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(54) **Title:** DUAL PRESSURE SENSOR SIGNAL CHAIN TO REMOVE MUTUALLY-COUPLED MRI INTERFERENCE

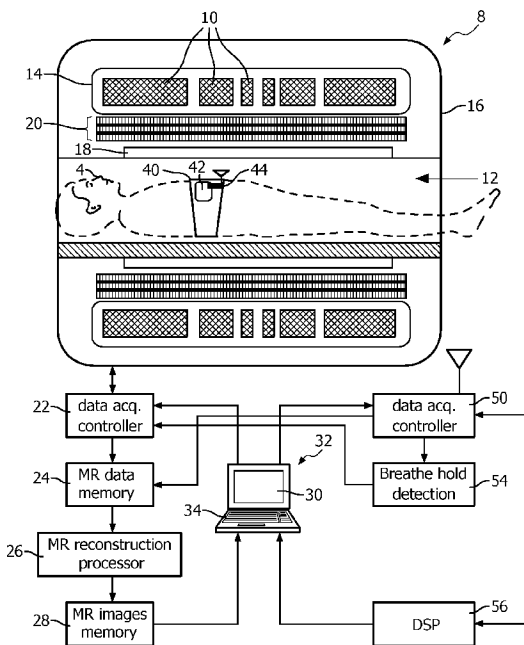


FIG. 1

(57) **Abstract:** Apparatus and methods provide a physiological status sensing device (40) for sensing a physiological status of a patient (4) and minimizing an amount of interference (78) generated during a magnetic resonance (MR) scan by a magnetic resonance (MR) system (8). The device (40) includes a first, active sensor (64) located to sense the physiological status and experience MR scan related interference and to generate a first signal (80) having a physiological status component (76) and an interference component (78). A second non-active sensor (70) is located closely adjacent to the first sensor (64) to experience substantially the same MR scan related interference (78) as the first sensor (64) and generate a second signal (82) having only the interference component (78). A circuit or processor (56, 84, 110, 116) subtractively combines the first (80) and second signals (82) to cancel the interference component (78).

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## DUAL PRESSURE SENSOR SIGNAL CHAIN TO REMOVE MUTUALLY- COUPLED MRI INTERFERENCE

### DESCRIPTION

The following relates to the medical arts, magnetic resonance arts, physiological monitoring arts, and related arts. It finds application in magnetic resonance imaging and other magnetic resonance applications that are beneficially monitored by electrocardiography, and the like.

When a patient is undergoing a magnetic resonance imaging (MRI) scan procedure, the patient is position in a static magnetic field ( $B_0$ ), e.g., inside the bore of the MRI scanner. Radiofrequency fields ( $B_1$ ), and gradient magnetic field pulses ( $G_x$ ,  $G_y$ ,  $G_z$ ) are applied and directed at the patient to induce resonance, spatially localize resonance signals, and the like. Electro medical devices inside or near the MRI bore, such as patient monitors and life support devices, are exposed to these types of fields. The  $B_0$  field acts as a strong electromagnet that attracts ferromagnetic objects towards the magnet. The  $B_0$  field is typically present as long as the magnet is powered (even when scans are not being performed). In addition, the  $B_1$  field is generated by an RF coil that emits radiofrequency waves into free space at frequencies related by the Larmor equation. These frequencies are, for example, approximately 64 MHz and 128 MHz for 1.5T and 3.0T magnets, respectively. The gradient fields are generated by gradient coils that momentarily alter the static magnetic field ( $B_0$ ) to produce a momentary change in magnetic field strength. Unlike the static field ( $B_0$ ), the radio frequency (RF) field ( $B_1$ ) and the MRI gradients ( $G_x$ ,  $G_y$ ,  $G_z$ ) are generated and used only during actual scan sequences. The combination of these three fields allow for image reconstruction.

MR-compatible products must operate within specifications in the presence of these interference sources. To avoid this interference, respiration monitors, for example, commonly include a bladder, which is mounted to or around a patient's waist within the fields. A pneumatic tube connects the bladder with appropriate electronics mounted away from the scanner, e.g., beyond the 5 gauss line, outside the shielded room, or the like. Other monitors use light, such as lasers, video cameras, or fiber optics, to sense physiological status and convey the monitored status to remote electronics.

The following provides a new and improved apparatus and methods which overcome the challenges discussed above and others.

In accordance with one aspect, a physiological status sensing device senses a physiological status of a patient and minimizes an amount of interference generated during a magnetic resonance scan. The device includes a first, active sensor which is  
5 located to sense the physiological status of the patient, experience the MR scan related interference, and output a first signal having a physiological status component and an interference component. A second non-active sensor is located closely adjacent to the first sensor to experience substantially the same MR related interference as the first sensor and output a second signal having the interference component. A circuit subtractively operates  
10 on the first and second signals to cancel the interference component.

In accordance with another aspect, a method for sensing the physiological status of a patient and minimizing an amount of interference generated during a magnetic resonance scan is provided. The physiological status and magnetic scan related interference are sensed by a first, active sensor to generate a first signal having a  
15 physiological status component and an interference component. The magnetic resonance scan related interference is also sensed by a second, non-active sensor positioned closely adjacent the first sensor to experience substantially the same MR scan related interference as the first sensor to generate a second signal having the interference component. The first and second signals are subtractively combined to cancel the interference component and  
20 generate a signal with the physiological status component.

One advantage resides in enabling sensor electronics to be placed in high field regions.

Another advantage resides in artifact-free or reduced physiological sensor signals.

25 Another advantage resides in compact size and elimination of pneumatic cabling.

Further advantages of the present invention will be appreciated to those of ordinary skill in the art upon reading and understand the following detailed description.

30

FIGURE 1 diagrammatically illustrates a magnetic resonance data acquisition system.

FIGURE 2 diagrammatically illustrates one embodiment of a respiratory sensor for use in the system of FIGURE 1 in combination with an interference filter for removing interference.

5 FIGURE 3 diagrammatically illustrates one embodiment of a sensor for use in the system of FIGURE 1 in combination with an interference filter for removing interference.

FIGURE 4 diagrammatically illustrates one embodiment of a sensor for use in the system of FIGURE 1 in combination with an interference filter for removing interference.

10 FIGURE 5 illustrates a method of monitoring physiological status of a patient in an MR environment.

Gradient fields ( $G_x, G_y, G_z$ ), in particular, are a primary source of MRI  
15 interference in other electro-medical devices operating inside or near an MRI bore. In a three-dimensional space, when an MR imaging gradient is introduced, this appears as a fast or pulsed change in field strength that is superimposed across the patient to allow spatial localization. During this time, MRI gradient interference is inductively coupled into electro-medical devices (via loop or dipole-antenna effects) and can appear as differential-  
20 mode (DM) or common-mode (CM) interference. Therefore, the MRI gradients generated by the gradient field magnet are a primary interference source and the electronics on the Printed Circuit Assembly (PCA) are the victim. Because the MRI system uses a highly homogenous static field and the MRI gradients appear as wavefronts across the patient or a specific part of the patient, any two locations, near or inside the bore, exposed to the  
25 gradient field pulses that are relatively close to each other and oriented in the same direction, will be exposed to similar or highly correlated electromagnetic (EM) fields. These similar electromagnetic fields are referred to herein as “mutually-coupled electromagnetic interference.” With this presumption of nearby devices being exposed to similar gradient fields, one embodiment of the present disclosure utilizes two pressure  
30 sensors mounted adjacent to each other and coupled to a signal chain architecture, to remove the electromagnetic interference that is mutually-coupled to both sensors.

