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Al-Ali

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(54) **LOW POWER PULSE OXIMETER**

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(63) Continuation of application No. 10/785,573, filed on Feb. 24, 2004, now Pat. No. 7,295,866, which is a continuation of application No. 10/184,028, filed on Jun. 26, 2002, now Pat. No. 6,697,658.

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USPC **600/323**; 600/310; 600/322
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USPC 600/309, 310, 322, 323, 324, 333, 600/473, 476; 356/41
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,960,128	A	10/1990	Gordon et al.
4,964,408	A	10/1990	Hink et al.
5,041,187	A	8/1991	Hink et al.
5,069,213	A	12/1991	Polczynski
5,163,438	A	11/1992	Gordon et al.
5,337,744	A	8/1994	Branigan
5,341,805	A	8/1994	Stavridi et al.
D353,195	S	12/1994	Savage et al.
D353,196	S	12/1994	Savage et al.
5,377,676	A	1/1995	Vari et al.
D359,546	S	6/1995	Savage et al.
5,431,170	A	7/1995	Mathews
D361,840	S	8/1995	Savage et al.
D362,063	S	9/1995	Savage et al.
5,452,717	A	9/1995	Branigan et al.
D363,120	S	10/1995	Savage et al.
5,456,252	A	10/1995	Vari et al.
5,482,036	A	1/1996	Diab et al.
5,490,505	A	2/1996	Diab et al.
5,494,043	A	2/1996	O'Sullivan et al.

(Continued)

FOREIGN PATENT DOCUMENTS

|		
EP	0 872 210 A1	10/1998
WO	WO 99/63883	12/1999

OTHER PUBLICATIONS

PCT International Search Report, App. No. PCT/US02/20675, App. Date: Jun. 28, 2002, 4 pages.

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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.

