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(54) **SYSTEMS, METHODS AND RELATED APPARATUS FOR DETERMINING PHYSIOLOGICAL PARAMETERS**

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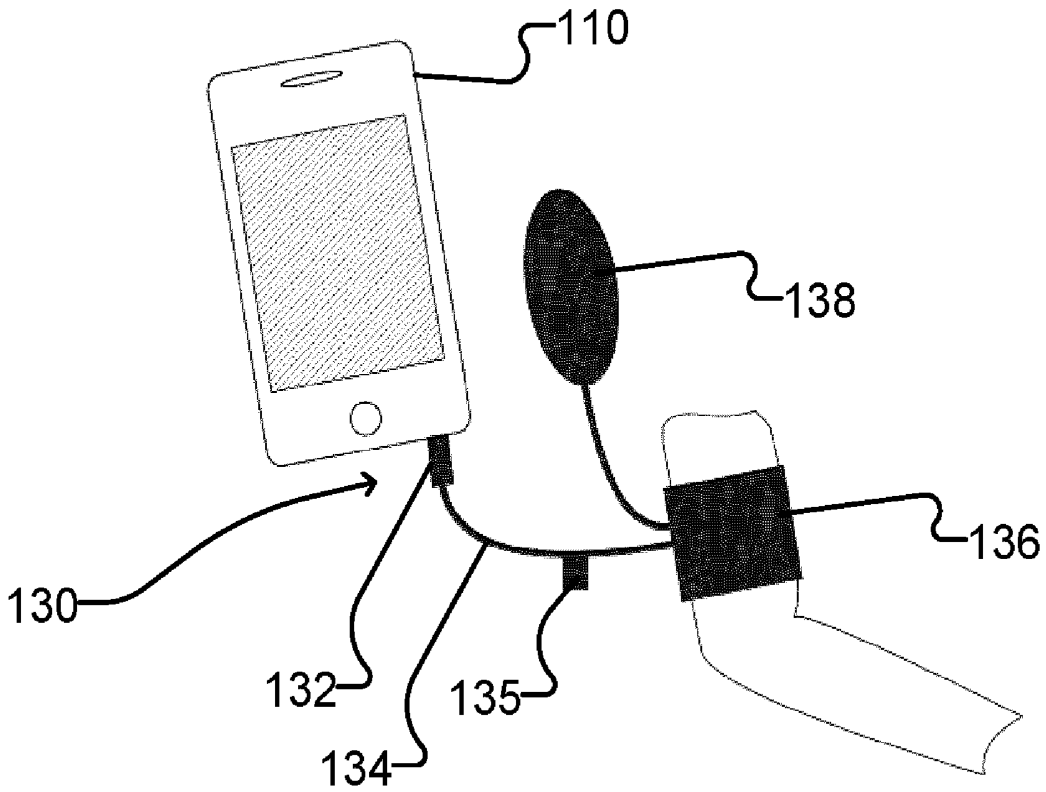
(57) **ABSTRACT**

Methods, systems and related apparatus are provided for controlling an electronic device to operate an external sensor connectable to an audio interface of the electronic device by applying a first harmonic driving signal to a first contact and a second harmonic driving signal to a second contact of the audio interface for driving the external sensor, receiving a response signal at a third contact of the audio interface, adjusting at least one of the first and second harmonic driving signals, determining one or more physiological parameters based on characteristics of the first and second harmonic driving signals and the response signal, and outputting the determined one or more physiological parameters.



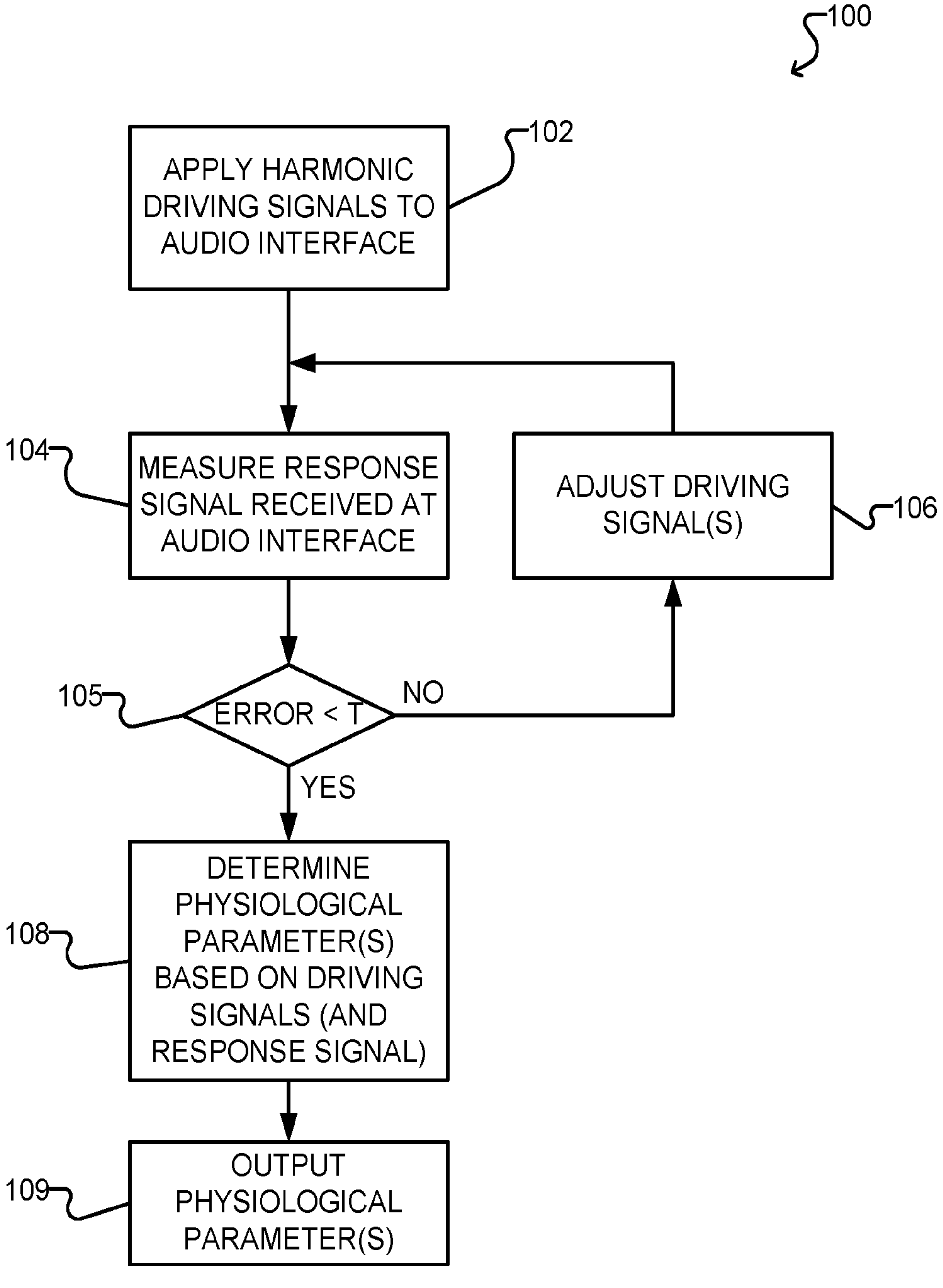

100
APPLY HARMONIC DRIVING SIGNALS TO AUDIO INTERFACE
102
MEASURE RESPONSE SIGNAL RECEIVED AT AUDIO INTERFACE
104
ADJUST DRIVING SIGNAL(S)
106
ERROR < T
105
NO
YES
DETERMINE PHYSIOLOGICAL PARAMETER(S) BASED ON DRIVING SIGNALS (AND RESPONSE SIGNAL)
108
OUTPUT PHYSIOLOGICAL PARAMETER(S)
109

Figure 1

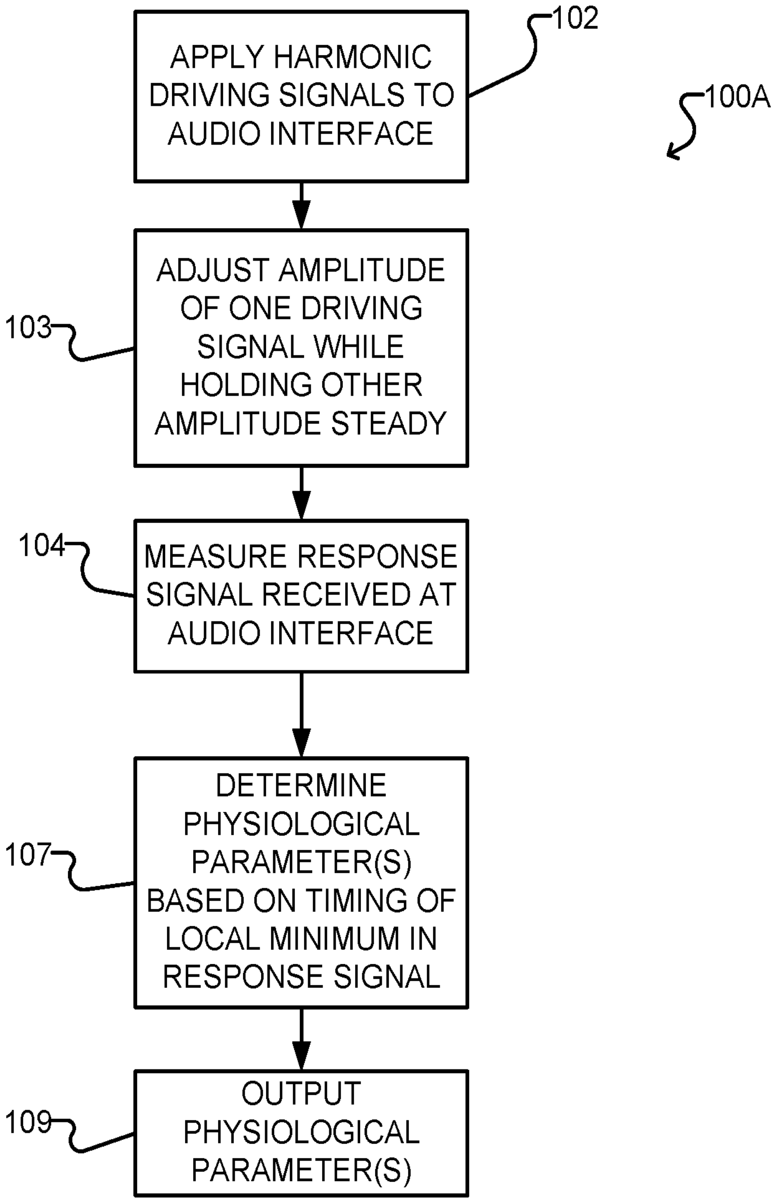

102
100A
APPLY HARMONIC DRIVING SIGNALS TO AUDIO INTERFACE
103
ADJUST AMPLITUDE OF ONE DRIVING SIGNAL WHILE HOLDING OTHER AMPLITUDE STEADY
104
MEASURE RESPONSE SIGNAL RECEIVED AT AUDIO INTERFACE
107
DETERMINE PHYSIOLOGICAL PARAMETER(S) BASED ON TIMING OF LOCAL MINIMUM IN RESPONSE SIGNAL
109
OUTPUT PHYSIOLOGICAL PARAMETER(S)

