(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
7 June 2012 (07.06.2012)

WIPO | PCT

(10) International Publication Number
WO 2012/074804 A1

(51) **International Patent Classification**:
A61B 5/1455 (2006.01)

(21) **International Application Number**:
PCT/US2011/061576

(22) **International Filing Date**:
21 November 2011 (21.11.2011)

(25) **Filing Language**: English

(26) **Publication Language**: English

(30) **Priority Data**:
12/956,062 30 November 2010 (30.11.2010) US

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(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

(54) **Title**: IMPROVED SNR THROUGH AMBIENT LIGHT CANCELLATION

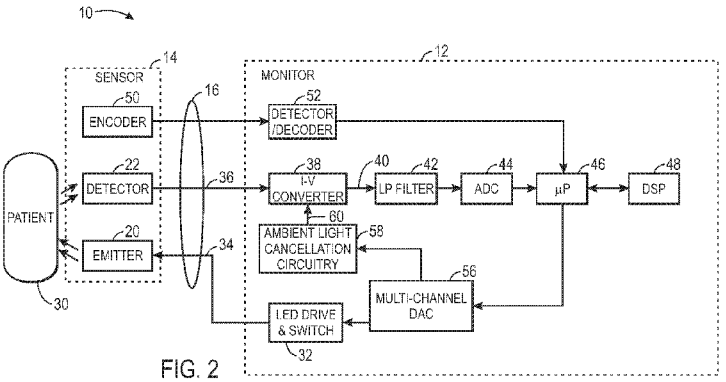


FIG. 2

(57) **Abstract**: Systems, methods, and devices for improved patient monitor signal processing with higher signal-to-noise ratio (SNR) are provided. In accordance with an embodiment, an electronic patient monitor may include drive circuitry, a current-to-voltage converter, and feedback circuitry. The drive circuitry may drive an emitter of a medical sensor with dark periods during which the emitter does not emit light, and the current-to-voltage converter may receive and amplify a photocurrent signal from a detector of the sensor. The feedback circuitry may provide a feedback signal to the current-to-voltage converter. The feedback signal, based at least in part on the output of the current-to-voltage converter during the dark periods, may cause the current-to-voltage converter to substantially exclude an ambient light component of the photocurrent. As a result, the current-to-voltage converter may employ a higher transimpedance without distorting the output voltage signal due to oversaturation, and thus may achieve a higher SNR.

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IMPROVED SNR THROUGH AMBIENT LIGHT CANCELLATION

BACKGROUND

The present disclosure relates generally to medical monitoring systems and, more particularly, to non-invasive medical monitoring systems employing optical sensors.

This section is intended to introduce the reader to various aspects of art that may be related to various aspects of the present disclosure, which are described and/or claimed below. This discussion is believed to be helpful in providing the reader with background information to facilitate a better understanding of the various aspects of the present disclosure. Accordingly, it should be understood that these statements are to be read in this light, and not as admissions of prior art.

A wide variety of devices have been developed for non-invasively monitoring physiological characteristics of patients. For example, a pulse oximetry sensor system may detect various patient blood flow characteristics, such as the blood-oxygen saturation of hemoglobin in arterial blood, the volume of individual blood pulsations supplying the tissue, and/or the rate of blood pulsations corresponding to each heart beat of a patient. To determine these physiological characteristics, light may be emitted into patient tissue, where the light may be scattered and/or absorbed in a manner dependent on such physiological characteristics.

Non-invasive medical sensor systems may include a medical sensor and an electronic patient monitor. The monitor may send driving signals to an emitter in the sensor, causing the sensor to emit light into pulsatile patient tissue. A detector in the medical sensor may detect the light after it has passed through the patient tissue, generating an electrical current proportional to the amount of detected light. This electrical current, referred to as a photocurrent, may be received by the patient monitor and converted into a voltage signal using a current-to-voltage (I-V) converter. The resulting voltage signal subsequently may be analyzed to determine certain physiological characteristics of the patient tissue.

When the I-V converter transforms the photocurrent from the photodetector to a voltage signal, thermal noise, also known as Johnson noise, may arise. The Johnson noise may be proportional to the square root of a transimpedance employed by the I-V converter, while the signal gain of the I-V converter may be directly proportional to the transimpedance. As a result, the higher the transimpedance, the lower the signal-to-noise ratio (SNR) of the I-V converter based on Johnson noise (e.g., when the transimpedance increases by a factor of ten, the SNR improves by a factor of $\sqrt{10}$). On the other hand, the higher gain brought about by the higher transimpedance may cause the I-V converter to amplify the photocurrent beyond a signal saturation region of the I-V converter, which may produce a distorted output voltage signal.

SUMMARY

A summary of certain embodiments disclosed herein is set forth below. It should be understood that these aspects are presented merely to provide the reader with a brief summary of these certain embodiments and that these aspects are not intended to limit the scope of this disclosure. Indeed, this disclosure may encompass a variety of aspects that may not be set forth below.

Embodiments of the present disclosure relate to systems, methods, and devices for improved patient monitor signal processing with higher signal-to-noise ratio (SNR). In accordance with an embodiment, an electronic patient monitor may include drive circuitry, a current-to-voltage converter, and feedback circuitry. The drive circuitry may drive an emitter of a medical sensor with dark periods during which the emitter does not emit light, and the current-to-voltage converter may receive and amplify a photocurrent signal from a detector of the sensor. The feedback circuitry may provide a feedback signal to the current-to-voltage converter. The feedback signal, based at least in part on the output of the current-to-voltage converter during the dark periods, may cause the current-to-voltage converter to substantially exclude an ambient light component of the photocurrent. As a result, the current-to-voltage converter may employ a higher transimpedance without distorting the output voltage signal due to oversaturation, and thus may achieve a higher SNR.

BRIEF DESCRIPTION OF THE DRAWINGS

Various aspects of this disclosure may be better understood upon reading the following detailed description and upon reference to the drawings in which:

FIG. 1 is a perspective view of a non-invasive medical sensor system, in accordance with an embodiment;

FIG. 2 is a block diagram of the medical sensor system of **FIG. 1**, in accordance with an embodiment;

FIG. 3 is a timing diagram representing emitter excitation that may be employed by the sensor system of **FIG. 1**, in accordance with an embodiment;

FIG. 4 is a schematic circuit diagram representing a current-to-voltage (I-V) converter employed in the system of **FIG. 1**, in accordance with an embodiment;

FIG. 5 is a flowchart describing an embodiment of a method for eliminating ambient light noise through the I-V converter of **FIG. 4**;

FIG. 6 is a flowchart describing another embodiment of a method for eliminating ambient light noise through the I-V converter of **FIG. 4**;

FIG. 7 is a plot modeling a photocurrent obtained from a detector of the medical sensor system of **FIG. 1**, in accordance with an embodiment;

FIG. 8 is a plot modeling an output voltage signal of the I-V converter of **FIG. 4** when the ambient light cancellation techniques described herein are not employed; and

FIG. 9 is a plot modeling an output voltage signal of the I-V converter of **FIG. 4** when the ambient light cancellation techniques described herein are employed, in accordance with an embodiment.

DETAILED DESCRIPTION

One or more specific embodiments will be described below. In an effort to provide a concise description of these embodiments, not all features of an actual implementation are described in the specification. It should be appreciated that in the development of any such actual implementation, as in any engineering or design project, numerous implementation-specific decisions must be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which may vary from one implementation to another. Moreover, it should be appreciated that such a development effort might be complex and time consuming, but would nevertheless be a routine undertaking of design, fabrication, and manufacture for those of ordinary skill having the benefit of this disclosure.

