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Lisogurski et al.

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(45) **Date of Patent: Jun. 11, 2019**

(54) **CAPACITANCE ENHANCED PHYSIOLOGICAL MEASUREMENTS**

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(73) Assignee: **Covidien LP**, Mansfield, MA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 321 days.

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(22) Filed: **Sep. 8, 2016**

(65) **Prior Publication Data**

US 2016/0374620 A1 Dec. 29, 2016

Related U.S. Application Data

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(Continued)

(51) **Int. Cl.**

A61B 5/1455	(2006.01)
A61B 5/00	(2006.01)
A61B 5/0205	(2006.01)
A61B 5/026	(2006.01)
A61B 5/0295	(2006.01)
A61B 5/0402	(2006.01)

(Continued)

(52) **U.S. Cl.**

CPC ***A61B 5/721*** (2013.01); ***A61B 5/0059*** (2013.01); ***A61B 5/0205*** (2013.01); ***A61B 5/0261*** (2013.01); ***A61B 5/0295*** (2013.01); ***A61B 5/0402*** (2013.01); ***A61B 5/1455*** (2013.01); ***A61B 5/14551*** (2013.01); ***A61B 5/6826*** (2013.01); ***A61B 5/6838*** (2013.01); ***A61B 5/746*** (2013.01); ***A61B 7/00*** (2013.01); *A61B 5/021* (2013.01); *A61B 5/02405* (2013.01); *A61B 5/02416* (2013.01); *A61B 5/053* (2013.01); *A61B 5/08* (2013.01); *A61B 5/085* (2013.01); *A61B 5/0816* (2013.01); *A61B 5/0826* (2013.01); *A61B 5/11* (2013.01); *A61B 5/14546* (2013.01); *A61B 5/14552* (2013.01); *A61B 2562/0214* (2013.01)

(58) **Field of Classification Search**

CPC ... A61B 5/1455; A61B 5/14551; A61B 5/721; A61B 5/0205; A61B 5/0295

See application file for complete search history.

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2014/0058217 A1 *	2/2014	Giovangrandi	A61B 5/14552	600/322

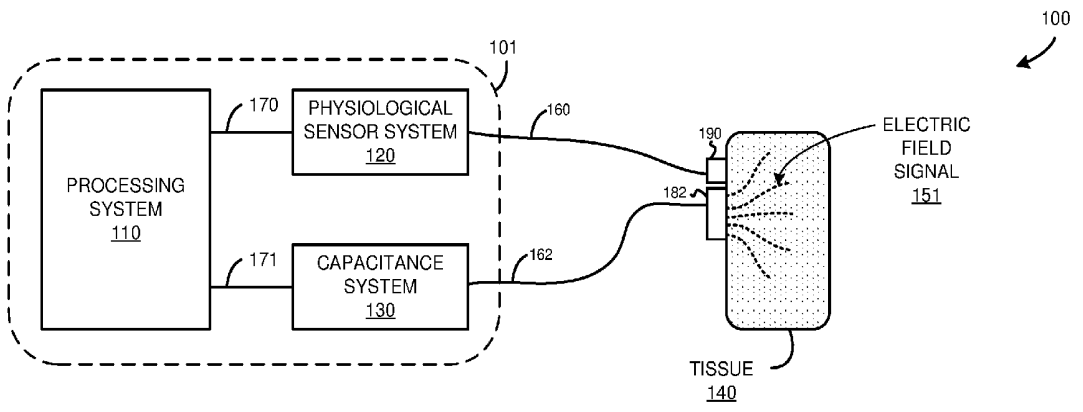
* cited by examiner

Primary Examiner — Eric F Winakur

(57) **ABSTRACT**

Systems, methods, apparatuses, and software for measuring and determining physiological parameters of a patient are presented. In one example, a physiological measurement system includes an optical system configured to emit one or more optical signals into tissue of a patient, and detect the one or more optical signals after propagation through the tissue. The physiological measurement system includes a capacitance system configured to apply one or more electric field signals to a single side of the tissue to determine a capacitance signal based at least on changes in the one or more electric field signals, and a processing system configured to process at least the one or more detected optical signals and the capacitance signal to determine a physiological parameter of the patient.

30 Claims, 21 Drawing Sheets



Related U.S. Application Data

(60) Provisional application No. 61/912,998, filed on Dec. 6, 2013.

(51) **Int. Cl.**

A61B 7/00	(2006.01)
A61B 5/024	(2006.01)
A61B 5/053	(2006.01)
A61B 5/08	(2006.01)
A61B 5/11	(2006.01)
A61B 5/021	(2006.01)
A61B 5/085	(2006.01)
A61B 5/145	(2006.01)

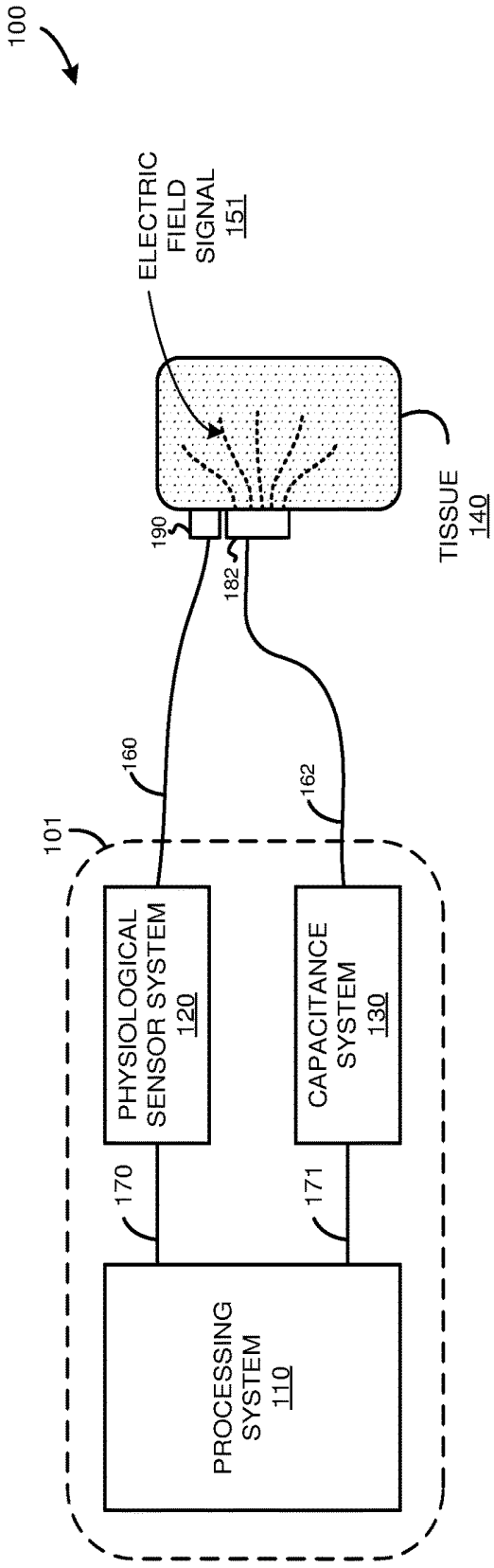

100
ELECTRIC FIELD SIGNAL 151
TISSUE 140
190
182
160
162
101
PHYSIOLOGICAL SENSOR SYSTEM 120
CAPACITANCE SYSTEM 130
170
171
PROCESSING SYSTEM 110

FIG. 1A

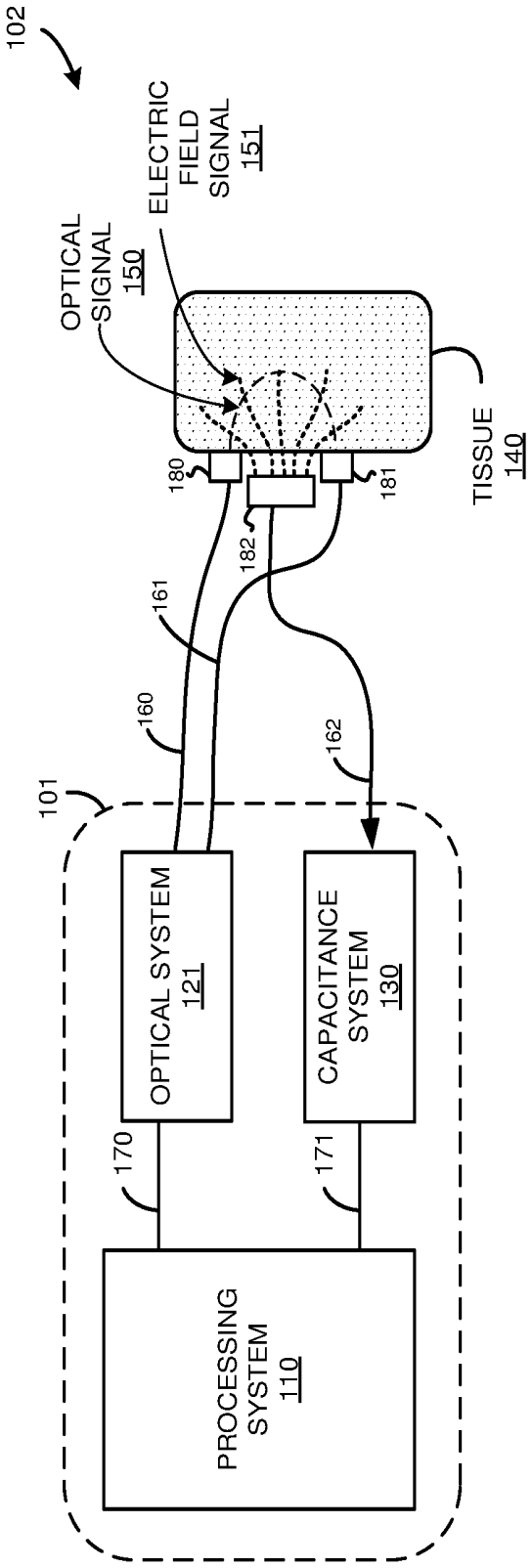

102
ELECTRIC FIELD SIGNAL 151
OPTICAL SIGNAL 150
TISSUE 140
180
181
182
161
160
162
101
OPTICAL SYSTEM 121
CAPACITANCE SYSTEM 130
170
171
PROCESSING SYSTEM 110

FIG. 1B

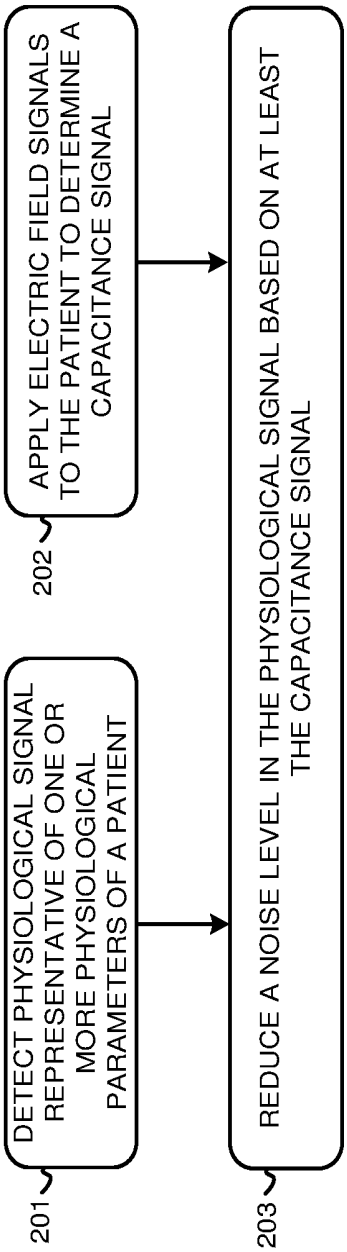

DETECT PHYSIOLOGICAL SIGNAL REPRESENTATIVE OF ONE OR MORE PHYSIOLOGICAL PARAMETERS OF A PATIENT
201
APPLY ELECTRIC FIELD SIGNALS TO THE PATIENT TO DETERMINE A CAPACITANCE SIGNAL
202
REDUCE A NOISE LEVEL IN THE PHYSIOLOGICAL SIGNAL BASED ON AT LEAST THE CAPACITANCE SIGNAL
203

FIG. 2

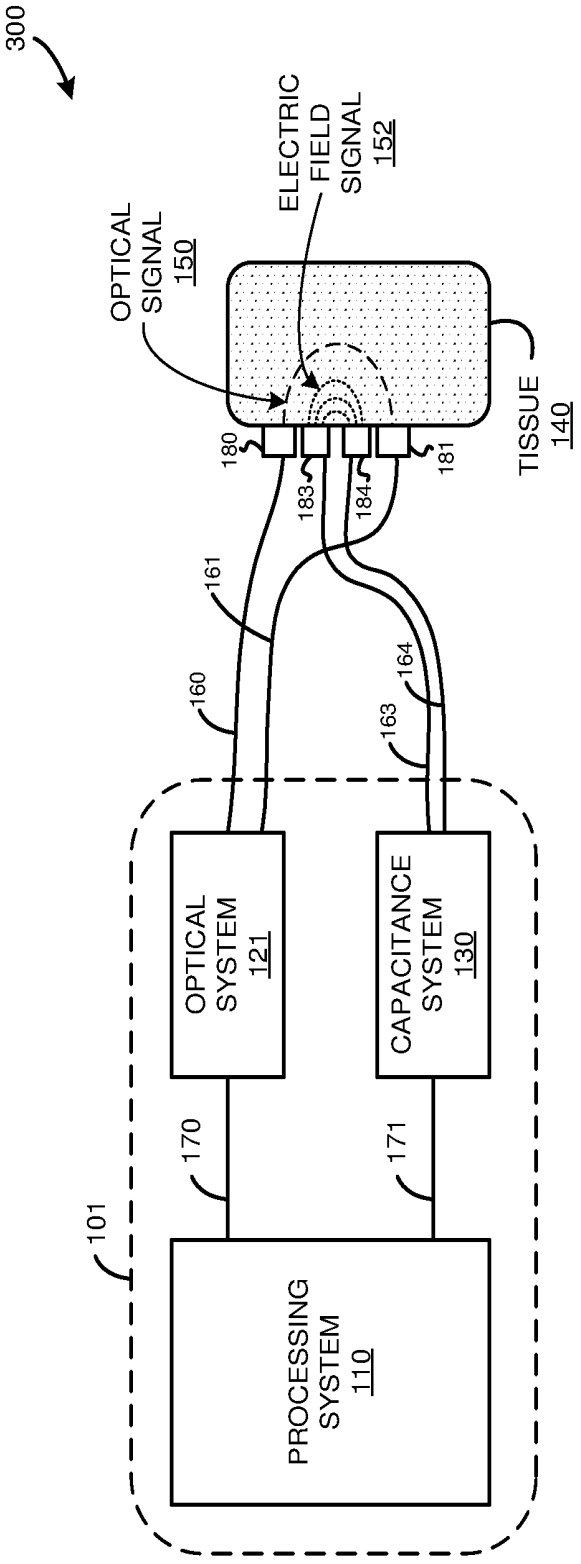

300
ELECTRIC FIELD SIGNAL 152
OPTICAL SIGNAL 150
TISSUE 140
180
181
183
184
161
160
164
163
OPTICAL SYSTEM 121
CAPACITANCE SYSTEM 130
170
171
101
PROCESSING SYSTEM 110

FIG. 3

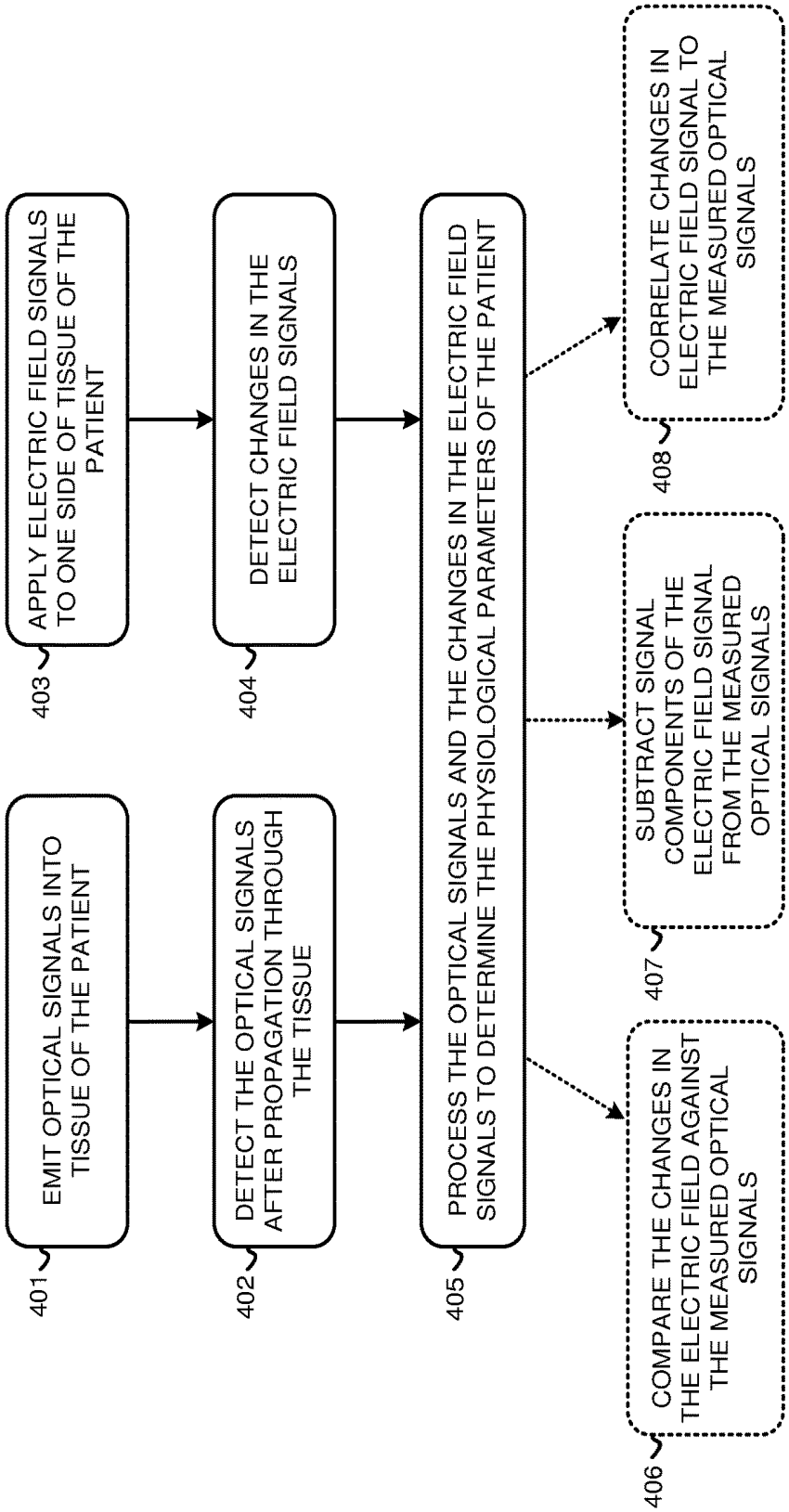

EMIT OPTICAL SIGNALS INTO TISSUE OF THE PATIENT
401
DETECT THE OPTICAL SIGNALS AFTER PROPAGATION THROUGH THE TISSUE
402
APPLY ELECTRIC FIELD SIGNALS TO ONE SIDE OF TISSUE OF THE PATIENT
403
DETECT CHANGES IN THE ELECTRIC FIELD SIGNALS
404
PROCESS THE OPTICAL SIGNALS AND THE CHANGES IN THE ELECTRIC FIELD SIGNALS TO DETERMINE THE PHYSIOLOGICAL PARAMETERS OF THE PATIENT
405
COMPARE THE CHANGES IN THE ELECTRIC FIELD AGAINST THE MEASURED OPTICAL SIGNALS
406
SUBTRACT SIGNAL COMPONENTS OF THE ELECTRIC FIELD SIGNAL FROM THE MEASURED OPTICAL SIGNALS
407
CORRELATE CHANGES IN ELECTRIC FIELD SIGNAL TO THE MEASURED OPTICAL SIGNALS
408

FIG. 4

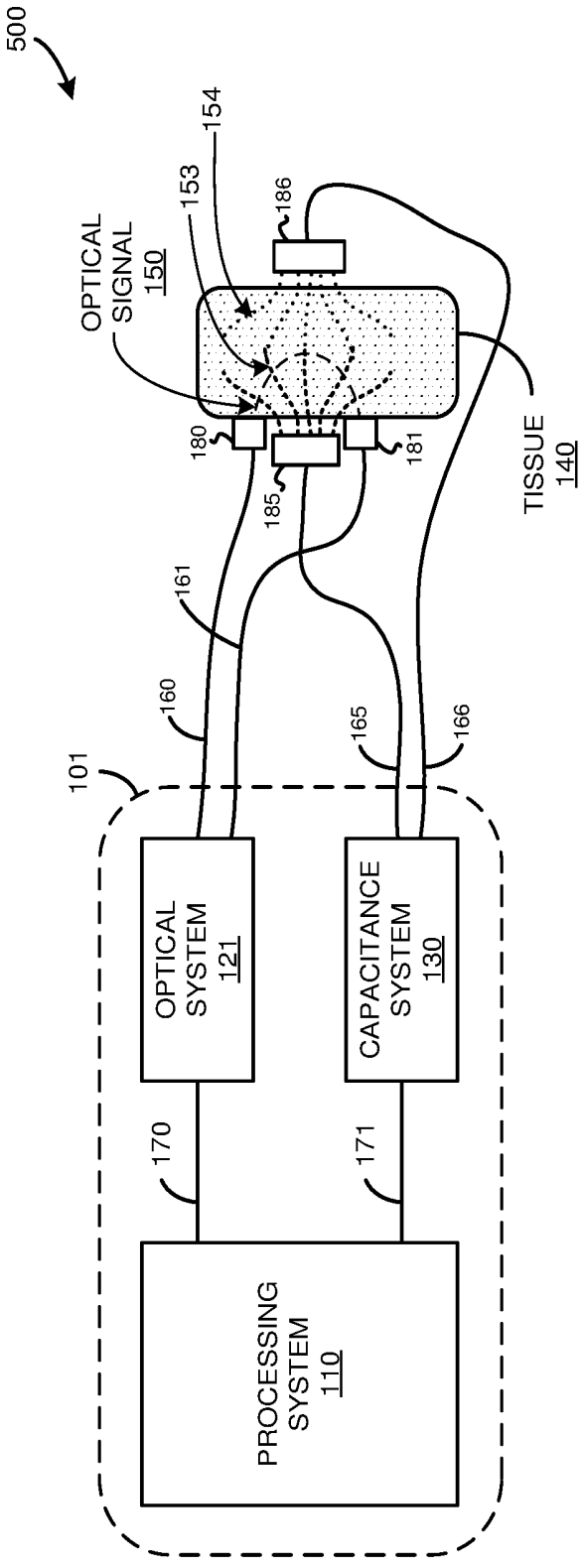

500
154
153
186
OPTICAL SIGNAL 150
180
181
185
TISSUE 140
161
160
165
166
101
OPTICAL SYSTEM 121
CAPACITANCE SYSTEM 130
170
171
PROCESSING SYSTEM 110

FIG. 5

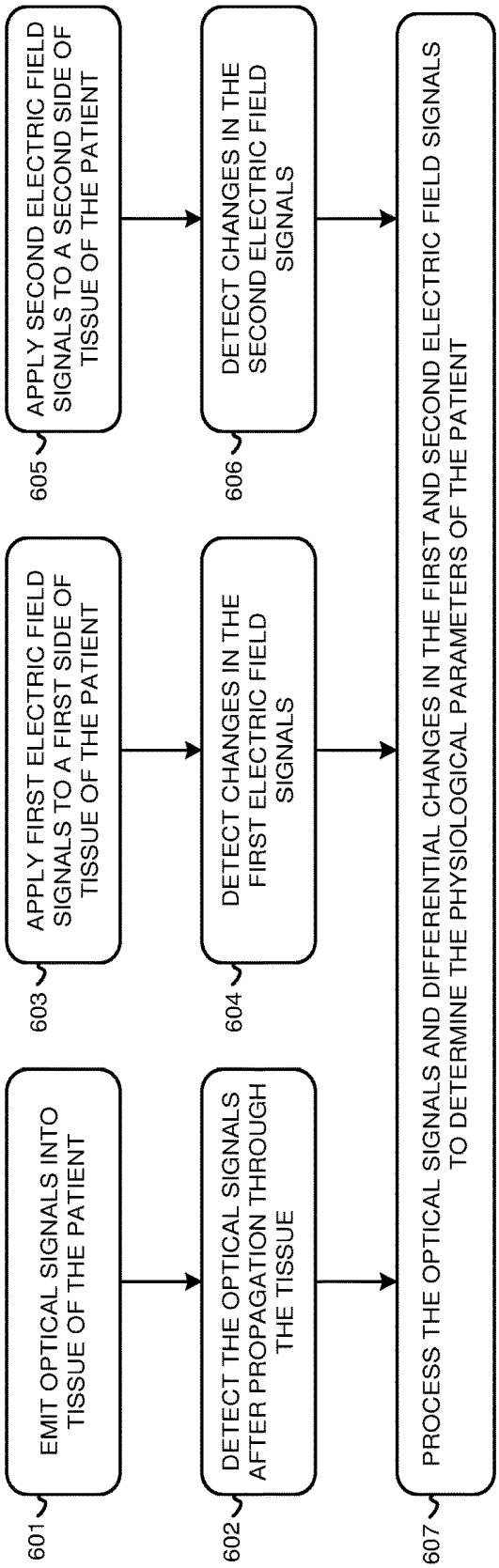

EMIT OPTICAL SIGNALS INTO TISSUE OF THE PATIENT
601
DETECT THE OPTICAL SIGNALS AFTER PROPAGATION THROUGH THE TISSUE
602
APPLY FIRST ELECTRIC FIELD SIGNALS TO A FIRST SIDE OF TISSUE OF THE PATIENT
603
DETECT CHANGES IN THE FIRST ELECTRIC FIELD SIGNALS
604
APPLY SECOND ELECTRIC FIELD SIGNALS TO A SECOND SIDE OF TISSUE OF THE PATIENT
605
DETECT CHANGES IN THE SECOND ELECTRIC FIELD SIGNALS
606
PROCESS THE OPTICAL SIGNALS AND DIFFERENTIAL CHANGES IN THE FIRST AND SECOND ELECTRIC FIELD SIGNALS TO DETERMINE THE PHYSIOLOGICAL PARAMETERS OF THE PATIENT
607