24 Claims, 11 Drawing Sheets
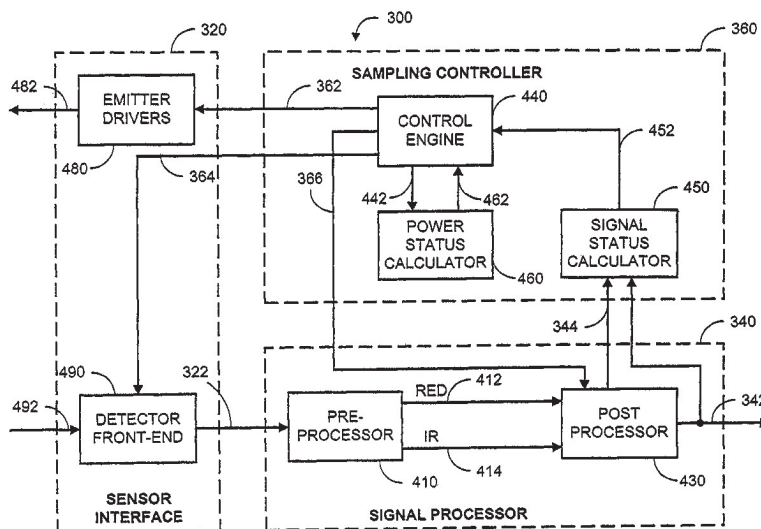
U.S. PATENT DOCUMENTS

5,533,511 A		7/1996	Kaspari et al.
5,561,275 A		10/1996	Savage et al.
5,562,002 A		10/1996	Lalin
5,590,649 A		1/1997	Caro et al.
5,602,924 A		2/1997	Durand et al.
5,632,272 A		5/1997	Diab et al.
5,638,816 A		6/1997	Kiani-Azarbayjany et al.
5,638,818 A		6/1997	Diab et al.
5,645,440 A		7/1997	Tobler et al.
5,685,299 A		11/1997	Diab et al.
D393,830 S		4/1998	Tobler et al.
5,743,262 A		4/1998	Lepper, Jr. et al.
5,758,644 A		6/1998	Diab et al.
5,760,910 A		6/1998	Lepper, Jr. et al.
5,769,785 A		6/1998	Diab et al.
5,782,757 A		7/1998	Diab et al.
5,785,659 A		7/1998	Caro et al.
5,791,347 A		8/1998	Flaherty et al.
5,810,734 A		9/1998	Caro et al.
5,823,950 A		10/1998	Diab et al.
5,827,969 A	*	10/1998	Lee et al. 600/455
5,830,131 A		11/1998	Caro et al.
5,833,618 A		11/1998	Caro et al.
5,860,919 A		1/1999	Kiani-Azarbayjany et al.
5,890,929 A		4/1999	Mills et al.
5,904,654 A		5/1999	Wohltmann et al.
5,919,134 A		7/1999	Diab
5,924,979 A		7/1999	Swedlow et al.
5,934,925 A		8/1999	Tobler et al.
5,940,182 A		8/1999	Lepper, Jr. et al.
5,995,855 A		11/1999	Kiani et al.
5,997,343 A		12/1999	Mills et al.
6,002,952 A		12/1999	Diab et al.
6,011,986 A		1/2000	Diab et al.
6,027,452 A		2/2000	Flaherty et al.
6,036,642 A		3/2000	Diab et al.
6,045,509 A		4/2000	Caro et al.
6,067,462 A		5/2000	Diab et al.
6,081,735 A		6/2000	Diab et al.
6,088,607 A		7/2000	Diab et al.
6,110,522 A		8/2000	Lepper, Jr. et al.
6,115,622 A	*	9/2000	Minoz 600/309
6,124,597 A		9/2000	Shehada
6,144,868 A		11/2000	Parker
6,151,516 A		11/2000	Kiani-Azarbayjany et al.
6,152,754 A		11/2000	Gerhardt et al.
6,157,850 A		12/2000	Diab et al.
6,165,005 A		12/2000	Mills et al.
6,184,521 B1		2/2001	Coffin, IV et al.
6,206,830 B1		3/2001	Diab et al.
6,229,856 B1		5/2001	Diab et al.
6,232,609 B1		5/2001	Snyder et al.
6,236,872 B1		5/2001	Diab et al.
6,241,683 B1		6/2001	Macklem et al.
6,256,523 B1		7/2001	Diab et al.
6,263,222 B1		7/2001	Diab et al.
6,278,522 B1		8/2001	Lepper, Jr. et al.
6,280,213 B1		8/2001	Tobler et al.
6,285,896 B1		9/2001	Tobler et al.
6,321,100 B1		11/2001	Parker
6,334,065 B1		12/2001	Al-Ali et al.
6,343,224 B1		1/2002	Parker
6,349,228 B1		2/2002	Kiani et al.
6,360,114 B1		3/2002	Diab et al.
6,368,283 B1		4/2002	Xu et al.
6,371,921 B1		4/2002	Caro et al.
6,377,829 B1		4/2002	Al-Ali
6,388,240 B2		5/2002	Schulz et al.
6,397,091 B2		5/2002	Diab et al.
6,402,690 B1	*	6/2002	Rhee et al. 600/323
6,430,525 B1		8/2002	Weber et al.
6,463,311 B1		10/2002	Diab
6,470,199 B1		10/2002	Kopotic et al.
6,501,975 B2		12/2002	Diab et al.
6,505,059 B1		1/2003	Kollias et al.
