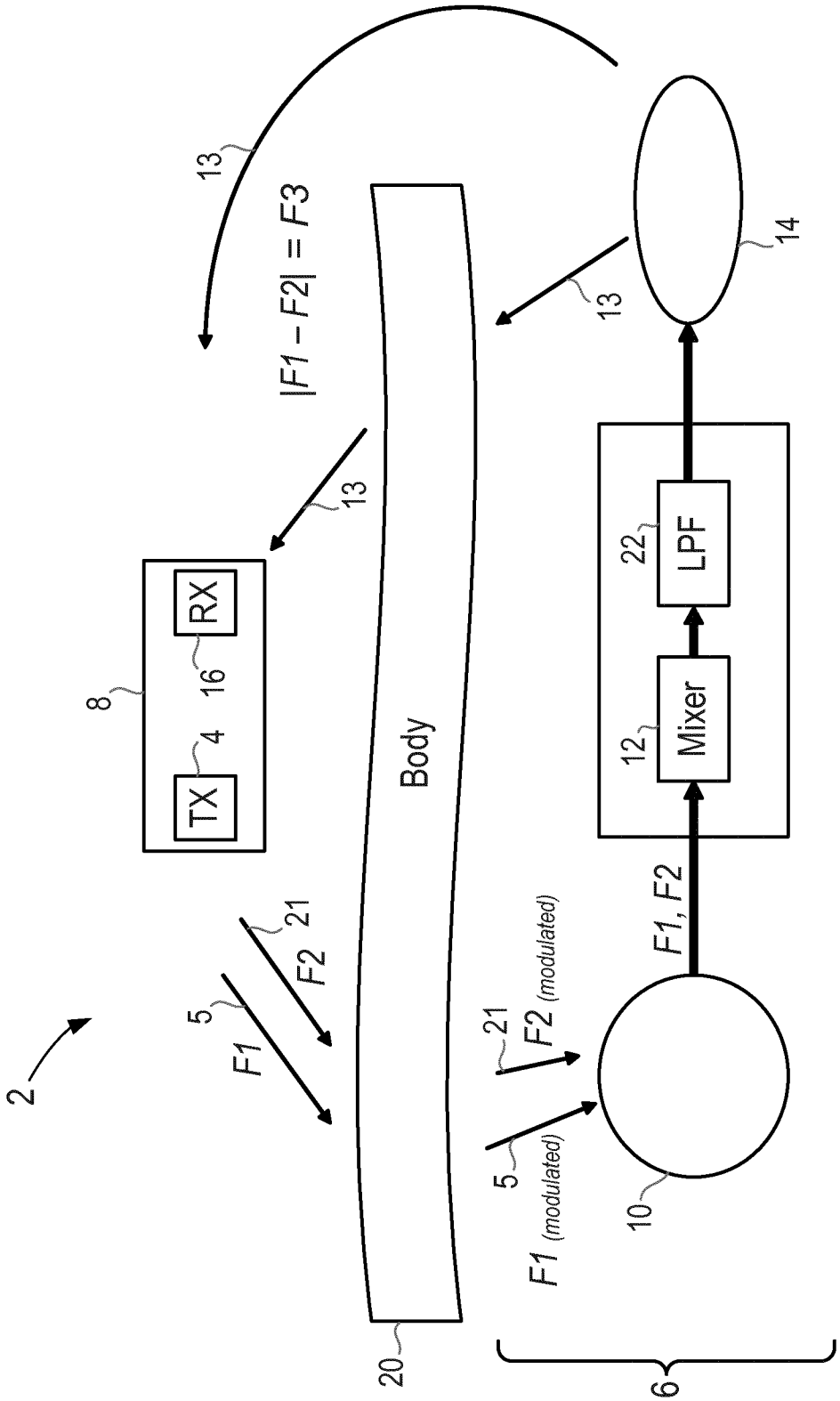
2
5
F1
21
F2
13
|F1 – F2| = F3
13
13
14
8
RX
16
TX
4
Body
20
22
LPF
12
Mixer
F1, F2
21
F2 (modulated)
5
F1 (modulated)
10
6