Figure 1A

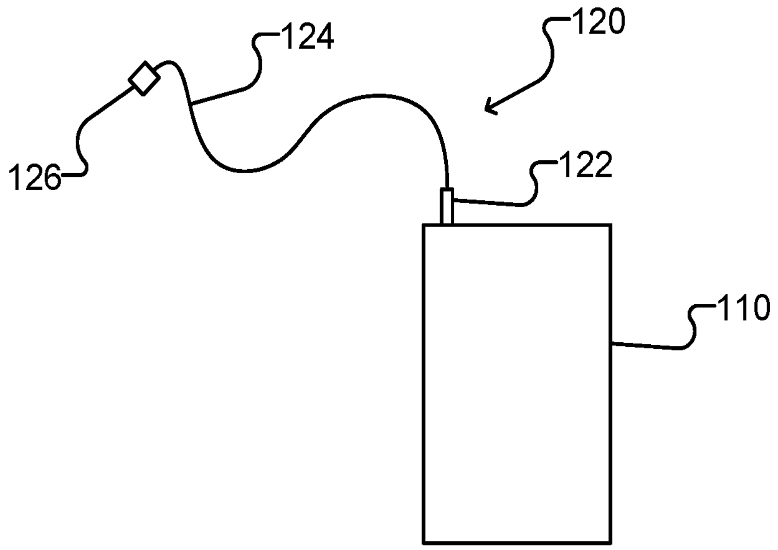


Figure 1B

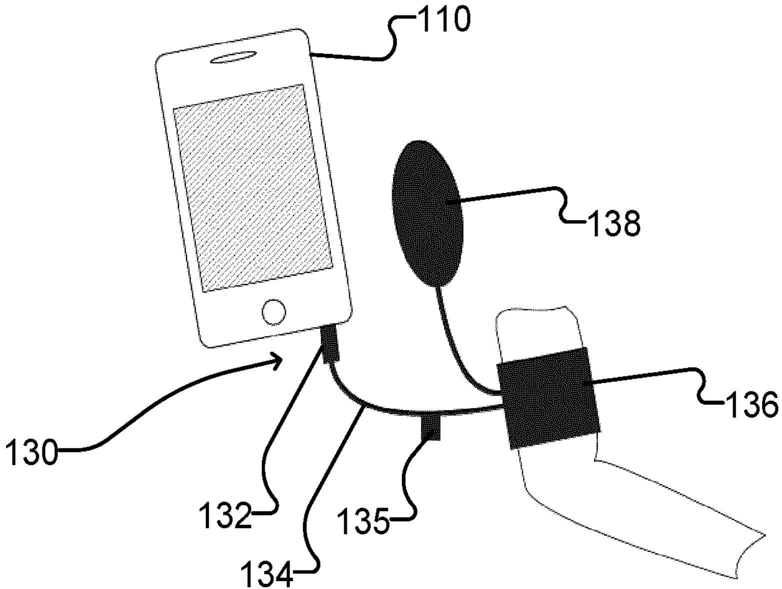


Figure 1C

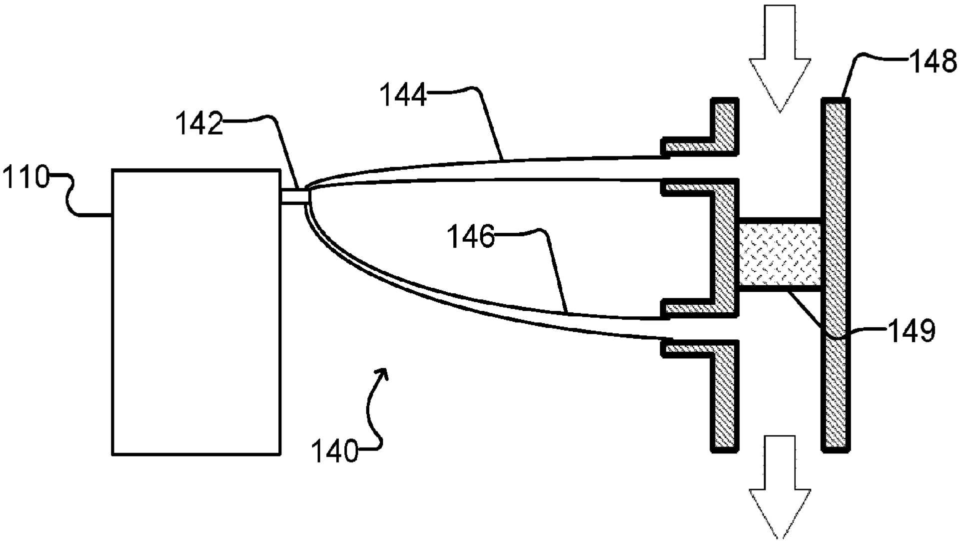


Figure 1D

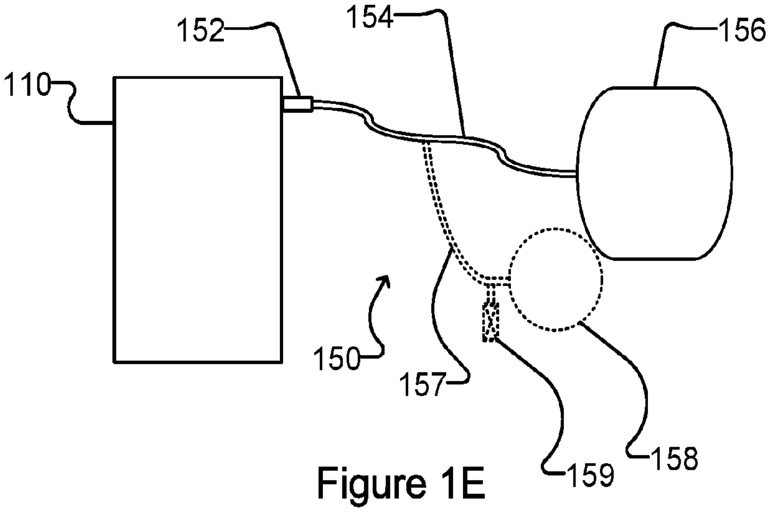


Figure 1E

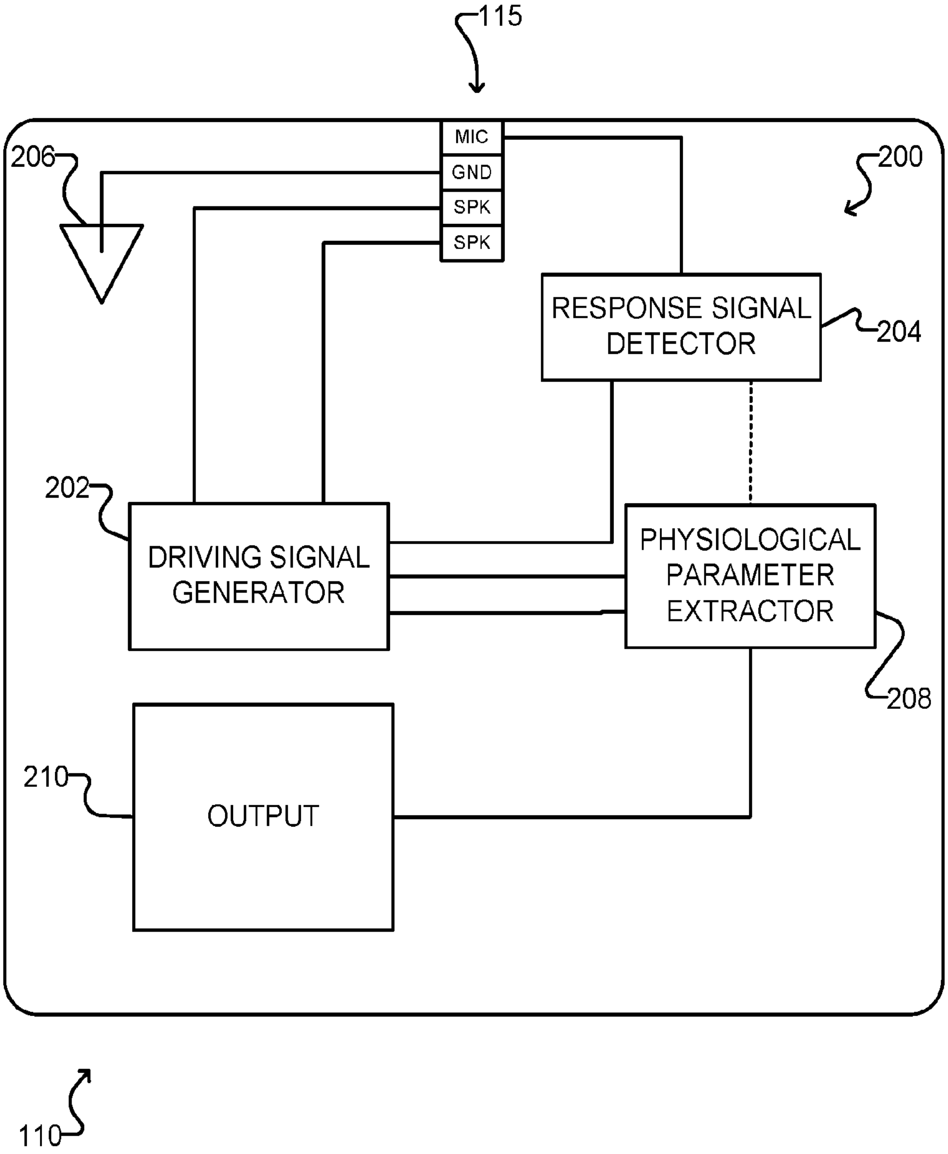

115
MIC
GND
SPK
SPK
206
200
RESPONSE SIGNAL DETECTOR
204
202
DRIVING SIGNAL GENERATOR
PHYSIOLOGICAL PARAMETER EXTRACTOR
208
210
OUTPUT
110

Figure 2

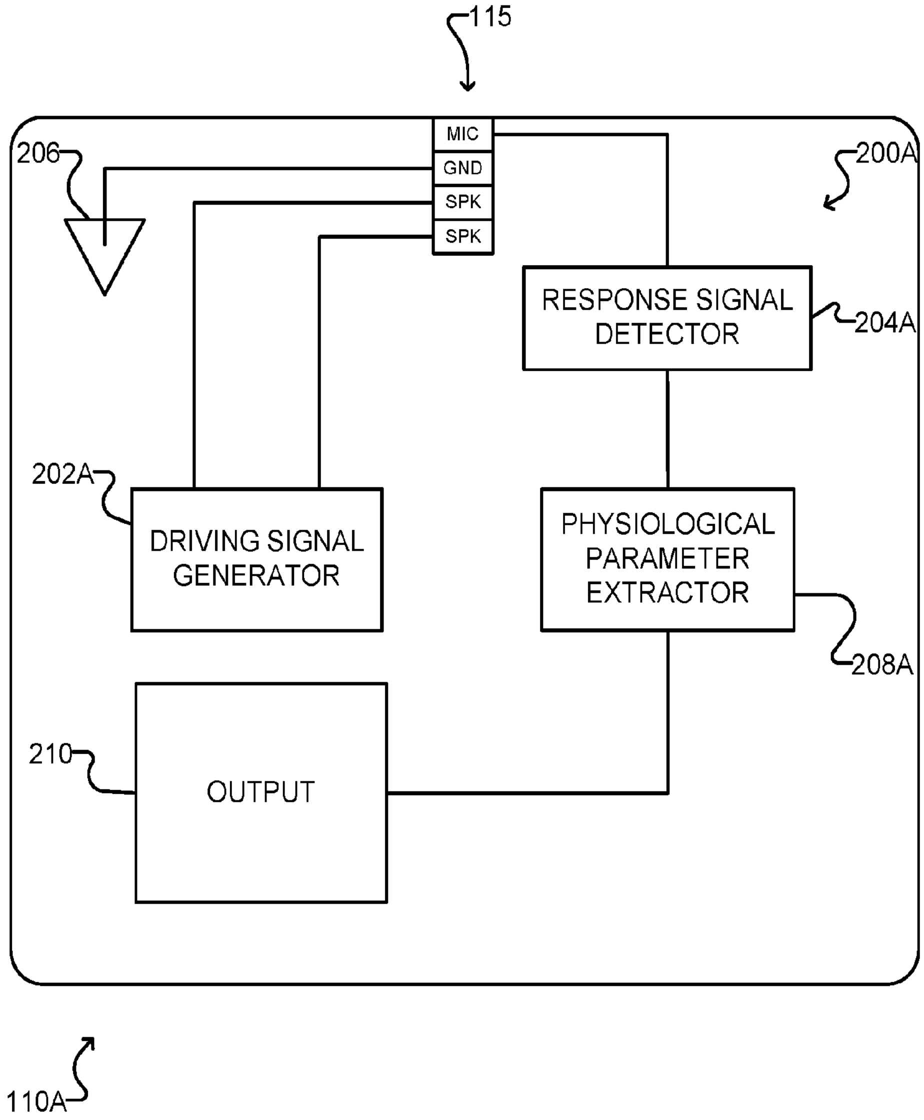

115
MIC
GND
SPK
SPK
206
200A
RESPONSE SIGNAL DETECTOR
204A
202A
DRIVING SIGNAL GENERATOR
PHYSIOLOGICAL PARAMETER EXTRACTOR
208A
210
OUTPUT
110A

