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Al-Ali

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(54) **LOW POWER PULSE OXIMETER**

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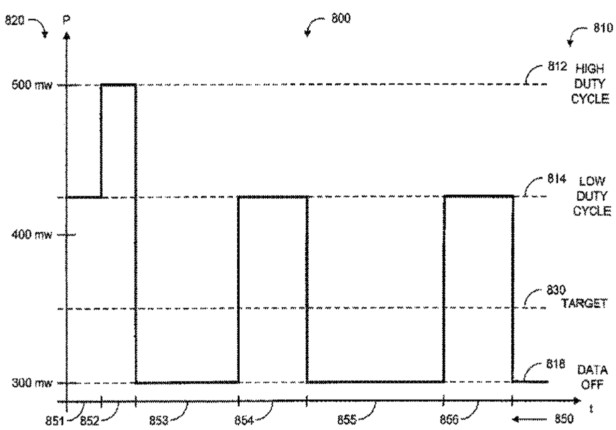
(57) **ABSTRACT**

A pulse oximeter may reduce power consumption in the absence of overriding conditions. Various sampling mechanisms may be used individually or in combination. Various parameters may be monitored to trigger or override a reduced power consumption state. In this manner, a pulse oximeter can lower power consumption without sacrificing performance during, for example, high noise conditions or oxygen desaturations.

16 Claims, 11 Drawing Sheets



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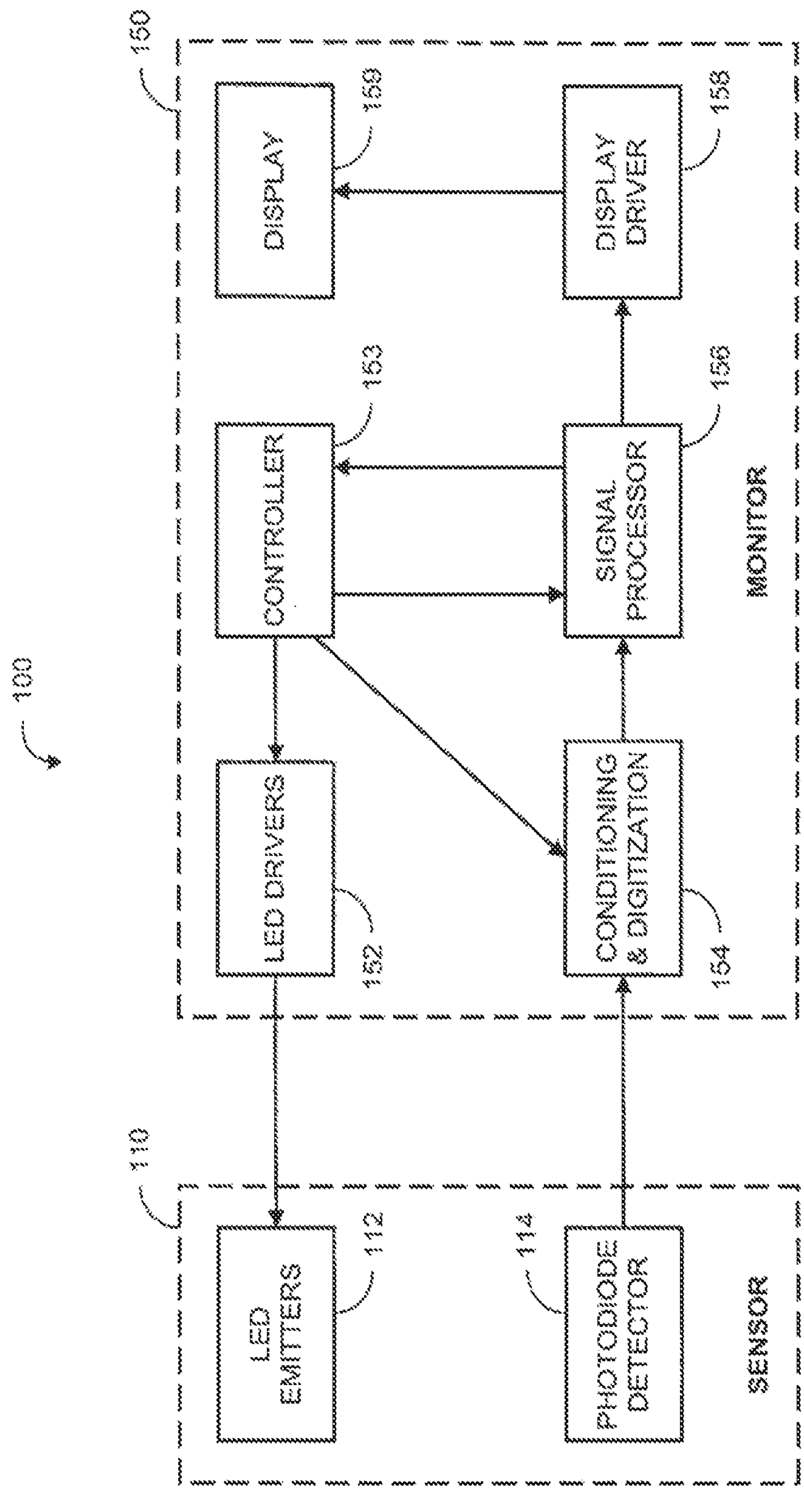


FIG. 1 (Prior Art)

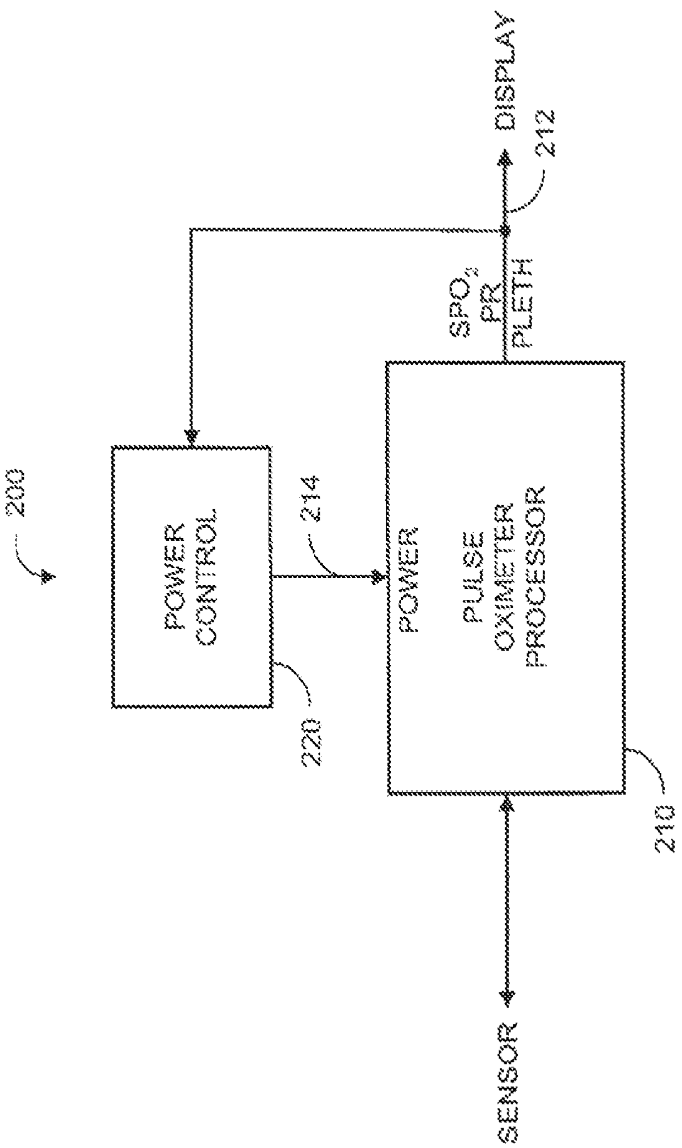
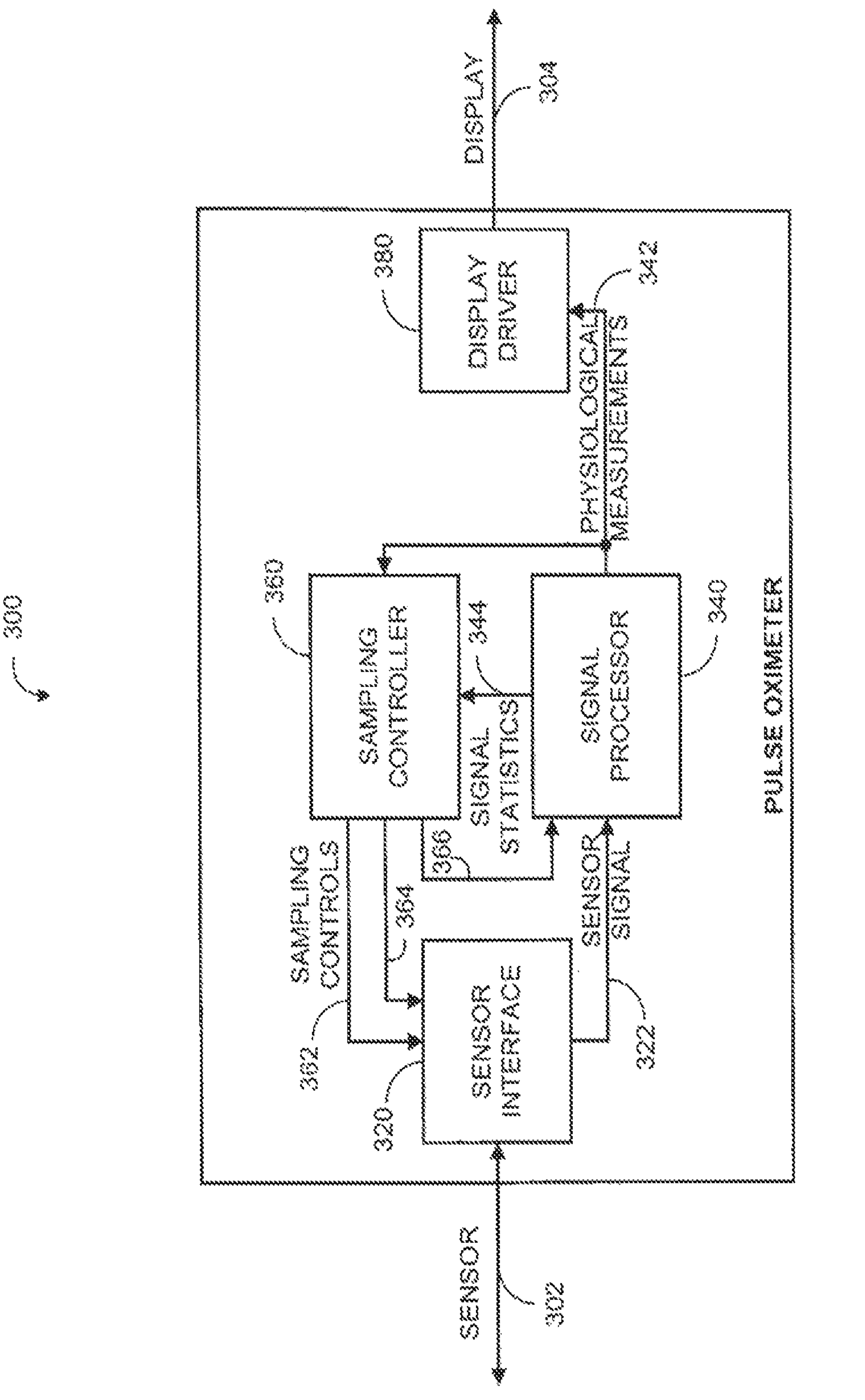