Present embodiments relate to medical sensor systems for non-invasively monitoring physiological patient characteristics. These systems may involve emitting light through patient tissue using an emitter and detecting an amount of light scattered by the patient tissue using a photodetector. The photodetector may generate a photocurrent, which may converted to an output voltage signal for use by an electronic patient monitor using a current-to-voltage (I-V) converter in the monitor. Such an output voltage signal may be analyzed to obtain physical parameters of the patient, including the blood-oxygen saturation of hemoglobin in arterial blood, the volume of individual blood pulsations supplying the tissue, and/or the rate of blood pulsations corresponding to each heart beat of a patient.

In certain embodiments, the I-V converter of the patient monitor may be a transimpedance amplifier with a signal-to-noise ratio (SNR) that improves with respect to thermal noise (e.g., Johnson noise) as a transimpedance of the I-V converter increases. Indeed, although such thermal noise may be proportional to the square root of the transimpedance, the signal gain is directly proportional to the transimpedance. Thus, increasing the transimpedance by a factor of 10 (e.g., from 100kΩ to 1MΩ) may improve the SNR of the I-V converter by a factor of $\sqrt{10}$, or approximately 3.

Such a higher gain may amplify the photocurrent beyond a saturation region of the I-V converter if the entire photocurrent is amplified and the output voltage signal of

the I-V converter may be distorted. Specifically, certain components of interest of the photocurrent may correspond to emitted light that passes through or is reflected by the patient tissue, but other components of the photocurrent may correspond to ambient light noise (e.g., lighting in a patient room). To ensure that the components of interest rather than the components of ambient light noise of the photocurrent are amplified by the I-V converter, present embodiments employ ambient light cancellation circuitry to provide a baseline for the I-V converter through a feedback mechanism.

In particular, during periods when the emitter of the medical sensor is not excited and therefore not emitting light into the patient, referred to as "dark periods", the photocurrent signal may include substantially only the components corresponding to ambient light. During these dark periods, the output voltage signal of the I-V converter may be monitored to determine the amount of ambient light being detected by the detector of the medical sensor. Based on the amount of ambient light, a feedback signal may be applied to the I-V converter, which may cause the I-V converter to amplify substantially only the components of interest of the photocurrent during the periods of time when the emitter of the medical sensor is excited. In this way, the I-V converter may avoid amplifying the components of interest of the photocurrent beyond a saturation region of the I-V converter when the I-V converter employs a higher transimpedance, and thus realizes a higher signal gain. Since the I-V converter may operate with a significantly higher SNR, the components of interest of the photocurrent may be smaller in magnitude. Accordingly, medical sensors used in a such medical sensor system may be designed using less powerful emitters and/or detectors, reducing costs, and/or medical sensor emitters may emit less light, improving patient comfort.

With the foregoing in mind, **FIG. 1** illustrates a perspective view of an embodiment of a non-invasive medical sensor system **10** involving an electronic patient monitor **12** and a medical sensor **14**. Although the embodiment of the system **10** illustrated in **FIG. 1** relates to pulse oximetry, the system **10** may be configured to obtain a variety of physiological measurements. For example, the system **10** may, additionally or alternatively, measure water fraction of tissue or perform other non-invasive medical monitoring techniques.

The patient monitor **12** may exchange signals with the medical sensor **14** via a communication cable **16**. The patient monitor **12** may include a display **18**, a memory, and various monitoring and control features. In certain embodiments, the patient monitor **12** may include a processor that may determine a physiological parameter of a patient based on these signals obtained from the medical sensor **14**. Indeed, in the presently illustrated embodiment of the system **10**, the medical sensor **14** is a pulse oximetry sensor that may non-invasively obtain pulse oximetry data from a patient. In other embodiments, the medical sensor **14** may represent any other suitable non-invasive optical sensor.

The medical sensor **14** may attach to pulsatile patient tissue (e.g., a patient's finger, ear, forehead, or toe). In the illustrated embodiment, the medical sensor **14** is configured to attach to a finger. An emitter **20** and a detector **22** may operate to generate non-invasive pulse oximetry data for use by the patient monitor **12**. In particular, the emitter **20** may transmit light at certain wavelengths into the tissue and the detector **22** may receive the light after it has passed through or is reflected by the tissue. The amount of light and/or certain characteristics of light waves passing through or reflected by the tissue may vary in accordance with changing amounts of blood contingents in the tissue, as well as related light absorption and/or scattering.

The emitter **20** may emit light from two or more light emitting diodes (LEDs) or other suitable light sources into the pulsatile tissue. The light that is reflected or transmitted through the tissue may be detected using the detector **22**, which may be a photodetector (e.g., a photodiode), once the light has passed through or has been reflected by the pulsatile tissue. When the detector **22** detects this light, the detector **22** may generate a photocurrent proportional to the amount of detected light, which may be transmitted through the cable **16** to the patient monitor **12**. As described in greater detail below, the patient monitor **12** may convert the photocurrent from the detector **22** into a voltage signal that may be analyzed to determine certain physiological characteristics of the patient.

As illustrated in **FIG. 2**, which describes the operation of the medical sensor system **10** in greater detail, the emitter **20** may emit light into a patient **30**, which may be

reflected by or transmitted through patient **30** and detected by the detector **22**. An LED drive and/or switch **32** may generate LED driving signals (e.g., LED current signals **34**) to cause the LEDs of the emitter **20** to become excited and emit the light into the patient **30**. In certain embodiments, the LED current signals **34** may include red wavelengths of between approximately 600-700 nm and/or infrared wavelengths of between approximately 800-1000 nm. In some embodiments, the LEDs of the emitter **20** may emit three or more different wavelengths of light. Such wavelengths may include a red wavelength of between approximately 620-700 nm (e.g., 660 nm), a far red wavelength of between approximately 690-770 nm (e.g., 730 nm), and an infrared wavelength of between approximately 860-940nm (e.g., 900 nm). Other wavelengths may include, for example, wavelengths of between approximately 500-600 nm and/or 1000-1100 nm. Regardless of the number and wavelength of LEDs driven by the LED drive and/or switch **32**, the LED current signals **34** may include at least one "dark period" during which no LEDs of the emitter **20** are being driven. During such dark periods, the emitter **20** may not emit any light into the patient **30** tissue.

The detector **22** may detect the emitted light that passes through or is reflected by the tissue of the patient **30** during the non-dark periods, generating a photocurrent **36** that varies depending on the amount and wavelength of light emitted by the emitter **20** and the various physiological characteristics of the patient **30**. In addition, the detector **22** may also generate a component of the photocurrent **36** in response to ambient light near the patient **30** (e.g., room lighting or light from windows). In general, such ambient light may be present at all times while the sensor **14** is attached to the patient **30**. In certain situations, such as when the patient **30** is in relatively intense light (e.g., if the patient is outdoors or under a surgical light), a greater part of the photocurrent **36** may be due to the ambient light than to the light passing through or reflected by the patient **30**.

A current-to-voltage (I-V) converter **38** may convert the photocurrent **36** from the detector **22** into an output voltage signal **40**, as discussed further below. The output voltage signal **40** may be filtered in a low pass (LP) filter **42** before being digitized in an analog-to-digital converter (ADC) **44** and received by a microprocessor **46**. The microprocessor **46**, which may be a microcontroller (e.g., a PIC microcontroller), may

perform certain processing operations based on the received data. In some embodiments, the microprocessor **46** may transfer certain data to another microprocessor, such as a digital signal processor (DSP) **48**, which may determine certain physiological parameters of the patient **30**.