Figure 2A

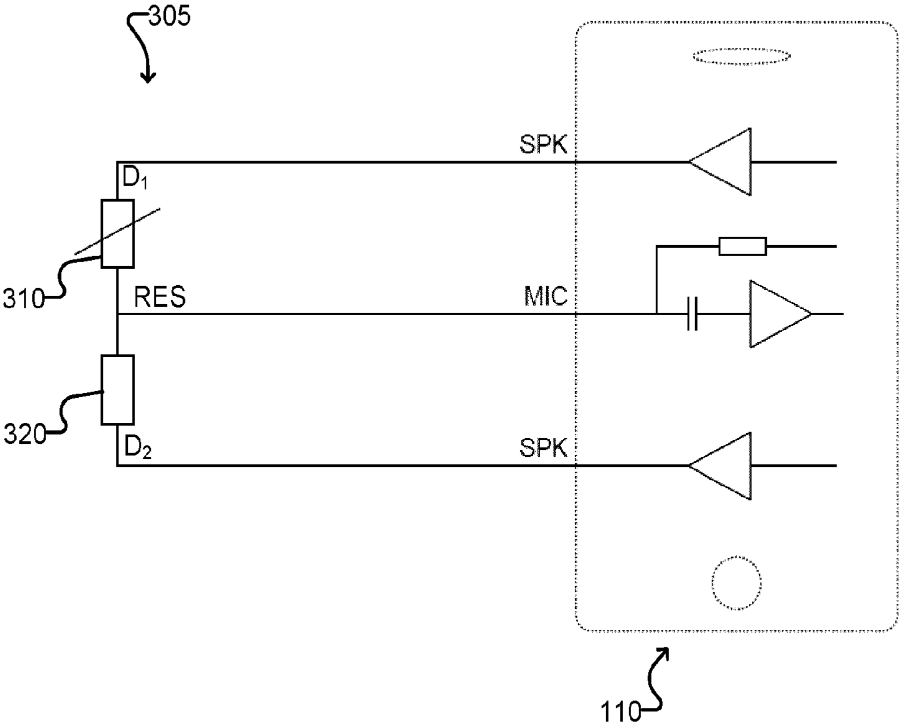


Figure 3

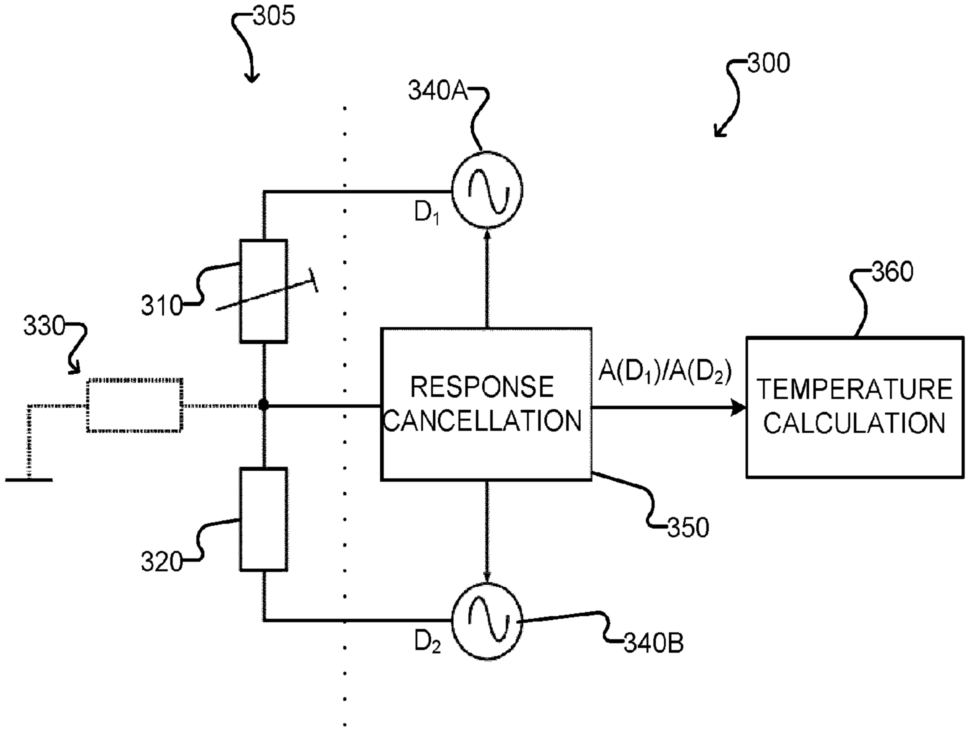


Figure 3A

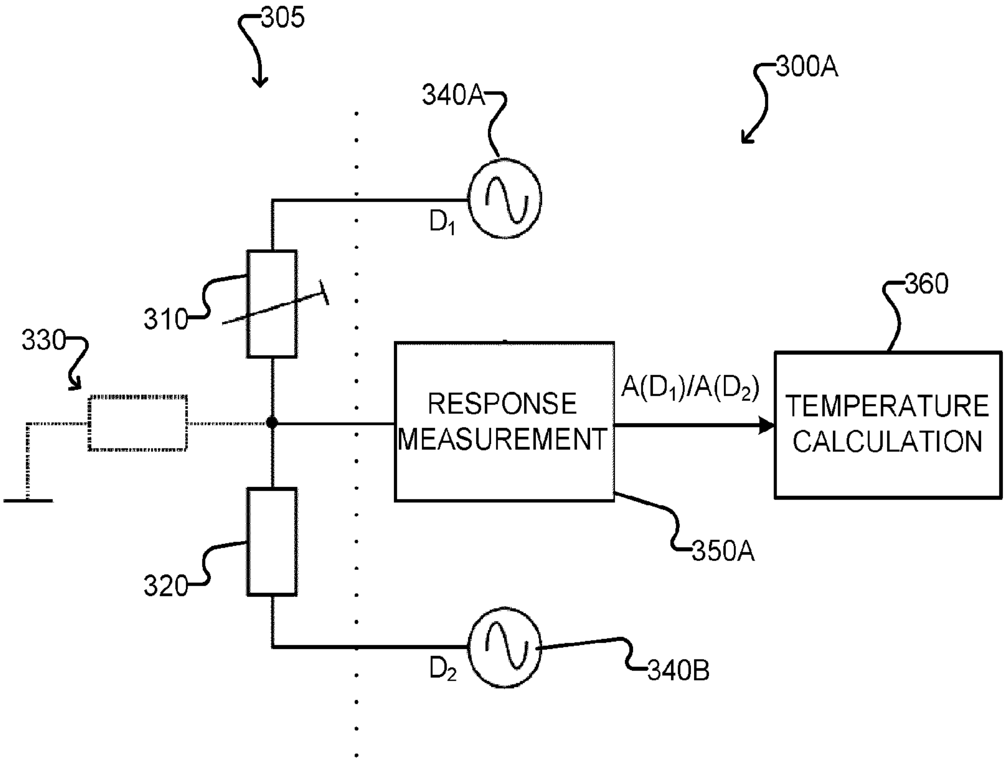

305
300A
340A
D_1
310
330
RESPONSE MEASUREMENT
$A(D_1)/A(D_2)$
360
TEMPERATURE CALCULATION
350A
320
D_2
340B

Figure 3B

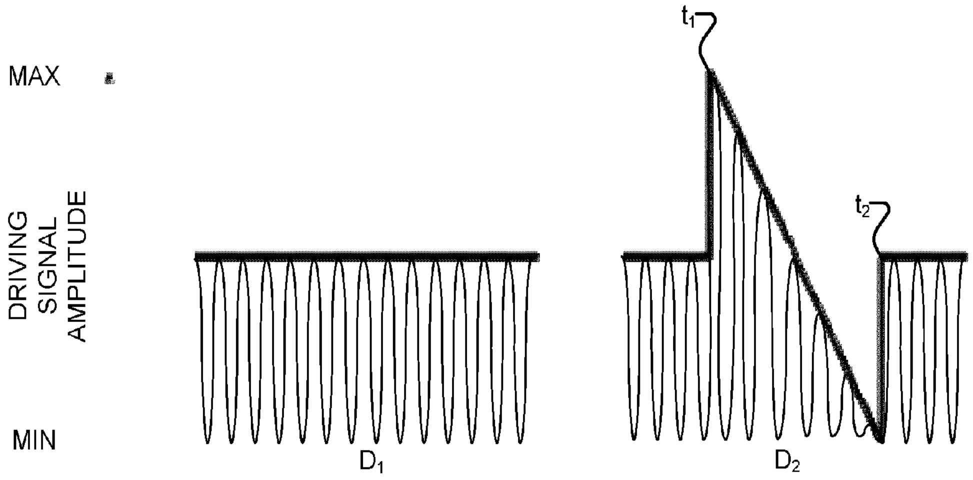


Figure 3C

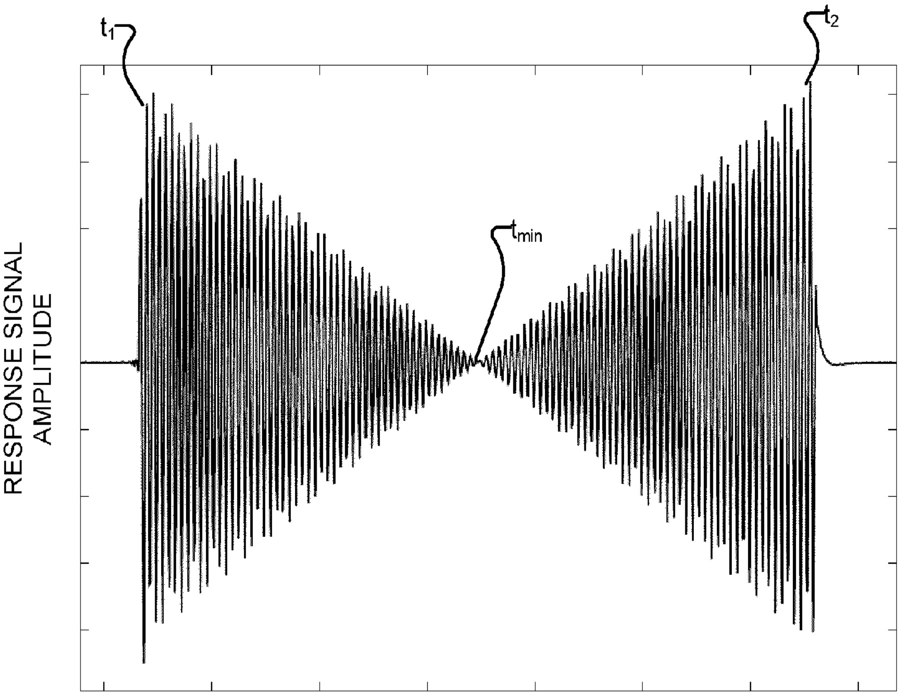


Figure 3D

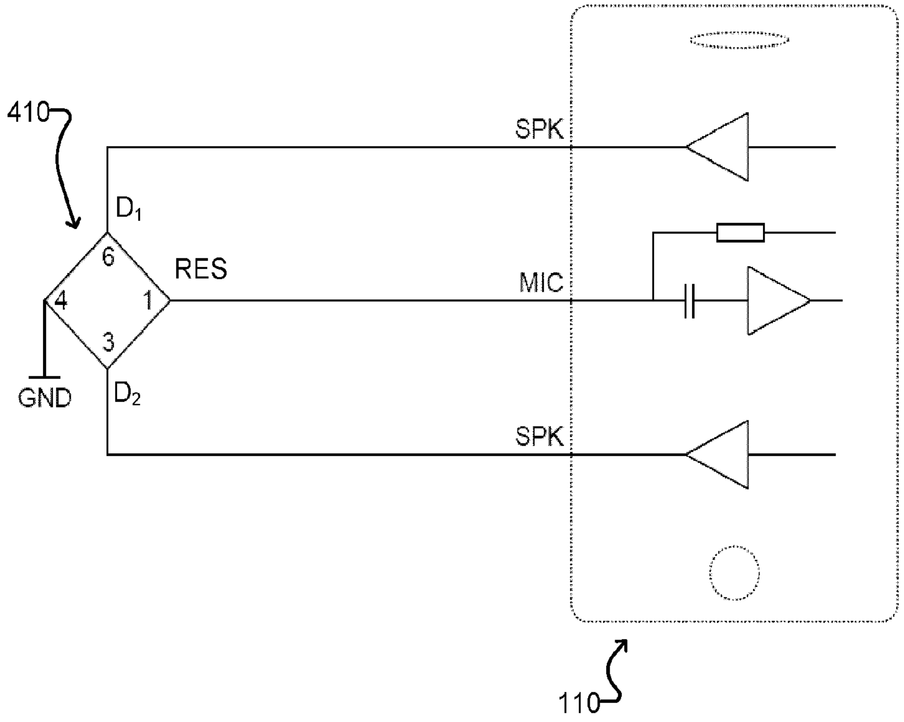


Figure 4

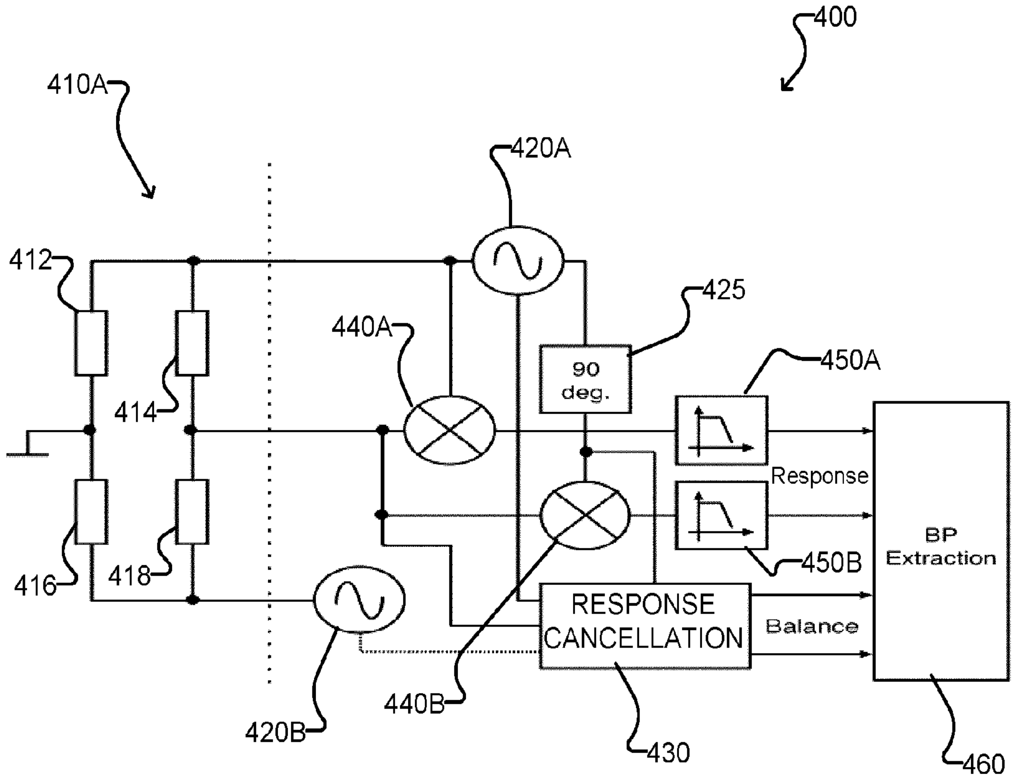


Figure 4A

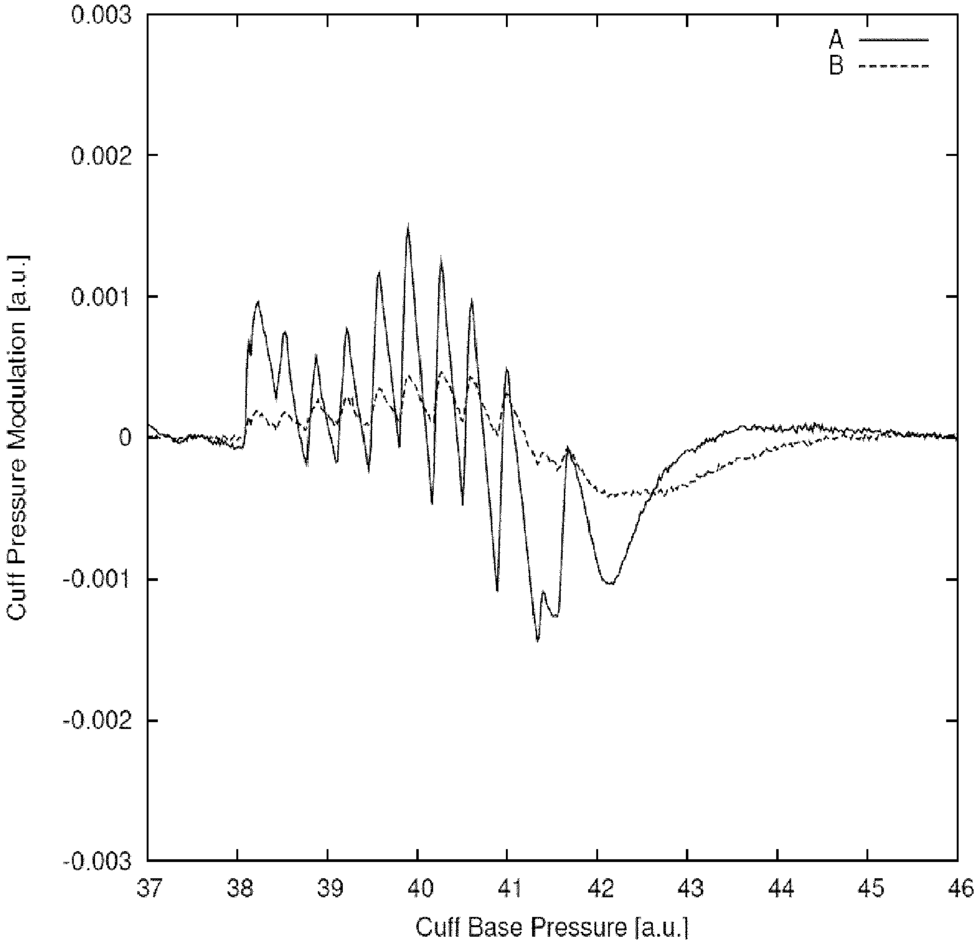

0.003
0.002
0.001
0
-0.001
-0.002
-0.003
37
38
39
40
41
42
43
44
45
46
Cuff Pressure Modulation [a.u.]
Cuff Base Pressure [a.u.]
A
B

Figure 4B