FIG. 2 (Prior Art)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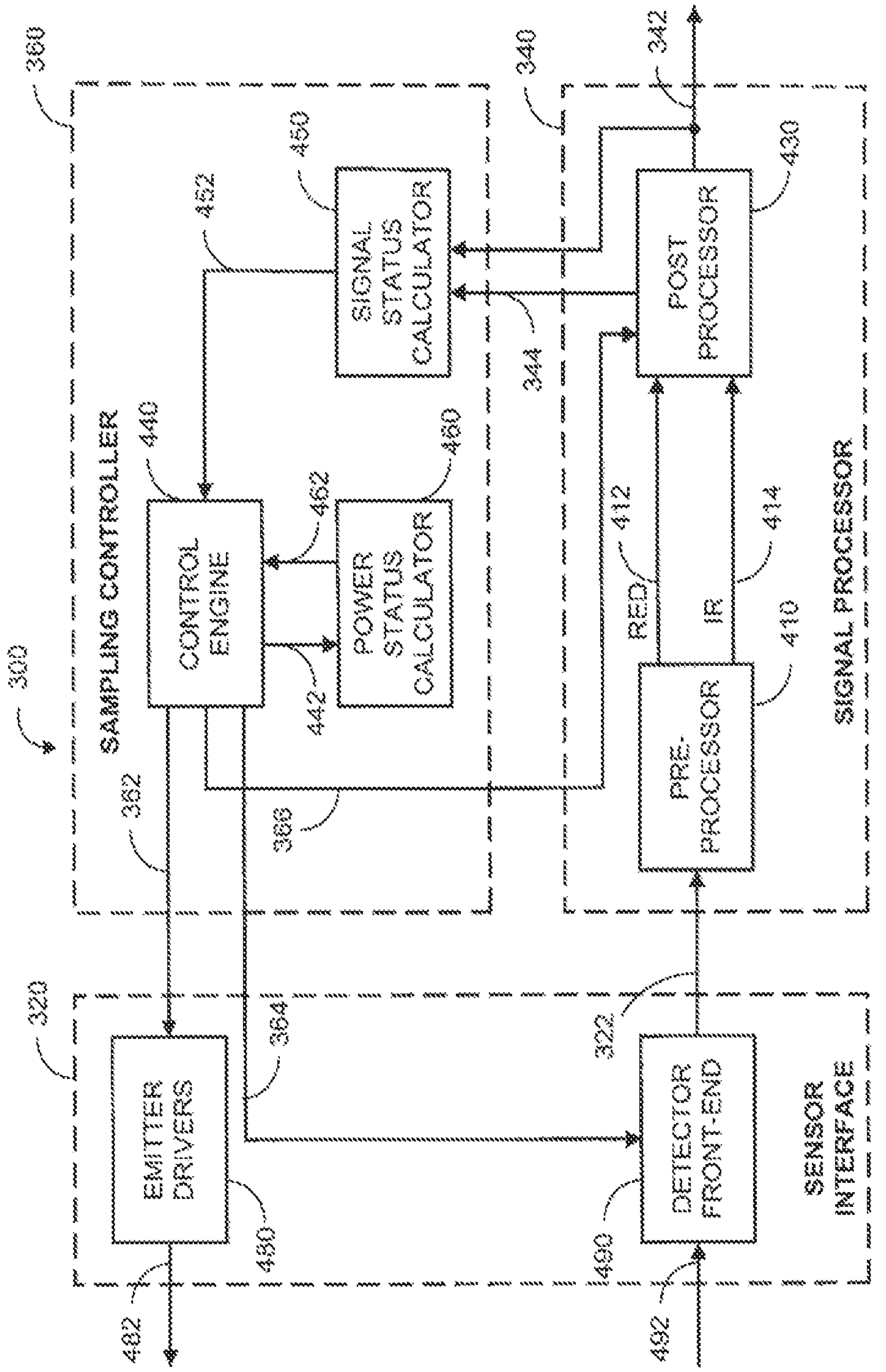
SENSOR
302
DISPLAY
304
PULSE OXIMETER
SENSOR INTERFACE
320
SENSOR SIGNAL
322
SIGNAL PROCESSOR
340
PHYSIOLOGICAL MEASUREMENTS
342
SIGNAL STATISTICS
344
SAMPLING CONTROLLER
360
SAMPLING CONTROLS
362
364
366
DISPLAY DRIVER
380

FIG. 3



300
360
SAMPLING CONTROLLER
CONTROL ENGINE
440
POWER STATUS CALCULATOR
460
442
462
SIGNAL STATUS CALCULATOR
450
452
362
366
340
SIGNAL PROCESSOR
PRE-PROCESSOR
410
RED
412
IR
414
POST PROCESSOR
430
344
342
320
SENSOR INTERFACE
EMITTER DRIVERS
480
482
364
DETECTOR FRONT-END
490
492
322