Figure 2

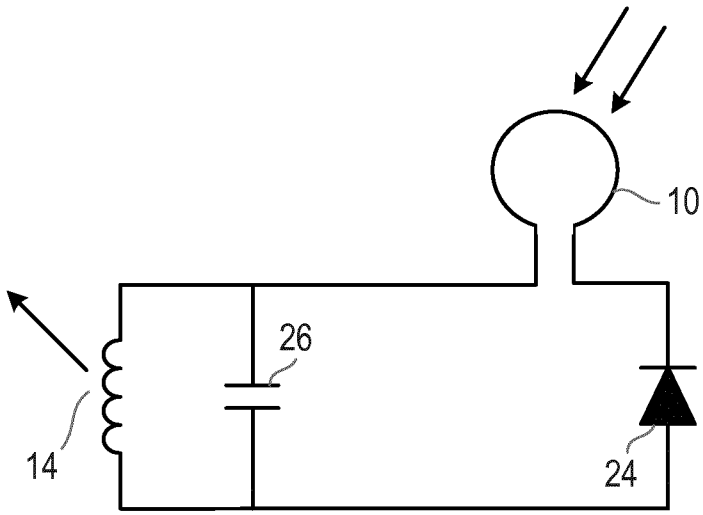

Figure 3

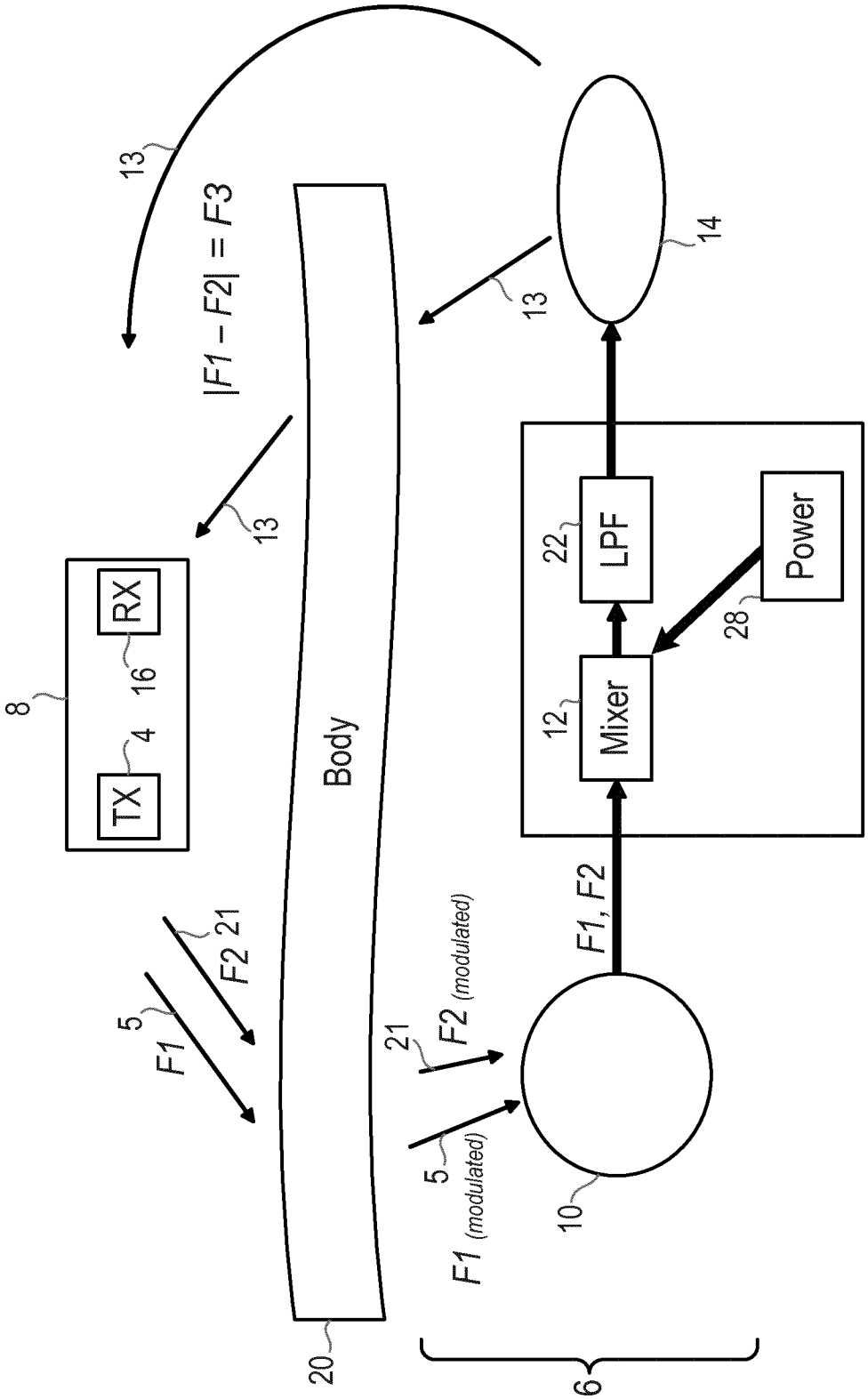
13
|F1 – F2| = F3
13
14
13
8
RX
16
TX
4
Body
22
LPF
Power
28
12
Mixer
F1, F2
21
F2 (modulated)
5
F1
21
F2
5
F1 (modulated)
10
20
6