In certain embodiments, the medical sensor **14** may also include an encoder **50** that may provide signals indicative of the wavelength of one or more light sources of the emitter **20**, which may allow for selection of appropriate calibration coefficients for calculating a physical parameter such as blood oxygen saturation. Some embodiments of the encoder **50** may indicate a propensity of the medical sensor **14** to detect ambient light to assist the patient monitor **12** in determining the feedback signal to provide to the I-V converter **38**. For example, the encoder 50 may provide an offset voltage representing a typical ambient light voltage, which may serve as an initial starting voltage of the feedback signal. The encoder **50** may, for instance, be a coded resistor, EEPROM or other coding devices (such as a capacitor, inductor, PROM, RFID, parallel resident currents, or a colorimetric indicator) that may provide a signal to the microprocessor **46** related to the characteristics of the medical sensor **14** to enable the microprocessor **46** to determine the appropriate calibration characteristics of the medical sensor **14**. Further, the encoder **50** may include encryption coding that prevents a disposable part of the medical sensor **14** from being recognized by a microprocessor **46** unable to decode the encryption. For example, a detector decoder **52** may be required to translate information from the encoder **50** before it can be properly handled by the processor **46**. In some embodiments, the encoder **50** and/or the detector decoder **52** may not be present.

As mentioned above, a portion of the photocurrent **36** from the detector **22** may be due to ambient light detected by the detector **22**. If the I-V converter **38** simply converted the entire photocurrent signal **36** into an output voltage signal **40** without accounting for components of the photocurrent signal **36** that correspond to the ambient light, the output voltage signal **40** could saturate and become distorted or the gain of the I-V converter **38** could be reduced to prevent such saturation, improving the SNR. To prevent signal distortion resulting from output voltage signal **40** saturation and/or to

improve the I-V converter **38** SNR, the patient monitor **12** may include certain circuitry to cancel the effect of ambient light on the photocurrent **36**.

In particular, the microprocessor **46** may sample the output voltage signal **40**, after being filtered in the LP filter **42** and digitized by the ADC **44**, during dark periods when the emitter **20** is not emitting any light. During such dark periods, substantially all of the photocurrent signal **36** may arise due to ambient light. Accordingly, the output voltage signal **40** obtained during the dark periods may also substantially only correspond to ambient light detected by the detector **22**. The resulting output voltage signal **46** obtained during dark periods may be used to cancel out the ambient light component of the photocurrent signal **36** in the I-V converter. The microprocessor **46** may determine a feedback signal that, when provided to the I-V converter **38**, causes the I-V converter **38** to largely exclude the ambient light component of the photocurrent **36** in a variety of manners, as discussed below.

A digital-to-analog converter (DAC) **56** may convert the digital value of the feedback signal to an analog value, and may provide the analog value to ambient light cancellation circuitry **58**. The ambient light cancellation circuitry **58** may generate a corresponding feedback signal **60** that may be provided to the I-V converter **38**. As noted above, the feedback signal **60** may cause the output voltage **40** of the I-V converter **38** to include substantially only emitted light that has passed through the patient **30** and detected by the detector **22**. Also, the microprocessor **46** may control the LED drive and/or switch **32** via the DAC **56**, which may be a multi-channel DAC to accommodate the signals provided to the LED drive and/or switch **32** and the ambient light cancellation circuitry **58**.

As noted above, to determine the feedback signal **60**, the photocurrent signal **36** may be sampled when the emitter **20** is not emitting any light into the patient **30**. Thus, the LED current signals **34** generally may include at least one dark period during which the ambient light component of the photocurrent **36** may be sampled. One embodiment of such LED current signals **34** and a resulting photocurrent signal **36** appear in a timing diagram **70** of **FIG. 3**. In the timing diagram **70**, a curve **72** represents a first of the LED

current signals **34** corresponding to a red wavelength LED, a curve **74** represents a second of the LED current signals **34** corresponding to an infrared (IR) wavelength, and a curve **76** represents the photocurrent signal **36**.

As illustrated, the LED current signals **34** may cause the various LEDs of the emitter **20** to become operative at certain times. For example, during red periods **78**, the curve **72** indicates that the first of the LED current signals **34** provides an operating current to red wavelength LEDs in the emitter **20**, which subsequently emit red wavelength light into the patient **30**. The detector **22** may accordingly detect an amount of red light passing through or reflected by the patient **30**, which may relate to certain characteristics of the tissue of the patient **30** when compared to the IR light (e.g., the blood-oxygen saturation of hemoglobin in arterial blood, the volume of individual blood pulsations supplying the tissue, and/or the rate of blood pulsations). The red light detected by the detector **22** is represented by an increase in the photocurrent signal **36** during the red period **78**, as illustrated by the curve **76**.

Similarly, during IR periods **80**, the curve **74** indicates that the second of the LED current signals **34** provides an operating current to IR wavelength LEDs in the emitter **20**, which subsequently emit IR wavelength light into the patient **30**. During the IR period **80**, the detector **22** may detect an amount of IR light passing through or reflected by the patient **30**, which may relate to certain characteristics of the tissue of the patient **30** as noted above. The IR light detected by the detector **22** is represented by an increase in the photocurrent signal **36** during the IR period **80**, as illustrated by the curve **76**.

During dark periods **82**, none of the LEDs of the emitter **20** are operative. Thus, during such dark periods **82**, the photocurrent **36** may only represent the amount of ambient light detected by the detector **22**, as illustrated by the curve **76**. Such a baseline ambient light component of the photocurrent **36** may be sampled and used to determine the feedback signal **60** applied to the I-V converter **38**. Various methods for determining the feedback signal **60** are described in greater detail below.

The application of the feedback signal **60** to the I-V converter **38** may prevent the ambient light component of the photocurrent **36** from being amplified by the I-V converter **38** during the red periods **78** and the IR periods **80**. Thus, when the feedback signal **60** is applied to the I-V converter **38**, substantially only the components of interest may be amplified and represented in the output voltage signal **40**. Indeed, as illustrated in **FIG. 4**, the I-V converter **38** may include a transimpedance amplifier formed by an operational amplifier (op amp) **84** with negative feedback through a transimpedance **R**. From the cable **16**, the photocurrent **36** may couple to the inverting (-) junction of the op amp **84** and output of the op amp **84**, separated by the transimpedance **R**. Rather than coupling the summing non-inverting (+) junction of the op amp **84** to ground, the non-inverting junction (+) may be coupled to the feedback signal **60**. As illustrated, the ambient light cancellation circuitry **58** may supply the feedback signal **60** and may include a voltage source **86** controlled by a control signal **88**. The control signal **88**, provided by the microprocessor **46** via the DAC **56**, may cause the ambient light cancellation circuitry **58** to provide the feedback signal **60** as determined by the microprocessor **46**.

The photocurrent **36** may pass across the transimpedance **R** and into the output node of the op amp **84**. Since the op amp **84** will actively cause the inverting (-) node to virtually match the voltage on the non-inverting (+) node, the output voltage signal **40** may be represented by the relationship $V_{OUT} = V_{FB} - IR$, where V_{OUT} represents the output voltage signal **40**, I represents the photocurrent signal **36**, R represents the transimpedance of the I-V converter **38**, and V_{FB} represents the feedback signal **60**. Both the gain and the amount of thermal Johnson noise of the I-V converter **38** are affected by the transimpedance **R**. That is, the gain may be directly proportional to the transimpedance **R**, while the Johnson noise may be proportional to the square root of the transimpedance **R**. As such, when the transimpedance **R** is 1 MΩ rather than 100kΩ (an increase of a factor of 10), the signal-to-noise ratio (SNR) of the I-V converter **38** may improve by a factor of $\sqrt{10}$, or approximately 3.

The higher SNR afforded by the higher transimpedance **R** could be negated by the higher gain provided by the higher transimpedance **R** unless the feedback signal **60** is

applied. In particular, converting the photocurrent signal **36** into the output voltage signal **40** using the higher gain could cause the I-V converter **38** to operate outside of the signal saturation region of the I-V converter **38**, which may distort the output voltage signal **40** and which becomes more likely at higher gains. To avoid such distortion, the feedback signal **60** may be determined such that the I-V converter **38** amplifies substantially only the components of the photocurrent **36** beyond the baseline ambient light component of the photocurrent **36** during the red period **78** and the IR period **80**.