FIG. 4

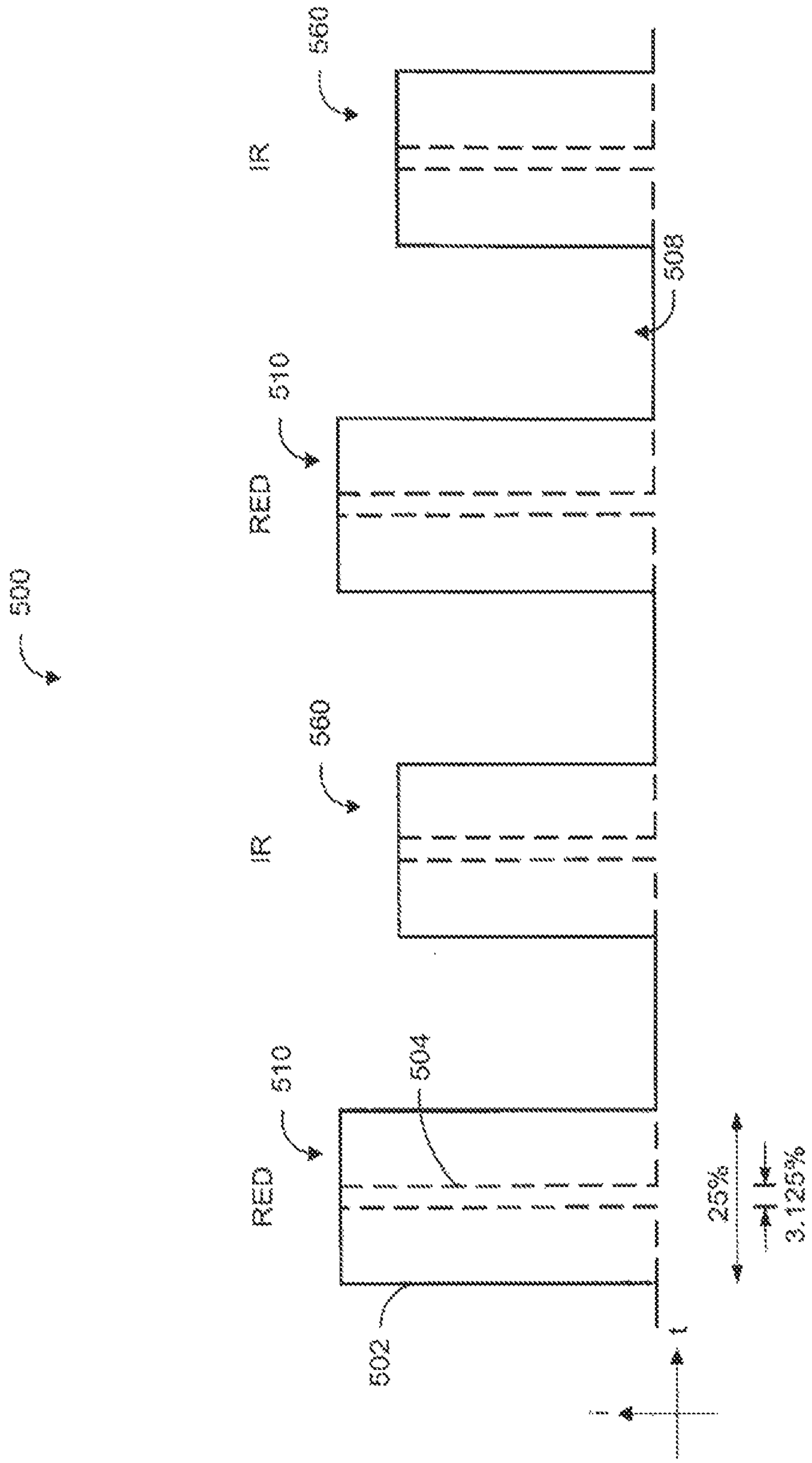


FIG. 5

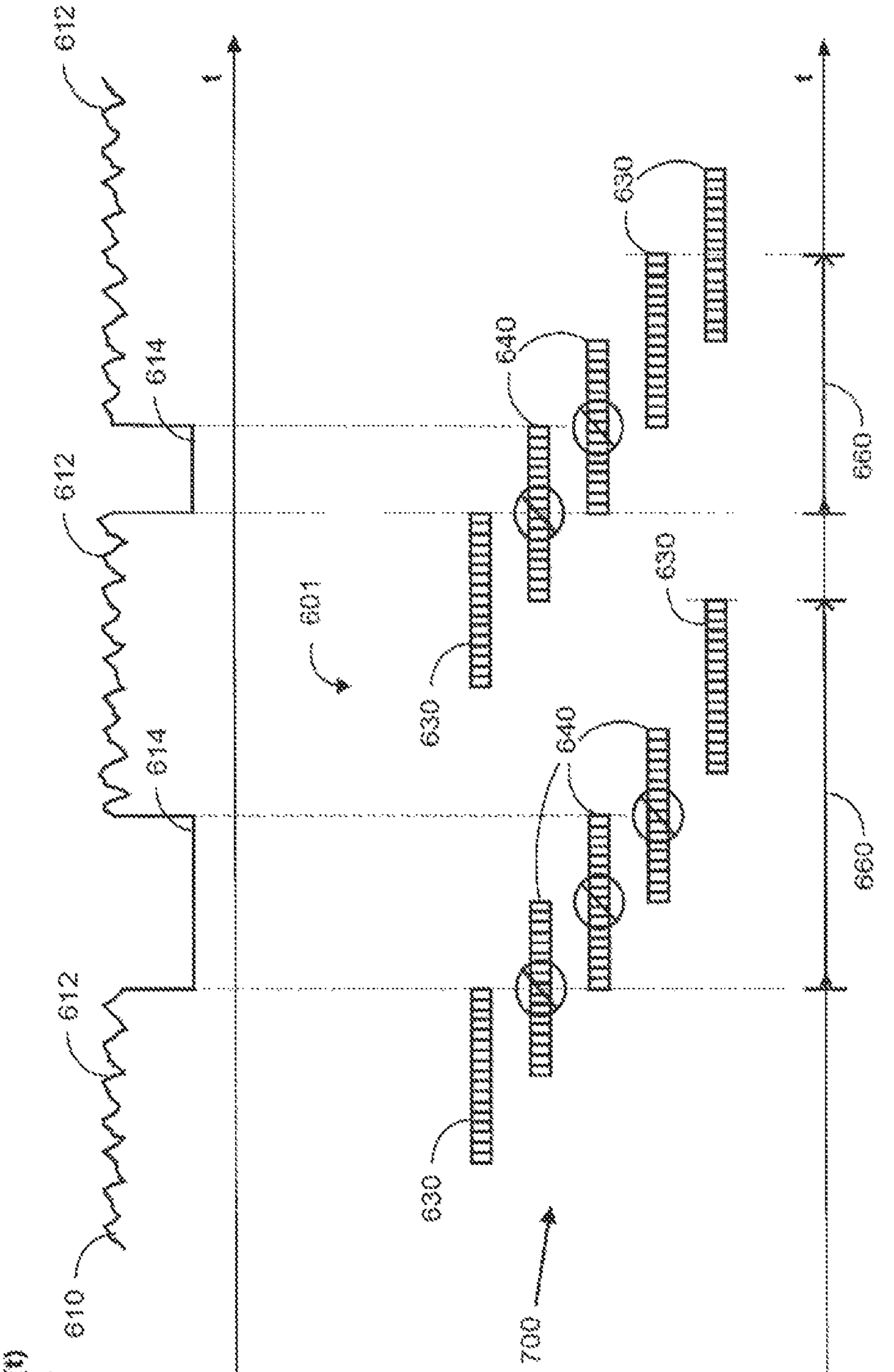

600
601
610
612
612
612
614
614
630
630
630
630
640
640
660
660
700
Y(t)
t
t

FIG. 6

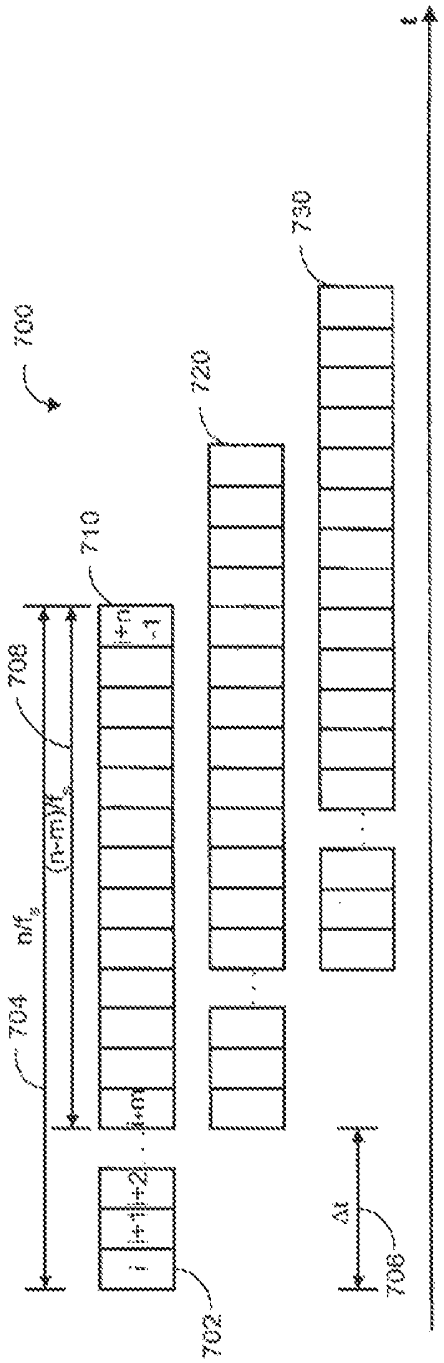


FIG. 7A

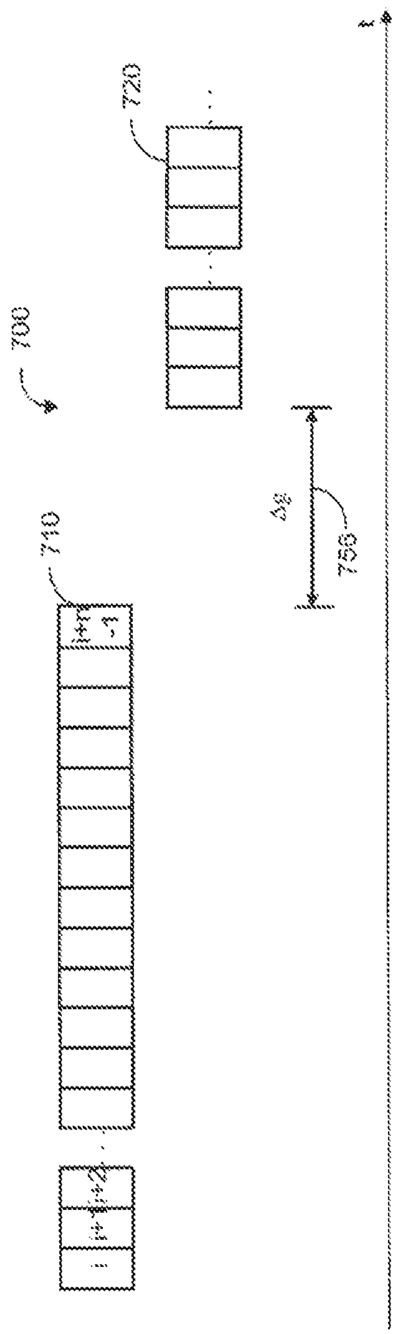
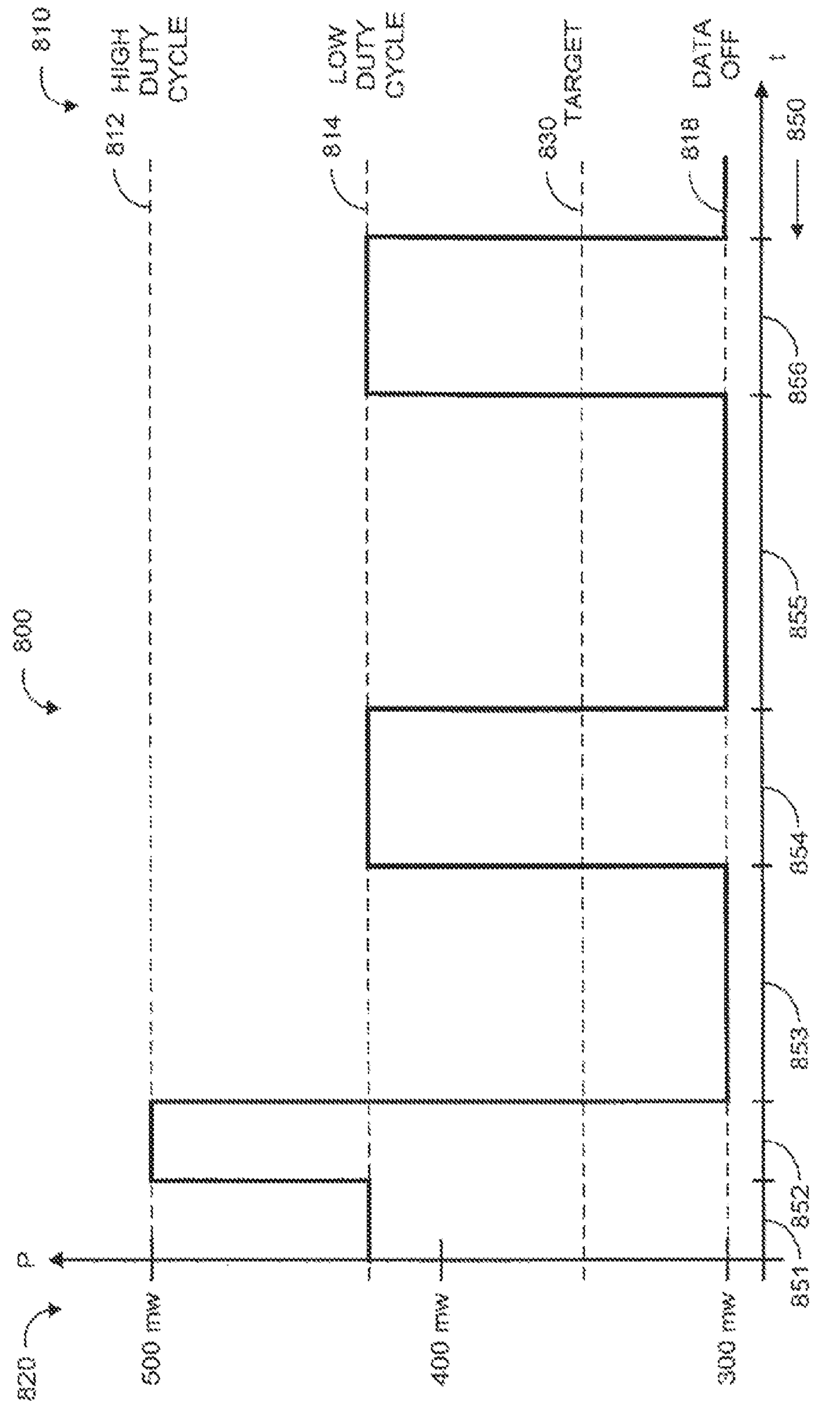