FIG. 6

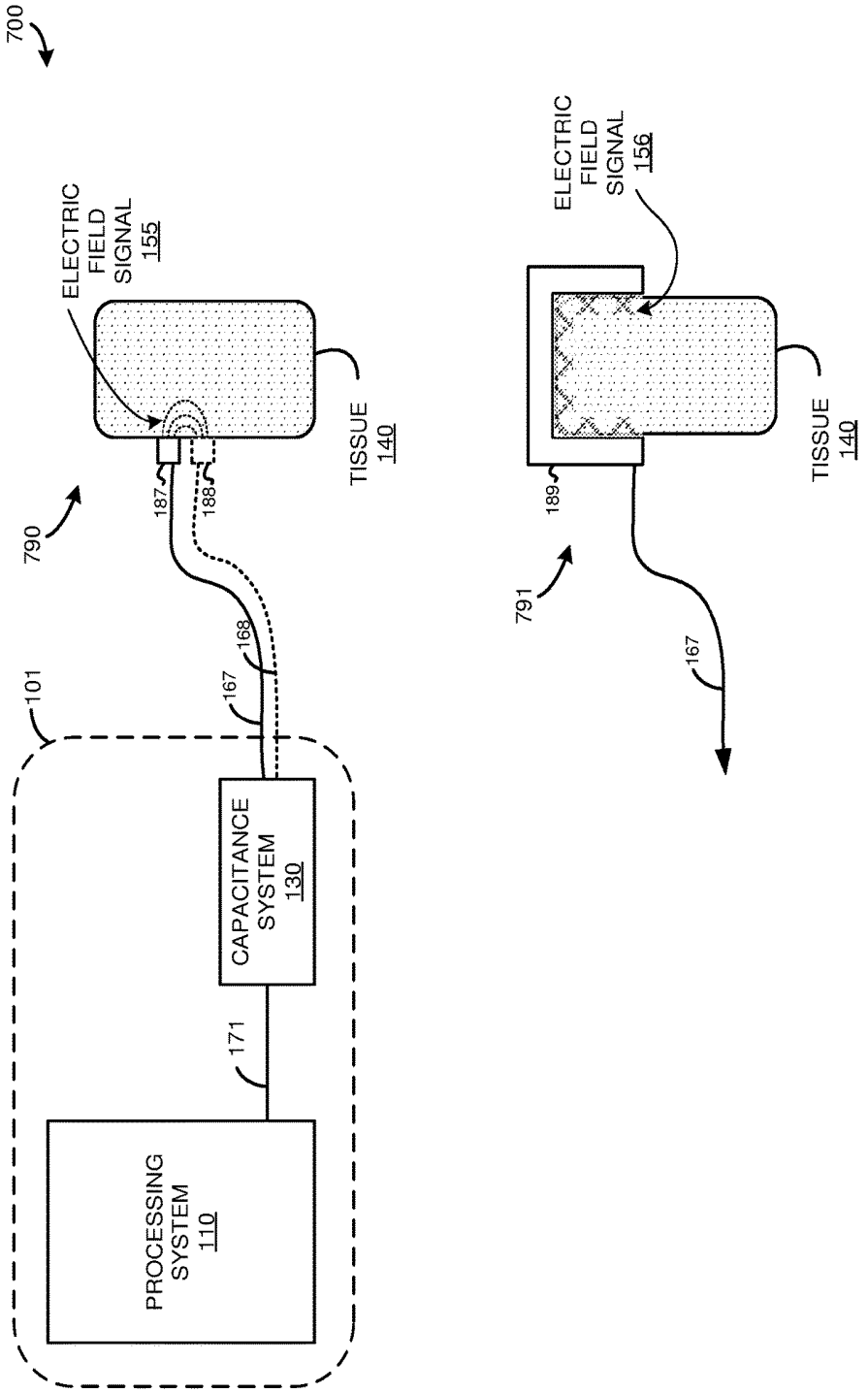

700
ELECTRIC FIELD SIGNAL 155
TISSUE 140
187
188
790
168
167
101
CAPACITANCE SYSTEM 130
171
PROCESSING SYSTEM 110
ELECTRIC FIELD SIGNAL 156
TISSUE 140
189
791
167

FIG. 7

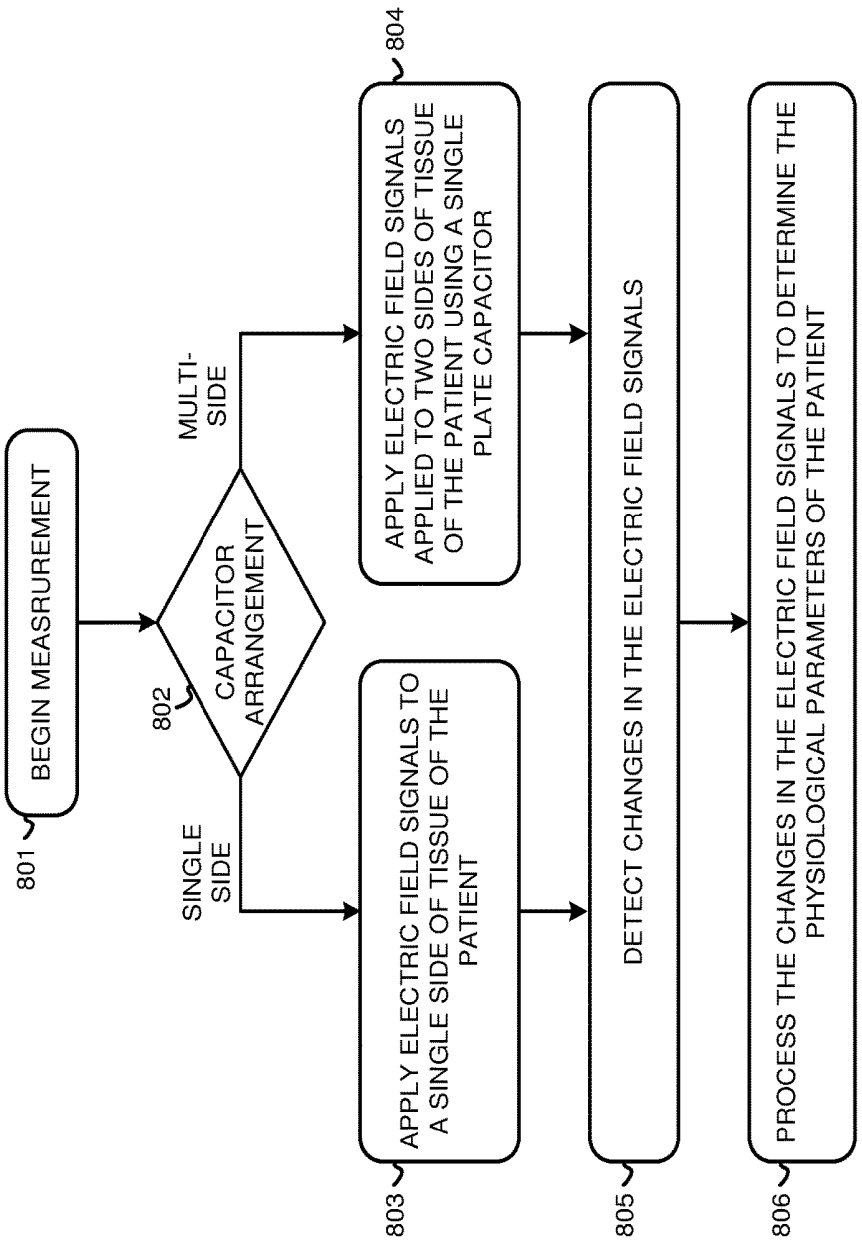

BEGIN MEASRUREMENT
801
CAPACITOR ARRANGEMENT
802
SINGLE SIDE
MULTI-SIDE
APPLY ELECTRIC FIELD SIGNALS TO A SINGLE SIDE OF TISSUE OF THE PATIENT
803
APPLY ELECTRIC FIELD SIGNALS APPLIED TO TWO SIDES OF TISSUE OF THE PATIENT USING A SINGLE PLATE CAPACITOR
804
DETECT CHANGES IN THE ELECTRIC FIELD SIGNALS
805
PROCESS THE CHANGES IN THE ELECTRIC FIELD SIGNALS TO DETERMINE THE PHYSIOLOGICAL PARAMETERS OF THE PATIENT
806

FIG. 8

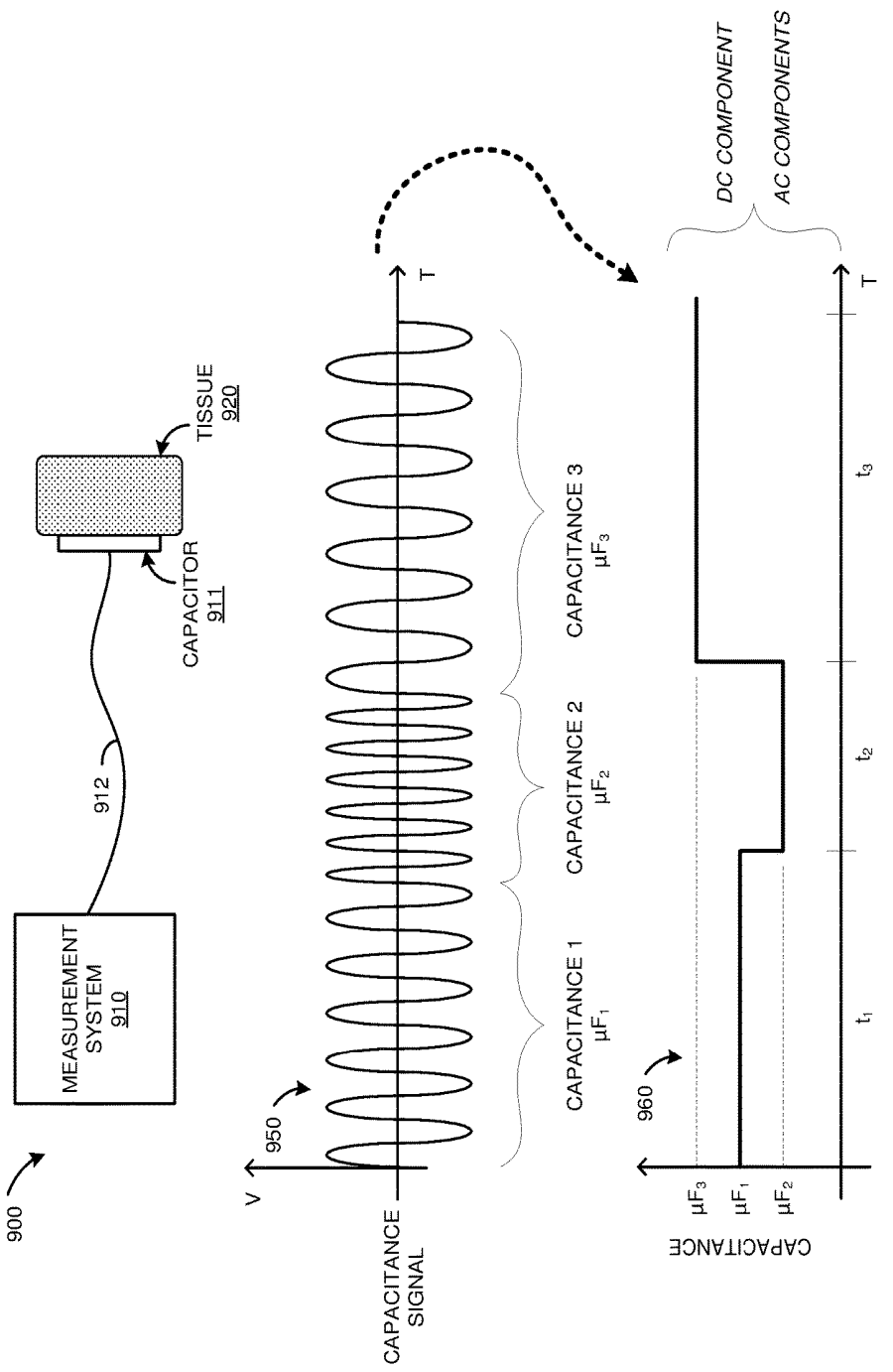

900
MEASUREMENT SYSTEM 910
912
CAPACITOR 911
TISSUE 920
950
V
T
CAPACITANCE SIGNAL
CAPACITANCE 1 μF1
CAPACITANCE 2 μF2
CAPACITANCE 3 μF3
960
DC COMPONENT
AC COMPONENTS
CAPACITANCE
μF3
μF1
μF2
t1
t2
t3
T

FIG. 9

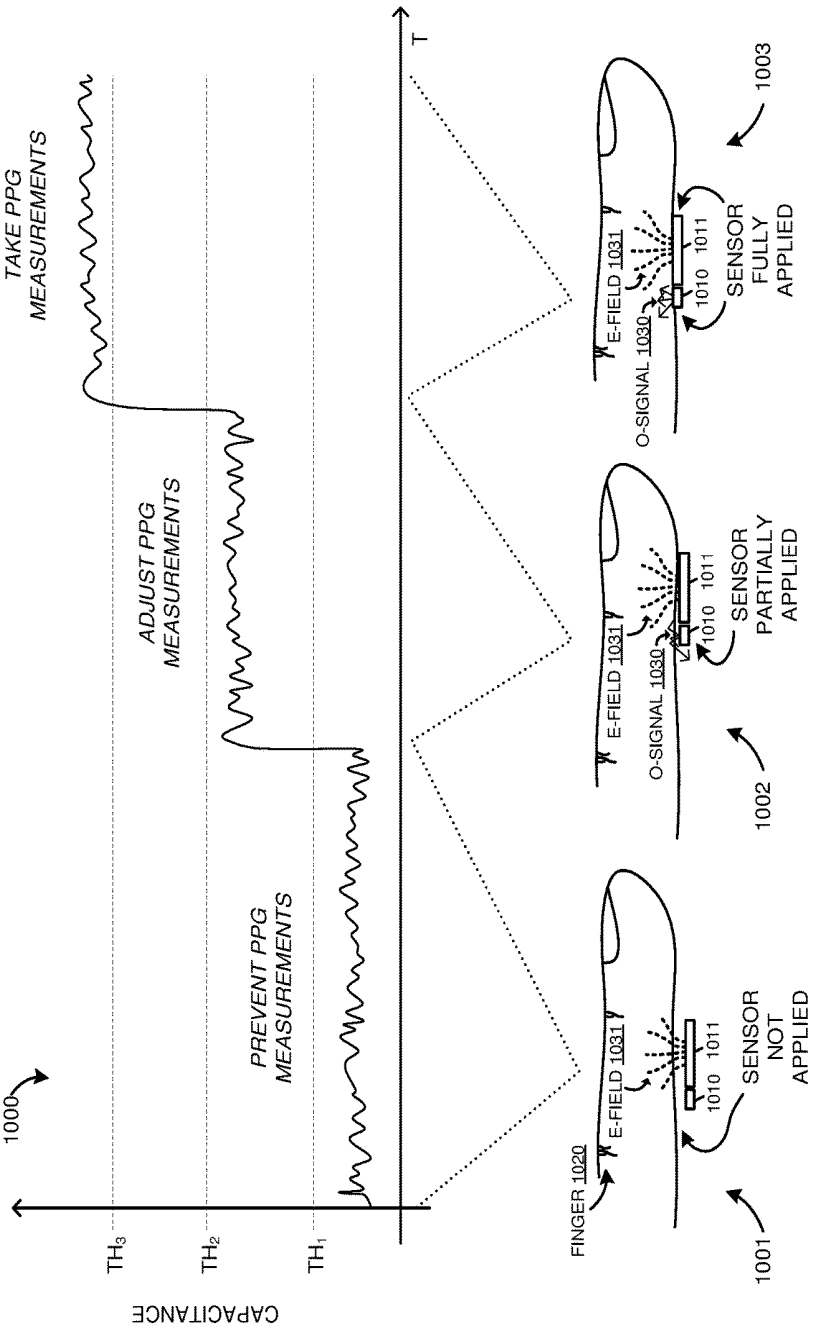

TAKE PPG MEASUREMENTS
ADJUST PPG MEASUREMENTS
PREVENT PPG MEASUREMENTS
1000
CAPACITANCE
TH3
TH2
TH1
T
FINGER 1020
E-FIELD 1031
1010
1011
SENSOR NOT APPLIED
1001
O-SIGNAL 1030
SENSOR PARTIALLY APPLIED
1002
SENSOR FULLY APPLIED
1003

FIG. 10

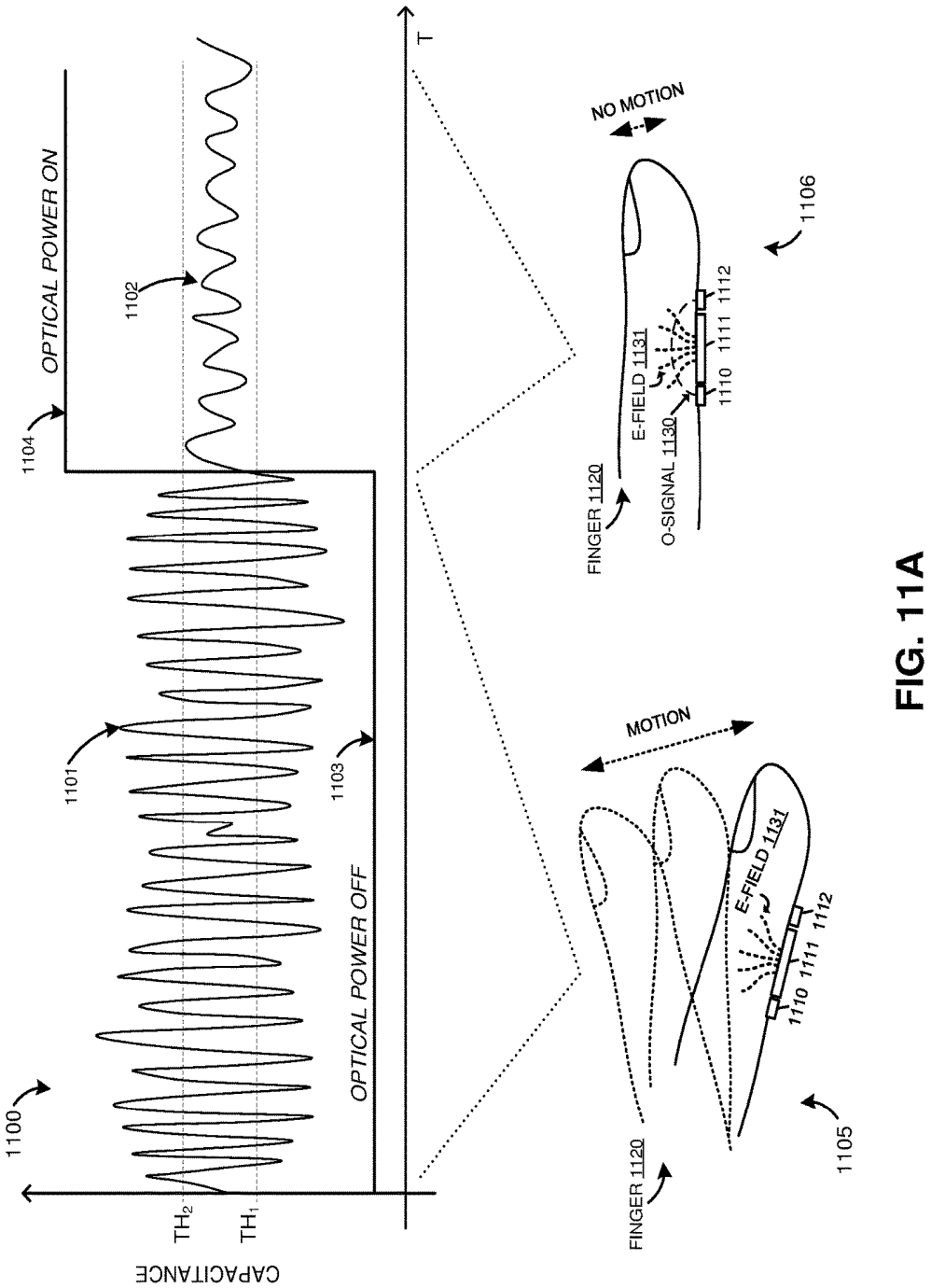

OPTICAL POWER ON
OPTICAL POWER OFF
CAPACITANCE
T
TH2
TH1
1100
1101
1102
1103
1104
NO MOTION
MOTION
FINGER 1120
E-FIELD 1131
O-SIGNAL 1130
1105
1106
1110 1111 1112

FIG. 11A

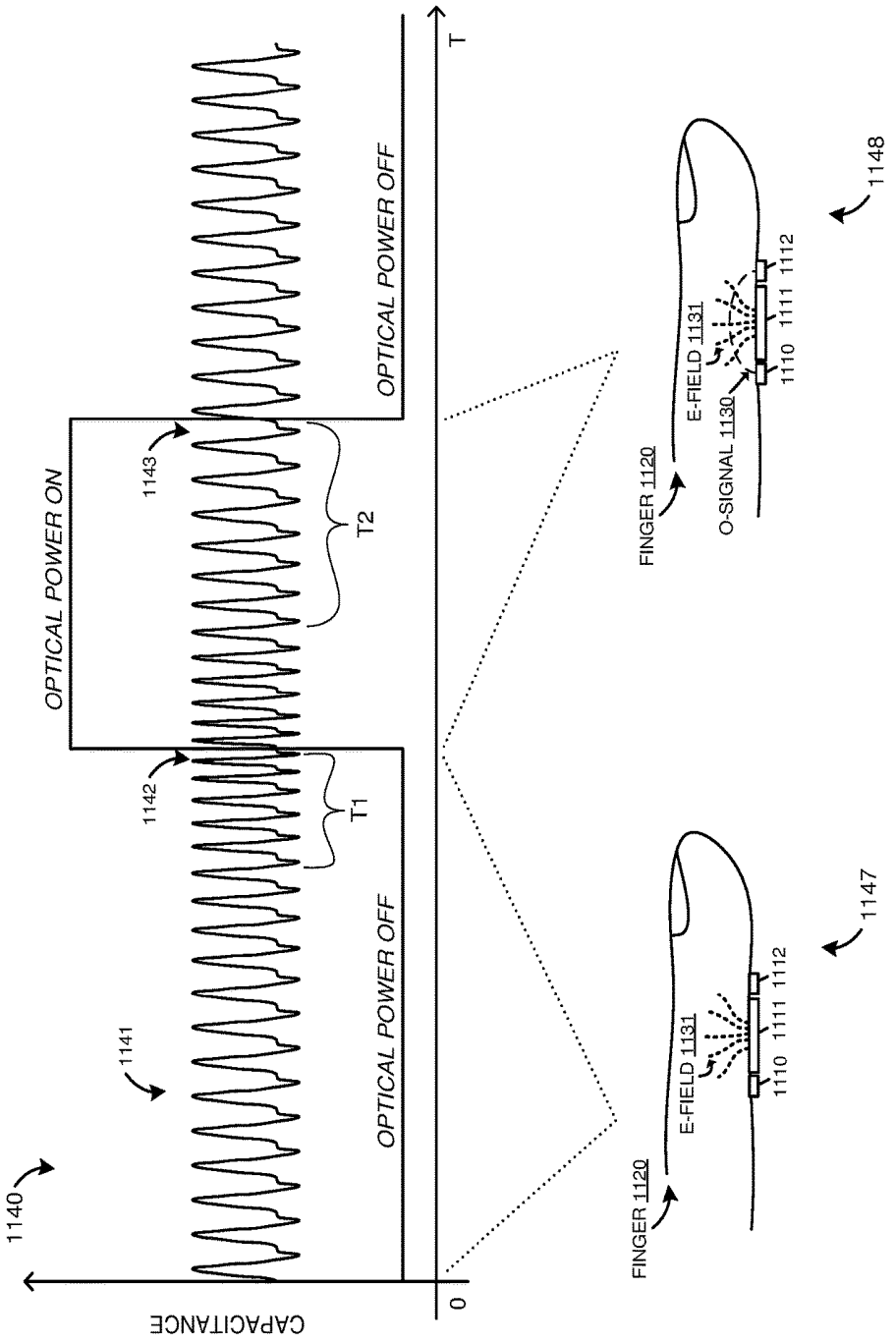

1140
CAPACITANCE
0
T
1141
OPTICAL POWER ON
OPTICAL POWER OFF
1142
T1
1143
T2
OPTICAL POWER OFF
FINGER 1120
E-FIELD 1131
1110 1111 1112
1147
FINGER 1120
O-SIGNAL 1130
E-FIELD 1131
1110 1111 1112
1148

FIG. 11B

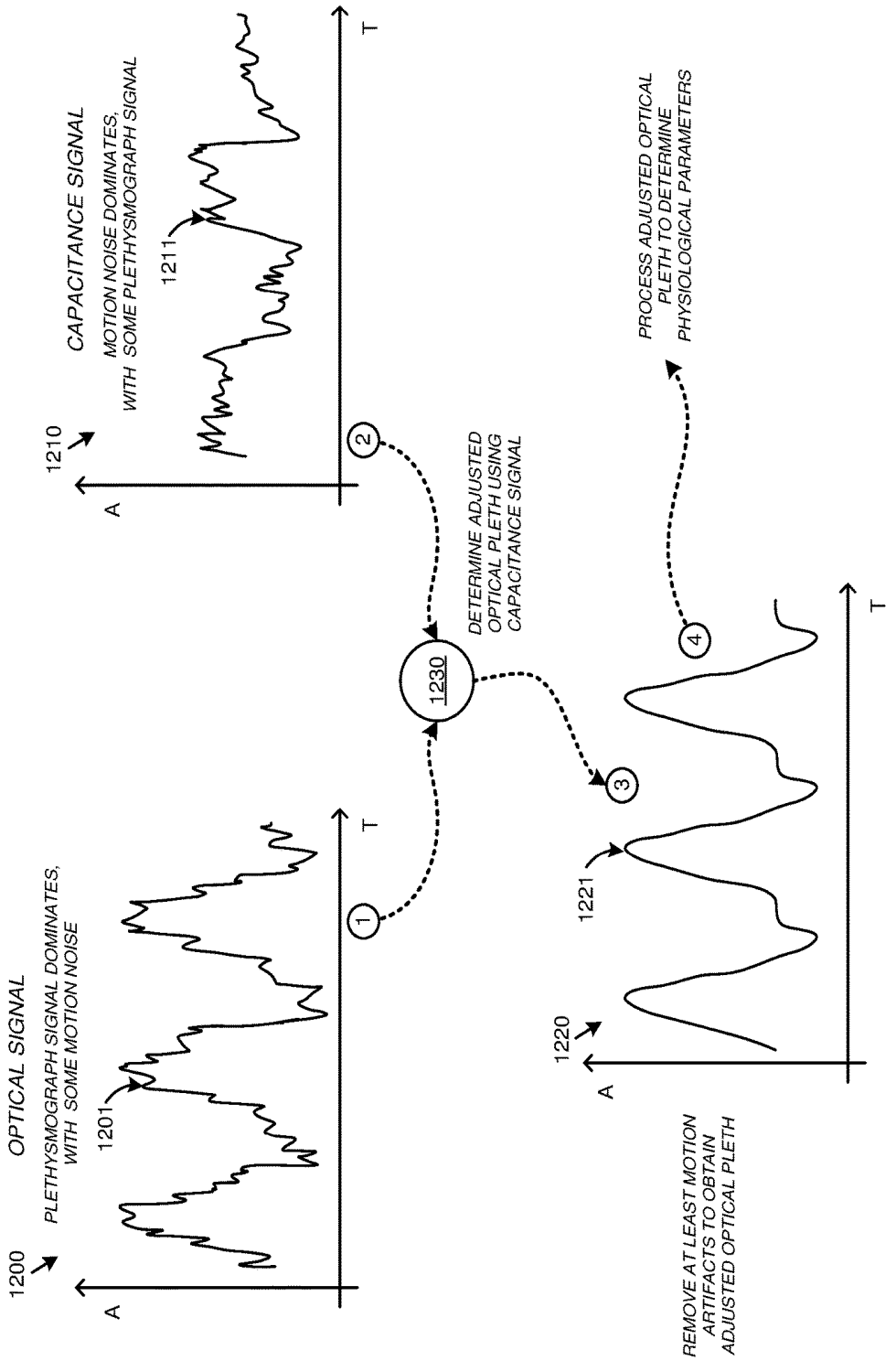

OPTICAL SIGNAL
PLETHYSMOGRAPH SIGNAL DOMINATES, WITH SOME MOTION NOISE
1200
1201
A
T
1
CAPACITANCE SIGNAL
MOTION NOISE DOMINATES, WITH SOME PLETHYSMOGRAPH SIGNAL
1210
1211
A
T
2
1230
DETERMINE ADJUSTED OPTICAL PLETH USING CAPACITANCE SIGNAL
3
1220
1221
A
T
REMOVE AT LEAST MOTION ARTIFACTS TO OBTAIN ADJUSTED OPTICAL PLETH
4
PROCESS ADJUSTED OPTICAL PLETH TO DETERMINE PHYSIOLOGICAL PARAMETERS