The feedback signal **60** applied during the red periods **78** and the IR periods **80** may be determined in a variety of ways. A flowchart **90** of **FIG. 5** represents one embodiment of operating the medical sensor system **10** to obtain physiological parameters of the patient **30** involving one such manner of determining the feedback signal **60**. The flowchart **90** may begin when the LED drive and/or switch **32** of patient monitor **12** drives the emitter **20** such that during the dark periods **82**, the emitter **20** does not emit any light (block **92**). As noted above, during these times substantially all of the light detected by the detector **22** may be ambient light. Thus, during one or more such dark periods **82**, the microprocessor **46** may cause the ambient light cancellation circuitry **58** to tie the feedback signal **60** to ground (block **94**), and the photocurrent **36** may be converted by the I-V converter **38** into the output voltage signal **40** before being analyzed by the microprocessor **46** (block **96**). The output voltage signal **40** obtained during the one or more dark periods **82** while the feedback signal **60** is set to a ground voltage may represent a baseline ambient light voltage of the photocurrent **36**. Thus, the microprocessor **46** may determine the feedback signal **60** to be applied during non-dark periods (e.g., the red period **78** and/or IR period **80**) to equal such an output voltage signal **40**. If multiple dark periods **82** are considered, the microprocessor **46** may average the output voltage signals **40** obtained during the multiple dark periods **82**.

Thereafter, during the non-dark periods (e.g., the red periods **78** and IR periods **80**), the microprocessor **46** may cause the ambient light cancellation circuitry **58** to provide the feedback signal **60** as equal to the determined baseline ambient light voltage (block **98**). When the photocurrent **36** is measured using the I-V converter **38** during the non-dark periods to obtain the output voltage signal **40**, which the microprocessor **46**

and/or DSP **48** may use to determine the physiological parameter of the patient **30** (block **100**), the output voltage signal **40** may substantially exclude ambient light noise. Moreover, since the output voltage signal **40** may include substantially only the components of interest of the photocurrent **36**, the I-V converter **38** may be much more likely to operate within a saturation region, ensuring that the output voltage signal **40** is not distorted as a result. The feedback signal **60** may thus also enable the use of higher transimpedances **R**, and thus to obtain higher I-V converter **38** SNR. The method of the flowchart **90** of **FIG. 5** may repeat indefinitely, refining the determination of the feedback signal **60** during subsequent dark periods **82**.

Another method of operating the medical sensor system **10** may involve determining the feedback signal **60** and applying the same feedback signal **60** across all periods of operation (e.g., the red periods **78**, the IR periods **80**, and the dark periods **82**), but varying the feedback signal **60** depending on the output voltage signal **40** obtained during the dark periods **82**. A flowchart **110** of **FIG. 6** may represent an embodiment of such a method. The flowchart **110** may begin when the LED drive and/or switch **32** of patient monitor **12** drives the emitter **20** such that during the dark periods **82**, the emitter **20** does not emit any light (block **112**). As noted above, during these times substantially all of the light detected by the detector **22** may be ambient light. The microprocessor **46** may cause the ambient light cancellation circuitry **58** to apply the feedback signal **60** at a starting voltage and, during the dark periods **82**, the photocurrent **36** may be converted by the I-V converter **38** into the output voltage signal **40** and analyzed by the microprocessor **46** (block **114**).

The output voltage signal **40** that is obtained during the one or more dark periods **82** while the feedback signal **60** is applied may represent an error signal. That is, the closer the feedback signal **60** is to the baseline ambient light voltage, the closer the output voltage signal **40** will be to 0V during the dark periods **82**. Thus, the microprocessor **46** may apply any suitable signal control technique to adjust the feedback signal **60** higher or lower depending on the output voltage signal **40** obtained during the dark periods **82**, such that during the dark periods **82**, the output voltage signal **40** is approximately 0V (block **116**). When the output voltage signal **40** is approximately 0V

during the dark periods **82**, the feedback signal **60** may be understood to equal approximately the ambient light voltage, and thus the I-V converter **38** may be understood effectively to cancel the ambient light component of the photocurrent **36**. In some embodiments, the microprocessor **46** may consider multiple dark periods **82** and averaging the obtained output voltage signals **40** before adjusting the feedback signal **60**.

The I-V converter **38** may measure the photocurrent **36** with the feedback signal **60** also applied to the I-V converter **38** during the non-dark periods. Based on the resulting output voltage signal **40**, the microprocessor **46** and/or the DSP **48** may determine the physiological parameter of the patient **30** (block **118**). Since the feedback signal **60** may cause the I-V converter **38** to substantially exclude ambient light noise, the output voltage signal **40** may include substantially only the components of interest of the photocurrent **36**. Moreover, as noted above, the I-V converter **38** may be much more likely to operate within a saturation region, ensuring that the output voltage signal **40** is not distorted due to operation outside the saturation region. The application of the feedback signal **60** may also enable the use of higher transimpedances **R**, and thus to obtain higher I-V converter **38** SNR. The method of the flowchart **110** of **FIG. 6** may repeat indefinitely, refining the determination of the feedback signal **60** during subsequent dark periods **82**.

Sample plots representing certain benefits of the present disclosure appear in **FIGS. 7-9**. In particular, **FIG. 7** represents an exemplary photocurrent **36** over time, **FIG. 8** represents a corresponding output voltage signal **40** obtained when the disclosed techniques are not employed, and **FIG. 9** represents a corresponding output voltage signal **40** obtained when the disclosed techniques are employed. Turning to **FIG. 7**, a plot **130** models a photocurrent **36** (ordinate **132**) over time (abscissa **134**). A curve **136** illustrates the manner in which the photocurrent **36** may change over various periods (e.g., the red periods **78**, the IR periods **80**, and the dark periods **82**). All periods include an ambient light component **138**, which represents the baseline amount of ambient light detected by the detector **22**. However, only during the periods in which the emitter **20** is emitting light (e.g., the red period **78** and the IR period **80**) does a component of interest **140** of the photocurrent **36** vary.

When the photocurrent **36** illustrated by the plot **130** is amplified by an I-V converter **38** that does not employ ambient light cancellation feedback in the manners described above (and/or includes a relatively low transimpedance **R**), the resulting output voltage signal **40** may suffer from certain problems. For example, a plot **142** of **FIG. 8** models the conversion of the photocurrent **36** of **FIG. 7** into an output voltage signal **40** in volts (ordinate **144**) over time (abscissa **146**) when the feedback signal **60** is not applied to the I-V converter **38**. The I-V converter **38** modeled in the plot **142** may also include a relatively low transimpedance **R**, and thus a relatively low SNR with respect to Johnson noise. As apparent from a curve **148**, which represents the changing output voltage signal **40** over time, a significant portion of the output voltage signal **40** could be representative of the ambient light component **138** of the photocurrent **36**. Indeed, such an ambient light voltage component **152** of the output voltage signal **40**, which may be present through all periods, could greatly exceed a component of interest **154** of the output voltage signal **40**, which may be present only when the emitter **20** is emitting light (e.g., the red period **78** and the IR period **80**).

Although the LP filter **42** generally may remove the ambient light voltage component **152**, leaving substantially only the component of interest **154**, the gain of the I-V converter **38** may remain relatively low to prevent the I-V converter **38** from operating beyond the region of saturation. As such, the SNR of the I-V converter **38** also may remain relatively lower. Indeed, as indicated by a numeral **156**, if the transimpedance **R** is too high, the output voltage signal **40** may exceed a saturation voltage V_{SAT} of the I-V converter **38**, resulting in signal distortion.