With reference to FIGURE 1, a magnetic resonance (MR) system includes a MR scanner **8** having a main magnet **10** that generates a static main ( $B_0$ ) magnetic field in an examination region **12**. In the illustrated embodiment, the main magnet **10** is a superconducting magnet disposed in a cryogenic vessel **14** employing helium or another  
5 cyrogenic fluid; alternatively a resistive main magnet can be used. In the illustrated embodiment, the magnet assembly **10, 14** is disposed in a generally cylindrical scanner housing **16** defining the examination region as a bore **12**, such as a cylindrical bore; alternatively, other geometries such as an open or other MR geometry can also be used. Magnetic resonance is excited and detected by one or more radio frequency coils ( $B_1$ ), such  
10 as an illustrated whole-body quadrature body coil **18** or one or more local coils or coil arrays such as a head coil or chest coil. The excited magnetic resonance is spatially encoded, phase- and/or frequency-shifted, or otherwise manipulated by magnetic field gradients selectively generated by a set of magnetic field gradient coils **20**.

The magnetic resonance scanner **8** is operated by a magnetic resonance data  
15 acquisition controller **22**, suitably embodied by a dedicated digital processing device, a suitably programmed general purpose computer, or so forth, to generate, spatially encode, and read out magnetic resonance data, such as projections or k-space samples, that are stored in a magnetic resonance data memory **24**. The acquired spatially encoded magnetic resonance data are reconstructed by a magnetic resonance reconstruction processor **26** to  
20 generate one or more images of a patient or subject **4** disposed in the examination region **12**. The reconstruction processor **26** employs a reconstruction algorithm comporting with the spatial encoding, such as a backprojection-based algorithm for reconstructing acquired projection data, or a Fourier transform-based algorithm for reconstructing k-space samples. The one or more reconstructed images are stored in a magnetic resonance images memory  
25 **28**, and are suitably displayed on a display **30** of a computer system **32**, or printed using a printer or other marking engine, or transmitted via the Internet or a digital hospital network, or stored on a magnetic disk or other archival storage, or otherwise utilized. The illustrated computer system **32** also includes one or more user input devices such as an illustrated keyboard **34**, or a mouse or other pointing-type input device, or so forth, which  
30 enables a radiologist, or other clinician user to manipulate images and, in the illustrated embodiment, interface with the magnetic resonance scanner controller **22**.

With continuing reference to FIGURE 1, the MR system includes a physiological status sensing device **40**, such as a pressure sensing device that includes one or more pressure transducers **42** operatively connected to the computer system **32**. The pressure transducer(s) may be included in a respiratory sensor, an invasive or non-invasive blood pressure sensor, or any other medical device operative to utilize pressure, light, or other non-electrical medium for acquiring patient data inside the bore **12** of the MR system. In one embodiment the physiological status sensing device **40** includes a belt or cuff **44** that extends around a patient's torso or a limb. The physiological status sensing device **40** senses pressure stimuli within the bore **12** and then wirelessly sends data to a monitoring signal acquisition device **50**. The physiological status sensing device **40** further includes a wireless transmitter (not shown) for sending wireless pressure signals to the monitoring signal acquisition device **50**. The present disclosure is not limited to a wireless telemetry and may also include a fiber optic, body coupled near field, wired solutions, or the like.

The monitor signal acquisition device **50**, in one embodiment, acquires pressure signals from the physiological status sensing device **40**, determines a respiratory or other physiological state, and stores the physiological state with the MR data in the MR data memory **24**. This physiological state information can be used for example in retrospective gating to sort the data by physiological state. In this manner, the MR data can be reconstructed based on respiratory or other physiological state.

In another embodiment, a breath hold detection circuit **54** detects the patient's breathe hold status and communicates the breathhold status to the MR data acquisition controller **22**. The MR data acquisition controller can use the breathhold status for prospective gating to limit data acquisition to a breathhold or other respiratory state. A digital signal processor **56** is also included for processing the physiological status signals, for example, to generate a respiratory cycle display on the monitor **30**. The present disclosure is not limited to respiratory monitoring, but is operable with any medical device for sensing pneumatic or other stimulus and processing the signals therefrom.

With reference to FIGURE 2, illustrates an exemplary embodiment of the physiological status sensing device **40** having a patient interface **60**, a signal processing chain **62** coupled thereto, and a transmitter **68**. The patient interface **60** comprises an invasive or non-invasive measuring element, for example, for a blood pressure module

such as a blood pressure dome **63**, or a pneumatic respiratory measurement system such as a bladder **61**. In the respiratory example, a belt or strap **44** extends around the patient's chest. As the patient's chest expands and contracts during breathing, the pressure in the bladder increases and decreases. A first or active pressure to electrical signal transducer  
5 **64**, such as a piezoresistive sensor, converts the breathing related pressure variations into electrical signals.

The first or active sensor **64** is mounted on a sensor module **66** with a second or dummy sensor **70**. The first sensor **64** and second sensor **70** are substantially identical pressure-to-electric converters, such as piezoresistive pressure transducers located  
10 closely adjacent to one another in a same direction and a same axis so that each sensor is exposed to a same amount of interference, such as a same magnetic gradients ( $G_x$ ,  $G_y$ ,  $G_z$ ) having substantially the same amplitudes and phases with one another. While both sensors are mounted adjacent to each other, only the first is active and actually connected to the bladder pressure dome to monitor pressure changes. The other second is a non-active  
15 (i.e., a dummy) sensor which is mounted so that it does not sense the pressure changes. In this manner, this first, active sensor **64** generates an output electrical signal which is the sum of a pressure component **76** indicative of pressure changes and a noise signal **78** indicative of the magnetic gradient interference, which is generated during actual scanning processes. The second, inactive sensor **70** outputs the same noise signal **78**, but has no  
20 pressure component.

In one embodiment, the first sensor **64** and the second sensor **70** comprise piezoresistive Wheatstone bridge circuits, which can be utilized for invasive pressure monitoring applications, for example. Wheatstone bridge circuits have a differential-mode voltage output that is proportional to a change in pressure. In this embodiment, the first  
25 sensor **64** and the second sensor **70** generate a first differential output **80** and a second differential output **82**, respectively, with each having a differential-mode output voltage. Typically, Wheatstone bridge circuits are constructed from four resistors, one of which has a calibration value ( $R_x$ ), one of which is variable ( $R_2$ ), e.g. with changes in pressure, and two of which are fixed and equal ( $R_1$  and  $R_3$ ), connected as the sides of a square. Two  
30 opposite corners of the square are connected to a source of electrical current, such as a battery. The other two opposite corners output the differential output. Wheatstone bridge

circuits are well known by one of ordinary skill in the art and provide many applications with principles that are not therefore explained in great detail herein.