6,515,273 B2		2/2003	Al-Ali
6,519,487 B1		2/2003	Parker
6,525,386 B1		2/2003	Mills et al.
6,526,300 B1		2/2003	Kiani et al.
6,541,756 B2		4/2003	Schulz et al.
6,542,764 B1		4/2003	Al-Ali et al.
6,580,086 B1		6/2003	Schulz et al.
6,584,336 B1		6/2003	Ali et al.
6,595,316 B2		7/2003	Cybulski et al.
6,597,932 B2		7/2003	Tian et al.
6,597,933 B2		7/2003	Kiani et al.
6,606,511 B1		8/2003	Ali et al.
6,632,181 B2		10/2003	Flaherty et al.
6,639,668 B1		10/2003	Trepagnier
6,640,116 B2		10/2003	Diab
6,643,530 B2		11/2003	Diab et al.
6,650,917 B2		11/2003	Diab et al.
6,654,624 B2		11/2003	Diab et al.
6,658,276 B2		12/2003	Kianl et al.
6,661,161 B1		12/2003	Lanzo et al.
6,671,531 B2		12/2003	Al-Ali et al.
6,678,543 B2		1/2004	Diab et al.
6,684,090 B2		1/2004	Ali et al.
6,684,091 B2		1/2004	Parker
6,697,656 B1		2/2004	Al-Ali
6,697,657 B1		2/2004	Shehada et al.
6,697,658 B2		2/2004	Al-Ali
RE38,476 E		3/2004	Diab et al.
6,699,194 B1		3/2004	Diab et al.
6,714,804 B2		3/2004	Al-Ali et al.
RE38,492 E		4/2004	Diab et al.
6,721,582 B2		4/2004	Trepagnier et al.
6,721,585 B1		4/2004	Parker
6,725,075 B2		4/2004	Al-Ali
6,728,560 B2		4/2004	Kollias et al.
6,735,459 B2		5/2004	Parker
6,745,060 B2		6/2004	Diab et al.
6,760,607 B2		7/2004	Al-Ali
6,770,028 B1		8/2004	Ali et al.
6,771,994 B2		8/2004	Kiani et al.
6,792,300 B1		9/2004	Diab et al.
6,813,511 B2		11/2004	Diab et al.
6,816,741 B2		11/2004	Diab
6,822,564 B2		11/2004	Al-Ali
6,826,419 B2		11/2004	Diab et al.
6,830,711 B2		12/2004	Mills et al.
6,850,787 B2		2/2005	Weber et al.
6,850,788 B2		2/2005	Al-Ali
6,852,083 B2		2/2005	Caro et al.
6,861,639 B2		3/2005	Al-Ali
6,898,452 B2		5/2005	Al-Ali et al.
6,920,345 B2		7/2005	Al-Ali et al.
6,931,268 B1		8/2005	Kiani-Azarbayjany et al.
6,934,570 B2		8/2005	Kiani et al.
6,939,305 B2		9/2005	Flaherty et al.
6,943,348 B1		9/2005	Coffin IV
6,950,687 B2		9/2005	Al-Ali
6,961,598 B2		11/2005	Diab
6,970,792 B1		11/2005	Diab
6,979,812 B2		12/2005	Al-Ali
6,985,764 B2		1/2006	Mason et al.
6,993,371 B2		1/2006	Kiani et al.
6,996,427 B2		2/2006	Ali et al.
6,999,904 B2		2/2006	Weber et al.
7,003,338 B2		2/2006	Weber et al.
7,003,339 B2		2/2006	Diab et al.
7,015,451 B2		3/2006	Dalke et al.
7,024,233 B2		4/2006	Ali et al.
7,027,849 B2		4/2006	Al-Ali
7,030,749 B2		4/2006	Al-Ali
7,039,449 B2		5/2006	Al-Ali
7,041,060 B2		5/2006	Flaherty et al.
7,044,918 B2		5/2006	Diab
7,067,893 B2		6/2006	Mills et al.
7,096,052 B2		8/2006	Mason et al.
7,096,054 B2		8/2006	Abdul-Hafiz et al.
7,132,641 B2		11/2006	Schulz et al.
7,142,901 B2		11/2006	Kiani et al.
7,149,561 B2		12/2006	Diab
7,186,966 B2		3/2007	Al-Ali
7,190,261 B2		3/2007	Al-Ali
7,215,984 B2		5/2007	Diab