Figure 4

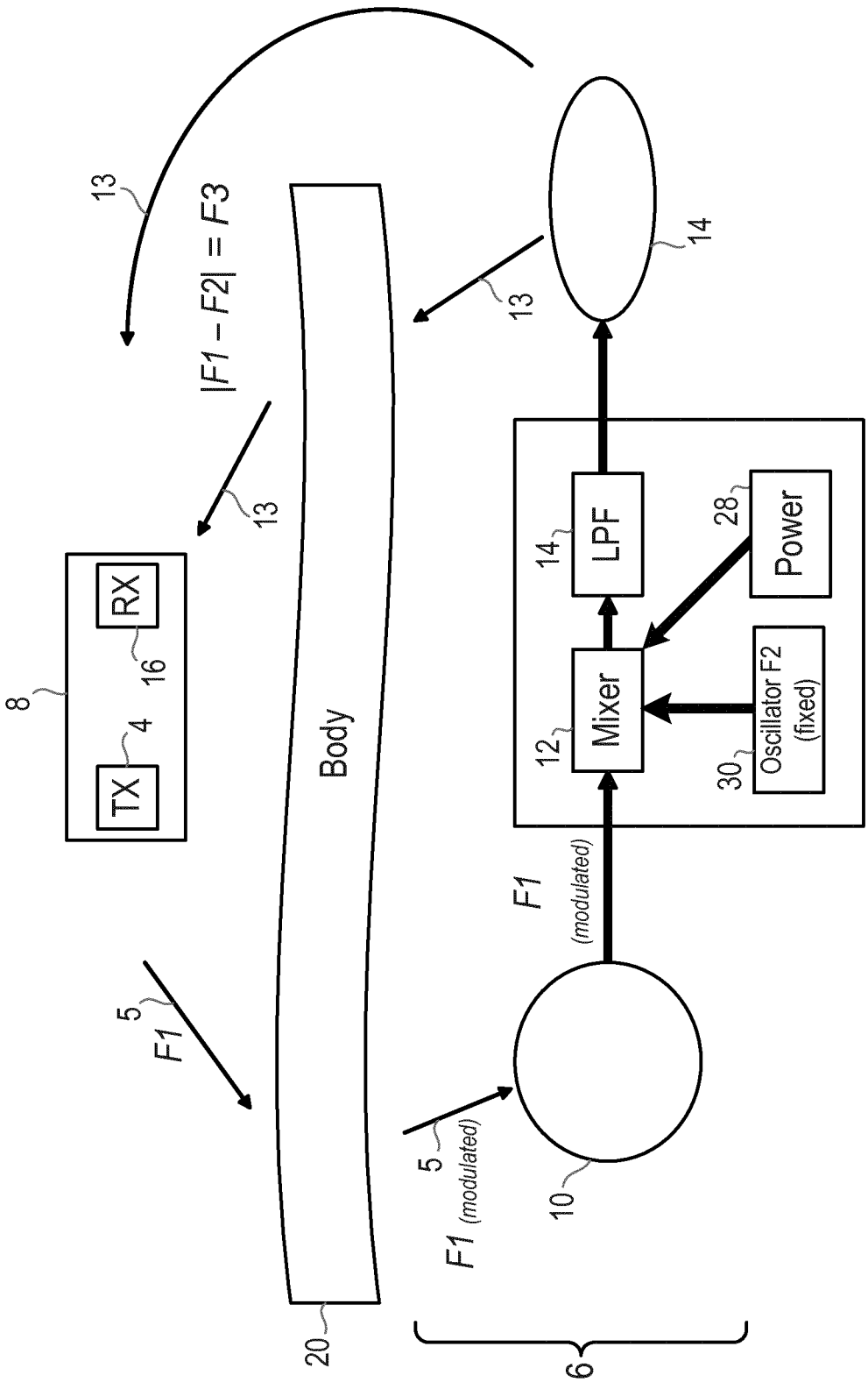
13
|F1 – F2| = F3
13
13
14
8
RX
16
TX
4
Body
14
LPF
28
Power
12
Mixer
30
Oscillator F2
(fixed)
F1
(modulated)
5
F1
5
F1 (modulated)
10
20
6