FIG. 12

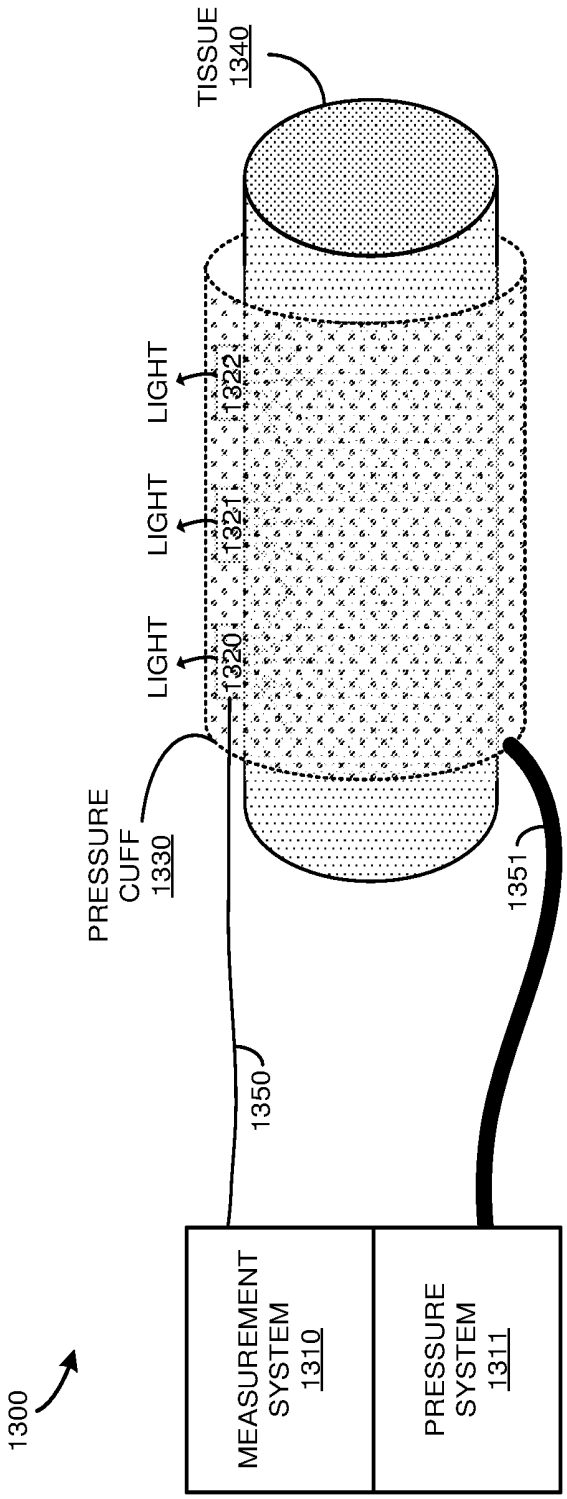

TISSUE
1340
LIGHT
1322
LIGHT
1321
LIGHT
1320
PRESSURE
CUFF
1330
1351
1350
MEASUREMENT
SYSTEM
1310
PRESSURE
SYSTEM
1311
1300

FIG. 13

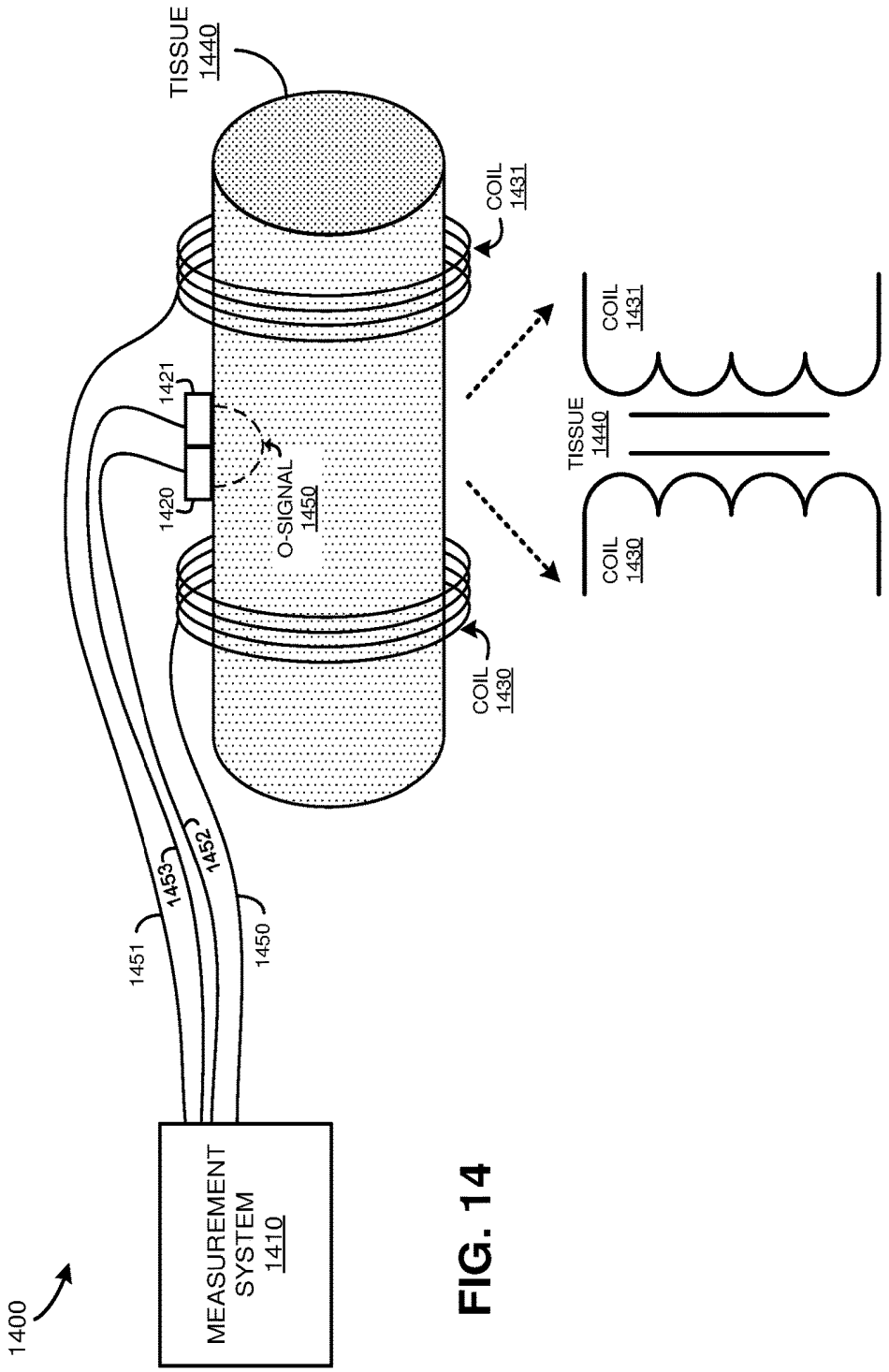

TISSUE
1440
COIL
1431
1421
1420
O-SIGNAL
1450
COIL
1430
1453
1452
1451
1450
MEASUREMENT
SYSTEM
1410
1400
COIL
1431
TISSUE
1440
COIL
1430

FIG. 14

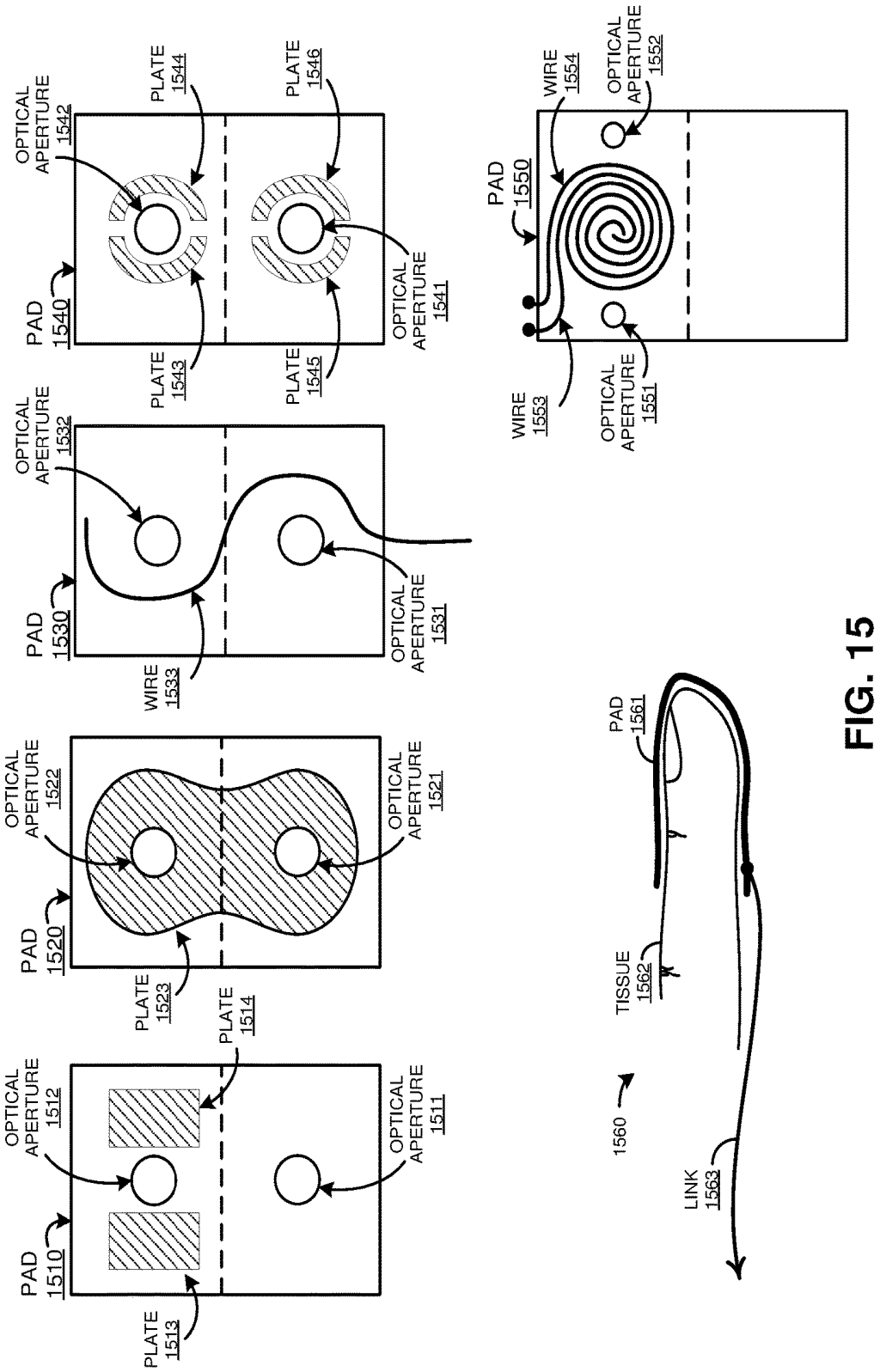

PAD 1510
OPTICAL APERTURE 1512
OPTICAL APERTURE 1511
PLATE 1513
PLATE 1514
PAD 1520
OPTICAL APERTURE 1522
OPTICAL APERTURE 1521
PLATE 1523
PAD 1530
OPTICAL APERTURE 1532
OPTICAL APERTURE 1531
WIRE 1533
PAD 1540
OPTICAL APERTURE 1542
OPTICAL APERTURE 1541
PLATE 1543
PLATE 1544
PLATE 1545
PLATE 1546
PAD 1550
WIRE 1554
OPTICAL APERTURE 1552
WIRE 1553
OPTICAL APERTURE 1551
1560
PAD 1561
TISSUE 1562
LINK 1563

FIG. 15

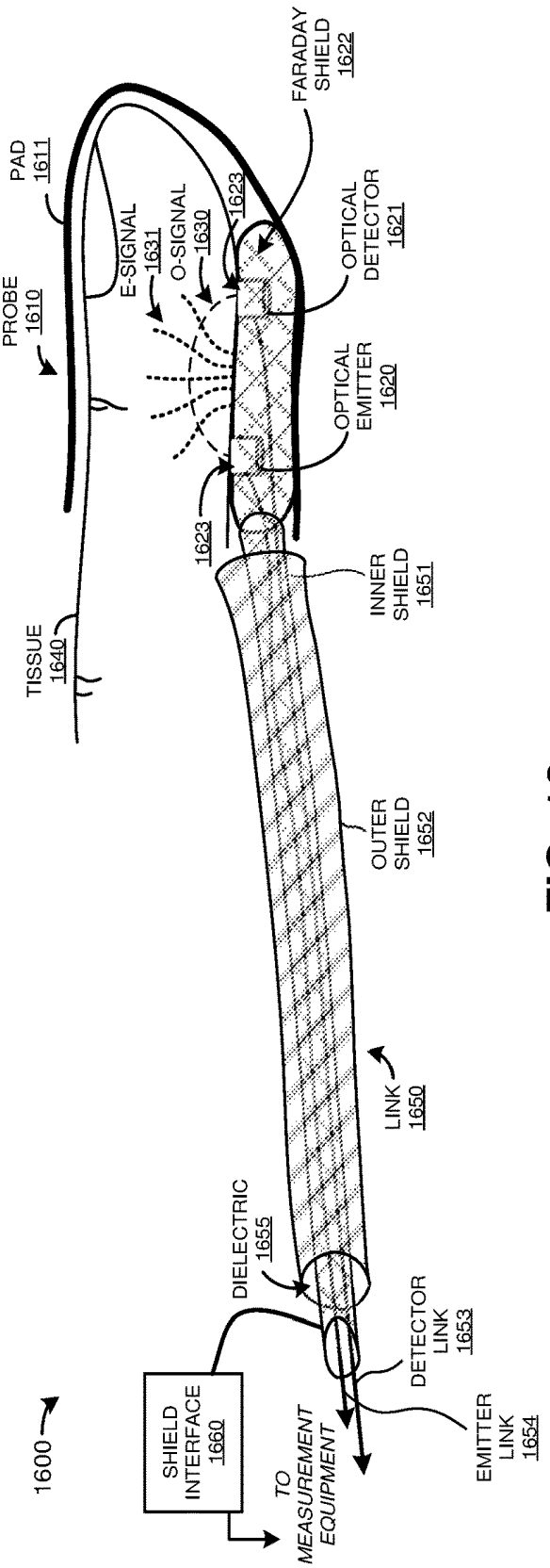

1600
PROBE 1610
PAD 1611
TISSUE 1640
E-SIGNAL 1631
O-SIGNAL 1630
1623
FARADAY SHIELD 1622
OPTICAL DETECTOR 1621
OPTICAL EMITTER 1620
1623
INNER SHIELD 1651
OUTER SHIELD 1652
LINK 1650
DIELECTRIC 1655
DETECTOR LINK 1653
EMITTER LINK 1654
SHIELD INTERFACE 1660
TO MEASUREMENT EQUIPMENT

FIG. 16

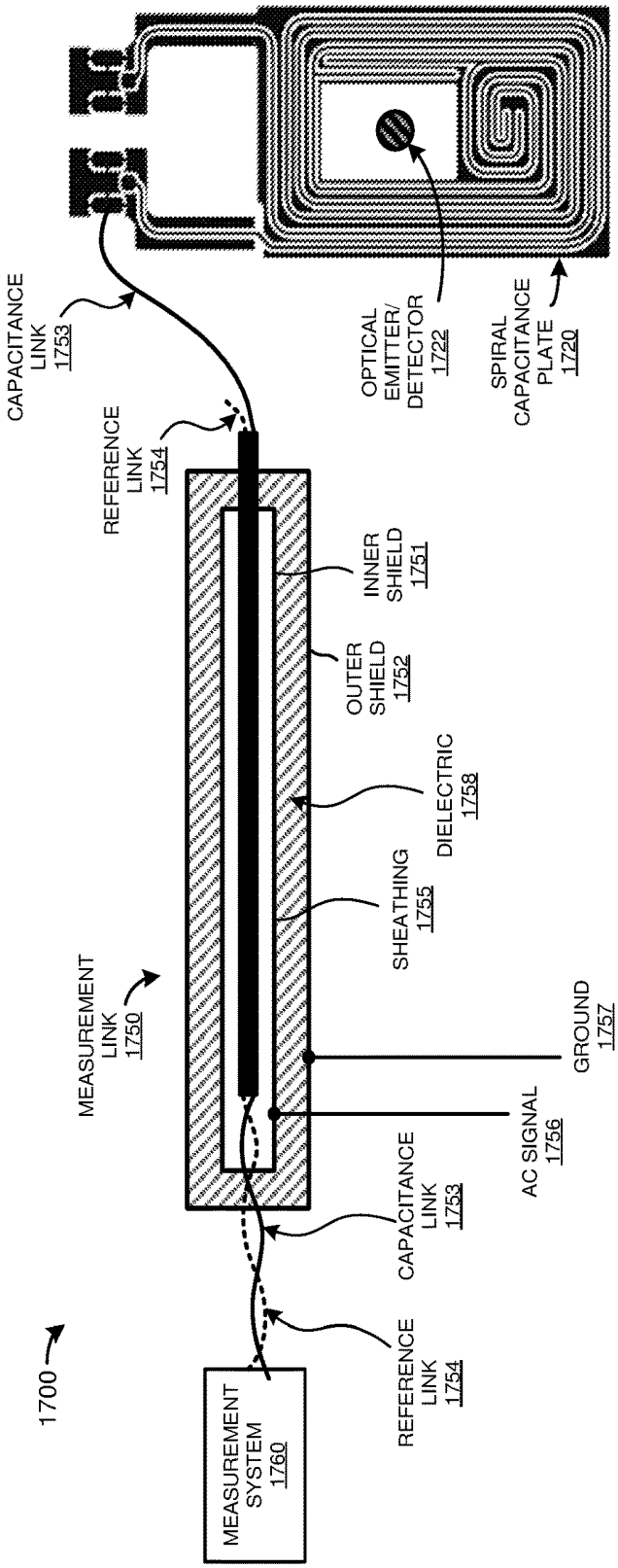

CAPACITANCE LINK 1753
REFERENCE LINK 1754
OPTICAL EMITTER/ DETECTOR 1722
SPIRAL CAPACITANCE PLATE 1720
INNER SHIELD 1751
OUTER SHIELD 1752
DIELECTRIC 1758
SHEATHING 1755
MEASUREMENT LINK 1750
GROUND 1757
AC SIGNAL 1756
CAPACITANCE LINK 1753
REFERENCE LINK 1754
1700
MEASUREMENT SYSTEM 1760

FIG. 17

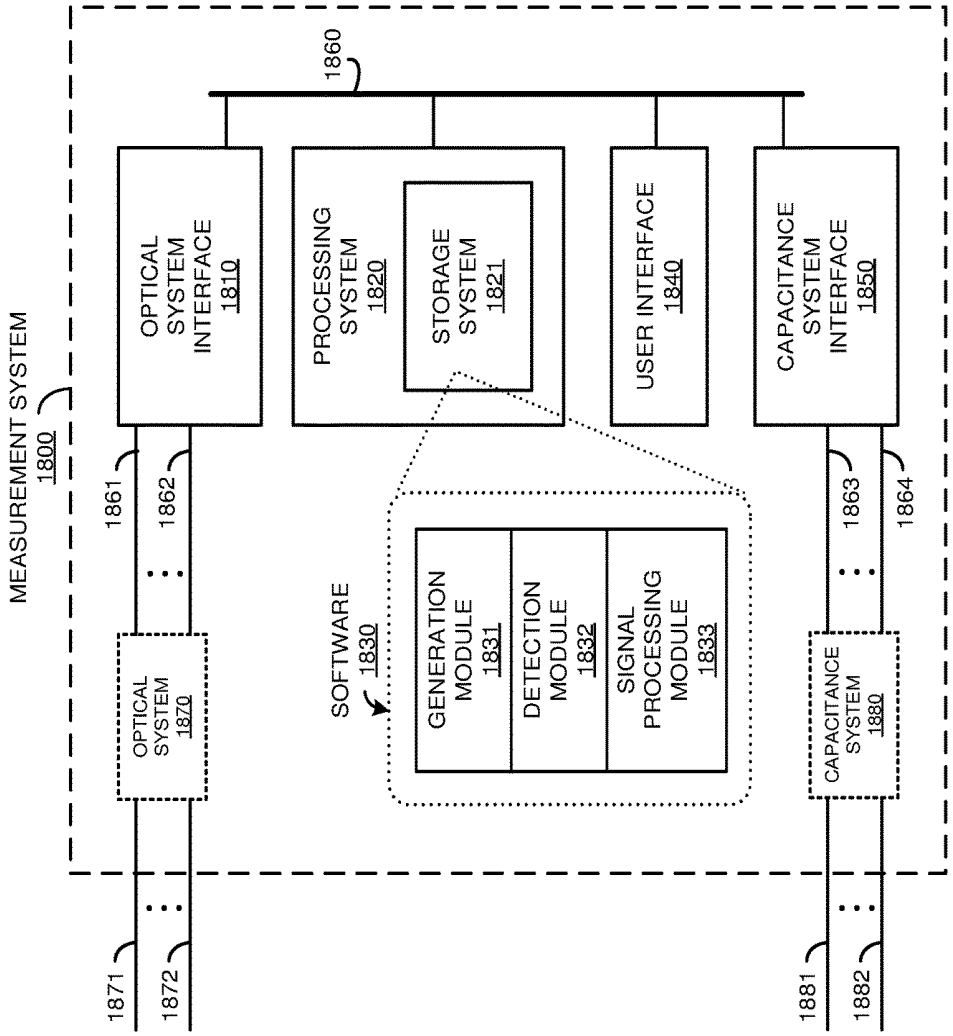

MEASUREMENT SYSTEM
1800
1860
OPTICAL SYSTEM INTERFACE 1810
PROCESSING SYSTEM 1820
STORAGE SYSTEM 1821
USER INTERFACE 1840
CAPACITANCE SYSTEM INTERFACE 1850
1861
1862
1863
1864
SOFTWARE 1830
GENERATION MODULE 1831
DETECTION MODULE 1832
SIGNAL PROCESSING MODULE 1833
OPTICAL SYSTEM 1870
CAPACITANCE SYSTEM 1880
1871
1872
1881
1882

FIG. 18

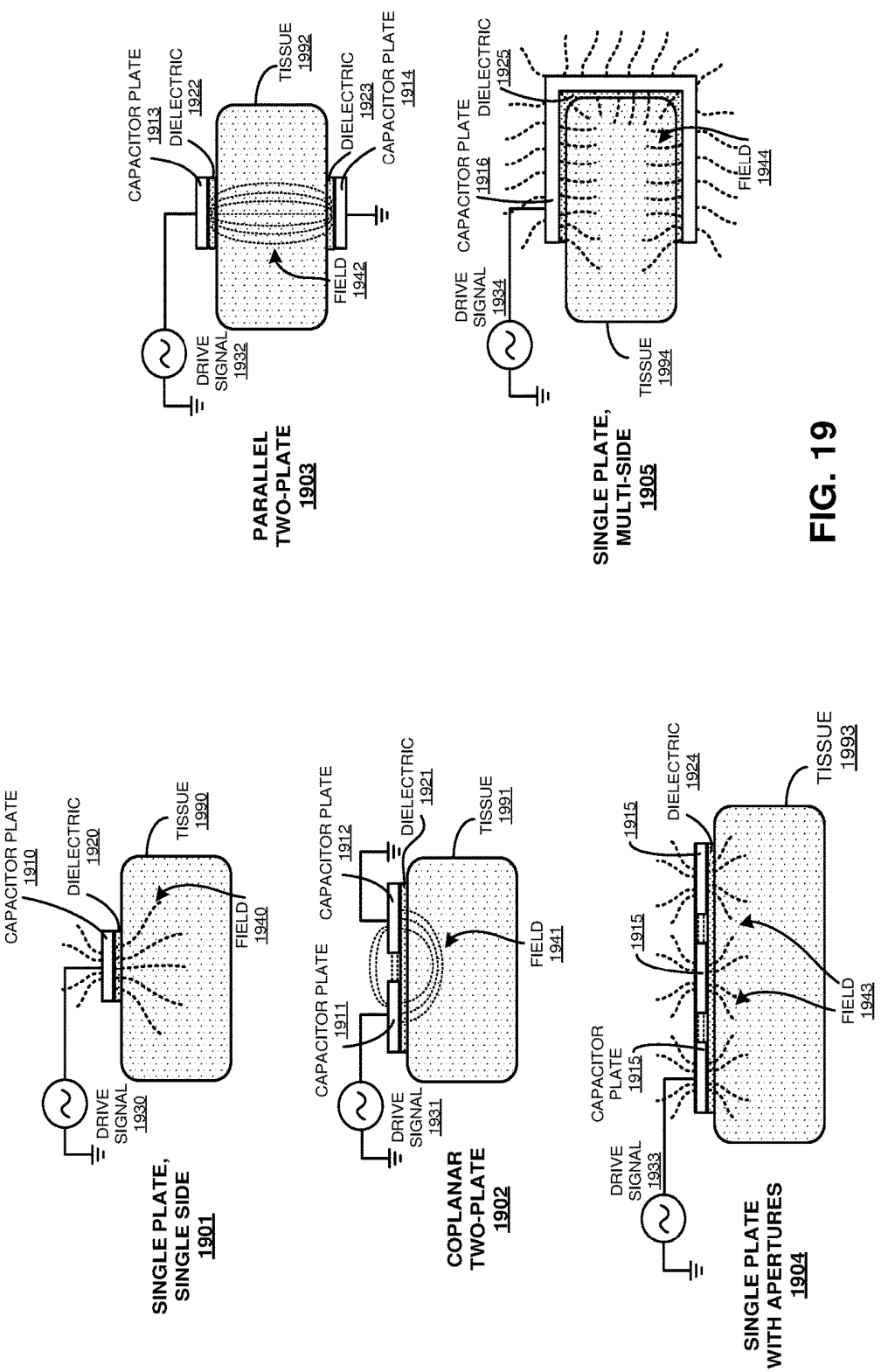

CAPACITOR PLATE 1910
DIELECTRIC 1920
TISSUE 1990
FIELD 1940
DRIVE SIGNAL 1930
SINGLE PLATE, SINGLE SIDE 1901
CAPACITOR PLATE 1912
CAPACITOR PLATE 1911
DIELECTRIC 1921
TISSUE 1991
FIELD 1941
DRIVE SIGNAL 1931
COPLANAR TWO-PLATE 1902
1915
1915
DIELECTRIC 1924
TISSUE 1993
FIELD 1943
CAPACITOR PLATE 1915
DRIVE SIGNAL 1933
SINGLE PLATE WITH APERTURES 1904
CAPACITOR PLATE 1913
DIELECTRIC 1922
TISSUE 1992
DIELECTRIC 1923
CAPACITOR PLATE 1914
FIELD 1942
DRIVE SIGNAL 1932
PARALLEL TWO-PLATE 1903
CAPACITOR PLATE 1916
DIELECTRIC 1925
FIELD 1944
DRIVE SIGNAL 1934
TISSUE 1994
SINGLE PLATE, MULTI-SIDE 1905

FIG. 19

CAPACITANCE ENHANCED PHYSIOLOGICAL MEASUREMENTS

RELATED APPLICATIONS

This patent application is a continuation of U.S. patent application Ser. No. 14/273,764 that was filed on May 9, 2014, and is entitled "CAPACITANCE ENHANCED PHYSIOLOGICAL MEASUREMENTS," which is also related to and claims priority to U.S. Provisional Patent Application No. 61/912,998, titled "CAPACITANCE ENHANCED OPTICAL PHYSIOLOGICAL MEASUREMENTS," filed Dec. 6, 2013, and which is hereby incorporated by reference in its entirety.

TECHNICAL FIELD

Aspects of the disclosure are related to the field of medical devices, and in particular, measuring physiological parameters of tissue.

TECHNICAL BACKGROUND

Various medical devices can non-invasively measure parameters of blood in a patient. Pulse oximetry devices are one such non-invasive measurement device, typically employing solid-state lighting elements, such as light-emitting diodes (LEDs) or solid state lasers, to introduce light into the tissue of a patient. The light is then detected to generate a photoplethysmogram (PPG). These photoplethysmography systems can also measure changes in blood volume of tissue of a patient and calculate various parameters such as heart rate, respiration rate, and oxygen saturation.