FIG. 7B



800
810
812
HIGH DUTY CYCLE
814
LOW DUTY CYCLE
830
TARGET
818
DATA OFF
t
850
820
P
500 mw
400 mw
300 mw
851
852
853
854
855
856

FIG. 8

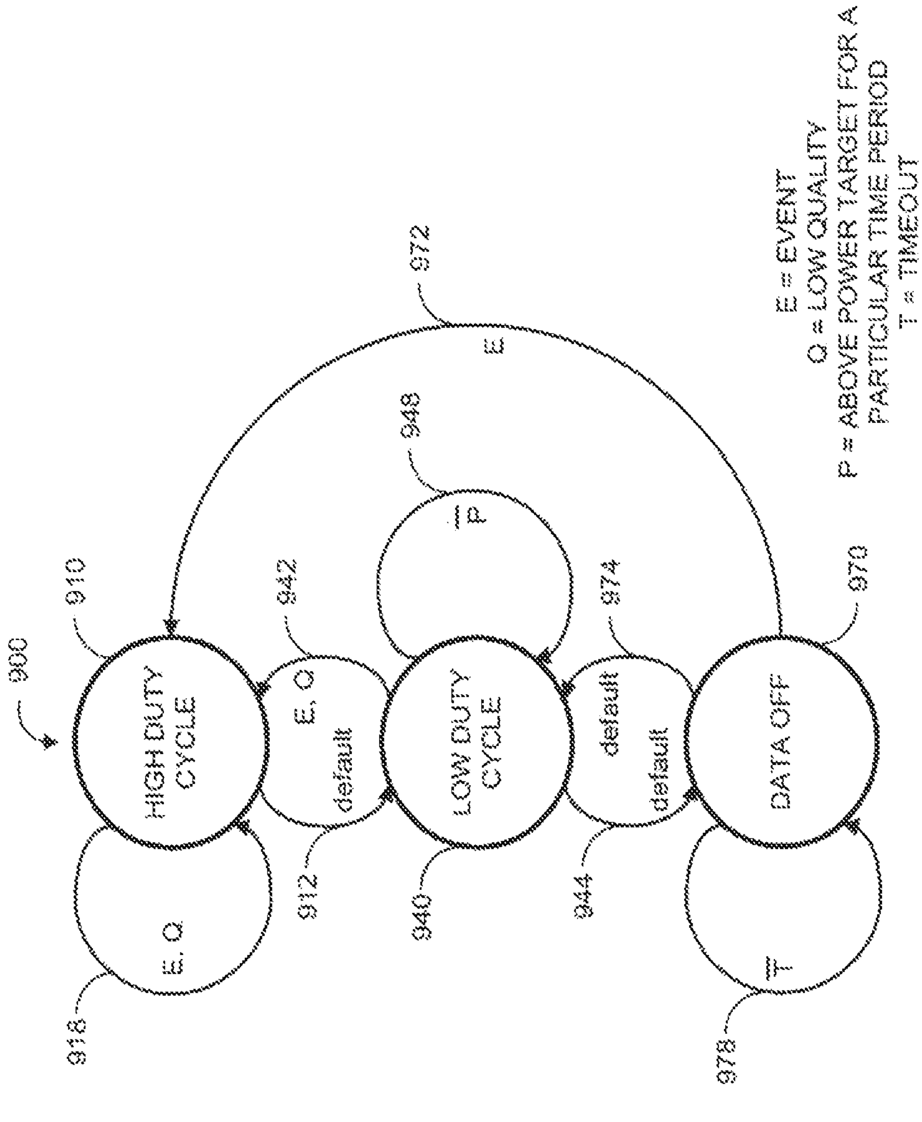

900
HIGH DUTY CYCLE
LOW DUTY CYCLE
DATA OFF
910
940
970
918
912
942
944
974
948
972
978
E, Q
E, Q
default
default
default
P̄
E
T̄
E = EVENT
Q = LOW QUALITY
P = ABOVE POWER TARGET FOR A PARTICULAR TIME PERIOD
T = TIMEOUT

FIG. 9

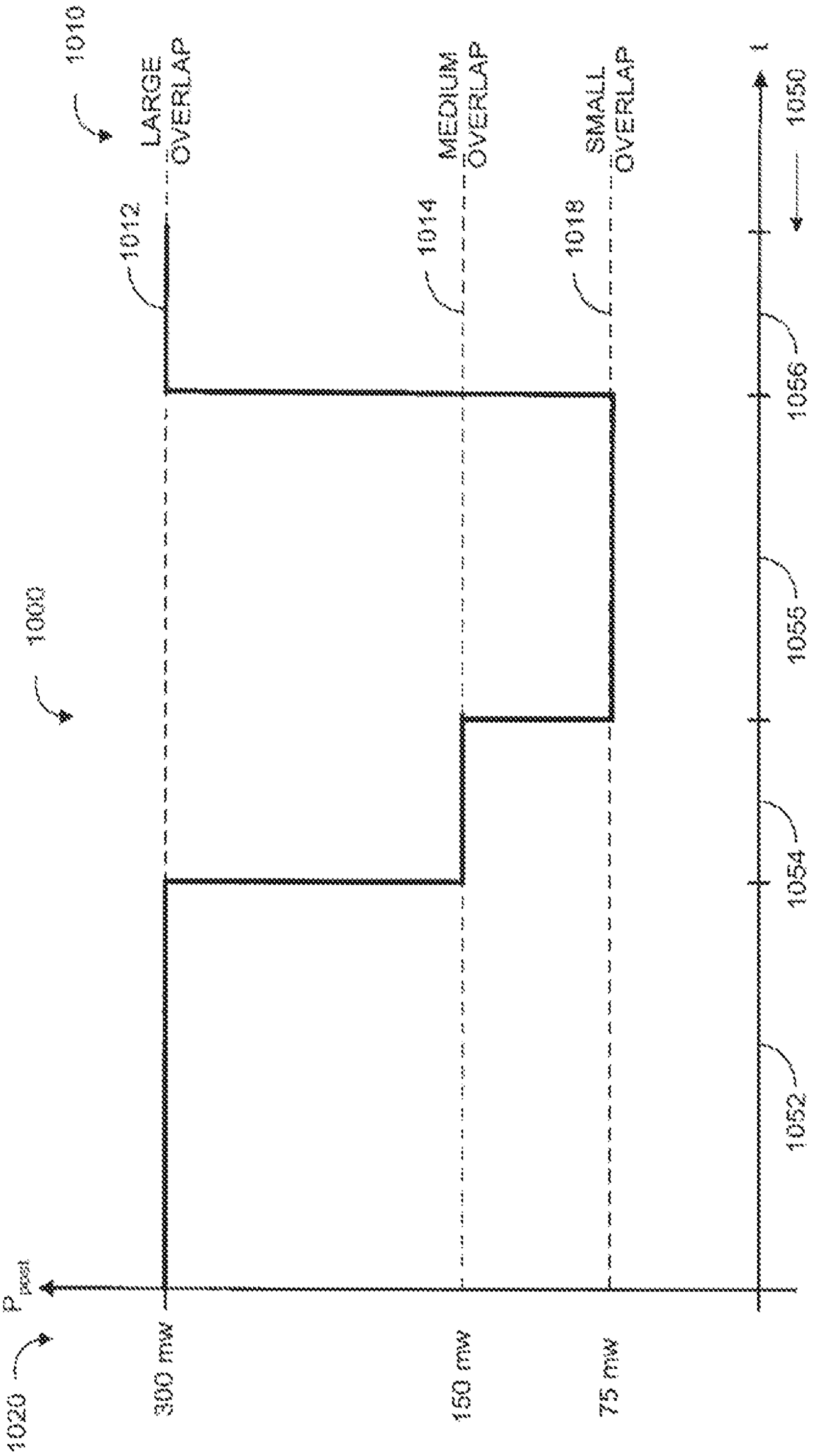

1000
1010
LARGE OVERLAP
MEDIUM OVERLAP
SMALL OVERLAP
1012
1014
1018
1020
P
300 mw
150 mw
75 mw
t
1050
1052
1054
1055
1056