The first differential output **80** and second differential output **82** from the first and second sensors, respectively, are coupled to an interference filter **84** with a first differential mode and common mode low pass filter **86** and a second differential mode and common mode low pass filter **88**, respectively, coupled therebetween. The filters **86** and **88** comprise differential mode filters that filter any signal that is differential in nature, such as the AC signal **76** generated by the pressure stimuli and any noise **78** that is electromagnetically coupled to both sensors. Both of the signals **76** and **78** are differential in nature (i.e., transmitted with two complementary signals), with a spectral band width of zero to 10 hertz for the pressure stimulus signal **76** and the coupled noise signal **78** extending up to about 30 kilohertz, for example. Consequentially, the differential mode filter serves to filter both of these signals. The electromagnetic interference components above a cutoff frequency above the frequency of the pressure signals, e.g. about 1 kilohertz, for example, are removed. This leaves the part of the noise signal that is in the same bandwidth as the pressure signal. The common mode part of the first and second filters addresses noise from pathways and devices of both signal paths (e.g., the sensor devices and differential output connections) in addition to any external interference.

With continued reference to FIGURE 2, the interference filter **84** includes a first instrument amplifier **90** and a second interference amplifier **92** respectively coupled to the first differential output **80** and the second differential output **82**. The first and second instrument amplifiers **90**, **92** each include a differential amplifier, which is a type of electronic device that multiplies the difference between two inputs by a constant factor or differential gain. A third and fourth differential mode and common mode low pass filter **94**, **96** further filters the differential outputs of respective amplifiers **90** and **92** before analog signals including the noise and AC pressure signal are converted at converters **98** and **100**. The converters **98** and **100** include fully differential analog to digital converters for converting analog signals to digital signals. These digital signals are afterwards either transmitted by the radio frequency transmitter **68** wirelessly at a frequency that does not interfere with the MR system scanning. Alternatively, the digital signals are sent out on an optic fiber, or other communication link (not shown). The DSP **56** discussed in conjunction with FIGURE 1, in one embodiment, filters the digital signal to remove the

remaining noise components of the signal by appropriate algorithms so that the pressure signal is locally and/or remotely displayed, for example, at display **30**. For example, the signal from converter **98** has a pressure signal component and a noise component and the signal from converter **100** has only the noise component. Because both noise components are the same, subtractively combining the signals leaves the pressure signal component. Consequently, two differential digital signals produced as output to the converters **98** and **100** are transmitted out of the bore and to a remote signal processing area. The DSP **56** could be located inside or outside the bore **12** of the MR system. MR imaging gradient artifacts and other interfering signals are thus effectively rejected and the stimulus pressure waveform is captured as a strong, clean signal.

The wiring of the pressure sensing device preferable has a length less than 5 cm to minimize a potential for the B<sub>1</sub> fields including current therein.

With reference to FIGURE 3, another embodiment of a pressure sensing device **40'** for minimizing an amount of interference generated during an MR scan in an MR system is illustrated. The device **40'** includes a signal chain architecture operable as an interference filter **110** for filtering mutually-coupled MR imaging (MRI) interference. A first differential output **80'** and a second differential output **82'** from a pressure sensing transducer **64'** and a like dummy transducer **70'** shielded from sensing pressure are supplied to the interference filter **110**.

The interference filter **110** includes a first instrument amplifier **91** and a second instrument amplifier **93** having a third output **112** and a fourth output **114**, respectively. Each amplifier includes a differential amplifier that receives a differential-mode output voltage and is configured to convert the voltage to a single-ended voltage output at the third and fourth outputs respectively. Each single-ended voltage is therefore generated from the outputs of an active pressure transducer **64'** and a non-active pressure transducer **70'**.

A third amplifier **116** receives as an input each single-ended output voltage from the first and second amplifiers **91**, **93** after being filtered by a third filter **115**. The third amplifier **116** subtracts the common mode signals to cancel the noise that is common to both inputs while amplifying the differential signals via the high common mode reduction capability therein, e.g., around 95 db at a unity gain or gain of zero decibels. For example, the third amplifier **116** is an instrumentation amplifier that removes the common

mode noise, amplifies the differential, and then transmits a clean pressure signal downstream to an ADC driver **120** with an ADC filter **122**, which decouples charge from the sampling nature of a converter **124**. The converter **124** includes an analog digital converter to convert the analog signals to digital format for further processing and transmission. Low pass filters are used to remove high frequency noise generated by the system and devices therein to achieve a deeper roll off of the pressure signal.

The digital signal generated from the converter **124** can be either transmitted by an RF transmitter (not shown) that does not interfere with the MR system, an optic fiber, or other communication link for digital processing. In addition, the digital signal could be transmitted from within the bore and to a local display or external interface for viewing.

In FIGURE 4, like elements with FIGURES 2 and 3 are denoted by the same reference numeral followed by a double prime (""). An active drive stage **126** integrated into a pressure sensing device **40''** for further interference rejection is illustrated. Dual pressure sensors including an active pressure sensor **68''** and a non-active pressure sensor **70''** that is prevented from sensing pressure are electromagnetically coupled to one another to transmit a similar differential noise signal at four different output terminals. A first pair of output terminals define a positive and negative differential mode voltage terminal pair **80''** which carry an AC pressure signal captured by the first sensor and a noise component. A second pair of output terminals define a differential mode pair **82''** which carry the component. A low pass filter **128** filters higher frequency signals at each terminal, which is interfaced with the active drive stage **126**.

The active drive stage **126** includes high impedance buffers **130** that receive each positive and negative compliment of the differential signals before interfacing with a first amplifier **132** and a second amplifier **134**. The buffers **130** are single-ended buffers that respectively receive each plus or minus differential voltage generated by the sensors **64''** and **70''**. Each output of differential outputs **80''** and **82''** are processed independently and fed to the first and second amplifiers **132** and **134**, respectively. The outputs of amplifiers **132**, **134** are subtractively combined by amplifier **116''** and converted to a digital pressure signal by an analog-to-digital converter **124''**. Consequently, the inputs to the instrument amplifiers **132** and **134** receive low impedance output signals, rather than a moderate impedance input source that they would receive if they were more directly

interfaced to the pressure transducers **68''** and **70''** as illustrated in FIGURE 3. The outputs of the buffers **130** are also connected with a tap **150** for directing the high impedance signal to a resistor averaging network **138**.

The high impedance output signals are averaged by the resistor averaging  
5 network **138** where each signal that is common to all the outputs of the buffers **130** is averaged with the other signals and outputted to an inverter **140** having a gain  $\beta$  device in parallel providing a gain factor  $\beta$  to the signal. The signal is further provided to a reference voltage terminal **144** to the active pressure sensor **68''**, which is illustrated as a Wheatstone bridge circuit with a reference voltage terminal **144** and a plus and minus differential  
10 voltage output terminals **146, 148** of the differential mode voltage output terminal **80''**. The same reference signal from the inverter **140** can be fed to the reference voltage terminal of the Wheatstone bridge of the dummy pressure transducer **70''**.