However, some conventional optical pulse oximetry devices only measure certain limited blood parameters, and lack the ability to measure other patient physiological parameters. Some optical pulse oximetry devices are also subject to patient-specific noise and inconsistencies which limit the accuracy of such devices. For example, monitoring infants or patients in intensive care units can be difficult. Motion of the patient and other incidental factors can lead to noise and inaccuracies of optical-based measurements. Some optical measurement systems are sensitive to shifts in venous blood volumes, introducing errors into arterial blood measurements.

Capacitive sensing has been employed to measure some physiological parameters by applying electric fields directly through tissue using two-plate capacitors having individual plates positioned on different sides of the tissue. This two-plate capacitive sensing can be combined with optical measurement to determine changes in volume of tissue due to cardiac pulsing.

OVERVIEW

Systems, methods, apparatuses, and software for measuring and determining physiological parameters of a patient are presented. In one example, a physiological measurement system includes an optical system configured to emit one or more optical signals into tissue of a patient, and detect the one or more optical signals after propagation through the tissue. The physiological measurement system includes a capacitance system configured to apply one or more electric field signals to a single side of the tissue to determine a capacitance signal based at least on changes in the one or more electric field signals, and a processing system configured to process at least the one or more detected optical signals and the capacitance signal to determine a physiological parameter of the patient.

BRIEF DESCRIPTION OF THE DRAWINGS

Many aspects of the disclosure can be better understood with reference to the following drawings. The components in the drawings are not necessarily to scale, emphasis instead being placed upon clearly illustrating the principles of the present disclosure. Moreover, in the drawings, like reference numerals designate corresponding parts throughout the several views. While several embodiments are described in connection with these drawings, the disclosure is not limited to the embodiments disclosed herein. On the contrary, the intent is to cover all alternatives, modifications, and equivalents.

FIG. **1**A is a system diagram illustrating a physiological measurement system.

FIG. **1**B is a system diagram illustrating a physiological measurement system.

FIG. **2** is a flow diagram illustrating a method of operating a physiological measurement system.

FIG. **3** is a system diagram illustrating a physiological measurement system.

FIG. **4** is a flow diagram illustrating a method of operating a physiological measurement system.

FIG. **5** is a system diagram illustrating a physiological measurement system.

FIG. **6** is a flow diagram illustrating a method of operating a physiological measurement system.

FIG. **7** is a system diagram illustrating a physiological measurement system.

FIG. **8** is a flow diagram illustrating a method of operating a physiological measurement system.

FIG. **9** is a diagram illustrating measurement of physiological parameters.

FIG. **10** is a diagram illustrating measurement of physiological parameters.

FIG. **11**A is a diagram illustrating measurement of physiological parameters.

FIG. **11**B is a diagram illustrating measurement of physiological parameters.

FIG. **12** is a diagram illustrating measurement of physiological parameters.

FIG. **13** is a system diagram illustrating a physiological measurement system.

FIG. **14** is a system diagram illustrating a physiological measurement system.

FIG. **15** is a diagram illustrating measurement pads for measurement of physiological parameters.

FIG. **16** is a system diagram illustrating a physiological measurement system.

FIG. **17** is a system diagram illustrating a physiological measurement system.

FIG. **18** is a block diagram illustrating a measurement system.

FIG. **19** is a diagram illustrating various capacitance configurations.

DETAILED DESCRIPTION

The examples discussed herein include systems, apparatuses, methods, and software for enhanced measurement of physiological parameters in patients. When optical measurements are employed to detect physiological parameters in tissue of a patient, optical signals associated with the optical

measurement can be subjected to various interference and noise, such as patient motion artifacts and patient-specific variability. Capacitance-based sensing can be employed to enhance or supplement the optical measurements to provide corrections, data stabilization, or additional sensing capabilities to optical-only measurement systems. In other examples, capacitance measurements are employed to detect physiological parameters in tissue of a patient without relying upon optical measurements.

In addition to the advantages and applications of the capacitance-enhanced optical and capacitance-based systems below, other applications such as fitness band monitors to monitor pulse, breathing rate, heart rate, sweating levels, oxygen levels, or other parameters of subjects performing athletic activities can include these capacitance and optical monitoring systems. For example, such systems are described below with respect to FIGS. **7-9**. Other examples include cuff pressure and moisture monitoring systems for tracheal tubes or for monitoring of premature babies.

The physiological parameters measured or determined by the capacitance-enhanced systems can include various plethysmograph (pleth) information, such as photoplethysmograms (PPG), PPG parameters, and temporal variability of PPG parameters (such as pleth morphology and pulse information). The physiological parameters measured or determined by the capacitance-enhanced systems can also include electrocardiography (ECG) information via capacitive sensing, pulse rate, respiratory rate, respiratory effort, blood pressure, oxygen concentrations, hemoglobin concentrations, total hemoglobin concentration (tHb), saturation of peripheral oxygen (SpO_2), SpO_2 variability, regional oxygen saturation (rSO_2), apnea conditions, arrhythmia, and saturation pattern detection among other parameters and characteristics, including combinations and variations thereof. Physiological measurements can be performed using the various examples herein. Some of these include determining respiration rate from a finger, pulse rate from a finger, motion of patient, continuous non-invasive blood pressure measurement (CNIBP), deltaPOP (a measurement of the variability of the pleth pulses), variability of optical pleth to determine vessel elasticity, dehydration, apnea detection and monitoring, and auto-regulation of patients. In addition, enhancements to measurement include body location detection to determine where sensors are applied on patient, smart blood pressure cuffs, blood pressure measurement triggered when blood pressure changes beyond thresholds, enhanced cuff position and accuracy detection, and skin type and color detection. Also, the measurement systems described herein can provide various improvements to conventional optical pulse oximetry using optical signals separately or in tandem with electric field signals. Some examples include motion correction due to patient movement, sensor on/off tissue or finger, ECG lock for pleth signals, checking assumptions and correlations of optical-only measurements, reducing time to post results to a doctor or patient, correction of measurements for DC shifts, sensor pressure correction on tissue, signal quality improvements, sensor fault detection, optical signal fault detection, signal processing tailoring to skin/blood types and conditions, detecting and correcting changes in skin properties due to moisture/sweat or elasticity, improved signal analysis using wavelet analysis of signals, pleth morphology, or FFT (Fast Fourier Transform), and power saving by turning off optical sensors/emitters when not applied on tissue properly.

In yet further examples, the capacitance signal can be employed to reduce noise or enhance measurement of other non-optical physiological sensors. Breathing monitors can be coupled to a capacitive sensor on a fingertip, and motion of the patient as determined by the capacitive sensor can scale or modify the readings captured by the breathing monitors. The capacitance signal can be used to cross-check other physiological sensors. For example, if a first sensor observes a low breathing rate or lack of breathing, a capacitive signal can be monitored to determine if the breathing sensor is faulty or reading an actual low breathing rate event. In infant monitoring environments, such as a neonatal intensive care unit (NICU), breathing monitors can be difficult to apply and maintain proper positioning on a moving infant. Capacitance based sensors, as discussed herein, can monitor breathing or pulse rate of the infant to determine if the breathing as monitored by the breathing monitor is valid or if the sensor has fallen off or been mis-aligned. Furthermore, capacitance based sensing can be used to replace bulky breathing monitor equipment for infants and instead use only a small adhesive pad with a capacitive sensor or a clip-on sensor with a capacitive element. Capacitance sensing can be used in a NICU to monitor activity and movement, such as to ensure that an infant is moving regularly.

As a first example of a measurement system for measuring physiological parameters of a patient, FIG. **1**A is presented. FIG. **1**A is a system diagram illustrating measurement system **100**. Elements of measurement system **100** measure one or more physiological parameters of tissue **140**. In the example shown in FIG. **1**A, measurement system **100** includes single plate capacitor **182** on a single side of tissue **140**, using tissue **140** as a dielectric.

Measurement system **100** includes processing system **110**, physiological sensor system **120**, and capacitance system **130**, with sensor node **190** and capacitance node **182** applied to tissue **140**. Processing system **110** and physiological sensor system **120** communicate over link **170**. Processing system **110** and capacitance system **130** communicate over link **171**. Physiological sensor system **120** and sensor node **190** are coupled over link **160**. Capacitance system **130** and capacitance node **182** are coupled over link **162**. In some examples, processing system **110**, physiological sensor system **120**, and capacitance system **130** are included in measurement equipment **101**. In addition to the capacitance and physiological sensors shown in FIG. **1**A, measurement system **100** can also include further sensors, such as accelerometers, temperature sensors, moisture sensors, blood pressure cuffs, or other physiological and environmental sensors.

In operation, physiological sensor system **120** is configured to receive instructions and signals from processing system **110** over link **170**. In some examples, physiological sensor system **120** is configured to perform signal detection and processing for signals received over link **160** and transfer information related to these signals to processing node **110** over link **170** for further processing and analysis. Physiological sensor system **120** can measure one or more physiological parameters of tissue **140** using sensor node **190**. Physiological sensor system **120**, along with sensor node **190**, can comprise at least one of a pulse oximetry system, an ECG system, an acoustic physiological parameter measurement system, a breathing monitor, and a pulse rate monitor, among other physiological measurement systems, including combinations thereof. Physiological sensor system **120** or processing system **110** can also receive physiological parameters or other physiological information from other equipment and systems, such as other monitoring and detection equipment not shown in FIG. **1**A. Capacitance system **130** is configured to receive instructions and signals from processing system **110** over link **171** to generate signals for emission as electric field signal **151**. Capacitance

system **130** is also configured to perform signal detection and processing for electric field signals monitored over link **162** and transfer information related to these signals to processing node **110** over link **171** for further processing and analysis.

In some examples, physiological sensor system **120** includes optical-based measurement equipment and systems. FIG. **1**B is a system diagram illustrating an example configuration of measurement system **102**. Elements of measurement system **102** in FIG. **1**B emit and detect optical and electric field signals in tissue **140** of a patient for measuring one or more physiological parameters of tissue **140**.

In the example shown in FIG. **1**B, measurement system **102** includes a single plate capacitor positioned proximate to a single side of tissue **140**. The single plate capacitor is included in capacitance node **180** in FIG. **1**B. The single plate capacitor of capacitance node **180** can be placed on tissue **140** in some examples. However, in other examples, such as shown in FIG. **1**B, the single plate capacitor of capacitance node **180** can have an air gap or have one or more layers of non-tissue material such as air, clothing, coatings, polymers, or other materials. Thus, in FIG. **1**B, the single plate capacitor is in a non-contact configuration with regard to tissue **140**. Also, the optical measurement system of FIG. **1**B is shown as a reflectance pulse oximetry configuration with optical emitter and detector equipment positioned on a same side of tissue **140**. Further examples can instead be employed, such as transmission pulse oximetry with optical emitter and detector equipment located on different sides of tissue **140**.

Measurement system **102** includes processing system **110**, optical system **121**, and capacitance system **130**, with optical nodes **180-181** and capacitance node **182** applied to tissue **140**. Processing system **110** and optical system **121** communicate over link **170**. Processing system **110** and capacitance system **130** communicate over link **171**. Optical system **121** and optical node **180** are coupled over link **160**. Optical system **121** and optical node **181** are coupled over link **161**. Capacitance system **130** and capacitance node **182** are coupled over link **162**. In some examples, processing system **110**, optical system **121**, and capacitance system **130** are included in measurement equipment **101**. In addition to capacitance and optical sensors, measurement system **102** can also include further sensors, such as accelerometers, temperature sensors, moisture sensors, blood pressure cuffs, or other physiological and environmental sensors.

In operation, optical system **121** is configured to receive instructions and signals from processing system **110** over link **170** to generate signals for emission as optical signal **150**. Optical system **121** is also configured to perform signal detection and processing for signals received over link **161** and transfer information related to these signals to processing node **110** over link **170** for further processing and analysis. Capacitance system **130** is configured to receive instructions and signals from processing system **110** over link **171** to generate signals for emission as electric field signal **151**. Capacitance system **130** is also configured to perform signal detection and processing for electric field signals monitored over link **162** and transfer information related to these signals to processing node **110** over link **171** for further processing and analysis. Capacitance system **130** can measure a capacitance signal which is described below in FIG. **2**.

As a first example operation of any of measurement systems **100** and **102**, FIG. **2** is provided. FIG. **2** is a flow diagram illustrating a method of operation of a measurement system. The operations of FIG. **2** are referenced below parenthetically. In FIG. **2**, physiological sensor system **120** detects (**201**) a physiological signal representative of one or more physiological parameters of a patient. As discussed in FIG. **1**A, physiological sensor system **120** can comprise any of a pulse oximetry system, an ECG system, an acoustic physiological parameter measurement system, a breathing monitor, and a pulse rate monitor, among other physiological measurement systems, including combinations thereof. Thus, physiological sensor system **120** can measure physiological signals related to physiological parameters of tissue **140** using at least sensor node **190**, or physiological sensor system **120** can monitor patient physiological parameters (in breathing monitor examples) to identify the physiological parameters.

Alternatively, physiological sensor system **120** can receive physiological parameters or other physiological information from other equipment and systems, such as external monitoring systems. In FIG. **2**, a physiological parameter can be measured by another system not included in FIG. **1**A, such as a capnometer, breathing rate measurement system, blood pressure system, pulse monitoring system, among others, including combinations thereof. Sensor system **120** can receive one or more physiological parameters from an external system instead of measuring signals related to physiological parameters.

Measurement system **102** of FIG. **1**B illustrates an optical measurement configuration to detect physiological signals. FIG. **1**B shows a pulse oximetry measurement system, namely optical system **121** and associated optical nodes **180-181**. Optical system **121** emits signals over link **160** for emission as optical signal **150** into tissue **140**, and optical node **180** emits optical signal **150** into tissue **140**. In some examples, link **160** is a wired or wireless signal link, and carries a measurement signal to optical node **180** which converts the measurement signal into an optical signal and emits optical signal **150** into tissue **140**. The optical signal can be emitted using a laser, laser diode, light emitting diode (LED), or other light emission device. In other examples, link **160** is an optical link, and carries an optical signal to optical node **180**. Optical node **180** can comprise tissue interface optics, such as lenses, prisms, or other optical fiber-to-tissue optics, which interface optical link **160** to tissue **140** for emission of optical signal **150**. One or more optical wavelengths can be used by optical node **180** to measure tissue **140**, and the one or more optical wavelengths can be selected based on various physiological factors, such as isosbestic wavelengths associated with blood components of tissue **140**. In a particular example, wavelengths such as 660 nm and 808 nm are employed.

Continuing in the pulse oximetry example of FIG. **1**B, optical system **121** detects the optical signals after propagation through the tissue. Optical node **181** receives optical signal **150** after propagation through tissue **140**. Optical system **121** receives signals over link **161** from optical node **181** representative of optical signal **150** after propagation through tissue **140**. In some examples, link **161** is a wired or wireless signal link, and carries a detection signal from optical node **181** which converts a received optical signal **150** into a detection signal after detecting optical signal **150** from tissue **140**. Optical signal **150** can be detected using a photodiode, avalanche photodiode, or other optical detection device, along with any associated tissue interface optics. In other examples, link **161** is an optical link, and carries an optical signal from optical node **181**. Optical node **181** can comprise tissue interface optics, such as described above for

node **180**, which interface optical link **161** to tissue **140** for capture of optical signal **150** after propagation through tissue **140**.

Capacitance system **130** applies (**202**) electric field signal **151** to tissue **140** to determine a capacitance signal. Capacitance system **130** generates one or more electric signals over link **162** to generate electric field signal **151** in tissue **140**. Link **162** is an electric signal link which drives capacitance node **182** to emit electric field **151** in tissue **140**. Electric field signal **151** can be applied by a capacitor portion of capacitance node **182**. In some examples, capacitance node **182** includes a single plate capacitor which uses tissue **140** as a dielectric. Tissue interface elements, such as pads, adhesives, clamps, and the like, can be included in capacitance node **182**. In many examples, electric field signal **151** is a modulated electric signal.

The capacitor portion, such as the single-plate capacitor employed in FIGS. **1**A and **1**B, can apply electric field **151** proximate to tissue **140**, which can include application of electric field signal **151** without contact of any capacitor plate portion of capacitance node to tissue **140**. In other examples, any associated capacitor plate portion of capacitance node **182** is positioned to contact tissue **140**. A contact example is shown in FIG. **1**A, while a non-contact example is shown in FIG. **1**B. Electric field signal **151** can comprise a modulated signal produced by circuitry of capacitance system **130** and transferred onto link **162** for application of electric field signal **151** to tissue **140** by capacitance node **182**.

Capacitance system **130** detects changes in electric field signal **151** to identify a capacitance signal. These changes in electric field signal **151** can be measured over link **162**. The capacitance signal can correspond to a change in capacitance of a capacitor portion of capacitance node **182** that can be detected by capacitance system **130**. The change in capacitance can be monitored as electric field signal **151** is applied to tissue and the capacitance signal can reflect the change in capacitance. Electric field signal **151** can comprise a modulated signal, such as a sine wave signal. Modulation circuitry used to produce electric field signal **151** can include a capacitor portion of capacitance node **182**. Changes in a capacitance value of a capacitor used to apply electric field signal **151** to tissue can be detected by capacitance system **130** as a change in modulation frequency or a change in power draw of the capacitor or associated modulation circuitry, among other detection methods. These changes in electric field signal **151** can also be measured by monitoring changes in a noise level, current draw, or other characteristics of electric field signal **151** as detected by capacitance system **130**. Capacitance system **130** can comprise capacitance-to-digital converter circuitry. The capacitance signal can be monitored concurrent with other physiological parameter monitoring, such as that described in operation **201**.

Electric field signal **151** can experience changes due to a change in the dielectric environment into which electric field signal **151** is applied. The dielectric environment can include any materials that are proximate to a capacitor plate which applies electric field signal **151**. Example materials in the dielectric environment include tissue **140**, clothing, air gaps, pads, coatings, casings, gels, or adhesives, among other materials. The changes can be due to physiological changes in tissue **140** or changes in the physiological environment of tissue **140**. The changes in electric field signal **151** can be caused by motion of tissue **140**, where the motion is caused by venous blood movement within tissue **140**, physical movement of tissue **140**—such as movement of a limb associated with tissue **140**, or due to changes in pressure/orientation of capacitance node **182** on tissue **140**.

In further examples, tissue **140**, or the associated patient, is connected electrically to an electrical reference potential, such as a ground potential. A low-resistance connection of tissue of the patient to the reference potential can be employed, such as a metallic bracelet worn by the patient, an electrical connection used for other physiological measurements, such as an ECG lead, or though tissue interface portions of system **100**. The tissue interface portions can include clamp-on probes, adhesive pads, conductive foams, or conducting gels which interface electrically to tissue of the patient. The electrical grounding or reference potential connection can be employed to enhance signal measurement of the single-plate capacitor. Some measurements of the capacitance signal can be affected by unwanted influence from the environment around tissue **140**, such as nearby objects, nearby people, things the patient is presently touching or contacting, among other influences. A reference or ground connection of tissue **140** or the associated patient can reduce unwanted noise and improve measurement signal amplitude.

Processing system **110** reduces (**203**) a noise level in the physiological signal based on at least the capacitance signal. In the example shown in FIG. **1**B, an optical signal is measured which might include noise or undesired signal artifacts. Physiological parameters determined from the physiological signal might be inaccurate due to this noise. However, in this example, measured physiological signals can have various noise or undesired signal artifacts reduced or removed using the capacitance signal. For example, various signal elements of the capacitance signal can be isolated and used to remove unwanted noise from the physiological signals and determine physiological parameters. The physiological signals can include those identified in operation **201**, such as by monitoring pulse oximetry-based physiological signals in FIG. **1**B, among others. In one example, the capacitance signal can be monitored to detect motion associated with tissue **140**. Signal elements of the capacitance signal due to motion of tissue **140** can be isolated and used to subtract unwanted motion-based noise artifacts from the pulse oximetry-based physiological signals. In examples where physiological parameters are received from external systems or equipment, processing system **110** can correct the physiological parameters using at least the capacitance signal to determine corrected physiological parameters of the patient.

In addition to correction of measured physiological signals using the capacitance signal, other enhanced measurements can be employed by measurement system **100**. For example, measurement system **100** can provide enhanced measurement beyond the optical measurement of FIG. **1**B due to the combination of optical and capacitance-based signals applied to tissue **140**. These enhancements can compensate optical readings for variation due to movement of tissue **140**, deformation of tissue **140**, and pressure of sensor portions applied to tissue **140**. In some examples, capacitance system **130** can detect when optical sensor portions, such as optical nodes **180-181** are or are not sufficiently applied to tissue **140**. Responsive to optical nodes **180-181** not being sufficiently applied to tissue, measurement system **100** can suspend measurement of optical signal **150**, prevent processing of optical signal **150** to determine physiological parameters, or alert an operator of measurement system **100** to an improper sensor application condition, among other operations. In other examples, a pressure-based compensation can be performed on optical

signal **150** based on electric field signal **151** to provide more accurate and stable measurements of optical signal **150**, as described below in FIG. **10**.

In addition to capacitance system **130** being used to compensate for variability in optical signals in tissue **140**, capacitance system **130** can be employed to add additional measurement capability to an optical-only measurement system. A pulse oximetry measurement to detect SpO_2 can be improved using capacitance system **130** and a single plate capacitor configuration, such as capacitance node **182**. An optical-only hemoglobin measurement of blood of tissue **140** can be improved, or an optical or electrical plethysmograph can be measured, by adding a single plate capacitor configuration, such as capacitance node **182**. A capacitive measurement can add additional measured parameters and can be employed in various hemoglobin and SpO_2 measurement methods to reduce a number of variables in associated blood parameter equations. For example, both optical and capacitive sensing can be used to reduce a number of unknown equation variables compared to an optical-only system. In some examples, respiratory rate of tissue **140** can be determined from heart rate changes detected using optical system **121** and capacitance system **130**.

In another example, a multi-level measurement process can be employed. A high level of accuracy using both optical and capacitive measurements can be employed to measure physiological parameters of tissue **140**, and a threshold condition can be established on one or more of the physiological parameters. If the threshold condition is not met, then a lower level of accuracy using only the capacitive measurements can be employed to monitor for the threshold condition. If the threshold condition is met during capacitive-only measurements, then optical system **121** can be engaged to provide the high level of accuracy for physiological measurement. As an example, a drop in oxygen saturation level is likely to trigger an increase in heart rate in a patient. A pulsatile signal indicative of heart rate can be detected from a capacitive measurement. Accordingly, a capacitive signal can be used to monitor heart rate while a pulse oximetry device is turned off to save power or reduce data collection requirements, without missing significant oxygen desaturation events. A pulse oximetry device can power down one or more emitters, such as LEDs, to save power. The capacitance signal can continue to track the heart rate and optionally cycle the LEDs on to confirm the heart rate and to check oxygen saturation. Examples of this multi-level measurement are discussed below regarding FIG. **11**B. In further examples, automatic gain control elements of a measurement system can use a capacitance signal to track phases of cardiac cycles and adjust brightness of associated optical emitters to increase signal-to-noise characteristics during desired segments of the cardiac cycle.

In yet further examples, a reduction in time to post results to a doctor or patient can be achieved using capacitance-enhanced measurements. For example, a capacitance-based measurement of a physiological signal can be monitored which can give a doctor or patient a quick and rough estimate of a physiological parameter. If a more detailed or more accurate measurement is desired, then another measurement system, such as an optical system, can be enabled.

Further examples of these various enhancements using capacitance-based measurements are described herein, such as in FIGS. **3-8**. As a first example, FIG. **3** is a system diagram illustrating measurement system **300**. Measurement system **300** includes at least capacitance nodes **183-184** and links **163-164**. Measurement system **300** is also shown including some similar elements as found in FIGS. **1**A and **1**B, although variations are possible. It should be understood that other physiological measurement elements can be included in system **300**. In FIG. **3**, capacitance nodes **183-184** are shown located an exemplary distance apart. This distance can be established based on calibration of the capacitance signal to a specific spacing, among other spacing. In FIG. **3**, a two-plate capacitor configuration is shown, with both capacitor plates located on the same side of tissue **140**.

Measurement system **300** emits and detects optical and electric field signals in tissue **140** of a patient for measuring one or more physiological parameters of tissue **140**. Measurement system **300** includes processing system **110**, optical system **121**, and capacitance system **130**, with optical nodes **180-181** and capacitance nodes **183-184** applied to tissue **140**. Processing system **110** and optical system **121** communicate over link **170**. Processing system **110** and capacitance system **130** communicate over link **171**. Optical system **121** and optical node **180** are coupled over link **160**. Optical system **121** and optical node **181** are coupled over link **161**. Capacitance system **130** and capacitance node **183** are coupled over link **163**. Capacitance system **130** and capacitance node **184** are coupled over link **164**. In some examples, processing system **110**, optical system **121**, and capacitance system **130** are included in measurement equipment **101**.

In operation, optical system **121** is configured to receive instructions and signals from processing system **110** over link **170** to generate signals for emission as optical signal **150**. Optical system **121** is also configured to perform signal detection and processing for signals received over link **161** and transfer information related to these signals to processing node **110** over link **170** for further processing and analysis. Capacitance system **130** is configured to receive instructions and signals from processing system **110** over link **171** to generate signals for emission as electric field signal **151**. Capacitance system **130** is also configured to perform signal detection and processing for electric field signals monitored over links **163-164** and transfer information related to these signals to processing node **110** over link **171** for further processing and analysis.

As an example operation of measurement system **300**, FIG. **4** is provided. FIG. **4** is a flow diagram illustrating a method of operation of measurement system **300**. The operations of FIG. **4** are referenced below parenthetically. In FIG. **4**, optical system **121** emits (**401**) optical signal **150** into tissue **140** of the patient. Optical system **121** emits signals over link **160** for emission as at least optical signal **150** into tissue **140**, and optical node **180** emits optical signal **150** into tissue **140**. In some examples, link **160** is an electric signal link, and carries an electrical signal to optical node **180** which converts the electrical signal into an optical signal and emits optical signal **150** into tissue **140**. The optical signal can be emitted using a laser, laser diode, light emitting diode (LED), or other light emission device. In other examples, link **160** is an optical link, and carries an optical signal to optical node **180**. Optical node **180** can comprise tissue interface optics which interface optical link **160** to tissue **140** for emission of optical signal **150**.

Optical system **121** detects (**402**) the optical signals after propagation through the tissue. Optical node **181** receives optical signal **150** after propagation through tissue **140**. Optical system **121** receives signals over link **161** from optical node **181** representative of optical signal **150** after propagation through tissue **140**. In some examples, link **161** is an electric signal link, and carries an electrical signal from optical node **181** which converts a received optical signal

150 into an electrical signal after detecting optical signal 150 in tissue 140. Optical signal 150 can be detected using a photodiode, avalanche photodiode, or other optical detection device, along with any associated tissue interface optics. In other examples, link 161 is an optical link, and carries an optical signal from optical node 181. Optical node 181 can comprise tissue interface optics which interface optical link 161 to tissue 140 for capture of optical signal 150 after propagation through tissue 140.

Capacitance system 130 applies (403) electric field signal 152 to tissue 140. Capacitance system 130 generates one or more electric signals over links 163-164 to generate electric field signal 152 in tissue 140. Links 163-164 are electric signal links which drive capacitance nodes 183-184 to emit electric field 152 in tissue 140. In this example, capacitance nodes 183-184 form a two-plate capacitor positioned on a single side of tissue 140, and uses tissue 140 as a dielectric. Tissue interface elements can be included in capacitance nodes 183-184. In many examples, electric field signal 152 is a modulated electric signal.

Capacitance system 130 detects (404) changes in electric field signal 152. Capacitance system 130 measures changes in electric field signal 152 over links 163-164. As the environment of tissue 140, the internals of tissue 140, and tissue 140 itself changes, associated changes in electric field signal 152 can be monitored by capacitance system 130. These changes can be reflected in a change in capacitance of a capacitor formed by capacitance nodes 183-184. In some examples, the changes in electric field signal 152 are due to motion of tissue 140, where the motion is caused by venous blood movement within tissue 140, physical movement of tissue 140, such as movement of a limb associated with tissue 140, or due to pressure/orientation of capacitance nodes 183-184 on tissue 140. In further examples, the changes in electric field signal 152 are due to changes in a capacitance value associated with capacitance nodes 183-184 due to variation in the dielectric environment of capacitance nodes 183-184. These changes can also be changes in a noise level, current draw, power level, or other characteristics of electric field signal 152 as detected by capacitance system 130.