Figure 5

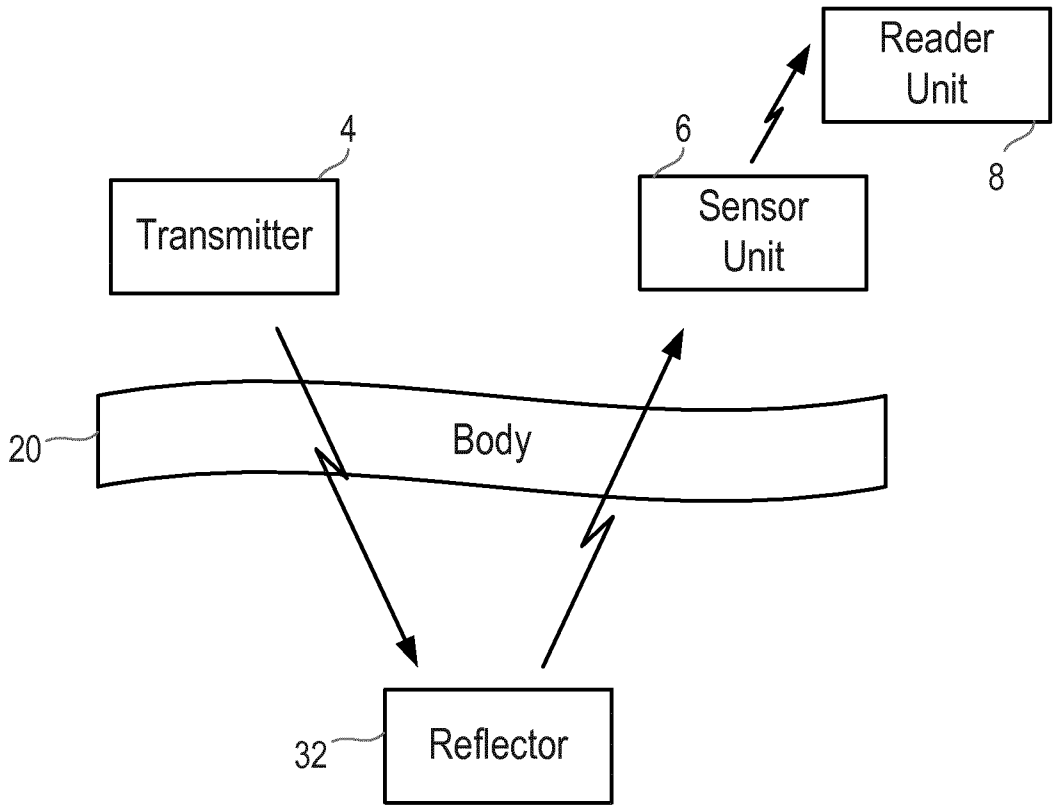
Reader Unit
8
6
4
Transmitter
Sensor Unit
20
Body
32
Reflector