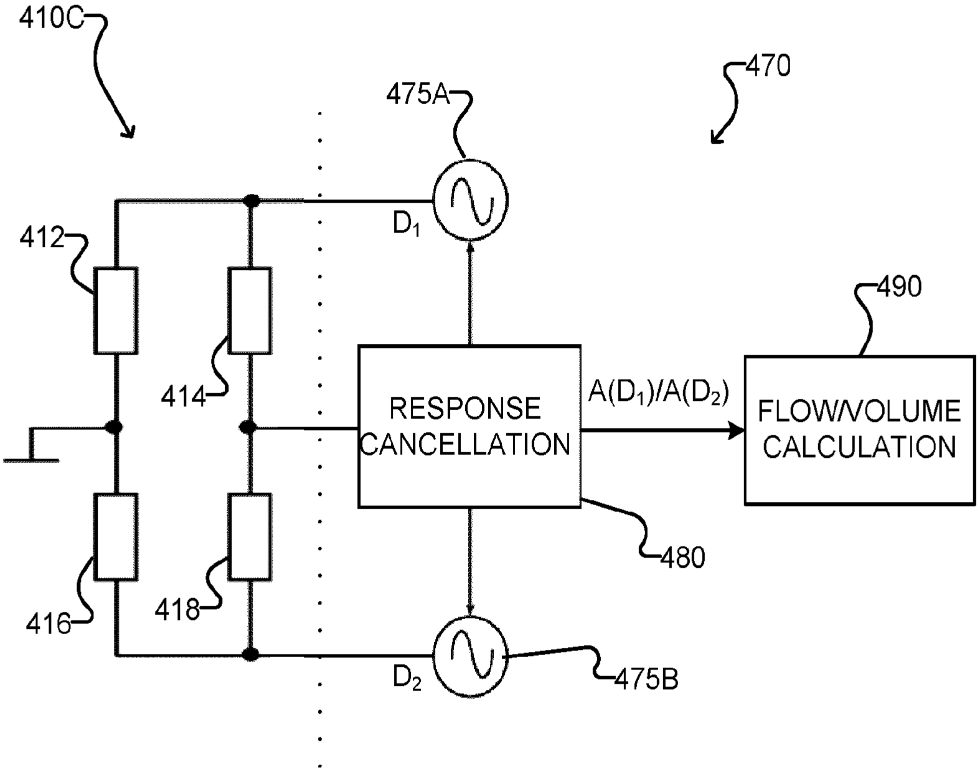

410C
470
475A
D_1
412
490
414
RESPONSE CANCELLATION
$A(D_1)/A(D_2)$
FLOW/VOLUME CALCULATION
480
416
418
D_2
475B

Figure 4C

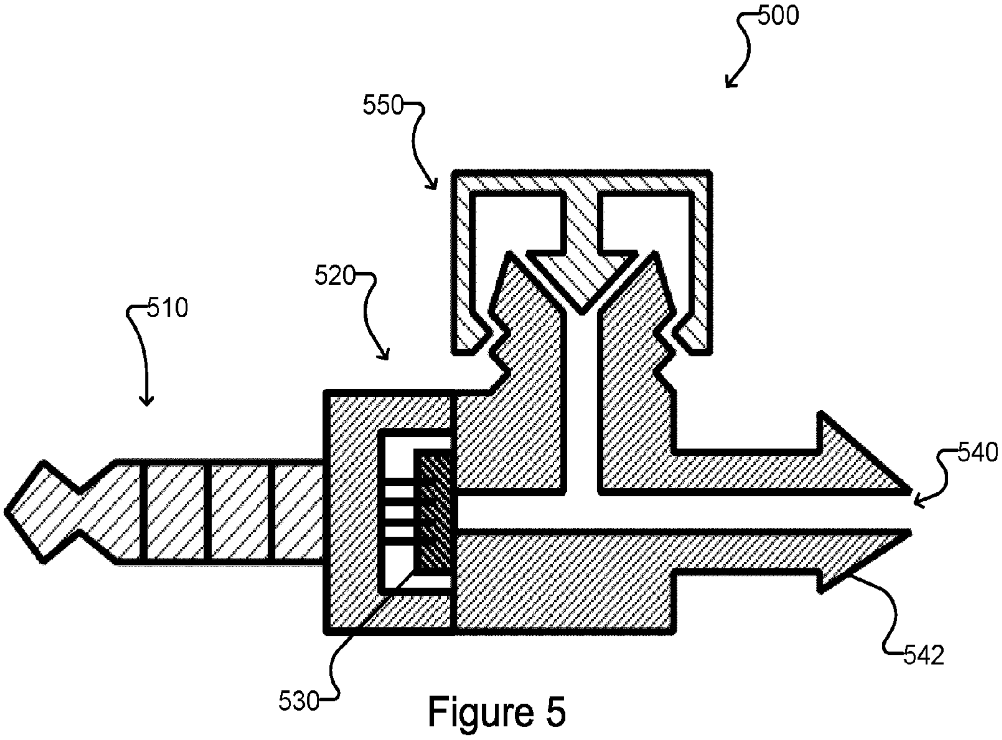


Figure 5

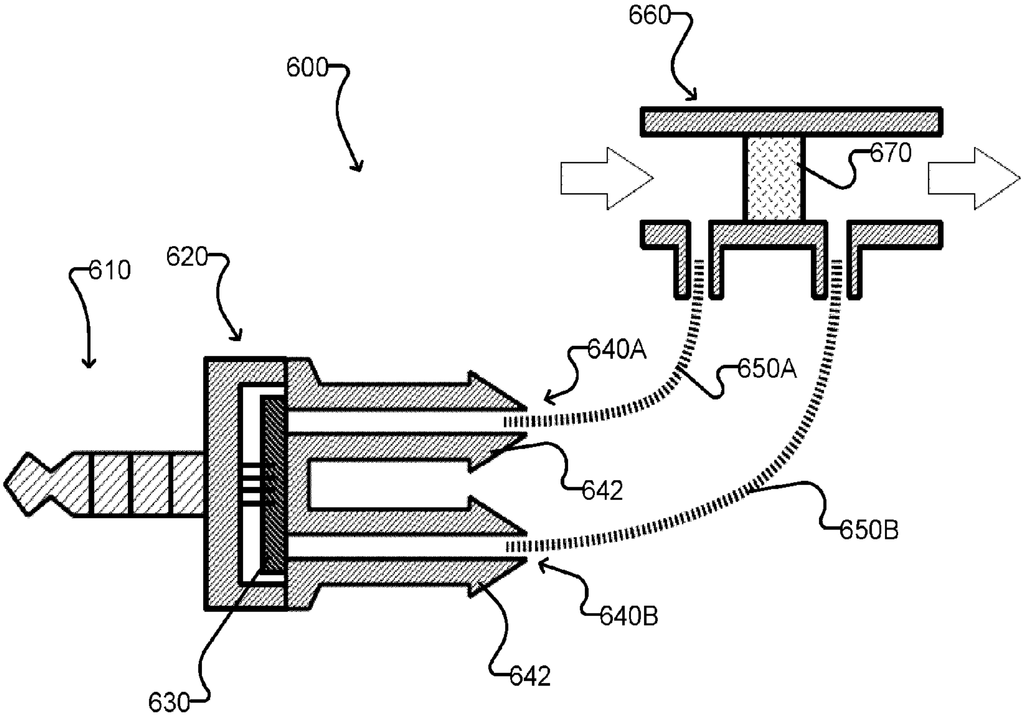


Figure 6

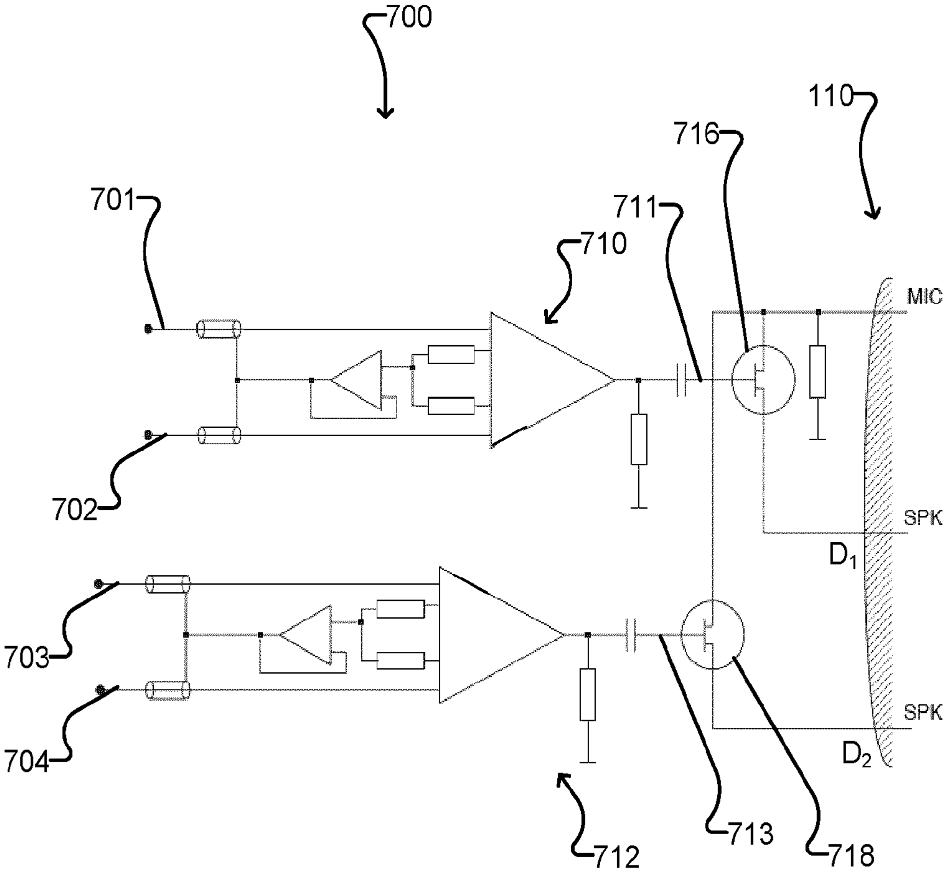


Figure 7

SYSTEMS, METHODS AND RELATED APPARATUS FOR DETERMINING PHYSIOLOGICAL PARAMETERS

FIELD

[0001] The present disclosure relates generally to determining physiological parameters of a patient. More particularly, the present disclosure relates to systems, methods and related apparatus for determining physiological parameters with sensors coupled to audio interfaces of electronic devices.