FIG. 10

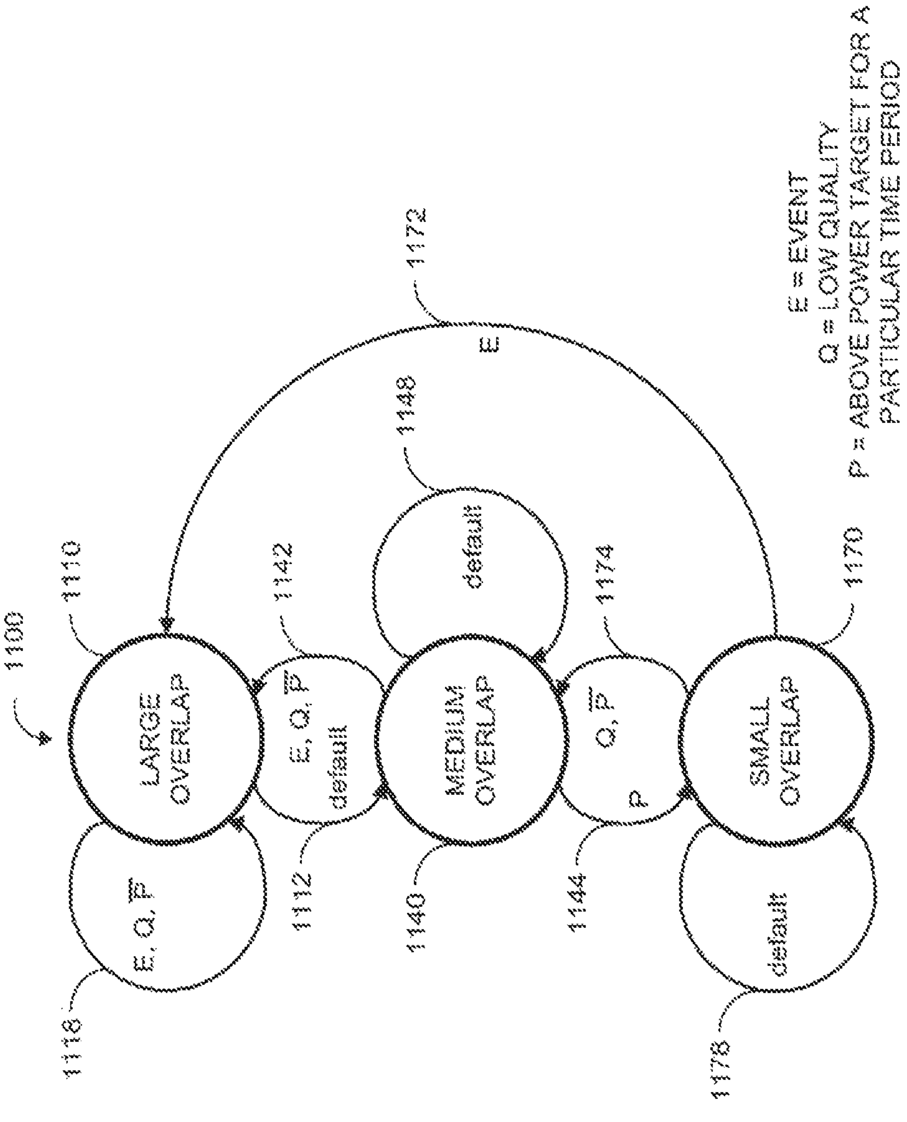

1100
LARGE OVERLAP
MEDIUM OVERLAP
SMALL OVERLAP
E, Q, $\overline{P}$
E, Q, $\overline{P}$
default
default
default
Q, $\overline{P}$
P
default
E
1110
1112
1118
1140
1142
1144
1148
1170
1172
1174
1178
E = EVENT
Q = LOW QUALITY
P = ABOVE POWER TARGET FOR A PARTICULAR TIME PERIOD

FIG. 11

LOW POWER PULSE OXIMETER

REFERENCE TO RELATED APPLICATIONS

The present application is a continuation of U.S. application Ser. No. 11/939,519, entitled "Low Power Pulse Oximeter," filed Nov. 13, 2007, which is a continuation of U.S. application Ser. No. 10/785,573, entitled "Low Power Pulse Oximeter," filed Feb. 24, 2004, now U.S. Pat. No. 7,295,866, which is a continuation of application Ser. No. 10/184,028, entitled "Low Power Pulse Oximeter," filed Jun. 26, 2002, now U.S. Pat. No. 6,697,658, which claims priority benefit under 35 U.S.C. §119(e) from U.S. Provisional Application No. 60/302,564, entitled "Low Power Pulse Oximeter," filed Jul. 2, 2001. The present application incorporates each of the foregoing disclosures herein by reference.

BACKGROUND OF THE INVENTION

Pulse oximetry is a widely accepted noninvasive procedure for measuring the oxygen saturation level of a person's arterial blood, an indicator of their oxygen supply. Oxygen saturation monitoring is crucial in critical care and surgical applications, where an insufficient blood supply can quickly lead to injury or death. FIG. **1** illustrates a conventional pulse oximetry system **100**, which has a sensor **110** and a monitor **150**. The sensor **110**, which can be attached to an adult's finger or an infant's foot, has both red and infrared LEDs **112** and a photodiode detector **114**. For a finger, the sensor is configured so that the LEDs **112** project light through the fingernail and into the blood vessels and capillaries underneath. The photodiode **114** is positioned at the finger tip opposite the fingernail so as to detect the LED emitted light as it emerges from the finger tissues. A pulse oximetry sensor is described in U.S. Pat. No. 6,088,607 entitled "Low Noise Optical Probe," which is assigned to the assignee of the present invention and incorporated by reference herein.

Also shown in FIG. **1**, the monitor **150** has LED drivers **152**, a signal conditioning and digitization front-end **154**, a signal processor **156**, a display driver **158** and a display **159**. The LED drivers **152** alternately activate the red and IR LEDs **112** and the front-end **154** conditions and digitizes the resulting current generated by the photodiode **114**, which is proportional to the intensity of the detected light. The signal processor **156** inputs the conditioned photodiode signal and determines oxygen saturation based on the differential absorption by arterial blood of the two wavelengths emitted by the LEDs **112**. Specifically, a ratio of detected red and infrared intensities is calculated by the signal processor **156**, and an arterial oxygen saturation value is empirically determined based on the ratio obtained. The display driver **158** and associated display **159** indicate a patient's oxygen saturation, heart rate and plethysmographic waveform.

SUMMARY OF THE INVENTION

Increasingly, pulse oximeters are being utilized in portable, battery-operated applications. For example, a pulse oximeter may be attached to a patient during emergency transport and remain with the patient as they are moved between hospital wards. Further, pulse oximeters are often implemented as plug-in modules for multiparameter patient monitors having a restricted power budget. These applications and others create an increasing demand for lower power and higher performance pulse oximeters. A conventional approach for reducing power consumption in portable electronics, typically utilized by devices such as calculators and notebook computers, is to have a "sleep mode" where the circuitry is powered-down when the devices are idle.

FIG. **2** illustrates a sleep-mode pulse oximeter **200** utilizing conventional sleep-mode power reduction. The pulse oximeter **200** has a pulse oximeter processor **210** and a power control **220**. The power control **220** monitors the pulse oximeter output parameters **212**, such as oxygen saturation and pulse rate, and controls the processor power **214** according to measured activity. For example, if there is no significant change in the oxygen saturation value over a certain time period, the power control **220** will power down the processor **210**, except perhaps for a portion of memory. The power control **220** may have a timer that triggers the processor **210** to periodically sample the oxygen saturation value, and the power control **220** determines if any changes in this parameter are occurring. If not, the power control **220** will leave the processor **210** in sleep mode.

There are a number of disadvantages to applying consumer electronic sleep mode techniques to pulse oximetry. By definition, the pulse oximeter is not functioning during sleep mode. Unlike consumer electronics, pulse oximetry cannot afford to miss events, such as patient oxygen desaturation. Further, there is a trade-off between shorter but more frequent sleep periods to avoid a missed event and the increased processing overhead to power-up after each sleep period. Also, sleep mode techniques rely only on the output parameters to determine whether the pulse oximeter should be active or in sleep mode. Finally, the caregiver is given no indication of when the pulse oximeter outputs were last updated.

One aspect of a low power pulse oximeter is a sensor interface adapted to drive a pulse oximetry sensor and receive a corresponding input signal. A processor derives a physiological measurement corresponding to the input signal, and a display driver communicates the measurement to a display. A controller generates a sampling control output to at least one of said sensor interface and said processor so as to reduce the average power consumption of the pulse oximeter consistent with a predetermined power target.

In one embodiment, a calculator derives a signal status output responsive to the input signal. The signal status output is communicated to the controller to override the sampling control output. The signal status output may indicate the occurrence of a low signal quality or the occurrence of a physiological event. In another embodiment, the sensor interface has an emitter driver adapted to provide a current output to an emitter portion of the sensor. Here, the sampling control output determines a duty cycle of the current output. In a particular embodiment, the duty cycle may be in the range of about 3.125% to about 25%.

In another embodiment, the sensor interface has a front-end adapted to receive the input signal from a detector portion of the sensor and to provide a corresponding digitized signal. Here, the sampling control output determines a powered-down period of the front-end. A confidence indicator responsive to a duration of the powered-down period may be provided and displayed.

In yet another embodiment, the pulse oximeter comprises a plurality of data blocks responsive to the input signal, wherein the sampling control output determines a time shift of successive ones of the data blocks. The time shift may vary in the range of about 1.2 seconds to about 4.8 seconds.