Processing system 110 processes (405) optical signal 150 and the changes in electric field signal 152 to determine the physiological parameters of the patient. In some examples, processing the changes in electric field signal 152 includes detecting motion or noise induced by tissue 140, such as by motion of tissue 140, motion of biological elements within tissue 140, environmental noise, signal noise, or other effects. These effects can be processed to correct for noise or motion artifacts of optical signal 150 to determine physiological parameters.

The processing performed in operation 405 can include different processing techniques. In a first example, processing system 110 compares (406) changes in electric field signal 152 against measured optical signal 150 to determine the physiological parameters. For example, signal components of electric field signal 152 can be compared to signal components of measured optical signal 150 to improve measured optical signal 150 and determine physiological parameters from the improved optical signal 150. A capacitance signal or changes in electric field signal 152 can be used to identify noise in a portion of measured optical signal 150, and then that portion can be de-weighted when processing measured optical signal 150 to determine a physiological parameter. A capacitance signal or changes in electric field signal 152 can be used to identify a period of noise in the capacitance signal or the changes in electric field signal 152, and this period of noise can be used to drop or exclude a correlating timewise portion of measured optical signal 150 during processing to determine any physiological parameters. Thus, noisy periods or portions of measured optical signal 150 can be excluded from calculation of physiological parameters.

In a second example, processing system 110 subtracts (407) signal components of electric field signal 152 from measured optical signal 150 to determine the physiological parameters. For example, signal components of electric field signal 152 can be subtracted from signal components of measured optical signal 150 to reduce noise in measured optical signal 150 and determine physiological parameters from the noise-reduced optical signal 150. A scaled or filtered portion of a capacitance signal or changes in electric field signal 152 can be subtracted from a correlated portion of measured optical signal 150.

In a third example, processing system correlates (408) changes in electric field signal 152 to measured optical signal 150 to determine the physiological parameters. For example, signal components of electric field signal 152 can be correlated to signal components of measured optical signal 150 to improve measured optical signal 150 and determine physiological parameters from the improved optical signal 150. Other processing techniques can be employed, such as those discussed herein, including combinations and variations thereof.

Measurement system 300 can provide enhanced measurement beyond optical measurement due to at least the combination of optical and capacitance-based signals applied to tissue 140. These enhancements can compensate optical readings for variables in movement of tissue 140, deformation of tissue 140, and pressure of sensor portions applied to tissue 140. In some examples, capacitance system 130 can detect when optical sensor portions, such as optical nodes 180-181 are sufficiently applied to tissue 140. Responsive to optical nodes 180-181 not being sufficiently applied to tissue, measurement system 100 can prevent measurement by optical signal 150 or prevent processing of at least optical signal 150 to determine physiological parameters. In other examples, a pressure-based compensation can be performed on optical signal 150 based on electric field signal 151 to provide more accurate and stable measurements of optical signal 150.

In addition to capacitance system 130 being used to identify and compensate for variability in the detected optical signals, capacitance system 130 can be employed to add additional measurement capability to an optical measurement system. A pulse oximetry measurement to detect SpO_2 can be improved using capacitance system 130 and a dual-plate, single-sided capacitor configuration, such as capacitance nodes 183-184. An optical hemoglobin measurement of blood of tissue 140 can be improved, or an optical or electrical plethysmograph can be measured, by adding a dual-plate, single-sided capacitor configuration, such as capacitance nodes 183-184. In some examples, respiratory rate of tissue 140 can be determined from heart rate changes detected using optical system 121 and capacitance system 130.

Further examples of these various enhancements using capacitance-based measurements are described herein, such as in FIG. 5. FIG. 5 is a system diagram illustrating measurement system 500. Measurement system 500 includes at least capacitance nodes 185-186 and links 165-166. Measurement system 500 is also shown including some similar elements as found in FIGS. 1A and 1B, although variations are possible. It should be understood that other

physiological measurement systems can be included in system **500**. FIG. **5** includes two single-plate capacitors, with each single plate capacitor positioned on a single side of tissue **140**. Also, each single plate capacitor can be applied onto tissue **140**, or can include an air gap and other materials that separate each single plate capacitor from tissue **140**. FIG. **5** shows an exemplary gap between tissue **140** and each single plate capacitor.

Measurement system **500** emits and detects optical and electric field signals in tissue **140** of a patient for measuring one or more physiological parameters of tissue **140**. Measurement system **500** includes processing system **110**, optical system **121**, and capacitance system **130**, with optical nodes **180-181** and capacitance nodes **185-186** applied to tissue **140**. Processing system **110** and optical system **121** communicate over link **170**. Processing system **110** and capacitance system **130** communicate over link **171**. Optical system **121** and optical node **180** are coupled over link **160**. Optical system **121** and optical node **181** are coupled over link **161**. Capacitance system **130** and capacitance node **185** are coupled over link **165**. Capacitance system **130** and capacitance node **186** are coupled over link **166**. In some examples, processing system **110**, optical system **121**, and capacitance system **130** are included in measurement equipment **101**.

In operation, optical system **121** is configured to receive instructions and signals from processing system **110** over link **170** to generate signals for emission as optical signal **150**. Optical system **121** is also configured to perform signal detection and processing for signals received over link **161** and transfer information related to these signals to processing node **110** over link **170** for further processing and analysis. Capacitance system **130** is configured to receive instructions and signals from processing system **110** over link **171** to generate signals for emission as electric field signals **153-154**. Capacitance system **130** is also configured to perform signal detection and processing for electric field signals monitored over links **165-166** and transfer information related to these signals to processing node **110** over link **171** for further processing and analysis.

As an example operation of measurement system **500**, FIG. **6** is provided. FIG. **6** is a flow diagram illustrating a method of operation of measurement system **500**. The operations of FIG. **6** are referenced below parenthetically. In FIG. **6**, optical system **121** emits (**601**) optical signal **150** into tissue **140** of the patient. Optical system **121** emits signals over link **160** for emission as optical signal **150** into tissue **140**, and optical node **180** emits optical signal **150** into tissue **140**. In some examples, link **160** is an electric signal link, and carries an electrical signal to optical node **180** which converts the electrical signal into an optical signal and emits optical signal **150** into tissue **140**. The optical signal can be emitted using a laser, laser diode, light emitting diode (LED), or other light emission device. In other examples, link **160** is an optical link, and carries an optical signal to optical node **180**. Optical node **180** can comprise tissue interface optics which interface optical link **160** to tissue **140** for emission of optical signal **150**.

Optical system **121** detects (**602**) the optical signals after propagation through the tissue. Optical node **181** receives optical signal **150** after propagation through tissue **140**. Optical system **121** receives signals over link **161** from optical node **181** representative of optical signal **150** after propagation through tissue **140**. In some examples, link **161** is an electric signal link, and carries an electrical signal from optical node **181** which converts a received optical signal **150** into an electrical signal after detecting optical signal **150** in tissue **140**. Optical signal **150** can be detected using a photodiode, avalanche photodiode, or other optical detection device, along with any associated tissue interface optics. In other examples, link **161** is an optical link, and carries an optical signal from optical node **181**. Optical node **181** can comprise tissue interface optics which interface optical link **161** to tissue **140** for capture of optical signal **150** after propagation through tissue **140**.

Capacitance system **130** applies (**603**) a first electric field as electric field signal **153** to tissue **140**. Capacitance system **130** generates one or more electric signals over link **165** to generate electric field signal **153** in tissue **140**. Link **165** is an electric signal link which drives capacitance node **185** to emit electric field **153** in tissue **140**. In this example, capacitance node **185** forms a single-plate capacitor positioned on a single side of tissue **140**, and uses tissue **140** as a dielectric. Tissue interface elements can be included in capacitance node **185**. In many examples, electric field signal **153** is generated by a modulated electric signal.

Capacitance system **130** detects (**604**) changes in electric field signal **153**. Capacitance system **130** measures changes in electric field signal **153** over link **165**. As the environment of tissue **140**, the internals of tissue **140**, and tissue **140** itself changes, associated changes in electric field signal **153** can be monitored by capacitance system **130**. In some examples, the changes in electric field signal **153** are due to motion of tissue **140**, where the motion is caused by venous blood movement within tissue **140**, physical movement of tissue **140**, such as movement of a limb associated with tissue **140**, or due to pressure/orientation of capacitance node **185** on tissue **140**. In further examples, the changes in electric field signal **153** are due to changes in a capacitance value associated with capacitance node **185** due to variation in the dielectric environment of capacitance node **185**. These changes can also be changes in a noise level, current draw, power level, or other characteristics of electric field signal **153** as detected by capacitance system **130**.

Capacitance system **130** applies (**605**) a second electric field as electric field signal **154** to tissue **140**. Capacitance system **130** generates one or more electric signals over link **166** to generate electric field signal **154** in tissue **140**. Link **166** is an electric signal link which drives capacitance node **186** to emit electric field **154** in tissue **140**. In this example, capacitance node **186** forms a single-plate capacitor positioned on a single side of tissue **140**, and uses tissue **140** as a dielectric. Capacitance node **186** is positioned on a different side of tissue **140** than capacitance node **185**. In some examples, each of capacitance nodes **185-186** are positioned on opposite sides of tissue **140**, such as a top and bottom of a finger or digit. In other examples, each of capacitance nodes **185-186** are positioned on adjacent sides of tissue **140**, such as a top and adjacent side of a finger or digit. Tissue interface elements can be included in capacitance node **186**. In many examples, electric field signal **154** is a modulated electric signal.

In some examples, capacitance system **130** is configured to emit electric field signal **153** and electric field signal **154** simultaneously, using each of capacitance node **185** and capacitance node **186** as separate single-plate capacitors. Single-plate operation can be achieved in some examples by using isolation circuitry, such as separate measurement and drive circuitry, transformers, opto-isolators, or other isolation elements to ensure single-plate operation. When simultaneous operation is performed, each of capacitance node **185** and capacitance node **186** can use similar or different modulation frequencies for the respective electric field signals. For example, non-interfering modulation frequencies

can be selected for each of electric field signal **153** and electric field signal **154**. Frequency hopping, chirping, or spread spectrum techniques can also be employed to minimize interference of simultaneous measurement using electric field signal **153** and electric field signal **154**. In further examples, the modulation frequency can be swapped after a first measurement is taken to perform a second measurement using simultaneous electric field signal **153** and electric field signal **154**. In yet further examples, the modulation frequency of an associated electric field signal can be selected to minimize interference with other measurement devices, such as other physiological measurement equipment monitoring the patient. Non-simultaneous emission of electric field signal **153** and electric field signal **154** can also be employed, such as when using a similar modulation frequency for each of electric field signal **153** and electric field signal **154**. For example, a sequential measurement using electric field signal **153** and electric field signal **154** can be employed.

Capacitance system **130** detects (**606**) changes in electric field signal **154**. Capacitance system **130** measures changes in electric field signal **154** over link **166**. As the environment of tissue **140**, the internals of tissue **140**, and tissue **140** itself changes, associated changes in electric field signal **154** can be monitored by capacitance system **130**. These changes can be reflected in a change in capacitance of a capacitor formed by capacitance node **186** due to changes in the dielectric environment of capacitance node **186**. The change in capacitance can be reflected in a capacitance signal monitored by capacitance system **130**. In some examples, the changes in electric field signal **154** are due to motion of tissue **140**, where the motion is caused by venous blood movement within tissue **140**, physical movement of tissue **140**, such as movement of a limb associated with tissue **140**, or due to pressure/orientation of capacitance node **186** on tissue **140**. In further examples, the changes in electric field signal **154** are due to changes in a capacitance value associated with capacitance node **186** due to variation in the dielectric environment of capacitance node **186**. These changes can also be changes in a noise level, current draw, power level, or other characteristics of electric field signal **154** as detected by capacitance system **130**.

Processing system **110** processes (**607**) optical signal **150**, the changes in first electric field signal **153**, and changes in second electric field signal **154** to determine the physiological parameters of the patient. In some examples, processing the changes in electric field signals **153-154** includes detecting motion or noise induced by tissue **140**, such as by motion of tissue **140**, motion of biological elements within tissue **140**, environmental noise, signal noise, or other effects. These effects can be used to correct for noise or motion artifacts of optical signal **150** to determine the physiological parameters. The processing performed in operation **607** can include different processing techniques, such as those described in FIG. **4**.

Further examples of these various enhancements using capacitance-based measurements are described herein, such as in FIG. **7**. FIG. **7** is a system diagram illustrating measurement system **700**. Measurement system **700** is also shown including some similar elements as found in FIGS. **1A** and **1B**, although variations are possible. Measurement system **700** also omits optical measurement elements as discussed in the previous examples. It should be understood that other physiological measurement systems can be included in system **700**.

FIG. **7** shows two example capacitor arrangements, namely arrangement **790** and **791**. Capacitor arrangement **790** illustrates one or more capacitance nodes **187-188** positioned on the same side of tissue **140**. In a first example of arrangement **790**, a single plate capacitor of capacitance node **187** is employed on a single side of tissue **140**. In a second example of arrangement **790**, a two-plate capacitor is employed via capacitance nodes **187-188**—with both capacitor plates of the two-plate capacitor positioned on a single side of tissue **140**. Capacitor arrangement **791** illustrates a single plate capacitor of capacitance node **189** that wraps around tissue **140**. Capacitance node **189** can comprise a rigid or flexible material to achieve the wrap-around feature illustrated in FIG. **7**. In some examples, capacitor plates associated with capacitance nodes **187-189** are positioned on tissue **140**, while in other examples, an air gap or other material separates the associated capacitor plates from tissue **140**.

Measurement system **700** emits and detects electric field signals in tissue **140** of a patient for measuring one or more physiological parameters of tissue **140**. Measurement system **700** includes processing system **110** and capacitance system **130**, with capacitance nodes **187-189** applied to tissue **140**. Processing system **110** and capacitance system **130** communicate over link **171**. Capacitance system **130** and capacitance node **187** are coupled over link **167**. Alternatively, capacitance system **130** and capacitance node **189** are coupled over link **167**. Capacitance system **130** and optional capacitance node **188** are coupled over link **168**. In some examples, processing system **110** and capacitance system **130** are included in measurement equipment **101**. Capacitance nodes **187-188** are shown as located an exemplary distance apart. This distance can be arbitrary, or can be established based on calibration of the capacitance signal to a specific spacing, among other spacing.

In operation, capacitance system **130** is configured to receive instructions and signals from processing system **110** over link **171** to generate signals for emission as electric field signal **155**. Alternatively, capacitance system **130** can be configured to receive instructions and signals from processing system **110** over link **171** to generate signals for emission as electric field signal **156**. Capacitance system **130** is also configured to perform signal detection and processing for electric field signals monitored over links **167-168** and transfer information related to these signals to processing node **110** over link **171** for further processing and analysis.

In further examples, one or more portions of measurement system **700** can be incorporated into a wearable device. For example, at least capacitance node **187** can be incorporated into a fitness wristband for monitoring of physiological parameters during fitness activities. This fitness wristband can include moisture and sweat protection to isolate elements of measurement system **700** from environmental exposure. Capacitance measurements for fitness can include breathing rate, heart rate, sweat levels, electrolyte loss rate, running pace, and changes thereto. In some examples, all elements of measurement system **700** are included in the fitness wristband, with capacitance node **187** configured to be located next to tissue of the fitness participant when worn, such as contacting skin of a wearer. It should be understood that one capacitor plate (such as capacitance node **187** or **189**) or two capacitor plates (such as capacitance nodes **187-188**) can be incorporated into the fitness wristband, as discussed above FIG. **7** and below for FIG. **8**. In some examples, such as in capacitor arrangement **791**, a flexible or bendable capacitor plate can be employed.

As an example operation of measurement system **700**, FIG. **8** is provided. FIG. **8** is a flow diagram illustrating a

method of operation of measurement system **700**. The operations of FIG. **8** are referenced below parenthetically. In FIG. **8**, a physiological measurement begins (**801**) and a selection of measurement style is selected based on a capacitor plate arrangement (**802**). In first capacitor plate arrangement, such as illustrated in arrangement **790**, one or more capacitor plates are positioned on a single side of tissue **140**. In a second capacitor plate arrangement, such as illustrated by arrangement **791**, a single capacitor plate is positioned on more than one side of tissue **140**, such as by wrapping around a finger or limb of a patient. Tissue interface elements can be included in capacitance nodes **187-189**, such as adhesives, clamps, pads, gels, and the like.

If a single side arrangement **790** is employed, capacitance system **130** applies (**803**) applies at least electric field signal **155** to a single side of tissue **140** of the patient. Capacitance system **130** generates one or more electric signals over link **167** and optionally link **168** to generate electric field signal **155** in tissue **140**. Links **167-168** are each electric signal links which drives associated capacitance nodes **187-188** to emit electric field **155** in tissue **140**. In a first example, capacitance node **187** is employed and capacitance node **188** is omitted. When only capacitance node **187** is employed, capacitance node **187** forms a single plate capacitor to emit electric field signal **155** into tissue **140**. In a second example, both capacitance node **187** and capacitance node **188** are employed. When both capacitance nodes **187-188** are employed, capacitance nodes **187-188** comprise a two-plate capacitor applied to the same side of tissue **140**. Capacitance nodes **187-188** can use tissue **140** as a dielectric. In many examples, electric field signal **155** is a modulated signal.

If a multi-side arrangement **791** is employed, capacitance system **130** applies (**804**) applies at least electric field signal **156** to more than one side of tissue **140** of the patient. Capacitance system **130** generates one or more electric signals over link **167** to generate electric field signal **156** in tissue **140**. Capacitance node **189** forms a single plate capacitor to emit electric field signal **156** into tissue **140**. Capacitance node **189** can use tissue **140** as a dielectric, as well as any associated air gaps or other materials. In many examples, electric field signal **156** is a modulated signal.

Capacitance system **130** detects (**805**) changes in electric field signal **155**, or alternatively electric field signal **156**. Capacitance system **130** measures changes in electric field signal **155/156** over one or more of links **167-168**. As the environment of tissue **140**, the internals of tissue **140**, and tissue **140** itself changes, associated changes in electric field signal **155/156** can be monitored by capacitance system **130**. These changes can be reflected in a change in capacitance of a capacitor formed by one or more of capacitance nodes **187-189** due to changes in the dielectric environment of an associated capacitance node **187-189**. These changes can be changes in a noise level, current draw, power level, or other characteristics of electric field signal **155/156** as detected by capacitance system **130**.

Processing system **110** processes (**806**) the changes in electric field signal **155** to determine the physiological parameters of the patient. In this example, the physiological parameter identified is a hemoglobin concentration of blood in tissue **140** of the patent. The hemoglobin concentration is measured using a single plate capacitor when capacitance node **187** or **189** are employed alone, or using a two-plate single-side capacitor when both capacitance nodes **187-188** are employed. Further physiological parameters can be measured, such as ECG information. The processing performed in operation **806** can include different processing techniques, such as those described in FIG. **4**.

Returning back to the elements of FIGS. **1-8**, processing system **110** comprises communication interfaces, computer systems, microprocessors, circuitry, non-transient computer-readable media, or other processing devices or software systems, and may be distributed among multiple processing devices. Processing system **110** can be included in the equipment or systems of optical system **121** or capacitance system **130**, or can be included in separate equipment or systems. Examples of processing system **110** may also include software such as an operating system, logs, utilities, drivers, databases, data structures, processing algorithms, networking software, and other software stored on non-transient computer-readable media.

Physiological sensor system **120** can comprise at least one of a pulse oximetry system, an ECG system, an acoustic physiological parameter measurement system, a breathing monitor, a blood pressure monitoring system, and a pulse rate monitor, among other physiological measurement systems, including combinations thereof. Physiological sensor system **120** can also receive physiological parameters or other physiological information from other equipment and systems, such as other monitoring and detection equipment not shown. For example, a separate monitoring device can be employed and live physiological data can be transferred by the separate monitoring device for receipt by physiological sensor system **120**. Physiological sensor system **120** can comprise transceivers, network interfaces, data links, and the like to receive this physiological data from the separate monitoring equipment. In another example, physiological sensor system **120** can instead monitor the physiological parameters itself, and include the associated monitoring equipment mentioned above. In further examples, physiological sensor system **120** can comprise environmental sensing equipment and systems, such as temperature sensing equipment, accelerometers, clocks, timers, chemical sensors, pressure sensors, or other sensing equipment to supplement patient monitoring equipment.

Optical system **121** can include electrical to optical conversion circuitry and equipment, optical modulation equipment, and optical waveguide interface equipment. Optical system **121** can include direct digital synthesis (DDS) components, CD/DVD laser driver components, function generators, oscillators, or other signal generation components, filters, delay elements, signal conditioning components, such as passive signal conditioning devices, attenuators, filters, and directional couplers, active signal conditioning devices, amplifiers, or frequency converters, including combinations thereof. Optical system **121** can also include switching, multiplexing, or buffering circuitry, such as solid-state switches, RF switches, diodes, or other solid state devices. Optical system **121** also can include laser elements such as a laser diode, solid-state laser, or other laser device, along with associated driving circuitry. Optical couplers, cabling, or attachments can be included to optically mate to links **160-161**. Optical system **121** can also include light detection equipment, optical to electrical conversion circuitry, photon density wave characteristic detection equipment, and analog-to-digital conversion equipment. Optical system **121** can include one or more photodiodes, phototransistors, avalanche photodiodes (APD), or other optoelectronic sensors, along with associated receiver circuitry such as amplifiers or filters. Optical system **121** can also include phase and amplitude detection circuitry and processing elements.

Capacitance system **130** can comprise modulation circuitry, digital to analog conversion circuitry, analog to digital conversion circuitry, capacitor to digital conversion

circuitry, amplifiers, impedance matching circuitry, analog switches, transceivers, processing circuitry, and other circuitry, including combinations thereof. Capacitance system **130** receives instructions from processing system **110** to drive electric field signals in tissue. Capacitance system **130** detects electric field properties of tissue and the environment around a patient and sensor equipment, as monitored by associated capacitance nodes. Capacitance system **130** can process the electric field properties from an analog format to a digital format for transfer to processing system **110**. In some examples, capacitance system **130** comprises a capacitance detector, which can detect changes in capacitance of associated capacitance nodes. Capacitance system **130** can include capacitance measurement components such as Analog Devices AD7745. Capacitance system **130** can include touch screen controllers or associated integrated processing devices, such as Kinetis K10 devices (Freescale Semiconductor, Inc.).

Tissue **140** illustrates a portion of the tissue of a patient undergoing measurement of a physiological parameter, and is represented by a rectangular element for simplicity in FIGS. **1**, **3**, **5**, and **7**. It should be understood that tissue **140** can represent a finger, fingertip, toe, earlobe, chest, foot, arm, leg, head, limb, forehead, or other tissue portion of a patient undergoing physiological parameter measurement. Tissue **140** can comprise muscle, fat, blood, vessels, bone, or other tissue components. The blood portion of tissue **140** can include tissue diffuse blood and arterial or venous blood. In some examples, tissue **140** is instead a test sample or representative material for calibration or testing of system **100**. The patient undergoing measurement can be any individual organism or group or organisms.

Links **160-161** can comprise optical links, wired electrical links, or wireless links. In examples where ones of links **160-161** comprise optical links, links **160-161** each comprise one or more optical waveguides, and use glass, polymer, air, space, or some other material as the transport media for transmission of light, and can each include multimode fiber (MMF) or single mode fiber (SMF) materials. A sheath or loom can be employed to bundle each of links **160-161** together for convenience. One end of each of links **160-161** mates with an associated component of optical system **121**, and the other end of each of links **160-161** is configured to interface with tissue **140** through an associated optical node **180-181**. Link **160** is configured to emit light via optical node **180** into tissue **140**, while link **161** is configured to receive light via optical node **181** from tissue **140**. Also, in examples where links **160-161** comprise optical links, optical nodes **180-181** can comprise one or more optical interfacing elements to interface the waveguide portions of links **160-161** to tissue **140**. In examples where ones of links **160-161** comprise wired electrical links, links **160-161** each comprise one or more wired for carrying electrical to and from ones of optical nodes **180-181**. In examples where ones of links **160-161** comprise wireless links, links **160-161** can include wireless signaling for exchanging communications between optical nodes **180-181** and optical system **121**.

Optical node **180** can comprise can include laser elements such as a laser diodes, solid-state lasers, light emitting diodes (LED), or other light emitting devices, along with associated driving circuitry and electrical-to-optical conversion circuitry. Optical node **181** can include light detection equipment, optical to electrical conversion circuitry, photon density wave characteristic detection equipment, and analog-to-digital conversion equipment. Optical node **181** can include one or more photodiodes, phototransistors, avalanche photodiodes (APD), or other optoelectronic sensors, along with associated receiver circuitry such as amplifiers or filters. Optical couplers, cabling, lenses, prisms, or attachments can be included in optical nodes **180-181** to optically mate tissue **140** to links **160-161**. In examples where links **160-161** are wireless links, optical nodes **180-181** can include wireless transceivers and antennas.

In FIGS. **1**, **3**, **5**, and **7**, link **160** and link **161** are shown coupled to optical nodes **180** and **181** which are located an exemplary distance apart, but can be located on the surface of tissue **140** at predetermined locations or distances. Although the term 'optical' is used herein for convenience, it should be understood that the optical measurement signals are not limited to visible light, and can comprise any light wavelength, such as visible, infrared, ultraviolet, or other signals.

Capacitance links **162-168** each comprise one or more electrical links for emitting or detecting an electric field in the environment of tissue **140**. In one example, link **162** is driven by a modulated electrical signal which produces a similarly modulated electric field **151**. Further figures include similar features. Capacitance links **162-168** can include wires, shields, coaxial links, twisted pair links, or other electrical links, including combinations thereof.

Capacitance nodes **182-189** comprise elements to induce associated electric field signals **151-155** in the environment of tissue **140** and detect an electric field in the environment of tissue **140**. In some examples, each capacitance node comprises a capacitor plate. Capacitance nodes **182-189** can be co-planar, single plate, fringe field or other capacitor styles using at least tissue **140** as a dielectric or as a plate of a capacitor system. Electric field signals **151-155** typically comprise one or more modulated signals which are induced as a variable electrostatic field in the environment and tissue **140**. The modulation frequency can be 10 kHz-50 GHz, among others, and include sine wave, square wave, or other signal characteristics. Electric field signals **151-155** can be a modulated signal selected based on the environment around tissue **140**, anticipated or detected interference, patient parameters (skin type, size, shape), maximum sensitivity to motion of patient/sensor, or other factors. In some example, the modulation signal of electric field signals **151-155** can be selected to not interfere with the optical drive frequency used in modulation of optical signal **150** or to not interfere with other physiological measurement equipment monitoring the patient. The modulation signal electric field signals **151-155** can be selected to interfere constantly with the optical signal **150** by driving one at a multiple of the other frequency. Alternatively, capacitive measurement using electric field signals **151-155** can be performed when an optical measurement is not being presently performed. In further examples, the modulation signal of electric field signals **151-155** can be swept through a range of modulation frequencies, such as to find an optimal frequency or to reduce dependency of the measurement of electric field signal **151** on various forms of interference. Frequency hopping, chirping, or spread spectrum techniques can also be employed to minimize interference of simultaneous measurement using multiple electric field signals.

In the examples of capacitance nodes, the associated capacitor plates can be positioned on tissue **140**, or located proximate and separated by a gap or distance from tissue **140**. The gaps between tissue **140** and ones of capacitance nodes can include air, dielectric materials, pads, coatings, adhesives, gels, clothing of the patient, or other dielectric materials.