BACKGROUND

[0002] Conventional thermometers, blood pressure measurement devices, spirometers, perineometers, ECGs, EEGs, and other devices for measuring physiological parameters are typically standalone units. Standalone electronic devices for measuring physiological parameters usually contain a power source, a microcontroller, local storage, and a custom display mechanism along with the basic circuit needed to perform the sensing. This makes for relatively complex systems, costly to manufacture, and with many points of potential failure. They are therefore limited in their functionality, difficult to upgrade, and/or relatively expensive.

[0003] It is, therefore, desirable to provide improved systems and methods for determining physiological parameters.

SUMMARY

[0004] Some aspects provide methods, systems and related apparatus for controlling an electronic device to operate an external sensor connectable to an audio interface of the electronic device by applying a first harmonic driving signal to a first contact and a second harmonic driving signal to a second contact of the audio interface for driving the external sensor, receiving a response signal at a third contact of the audio interface, adjusting at least one of the first and second harmonic driving signals, determining one or more physiological parameters based on characteristics of the first and second harmonic driving signals and the response signal, and outputting the determined one or more physiological parameters.

[0005] One aspect provides a system comprising a driving signal generator for applying a first harmonic driving signal to a first contact and a second harmonic driving signal to a second contact of the audio interface for driving the external sensor and adjusting at least one of the first and second harmonic driving signals, a response signal detector for receiving a response signal at a third contact of the audio interface, a physiological parameter extractor for determining one or more physiological parameters based on characteristics of the first and second harmonic driving signals and the response signal, and an output for outputting the determined one or more physiological parameters.

[0006] Another aspect provides a thermometer for connecting to an audio interface of an electronic device, the thermometer comprising a jack plug having first and second contacts for receiving first and second harmonic driving signals from the electronic device and a third contact for returning a response signal to the electronic device, and a temperature sensor consisting essentially of a thermistor connected between the first and third contacts and a reference resistor connected between the second and third contacts.

[0007] Another aspect provides an adaptor for connecting to an audio interface of an electronic device, the adaptor comprising a jack plug having first and second contacts for receiving first and second harmonic driving signals from the electronic device and a third contact for returning a response signal to the electronic device, and a pressure sensor having a pressure sensitive area, the pressure sensor connected as a bridge across the first and second contact to provide the response signal to the third contact, between the first and third contacts and a reference resistor connected between the second and third contacts.

[0008] Other aspects and features of the present disclosure will become apparent to those ordinarily skilled in the art upon review of the following description of specific embodiments in conjunction with the accompanying figures.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] Embodiments of the present disclosure will now be described, by way of example only, with reference to the attached Figures.

[0010] FIG. **1** is a flowchart illustrating a method for controlling an external sensor through an audio interface of an electronic device according to one embodiment.

[0011] FIG. **1**A is a flowchart illustrating a method for controlling an external sensor through an audio interface of an electronic device according to another embodiment.

[0012] FIG. **1**B schematically illustrates an electronic device connected to control an example thermometer according to one embodiment.

[0013] FIG. **10** schematically illustrates an electronic device connected to control an example sphygmomanometer according to one embodiment.

[0014] FIG. **1**D schematically illustrates an electronic device connected to control an example spirometer according to one embodiment.

[0015] FIG. **1**E schematically illustrates an electronic device connected to control an example perineometer according to one embodiment.

[0016] FIG. **2** schematically illustrates an example system for controlling an electronic device to operate an external sensor connectable to an audio interface of the electronic device according to one embodiment.

[0017] FIG. **2**A schematically illustrates an example system for controlling an electronic device to operate an external sensor connectable to an audio interface of the electronic device according to another embodiment.

[0018] FIG. **3** schematically illustrates an example temperature sensor circuit according to one embodiment.

[0019] FIG. **3**A schematically illustrates an example control system for operating the temperature sensor according to one embodiment.

[0020] FIG. **3**B schematically illustrates an example control system for operating the temperature sensor according to one embodiment.

[0021] FIG. **3**C schematically illustrates example driving signals of the control system of FIG. **3**B.

[0022] FIG. **3**D schematically illustrates an example response signal of the control system of FIG. **3**B.

[0023] FIG. **4** schematically illustrates an example pressure sensor circuit for a sphygmomanometer or a spirometer according to one embodiment.

[0024] FIG. **4**A schematically illustrates an example control system for operating a sphygmomanometer sensor according to one embodiment.

[0025] FIG. **4**B is a graph showing example blood pressure output from a sphygmomanometer sensor operated through an audio interface according to one embodiment.

[0026] FIG. **4**C schematically illustrates an example control system for operating a spirometer sensor according to one embodiment.

[0027] FIG. **5** shows an example sphygmomanometry audio interface adaptor according to one embodiment.

[0028] FIG. **6** shows an example spirometry audio interface adaptor according to one embodiment.

[0029] FIG. **7** schematically illustrates an example electrocardiogram (ECG) sensor circuit according to one embodiment.

DETAILED DESCRIPTION

[0030] Generally, the present disclosure provides methods and systems for controlling external sensors through audio interfaces of electronic devices. Example embodiments are described herein with reference to hand held electronic devices such as smartphones or the like, but it is to be understood that the systems and methods described herein may be implemented in any type of electronic device with an audio interface and suitable signal generating and processing capabilities, including without limitation smartphones, feature phones, personal digital assistants, tablet computers, netbook computers, laptop computers, portable gaming systems, portable music players equipped with processors, desktop computers, or the like.

[0031] Performing medical sensor measurements with portable devices such as mobile phones is advantageous for purposes of recording and transmitting readings, providing power to the sensor, data storage, powerful processors for advanced analytics, ease of upgrade and addition of application features, as well as facilitating a better user interface. Enhanced user interaction is possible through the versatile input and output mechanisms of a mobile phone, allowing for example to input supporting patient information, to guide the patient for ensuring optimal sensor placement, and to provide a richer feedback with the results, including treatment options, graphing of historic data trends and other relevant context.

[0032] By providing sensors connected directly to a mobile phone or other electronic device, embodiments disclosed herein eliminate the need for many components of typical standalone devices for measuring vital signs or other physiological parameters (such as separate power sources, microcontrollers, custom displays, etc.), as their functions are inherent to the mobile phone itself. These embodiments reduce the complexity of the sensor design and lower the cost of sensor manufacture. Due to the relative ease of software upgrades, the application controlling the sensor can be incrementally improved and updated. Embodiments described herein are configured to take advantage of the near universality of the audio interface in modern electronic devices. Certain embodiments also leverage the relatively high level of standardization of audio jacks and jack plugs. Furthermore, the consumer grade audio codecs in many electronic devices use sophisticated signal converters to achieve resolutions of 16 bits (15 ppm) or more. This by far outperforms the converters found in most custom microcontroller implementations that typically have resolutions of 10 bits (1000 ppm). This hardware level improvement of almost 100 times in signal quality can be leveraged to significantly improve the accuracy of the sensor readings. In addition, standard audio input and output signal levels and impedance ranges are directly compatible with a wide range of sensor types. In particular certain embodiments use sensors comprising bridge circuits of passive components for measurements, such as is the case for pressure and temperature sensing as discussed below.

[0033] There is however a significant difference between the audio interface and typical sensor interfaces in that the audio signal channel is designed to operate strictly on AC signals, whereas conventional sensor interfaces rely on DC signals for sensor actuation and detection. While it is possible to use an audio signal line to transmit DC sensor signals by means of amplitude and/or frequency modulation of AC carrier signals that are encoded and decoded at each end of the audio channel, this would require the presence of additional converter electronics between the sensor and the phone audio connector, which would be detrimental to the purpose of using a phone or other electronic device for eliminating custom electronics, as well as reintroduce the need for a separate sensor power source.

[0034] The standard microphone connection of an audio interface such as a mobile phone headset jack outputs a small voltage, which is used to drive the electret microphones commonly found in headsets. This "microphone bias" is sufficient to drive a single transistor or single ultra-low power device, but not to power a typical full sensor interface or signal conversion circuit.

[0035] Certain embodiments fully leverage the advantages and capabilities of modern electronic devices by employing sensor control methods and systems that are inherently AC in nature, such that the sensor input and output can be connected directly to the audio channel without additional signal conversion or conditioning, and without the need for a power source other than the microphone bias. This requires a new approach to sensor actuation, signal detection and processing.

[0036] FIG. **1** shows an example method **100** for controlling an external sensor through an audio interface according to one embodiment. As described further below, method **100** may be executed by an electronic device to operate a variety of sensors, including without limitation thermometers, sphygmomanometers, perineometers, ECG and EEG monitors, and spirometers. In some embodiments, a sensor circuit is connected as an AC bridge across the contacts of an audio interface, and driving signals are applied to the arms of the bridge and adjusted to minimize a response signal detected from a central point of the bridge.

[0037] Method **100** comprises applying harmonic driving signals to a pair of contacts of the audio interface at block **102**. At block **104** a response signal received at another contact of the audio interface is measured. At block **105** method **100** determines whether the response signal is within a predetermined threshold of zero. If not, method **100** proceeds to adjust either one or both of the driving signals at block **106** to reduce the response signal. As one skilled in the art will appreciate, blocks **104**-**106** constitute a feedback loop for minimizing the response signal, may be executed substantially simultaneously, and may be implemented in a variety of ways.

[0038] When the response signal is minimized, method **100** proceeds to block **108**, where one or more physiological parameters are determined based on characteristics of the driving signals applied to minimize the response signal. In some embodiments, physiological parameters may be determined based on a ratio of the amplitudes of the applied driving signals. In some embodiments, method **100** may also comprise detecting small variations of the response signal, and determining physiological parameters based on variations of the response signal at block **108**. At block **109** the physiological parameter(s) are output to the patient and/or other user(s). For example, outputting physiological parameters may comprise displaying the physiological parameters on a display of the electronic device, generating audible signals with built-in speakers of the electronic device, generating a haptic signal, storing the physiological parameters in memory of the electronic device, sending the physiological parameters to one or more other devices using any suitable communication protocols available at the electronic device, passing the physiological parameters to another application through a programmatic interface, or any other form of output.

[0039] FIG. **1**A shows an example method **100**A for controlling an external sensor through an audio interface according to another embodiment. Method **100**A may be executed by an electronic device to operate a variety of sensors, including without limitation thermometers, sphygmomanometers, spirometers, EEG and ECG monitors, and perineometers. In some embodiments, such as shown in FIG. **3**B for the case of a thermometer, a sensor circuit is connected as an AC bridge across the contacts of an audio interface, and driving signals are applied to the arms of the bridge and adjusted by applying a predetermined amplitude profile to determine when a response signal detected from a central point of the bridge is minimized.

[0040] Method **100**A comprises applying harmonic driving signals to a pair of contacts of the audio interface at block **102**. At block **103**, the amplitude of one of the driving signals is adjusted according to a predetermined amplitude profile (e.g., a linear ramp as in the example of FIG. **3**C discussed below, or other predictably varying amplitude), and the amplitude of the other driving signal is held constant (e.g., at about % of the maximum amplitude as in the example of FIG. **3**C discussed below, or other substantially constant amplitude). At block **104** a response signal received at another contact of the audio interface is measured. As discussed further below, the time at which the response signal exhibits a local minimum is detected at block **104**, and from the timing of this local minimum in the response signal, the ratio of amplitudes of driving signals which caused the local minimum may be determined. At block **107** one or more physiological parameters are determined based on the timing of the local minimum in the response signal. At block **109** the physiological parameter(s) are output to the patient and/or other user(s) as discussed above with reference to method **100**.

[0041] FIGS. **1**B-E illustrate example embodiments wherein an electronic device **110** is used to operate a variety of external sensors. The examples of FIGS. **1**B-E are directed to thermometry, sphygmomanometry, spirometry, and perineometry applications but it is to be understood that other embodiments may be directed to other applications. For example, other types of sensors including, without limitation, electrocardiogram (ECG) and electroencephalogram (EEG) sensors may be connected to audio interfaces of electronic devices in other embodiments.

[0042] FIG. **1**B shows an electronic device **110** connected to an example thermometer **120** according to one embodiment. Thermometer **120** comprises a connector **122**, a cable **124** and a probe **126**. Cable **124** may advantageously provide a user with flexibility in placement of probe **126**, but is not required in all embodiments. For example, in some embodiments probe **126** may be directly attached to connector **122**, may be incorporated into connector **122**, or may be coupled to connector **122** by other means (e.g. coupled to a rigid or flexible member attached to connector **122**). Probe **126** comprises temperature sensing circuit elements which may be controlled by device **110** to obtain temperature readings, as described further below.

[0043] FIG. **1**C shows an electronic device **110** connected to an example sphygmomanometer **130** according to one embodiment. Sphygmomanometer **130** comprises a connector **132**, a pressure tube **134**, an inflatable cuff **136**, and a pressure source **138**. Pressure source **138** may be a hand-operated pump, as shown in the illustrated embodiment, or it may be a powered pump, or some other source of pressure. A leak valve **135** may be provided on tube **134**. Alternatively, a leak valve may be incorporated into connector **132**, as described further below, or elsewhere in the device, according to other embodiments. Cuff **136** may be wrapped around a patient's limb (e.g. arm) and pressure source **138** may be used to inflate cuff **136**, and the pressure in cuff **136** is communicated through tube **134** to a pressure sensor in connector **132**. The pressure sensor in connector **132** may be controlled by device **110** to measure variations in the pressure in cuff **136**, which may be analyzed to extract a variety of physiological parameters, including systolic, mean and diastolic blood pressure, respiratory rate, and heart rate, as described further below. The pressure sensor may also be situated elsewhere in the device, according to other embodiments. For example, the pressure sensor may be located closer to or at the cuff **136**, and connected to connector **132** by wiring.