An aspect of a low power pulse oximetry method comprises the steps of setting a power target and receiving an input signal from a pulse oximetry sensor. Further steps include calculating signal status related to the input signal, calculating power status related to the power target, and sampling based upon the result of the calculating signal status and the calculating power status steps.

In one embodiment, the calculating signal status step comprises the substeps of receiving a signal statistic related to the input signal, receiving a physiological measurement related to the input signal, determining a low signal quality condition from the signal statistic, determining an event occurrence from the physiological measurement, and indicating an override based upon the low signal quality condition or the event occurrence. The calculating power status step may comprise the substeps of estimating an average power consumption for at least a portion of the pulse oximeter, and indicating an above power target condition when the average power consumption is above the power target. The sampling step may comprise the substep of increasing sampling as the result of the override. The sampling step may also comprise the substep of decreasing sampling as the result of the above power target condition, except during the override.

Another aspect of a low power pulse oximetry method comprises the steps of detecting an override related to a measure of signal quality or a physiological measurement event, increasing the pulse oximeter power to a higher power level when the override exists, and reducing the pulse oximeter power to a lower power level when the override does not exist. The method may comprise the further steps of predetermining a target power level for a pulse oximeter and cycling between the lower power level and the higher power level so that an average pulse oximeter power is consistent with the target power level.

In one embodiment, the reducing step comprises the substep of decreasing the duty cycle of an emitter driver output to the sensor. In another embodiment, the reducing step comprises the substep of powering-down a detector front-end. A further step may comprise displaying a confidence indicator related to the duration of the powering-down substep. In yet another embodiment, the reducing step comprises the substep of increasing the time-shift of post-processor data blocks.

Another aspect of a low power pulse oximeter comprises a sensor interface adapted to receive an input signal from a sensor, a signal processor configured to communicate with the sensor interface and to generate an internal parameter responsive to the input signal, and a sampling controller responsive to the internal parameter so as to generate a sampling control to alter the power consumption of at least one of the sensor interface and the signal processor. The signal processor may be configured to generate an output parameter and the sampling controller may be responsive to a combination of the internal and output parameters so as to generate a sampling control to alter the power consumption of at least one of the sensor interface and the signal processor. The internal parameter may be indicative of the quality of the input signal. The output parameter may be indicative of oxygen saturation.

In another embodiment, the sampling controller is responsive to a predetermined power target in combination with the internal parameter so as to generate a sampling control to alter the power consumption of at least one of the sensor interface and the signal processor. The signal processor may be configured to generate an output parameter and the sampling controller may be responsive to a combination of the internal and output parameters and the power target so as to generate a sampling control to alter the power consumption of at least one of the sensor interface and the signal processor. The sensor interface may comprise an emitter driver and the sampling control may modify a duty cycle of the emitter driver. The sensor interface may comprise a detector front-end and the sampling control may intermittently power-down the detector front-end. The processor may generate a plurality of data blocks corresponding to the input signal, where each of the data blocks have a time shift from a preceding one of the data blocks, and where the sampling control may determine the amount of the time shift.

A further aspect of a low power pulse oximeter comprises an interface means for communicating with a sensor, a processor means for generating an internal parameter and an output parameter, and a controller means for selectively reducing the power consumption of at least one of the interface means and the processor means based upon the parameters. In one embodiment, the interface means comprises a driver means for determining the duty cycle of emitter current to the sensor, the driver means being responsive to the controller means. In another embodiment, the interface means comprises a detector front-end means for receiving an input signal from the sensor, the power for the detector front-end means being responsive to the controller means. In yet another embodiment, the processor means comprises a post-processor means for determining a time shift between data blocks, the post-processor means being responsive to the controller means. In a further embodiment, the controller means comprises a signal status calculator means for generating an indication of a low signal quality or a physiological event based upon at least one of an internal signal statistic and an output physiological measurement, and a control engine means in communications with the signal status calculator means for generating a sampling control responsive to the indication. In yet a further embodiment, the controller means comprises a power status calculator means for generating a power indication of power consumption relative to a power target, and a control engine means in communications with the power status calculator means for generating a sampling control responsive to the power indication.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of a conventional pulse oximeter sensor and monitor;

FIG. **2** is a block diagram of a pulse oximeter having a conventional sleep mode;

FIG. **3** is a top-level block diagram of a low power pulse oximeter;

FIG. **4** is a detailed block diagram of a low power pulse oximeter illustrating a sensor interface, a signal processor and a sampling controller;

FIG. **5** is a graph of emitter drive current versus time illustrating variable duty cycle processing;

FIG. **6** is a graph of oxygen saturation versus time illustrating intermittent sample processing;

FIGS. **7**A-B are graphs of data buffer content versus time illustrating variable data block overlap processing;

FIG. **8** is a graph of power versus time illustrating power dissipation conformance to an average power target using variable duty cycle and intermittent sample processing;

FIG. **9** is a state diagram of the sampling controller for variable duty cycle and intermittent sample processing;

FIG. **10** is a graph of power versus time illustrating power dissipation using variable data block overlap processing; and

FIG. **11** is a state diagram of the sampling controller for variable data block overlap processing.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. **3** illustrates one embodiment of a low power pulse oximeter. The pulse oximeter **300** has a sensor interface **320**, a signal processor **340**, a sampling controller **360** and a display driver **380**. The pulse oximeter **300** also has a sensor port **302** and a display port **304**. The sensor port **302** connects to an external sensor, e.g. sensor **110** (FIG. **1**). The sensor interface **320** drives the sensor port **302**, receives a corresponding input signal from the sensor port **302**, and provides a conditioned and digitized sensor signal **322** accordingly. Physiological measurements **342** are input to a display driver **380** that outputs to the display port **304**. The display port **304** connects to a display device, such as a CRT or LCD, which a healthcare provider typically uses for monitoring a patient's oxygen saturation, pulse rate and plethysmograph.

As shown in FIG. **3**, the signal processor **340** derives the physiological measurements **342**, including oxygen saturation, pulse rate and plethysmograph, from the input signal **322**. The signal processor **340** also derives signal statistics **344**, such as signal strength, noise and motion artifact. The physiological measurements **342** and signal statistics **344** are input to the sampling controller **360**, which outputs sampling controls **362**, **364**, **366** accordingly. The sampling controls **362**, **364**, **366** regulate pulse oximeter power dissipation by causing the sensor interface **320** to vary the sampling characteristics of the sensor port **302** and by causing the signal processor **340** to vary its sample processing characteristics, as described in further detail with respect to FIG. **4**, below. Advantageously, power dissipation is responsive not only to output parameters, such as the physiological measurements **342**, but also to internal parameters, such as the signal statistics **344**.

FIG. **4** illustrates further detail regarding the sensor interface **320**, the signal processor **340** and the sampling controller **360**. The sensor interface **320** has emitter drivers **480** and a detector front-end **490**. The emitter drivers **480** are responsive to a sampling control **362**, described below, and provide emitter drive outputs **482**. The emitter drive outputs **482** activate the LEDs of a sensor attached to the sensor port **302** (FIG. **3**). The detector front-end **490** receives an input signal **492** from a sensor attached to the sensor port **302** (FIG. **3**) and provides a corresponding conditioned and digitized input signal **322** to the signal processor **340**. A sampling control **364** controls power to the detector front-end **490**, as described below.

As shown in FIG. **4**, the signal processor **340** has a pre-processor **410** and a post processor **430**. The pre-processor **410** demodulates red and IR signals from the digitized signal **322**, performs filtering, and reduces the sample rate. The pre-processor provides a demodulated output, having a red channel **412** and an IR channel **414**, which is input into the post-processor **430**. The post processor **430** calculates the physiological measurements **342** and the signal statistics **344**, which are output to a signal status calculator **450**. The physiological measurements **342** are also output to a display driver **380** (FIG. **3**) as described above. A pulse oximetry signal processor is described in U.S. Pat. No. 6,081,735 entitled "Signal Processing Apparatus," which is assigned to the assignee of the present invention and incorporated by reference herein.

Also shown in FIG. **4**, the sampling controller **360** has a control engine **440**, a signal status calculator **450** and a power status calculator **460**. The control engine **440** outputs sampling controls **362**, **364**, **366** to reduce the power consumption of the pulse oximeter **300**. In one embodiment, the control engine **440** advantageously utilizes multiple sampling mechanisms to alter power consumption. One sampling mechanism is an emitter duty cycle control **362** that is an input to the emitter drivers **480**. The emitter duty cycle control **362** determines the duty cycle of the current supplied by the emitter drive outputs **482** to both red and IR sensor emitters, as described with respect to FIG. **5**, below. Another sampling mechanism is a front-end control **364** that intermittently removes power to the detector front-end **490**, as described with respected to FIG. **6**, below. Yet another sampling mechanism is a data block overlap control **366** that varies the number of data blocks processed by the post processor **430**. These various sampling mechanisms provide the flexibility to reduce power without sacrificing performance during, for example, high noise conditions or oxygen desaturation events, as described below in further detail.

The sampling controls **362**, **364**, **366** modify power consumption by, in effect, increasing or decreasing the number of input samples received and processed. Sampling, including acquiring input signal samples and subsequent sample processing, can be reduced during high signal quality periods and increased during low signal quality periods or when critical measurements are necessary. In this manner, the control engine **440** regulates power consumption to satisfy a predetermined power target, to minimize power consumption, or to simply reduce power consumption, as described with respect to FIGS. **8** and **10**, below. The current state of the control engine is provided as a control state output **442** to the power status calculator **460**. The control engine **440** utilizes the power status output **462** and the signal status output **452** to determine its next control state, as described with respect to FIGS. **9** and **11**, below.