Figure 6

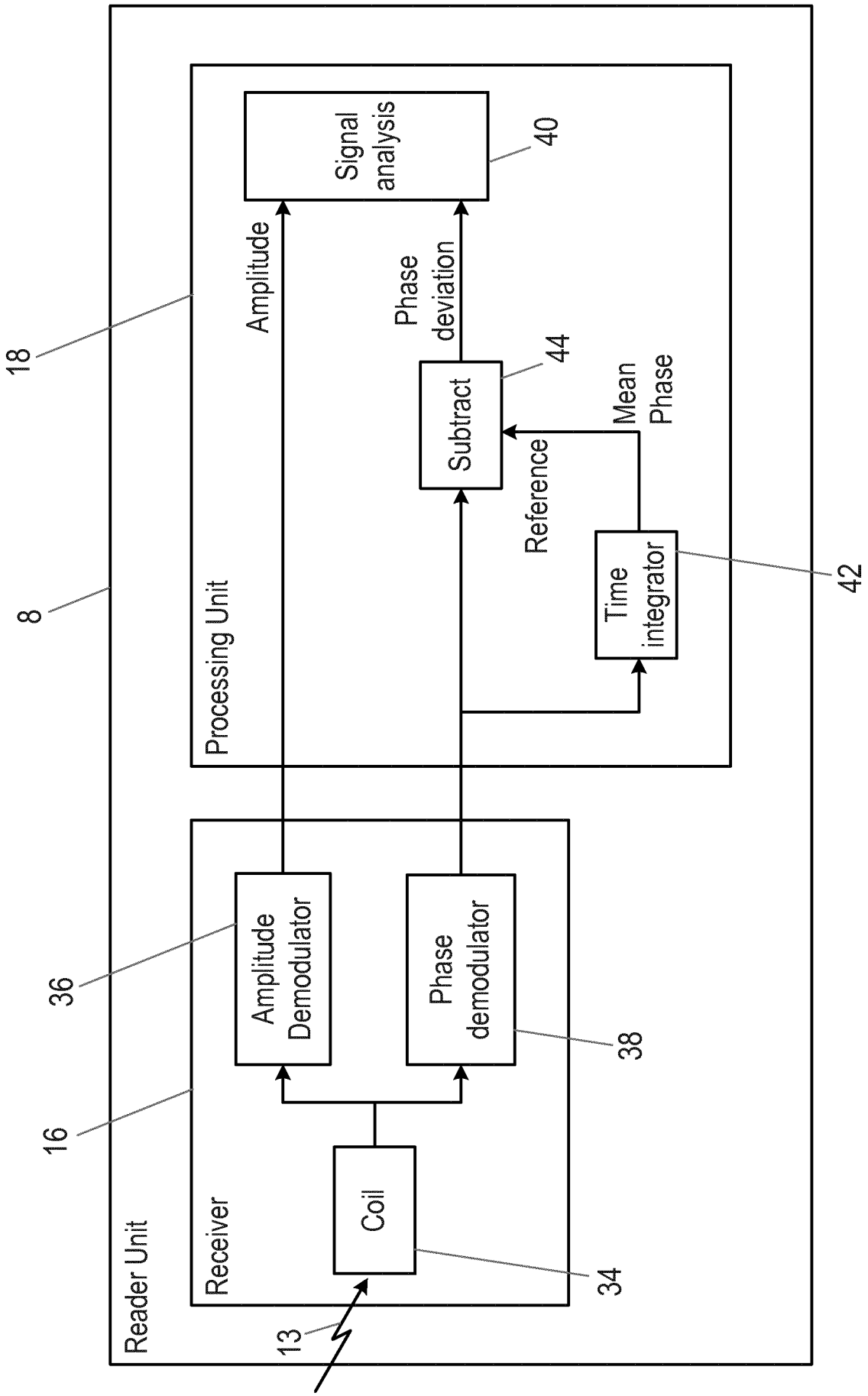
Reader Unit
Receiver
Coil
Amplitude Demodulator
Phase demodulator
Processing Unit
Signal analysis
Subtract
Time integrator
Amplitude
Phase deviation
Reference
Mean Phase
8
16
18
13
34
36
38
40
42
44