In further examples, ones of capacitance nodes **182-189** comprise a Faraday shield or electromagnetic interference

(EMI) shield associated with link **160** or **161**. The shield of link **160** or **161** can be repurposed as a plate of a capacitor and thus driven to create or monitor an electric field signal. Changes in electric field signals can also be detected using the shield. In further examples, optical node **180** or **181** includes a Faraday shield or EMI shield which surrounds associated optical or electrical elements of optical node **180** or **181**. This Faraday shield or EMI shield associated with optical node **180** or **181** can be used as a capacitor plate to generate electric field signals and detect changes in electric field signals. The patient under measurement can also be electrically grounded in some single-plate capacitor examples. Further examples of a Faraday shield and other twisted pair arrangements are discussed in FIGS. **16** and **17**.

In some examples of capacitance nodes, a single-plate capacitor is employed and positioned on one side of tissue **140**. The return path or ground connection of a single-plate single-side capacitor configuration is typically tissue **140** and the earth or nearby structural environment around tissue **140**. In other examples, capacitance nodes comprise two plate elements positioned next to each other but on the same side of tissue **140**. In two-plate, single-side configurations, plates of capacitance nodes can be positioned on the same side of the fingertip as each other. One plate of a capacitance node can be the 'positive' or driven portion, while the other plate of a capacitance node can be the 'negative' or return/ground/reference portion. Other configurations of signal polarity can be employed. In yet other examples, such as FIGS. **5-6**, a two separate single-plate capacitors which are positioned on a different sides of tissue **140** are employed. A first measurement can be performed using a two-plate, two-side measurement with a first plate of a capacitance node and a second plate of another capacitance node. A second measurement can be performed using a single-plate, single-side measurement with the first plate of a capacitance node. A third measurement can be performed using a single-plate, single-side measurement with the second plate of another capacitance node.

In further examples of capacitance nodes, a capacitive touch surface or touch screen can be employed. A capacitive touch surface or touch screen can detect pressure and touch of tissue on the touch screen and can be used to detect sensor on/off conditions, among assisting with optical measurement of physiological parameters.

Links **170-171** each use metal, glass, optical, air, space, or some other material as the transport media, and comprise analog, digital, RF, optical, modulated, or power signals, including combinations thereof. Links **170-171** can each use various communication protocols or formats, such as Serial Peripheral Interface (SPI), Synchronous or Asynchronous Serial Ports, external bus interface, Controller Area Network (CAN) bus, Inter-Integrated Circuit (I2C), 1-Wire, Radio Frequency Identification (RFID), optical, circuit-switched, Internet Protocol (IP), Ethernet, wireless, Bluetooth, communication signaling, or some other communication format, including combinations, improvements, or variations thereof. Links **170-171** can each be direct links or may include intermediate networks, systems, or devices, and can each include a logical network link transported over multiple physical links.

Links **160-168** and **170-171** may each include many different signals sharing the same associated link, as represented by the associated lines in FIGS. **1**, **3**, **5**, and **7**, comprising channels, forward links, reverse links, user communications, overhead communications, frequencies, wavelengths, carriers, timeslots, spreading codes, logical transportation links, packets, or communication directions.

The measurement systems discussed above in FIGS. **1-8** can be applied to further examples. Some of the examples are discussed below in FIGS. **9-19**, although it should be understood that different measurement systems and associated elements can be employed in FIGS. **9-19**.

FIG. **9** is a diagram illustrating measurement of physiological parameters. FIG. **9** includes measurement environment **900**, graph **950**, and graph **960**. Measurement environment **900** includes measurement system **910**, capacitor **911**, and measurement link **912**, with capacitor **911** configured to measured properties of tissue **920**. In operation, measurement system **910** drives a modulated electrical signal onto link **912** to drive capacitor **911** and measure tissue **920**. In this example capacitor **911** is a single-side, single-plate capacitor, although it should be understood that a two-plate capacitor or a multi-side, single-plate capacitor can instead be employed.

Graph **950** illustrates an example capacitance signal as found on link **912**. The capacitance signal can be representative of a changing capacitance as monitored by measurement system **910**, such as due to changes in an electric field signal applied to tissue **920**. In one example, capacitor **911** can be included in an oscillator circuit along with circuit elements of measurement system **910** to establish a modulated electric field signal in tissue **920**. The capacitance measured for capacitor **911** by measurement system **910** can vary in time due to a corresponding change in the dielectric environment of capacitor **911**. The dielectric environment of capacitor **911** can change due to changes in many factors, such as tissue **920**, the environment of tissue **920**, motion of tissue **920**, and variation in internal elements of tissue **920**, among others. These capacitance changes can be seen in graph **950** as a change in oscillation frequency of the capacitance signal. Graph **950** is simplified to emphasize changes in frequency or wavelength of the measurement signal. In other examples, noise, amplitude variations, rapid frequency changes, and other signal variations can be observed. To identify graph **950**, a capacitance monitoring circuit or system can be employed, such as a capacitance to digital converter circuit. In other examples, a power or current draw of a circuit that includes capacitor **911** is monitored to determine the change in capacitance and graph **950**. Other techniques can be employed, such as monitoring transmission line capacitive coupling.

Graph **960** illustrates the changes in capacitance over time as detected by measurement system **910**. Graph **960** can be derived from graph **950** by determining changes in capacitance based on the frequency changes in graph **950**. Link **912** indicates a first capacitance for time t_1, a second capacitance for time t_2, and a third capacitance for time t_3. Although the changes in capacitance in this example are highly simplified, real-world measurements can include changes in noise, dynamic AC components, DC shifts, among other factors. These various changes in capacitance can be used to extract characteristics of the capacitance signal to determine physiological parameters, such as hemoglobin measurements, and also to aid in physiological measurements made with optical sensing equipment, such as PPG measurements. Further examples of capacitance enhanced measurements are discussed below.

The various signal components of the measured capacitance signal can include components that are representative of physiological parameters, or can be used to calculate physiological parameters, such as hemoglobin parameters. For example, AC components and DC components of the capacitance signal can be compared or correlated to determine hemoglobin parameters or changes in hemoglobin

parameters of a patient. In further examples, AC components and DC components of the capacitance signal can be processed to determine breathing rates, pulse rates, ECG information, and other physiological parameters discussed herein.

In further examples, one or more portions of system **900** can be incorporated into a wearable device. For example, at least capacitor **911** can be incorporated into a fitness wristband for monitoring of physiological parameters during fitness activities. This fitness wristband can include moisture and sweat protection to isolate elements of system **900** from environmental exposure. Capacitance measurements for fitness can include breathing rate, heart rate, sweat levels, electrolyte loss rate, running pace, and changes thereto. In some examples, all elements of system **900** are included in the fitness wristband, with capacitor **911** configured to be located next to tissue of the fitness participant when the wristband is worn.

FIG. **10** is a diagram illustrating measurement of physiological parameters. FIG. **10** includes graph **1000** and associated pressure configurations **1001-1003**. FIG. **10** illustrates capacitance-based identification of pressure changes that may affect PPG measurements, although the identification of pressure changes can be applied to other physiological measurements. FIG. **10** includes three different sensor configurations, namely a "sensor not applied" configuration **1001**, a "sensor partially applied" configuration **1002**, and a "sensor fully applied" configuration **1003**. Each pressure configuration **1001-1003** corresponds to a different region on graph **1000**, as indicated by the dotted lines. Graph **1000** includes an x-axis which represents "time" (T) and a y-axis which represents "capacitance" which can be measured in Farads, such as picofarads (pF). Three capacitance thresholds are indicated in graph **1000**, namely threshold **1** (TH_1), threshold **2** (TH_2), and threshold **3** (TH_3), and will be discussed in greater detail below.

Each configuration **1001-1003** includes optical sensor **1010** and capacitance sensor **1011** as applied to finger **1020**. Optical sensor **1010** is configured to emit and detect optical signal **1030** in finger **1020** to determine a PPG waveform. Capacitance sensor **1011** is configured to emit and detect electric field signal **1031** in proximity to finger **1020**. Optical sensor **1010** can include elements discussed herein for optical nodes **180-181** in FIGS. **1-8**, although variations are possible. Capacitance sensor **1011** can include elements as discussed herein for capacitance nodes **182-189** in FIGS. **1-8**, although variations are possible. In this example, capacitance sensor **1011** comprises a single plate capacitor, and uses at least finger **1020** as a dielectric for the single plate capacitor. In further examples, two-plate capacitors can be employed.

Optical sensor **1010** and capacitance sensor **1011** can be coupled together physically, and share a common structural support. The common structural element can allow for contact of sensor elements with finger **1020**. This common structural support can comprise a rigid carrier, such as clip-on finger probe, or can include a flexible carrier such as an adhesive pad that can be fit onto finger **1020**. Further examples of pads are discussed in FIGS. **15** and **16**.

Although omitted for clarity in FIG. **10**, optical sensor **1010** can be coupled to further measurement equipment and systems, such as processing system **110** or optical system **121** in FIGS. **1-8**, although variations are possible. Also, although omitted for clarity in FIG. **10**, capacitance sensor **1011** can be coupled to further measurement equipment and systems, such as processing system **110** or capacitance system **130** in FIGS. **1-8**, although variations are possible. Finger **1020** is shown as representing tissue under measurement by sensors **1010-1011**. Other tissue portions can instead be included, such as a forehead, chest, toe, limb, or other tissue of a patient, including combinations thereof.

A capacitance level measured by capacitance sensor **1011** can relate to a pressure of capacitance sensor **1011** on finger **1020**. FIG. **10** indicates three discrete pressure configurations of the sensors onto finger **1020** as correlated to three different capacitance thresholds, TH_1, TH_2, and TH_3. Although various random noise might be detected by capacitance sensor **1011**, a DC component can be correlated to a pressure of capacitance sensor **1011** on finger **1020** and a pressure of likewise optical sensor **1010** on finger **1020**. Also, motion noise based at least on movement of finger **1020** or elements internal to finger **1020** can be measured by capacitance sensor **1011**. However, this motion noise typically leads to AC components of the capacitance signal measured by capacitance sensor **1011**. Further examples of motion detection are discussed in at least FIG. **11**A below.

Configuration **1001** shows a "sensor not applied" condition. In configuration **1001**, capacitance sensor **1011** measures a first capacitance level, as indicated in graph **1000**. This first capacitance level might have a certain amount of random noise in it, but on average, the first capacitance level is below a first capacitance threshold (TH_1). When the average capacitance level measured by capacitance sensor **1011** is below TH_1, then an associated measurement system can determine that optical sensor **1010** has not been properly applied to finger **1020**. The capacitance level can be affected by finger **1020** due to finger **1020** being too far away from the capacitor portion of capacitance sensor **1011** or the sensor portions completely off finger **1020**, thus providing a first level of dielectric influence for the capacitor portion of capacitance sensor **1011**.

When the capacitance level is below TH_1, then the measurement system associated with optical sensor **1010** can at least prevent optical signal **1031** from being emitted. The measurement system can turn off optical emitter elements of optical sensor **1010**, such as removing power from a laser diode or LED portion of optical sensor **1010** that emits optical signal **1031**. By turning off the power to the emitter portion of optical sensor **1010**, the measurement system can save power and allow associated equipment to operate in a low power mode, or a battery-save mode. Additionally, the measurement system can prevent measurement and determination of physiological parameters when optical sensor **1010** is not properly applied to finger **1020**, preventing erroneous or inaccurate measurement results when optical sensor **1010** is not properly applied. Furthermore, various alarms for healthcare professionals or measurement systems that are related to physiological measurement of finger **1020** can be modified or disabled due to optical sensor **1010** not properly on finger **1020**. Configuration **1001** can prompt an associated measurement system to alert or signal an operator of the measurement system than the sensor has not been applied properly. Configuration **1001** can prompt an associated measurement system to alert or signal that any associated optical measurements taken are potentially inaccurate.

Configuration **1002** shows a "sensor partially applied" condition. In configuration **1002**, capacitance sensor **1011** measures a second capacitance level, as indicated in graph **1000**. This second capacitance level might have a certain amount of random noise in it, but on average, the second capacitance level is below a second capacitance threshold (TH_2) and above the first capacitance level (TH_1). When the average capacitance level measured by capacitance sensor

1011 is below TH_2, but above TH_1, then an associated measurement system can determine that optical sensor 1010 has been only partially applied to finger 1020. The capacitance level can be affected by finger 1020 due to finger 1020 being too far away from the capacitor portion of capacitance sensor 1011, not having enough pressure applied by the sensor portions onto finger 1020, or the surface area of the sensor portions not contacting finger 1020 a desired amount, and thus providing a second level of dielectric influence for the capacitor portion of capacitance sensor 1011.

When the capacitance level is below TH_2, but above TH_1, then the measurement system associated with optical sensor 1010 can adjust measurement of physiological parameters, and can act in a few different ways. In a first example, the measurement system can at least prevent optical signal 1031 from being emitted, prevent optical measurement from occurring, or prevent an alarm from being produced, much like when the average capacitance level is below TH_1. In a second example, the measurement system can instead perform optical measurement using optical sensor 1010 but modify the measurement based on the capacitance level. For example, the measurement system can identify an average capacitance level of a capacitor of capacitance sensor 1011 and scale optical measurement by optical sensor 1010 based on at least the capacitance level. The scaling can encompass selecting calculation coefficients for calculating physiological parameters based on optical signal 1031, such as calculations used in determining a PPG. The scaling can encompass changing an amplification level associated with signal processing elements used in optical detection and optical measurement using optical signal 1031. In a third example, an intensity level of optical signal 1031 can be modified based on the capacitance level, so that at a lower capacitance level a higher intensity of optical signal 1031 is employed and at a higher capacitance level a lower intensity is employed for optical signal 1031. As with configuration 1001, configuration 1002 can prompt an associated measurement system to alert or signal an operator of the measurement system than the sensor has not been applied properly. Configuration 1002 can prompt an associated measurement system to alert or signal that any associated optical measurements taken are potentially inaccurate.

Configuration 1003 shows a "sensor fully applied" condition. In configuration 1003, capacitance sensor 1011 measures a third capacitance level, as indicated in graph 1000. This third capacitance level might have a certain amount of random noise in it, but on average, the third capacitance level is above a third capacitance threshold (TH_3). When the average capacitance level measured by capacitance sensor 1011 is above TH_3, then an associated measurement system can determine that optical sensor 1010 has been fully or properly applied to finger 1020. The capacitance level above TH_3 can occur when the sensors are applied at a desired pressure and contact area to finger 1020, and thus providing a third level of dielectric influence for the capacitor portion of capacitance sensor 1011.

When the capacitance level is above TH_3, then the measurement system associated with optical sensor 1010 can emit optical signal 1031 into finger 1020. The measurement system can turn on optical emitter elements of optical sensor 1010, such as providing power to a laser diode or LED portion of optical sensor 1010 that emits optical signal 1031. By turning on the power to the emitter portion of optical sensor 1010 only above TH_3, the measurement system can save power and allow associated equipment to operate in a low power mode until sensor portions are properly applied to finger 1020. Additionally, the measurement system can now measure and determine physiological parameters, such PPG measurement, when optical sensor 1010 is properly applied to finger 1020, preventing erroneous or inaccurate measurement results when optical sensor 1010 is not properly applied. Configuration 1003 can prompt an associated measurement system to alert or signal an operator of the measurement system than the sensor has been applied properly. Configuration 1003 can prompt an associated measurement system to alert or signal that any associated optical measurements taken are accurate.

In further examples, the measurement system can process the properties of one or more electric field signals to determine a where on the body of a patient a capacitor plate has been placed or located. This determination can help to identify an improper location of the plate on the patient. In some examples, a user interface included in the measurement system is configured to alert an operator of the measurement system when the placement comprises the at least one capacitor plate improperly applied to the tissue of the patient. For example, different locations on the body, such as a finger, ear, nose, forehead, or other location, exhibit different electric field properties, capacitance, change in capacitance, or capacitance measurements. These differences may be measured and noted, such as by measuring them at different modulation frequencies, to first characterize various body locations. Later, when sensor portions are placed on tissue, the capacitance system can measure these properties to identify where the sensor has been placed. For example, the system can determine that the sensor has been placed on a forehead instead of a finger. Measurement parameters can be modified based on the body location and placement, such as loading correct calculation coefficients based on the placement or body location. An error message or alert can be provided to an operator if a sensor that is designed for one or more body locations is applied to a different or incompatible body location.

In addition to placement of a sensor on a particular body part of a patient, properties of the tissue can be detected. For example, a skin type, skin moisture content, skin elasticity, or other tissue parameters can be identified with a capacitance signal. Measurements of physiological signals, such as optical measurements, can be corrected or adjusted based on the skin or tissue parameters identified by the capacitance signal, such as scaling calculation coefficients, adjusting intensity of measurement signal sources, adjusting sensitivity or gain of detection elements, among other adjustments, including combinations thereof.

FIG. 10, discussed above, changes in average or "DC" capacitance levels due to pressure of a capacitance sensor on tissue. FIGS. 11A-11B, in contrast, discusses dynamic changes or "AC" capacitance levels due to dynamic conditions, such as movement or motion of tissue undergoing measurement (FIG. 11A) or due to changing physiological characteristics of the tissue or patient undergoing measurement (FIG. 11B), among other dynamic conditions, including combinations thereof.

FIG. 11A is a diagram illustrating measurement of physiological parameters. FIG. 11A includes graph 1100 and two different motion configurations, namely a "sensor in motion" configuration 1105, and a "sensor not in motion" configuration 1106. Each motion configuration 1105-1106 corresponds to a different region on graph 1100, as indicated by the dotted lines. Graph 1100 includes an x-axis which represents "time" (T) and a y-axis which represents "capacitance" which can be measured in Farads, such as picofarads (pF). A capacitance threshold region is indicated in graph

1100, namely the region between threshold 1 (TH_1) and threshold 2 (TH_2), and will be discussed in greater detail below.

Each sensor configuration **1105-1106** includes optical emitter **1110**, optical detector **1112**, and capacitance node **1111** as applied to finger **1120** or other patient tissue. Optical emitter **1110** is configured to emit optical signal **1130** in finger **1120**. Optical detector **1112** is configured to detect optical signal **1130** after propagation in finger **1120**. Capacitance node **1111** is configured to emit and detect electric field signal **1131** in proximity to finger **1120**. Optical emitter **1110** and optical detector **1112** can include elements discussed herein for optical nodes **180-181** in FIGS. **1-8**, although variations are possible. Capacitance node **1111** can include elements as discussed herein for capacitance nodes **182-189** in FIGS. **1-8**, although variations are possible. In this example, capacitance node **1111** comprises a single plate capacitor, and uses at least finger **1120** as a dielectric for the single plate capacitor. In further examples, two-plate capacitors can be employed.

Optical emitter **1110**, optical detector **1112**, and capacitance node **1111** can be coupled together physically, and share a common structural support. The common structural element can allow for contact of sensor elements with finger **1120**. This common structural support can comprise a rigid carrier, such as clip-on finger probe, or can include a flexible carrier such as an adhesive pad that can be fit onto finger **1120**. Further examples of pads are discussed in FIGS. **15-17**.

Although omitted for clarity in FIG. **11**A, optical emitter **1110** and optical detector **1112** can be coupled to further measurement equipment and systems, such as processing system **110** or optical system **121** in FIGS. **1-8**, although variations are possible. Also, although omitted for clarity in FIG. **11**A, capacitance node **1111** can be coupled to further measurement equipment and systems, such as processing system **110** or capacitance system **130** in FIGS. **1-8**, although variations are possible. Finger **1120** is shown as representing tissue under measurement by sensors **1110-1112**. Other tissue portions can instead be included, such as a forehead, chest, toe, limb, or other tissue of a patient, including combinations thereof.

Configuration **1105** shows a "sensor in motion" condition. In configuration **1105**, capacitance node **1111** measures a capacitance signal **1101**, as indicated in graph **1100**. This capacitance signal might include large variations, such as AC noise due to motion of finger **1120** or motion of components within finger **1120**. These large variations can be considered to be a noise component of the capacitance signal. The variation can be periodic and correlated to a movement of finger **1120**, such as when finger **1120** is being "waved" regularly or tapped against a surface. The variation can be quasi-random, such as when finger **1120** is being moved in a random manner. Motion of components within finger **1120** can also contribute to an AC noise signal, such as due to sloshing of blood in vessels of finger **1120**. Each peak or valley in signal **1101** of graph **1100** might correspond to an impulse of movement experienced by finger **1120**, such as sudden change in direction or motion. Motion artifacts can also be related to changes in sensor contact pressure with body tissue. The capacitive sensor of FIG. **11**A also detects movements of the sensor relative to finger **1120**, such as due to changes in sensor contact pressure.

As shown in graph **1100**, capacitance signal **1101** has a variation level that exceeds a noise threshold range (TH_1-TH_2). That is, the amplitude of the AC portion of signal capacitance **1101** is larger than a threshold, such as the difference between two capacitance levels TH_1 and TH_2. As with FIG. **9**, the capacitance level can be affected by finger **1120** due to finger **1120** being too far away from the capacitor portion of capacitance node **1111**, a sensor misapplication, or sensor contact pressure variation. It should be understood that operations in FIG. **9** can be combined with operations in FIG. **11**A.

When the capacitance level measured by capacitance node **1111** rises above and falls below the threshold range TH_1-TH_2, or when the AC amplitude of capacitance signal **1101** exceeds a threshold amount, then an associated measurement system can determine that too much noise due to motion will also occur for any optical measurement performed by optical detector **1112**. Accordingly, the associated measurement system can disable measurement of optical signals in finger **1120** when the capacitance level exceeds the threshold range. Optical emitter **1110** can have power turned off when the capacitance level or noise exceeds the threshold range, such as indicated by "optical power off" signal **1103** in graph **1100**. The measurement system removes power from a laser diode or LED portion of optical emitter **1110** that emits optical signal **1130**. By turning off the power to optical emitter **1120**, the measurement system can save power and allow associated equipment to operate in a low power mode. Additionally, the measurement system can prevent measurement and determination of physiological parameters when the threshold range is exceeded, preventing erroneous or inaccurate measurement results when motion of finger **1120** can introduce undesirable noise or artifacts into measurement. Alternatively, when the threshold range is exceeded, an associated measurement system can alert or signal an operator of the measurement system than the sensor is experiencing noise or being moved too rapidly. An associated measurement system can alert or signal an operator that any associated optical measurements taken are potentially inaccurate. Although a threshold capacitance range is discussed, in other examples a magnitude of noise in signal **1101** or an amplitude of signal **1101** might exceed a threshold level.

When the capacitance level measured by capacitance node **1111** falls within the threshold range, then an associated measurement system can enable measurement of optical signals in finger **1120**. Signal **1102** of graph **1100** can indicate a low motion or low noise condition. Optical emitter **1110** can have power turned on when the capacitance level or noise falls within the threshold range, such as indicated by "optical power on" signal **1104** in graph **1100**. The measurement system supplies power to a laser diode or LED portion of optical emitter **1110** that emits optical signal **1130**.

The measurement system can perform measurement and determination of physiological parameters when the capacitance signal is within the threshold range, preventing erroneous or inaccurate measurement results when motion of finger **1120** can introduce undesirable noise or artifacts into measurement. An associated measurement system can alert or signal an operator that any associated optical measurements taken are accurate regarding motion-based noise. For example, when an optical measurement is experiencing a noisy condition, such as due to motion-based noise or other noise sources, a display on the measurement system can indicate to an operator that the optical measurement is currently noisy or exceeds a noise threshold for accurate measurement. In further examples, a capacitance signal, such as measured by capacitance node **1111**, can be used as a trigger for displaying physiological parameters on a monitor or display when a threshold condition is met.

When the capacitance level measured by capacitance node **1111** rises above and falls below the threshold range TH_1-TH_2, or when the AC amplitude of capacitance signal **1101** exceeds a threshold amount, then an associated measurement system can detect that the tissue under measurement is in motion. This capacitance-based motion detection can be employed to monitor movement of a patient, such as movement of a baby in a NICU environment, or to monitor movement of a comatose or bed-ridden patient. When the capacitance level measured by capacitance node **1111** falls within the threshold range, then an associated measurement system can detect that the tissue under measurement is not in motion. Multiple body parts can be monitored using multiple capacitive motion sensors to determine when various limbs, head, body, or other body parts are moved. Additionally, the patterns of capacitance signals **1101**-**1102** can be characterized. This characterization can include identifying patterns or 'fingerprints' in the motion-based noise. For example, a finger tapping can be characterized as a first pattern, while a hand waving can be characterized by a second pattern. The patterns can comprise patterns in amplitude, frequency, phase, or other characterizations. Measured patterns can be compared against a database of previously determined patterns to establish the particular movement or motion type. Motion of the patient or the tissue under measurement can be used to alert medical personnel or logged by the measurement system. The alerts or logs can indicate what pattern of motion is occurring or which limb is being moved by the patient.

FIG. **11**B is a diagram illustrating measurement of physiological parameters. FIG. **11**B includes some similar elements at FIG. **11**A, such as elements **1110**-**1112**, **1120**, and **1130**-**1131**, although variations are possible. FIG. **11**B includes graph **1140** and two different optical sensor power configurations, namely an "optical power off" configuration **1147**, and an "optical power on" configuration **1148**. Each configuration corresponds to a different region on graph **1140**, as indicated by dotted lines below graph **1140**. Graph **1100** is a graph of a physiological parameter and includes an x-axis which represents "time" (T) and a y-axis which represents "capacitance" which can be measured in Farads, such as picofarads (pF).

Each configuration **1147**-**1148** includes optical emitter **1110**, optical detector **1112**, and capacitance node **1111** as applied to finger **1120** or other patient tissue. Optical emitter **1110** is configured to emit optical signal **1130** in finger **1120**. Optical detector **1112** is configured to detect optical signal **1130** after propagation in finger **1120**. Capacitance node **1111** is configured to emit and detect electric field signal **1131** in proximity to finger **1120**. Optical emitter **1110** and optical detector **1112** can include elements discussed herein for optical nodes **180**-**181** in FIGS. **1**-**8**, although variations are possible. Capacitance node **1111** can include elements as discussed herein for capacitance nodes **182**-**189** in FIGS. **1**-**8**, although variations are possible. In this example, capacitance node **1111** comprises a single plate capacitor, and uses at least finger **1120** as a dielectric for the single plate capacitor. In further examples, two-plate capacitors can be employed. Although omitted for clarity in FIG. **11**B, optical emitter **1110** and optical detector **1112** can be coupled to further measurement equipment and systems, such as processing system **110** or optical system **121** in FIGS. **1**-**8**, although variations are possible. Also, although omitted for clarity in FIG. **11**B, capacitance node **1111** can be coupled to further measurement equipment and systems, such as processing system **110** or capacitance system **130** in FIGS. **1**-**8**, although variations are possible. Finger **1120** is shown as representing tissue under measurement by sensors **1110**-**1112**. Other tissue portions can instead be included, such as a forehead, chest, toe, limb, or other tissue of a patient, including combinations thereof.

Capacitance node **1111** measures a capacitance signal **1141**, as indicated in graph **1140**. This capacitance signal might include variations due to a physiological parameter, such as a pulse, breathing rate, or heart rate, among others. Noise and motion artifacts can also be included in capacitance signal **1141**, such as discussed in FIG. **11**A, but these artifacts are omitted in this example for clarity.

Optical power is applied to optical emitter **1110** as-needed to ensure a targeted level of detail in measurement of the physiological parameter monitored by capacitance node **1111**. Capacitance node **1111** can monitor the physiological parameter, but the associated capacitance signal might have a lower accuracy or lower resolution than an optical system. Thus, capacitance node **1111** is employed to provide a less accurate measurement of a physiological parameter until a more accurate measurement is desired. In this example, if the patient is in a steady-state or stable condition at a certain time, then the optical power can be in an 'off' condition for optical emitter **1110** to reduce power consumption and reduce any associated data logging requirements. At some point, the physiological parameter that is monitored by capacitance node **1111** crosses a parameter threshold and a higher accuracy reading is desired. Responsive to the physiological parameter crossing the physiological threshold, a measurement system can enable measurement using an optical signal, namely optical signal **1130**. Once the physiological parameter has dropped below a physiological threshold, then the optical power can be removed again and optical measurement can be suspended.