Further shown in FIG. **4**, the signal status calculator **450** receives physiological measurements and signal statistics from the post processor **430** and determines the occurrence of an event or a low signal quality condition. An event determination is based upon the physiological measurements output **342** and may be any physiological-related indication that justifies the processing of more sensor samples and an associated higher power consumption level, such as an oxygen desaturation, a fast or irregular pulse rate or an unusual plethysmograph waveform to name a few. A low signal quality condition is based upon the signal statistics output **344** and may be any signal-related indication that justifies the processing of more sensor samples and an associated higher power consumption level, such as a low signal level, a high noise level or motion artifact to name a few. The signal status calculator **450** provides the signal status output **452** that is input to the control engine **440**.

In addition, FIG. **4** shows that the power status calculator **460** has a control state input **442** and a power status output **462**. The control state input **442** indicates the current state of the control engine **440**. The power status calculator **460** utilizes an internal time base, such as a counter, timer or real-time clock, in conjunction with the control engine state to estimate the average power consumption of at least a portion of the pulse oximeter **300**. The power status calculator **460** also stores a predetermined power target and compares its power consumption estimate to this target. The power status calculator **460** generates the power status output **462** as an indication that the current average power estimate is above or below the power target and provides this output **462** to the control engine **440**.

FIG. **5** illustrates emitter driver output current versus time. The graph **500** depicts the combination of a red LED drive current **510** and an IR drive current **560**. The solid line graph **502** illustrates drive currents having a high duty cycle. The dashed line graph **504** illustrates drive currents having a low duty cycle. In a typical pulse oximeter, the duty cycle of the drive signals is constant and provides sufficient dark bands **508** to demodulate the detector response into red and IR channels. The emitter drivers **480** (FIG. **4**), however, require a significant portion of the overall pulse oximeter power budget. Intermittently reducing the drive current duty cycle can advantageously reduce power dissipation without compromising signal integrity. As an example, a low power pulse oximeter implementation nominally consuming 500 mw may be able to reduce power consumption on the order of 70 mw by such drive current duty cycle reductions. In a preferred embodiment, the drive current duty cycle is varied within a range from about 25% to about 3.125%. In a more preferred embodiment, the drive current duty cycle is intermittently reduced from about 25% to about 3.125%. In conjunction with an intermittently reduced duty cycle or as an independent sampling mechanism, there may be a "data off" time period longer than one drive current cycle where the emitter drivers **480** (FIG. **4**) are turned off. The detector front-end **490** (FIG. **4**) may also be powered down during such a data off period, as described with respect to FIGS. **8** and **9**, below.

FIG. **6** is a graph **600** of a pre-processor output signal **610** over time depicting the result of intermittent sampling at the detector front-end **490** (FIG. **4**). The output signal **610** is a red channel **412** (FIG. **4**) or an IR channel **414** (FIG. **4**) output from the pre-processor **410** (FIG. **4**), which is input to the post processor **430** (FIG. **4**), as described above. The output signal **610** has "on" periods **612**, during which time the detector front-end **490** (FIG. **4**) is powered-up and "off" periods **614**, during which time the detector front-end **490** (FIG. **4**) is powered-down. The location and duration of the on periods **612** and off periods **614** are determined by the front-end control **364** (FIG. **4**).

Also shown in FIG. **6** is a corresponding timeline **601** of overlapping data blocks **700**, which are "snap-shots" of the pre-processor output signal **610** over specific time intervals. Specifically, the post processor **430** (FIG. **4**) processes a sliding window of samples of the pre-processor output signal **610**, as described with respect to FIGS. **7**A-B, below. Advantageously, the post processor **430** (FIG. **4**) continues to function during off portions **614**, marking as invalid those data blocks **640** that incorporate off portions **614**. A freshness counter can be used to measure the time period **660** between valid data blocks **630**, which can be displayed on a pulse oximeter monitor as an indication of confidence in the current measurements.

FIGS. **7**A-B illustrate data blocks **700**, which are processed by the post processor **430** (FIG. **4**). Each data block **700** has n samples **702** of the pre-processor output and corresponds to a time interval **704** of n/f_s, where f_s is the sample frequency. For example, in one embodiment n=600 and f_s=62.5 Hz. Hence, each data block time interval **704** is nominally 9.6 sec.

As shown in FIG. **7**A, each data block **700** also has a relative time shift **706** from the preceding data block, where is an integral number of sample periods. That is, $=m/f_s$, where m is an integer representing the number of samples dropped from the preceding data block and added to the succeeding data block. In the embodiment described above, m=75 and =1.2 sec, nominally. The corresponding overlap **708** of two adjacent data blocks **710**, **720** is $(n-m)/f_s$. In the embodiment described above, the overlap **708** is nominally 9.6 sec−1.2 sec=8.4 sec. The greater the overlap **708**, i.e. the smaller the time shift **706**, the more data blocks there are to process in the post-processor **430** (FIG. **4**), with a corresponding greater power consumption. The overlap **708** between successive data blocks **710**, **720** may vary from n−1 samples to no samples, i.e. no overlap. Also, as shown in FIG. **7**B, there may be a sample gap **756** or negative overlap, i.e. samples between data blocks that are not processed by the post-processor, allowing further post-processor power savings. Sample gaps **756** may correspond to detector front-end off periods **614** (FIG. **6**).

FIG. **8** illustrates an exemplar power consumption versus time profile **800** for the pulse oximeter **300** (FIG. **3**) during various control engine states. In one embodiment, the control engine **440** (FIG. **4**) has three states related to the sampling control outputs **362**, **364** that affect pulse oximeter power consumption accordingly. One of ordinary skill in the art will recognize that the control engine **440** (FIG. **4**) may have greater or fewer states and associated power consumption levels. The profile **800** shows the three control engine states **810** and the associated power consumption levels **820**. These three states are high duty cycle **812**, low duty cycle **814** and data off **818**.

In the high duty cycle state **812**, the control engine **440** (FIG. **4**) causes the emitter drivers **480** (FIG. **4**) to turn on sensor emitters for a relatively long time period, such as 25% on time for each of the red **510** and IR **560** drive currents. In the low duty cycle state **814**, the control engine **440** (FIG. **4**) causes the emitter drivers **480** (FIG. **4**) to turn on sensor emitters for a relatively short time period, such as 3.125% of the time for each of the red **510** and IR **560** drive currents. In the data off state **818**, the control engine **440** (FIG. **4**) turns off the emitter drivers **480** (FIG. **4**) and powers down the detector front-end **490** (FIG. **4**). Also shown is a predetermined target power consumption level **830**. The control engine **440** (FIG. **4**) alters the sensor sampling of the pulse oximeter **300** (FIG. **3**) so that the average power consumption matches the target level **830**, as indicated by the power status output **462** (FIG. **4**), except when overridden by the signal status output **452** (FIG. **4**).

As shown in FIG. **8**, power consumption changes according to the control states **810** during each of the time intervals **850**. In a first time interval **851**, the pulse oximeter is in a low duty cycle state **814** and transitions to a high duty cycle state **812** during a second time interval **852** due to an event or low quality signal. During a third time interval **853**, the pulse oximeter is able to enter the data off state **818**, during which time no sensor samples are processed. In a forth time interval **854**, sensor samples are again taken, but at a low duty cycle **814**. During the fifth and sixth time intervals **855**, **856**, sensor samples are shut off and turned on again as the pulse oximeter **300** (FIG. **3**) alternates between the data off state **818** and the low duty cycle state **814** so as to maintain an average power consumption at the target level **830**.

FIG. **9** illustrates a state diagram **900** for one embodiment of the control engine **440** (FIG. **4**). In this embodiment, there are three control states, high duty cycle **910**, low duty cycle **940** and data off **970**, as described with respect to FIG. **8**, above. If the control state is data off **970**, an event triggers a data-off to high-duty-cycle transition **972**. If the control state is low duty cycle **940**, an event similarly triggers a low-duty cycle to high-duty-cycle transition **942**. In this manner, the occurrence of an event initiates high duty sensor sampling, allowing high fidelity monitoring of the event.

Similarly, if the control state is low duty cycle **940**, low signal quality triggers a low-duty cycle to high-duty-cycle transition **942**. In this manner, low signal quality initiates higher duty sensor sampling, providing, for example, a larger signal-to-noise ratio.

Also shown in FIG. **9**, if the control state is high duty cycle **910** and either an event is occurring or signal quality is low, then a null transition **918** maintains the high duty cycle state **910**. If the pulse oximeter is not above the power target for more than a particular time interval, a null transition **948** maintains the low duty cycle state **940**, so that sampling is turned-off only when necessary to track the power target. Further, if the control state is data off **970** and no time-out has occurred, a null transition **978** maintains the data off state **970**, providing a minimum power consumption.

In addition, FIG. **9** shows that when the control state is in a high duty cycle state **910**, if neither an event nor low signal quality are occurring, then a high-duty-cycle to low-duty-cycle transition **912** occurs by default. Also, if the control state is low duty cycle **940**, if neither an event nor low signal quality are occurring and the power consumption is above the target level for longer than a particular time interval, a low-duty-cycle to data-off transition **944** occurs by default, allowing power consumption to come down to the target level. Further, if the control state is data off **970**, if no event occurs and a timeout does occur, a data-off to low-duty-cycle transition **974** occurs by default, preventing excessively long periods of no sensor sampling.

FIG. **10** illustrates an exemplar power consumption versus time profile **1000** for the post processor **430** (FIG. **4**) during various control engine states. In one embodiment, the control engine **440** (FIG. **4**) has three states related to the sampling control output **366** (FIG. **4**) that affect post processor power consumption accordingly. One of ordinary skill in the art will recognize that the control engine may have greater or fewer states and associated power consumption levels. The profile **1000** shows the three control engine states **1010** and the associated post processor power consumption levels **1020**. These three states are large overlap **1012**, medium overlap **1014** and small overlap **1018**.