An example methodology **500** for removing interference from within an MRI bore during scanning is illustrated in FIGURE 5. While the method **500** is illustrated  
15 and described below as a series of acts or events, it will be appreciated that the illustrated ordering of such acts or events are not to be interpreted in a limiting sense. For example, some acts may occur in different orders and/or concurrently with other acts or events apart from those illustrated and/or described herein. In addition, not all illustrated acts may be required to implement one or more aspects or embodiments of the description herein.  
20 Further, one or more of the acts depicted herein may be carried out in one or more separate acts and/or phases.

The method **500** initializes at start and at **502** a pressure signal is acquired by locating a first, active sensor. In one embodiment, the first sensor is located closely adjacent to the second, dummy sensor so that the first sensor and second sensor are  
25 exposed to an interference that is substantially equal or the same in amplitude and phase. In one embodiment, two sensors are piezoresistive Wheatstone bridge circuits that are intended for invasive pressure monitoring applications. Physically, both pressure transducers are mounted closely adjacent to each other in the same direction and axis so that both sensors are exposed to similar levels of interference, such as the gradient pulse  
30 fields. While both sensors are mounted adjacent to each other, only one is actually receiving a pressure stimulus and the other is prevented from receiving a pressure stimulus. Both receive highly correlated electromagnetic interference. Wheatstone bridge circuits

have a differential-mode voltage output that is proportional to a change in pressure. Since there are two sensors, there are two differential voltages at the input to the analog front-end. Therefore, the pressure signal together with interference is transmitted from the first sensor as a first differential mode voltage signal to a circuit having a first amplifier circuit  
5 at **508**, and the second sensor transmits a second differential mode voltage signal to a second amplifier at **510**.

In one embodiment, the first and second amplifiers are two high-speed instrumentation amplifiers that convert the differential-mode output voltage from the two pressure transducers into two single-ended voltages at **512**; alternatively, the outputs could  
10 be differential outputs if the amplifiers are differential amplifiers. In this stage, both amplifiers capture similar interfering fields, while only one also captures a pressure signal.

At **514** the interference that is common mode interference of both the first and second differential mode voltage signals is canceled by subtracting the interference component from the first and second signals. For example, the single ended mode voltage  
15 signals are operatively connected to a difference amplifier. Because the instrumentation amplifier is a difference amplifier, the next stage, another instrumentation amplifier, for example, takes the difference between these two signals which are: [Pressure Signal + Noise<sub>cm</sub> ] and [Noise<sub>cm</sub> ]. In another embodiment, the signals are digitized and digitally subtracted.

An advantage of the method is that it is effective in cancelling MRI gradient artifact in various applications that use a piezoresistive pressure transducer and is not  
20 limited to any one particular application or field of application. The pressure signal consequently can be wireless transmitted from within the bore of an MR system. A majority of interference is inductively coupled at the pressure transducer through Faraday's law of induction and effectively canceled.  
25

The invention has been described with reference to the preferred embodiments. Modifications and alterations may occur to others upon reading and understanding the preceding detailed description. It is intended that the invention be  
30 construed as including all such modifications and alterations insofar as they come within the scope of the appended claims or the equivalents thereof.

## CLAIMS

Having thus described the embodiments, the invention is now claimed to be:

1. A physiological status sensing device (40, 40', 40'') for sensing a physiological status of a patient (4) and minimizing an amount of interference (78) generated during a magnetic resonance (MR) scan by a magnetic resonance (MR) system (8), the device (40) comprising:

a first, active sensor (64, 64', 64'') located to sense the physiological status and experience MR scan related interference and to output a first signal (80, 80', 80'') having a physiological status component (76) and an interference component (78);

a second, non-active sensor (70, 70', 70'') located closely adjacent to the first sensor (64, 64', 64'') to experience substantially the same MR scan related interference as the first sensor (64, 64', 64'') and output a second signal (82, 82', 82'') having the interference component (78); and

a circuit (50, 84, 110, 110', 116, 116') which subtractively operates on the first (80, 80', 80'') and second signals (82) to cancel the interference component (78).

2. The device (40, 40', 40'') according to claim 1, wherein the first sensor (64) includes a first piezoresistive pressure transducer which senses a pressure (76) related to the physiological status and the second sensor (70, 70', 70'') includes a second piezoresistive pressure transducer (42) of like construction with the first piezoelectric pressure transducer, the second pressure transducer being positioned to experience substantially the same MR scan related interference as the first piezoresistive transducer and not sense the pressure (76).

3. The device (40, 40', 40'') according to either one of claims 1 and 2, wherein the first (64, 64', 64'') and second sensors (70, 70', 70'') have like construction and are mounted with a common orientation to a common substrate.

4. The device (40, 40', 40'') according to any one of claims 1-3 further including:

an interference filter unit (110, 110', 110'') that is electrically coupled to the first signal (80, 80', 80'') having a first differential output (80, 80', 80'') and the second signal (82, 82', 82'') having a second differential output (82, 82', 82'') of the first sensor (64, 64', 64'') and the second sensor (70, 70', 70'') respectively, and removes the interference component (78) from the first (80, 80', 80'') and the second differential output (82, 82', 82''), and transmits the pressure signal (76), the first (80, 80', 80'') and the second differential output (82, 82', 82'') each have complementary output signals transmitted thereat.

5. The device (40, 40', 40'') according to any one of claims 1-3 wherein the circuit (110, 110', 110'') includes:

a first amplifier (91, 132) coupled to the first sensor (64, 64', 64'') and having a third output (112);

a second amplifier (93, 134) coupled to the second sensor (70, 70', 70'') and having a fourth output (114);

a differential amplifier (116, 116', 116'') which subtractively combines the third and fourth outputs to generate a pressure signal; and

a converter (124, 124', 124'') which digitizes the pressure signal.

6. The device according to any one of claims 1-5, wherein at least one of the active sensor (64'') and the non-active sensor (70'') are in a Wheatstone bridge and further including:

an active driver stage (126) coupled to a reference terminal (144) of the first, active sensor (64'') and including:

high impedance buffers (130) coupled to the first sensor (64'') and the second non-active sensor (70'') to provide a high impedance output (136) at each sensor output (80'', 82'');

a resistor averaging network (138) that averages each high impedance output (136) of the high impedance buffers (130) and generates an averaged signal therefrom; and

a gain device ( $\beta$ ) coupled to an inverter (140) that inverts the averaged signal and biases the Wheatstone bridge with the inverted averaged signal.

7. The device (40, 40', 40'') according to any one of claims 1-6, wherein the physiological status is a respiratory state and function including:

a belt or strap (44) configured to encircle the patient's waist;

a bladder (61) mounted to the belt (44) to be compressed during the patient's respiratory cycle; and

the first sensor (64, 64', 64'') connected to the bladder to sense pressure therein.

8. The device (40, 40', 40'') according to any one of claims 1-6, wherein the physiological status is a blood pressure state and further including:

a dome (63) mounted to be compressed with changes in blood pressure; and

the first sensor (64, 64', 64'') connected to the dome (63) to sense pressure therein.

9. An MRI system comprising:

a main magnet (10) which generates a static magnetic field in a patient;

gradient coils (20) which imposes or imposing gradient magnetic fields on the static magnetic field;

radio frequency coils (18) which induces radio frequency fields;

a controller (22) which controls the gradient coils and the radiofrequency coils to acquire magnetic resonance information from the patient; and

the physiological status sensing device (40, 40', 40'') **according to any one of claims 1-8.**

10. The MRI system according to claim 9, wherein the controller (22) receives the output of the physiological status sensing device and controls the gradient and radiofrequency coils to acquire magnetic resonance information during a preselected physiological status of the patient.