In the example shown in FIG. **11**B, graph **1140** illustrates a rhythmic capacitance signal that indicates a rhythmic physiological parameter, such as a pulse rate, heart rate, breathing rate, and the like. The rhythm of physiological parameter can vary in frequency over time, such as due to health or stability changes in the patient being monitored. Notably, during time T**1** the capacitance signal increases in frequency and during time T**2** the capacitance signal decreases in frequency. A rising frequency threshold is reached at point **1142** which triggers optical measurement using optical signal **1130**. This optical measurement continues for the physiological parameter until another falling frequency threshold is reached at point **1143** which halts optical measurement using optical signal **1130**. Steady-state measurement using the capacitance signal can continue after the optical measurement has ceased.

It should be noted that the measurement or non-measurement using optical signal **1130** can be achieved in several ways. In a first example, such as shown in graph **1140**, power to optical emitter **1110** or optical detector **1112** can be selectively provided or removed to enable or disable the associated optical measurement elements. An associated measurement system can supply or remove power to a laser diode or LED portion of optical emitter **1110** that emits optical signal **1130**. In a second example, power can remain active for optical emitter **1110** or optical detector **1112**, but a measurement system can ignore measurements using the optical systems when not desired.

Multiple body parts can be monitored using multiple capacitive motion sensors to determine when more accurate measurement of physiological parameters for various limbs, head, body, or other body parts are desired. In some examples, the patterns of capacitance signal **1141** can be characterized. This characterization can include identifying

patterns or 'fingerprints' in the physiological parameters monitored by capacitance node **1111**. The patterns can comprise patterns in amplitude, frequency, phase, or other characterizations that trigger a measurement signal to monitor the physiological parameter optically, or using other measurement apparatuses. Measured patterns can be compared against a database of previously determined patterns to establish the particular threshold or pattern. Enabling or disabling of the optical measurement can also alert medical personnel to a change in patient condition or can be logged by the measurement system.

FIG. **12** is a diagram illustrating measurement of physiological parameters. FIG. **12** includes three graphs, namely optical signal graph **1200**, capacitance signal graph **1210**, and processed graph **1220**. FIG. **12** illustrates one example process to identify a corrected plethysmograph of tissue of a patient. Data from optical and capacitance measurements are processed to identify a plethysmograph with motion and noise artifacts removed. The processing of the various data can be performed by any measurement system or processing system discussed herein, such as processing system **110** of FIGS. **1-8**. Processing node **1230** is also included to illustrate an example processing system that processes the various signals in FIG. **12** to identify a corrected plethysmograph. Processing node **1230** can include elements of any processing system as discussed herein.

Graph **1200** illustrates optical signal **1201** formed from data derived from an optical measurement of tissue. In typical examples, graph **1200** represents a PPG which comprises an optically measured plethysmograph, such as performed using optical system **121** of FIG. 1B. However, optical signal **1201** includes various noise elements, such as due to motion or other noise sources. In graph **1200**, the plethysmograph signal dominates, with motion noise layered on top of the plethysmograph signal.

Graph **1210** illustrates capacitance signal **1211** formed from data derived from a capacitance-based measurement of tissue. In typical examples, graph **1210** represents a time-wise changing capacitance signal, such as performed using capacitance system **130** of FIGS. **1-8** based on changes in electric field signals or capacitance. However, capacitance signal **1211** includes various noise elements, such as due to motion or other noise sources, as well as signal elements of a plethysmograph signal. In graph **1210**, the noise artifacts dominate, with a plethysmograph signal layered on top of the motion noise signal. It should be understood that different variations of noise and plethysmograph signals can be measured than those shown in FIG. **12**.

Graph **1220** illustrates a processed signal, taking into account signal elements of optical signal **1201** and capacitance signal **1211**. A processing system can adjust the optical plethysmograph using the capacitance signal to reduce a noise level in the optical plethysmograph. A processing system can correct the optical plethysmograph using the capacitance signal to reduce a noise level in the optical plethysmograph. In some examples, optical signal **1201** and capacitance signal **1211** are processed to determine common noise elements, such as motion artifacts, due to motion of the tissue under measurement. Common noise elements that are correlated between both signals can be removed from the optical plethysmograph signal by subtracting the capacitance signal, or a scaled or filtered version or portion of the capacitance signal, from signal **1201** to form a smooth PPG signal **1221**. This noise cancellation or noise rejection for optical signals can allow for determination of an adjusted PPG **1220**. This adjusted PPG can be used to determine physiological parameters to provide enhanced detection of deltaPOP, respiratory rate, respiratory effort, SpO_2, heart rate, or other physiological parameters.

Processing node **1230** can be configured to process changes in the one or more electric field signals to determine at least one noise component in the changes in the one or more electric field signals caused by the motion of the tissue of the patient. Processing node **1230** can process the at least one noise component in the changes in the one or more electric field signals to reduce at least one noise component in the one or more optical signals to determine corrected physiological parameters of the patient, such as a corrected plethysmograph. Processing node **1230** can find correlated noise components to select components of the electric field signals to reduce noise in the optical signals. These noise components can be correlated in time, such as correlating transient events due to movement, or can be correlated in frequency, such as correlating certain noise frequencies of the capacitance signal to similar noise frequencies in the optical signal to cancel the noise frequencies out of the optical signal. Wavelet or frequency domain processing can be employed to identify common noise elements between the optical signals and the capacitance signals. These correlated, noisy portions of the capacitive signal can be used to identify and remove noise from the optical signal, such as by subtracting noise components from the optical signal, as discussed herein.

Instead of or in addition to removing noise from the optical signal, processing node **1230** can assign a weighting or quality indicator of the optical signals when the capacitance signals indicated large transient noise events. For examples, processing node **121** can process the one or more optical signals with a first, lower, processing weight when the noise level of the capacitance signal exceeds a noise threshold and process the one or more optical signals with a second, higher, processing weight when the noise level of the capacitance signal does not exceed the noise threshold. Processing node **1230** can identify noisy periods using the capacitance signal and avoid optical measurements during noisy periods, or indicate poor quality of measurements by changing a light or indicator based on a confidence level of the optical measurements. In other examples, where physiological parameters are being logged, a confidence indication can accompany any optical measurements to indicate noisy periods so a user or processing system can give appropriate weighting to optical measurement data.

The capacitance signal can be compared to the optical signal to determine physiological events. These events can include sudden changes or movements of the patient which can indicate a seizure or other transient movement event. Another event includes blood loss by the patient, which can be identified when a capacitance signal remains roughly unchanged but an optical signal deviates greatly, which may occur if a patient is bleeding profusely.

Further signal processing can be performed utilizing both the capacitance based measurements and the optical based measurements. For example, processing node **1230** can determine severity of motion artifacts in a PPG or power of artifacts at certain frequencies of a PPG to determine at what frequencies of a PPG waveform might be corrupt or poor quality. Processing node **1230** can determine impulse response from the capacitance signal and apply this impulse response to a PPG waveform. The impulse response can be employed in a finite impulse response (FIR) filter, where the capacitance signal is input to the FIR, and the FIR output is subtracted from a PPG. Filter coefficients can be adapted over time based on measurements of the capacitance signals.

A fundamental frequency of a PPG can be determined by processing system **1230**, and a spectrum of a noise signal can be derived from capacitance signal with a high pass or bandpass filter. The PPG waveform can be filtered to remove noise that is at one or more fundamental frequencies of the noise waveform. In some examples, the fundamental frequencies of the PPG waveform correlate to a heart rate, and noise can be removed from other frequencies to smooth out a signal that contains the remaining fundamental frequencies. A comb filter can be employed by processing system **1230** to extract only heart rate harmonics of a heart rate from a PPG, and eliminate an Nth harmonic of the heart rate signal if the Nth harmonic is found to be excessively noisy as determined by the capacitance signal. The time epoch to calculate the spectrum of noise from the capacitance signal may vary in duration depending on what frequency of noise is to be eliminated. Other methods such as correlations, independent component analysis (ICA), pleth morphology, FFT, or wavelet analysis may be used for noise mitigation or subtraction. Correction of measurements for DC shifts can also be improved by comparing the capacitance signal to a measured physiological signal.

Furthermore, processing node **1230** can process the capacitance signal to provide an input to an ensemble averaging algorithm. This input, which may be referred to as a lock signal, can be employed in ensemble averaging as a clock signal to lock a PPG signal to the clock to improve the ensemble averaging and establish a consistent periodic averaging. In ensemble averaging, the capacitance signal can also be employed to indicate a confidence level for each individual averaging of the ensemble based on a measured noise level. The capacitance signal can be used to determine an instantaneous noise level which can indicate a confidence level of the optical measurement. When the optical measurements are used in an ensemble averaging process, when a high instantaneous noise is monitored for a portion of the optical signal, then that portion of the optical signal can receive a lower weighting in the ensemble average. Less noisy portions of the optical signal can be given a higher weighting in the ensemble average. The weighting can be correlated to a noise level measured by the capacitance signal. In another example, an ensemble average weight can be modified based on likelihood of noise in a physiological parameter, such a PPG. The likelihood of noise can be established by monitoring a capacitance signal and identifying when noise of the capacitance signal indicates a concurrently measured physiological parameter is subject to similar noise. For example, an optical signal used to measure a PPG can have an ensemble average weight modified when a concurrent capacitance measurement indicates noise.

FIG. **13** is a system diagram illustrating physiological measurement system **1300**. System **1300** includes measurement system **1310** and pressure system **1311**, with capacitive sensors **1320-1322**, and pressure cuff **1330** applied to tissue **1340**. Measurement system **1310** and capacitive sensors **1320-1322** communicate over link **1350**, which can include one or more links for each capacitive sensor.

Pressure system **1311** supplies air pressure to pressure cuff **1330** over pneumatic link **1351**. Pressure system **1311** and pressure cuff **1330** can be included in sphygmomanometer equipment. Tissue **1340** comprises tissue of a patient under measurement of physiological parameters. Tissue **1340** can comprise an arm, leg, limb, finger, or other tissue element. Measurement system **1310** can include elements described herein for measurement equipment **101** in FIGS. **1-8**, although variations are possible.

Each of capacitive sensors **1320-1322** are distributed across pressure cuff **1330** to lie in proximity with tissue **1340** and emit associated electric fields into the surrounding environment of each sensor. When pressure cuff **1330** is placed over tissue **1340** for measurement of blood pressure, sensors **1320-1322** are also placed in proximity to tissue **1340**.

Capacitance of each of capacitive sensors **1320-1322** can be employed to detect correct orientation, application, or alignment of pressure cuff **1330** on tissue **1340**. For example, pressure cuff **1330** might be applied too loosely, too tightly, be of an incorrect size for the patient, or have poor contact with tissue **1340**. As the capacitance measured by each of capacitive sensors **1320-1322** is monitored, these configurations of pressure cuff **1330** can be monitored and alerted. Pressure modulations due to blood pumping in tissue **1340** can induce capacitance modulations in capacitive sensors **1320-1322**. These capacitance modulations can be monitored to determine proper magnitudes or amplitudes to establish if correct pressure is being applied by pressure cuff **1330** to tissue **1340**.

In other examples, capacitive sensors **1320-1322** can detect where pressure modulations are greatest, and alert an operator of measurement system **1310** to reposition cuff **1330**. Greatest modulations are typically preferred in the center of cuff **1330**, and capacitive sensors **1320-1322** can be employed by an operator to ensure correct positioning and pressure of cuff **1330** on tissue **1340**.

Further examples include measurement system **1310** producing a warning or alarm if an incorrect cuff size or cuff position is used based on cuff pressure measured by capacitive sensors **1320-1322**. Measurement system **1310** can illuminate one or more indicator lights, such as LEDs, on cuff **1330** to indicate where the largest pressure modulation or oscillation is presently found, based on pressure measured by capacitive sensors **1320-1322**, and an operator can reposition cuff **1330** to align the largest oscillation to the center of cuff **1330** using the indicator lights as a guide. Previous measurements of capacitive sensors **1320-1322** can be stored for later use when re-applying cuff **1330** to help guide cuff inflation or positioning.

Measurement of blood pressure of tissue **1340** can also be enhanced by capacitive sensors **1320-1322**. Specifically, a capacitance-based pressure measurement can be determined by each of capacitive sensors **1320-1322**. This capacitance-based pressure measurement can be used to adjust pressure of a multi-chamber cuff to adjust pressure of each chamber based on a desired pressure and the capacitance-based measurement of current pressure. Cuff size can be variable based on pressure, and capacitive sensors **1320-1322** can indicate when a desired pressure or size is achieved. Correction of various measurement parameters can also occur based on capacitance-based pressure measurement. For example, regions of cuff **1330** with higher pressure can have a first level of measurement correction included, while regions of cuff **1330** with lower pressure can have a second level of measurement correction included. The correction can include scaling values measured for systolic, diastolic, or mean arterial pressure based on pressure measurements found at each of capacitive sensors **1320-1322**. In addition, pressure measurements of cuff **1330** performed by capacitive sensors **1320-1322** can indicate confidence values for the blood pressure measurements, leading to a quality score that scales based on a desired pressure of cuff **1330** and an actual pressure of cuff **1330**. Sensors may also aid in smarter cuff inflation and deflation profiles, leading to faster or more accurate measurements with less patient discomfort.

Capacitive sensors **1320-1322** can comprise thin metallic plates, metallic grids, metallic patches, or other capacitor plate materials. Although capacitive sensors **1320-1322** are included in FIG. **13**, other sensor types could instead be employed to detect variable pressure of cuff **1330** on tissue **1340**, such as impedance sensors, resistance sensors, inductance sensors, or pressure sensors, including combinations thereof.

FIG. **14** is a system diagram illustrating physiological measurement system **1400**. System **1400** includes measurement system **1410**, with optical emitter **1420**, optical detector **1421**, and inductive coils **1430-1431** applied to tissue **1440**. Measurement system **1410** and inductive coil **1430** communicate over link **1450**. Measurement system **1410** and inductive coil **1431** communicate over link **1451**. Measurement system **1410** and optical emitter **1420** communicate over link **1452**. Measurement system **1410** and optical detector communicate over link **1453**.

Measurement system **1410** can include elements described for measurement equipment **101** in FIGS. **1-8**, although variations are possible. Likewise, optical emitter and optical detector **1420-1421** can include elements described for optical emitter and detector **180-181** in FIG. **1**B, although variations are possible. Links **1450-1451** are electric links for carrying a time-based electrical signal to ones of coils **1430-1431**. Links **1452-1453** comprise elements described herein for links **160-161**, although variations are possible.

An electrical schematic representation of inductive coils **1430-1431** and tissue **1440** is shown at the bottom of FIG. **14**. In operation, at least one of coils **1430-1431** are powered by a modulated electrical signal to create a transformer, with tissue **1440** acting as a pseudo-core to the transformer. In one example, coil **1430** acts as a transmitter and coil **1431** acts as a receiver, although the opposite configuration is possible. When operating, magnetic fields will be induced in tissue **1440** by the coils. Tissue **1440** will have a variable magnetic permeability, such as due to changes in blood components, pulsing of arterial or venous blood, among other variations. As the magnetic permeability of tissue **1440** changes with time, parameters such as pulsing of blood, hydration, blood oxygenation, hemoglobin movement, and other physiological measurements can be extracted from the changes in magnetic permeability.

In a first example measurement, variations in magnetic permeability can be detected by measurement system **1410** and these variations can represent a pulsatile waveform. The pulsatile waveform can be indicative of a pulse in tissue **1440**. Measurement system **1410** can use this pulsatile waveform to determine physiological parameters, or to supplement and enhance other physiological measurements. For example, optical emitter **1420** emits optical signal **1450** into tissue **1440** and optical detector **1421** detects optical signal **1450** after propagation in tissue **1440**. The pulsatile waveform detected using inductive coils **1430-1431** can be used to cross-check a PPG monitored by optical sensors **1420-1421**. This cross-check can verify that a PPG signal is valid, or reduce the number of false alarms associated with a PPG monitoring system due to optical sensors improperly applied to tissue **1440** or entirely off of tissue **1440**. To verify that a PPG signal is valid, a pulsatile waveform detected using inductive coils **1430-1431** can be correlated or aligned to a PPG measured by optical sensors **1420-1421**. If a pulsatile waveform detected using inductive coils **1430-1431** correlates to a PPG measured by optical sensors **1420-1421**, then the PPG can be considered valid. However, if the PPG measured by optical sensors **1420-1421** does not correlate or align to that measured using inductive coils **1430-1431**, then the PPG can be considered suspect or invalid, and an operator can be notified of a possible discrepancy or error in the measurements.

FIG. **15** is a diagram illustrating measurement pads for measurement of physiological parameters. FIG. **15** includes **5** pad configurations, namely pads **1510**, **1520**, **1530**, **1540**, and **1550**. Each of pads **1510**, **1520**, **1530**, **1540**, and **1550** can comprise any bio compatible material for interfacing with tissue of a patient. Adhesive can be included in any of pads **1510**, **1520**, **1530**, **1540**, and **1550** to attach to tissue of a patient, or other mechanical attachment elements can be included, such as clips, springs, bands, and the like. Each of pads **1510**, **1520**, **1530**, **1540**, and **1550** can be used for the various capacitive node or optical node sensor elements herein, and other variations are possible. Each measurement pad may be attached to or integrally incorporated into a sensor that is configured to attach to or interface with the tissue to be measured.

As shown in system **1560**, an example finger as tissue **1562** has an exemplary pad **1561** applied thereto. Link **1563** supplies any signaling and shielding appropriate for measurement or sensor elements of pad **1561**. Pad **1561** can be applied to one side or more than one side of tissue **1562**, such as a top and bottom of a finger as shown. Capacitor elements can be included in pad **1561** to lie in proximity to one or both sides of tissue **1562**.

Turning now to each of pads **1510**, **1520**, **1530**, **1540**, and **1550** each pad is intended to be folded over an extremity, such as a finger or toe, as indicated by the dotted fold line on each pad. Alternatively, each pad can be applied generally flat to tissue such as a forehead, chest, leg, arm, and the like. Although not shown for clarity in FIG. **15**, each capacitive element can include an associated electrical link for connection with a measurement system, along with any associated shielding and ground pads. Likewise, optical measurement elements can be included in each pad, with each pad indicating two optical apertures. A first of the optical apertures can be employed for one or more optical emitters, while a second of the optical apertures can be employed for one or more optical detectors. When multiple emitters are included in a pad, more than one optical wavelength can be employed. In some examples, both an optical emitter and detector are employed in each optical aperture, with each optical emitter-detector pair dedicated to a different wavelength of light.

Pad **1510** includes two conductive plates **1513-1514** as capacitor plates. Capacitor plates **1513-1514** are positioned on either side of optical aperture **1512**. Capacitor plates **1513-1514** can be flexible and metallic for conforming to tissue once applied with pad **1510**. Capacitor plates **1513-1514** can comprise thin metallic sheets, metallic plates, or metallic grids, along with other configurations. Each of capacitor plates **1513-1514** can be employed as a single plate capacitor, or both plates can be combined into a two-plate capacitor. Pad **1510**, when wrapped around a finger or toe, or when placed flat onto tissue, can provide two single-plate capacitors on a single side of tissue, or one two-plate capacitor on a single side of tissue.

Pad **1520** includes conductive plate **1523** as a capacitor plate. Capacitor plate **1523** is positioned around both of optical apertures **1521-1522**. Capacitor plate **1523** can be flexible and metallic for conforming to tissue once applied with pad **1520**. Capacitor plate **1523** can comprise a thin metallic sheet, metallic plate, or metallic grid, along with other configurations. Capacitor plate **1523** can be employed as a single plate capacitor. Pad **1520**, when wrapped around

a finger or toe, can provide a single-plate capacitor that extends around two sides of tissue. Alternatively, when placed flat onto tissue, pad **1520** can provide a single-plate capacitor that is positioned on one side of tissue.

Pad **1530** includes capacitor plate **1533**. Capacitor plate **1533** is positioned around both of optical apertures **1531-1532** in a serpentine fashion. Capacitor plate **1533** can be flexible and metallic for conforming to tissue once applied with pad **1530**. Capacitor plate **1533** can comprise a thin metallic wire or narrow flat sheet (such as a circuit trace), along with other configurations. Capacitor plate **1533** can be employed as a single plate capacitor. Pad **1530**, when wrapped around a finger or toe, can provide a single-plate capacitor that extends around two sides of tissue. Alternatively, when placed flat onto tissue, pad **1530** can provide a single-plate capacitor that is positioned on one side of tissue.

Pad **1540** includes four conductive plates **1543-1546** as capacitor plates. Capacitor plates **1543-1544** are positioned on either side of optical aperture **1542**. Capacitor plates **1545-1546** are positioned on either side of optical aperture **1541**. Capacitor plates **1543-1546** can be flexible and metallic for conforming to tissue once applied with pad **1540**. Capacitor plates **1543-1546** can comprise thin metallic sheets, metallic plates, or metallic grids, along with other configurations. Each of capacitor plates **1543-1546** can be employed as a single plate capacitor, or in pairs to form two-plate capacitors around each associated optical aperture. Pad **1540**, when wrapped around a finger or toe, can provide four single-plate capacitors on two sides of tissue, or two dual-plate capacitors on two sides of tissue. Alternatively, when placed flat onto tissue, pad **1540** can provide various capacitor plate configurations positioned on one side of tissue.

Pad **1550** includes two conductive wires **1553-1554** as capacitor plates. Capacitor plates **1553-1554** are positioned between both of optical apertures **1551-1552** in a spiral fashion. Capacitor plates **1553-1554** can be flexible and metallic for conforming to tissue once applied with pad **1550**. Capacitor plates **1553-1554** can comprise thin metallic wires or narrow flat sheets (such as a circuit traces), along with other configurations. Each of capacitor plates **1553-1554** can be employed as a single plate capacitor, or both plates can be combined into a two-plate capacitor. Pad **1550**, when wrapped around a finger or toe, can provide a single-plate capacitor that extends around two sides of tissue. Alternatively, when placed flat onto tissue, pad **1550** can provide a single-plate capacitor that is positioned on one side of tissue.

FIG. **16** is a system diagram illustrating physiological measurement system **1600**. System **1600** illustrates usage of an electromagnetic shield or faraday shield of a pulse oximetry sensor as a capacitive plate. System **1600** includes pulse oximetry probe **1610**, optical emitter **1620**, optical detector **1621**, faraday shield **1622**, measurement link **1650**, and shield interface **1660**, applied to tissue **1640**. Measurement link **1650** is a coaxial link that further includes outer shield **1652**, inner shield **1651**, detector link **1653**, and emitter link **1654**. Although one link per emitter/detector is shown in FIG. **16**, more the one link can instead be employed. Further measurement equipment, such as processing systems, optical systems, and capacitance systems, are omitted for clarity from FIG. **16**.

Pulse oximetry probe **1610** comprises a structural element to position sensing portions of measurement system **1600** onto tissue **1640**, such as clips, pads, bands, springs, and the like. In FIG. **16**, an example pad **1611** is used as the structural element. Pulse oximetry probe **1610** includes optical emitter **1620** and optical detector **1621** for emitting optical signals **1630** into tissue **1640** for measurement of physiological parameters, such as pulse and SpO_2 of blood. In some examples, pulse oximetry probe **1610** comprises a modified MAX-A pulse oximetry probe available from Covidien LP (Boulder, Colo.).

To provide a level of environmental and electromagnetic shielding for at least emitter **1620** and detector **1621**, faraday shield **1622** is provided to surround at least emitter **1620** and detector **1621**. Faraday shield **1622** comprises a metal or metallic surround or enclosure with associated optical apertures **1623** to allow emission or detection of optical signal **1630**. Faraday shield **1622** can comprise a braided shield or wire mesh configuration.

In this example, inner shield **1651** is electrically connected to faraday shield **1622**. In some examples, inner shield **1651** is extended to create faraday shield **1622** around at least emitter **1620** and detector **1621**. Inner shield **1651** also includes and surrounds emitter link **1654** and detector link **1653**. Outer shield **1652** surrounds inner shield **1651**, along with any additional wires or links that might be included in link **1650**. In this example, outer shield **1652** is not electrically connected to inner shield **1651** and is isolated by dielectric **1655**, such as a sheathing or coaxial insulator. Furthermore, outer shield **1652** is not electrically connected to faraday shield **1622** in this example.

In operation, optical signals **1630** are emitted by optical emitter **1620** into tissue **1640** after probe **1610** is applied to tissue **1640**. Optical detector **1621** detects optical signal **1630** after propagation through tissue **1640**. Optical emitter **1620** and optical detector **1621** communicate with measurement equipment, not shown for clarity, over associated links **1653-1654**. Optical emitter **1620** includes LED or laser diode equipment and receives an electrical signal over link **1654**. Likewise, optical detector **1621** includes optical detection elements, such as photodiodes, photodetectors, or other optical sensors, and transfers electrical signals representative of the optical signals detected to measurement equipment over link **1653**. Inner shield **1651** is provided as an electromagnetic interference (EMI) shield for not only optical emitter **1620** and optical detector **1621**, but for also links **1653-1654**. In some examples, faraday shield **1622** does not surround optical emitter **1620** and instead surrounds optical detector **1621** and associated links.

Faraday shield **1622** can be employed as a single plate capacitor when placed in proximity to tissue **1640**. An ambient electric field can be detected by faraday shield **1622** which can be indicative of proximity to tissue **1640**. When an ambient signal is used, then a calibration routine can be performed which establishes measurement thresholds for using faraday shield **1622** as a capacitive plate. These thresholds can indicate when probe **1610** is placed on tissue **1640** or off of tissue **1640**. The thresholds can be determined by having an operator take a first measurement when probe **1610** is not on tissue **1640** and a second measurement once probe **1610** is properly placed on tissue **1640**. In this manner, measurement equipment can detect when probe **1610** has fallen off or been removed from tissue **1640** and alert monitoring personnel accordingly.

Alternatively, an electrical signal **1631** can be driven onto faraday shield **1622** by inner shield **1651** to emit an electrical signal into tissue **1640** as discussed herein for single plate capacitors. When electrical signals are driven onto faraday shield **1622** by measurement equipment, then processes as discussed herein can be employed to detect when probe **1610** is placed on or is off of tissue **1640**. As with the ambient measurement above, appropriate thresholds for

probe on/off conditions can be determined. Measurement equipment can then detect when probe **1610** has fallen off or been removed from tissue **1640** and alert monitoring personnel accordingly.

Using faraday shield **1622** as a capacitor plate can introduce noise onto the EMI shielding for at least optical detector **1621**. To mitigate this noise, shield interface **1660** can be employed. Shield interface **1660** can include one or more analog switches, digital-to-analog converters, or other high-impedance interface circuitry to isolate inner shield **1651** from measurement equipment attempting to detect sensor on/off conditions. When a measurement for sensor on/off is desired, then measurement equipment can be electrically connected by enabling an analog switch to drive a signal onto inner shield **1651** using a lower impedance connection. Likewise, a normally off high-impedance output of a digital-to-analog converter can be enabled to drive a signal onto inner shield **1651**. The measurement signal driven onto inner shield **1651** can be driven by a general purpose **110** pin of a microprocessor as a pulse-width modulated signal, with or without analog filtering.

For example, if an optical measurement using optical emitter **1620** and optical detector **1621** indicates an error condition for the patient undergoing physiological measurement, then before an alert is generated based on the optical measurement, the capacitive measurement using faraday shield **1622** is performed. Shield interface **1660** can drive a measurement signal onto inner shield **1651** which drives electrical field signal **1631** from faraday shield **1622**. Based on monitoring this measurement signal a determination can be made whether or not probe **1610** is actually on tissue **1640** or has been removed or fallen off. Alerts for medical personnel or medical logs can be adjusted based on whether probe **1610** is on tissue **1640** or not.