7,215,986 B2	5/2007	Diab	
7,221,971 B2	5/2007	Diab	
7,225,006 B2	5/2007	Al-Ali et al.	
7,225,007 B2	5/2007	Al-Ali	
RE39,672 E	6/2007	Shehada et al.	
7,239,905 B2	7/2007	Kiani-Azarbayjany et al.	
7,245,953 B1	7/2007	Parker	
7,254,431 B2	8/2007	Al-Ali	
7,254,433 B2	8/2007	Diab et al.	
7,254,434 B2	8/2007	Schulz et al.	

7,272,425 B2	9/2007	Al-Ali	
7,274,955 B2	9/2007	Kiani et al.	
D554,263 S	10/2007	Al-Ali	
7,280,858 B2	10/2007	Al-Ali et al.	
7,289,835 B2	10/2007	Mansfield et al.	
7,292,883 B2	11/2007	De Felice et al.	
7,295,866 B2	11/2007	Al-Ali	
2005/0234317 A1	10/2005	Kiani	

* cited by examiner
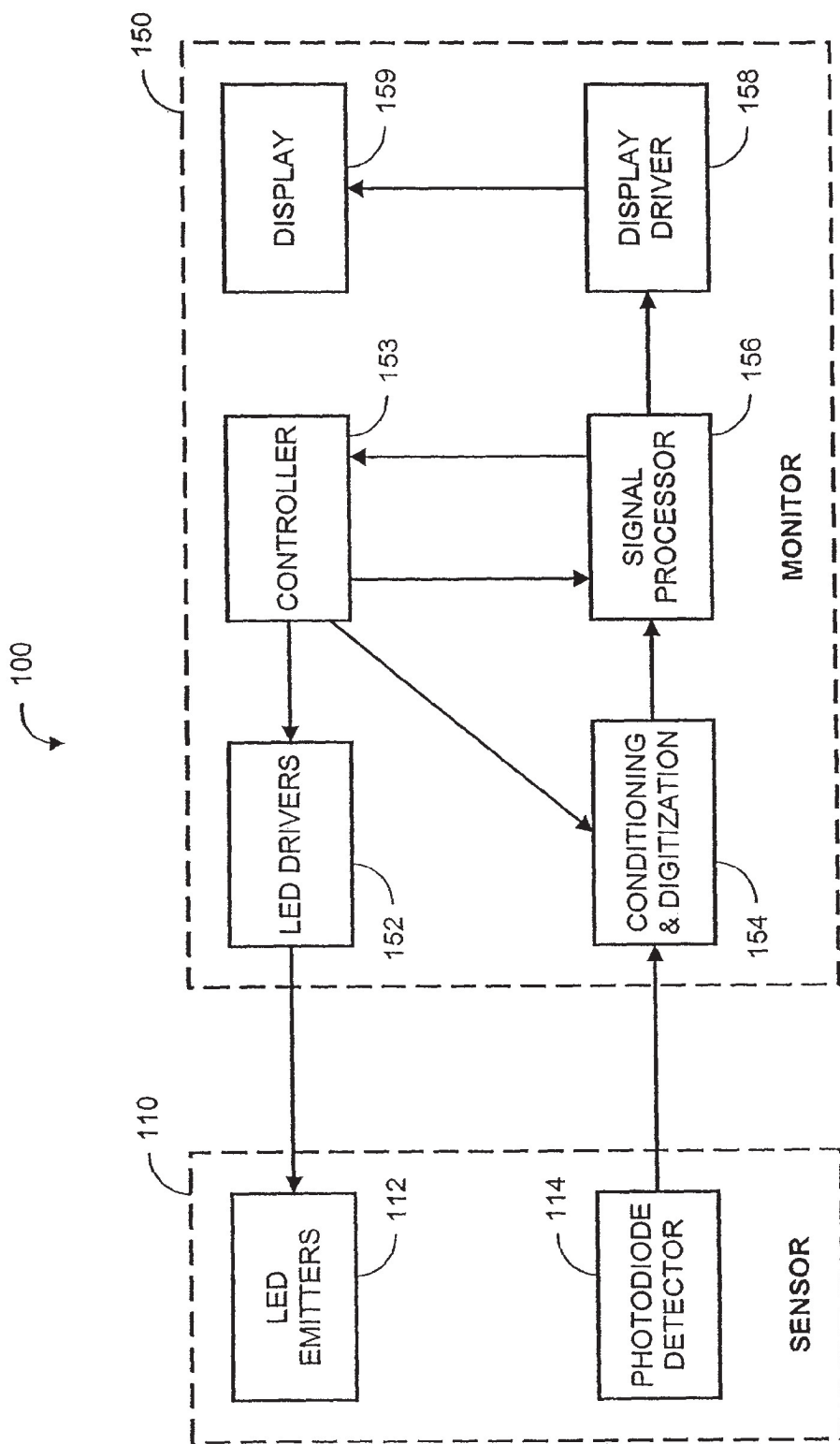
FIG. 1 (Prior Art)
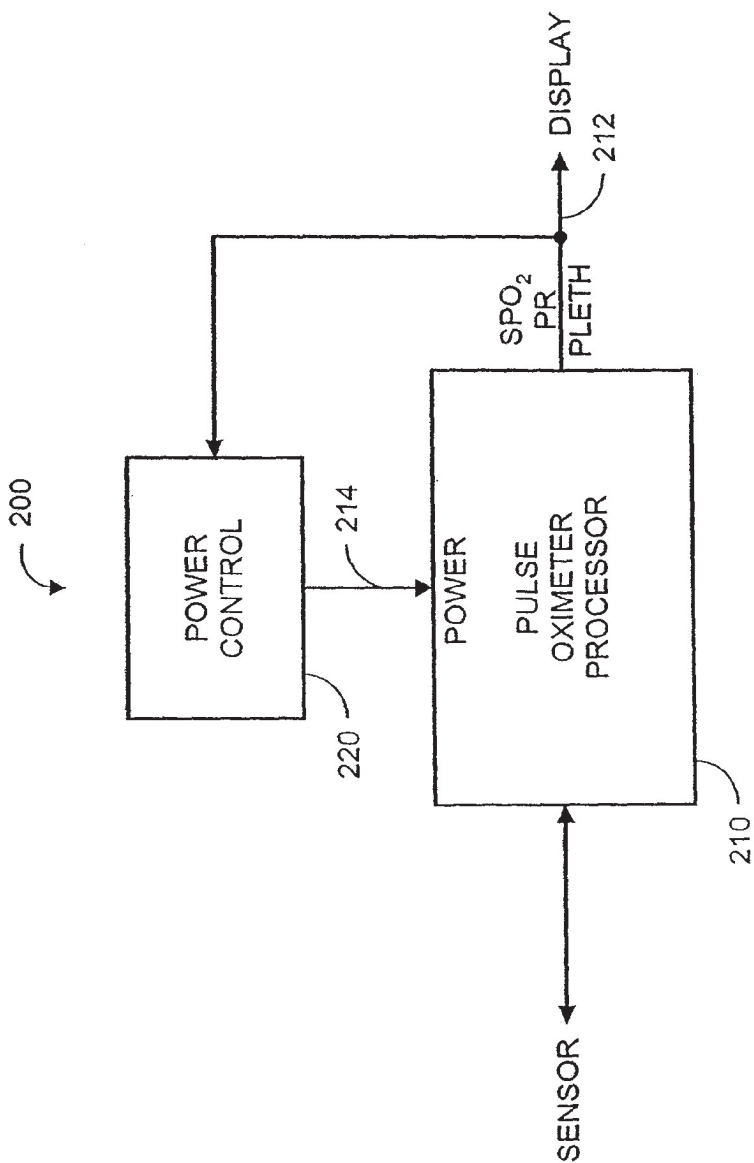