11. The MRI system according to claim 9, further including:  
a reconstruction processor (26) which receives the output of the physiological status sensing device and reconstructs images of the patient in one or more selected physiological status.

12. A method (500) for sensing a physiological status of a patient (4) and minimizing an amount of interference generated during a magnetic resonance (MR) scan, the method comprising:

with a first, active sensor (64, 64', 64'') sensing the physiological status and MR scan related interference and to generate a first signal (80, 80', 80'') having a physiological status component (76) and an interference component (78);

with a second non-active sensor (70) positioned closely adjacent to the first sensor (64, 64', 64'') to experience substantially the same MR scan related interference as the first sensor (64, 64', 64'') sensing the MR scan related interference and generating a second signal (82) having the interference component; and

subtractively combining the first and second signals to cancel the interference component (78) and generate a signal with the physiological status component.

13. The method according to claim 12, further including:  
mounting the first (64) and second sensors (70) to the patient closely adjacent each other and with a common orientation (72) such that both sensors sense the same noise component.

14. The method according to either one of claims 13 and 14, wherein sensing the physiological status includes:

sensing changes in pressure.

15. The method according to claims 12-14, wherein the sensed physiological status varies in a predefined frequency range and further including:

filtering the first and second signals to remove frequency components above the predefined frequency range.

16. A method for operating an MRI system comprising:  
generating static magnetic fields in a patient;  
imposing gradient magnetic fields on the static magnetic fields;  
imposing radio frequency fields to induce magnetic resonance in the patient;  
acquiring magnetic resonance information from the patient and  
sensing a physiological status of the patient with the method **according to any one of claims 12-15.**

17. The MRI method according to claim 16, further including:  
using the physiological status component to control imposing the gradient magnetic fields and the radio frequency fields to acquire the magnetic resonance information only when the patient has a selected physiological status.

18. The MRI method according to claim 16, further including:  
reconstructing the acquired magnetic resonance information into images;  
and  
using the physiological status component to control the reconstructing to reconstruct the images from magnetic resonance information when the patient had one or more selected physiological status.

19. A pressure sensing device (40) for sensing a pressure signal (76) and minimizing an amount of interference (78) generated during a magnetic resonance (MR) scan in a magnetic resonance (MR) system (8) having a bore, comprising:

a first active piezoresistive sensor (64) located proximate to the bore of the MR system (8) that is configured to sense a pressure stimulus for the pressure signal (76) to be generated thereat and the amount of interference (78) generated, comprising a first differential output (80);

a second non-active sensor (70) adjacent to and electromagnetically coupled to the first sensor (64) that is configured to sense the amount of interference (78) generated only, comprising a second differential output (82); and

an interference filter unit (110) that is electrically coupled to the first differential output (80) and the second differential output (82) of the first sensor (64) and

the second sensor (70) respectively, and configured to subtractively cancel the amount of interference (78) from the first (80) and the second differential output (82); and

a transmitter device (68) coupled to the interference filter unit (110) and configured to wirelessly transmit the pressure signal (76).

20. The device of claim 19, wherein the first sensor (64) and the second sensor (70) comprises a pressure transducer respectively located inside the bore and adjacent to one another in a same direction (72) and a same axis (74) so that the first sensor (64) and the second sensor (70) are exposed to the amount of interference (78) comprising a substantially equal amplitude and phase at each sensor, and configured to invasively sense pressure stimuli for an invasive pressure monitoring device, wherein the first sensor (64) comprises a Wheatstone bridge circuit that is configured to output a differential-mode signal (80) that is proportional to a change in pressure (76).