Figure 7

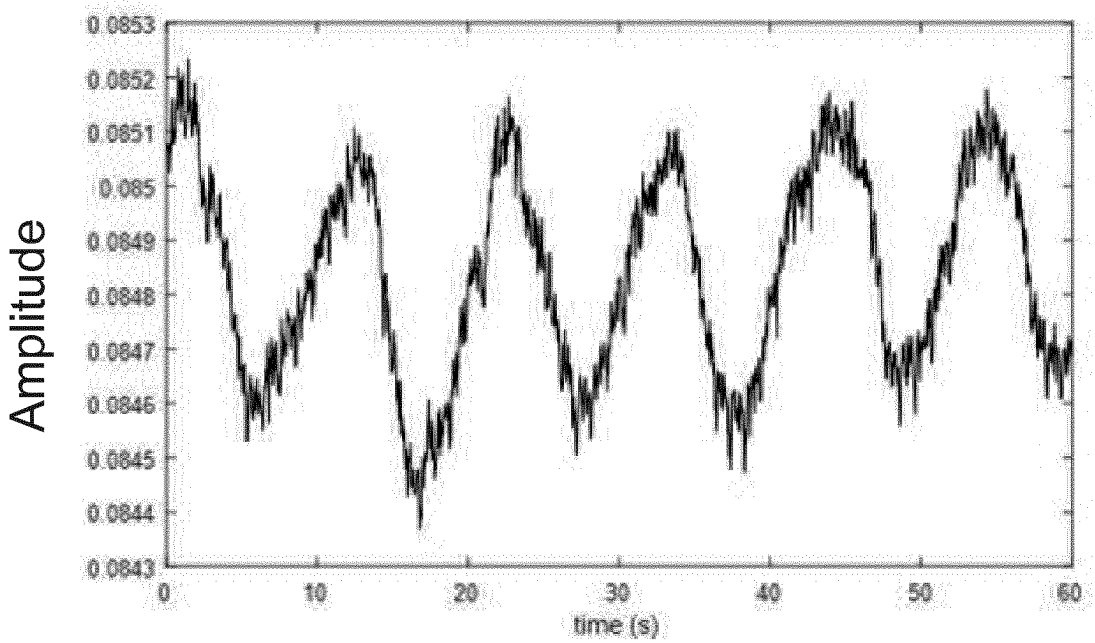

Figure 8

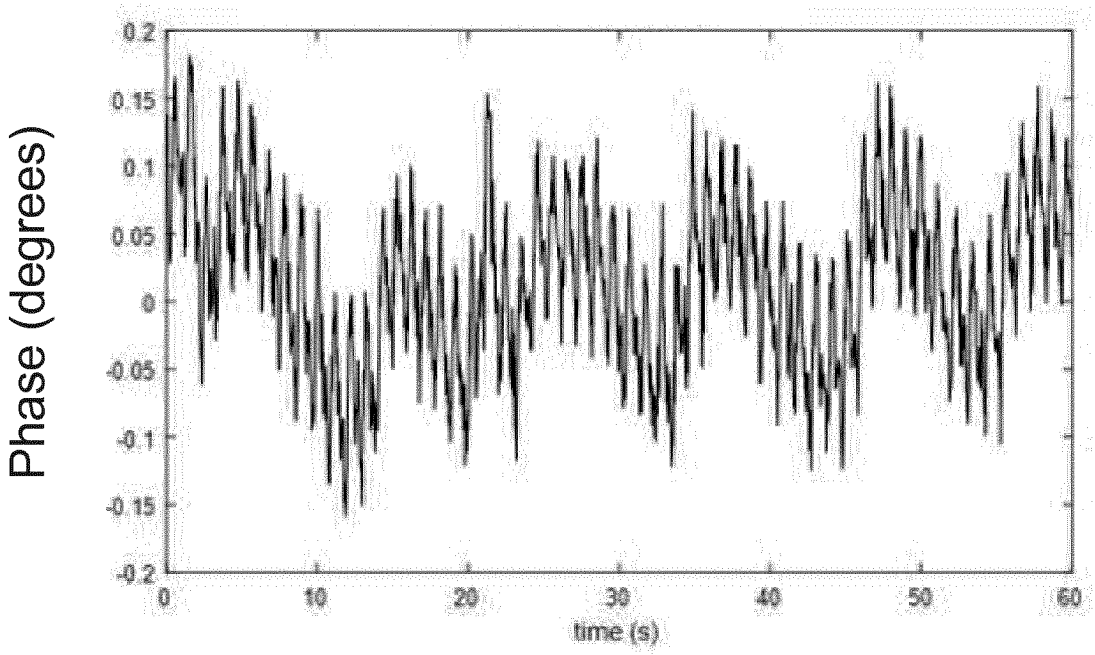

Figure 9