Further methods can be employed to mitigate unwanted interference caused by driving an active signal onto faraday shield **1622** and inner shield **1651**. In a first example, inner shield **1651** is driven at more than one modulation frequency at different times, so that resistance and capacitance can be derived from different measurements. In another example, the driven signal is frequency hopped or employs spread spectrum techniques to minimize emitting electromagnetic interference by faraday shield **1622**. In yet another example, both inner shield **1651** and outer shield **1652** are driven actively when a capacitance measurement is desired, but each of inner shield **1651** and outer shield **1652** are driven with differential/complementary signals to minimize interference. In further examples, a dummy wire is present in link **1650**, or outer shield **1652** is employed as a reference wire, to monitor and cancel environmental interference, such as EMI from lighting, measurement equipment, patients touching conductive objects, ambient EMI, or other sources of EMI. A dummy wire is discussed further in FIG. **17**. Regardless of the method, measurement times are typically kept short to minimize interference and to minimize displacement of optical measurements.

FIG. **17** is a system diagram illustrating physiological measurement system **1700**. System **1700** illustrates usage of spiral capacitance plate **1720** along with a differential measurement link arrangement of link **1750**. System **1700** includes spiral capacitance plate **1720**, optical emitter/detector **1722**, measurement link **1750**, and measurement system **1760**. Spiral capacitance plate **1720** can be applied to tissue, such as a finger or forehead. Measurement link **1750** is a coaxial link with an internal twisted pair of wires. Measurement link **1750** includes outer shield **1752**, inner shield **1751**, capacitance link **1753**, and reference link **1754**. Measurement link **1750** can include further capacitance links to interface with plate **1720**. Measurement link **1750** can also include optical links or other electrical links used for optical emitter/detector **1722**, but these are omitted for clarity in FIG. **17**. In some examples, measurement system **1760** comprises a capacitance to digital converter to convert signals detected over link **1753** into a digital format. Further measurement equipment, such as processing systems, optical systems, and capacitance systems, are also omitted for clarity from FIG. **17**.

Spiral capacitance plate **1720** comprises structural elements to position sensing portions of measurement system **1700** onto tissue **1740**, such as clips, pads, bands, springs, and the like. Spiral capacitance plate **1720** comprises one or more wires, such as circuit traces, that comprise individual capacitor plates. The spiral capacitance wires of plate **1720** allow for larger sensor surface area to sense various physiological parameters in tissue. Plate **1720** can include a single spiral wire or can include multiple, such as two shown in FIG. **17**. Plate **1720** includes a central aperture through which optical emitter/detector **1722** can emit/detect optical signals **1730** into tissue for measurement of physiological parameters, such as pulse and SpO_2 of blood.

In this example, inner shield **1751** creates a faraday shield around at least links **1753-1754**. Inner shield **1751** can be electrically connected to an AC signal source. Outer shield **1752** surrounds inner shield **1751**, along with any additional wires or links that might be included in link **1750**. Also in this example, outer shield **1752** creates a faraday shield around at least links **1753-1754** and inner shield **1751**. Outer shield **1752** is not electrically connected to inner shield **1751** and is isolated by dielectric **1758**, which can include sheathing **1755** or coaxial insulator material. Furthermore, outer shield **1752** can be optionally connected to ground or a reference potential.

Measurement link **1750** comprises a two shield system (**1751-1752**) with a twisted pair wire inside. In the twisted pair, one wire (**1753**) acts as a conductor for a single plate capacitor **1720** and the second wire (**1754**) acts as a 'dummy' reference conductor wire. When a person grabs both wires simultaneously, both wires indicate a change in capacitance of a similar magnitude, which can be subtracted out as a common mode signal, leaving behind the desired signal measured using capacitance link **1753**. When only capacitance link **1753** or capacitance plate **1720** are contacted or proximate to tissue, then the common mode signal will be smaller and less of a factor in measurement processing. Higher twists per inch in the twisted pair can aid to keep the wires electromagnetically coupled. An electrically driven shield around the twisted pair, such as inner shield **1751**, acts as a shield but also can minimize electromagnetic coupling onto the twisted pair, in part because energy will not typically flow between two wires of the same potential. An optional second shield (outer shield **1752**) around inner shield **1751** should be grounded to act as a mitigation of radiated emissions from inner shield **1751** when inner shield **1751** is electrically driven, such as by an AC signal. In another example, both inner shield **1751** and outer shield **1752** are driven actively when a capacitance measurement is desired, but each of inner shield **1751** and outer shield **1752** are driven with differential/complementary signals to minimize interference. In further examples, reference link **1754** can be used to monitor and cancel environmental interference, such as EMI from lighting, measurement equipment, patients touching conductive objects, ambient EMI, or other sources of EMI.

In operation, optical signals are emitted by optical emitter/detector **1722** into tissue. Optical emitter/detector **1722** optical signals after propagation through tissue. Optical emitter/detector **1722** communicate with measurement equipment, not shown for clarity, over associated links. Optical emitter/detector **1722** include LED or laser diode equipment and optical detection elements, such as photodiodes, photodetectors, or other optical sensors, and transfers electrical signals representative of the optical signals detected to measurement equipment. Plate **1720** can be employed as a single plate capacitor or two plate capacitor when placed in proximity to tissue. An electrical signal can be driven onto plate **1720** by capacitance link **1753** to emit an electrical signal into tissue as discussed herein for single plate capacitors or two plate capacitors. Measurement system **1760** can monitor changes in an electric field or changes in a capacitance signal associated with the electric field emitted by plate **1720** to determine physiological parameters. Measurement system **1760** can use the capacitance signals to modify or correct measurements performed using the optical elements, among other operations as discussed herein.

FIG. **18** is a block diagram illustrating measurement system **1800**, as an example of elements of measurement equipment **101** in FIGS. **1-8**, measurement system **910** in FIG. **9**, measurement system **1310** in FIG. **13**, or measurement system **1410** in FIG. **14**, although these can use other configurations. Measurement system **1800** includes optical system interface **1810**, processing system **1820**, user interface **1840**, capacitance system interface **1850**, and optionally optical system **1870** and capacitance system **1880**. Optical system interface **1810**, processing system **1820**, user interface **1840**, and capacitance system interface **1850** are shown to communicate over a common bus **1860** for illustrative purposes. It should be understood that discrete links can be employed, such as communication links or other circuitry. Measurement system **1800** may be distributed or consolidated among equipment or circuitry that together forms the elements of measurement system **1800**.

Optical system interface **1810** comprises a communication interface for communicating with other circuitry and equipment, such as with optical system **1870**. Optical system interface **1810** can include transceiver equipment exchanging communications over one or more of the associated links **1861-1862**. It should be understood that optical system interface **1810** can include multiple interfaces, pins, transceivers, or other elements for communicating with multiple external devices. Optical system interface **1810** also receives command and control information and instructions from processing system **1820** or user interface **1840** for controlling the operations of optical system interface **1810**. Links **1861-1862** can each use various protocols or communication formats as described herein for links **180-181**, including combinations, variations, or improvements thereof.

Processing system **1820** includes storage system **1821**. Processing system **1820** retrieves and executes software **1830** from storage system **1821**. In some examples, processing system **1820** is located within the same equipment in which optical system interface **1810**, user interface **1840**, or capacitance system interface **1850** are located. In further examples, processing system **1820** comprises specialized circuitry, and software **1830** or storage system **1821** can be included in the specialized circuitry to operate processing system **1820** as described herein. Storage system **1821** can include a non-transitory computer-readable medium such as a disk, tape, integrated circuit, server, flash memory, or some other memory device, and also may be distributed among multiple memory devices.

Software **1830** may include an operating system, logs, utilities, drivers, networking software, tables, databases, data structures, and other software typically loaded onto a computer system. Software **1830** can contain application programs, server software, firmware, processing algorithms, or some other form of computer-readable processing instructions. When executed by processing system **1820**, software **1830** directs processing system **1820** to operate as described herein, such as instruct optical or capacitance systems to generate optical or electrical signals for measurement of physiological parameters of patients, receive signals representative of optical or capacitance measurements of patients, and process at least the received signals to determine physiological parameters of patients, among other operations.

In this example, software **1830** includes generation module **1831**, detection module **1832**, and signal processing module **1833**. It should be understood that a different configuration can be employed, and individual modules of software **1830** can be included in different equipment in measurement system **1800**. Generation module **1831** determines parameters for optical or capacitance signals, such as modulation parameters, signal strengths, amplitude parameters, voltage parameters, on/off conditions, or other parameters used in controlling the operation of optical systems and capacitance systems over ones of links **1861-1864**. Generation module **1831** directs optical system **1870** and capacitance system **1880** to perform physiological measurements, and can selectively apply or remove power from various detection sensors, emitters, capacitors, and other sensor elements. Detection module **1832** receives characteristics of optical and capacitance signals as detected by external circuitry. Signal processing module **1833** processes the received characteristics of optical and capacitance signals to determine physiological parameters, among other operations.

User interface **1840** includes equipment and circuitry to communicate information to a user of measurement system **1800**, such as alerts, measurement results, and measurement status. Examples of the equipment to communicate information to the user can include displays, indicator lights, lamps, light-emitting diodes, haptic feedback devices, audible signal transducers, speakers, buzzers, alarms, vibration devices, or other indicator equipment, including combinations thereof. The information can include blood parameter information, waveforms, summarized blood parameter information, graphs, charts, processing status, or other information. User interface **1840** also includes equipment and circuitry for receiving user input and control, such as for beginning, halting, or changing a measurement process or a calibration process. Examples of the equipment and circuitry for receiving user input and control include push buttons, touch screens, selection knobs, dials, switches, actuators, keys, keyboards, pointer devices, microphones, transducers, potentiometers, non-contact sensing circuitry, or other human-interface equipment.

Capacitance system interface **1850** comprises a communication interface for communicating with other circuitry and equipment, such as with capacitance system **1880**. Capacitance system interface **1850** can include transceiver equipment exchanging communications over one or more of the associated links **1863-1864**. It should be understood that capacitance system interface **1850** can include multiple interfaces, pins, transceivers, or other elements for communicating with multiple external devices. Capacitance system

interface **1850** also receives command and control information and instructions from processing system **1850** or user interface **1840** for controlling the operations of capacitance system interface **1850**. Links **1863-1864** can each use various protocols or communication formats as described herein for links **170-171**, including combinations, variations, or improvements thereof.

Bus **1860** comprises a physical, logical, or virtual communication link, capable of communicating data, control signals, and communications, along with other information. In some examples, bus **1860** is encapsulated within the elements of measurement system **1800**, and may be a software or logical link. In other examples, bus **1860** uses various communication media, such as air, space, metal, optical fiber, or some other signal propagation path, including combinations thereof. Bus **1860** can be a direct link or might include various equipment, intermediate components, systems, and networks.

Optical system **1870** can include electrical to optical conversion circuitry and equipment, optical modulation equipment, and optical waveguide interface equipment. Optical system **1870** can include direct digital synthesis (DDS) components, CD/DVD laser driver components, function generators, oscillators, or other signal generation components, filters, delay elements, signal conditioning components, such as passive signal conditioning devices, attenuators, filters, and directional couplers, active signal conditioning devices, amplifiers, or frequency converters, including combinations thereof. Optical system **1870** can also include switching, multiplexing, or buffering circuitry, such as solid-state switches, RF switches, diodes, or other solid state devices. Optical system **1870** also can include laser elements such as a laser diode, solid-state laser, or other laser device, along with associated driving circuitry. Optical couplers, cabling, or attachments can be included to optically mate to links **1871-1872**. Optical system **1870** can also include light detection equipment, optical to electrical conversion circuitry, photon density wave characteristic detection equipment, and analog-to-digital conversion equipment. Optical system **1870** can include one or more photodiodes, phototransistors, avalanche photodiodes (APD), or other optoelectronic sensors, along with associated receiver circuitry such as amplifiers or filters. Optical system **1870** can also include phase and amplitude detection circuitry and processing elements. Links **1871-1872** can each use various signal formats as described herein for links **161-162**, including combinations, variations, or improvements thereof.

Capacitance system **1880** comprises one or more electrical interfaces for applying one or more electric field signals to tissue of a patient over electrical links **1881-1882**. In some examples, capacitance system **1880** drives one or more capacitor plates that are placed in proximity to tissue of a patient. Capacitance system **1880** can include transceivers, amplifiers, modulators, capacitance monitoring systems and circuitry, impedance matching circuitry, human-interface circuitry, electrostatic discharge circuitry, and electromagnetic shield interface circuitry, including combinations thereof. It should be understood that capacitance system interface **1850** can include multiple interfaces, pins, transceivers, or other elements for communicating with multiple external devices. Capacitance system interface **1880** also can receive command and control information and instructions from capacitance system interface **1850** for controlling the operations of capacitance system **1880**. Links **1881-1882** can each use various signal formats as described herein for links **162-168**, including combinations, variations, or improvements thereof.

FIG. **19** is a diagram illustrating various capacitance configurations. FIG. **19** includes four different capacitance measurement configurations, namely single plate configuration **1901**, coplanar two-plate configuration **1902**, parallel two-plate configuration **1903**, single plate with apertures configuration **1904**, and single plate, multi-side configuration **1905**. Other capacitor plate configurations are possible, such as discussed herein.

Single plate configuration **1901** includes capacitor plate **1910** which is separated from tissue **1990** by dielectric **1920**. In some examples, dielectric **1920** is omitted. Dielectric **1920** can comprise a dielectric material or an air gap, including combinations thereof. Capacitor plate **1910** is driven by drive signal **1930** to produce electric field **1940** in proximity of tissue **1990**. In this configuration, field **1940** comprises an electric field which can extend to infinity or can use tissue **1990** as a second capacitive plate. In some examples, tissue **1990** is connected to a ground potential. Configuration **1901** can be an example of capacitance node **182** of FIGS. **1A-1B**, capacitance nodes **185-186** in FIG. **5**, or capacitance node **187** or **189** in FIG. **7**, among others, including variations thereof. In the example shown in FIG. **19**, capacitor plate **1910** is positioned on one side of tissue **1990**. In further examples, single capacitor plate **1910** can wrap around more than one side of tissue **1990**, such as capacitor plate **189** in FIG. **7** or pad **1530** of FIG. **15**.

Coplanar two-plate configuration **1902** includes capacitor plates **1911-1912** which are separated from tissue **1991** by dielectric **1921**. In some examples, dielectric **1921** is omitted. Dielectric **1921** can comprise a dielectric material or an air gap, including combinations thereof. Capacitor plate **1911** is driven by drive signal **1931** to produce electric field **1941** in proximity of tissue **1991**, with capacitor plate **1912** connected to a ground potential. In this configuration, field **1941** comprises an electric field between capacitor plates **1911-1912**. The portion of field **1941** that penetrates into tissue **1991** comprises a fringe field of a two-plate capacitor formed by capacitor plates **1911-1912**. In some examples, tissue **1991** is connected to a ground potential. Configuration **1902** can be an example of capacitance nodes **183-184** of FIG. **3** or capacitance nodes **187-188** in FIG. **7**, among others, including variations thereof. In the example shown in FIG. **19**, capacitor plates **1911-1912** are positioned on the same side of tissue **1990**.

Parallel two-plate configuration **1903** includes capacitor plates **1913-1914** which are separated from tissue **1992** by associated dielectric **1922-1923**. In some examples, dielectric **1922-1923** are omitted. Dielectric **1922-1923** can comprise a dielectric material or an air gap, including combinations thereof. Capacitor plates **1913-1914** are driven by drive signal **1932** to produce electric field **1942** in proximity of tissue **1992**, with capacitor plate **1914** connected to a ground potential. In this configuration, field **1942** comprises an electric field between capacitor plates **1913-1914**. The portion of field **1942** that penetrates into tissue **1992** comprises a field of a two-plate capacitor formed by capacitor plates **1913-1914**. In some examples, tissue **1992** is connected to a ground potential. Configuration **1903** can be an example of pad **1540** of FIG. **15**, among others, including variations thereof. In the example shown in FIG. **19**, capacitor plates **1913-1914** are positioned on different, opposing, sides of tissue **1990**.

Single plate with apertures configuration **1904** includes capacitor plate **1915** which is separated from tissue **1993** by dielectric **1924**. In some examples, dielectric **1924** is omitted. Dielectric **1924** can comprise a dielectric material or an air gap, including combinations thereof. Capacitor plate

1915 is driven by drive signal 1933 to produce electric field 1943 in proximity of tissue 1993. In this configuration, field 1943 comprises an electric field which can extend to infinity or can use tissue 1993 as a second capacitive plate. In some examples, tissue 1993 is connected to a ground potential. Configuration 1904 can be an example of pad 1520 of FIG. 15 or pad 17 of FIG. 17. Configuration 1904 can also be an example of capacitance node 182 of FIGS. 1A-1B, capacitance nodes 185-186 in FIG. 5, or capacitance node 187 or 189 in FIG. 7, among others, when one or more apertures are included. In the example shown in FIG. 19, capacitor plate 1915 is positioned on one side of tissue 1993. In further examples, single capacitor plate 1915 can wrap around more than one side of tissue 1993, such as capacitor plate 189 in FIG. 7, pad 1520 of FIG. 15, or configuration 1905 in FIG. 19.

Single plate, multi-side configuration 1905 includes capacitor plate 1916 which is separated from tissue 1994 by dielectric 1925. In some examples, dielectric 1925 is omitted. Dielectric 1925 can comprise a dielectric material or an air gap, including combinations thereof. Capacitor plate 1916 is driven by drive signal 1934 to produce electric field 1944 in proximity of tissue 1994. In this configuration, field 1944 comprises an electric field which can extend to infinity or can use tissue 1994 as a second capacitive plate. In some examples, tissue 1994 is connected to a ground potential. Configuration 1905 can be an example of capacitance node 189 of FIG. 7, or pads 1520 or 1530 of FIG. 15, among others. In the example shown in FIG. 19, capacitor plate 1916 wraps around more than one side of tissue 1994.

The included descriptions and drawings depict specific embodiments to teach those skilled in the art how to make and use the best mode. For the purpose of teaching inventive principles, some conventional aspects have been simplified or omitted. Those skilled in the art will appreciate variations from these embodiments that fall within the scope of the invention. Those skilled in the art will also appreciate that the features described above can be combined in various ways to form multiple embodiments. As a result, the invention is not limited to the specific embodiments described above.

What is claimed is:

1. A physiological measurement system, comprising:
an optical system configured to emit one or more optical signals into tissue of a patient, and detect the one or more optical signals after propagation through the tissue;
a capacitance system configured to apply one or more electric field signals to a single side of the tissue to determine a capacitance signal based at least on changes in the one or more electric field signals; and
a processing system configured to process at least the one or more detected optical signals to determine a first estimate of a physiological parameter of the patient, and process at least the capacitance signal to determine a second estimate of the physiological parameter of the patient.

2. The measurement system of claim 1, comprising:
the capacitance system configured to apply the one or more electric field signals to the single side of the tissue using one or more capacitor plates that do not contact the tissue.

3. The measurement system of claim 1, comprising:
the capacitance system configured to apply the one or more electric field signals to the single side of the tissue using a single plate capacitor.

4. The measurement system of claim 1, comprising:
the capacitance system configured to apply the one or more electric field signals to the single side of the tissue using a two plate capacitor.

5. The measurement system of claim 1, wherein the capacitance system includes at least one capacitor plate, and wherein the processing system is configured to process the capacitance signal to determine a placement of the at least one capacitor plate with respect to the tissue.

6. The measurement system of claim 5, further comprising:
a user interface configured to generate an alert when the placement comprises the at least one capacitor plate improperly applied to the tissue.

7. A physiological measurement system, comprising:
an optical system configured to emit one or more optical signals into tissue of a patient, and detect the one or more optical signals after propagation through the tissue;
a capacitance system configured to apply one or more electric field signals to a single side of the tissue to determine a capacitance signal based at least on changes in the one or more electric field signals, wherein the capacitance system includes at least one capacitor plate; and
a processing system configured to process at least the one or more detected optical signals and the capacitance signal to determine a physiological parameter of the patient, wherein the processing system is configured to:
process the capacitance signal to determine a placement of the at least one capacitor plate with respect to the tissue; and
compare the capacitance signal to a threshold and determine the placement based on the comparison.

8. The measurement system of claim 7, wherein the one or more detected optical signals comprise an optical plethysmograph, and wherein the processing system is configured to adjust the optical plethysmograph based on the capacitance signal.

9. The measurement system of claim 7, wherein the processing system is configured to subtract a scaled version of the capacitance signal from a correlating portion of the one or more detected optical signals.

10. The measurement system of claim 7, wherein the processing system is configured to use the capacitance signal to identify when noise exceeds a threshold in a portion of the one or more detected optical signals, and de-weight the portion of the one or more detected optical signals when determining the physiological parameter.

11. The measurement system of claim 7, wherein the processing system is configured to use the capacitance signal to identify when noise exceeds a threshold in a portion of the one or more detected optical signals, and omit the portion of the one or more detected optical signals when determining the physiological parameter.

12. The measurement system of claim 7, wherein the processing system is configured to use the capacitance signal to identify when noise exceeds a threshold in the one or more detected optical signals and responsively generate an alert.

13. The measurement system of claim 7, wherein the physiological parameter comprises one or more of a respiratory effort, respiratory rate, pulse rate, hemoglobin concentration, oxygen saturation of blood (SpO_2), SpO_2 variability, apnea condition, arrhythmia, auto regulation, saturation pattern detection, blood pressure, and temporal variability of photoplethysmogram (PPG) parameters.

14. A physiological measurement system, comprising:
an optical system configured to emit one or more optical signals into tissue of a patient, and detect the one or more optical signals after propagation through the tissue; a capacitance system configured to apply one or more electric field signals to a single side of the tissue to determine a capacitance signal based at least on changes in the one or more electric field signals, wherein the capacitance system includes at least one capacitor plate;
a processing system configured to:
identify a body part of the patient to which the one or more electric field signals are applied based at least on the placement;
process the capacitance signal to determine a placement of the at least one capacitor plate with respect to the tissue; and
process at least the one or more detected optical signals and the capacitance signal to determine a physiological parameter of the patient.

15. A physiological measurement system, comprising:
an optical system configured to emit one or more optical signals into tissue of a patient, and detect the one or more optical signals after propagation through the tissue;
a capacitance system configured to apply one or more electric field signals in proximity to the tissue using one or more capacitor plates that do not contact the tissue to determine a capacitance signal; and
a processing system configured to process at least the one or more detected optical signals to determine a first estimate of a physiological parameter of the patient, and process at least the capacitance signal to determine a second estimate of the physiological parameter of the patient.

16. The measurement system of claim 15, comprising:
the capacitance system configured to apply the one or more electric field signals in proximity to a single side of the tissue.

17. The measurement system of claim 16, comprising:
the capacitance system configured to apply the one or more electric field signals in proximity to the single side of the tissue using a single plate capacitor that does not contact the tissue.

18. The measurement system of claim 16, comprising:
the capacitance system configured to apply the one or more electric field signals in proximity to the tissue using a two plate capacitor, wherein each plate of the two plate capacitor does not contact the tissue.

19. The measurement system of claim 15, comprising:
the capacitance system configured to apply the one or more electric field signals in proximity to the tissue using a two plate capacitor, wherein the tissue is positioned between capacitor plates of the two plate capacitor and the capacitor plates do not contact the tissue.

20. The measurement system of claim 15, comprising:
the processing system configured to process the capacitance signal to determine a placement of at least one capacitor plate with respect to the tissue.

21. A physiological measurement system, comprising:
an optical system configured to emit one or more optical signals into tissue of a patient, and detect the one or more optical signals after propagation through the tissue;
a capacitance system configured to apply one or more electric field signals in proximity to the tissue using one or more capacitor plates that do not contact the tissue to determine a capacitance signal; and
a processing system configured to:
process at least the one or more detected optical signals and the capacitance signal to determine a physiological parameter of the patient;
process the capacitance signal to determine a placement of at least one capacitor plate with respect to the tissue; and
compare the capacitance signal to a threshold and determine the placement based on the comparison.

22. A physiological measurement system, comprising:
an optical system configured to emit one or more optical signals into tissue of a patient, and detect the one or more optical signals after propagation through the tissue;
a capacitance system configured to apply one or more electric field signals in proximity to the tissue using one or more capacitor plates that do not contact the tissue to determine a capacitance signal; and
a processing system configured to:
process at least the one or more detected optical signals and the capacitance signal to determine a physiological parameter of the patient; and
process the capacitance signal to determine a placement of at least one capacitor plate with respect to the tissue, wherein the placement comprises a body part of the patient.

23. The measurement system of claim 22, wherein the one or more detected optical signals comprise an optical plethysmograph, and wherein the processing system is configured to adjust the optical plethysmograph with the capacitance signal.

24. The measurement system of claim 22, wherein the processing system is configured to subtract a scaled version of the capacitance signal from a correlating portion of the one or more detected optical signals.

25. The measurement system of claim 22, wherein the processing system is configured to use the capacitance signal to identify when noise exceeds a threshold in a portion of the one or more detected optical signals, and de-weight the portion of the one or more detected optical signals when determining the physiological parameter.

26. The measurement system of claim 22, wherein the processing system is configured to use the capacitance signal to identify when noise exceeds a threshold in a portion of the one or more detected optical signals, and omit the portion of the one or more detected optical signals when determining the physiological parameter.

27. The measurement system of claim 22, wherein the processing system is configured to use the capacitance signal to identify when noise exceeds a threshold in the one or more detected optical signals and responsively generate an alert.

28. The measurement system of claim 22, wherein the physiological parameter comprises one or more of a respiratory effort, respiratory rate, pulse rate, hemoglobin concentration, oxygen saturation of blood (SpO_2), SpO_2 variability, apnea condition, arrhythmia, auto regulation, saturation pattern detection, blood pressure, and temporal variability of photoplethysmogram (PPG) parameters.

29. A method of operating a physiological measurement system, the method comprising:
emitting one or more optical signals into tissue of a patient, and detecting the one or more optical signals after propagation through the tissue;

applying one or more electric field signals to a single side of the tissue;

determining a capacitance signal based at least on changes in the one or more electric field signals; and

processing at least the one or more detected optical signals to determine a first estimate of a physiological parameter of the patient, and process at least the capacitance signal to determine a second estimate of the physiological parameter of the patient.

30. The method of claim **29**, further comprising:

applying the one or more electric field signals to the single side of the tissue using one or more capacitor plates that do not contact the tissue.

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专利名称(译)	电容增强了生理测量		
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[标]申请(专利权)人(译)	柯惠有限合伙公司		
申请(专利权)人(译)	COVIDIEN LP		
当前申请(专利权)人(译)	COVIDIEN LP		
[标]发明人	LISOGURSKI DANIEL MEEHAN CHRISTOPHER J MORLAND ERIC SCHLOTTAU FRISO		
发明人	LISOGURSKI, DANIEL MEEHAN, CHRISTOPHER J. MORLAND, ERIC SCHLOTTAU, FRISO		
IPC分类号	A61B5/1455 A61B5/00 A61B5/026 A61B7/00 A61B5/0402 A61B5/0295 A61B5/0205 A61B5/024 A61B5/053 A61B5/08 A61B5/11 A61B5/021 A61B5/145 A61B5/085		
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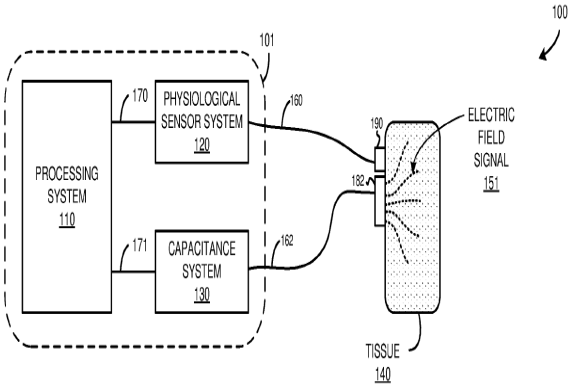
摘要(译)

提出了用于测量和确定患者的生理参数的系统，方法，装置和软件。在一个示例中，生理测量系统包括光学系统，该光学系统被配置为将一个或多个光学信号发射到患者的组织中，并且在传播通过组织之后检测一个或多个光学信号。生理测量系统包括电容系统和处理系统，该电容系统被配置为将一个或多个电场信号施加到组织的单侧以至少基于一个或多个电场信号的变化来确定电容信号，并且处理系统被配置为处理至少一个或多个检测到的光信号和电容信号用于确定患者的生理参数。