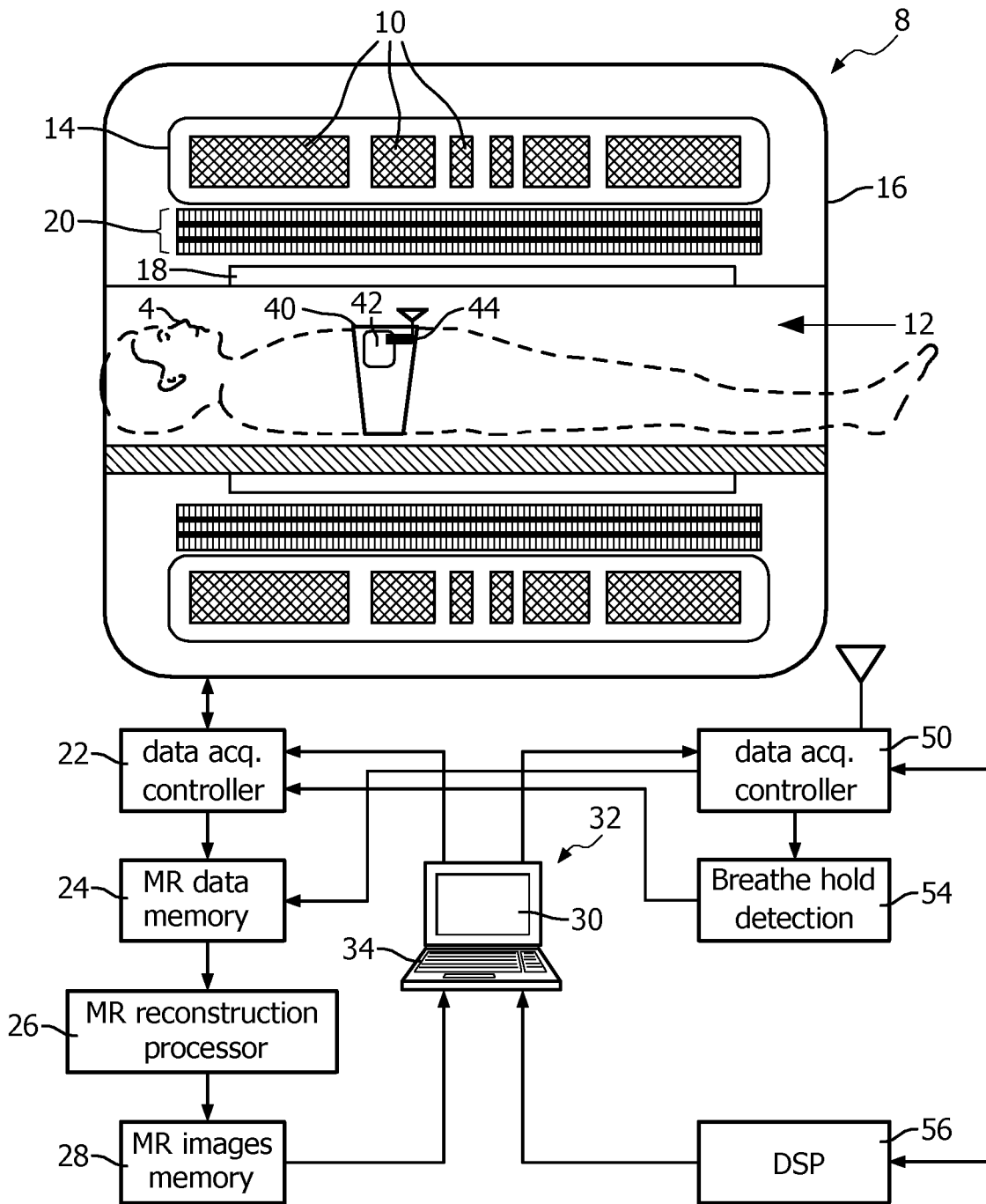


FIG. 1

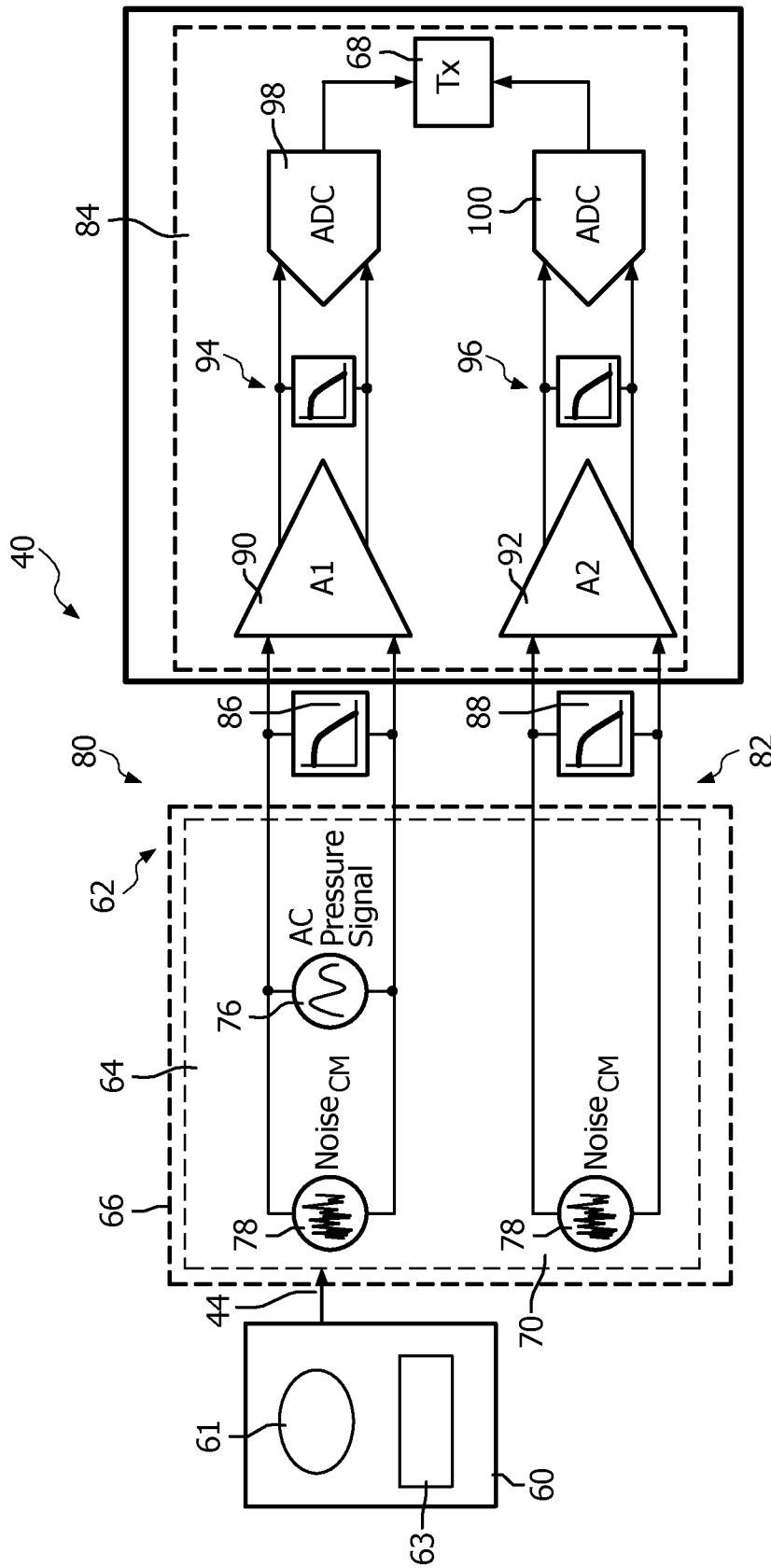


FIG. 2

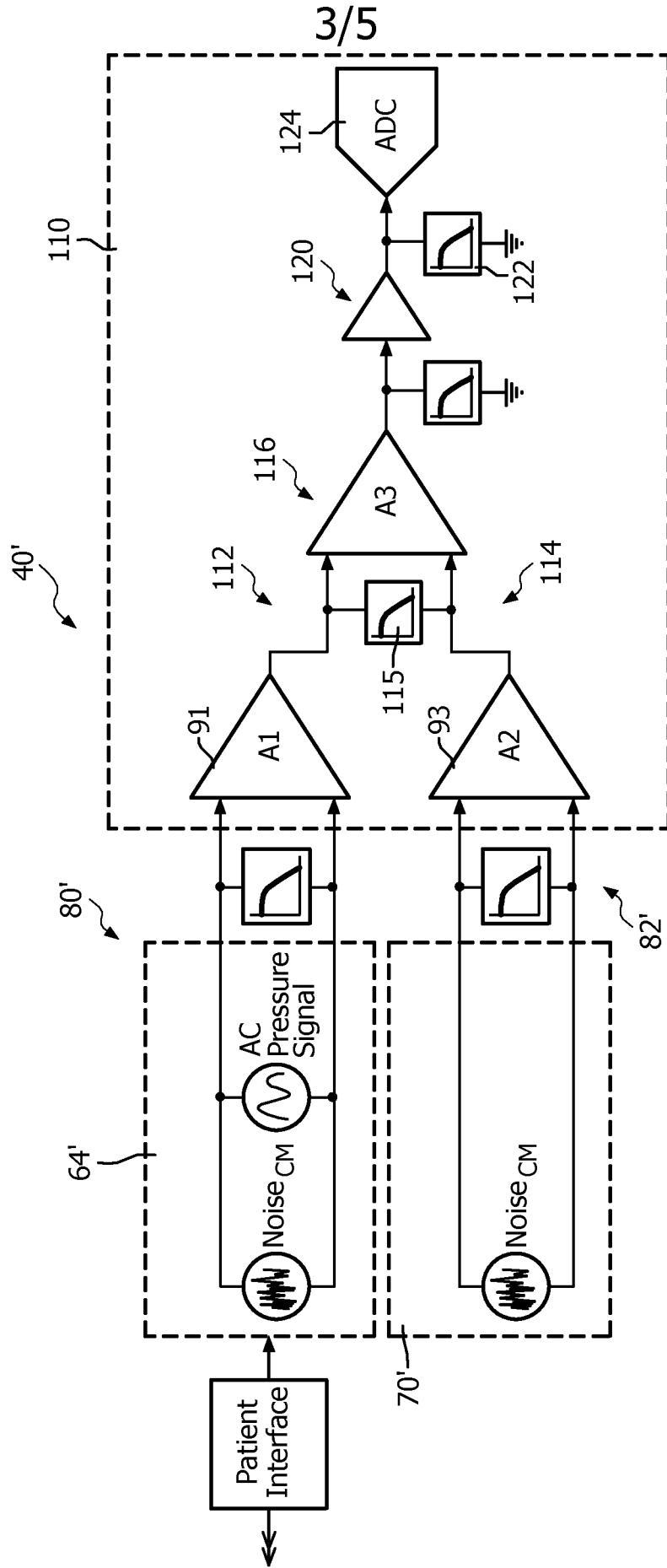


FIG. 3

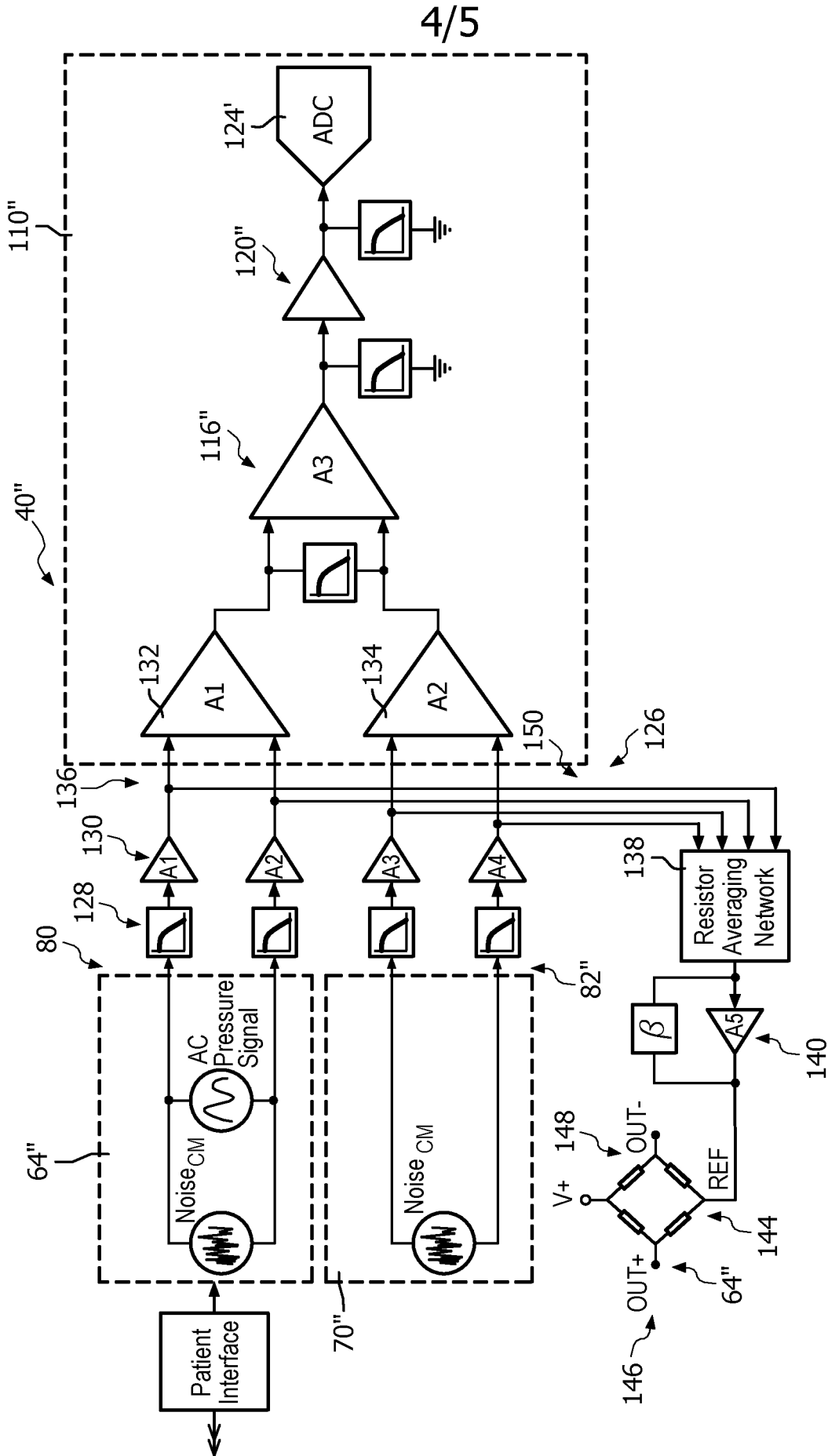


FIG. 4

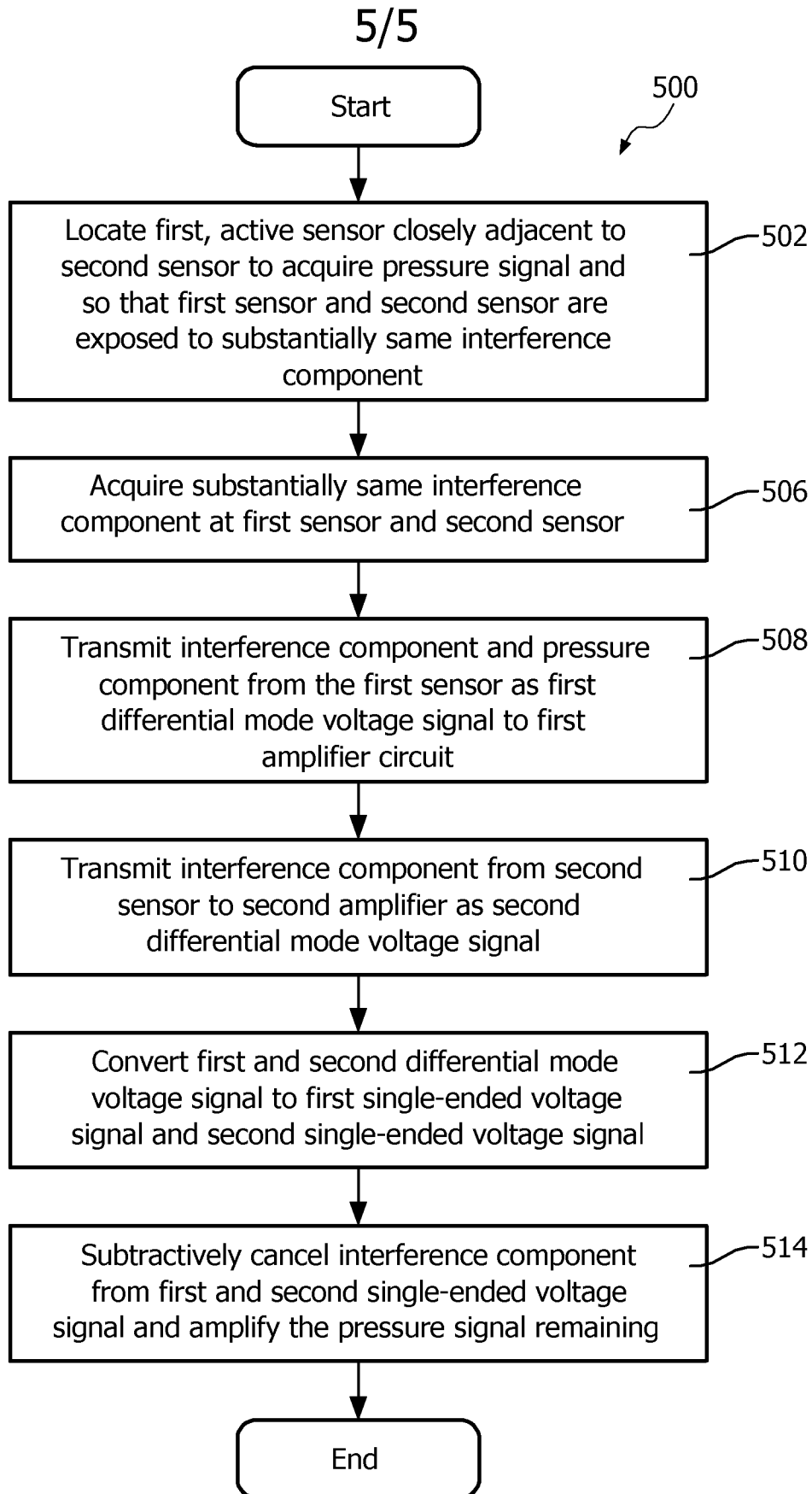


FIG. 5

INTERNATIONAL SEARCH REPORT

International application No  
PCT/IB2011/053093

A. CLASSIFICATION OF SUBJECT MATTER  
INV. G01R33/567 A61B5/113 A61B5/055  
ADD.  
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)  
G01R A61B G01D

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 practical, search terms used)  
EPO-Internal, BIOSIS, COMPENDEX, EMBASE, INSPEC, MEDLINE, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	MICHAEL K LAUDON ET AL: "Minimizing Interference from Magnetic Resonance Imagers During Electrocardiography", IEEE TRANSACTIONS ON BIOMEDICAL ENGINEERING, IEEE SERVICE CENTER, PISCATAWAY, NJ, USA, vol. 45, no. 2, 1 February 1998 (1998-02-01), XP011006497, ISSN: 0018-9294 the whole document	1,3,5,6, 9-13, 15-18
A	US 2007/172029 A1 (FELMLEE JOEL P [US] ET AL) 26 July 2007 (2007-07-26)  paragraphs [0007], [0016], [0018], [0034]  ----- -/--	1,2,4,7, 8,14,19, 20

Further documents are listed in the continuation of Box C.

See patent family annex.

\* Special categories of cited documents :

- "A" document defining the general state of the art which is not considered to be of particular relevance
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- "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  21 October 2011	Date of mailing of the international search report  31/10/2011