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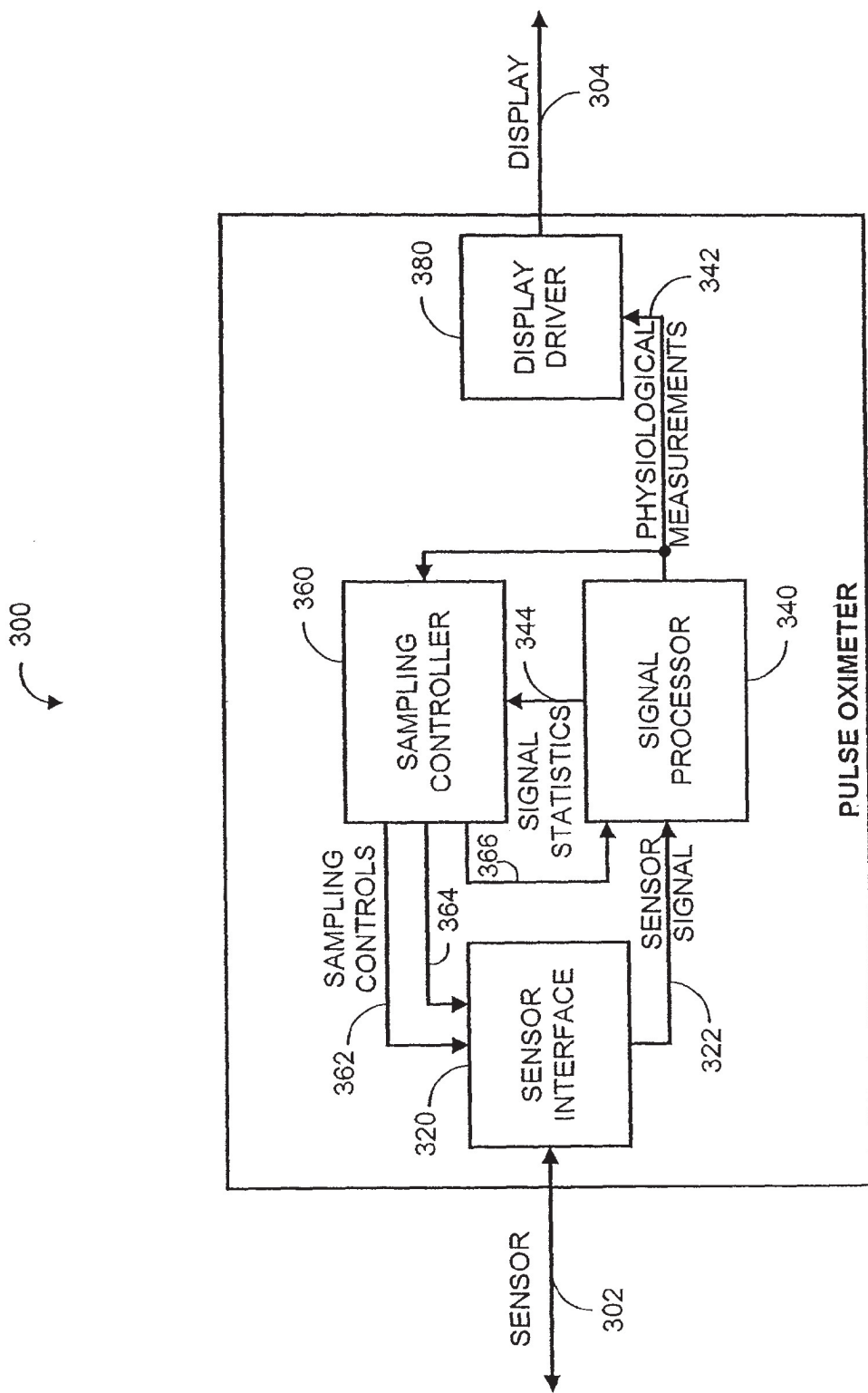
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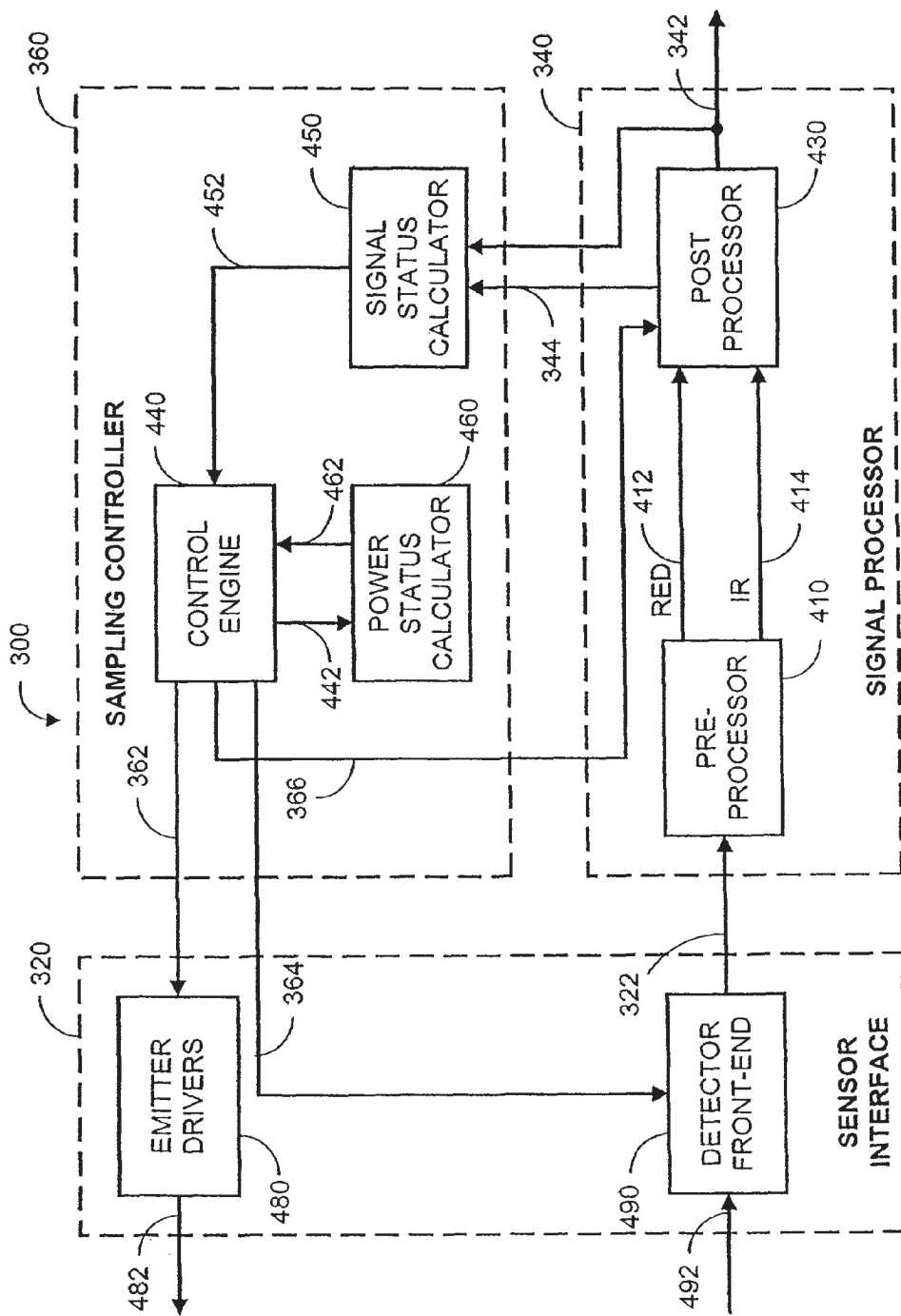