On the other hand, when the feedback signal **60** is determined and applied as disclosed herein, the I-V converter **38** may employ a higher transimpedance **R** without such problems. Accordingly, the SNR of the I-V converter **38** may be correspondingly improved. **FIG. 9** illustrates a plot **158** modeling the conversion of the photocurrent **36** of **FIG. 7** into an output voltage signal **40** in volts (ordinate **160**) over time (abscissa **162**) when the techniques described herein are employed. When the feedback signal **60** is applied as discussed above, the ambient light component **138** of the photocurrent **36**

may be largely cancelled. Thus, as illustrated by a curve **164** representing the output voltage signal **40**, the output voltage signal **40** may substantially only include the component of interest **154**. Moreover, since the I-V converter **38** may employ a higher transimpedance **R** without operating beyond a signal saturation region (numeral **166**), the I-V converter **38** may also operate with a higher SNR with respect to Johnson noise.

As apparent from the curve **164**, the component of interest **154** may be substantially more amplified when the I-V converter **38** employs a higher transimpedance **R** and thus achieves a higher gain and a higher SNR. With such improvements in signal processing, the photocurrent **36** could be significantly reduced while still achieving results comparable to those achieved with conventional designs and higher photocurrents **36**. Indeed, with the disclosed techniques, the emitters **20** may be driven with less current and less light may be emitted into the patient **30** and/or the emitters **20** may be smaller and/or weaker while still providing useful physiological data about the patient **30**.

The specific embodiments described above have been shown by way of example, and it should be understood that these embodiments may be susceptible to various modifications and alternative forms. It should be further understood that the claims are not intended to be limited to the particular forms disclosed, but rather to cover all modifications, equivalents, and alternatives falling within the spirit and scope of this disclosure.

CLAIMS

What is claimed is:

1. A patient monitor comprising:

drive circuitry configured to cause an emitter of a medical sensor to emit light into a patient tissue, wherein the emitter does not emit the light during a dark period;

a current-to-voltage converter configured to convert a photocurrent signal generated by a detector of the medical sensor in response to light received by the detector to obtain an output voltage signal, wherein the received light includes emitted light that has interacted with the patient tissue and ambient light when the emitter is emitting the light and wherein the received light includes the ambient light during the dark period; and

feedback circuitry configured to provide a feedback signal to the current-to-voltage converter, wherein the feedback signal causes the current-to-voltage converter to substantially remove a component of the output voltage signal that corresponds to the ambient light when the emitter is emitting the light.

2. The patient monitor of claim 1, wherein the current-to-voltage converter comprises an operational amplifier and wherein the feedback circuitry is configured to provide the feedback signal to a non-inverting junction of the operational amplifier.

3. The patient monitor of claim 1, wherein the feedback circuitry is configured to provide the feedback signal both during the dark period and when the emitter is emitting the light.

4. The patient monitor of claim 3, wherein the feedback signal is configured to cause the current-to-voltage converter to output approximately 0V during the dark period.

5. The patient monitor of claim 1, wherein the feedback circuitry is configured to provide a ground voltage to the current-to-voltage converter during the dark period rather than the feedback signal.

6. The patient monitor of claim 5, wherein the feedback signal approximately equals the output voltage signal obtained during the dark period.

7. The patient monitor of claim 1, comprising processing circuitry configured to determine the feedback signal based at least in part on the output voltage signal obtained during the dark period.

8. The patient monitor of claim 7, wherein the processing circuitry is configured to determine the feedback signal based at least in part on a plurality of values of the output voltage signal obtained during a respective plurality of dark periods.

9. The patient monitor of claim 1, comprising patient parameter determination circuitry configured to determine a patient parameter based at least in part on the output voltage signal obtained when the emitter is emitting light.

10. A method comprising:

measuring, using a current-to-voltage converter, a photocurrent signal from a detector of a medical sensor while an emitter of the medical sensor is not emitting light to obtain a first output voltage signal, wherein the first output voltage signal corresponds primarily to a noise component of the photocurrent signal;

applying a feedback signal to the current-to-voltage converter, wherein the feedback signal is based at least in part on the first output voltage signal; and

measuring, using the current-to-voltage converter while the feedback signal is applied, the photocurrent signal while the emitter of the medical sensor is emitting light to obtain a second output voltage signal, wherein the feedback signal causes the current-to-voltage converter to output the second output voltage signal such that the second output voltage signal corresponds substantially only to a component of the photocurrent signal other than the noise component.

11. The method of claim 10, wherein the first output voltage signal corresponds primarily to a component of the photocurrent signal representing ambient light detected by the detector of the medical sensor.

12. The method of claim 10, wherein the second output voltage signal corresponds primarily to a component of the photocurrent signal representing light emitted by the emitter and detected by the detector of the medical sensor.

13. The method of claim 10, wherein the feedback signal is applied to a non-inverting junction of an operational amplifier of the current-to-voltage converter.

14. The method of claim 10, wherein the feedback signal causes the first output voltage signal to equal approximately 0V when the photocurrent signal is measured while the emitter of the medical sensor is not emitting light.

15. The method of claim 10, wherein the feedback signal is not applied when the photocurrent signal is measured while the emitter of the medical sensor is not emitting light and wherein the feedback signal applied when the emitter of the medical sensor is emitting light is approximately equal to the first output voltage signal.

16. A system comprising:

a medical sensor comprising:

an emitter configured to emit light into a patient based on emitter driving signals; and

a detector configured to detect light and to generate a detector signal based on the detected light, wherein the detector signal includes a first component based on emitted light that passes through the patient and a second component based on ambient light; and

a patient monitor comprising:

emitter driving circuitry configured to generate the emitter driving signals, wherein the emitter driving signals are configured to cause the emitter not to emit light during at least one dark period;

signal amplifier circuitry configured to amplify substantially only the first component of the detector signal based

on a feedback signal when the emitter is emitting light into the patient; and

feedback signal determination circuitry configured to determine the feedback signal based at least in part on the output signal obtained during the at least one dark period.

17. The system of claim 16, wherein the signal amplifier circuitry comprises a transimpedance amplifier configured to amplify the first component of the detector signal within a signal saturation region of the transimpedance amplifier.

18. The system of claim 17, wherein the transimpedance amplifier has a transimpedance greater than 100 kΩ.

19. The system of claim 17, wherein the transimpedance amplifier has a transimpedance greater than 1 MΩ.

20. The system of claim 16, wherein the feedback signal determination circuitry comprises a processor configured to determine a digital value of the feedback signal, wherein the patient monitor comprises a digital to analog converter configured to transform the digital value of the feedback signal to the feedback signal and wherein the patient monitor comprises feedback circuitry configured to apply the feedback signal to the signal amplifier circuitry.