As shown in FIG. **10**, in the large overlap state **1012**, the control engine **440** (FIG. **4**) causes the post processor to process data blocks that have a comparatively small time shift **706** (FIG. 7A), and the post processor exhibits relatively high power consumption under these conditions, say 300 mw. In the medium overlap state **1014**, the control engine **440** (FIG. **4**) causes the post processor to process data blocks that have a comparatively larger time shift **706** (FIG. 7A). For example, the data blocks may be time shifted twice as much as for the large overlap state **1012**, and, as such, the post processor performs only half as many computations and consumes half the nominal power, say 150 mw. In the small overlap state **1018**, the control engine **440** (FIG. **4**) causes the post processor to process data blocks that have a comparatively large time shift. For example, the data blocks may be time shifted twice as much as for the medium overlap state **1014**. As such, the post processor performs only a quarter as many computations and consumes a quarter of the nominal power, say 75 mw, as for the large overlap state **1012**. In one embodiment, the control engine **440** (FIG. **4**) alters the data block overlap of the post processor in conjunction with the duty cycle of the emitter drivers described with respect to FIG. **5**, above, and the front-end sampling described with respect to FIG. **6**, above, so that the average power consumption of the pulse oximeter matches a target level indicated by the power status output **462** (FIG. **4**) or so that the power consumption is otherwise reduced or minimized.

In a preferred embodiment, data blocks are time shifted by either about 0.4 sec or about 1.2 sec, depending on the overlap state of the control engine **440** (FIG. **4**). In a more preferred embodiment, the data blocks are varied between about 1.2 sec and about 4.8 sec. In a most preferred embodiment, the data blocks are time shifted by either about 1.2 sec, about 2.4 sec or about 4.8 sec, depending on the overlap state of the control engine **440** (FIG. **4**). Although the post-processing of data blocks is described above with respect to only a few overlap states and a corresponding number of particular data block time shifts, there may be many overlap states and a corresponding range of data block time shifts.

Further shown in FIG. **10**, power consumption **1020** changes according to the control states **1010** during each of the time intervals **1050**. In a first time interval **1052**, the post processor is in a large overlap state **1012** and transitions to a medium overlap state **1014** during a second time interval **1054**, so as to meet a power target during a high signal quality period, for example. During a third time interval **1055**, the post processor enters a small overlap state **1018**, for example to meet a power target by further reducing power consumption. In a forth time interval **1056**, the post processor transitions back to a large overlap state **1012**, such as during an event or low signal quality conditions.

FIG. **11** illustrates a state diagram **1100** for one embodiment of the control engine **440** (FIG. **4**). These states may function in parallel with, or in combination with, the sampling states described with respect to FIG. **9**, above. In the illustrated embodiment, there are three control states, large overlap **1110**, medium overlap **1140** and small overlap **1170**, as described with respect to FIG. **10**, above. If the control state is small overlap **1170**, an event triggers a small overlap to large overlap transition **1172**. If the control state is medium overlap **1140**, an event similarly triggers a medium overlap to large-overlap transition **1142**. In this manner, the occurrence of an event initiates the processing of more data blocks, allowing more robust signal statistics and higher fidelity monitoring of the event. Similarly, if the control state is medium overlap **1140**, low signal quality triggers a medium overlap to large overlap transition **1142**. In this manner, low signal quality initiates the processing of more data blocks, providing more robust signal statistics during lower signal-to-noise ratio periods.

Also shown in FIG. **11**, if the control state is large overlap **1110** and either an event is occurring or signal quality is low, then a null transition **1118** maintains the large overlap state **1110**. If the pulse oximeter is not above the power target for more than a particular time interval, a null transition **1148** maintains the medium overlap state **1140**, so that reduced data processing occurs only when necessary to track the power target. Further, if the control state is small overlap **1170**, a null transition **1178** maintains this power saving state until the power target is reached or an event or low signal quality condition occurs.

In addition, FIG. **11** shows that when the control state is in a large overlap state **1110**, if neither an event nor low signal quality are occurring, then a large overlap to medium overlap transition **1112** occurs by default. Also, if the control state is medium overlap **1140**, if the power consumption is above the target level for longer than a particular time interval and no low signal quality condition or event is occurring, a medium overlap to small overlap transition **1174** occurs, allowing power consumption to come down to the target level. Further, if the control state is small overlap **1170**, if no event occurs but the power target has been met, a small overlap to medium overlap transition **1174** occurs.

A low power pulse oximeter embodiment is described above as having a power status calculator **460** (FIG. **4**) and an associated power target. Another embodiment of a low power pulse oximeter, however, functions without either a power status calculator or a power target, utilizing the sampling controls **362**, **364**, **366** (FIG. **3**) in response to internal parameters and/or output parameters, such as signal statistics **344** (FIG. **3**) and/or physiological measurements **342** (FIG. **3**) to reduce power consumption except during, say, periods of low signal quality and physiological events.

One of ordinary skill in the art will recognize that various state diagrams are possible representing control of the emitter drivers, the detector front-end and the post-processor. Such state diagrams may have fewer or greater states with differing transitional characteristics and with differing relationships between sampling mechanisms than the particular embodiments described above. In relatively simple embodiments of the control engine **440** (FIG. **4**), only a single sampling mechanism is used, such as the sampling mechanism used to vary the duty cycle of the emitter drivers. The single sampling mechanism may be based only upon internal parameters, such as signal quality, only upon output parameters, such as those that indicate the occurrence of physiological events, or upon a combination of internal and output parameters, with or without a power target.

In relatively more complex embodiments of the control engine **440** (FIG. **4**), sampling mechanisms are used in combination. These sampling mechanisms may be based only upon internal parameters, only upon output parameters, or upon a combination of internal and output parameters, with or without a power target. In a particular embodiment, the emitter duty-cycle, front-end duty-cycle and data block overlap sampling mechanisms described above are combined. A "reduced overlap" state relating to the post-processing of data blocks is added to the diagram of FIG. **9** between the "low duty cycle" state and the "data off" state. That is, sampling is varied between a high duty cycle state, a low duty cycle state, a reduced overlap state and a data off state in response to signal quality and physiological events, with or without a power target.

The low power pulse oximeter has been disclosed in detail in connection with various embodiments. These embodiments are disclosed by way of examples only and are not to limit the scope of the claims that follow. One of ordinary skill in the art will appreciate many variations and modifications.

What is claimed is:

1. A method of managing power consumption during continuous patient monitoring by adjusting behavior of a pulse oximetry system, the method comprising:

by a pulse oximetry system,

driving one or more light sources configured to emit light into tissue of a monitored patient, wherein said one or more light sources operate on a duty cycle having an active time and an inactive time;

receiving one or more signals from one or more detectors configured to detect said light after attenuation by said tissue;

operating said pulse oximetry system at, at least, a first power consumption level or a second power consumption level;

determining measurement values for one or more physiological parameters of a patient using said received one or more signals at said first power consumption level, wherein said active time of said duty cycle having a first duration at said first power consumption level;

determining measurement values for said one or more physiological parameters of a patient using said received one or more signals at said second power consumption level, wherein said active time of said duty cycle having a second duration at said second power consumption level, wherein said first duration is longer than said second duration;

determining processing characteristics at said second power consumption level;

determining an estimate of average power consumption of at least a portion of components of said pulse oximetry system;

cycling operation of said pulse oximetry system between said first power consumption level and said second power consumption level so that the average power consumption of said at least a portion of components of said pulse oximetry system is consistent with a predetermined target power consumption threshold, wherein operating said pulse oximetry system at said second power consumption level is based, at least in part, on said processing characteristics.

2. The method of claim **1**, wherein said first power consumption level is higher than said second power consumption level.

3. The method of claim **1**, wherein operating at said second power consumption level comprises altering activation of an attached sensor, said sensor positioning said light sources and said detectors proximate said tissue.

4. The method of claim **3**, wherein said altering activation of said sensor comprises reducing a duty cycle of said sensor.

5. The method of claim **1**, wherein said processing characteristics comprise signal characteristics from one or more light sensitive detectors.

6. The method of claim **5**, wherein said signal characteristics comprise signal strength.

7. The method of claim **5**, wherein said signal characteristics comprise a presence of noise.

8. The method of claim **5**, wherein said signal characteristics comprise a presence of motion induced noise.

9. A pulse oximetry system configured to manage power consumption during patient monitoring, said pulse oximetry system comprising:

an input configured to receive at least one signal responsive to light detected after attenuation by body tissue of a patient by a noninvasive sensor, wherein said light received from one or more light sources operating on a duty cycle having an active time and an inactive time; and

one or more processors configured to:

operate said pulse oximetry system at, at least, a first power consumption level or a second power consumption level;

using said at least one received signals, determine measurement values for one or more physiological parameters of a patient at said first power consumption level or at said second power consumption level, wherein said active time of said duty cycle having a first duration at said first power consumption level, and said active time of said duty cycle having a second duration at said second power consumption level, wherein said first duration is longer than said second duration;

determine processing characteristics at said second power consumption level;

cycle operation of said pulse oximetry system between said first power consumption level and said second power consumption level so that average power consumption of at least a portion of components of said pulse oximetry system is consistent with a predetermined target power consumption threshold, wherein operating said pulse oximetry system at said second power consumption level is based, at least in part, on said processing characteristics.

10. The pulse oximetry system of claim **9**, wherein said first power consumption level is higher than said second power consumption level.

11. The pulse oximetry system of claim **9**, wherein during operation of said pulse oximetry system at said second power consumption level said one or more processors alter activation of an attached sensor, said sensor positioning said light sources and said detectors proximate said tissue.

12. The pulse oximetry system of claim **11**, wherein said altering activation of said sensor comprises reducing a duty cycle of said sensor.

13. The pulse oximetry system of claim **9**, wherein said processing characteristics comprise signal characteristics from one or more light sensitive detectors.

14. The pulse oximetry system of claim **13**, wherein said signal characteristics comprise signal strength.

15. The pulse oximetry system of claim **13**, wherein said signal characteristics comprise a presence of noise.

16. The pulse oximetry system of claim **13**, wherein said signal characteristics comprise a presence of motion induced noise.

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摘要(译)

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