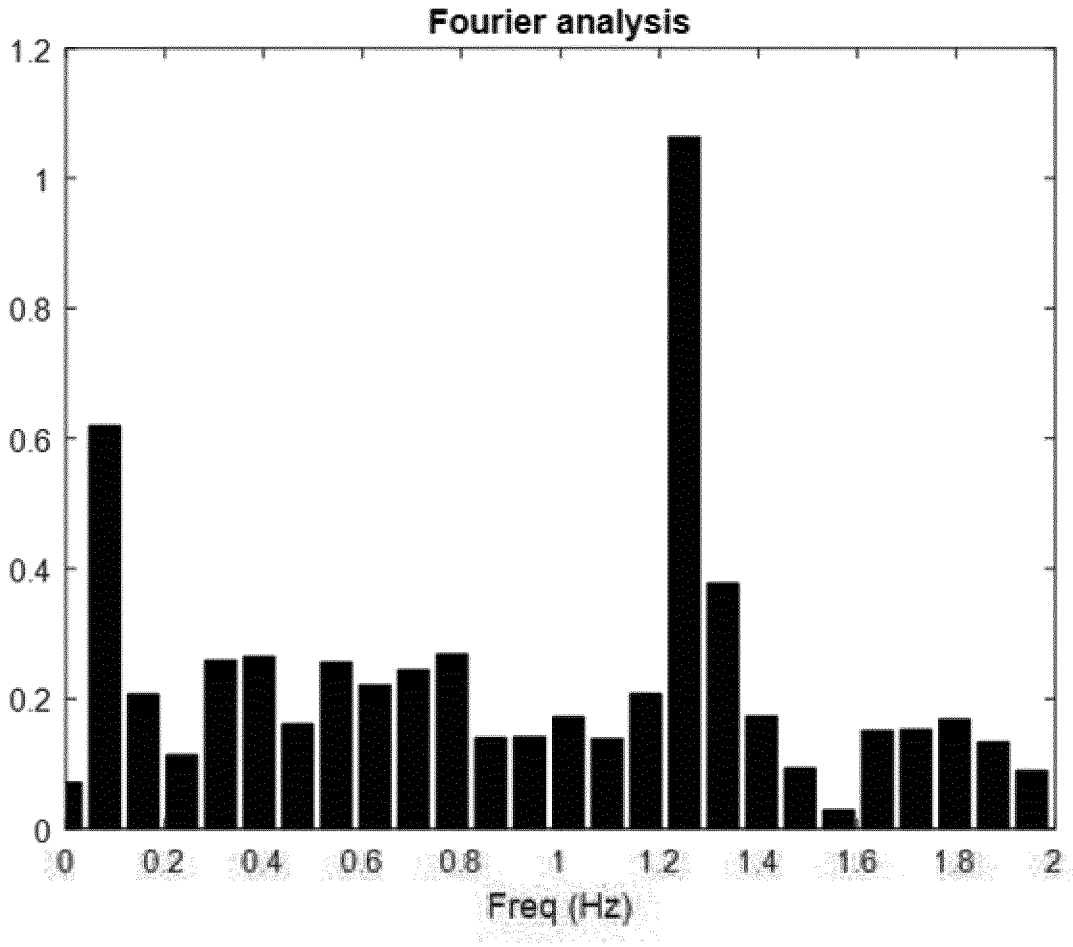
Fourier analysis
1.2
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Freq (Hz)