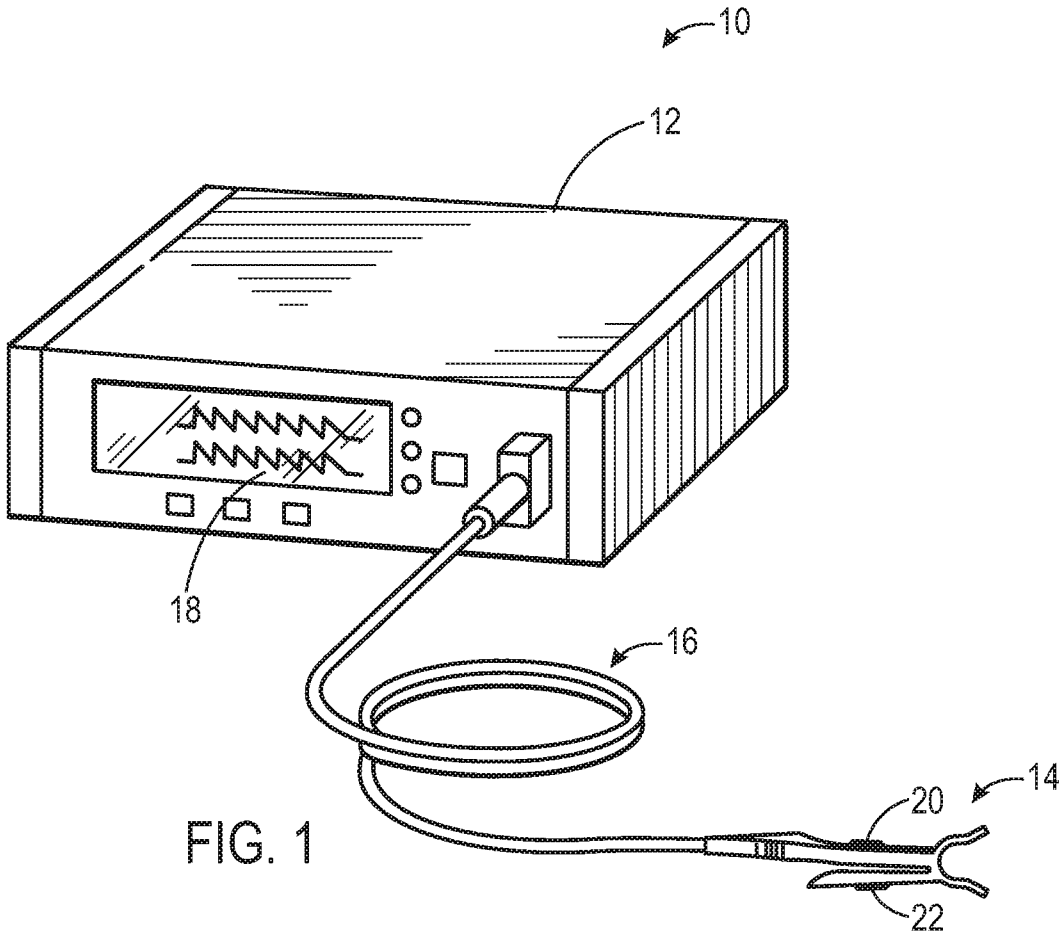


FIG. 1

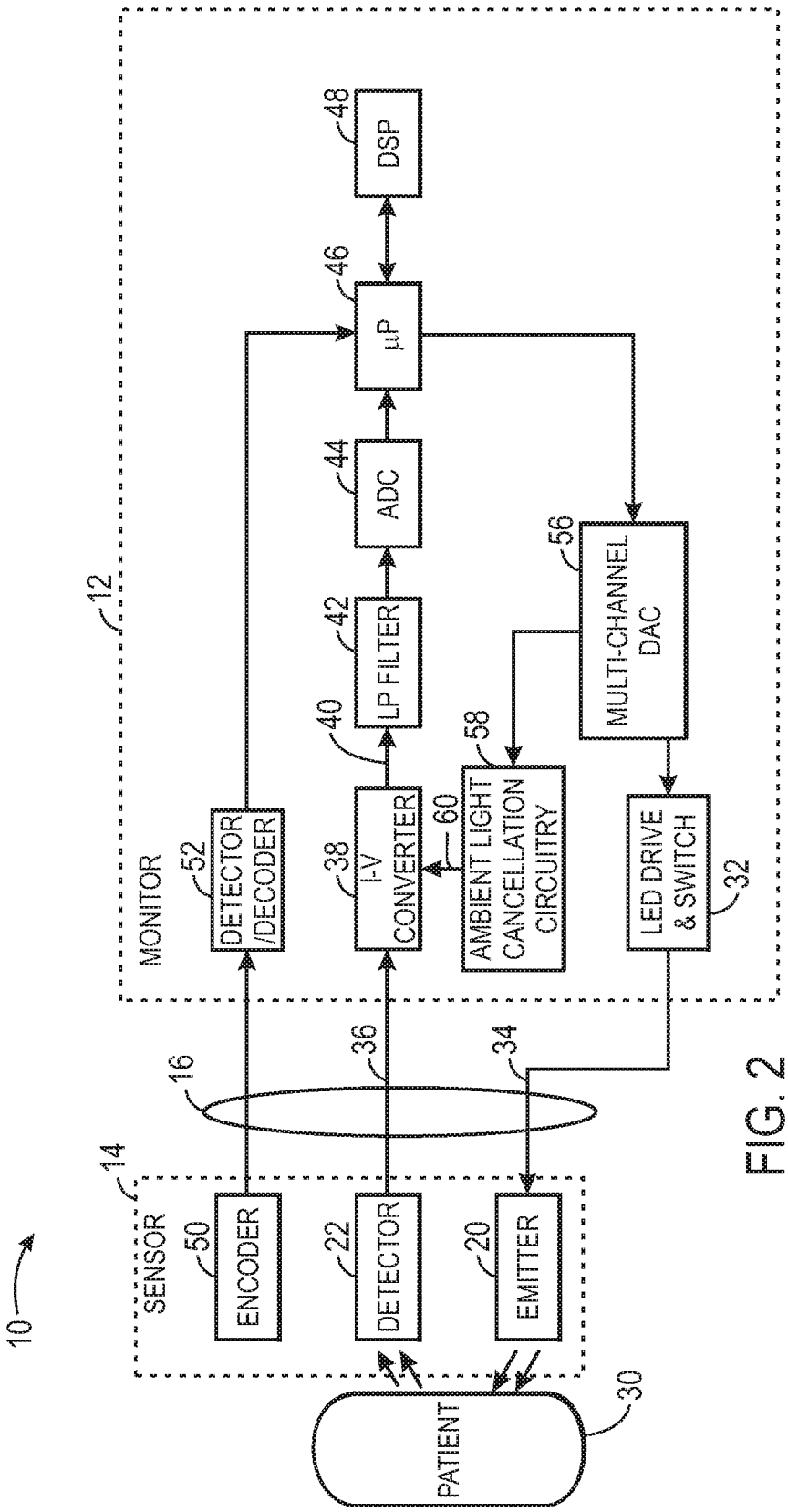

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ENCODER
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22
EMITTER
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PATIENT
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DETECTOR /DECODER
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I-V CONVERTER
38
LP FILTER
42
ADC
44
µP
46
DSP
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MULTI-CHANNEL DAC
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LED DRIVE & SWITCH
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34
36
40