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer  Skalla, Jörg

## INTERNATIONAL SEARCH REPORT

 International application No  
 PCT/IB2011/053093

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 2008/269581 A1 (WOOD KIM [CA] ET AL) 30 October 2008 (2008-10-30) paragraphs [0044], [0049], [0050] -----	1,8
A	WO 2007/134144 A2 (INVIVO CORP [US]; FISHER STEPHEN DOUGLAS [US]; HARWELL ROBERT A [US];) 22 November 2007 (2007-11-22) paragraph [0025] - paragraph [0027] -----	1,8
A	US 5 209 233 A (HOLLAND G NEIL [US] ET AL) 11 May 1993 (1993-05-11) sentence 4 - sentence 20 -----	1,2,7,9, 12,19
A	US 2003/018248 A1 (KREGER KEVIN SCOTT [US] ET AL) 23 January 2003 (2003-01-23) paragraph [0003] - paragraph [0008] paragraph [0022] - paragraph [0028]; claim 12 -----	1,9,12

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No PCT/IB2011/053093
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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2007172029	A1	26-07-2007	NONE
-----			
US 2008269581	A1	30-10-2008	EP 2140235 A1 06-01-2010
			US 2008269581 A1 30-10-2008
			WO 2008128350 A1 30-10-2008
-----			
WO 2007134144	A2	22-11-2007	CN 101548194 A 30-09-2009
			CN 101553167 A 07-10-2009
			CN 101557756 A 14-10-2009
			CN 101563030 A 21-10-2009
			CN 101588754 A 25-11-2009
			EP 2020839 A2 11-02-2009
			EP 2020916 A2 11-02-2009
			EP 2020917 A2 11-02-2009
			EP 2024758 A2 18-02-2009
			EP 2069987 A2 17-06-2009