[0044] FIG. **1**D shows an electronic device **110** connected to an example spirometer **140** according to one embodiment. Spirometer **140** comprises a connector **142**, a pair of pressure tubes **144** and **146**, and a breathing tube **148** having a partial obstruction **149** therein. Tubes **144** and **146** communicate pressures from opposite sides of obstruction **149** to a differential pressure sensor in connector **142**. Obstruction **149** is configured such that when a patient breathes through breathing tube **148** in the direction indicated by the arrows in FIG. **1**D, the pressure in tube **144** will be greater than the pressure in tube **146**. The differential pressure sensor in connector **142** may be controlled by device **110** to measure variations in the pressure across obstruction **149**, which may be analyzed to extract a variety of physiological parameters, including lung capacity and air flow measurements, as described further below.

[0045] FIG. **1**E shows an electronic device **110** connected to an example perineometer **150** according to one embodiment. Perineometer **150** comprises a connector **152**, a pressure tube **154**, and an inflatable member **156** which may be inserted into the vagina. Tube **154** communicates pressure from member **156** to a pressure sensor in connector **152**. Perineometer **150** may also optionally comprise another pressure tube **157** connecting a manually operable air bulb **158** to pressure tube **154**. The air bulb **158** may be used to inflate member **156**, and a pressure release valve **159** may be provided on pressure tube **157** to prevent over-inflation. The pressure sensor in connector **152** may be controlled by device **110** to measure variations in the pressure applied to member **156**, which may be analyzed to extract a variety of physiological parameters, including the strength of voluntary contractions of the pelvic floor muscles, as described further below. Alternatively, a mechanically compressible member may be provided in place of inflatable member **156**. The mechanically compressible member may comprise a strain gauge-type pressure sensor such as, for example, one or more piezoelectric or piezoresistive elements that are coupled to the audio interface of device **110** through connector **152** and suitable wiring.

[0046] FIG. **2** shows an example system **200** according to one embodiment. System **200** may be implemented in an electronic device **110** to control an audio interface **115** to operate an external sensor and process the response signals (which, when used as feedback to modify the driving signals, are conventionally referred to as "error signals", and are commonly sought to be minimized by the feedback process) from the sensor. In the illustrated embodiment, audio interface **115** comprises a TRRS (tip, ring, ring, sleeve) audio interface wherein the tip and first ring comprise speaker contacts SPK, the second ring comprises a ground contact GND, and the sleeve comprises a microphone contact MIC, but it is to be understood that different types of audio interfaces may be used. For example, some embodiments may use a TRRS audio interface with a different arrangement of contacts. Some embodiments may use a pair of TRS type interfaces (e.g., a speaker output interface and a microphone input interface). Some embodiments may use differently configured audio interfaces with a plurality of contacts for sending and receiving electrical signals. In the illustrated embodiment, system **200** comprises a driving signal generator **202** for applying harmonic driving signals to speaker contacts SPK, and a response signal detector **204** for detecting a response signal received at microphone contact MIC. An internal ground **206** is connected to ground contact GND.

[0047] Response signal detector **204** provides feedback to driving signal generator **202** for adjusting the driving signals to minimize the response signal. Driving signal generator **202** provides a physiological parameter extractor **208** with characteristics of the driving signals (e.g. phase and amplitude) that minimize the response signal. In some embodiments physiological parameter extractor **208** receives a balance signal indicating a ratio of amplitudes of the driving signals. In some embodiments physiological parameter extractor **208** may also receive one or more signals generated based on the response signal received by response signal detector **204**, as indicated by the dotted line connecting response signal detector **204** and physiological parameter extractor **208**. Physiological parameter extractor **208** determines one or more physiological parameters based on characteristics of the driving signals, and optionally based on the response signal, as described further below, and provides the determined physiological parameter(s) for output at output **210**.

[0048] FIG. **2**A shows an example system **200**A according to another embodiment, which may also be implemented in an electronic device **110** to control an audio interface **115** to operate an external sensor and process the response signals from the sensor. Similar to system **200** of FIG. **2**, system **200**A comprises a driving signal generator **202**A for applying harmonic driving signals to speaker contacts SPK, and a response signal detector **204**A for detecting a response signal received at microphone contact MIC, and an internal ground **206** is connected to ground contact GND. System **200**A differs from system **200** in that driving signal generator **202**A does not receive any feedback, but instead adjusts one of the driving signals in a pre-determined pattern. The pre-determined pattern may be fixed or may be selected according to some detected condition or signal. For example, if a specific characteristic of the response signal, such as a minimum value, were detected, a pre-determined pattern that narrows the range of amplitudes to sweep through to values immediate to the region where the minimum value occurred might be selected.

[0049] Response signal detector **204**A detects a local minimum in the amplitude of the response signal, and determines timing information thereof. The timing information of the local minimum in the response signal may be used by response signal detector **204**A in conjunction with predetermined characteristics of the driving signals to determine the ratio of driving signals that caused the local minimum, and the ratio of driving signals may be provided to physiological parameter extractor **208**A. Alternatively, the timing information may be provided directly to physiological parameter extractor in **208**A. Physiological parameter extractor **208**A determines one or more physiological parameters based on the signal from response signal detector **204**A, as described further below, and provides the determined physiological parameter(s) for output at output **210**. In other embodiments, other characteristics of the response signal including without limitation a maximum, an inflection point, or a specific non-zero value may be detected and provided to the physiological parameter extractor **208**A.

Example Thermometry Embodiments

[0050] A clinical thermometer is used to measure human body temperature. Body temperature reflects relative health, and a significantly elevated or lowered temperature can indicate illness. Conventional electronic clinical thermometers use a thermistor probe to measure temperature at a point that best approximates core body temperature, typically the mouth, armpit or rectum, and display the result with a resolution of typically 0.1 degrees. The accuracy of these devices is usually less, typically +/−0.2 degrees. Sufficiently accurate thermometers can be used to help predict female fertile periods by measuring basal body temperature (BBT). BBT is the lowest temperature reached while resting and is obtained in the morning after sleep. BBT typically peaks at least 0.4 degrees higher than normal over a 48-hour period when ovulation has occurred, and remains elevated until menstruation begins. A woman can use this method to predict ovulation by charting temperatures for several cycles to predict optimal likelihood of fertility. Accurate thermometers are also useful in a variety of other situations, as known in the art.

[0051] Certain embodiments provide low cost, robust and accurate thermometers which may be connected to audio interfaces of electronic devices. By eliminating all hardware for processing, storing, and displaying the measured temperature, and instead interfacing the thermistor directly to the audio port of a mobile phone or other portable electronic device, the complexity, cost and materials required for clinical grade thermometers can be significantly reduced.

[0052] FIG. **3** shows an example thermometer circuit **305** connected to two speaker contacts SPK and a microphone contact MIC of an electronic device **110**. A temperature sensitive circuit element **310** is connected between a first of the speaker contacts and the microphone contact MIC, and a reference circuit element **320** is connected between a second of the speaker contacts SPK and the microphone contact MIC. In some embodiments, circuit **305** may include only a single thermistor as temperature sensitive circuit element **310** and a single reference resistor as reference circuit element **320**. Such an arrangement would advantageously minimize the cost of circuit **305**. However, it is to be understood that additional components may be included in other embodiments, such as for example, one or more additional resistors or thermistors connected in series or parallel. In some embodiments, circuit **305** may also comprise a ground connection **330**, as shown in FIG. **3**A.

[0053] FIG. **3**A shows an example control system **300** for obtaining temperature measurements with thermometer circuit **305**. Control system **300** comprises signal sources **340**A and **340**B which drive contacts of the audio interface (e.g. the left and right audio output ports) with harmonic driving signals D_1 and D_2 of a selected frequency, typically in the range from about 100 Hz to about 10000 Hz. A response cancellation block **350** adjusts the amplitude of one (or both) of these signals until the response signal RES recorded by the microphone input is at a minimum. Response cancellation block **350** may also adjust the phase of one (or both) of the driving signals, for example to compensate for impedances of elements **310** and **320**. The ratio of the amplitudes of the driving signals $A(D_1)/A(D_2)$, which is proportional to the ratio of the resistances of elements **310** and **320**, is provided to a temperature calculation block **360** for determining the temperature.

[0054] With reference to an example embodiment comprising only two electrical components, they may be a thermistor having a variable resistance R and a reference resistor having a known resistance R_{ref}. The reference resistor may be chosen to have a resistance close to that of the thermistor at a desired temperature. The desired temperature may vary depending on the intended use of the thermometer. For example, in some embodiments the desired temperature may be about room temperature, about body temperature, or anywhere in between. The ratio of driving amplitudes $A(D_1)/A(D_2)$ is now equivalent to the balance of resistances b ($b=R/R_{ref}$) and the temperature can be determined from:

$$T = \left\{\frac{1}{\beta}\ln\left(\frac{R}{R_0} + \frac{1}{T_0}\right)\right\}^{-1}$$

where T is the temperature in Kelvin, $R=bR_{ref}$ the thermistor resistance at the measured temperature, R_0 is the resistance of the thermistor at a reference Kelvin temperature T_0, and β is the thermal material constant of the thermistor. By nature of the null-detector arrangement the output and input gain of the mobile device does not enter the measurement.

[0055] Balancing of the driving signals in embodiments such as the example of FIG. **3**A can be achieved by any suitable method, including those known in the art. An example embodiment uses a Widrow-Hoff least mean square approach as set out in the following pseudo-code:

```
Input : Time in seconds time, microphone input signal input
Output: Audio output signals output1, output2
ω: Audio signal angular frequency
converge: Bridge convergence factor
balance[2]: Audio bridge quadrature balance
begin
  | s = sin(ω × time)
  | c = cos(ω × time)
  | output1 = s
  | output2 = balance[0] × s + balance[1] × c
  | balance[0] = balance[0] − converge × input × s
  | balance[1] = balance[1] − converge × input × c
end
```

[0056] The bridge convergence factor is determined based on electrical noise and latency at the audio interface of the electronic device used to implement the control system. If for example the convergence factor is too large, the adjusted driving signal applied to one of the outputs of the audio interface may oscillate or diverge in an unstable manner.

[0057] In addition to ultra-low cost, an additional benefit of temperature sensors according to embodiments with control systems such as the example of FIG. **3**A is that the audio interface has high resolution, and the precision of the temperature measurement is on the order of 0.01 degrees, significantly better than many conventional standalone thermometers. This makes thermometers according to such embodiments practical for basal body and a variety of other temperature measurements.

[0058] A dynamic temperature sensing control system such as system **300** of FIG. **3**A advantageously provides a continuous update of the temperature values. However, such a system can be sensitive to latency and synchronicity of the audio output and input signals. As such, a dynamic temperature sensing control system or method that relies on response signal feedback can be adversely affected when implemented in electronic devices with poor, variable or unknown audio capabilities. In such cases a control system or method that works without the use of feedback can be desirable.

[0059] The temperature should preferably be assessed from the measurement of the bridge balance point, as otherwise gain factors and non-linearities in the audio signal channels will affect the readings. Without using any feedback, a control system may perform a sweep to determine the minimum balance point. This can be done with a variety of waveform amplitude shapes, constructed such that the beginning of the sweep can be determined without knowledge of the phase relationship between the input and the output signals. In some embodiments, such control systems are operable to measure temperature with a precision on the order of 0.1 degrees. An example of such a control system is discussed below with reference to FIGS. **3**B-D.

[0060] FIG. **3**B shows an example control system **300**A for obtaining temperature measurements with thermometer circuit **305**. Control system **300**A comprises signal sources **340**A and **340**B which drive contacts of the audio interface (e.g. the left and right audio output ports) with harmonic driving signals D_1 and D_2 of a selected frequency, for example in the range from about 1000 Hz to about 5000 Hz. Driving signal D_1 is applied with substantially constant amplitude as shown in the left plot of FIG. **3**C. The amplitude of driving signal D_1 may, for example, be about one half of a maximum amplitude that can be applied to the audio output contacts. Driving signal D_2 is initially applied with a substantially constant amplitude, then at time t_1 the amplitude of driving signal D_2 is adjusted to the maximum amplitude then ramped linearly downwardly to a minimum amplitude (e.g. 0) at time t_2, after which it returns to the substantially constant amplitude as shown in the right plot of FIG. **3**C. The linear ramp shown in the right plot of FIG. **3**C may be provided in driving signal D_2 periodically, and/or in response to a signal to initiate a temperature measurement.

[0061] A linear ramp is provided in the example amplitude profile shown in FIG. **3**C, but other embodiments may provide different amplitude profiles. For example, in some embodiments the amplitude of one of the driving signals may sweep through less than the full range of amplitudes that can be applied to the audio output contacts. In some embodiments, instead of a linear ramp the amplitude may vary logarithmically, exponentially, or in another defined pattern.