FIG. 2

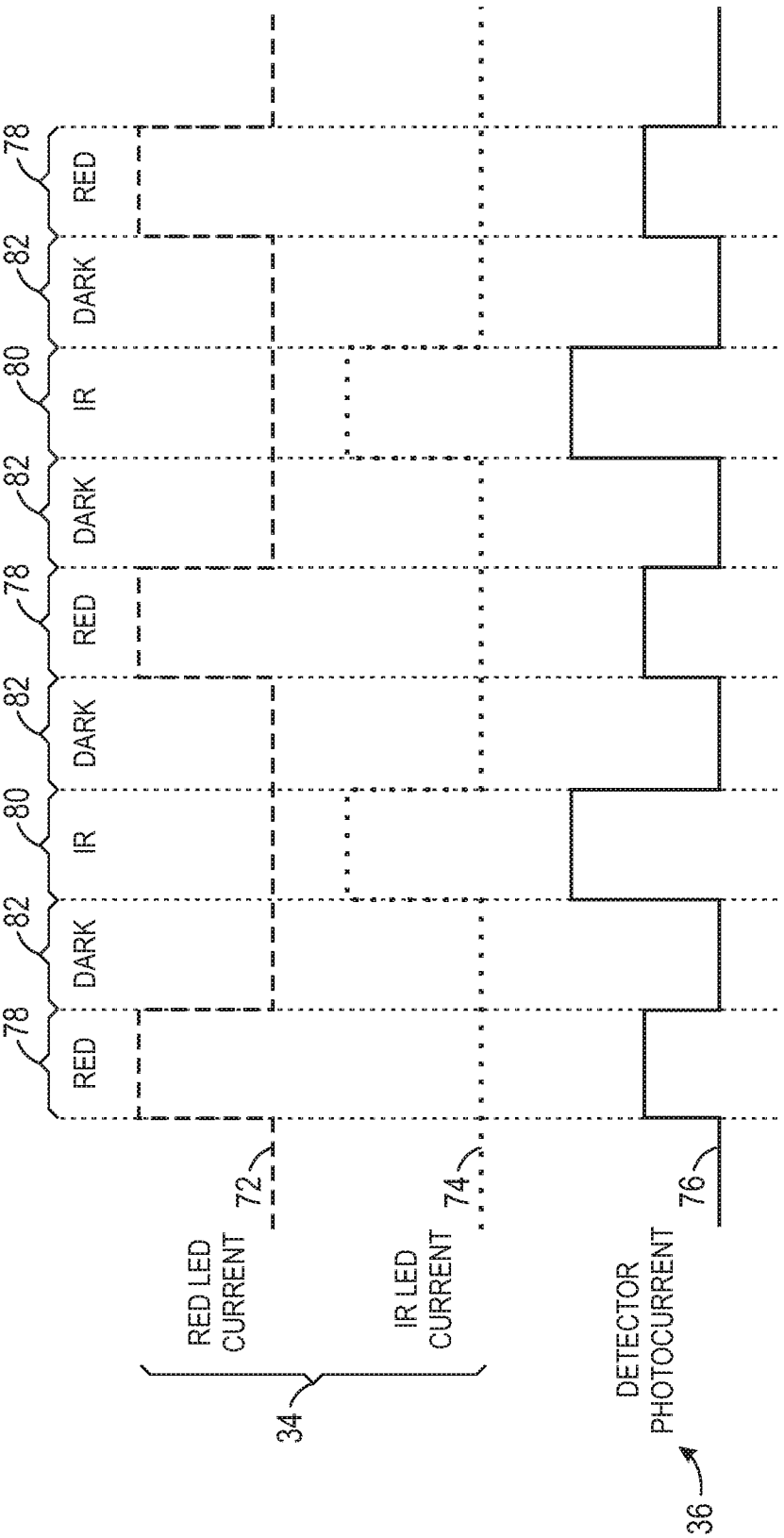

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IR LED CURRENT
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DETECTOR PHOTOCURRENT
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FIG. 3