			US 2010036236 A1 11-02-2010
			US 2010188208 A1 29-07-2010
			US 2010191069 A1 29-07-2010
			US 2010192141 A1 29-07-2010
			WO 2007134143 A2 22-11-2007
			WO 2007134144 A2 22-11-2007
			WO 2007134146 A2 22-11-2007
			WO 2007134156 A2 22-11-2007
			WO 2007134165 A2 22-11-2007
-----			
US 5209233	A	11-05-1993	NONE
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US 2003018248	A1	23-01-2003	NONE
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专利名称(译)	双压力传感器信号链可消除相互耦合的MRI干扰		
公开(公告)号	<a href="#">EP2596376A1</a>	公开(公告)日	2013-05-29
申请号	EP2011752639	申请日	2011-07-12
[标]申请(专利权)人(译)	皇家飞利浦电子股份有限公司		
申请(专利权)人(译)	皇家飞利浦电子N.V.		
当前申请(专利权)人(译)	皇家飞利浦N.V.		
[标]发明人	REY EDUARDO MARIO CATES HAROLD JOSEPH		
发明人	REY, EDUARDO MARIO CATES, HAROLD JOSEPH		
IPC分类号	G01R33/567 A61B5/113 A61B5/055 A61B5/00 A61B5/0205 A61B5/021 G01R33/28		
CPC分类号	A61B5/0205 A61B5/0004 A61B5/0059 A61B5/0077 A61B5/021 A61B5/055 A61B5/1135 A61B5/6831 A61B5/7217 A61B5/7225 A61B5/725 A61B5/7285 A61B5/7289 G01R33/28 G01R33/5673		
优先权	61/366988 2010-07-23 US		
其他公开文献	EP2596376B1		
外部链接	<a href="#">Espacenet</a>		

#### 摘要(译)

装置和方法提供生理状态感测装置 ( 40 ) , 用于感测患者 ( 4 ) 的生理状态并最小化磁共振 ( MR ) 系统在磁共振 ( MR ) 扫描期间产生的干扰量 ( 78 ) ( 8 ) 。装置 ( 40 ) 包括第一有源传感器 ( 64 ) , 其定位成感测生理状态并经历MR扫描相关干扰并产生具有生理状态分量 ( 76 ) 和干扰分量 ( 78 ) 的第一信号 ( 80 ) 。 。第二非活动传感器 ( 70 ) 紧邻第一传感器 ( 64 ) 定位, 以体验与第一传感器 ( 64 ) 基本相同的MR扫描相关干扰 ( 78 ) , 并产生仅具有第一传感器 ( 64 ) 的第二信号 ( 82 ) 。干扰成分 ( 78 ) 。电路或处理器 ( 56,84,110,116 ) 相减地组合第一 ( 80 ) 和第二信号 ( 82 ) 以消除干扰分量 ( 78 ) 。