[0062] The resulting response signal RES received at the microphone input is shown in FIG. **3**D, and is characterized by a local minimum at time t_{min} with peaks on either side at times t_1 and t_2. A response measurement block **350**A detects the initial spike in the response signal at time t_1 and a local minimum at time t_{min}. The response measurement block **350**A determines the ratio of the amplitudes of the driving signals $A(D_1)/A(D_2)$ based on the relative timings of the minimum at t_{min} and the initial spike at t_1 (or alternatively, based on the relative timings of the minimum at t_{min} and the trailing spike at t_2). The ratio of the amplitudes of the driving signals $A(D_1)/A(D_2)$ is provided to a temperature calculation block **360** for determining the temperature as discussed above. Alternatively, the relative timings of the minimum and one or both of the spikes may be provided directly to the temperature calculation block.

[0063] The frequency of the driving signals in the FIG. **3**C example are preferably about 1000-5000 Hz, and the linear ramp shown in the right plot of FIG. **3**C preferably has a duration of about 0.05 to 0.5 seconds. Such driving signals allow multiple sets of data points to be obtained within one second. A stable temperature reading may thus be extracted by basic filtering such as, for example, moving average or median filtering, combinations thereof, finite impulse response (FIR) filtering, infinite impulse response (IIR) filtering, etc.

[0064] The temperature of a probe with a temperature sensitive element takes some time to reach equilibrium with the temperature of an area of the body it is in contact with. In some embodiments, predictive algorithms may be used to predict the temperatures, as disclosed for example in U.S. Pat. No. 7,318,004.

Example Sphygmomanometry, Spirometry, and Perineometry Embodiments

[0065] A sphygmomanometer is a widely used device for the measurement of blood pressure, composed of an inflatable cuff to restrict blood flow, and a mercury or mechanical manometer to measure the pressure. Manual and semi-automatic devices are typically inflated with a bulb, while automated (digital) models typically use motorized inflation/deflation and read the pressure with an electronic sensor. Pressure measurements by sphygmomanometer may be used to determine a variety of physiological parameters relating to cardiovascular blood circulation including mean, systolic and diastolic blood pressure and heart rate. They may also be used to measure other physiological parameters such as respiration rate.

[0066] A spirometer is a widely used device used to measure various air flow characteristics of a patient's breathing. A typical spirometer functions as a flow meter that measures inspired and expired air volume over time. Spirometry may, for example, be used to measure a variety of respiratory parameters. Example measurements include:

[0067] TLC Total lung capacity: the volume of air in the lungs at maximal inflation

[0068] RV Residual volume: the volume of air remaining in the lungs after a maximal exhalation.

[0069] ERV Expiratory reserve volume: the maximal volume of air that can be exhaled from the end-expiratory position

[0070] IRV Inspiratory reserve volume: the maximal volume of air that can be inhaled from the end-inspiratory level

[0071] IC Inspiratory capacity: the sum of IRV and TV

[0072] IVC Inspiratory vital capacity: the maximum volume of air inhaled from the point of maximum expiration

[0073] VC Vital capacity: the volume equal to TLC-RV

[0074] VT Tidal volume: that volume of air moved into or out of the lungs during quiet breathing

[0075] FRC Functional residual capacity: the volume in the lungs at the end-expiratory position

[0076] RV/TLC % Residual volume expressed as percent of TLC

[0077] VA Alveolar gas volume

[0078] VL Actual volume of the lung including the volume of the conducting airway.

[0079] FVC Forced vital capacity: (e.g. from a maximally forced expiratory effort)

[0080] FEV1 Volume that has been exhaled at the end of the first second of forced expiration

[0081] FEFx Forced expiratory flow related to some portion of the FVC curve;

[0082] FEFmax The maximum instantaneous flow achieved during a FVC maneuver

[0083] FIF Forced inspiratory flow

[0084] PEF The highest forced expiratory flow measured with a peak flow meter

[0085] MVV Maximal voluntary ventilation: volume of air expired in a specified period during repetitive maximal effort.

[0086] A perineometer is a device for measuring voluntary contractions of the pelvic floor muscles. Perineometers may be used to measure the air pressure variations from an inflatable bladder, bulb or tube inserted into the vagina, or the mechanical strain variations from a strain gauge in a mechanically compressible member inserted into the vagina. Perineometric measurements may be used for such purposes as Kegel exercises or similar muscular function measurements. The sensor measurement data is then analyzed to determine the strength of the muscular contractions and other physiological parameters. In other embodiments, the strength of contractions of various other muscles may be measured by configuring air pressure or mechanical strain gauge sensors in a variety of devices that may be appropriately squeezed or compressed, including without limitation grips that measure forearm strength at the hand.

[0087] Example embodiments disclosed herein eliminate the need for conventional custom electronics of a digital sphygmomanometer, spirometer or perineometer by providing methods and systems for operating pressure sensors connectable to an electronic device such as a smartphone or media player by interfacing a pressure sensor directly through the audio interface of the device. Some embodiments use a commercially available pressure sensor comprising a piezoresistive bridge, which is operated in AC mode at standard audio signal levels, as described further below.

[0088] FIG. **4** shows an example pressure sensor **410** connected to two speaker contacts SPK, a microphone contact MIC and a ground contact of an electronic device **110**. Pressure sensor **410** may, for example, comprise a piezoresistive bridge configured to measure any of gauge, differential and/or absolute pressure. Pressure sensor **410** may, for example comprise a commercially available piezoelectric pressure sensor (such as, for example, a MPX2010 Series Pressure Sensor from Freescale Semiconductor, Inc., or a 2SMPP MEMS Gauge Pressure Sensor from Omron Electronic Components LLC). Such pressure sensors are specified to be provided with DC supply voltage, but may be operated by providing them with harmonic driving signals D_1 and D_2 and measuring a response signal RES through the audio interface as described below. In some embodiments, systems used to process the signal from the pressure sensor comprise an AC auto-balancing bridge that continuously adjusts the amplitude and phase relationship of the two audio output channels in order to minimize the bridge response signal at the microphone input, and a dual-phase lockin-amplifier that does phase-locked detection of the response signal itself.

[0089] FIG. **4**A shows an example control system **400** for obtaining blood pressure measurements with a piezoelectric pressure sensor **410**A comprising a first pair of elements **412** and **414** connected to receive driving signal D_1 and a second pair of elements **416** and **418** connected received driving signal D_2. Control system **400** comprises signal sources **420**A and **420**B which drive contacts of the audio interface (e.g. the left and right audio output ports) with harmonic signals D_1 and D_2 of a selected frequency, typically in the range from about 100 Hz to about 10000 Hz.

[0090] A response cancellation block **430** receives a response signal from sensor **410**A and controls signal sources **420**A and/or **420**B to minimize the response signal. The response signal is also multiplied by one of the driving signals (D_1 in the illustrated embodiment) and a phase shifted driving signal (generated by phase shift block **425**) by multipliers **440**A and **440**B, respectively. The multiplied response signals are low pass filtered at filter blocks **450**A and **450**B, and then provided as a response input to a blood pressure extraction block **460**. Blood pressure extraction block **460** is also provided with a balance input (e.g., the ratio of amplitudes of the driving signals) from response cancellation block **430**.

[0091] At blood pressure extraction block **460**, the balance input can be used to determine the absolute pressure at any given time. Lock-in amplification of the response signal may be used to provide a high resolution reading of the blood pressure modulation.

[0092] FIG. **4**B is a graph showing exemplary output of blood pressure modulation which may be measured by a system such as system **400**, with the solid trace (labeled 'A' in the legend of FIG. **4**B) showing the in-phase component of an example lock-in amplified response signal, and the dashed trace (labeled 'B' in the legend of FIG. **4**B) showing the out-of-phase component of the example lock-in amplified response signal. The systolic, mean and diastolic blood pressure as well has the heart rate can be extracted from this output using standard published techniques. Other physiological parameters such as respiration rate may also be extracted.

[0093] A system such as system **400** of FIG. **4**A may also be connected to a differential pressure sensor for spirometry applications, with blood pressure extraction block **460** replaced or supplemented with an air flow and/or air volume calculation block configured to determine various respiratory parameters. Alternatively, a differential pressure sensor **410**C may be coupled to a simplified control system **470** as shown in FIG. **4**C for measurement of airflow. Control system **470** comprises a pair of signal sources **475**A and **475**B and a response cancellation block **480** which may be substantially similar to sources **340**A and **340**B and block **350** discussed above with respect to FIG. **3**A, and as such will not be described again. Control system **470** also comprises a flow/volume calculation block **490** which is configured to determine various respiratory parameters from the ratio of driving amplitudes $A(D_1)/A(D_2)$.

[0094] A system such as system **470** of FIG. **4**C may also be connected to a pressure sensor coupled to an inflatable member or within a mechanically compressible member for perineometry applications, with flow/volume calculation block **490** replaced or supplemented with a calculation of the strength of voluntary muscle contractions in the patient based on the pressure sensor readings.

[0095] In an alternate embodiment, the perineometry sensor may comprise a strain gauge within a mechanically compressible member. The strain gauge sensor registers the degree of mechanical strain imposed by the muscular contractions. Strain gauges may be implemented in a variety of forms including mechanical, electrically resistive or capacitive, piezoresistive, fiber-optical, as well as other implementations of similar functionality. Strain gauge sensors may be implemented in an analogous manner as an air pressure sensor in a circuit similar to FIG. **4**.

[0096] In example embodiments the stereo audio output is used to apply an AC voltage across the bridge of a sensor and the bridge response signal is recorded by the microphone input. No additional components are needed in these circuits. Methods and systems disclosed herein make it possible to replace the manometer of a conventional sphygmomanometer, or the sensor circuitry of a spirometer, with a small and inexpensive adaptor that plugs directly into the audio interface of a mobile or other electronic device.

[0097] FIG. **5** shows an example sphygmomanometry audio interface adaptor **500** according to one embodiment, and FIG. **6** shows an example spirometry audio interface adaptor **600** according to one embodiment. The adaptor **500** of FIG. **5** could also be used with a perineometer having an inflatable member, with or without the leak valve **550**. Each of adaptors **500** and **600** comprise a standard TRRS-type audio plug **510** or **610** at one end. It is to be understood that different types of audio interface connectors may be used in other embodiments, as discussed above. Each of adaptors **500** and **600** also comprise a housing **520**/**620** containing a pressure sensor **530**/differential pressure sensor **630**. Pressure sensor **530** and differential pressure sensor **630** are directly wired to plugs **510** and **610**, respectively, in the illustrated embodiments.

[0098] Adaptor **500** of FIG. **5** comprises a passage **540** in fluid communication with a pressure sensitive area of sensor **530**. A tube connector **542** (e.g., a ¼ inch barbed hose adapter) may be provided to facilitate coupling a pressure tube connected to a cuff (not shown) to passage **540**. Adaptor **500** may also comprise a leak valve **550** for allowing air to leave the pressure tube. While motorized pump inflation/deflation of the cuff is convenient, it consumes considerable power that would require a separate power source. For this reason a scheme of fixed bleed deflation has been implemented, wherein the cuff is manually inflated to a point higher than the systolic pressure of the subject, and a leak valve is then used to slowly ramp the pressure through the clinically relevant regime. Alternatively, a leak valve may be provided in the pressure tube. In other embodiments, the pressure sensor may be located outside the audio jack plug adaptor **500**, as for example when the sensor may be connected to the jack plug or other adaptor via an electrical cable or other means.

[0099] Adaptor **600** of FIG. **6** comprises a pair of passages **640**A and **640**B in fluid communication with a pair of pressure sensitive areas of sensor **630**. Tube connectors **642** (e.g., ¼ inch barbed hose adapters) may be provided to facilitate coupling pressure tubes **650**A and **650**B to passages **640**A and **640**B, respectively. Pressure tubes **650**A and **650**B are in fluid communication with a breathing tube **660** on opposite sides of a partial obstruction **670** as described above.

Other Embodiments

[0100] The example embodiments discussed above are directed thermometry, sphygmomanometry, spirometry, and perineometry applications, but it is to be understood that other embodiments may be directed to other applications. For example, other types of sensors, including without limitation ECG sensors and EEG sensors, may be connected to audio interfaces of electronic devices in other embodiments.

[0101] FIG. **7** schematically illustrates an example electrocardiograph (ECG) sensor **700** connected to contacts of an electronic device **110** according to one embodiment. Sensor **700** comprises leads **701**, **702**, **703**, and **704** (e.g. electrodes) which are coupled to a patient's body. Amplification circuits **710** and **712** are connected to leads **701**-**704** for measuring the differential voltage between the leads. In particular, circuit **710** generates a response signal **711** based on the differential voltage between leads **701** and **702**, and circuit **712** generates a response signal **713** based on the differential voltage between leads **703** and **704**. Response signals **711** and **713** are provided to transistors **716** and **718**, respectively. Harmonic driving signals D_1 and D_2 generated by the audio output ports (for example, at a frequency in the range 100 Hz-100 kHz) are also respectively provided to transistors **716** and **718**, where the driving signals D_1 and D_2 are modulated with the response signals **711** and **713**. The resulting superposed modulated signals are received as a response signal at the microphone input, and the response signal is demodulated by a software-implemented control system to recover the original ECG waveforms. Such an arrangement overcomes the limiting audio system high-pass input filter, which will otherwise distort a low-frequency signal like an ECG waveform which may be typically 0.1 Hz to 50 Hz. Some systems in the prior art may utilize modulation of the original ECG signal to enable it to be carried through an analog system. However, they typically generate the modulation frequency within the sensor and do not drive the modulation circuit with the audio system. A similar implementation may be used for operating an EEG sensor to receive EEG signals through the audio system.