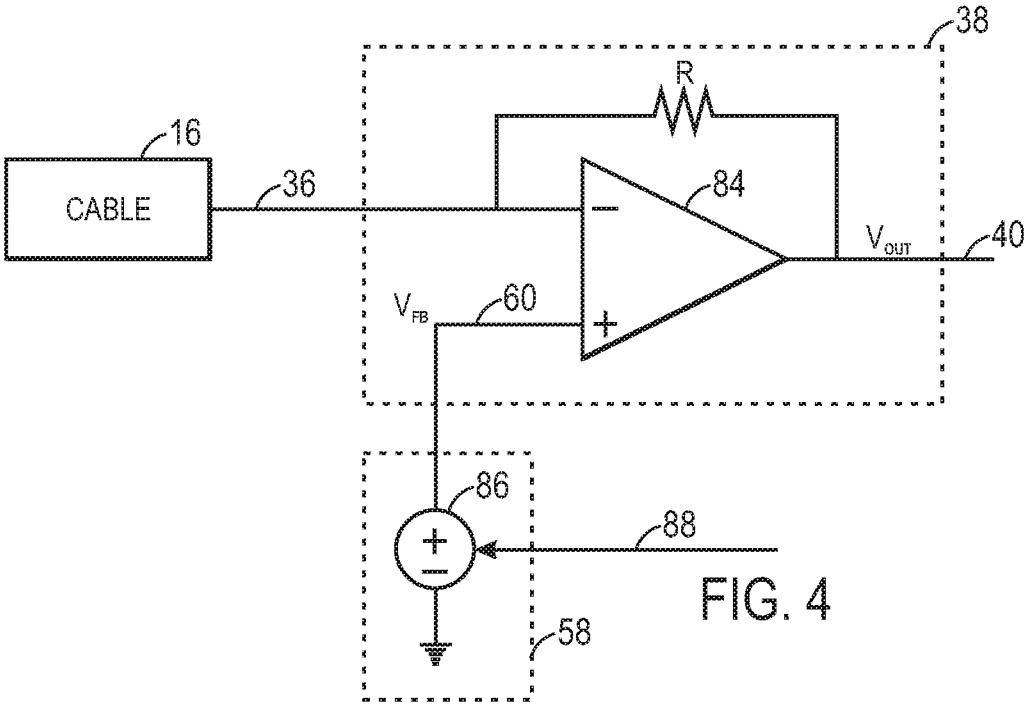


FIG. 4

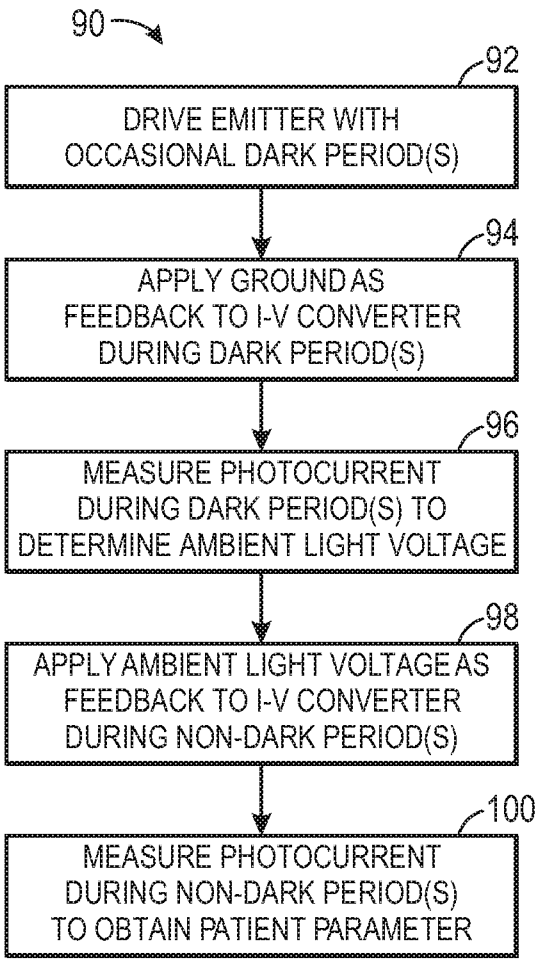


FIG. 5

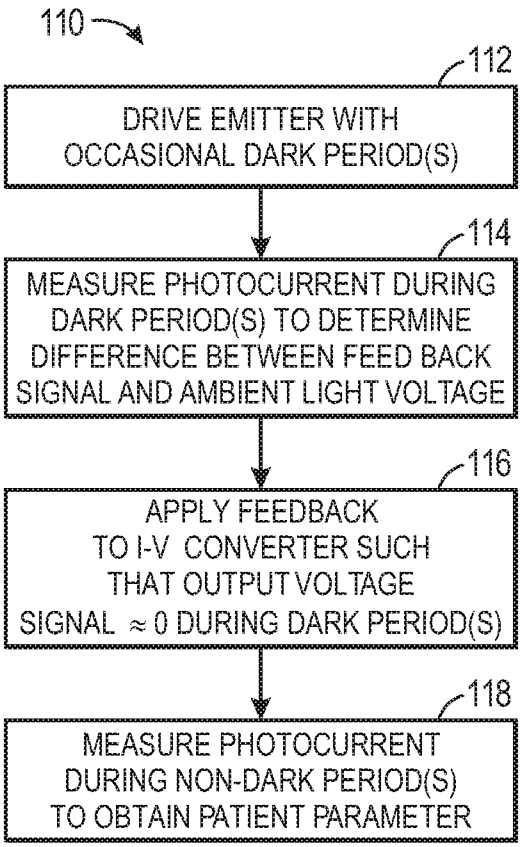


FIG. 6

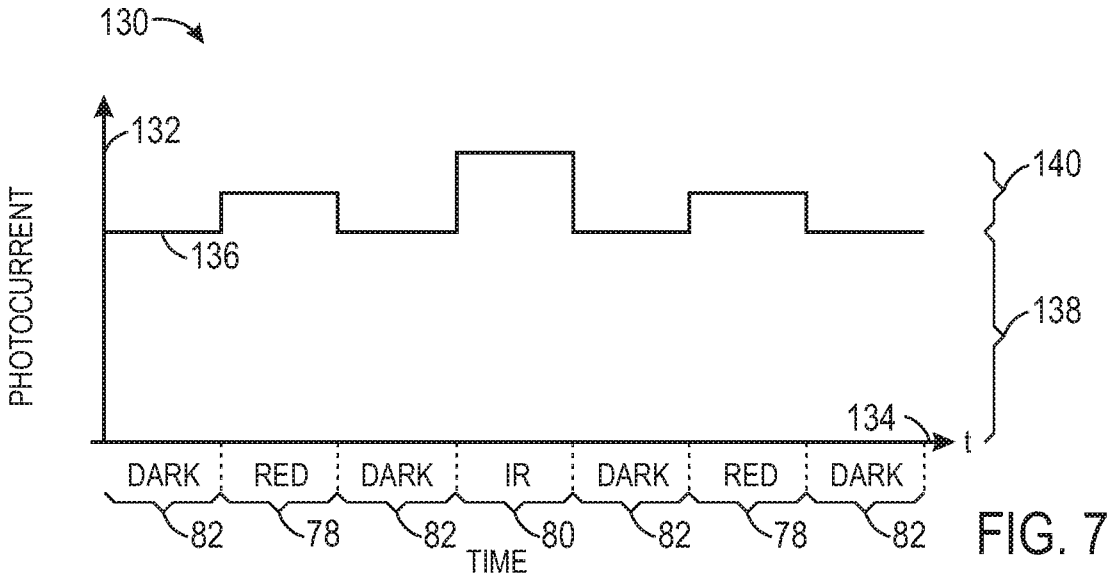


FIG. 7

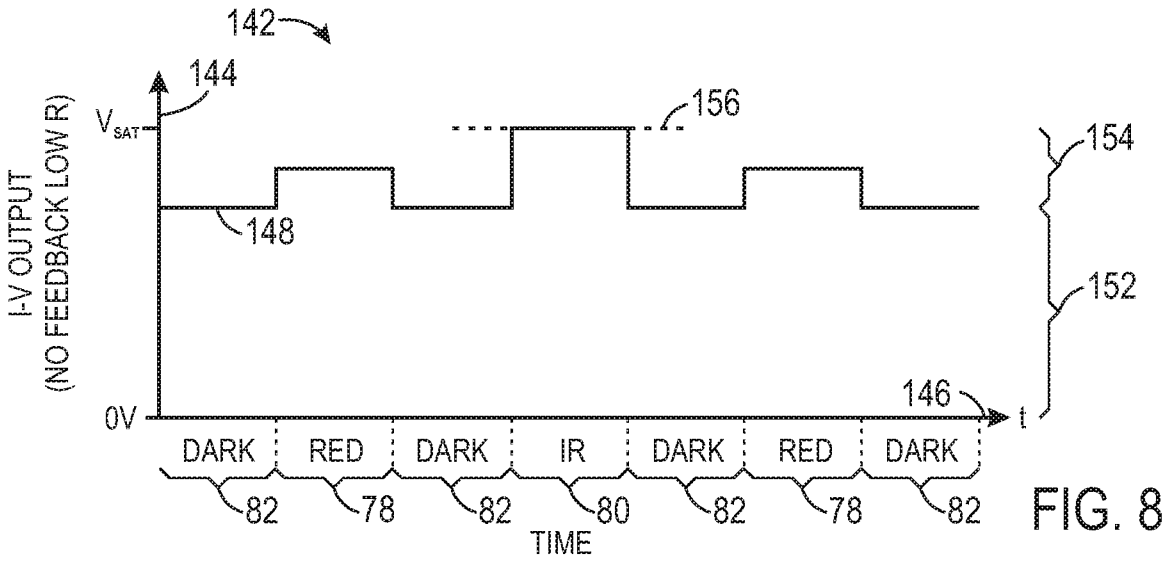


FIG. 8

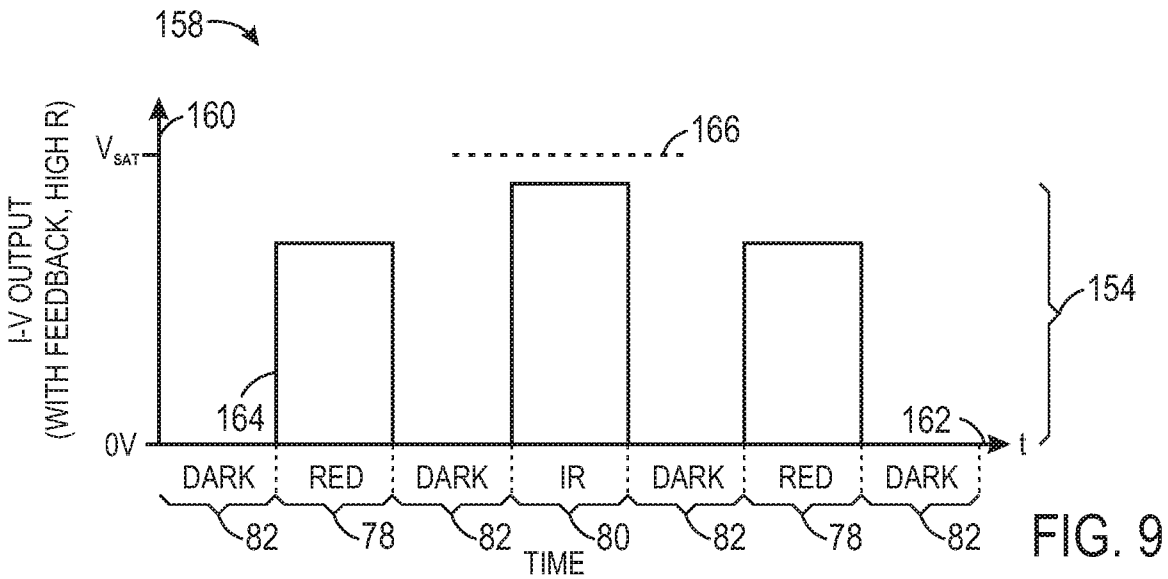


FIG. 9

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2011/061576

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61B5/1455
ADD.

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

B. FIELDS SEARCHED

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

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 4 040 747 A (WEBSTER DONALD R) 9 August 1977 (1977-08-09) column 7, line 40 - column 8, line 47; figures 4,5	1-17 2,13

X Y	US 4 781 195 A (MARTIN ALAN D [US]) 1 November 1988 (1988-11-01) column 3, line 36 - column 8, line 19 column 10, lines 13-38	1,3-12, 14,16,17 2,13

X	WO 2005/010568 A2 (TITAN CORP [US]; BRYARS JOHN DENNY [US]) 3 February 2005 (2005-02-03) page 7, paragraphs 2,3; figure 3	1,2,10, 13,16

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
1 March 2012	29/03/2012

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

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2011/061576

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