Figure 10

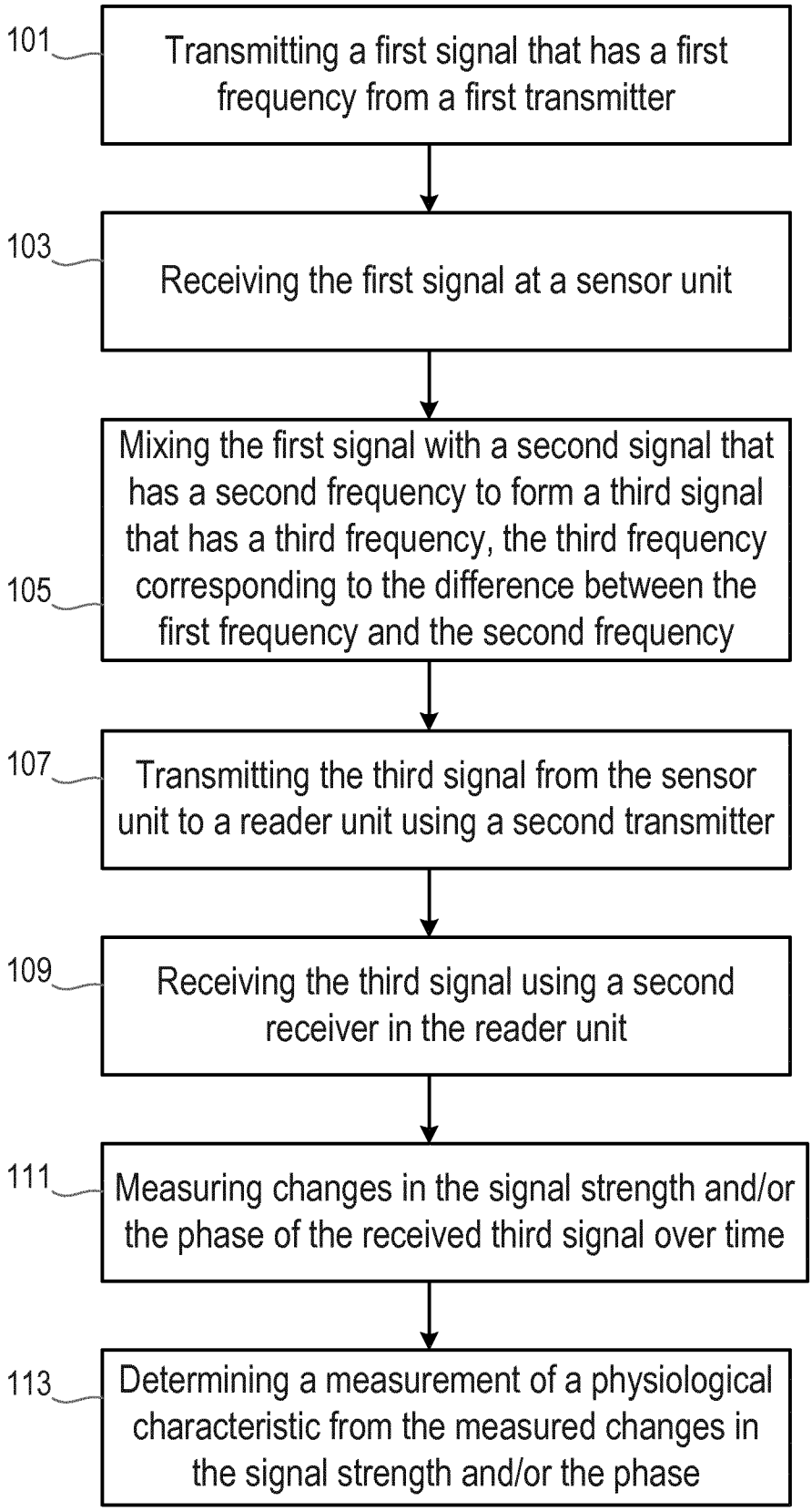
101
Transmitting a first signal that has a first frequency from a first transmitter
103
Receiving the first signal at a sensor unit
105
Mixing the first signal with a second signal that has a second frequency to form a third signal that has a third frequency, the third frequency corresponding to the difference between the first frequency and the second frequency
107
Transmitting the third signal from the sensor unit to a reader unit using a second transmitter
109
Receiving the third signal using a second receiver in the reader unit
111
Measuring changes in the signal strength and/or the phase of the received third signal over time
113
Determining a measurement of a physiological characteristic from the measured changes in the signal strength and/or the phase

Figure 11

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/056073

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61B5/05 A61B5/053 A61B5/00
ADD. A61B5/0205 A61B5/024 A61B5/0295 A61B5/08

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
A61B G01S A61M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6 132 371 A (DEMPSEY MICHAEL K [US] ET AL) 17 October 2000 (2000-10-17) abstract; figures 1-3 column 2, line 30 - column 3, line 25 column 3, line 35 - column 7, line 8	1-15
A	US 2016/058364 A1 (IONESCU MIHAI ADRIAN [CH] ET AL) 3 March 2016 (2016-03-03) abstract; figures 1-3 paragraphs [0012] - [0024], [0026] - [0038]	1-15
A	US 2014/163343 A1 (HENEGHAN CONOR [IE] ET AL) 12 June 2014 (2014-06-12) abstract; figures 1-11 paragraphs [0017] - [0022], [0038] - [0040], [0046], [0047], [0050] - [0061], [0084] - [0092]	1-15

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 May 2017	06/06/2017

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Carta, Riccardo

1

Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/056073

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2013/231550 A1 (WEINSTEIN URIEL [IL] ET AL) 5 September 2013 (2013-09-05) abstract; figures 1-10 paragraphs [0007] - [0011], [0020], [0037] - [0039], [0041] - [0053], [0057] - [0060]	1-15
A	US 2015/327774 A1 (KIM TAE WOOK [KR] ET AL) 19 November 2015 (2015-11-19) abstract; figures 1,2,5,19 paragraphs [0006] - [0029], [0062] - [0066], [0071] - [0075], [0079], [0080] - [0096], [0134] - [0139], [0184] - [0207]	1-15

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2017/056073

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 6132371 A	17-10-2000	NONE	
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