[0102] Although example embodiments have been described herein with the reference to the accompanying drawings, it is to be understood that the invention is not limited to those exact constructions and operations, and that various other changes and modifications may be made by one skilled in the art without departing from the scope or spirit of the invention.

[0103] Embodiments of the invention may be implemented using specifically designed hardware, configurable hardware, programmable data processors configured by the provision of software (which may optionally comprise 'firmware') capable of executing on the data processors, special purpose computers or data processors that are specifically programmed, configured, or constructed to perform one or more steps in a method as explained in detail herein and/or combinations of two or more of these. Examples of specifically designed hardware are: logic circuits, application-specific integrated circuits ("ASICs"), large scale integrated circuits ("LSIs"), very large scale integrated circuits ("VLSIs") and the like. Examples of configurable hardware are: one or more programmable logic devices such as programmable array logic ("PALs"), programmable logic arrays ("PLAs") and field programmable gate arrays ("FPGAs"). Examples of programmable data processors are: microprocessors, digital signal processors ("DSPs"), embedded processors, graphics processors, math co-processors, general purpose computers, server computers, cloud computers, mainframe computers, computer workstations, and the like. For example, one or more data processors in a control circuit for a device may implement methods as described herein by executing software instructions in a program memory accessible to the processors.

[0104] Processing may be centralized or distributed. Where processing is distributed, information including software and/or data may be kept centrally or distributed. Such information may be exchanged between different functional units by way of a communications network, such as a Local Area Network (LAN), Wide Area Network (WAN), or the Internet, wired or wireless data links, electromagnetic signals, or other data communication channel.

[0105] For example, while processes or blocks are presented in a given order, alternative examples may perform routines having steps, or employ systems having blocks, in a different order, and some processes or blocks may be deleted, moved, added, subdivided, combined, and/or modified to provide alternative or sub-combinations. Each of these processes or blocks may be implemented in a variety of different ways. Also, while processes or blocks are at times shown as being performed in series, these processes or blocks may instead be performed in parallel, or may be performed at different times.

[0106] In addition, while elements are at times shown as being performed sequentially, they may instead be performed simultaneously or in different sequences. It is therefore intended that the following claims are interpreted to include all such variations as are within their intended scope.

[0107] In some embodiments, the invention may be implemented in software. For greater clarity, "software" includes any instructions executed on a processor, and may include (but is not limited to) firmware, resident software, microcode, and the like. Both processing hardware and software may be centralized or distributed (or a combination thereof), in whole or in part, as known to those skilled in the art. For example, software and other modules may be accessible via local memory, via a network, via a browser or other application in a distributed computing context, or via other means suitable for the purposes described above.

[0108] Software and other modules may reside on servers, workstations, personal computers, tablet computers, data encoders, data decoders, PDAs, mobile phones, media players, and other devices suitable for the purposes described herein. Those skilled in the relevant art will appreciate that aspects of the system can be practiced with any suitable communications, data processing, or computer system configurations, including: Internet appliances, hand-held devices (including personal digital assistants (PDAs)), wearable computers, all manner of cellular or mobile phones, multi-processor systems, microprocessor-based or programmable consumer electronics (e.g., video projectors, audio-visual receivers, displays, such as televisions, and the like), set-top boxes, network PCs, mini-computers, mainframe computers, and the like.

[0109] Where a component (e.g. a software module, processor, controller, assembly, device, circuit, etc.) is referred to above, unless otherwise indicated, reference to that component (including a reference to a "means") should be interpreted as including as equivalents of that component any component which performs the function of the described component (i.e., that is functionally equivalent), including components which are not structurally equivalent to the disclosed structure which performs the function in the illustrated exemplary embodiments of the invention.

[0110] Embodiments of the disclosure can be represented as a computer program product stored in a machine-readable medium (also referred to as a computer-readable medium, a processor-readable medium, or a computer usable medium having a computer-readable program code embodied therein). The machine-readable medium can be any suitable tangible, non-transitory medium, including magnetic, optical, or electrical storage medium including a diskette, compact disk read only memory (CD-ROM), memory device (volatile or non-volatile), or similar storage mechanism. The machine-readable medium can contain various sets of instructions, code sequences, configuration information, or other data, which, when executed, cause a processor to perform steps in a method according to an embodiment of the disclosure. Those of ordinary skill in the art will appreciate that other instructions and operations necessary to implement the described implementations can also be stored on the machine-readable medium. The instructions stored on the machine-readable medium can be executed by a processor or other suitable processing device, and can interface with circuitry to perform the described tasks.

[0111] Specific examples of systems, methods and apparatus have been described herein for purposes of illustration. These are only examples. The technology provided herein can be applied to systems other than the example systems described above. Many alterations, modifications, additions, omissions and permutations are possible within the practice of this invention. This invention includes variations on described embodiments that would be apparent to the skilled addressee, including variations obtained by: replacing features, elements and/or steps with equivalent features, elements and/or steps; mixing and matching of features, elements and/or steps from different embodiments; combining features, elements and/or steps from embodiments as described herein with features, elements and/or steps of other technology; and/or omitting features, elements and/or steps from described embodiments.

[0112] It is therefore intended that the following appended claims and claims hereafter introduced are interpreted to include all such modifications, permutations, additions, omissions and sub-combinations as may reasonably be inferred. The scope of the claims should not be limited by the preferred embodiments set forth in the examples, but should be given the broadest interpretation consistent with the description as a whole. In the preceding description, for purposes of explanation, numerous details are set forth in order to provide a thorough understanding of the embodiments. However, it will be apparent to one skilled in the art that these specific details are not required. In other instances, well-known electrical structures and circuits are shown in block diagram form in order not to obscure the understanding. For example, specific details are not provided as to whether the embodiments described herein are implemented as a software routine, hardware circuit, firmware, or a combination thereof.

[0113] The above-described embodiments are intended to be examples only. Alterations, modifications and variations can be effected to the particular embodiments by those of skill in the art without departing from the scope, which is defined solely by the claims appended hereto.

What is claimed is:

1. A method for controlling an electronic device to operate an external sensor connectable to an audio interface of the electronic device, the audio interface comprising a plurality of contacts, the method comprising:

applying a first harmonic driving signal to a first contact and a second harmonic driving signal to a second contact of the audio interface for driving the external sensor;

receiving a response signal at a third contact of the audio interface;

adjusting at least one of the first and second harmonic driving signals;

determining one or more physiological parameters based on characteristics of the first and second harmonic driving signals and the response signal; and

outputting the determined one or more physical parameters.

2. A method according to claim **1** wherein adjusting comprises providing feedback based on the response signal for modifying one of the driving signals to minimize the response signal.

3. A method according to claim **1** wherein adjusting comprises maintaining a substantially constant amplitude of the first driving signal while sweeping an amplitude of the second harmonic driving signal through a predetermined range.

4. A method according to claim **3** wherein sweeping the amplitude comprises sweeping through a range between a maximum amplitude of the audio interface and zero, and the substantially constant amplitude is about one half of the maximum amplitude.

5. A method according to claim **3** wherein sweeping comprises linearly ramping the amplitude.

6. A method according to claim **3** comprising determining a ratio of driving signals based on timing information of a local minimum in the received response signal.

7. A method according to claim **3** wherein the external sensor comprises a temperature sensor, comprising determining a temperature based on the timing information of the local minimum in the received response signal.

8. A method according to claim **1** wherein the external sensor comprises a temperature sensor, comprising determining a temperature based on a ratio of amplitudes of the driving signals.

9. A method according to claim **7** wherein the temperature sensor consists essentially of a thermistor and a reference resistor.

10. A method according to claim **1** wherein the external sensor comprises a pressure sensor.

11. A method according to claim **10** comprising multiplying the response signal by one of the driving signals and a phase shifted version of one of the driving signals to generate a response input and determining one or more physiological parameters based on the response input.

12. A method according to claim **11** comprising determining mean blood pressure, systolic blood pressure, diastolic blood pressure, and/or heart rate based on the response input and a ratio of amplitudes of the driving signals.

13. A method according to claim **10** wherein the pressure sensor is coupled to receive pressure from an inflatable member.

14. A method according to claim **10** wherein the pressure sensor is within a mechanically compressible member.

15. A method according to claim **13** comprising determining a strength of muscular contractions based on a ratio of amplitudes of the driving signals.

16. A method according to claim **10** wherein the pressure sensor comprises a differential pressure sensor.

17. A method according to claim **11** wherein the pressure sensor comprises a differential pressure sensor, comprising determining respiratory parameters based on the response input and a ratio of amplitudes of the driving signals.

18. A system for controlling an electronic device to operate an external sensor connectable to an audio interface of the electronic device, the audio interface comprising a plurality of contacts, the system comprising:

- a driving signal generator for applying a first harmonic driving signal to a first contact and a second harmonic driving signal to a second contact of the audio interface for driving the external sensor and adjusting at least one of the first and second harmonic driving signals;
- a response signal detector for receiving a response signal at a third contact of the audio interface;
- a physiological parameter extractor for determining one or more physiological parameters based on characteristics of the first and second harmonic driving signals and the response signal; and
- an output for outputting the determined one or more physical parameters.

19. A system according to claim **18** wherein the driving signal generator receives feedback based on the response signal for modifying one of the driving signals to minimize the response signal.

20. A system according to claim **19** wherein the driving signal generator maintains a substantially constant amplitude of the first driving signal while sweeping an amplitude of the second harmonic driving signal through a predetermined range.

21. A system according to claim **20** wherein the driving signal generator sweeps the amplitude of the second harmonic driving signal through a range between a maximum amplitude of the audio interface and zero, and the substantially constant amplitude is about one half of the maximum amplitude.

22. A system according to claim **20** wherein the driving signal generator sweeps the amplitude of the second harmonic driving signal by linearly ramping the amplitude.

23. A system according to claim **20** wherein one of the response signal detector and the physiological parameter extractor determines a ratio of driving signals based on timing information of a local minimum in the received response signal.

24. A system according to claim **20** wherein the external sensor comprises a temperature sensor, wherein the physiological parameter extractor determines a temperature based on the timing information of the local minimum in the received response signal.

25. A system according to claim **18** wherein the external sensor comprises a temperature sensor, wherein the physiological parameter extractor determines a temperature based on a ratio of amplitudes of the driving signals.

26. A system according to claim **24** wherein the temperature sensor consists essentially of a thermistor and a reference resistor.

27. A system according to claim **18** wherein the external sensor comprises a pressure sensor.

28. A system according to claim **27** wherein the response signal detector multiplies the response signal by one of the driving signals and a phase shifted version of one of the driving signals to generate a response input and the physiological parameter extractor determines one or more physiological parameters based on the response input.

29. A system according to claim **28** wherein the physiological parameter extractor determines mean blood pressure, systolic blood pressure, diastolic blood pressure, and/or heart rate based on the response input and a ratio of amplitudes of the driving signals.

30. A system according to claim **27** wherein the pressure sensor is coupled to receive pressure from an inflatable member.

31. A system according to claim **27** wherein the pressure sensor is within a mechanically compressible member.

32. A system according to claim **30** wherein the physiological parameter extractor determines a strength of muscular contractions based on a ratio of amplitudes of the driving signals.

33. A system according to claim **27** wherein the pressure sensor comprises a differential pressure sensor.

34. A system according to claim **28** wherein the pressure sensor comprises a differential pressure sensor, wherein the physiological parameter extractor determines respiratory parameters based on the response input and a ratio of amplitudes of the driving signals.

35. A thermometer for connecting to an audio interface of an electronic device, the thermometer comprising:

- a jack plug having first and second contacts for receiving first and second harmonic driving signals from the electronic device and a third contact for returning a response signal to the electronic device; and
- a temperature sensor consisting essentially of a thermistor connected between the first and third contacts and a reference resistor connected between the second and third contacts.

36. An adaptor for connecting to an audio interface of an electronic device, the adaptor comprising:

- a jack plug having first and second contacts for receiving first and second harmonic driving signals from the electronic device and a third contact for returning a response signal to the electronic device; and,
- a pressure sensor having a pressure sensitive area, the pressure sensor connected as a bridge across the first and second contact to provide the response signal to the third contact, between the first and third contacts and a reference resistor connected between the second and third contacts.

37. An adaptor according to claim **36** comprising a housing encasing the pressure sensitive area and having a passage in fluid communication with the pressure sensitive area.

38. An adaptor according to claim **37** wherein the pressure sensor comprises a differential pressure sensor having two pressure sensitive areas, and wherein the housing has two passages, with one passage connected to each of the pressure sensitive areas.

39. An adaptor according to claim **37** wherein the housing comprises a tube connector for coupling the passage to a pressure tube.

40. An adaptor according to claim **36** comprising a mechanically compressible member, wherein the pressure sensor is contained within the mechanically compressible member.

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专利名称(译)	用于确定生理参数的系统，方法和相关设备		
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摘要(译)

提供了用于控制电子设备以通过将第一谐波驱动信号施加到第一触点并且将第二谐波驱动信号施加到第二触点的第二触点来操作可连接到电子设备的音频接口的外部传感器的方法，系统和相关设备。用于驱动外部传感器的音频接口，在音频接口的第三触点处接收响应信号，调整第一和第二谐波驱动信号中的至少一个，基于第一和第二谐波驱动的特性确定一个或多个生理参数信号和响应信号，并输出确定的一个或多个生理参数。