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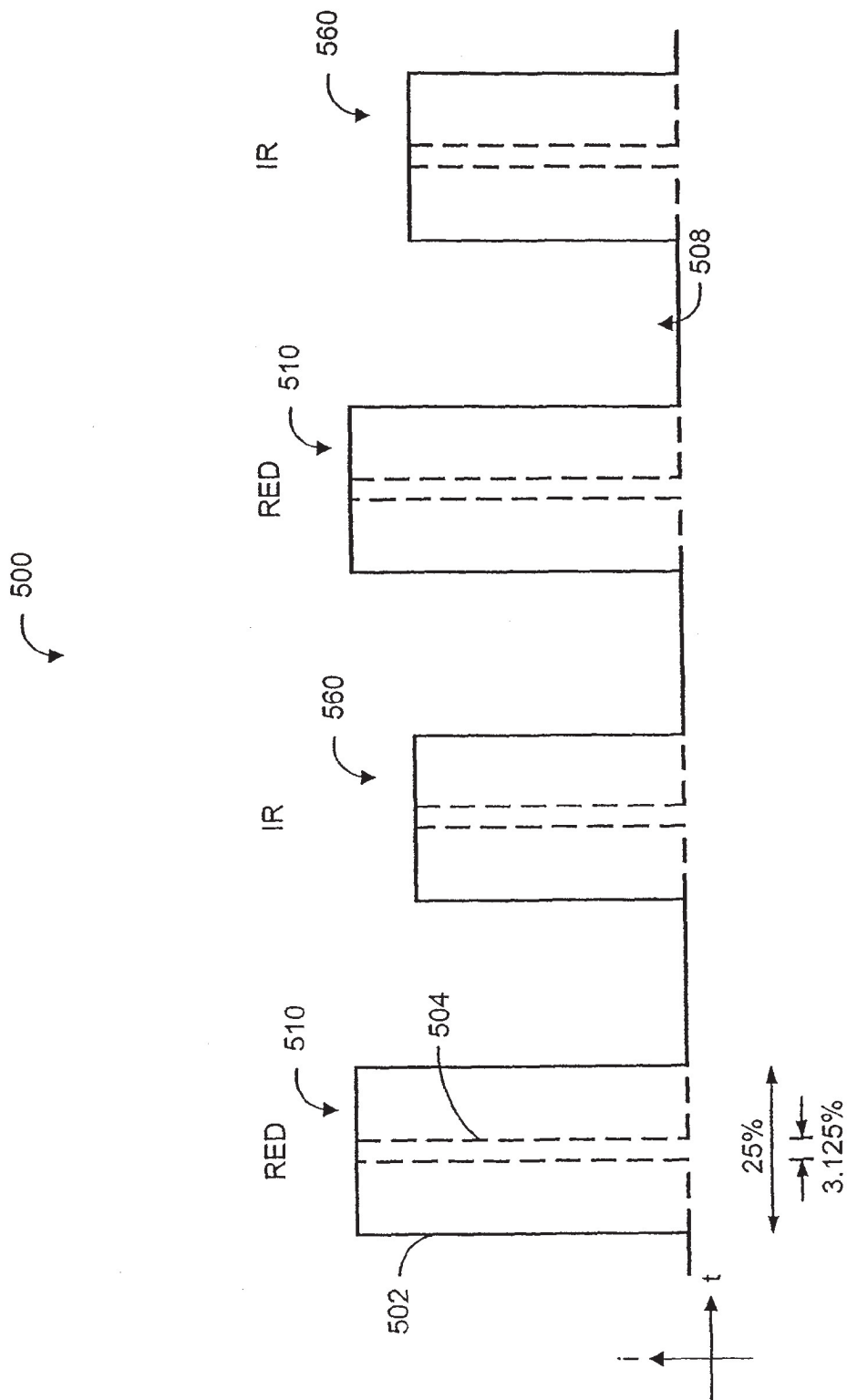
FIG. 5

FIG. 6

FIG. 7A

FIG. 7B

FIG. 8

E = EVENT
Q = LOW QUALITY
P = ABOVE POWER TARGET FOR A
PARTICULAR TIME PERIOD
T = TIMEOUT

FIG. 9

FIG. 10

FIG. 11

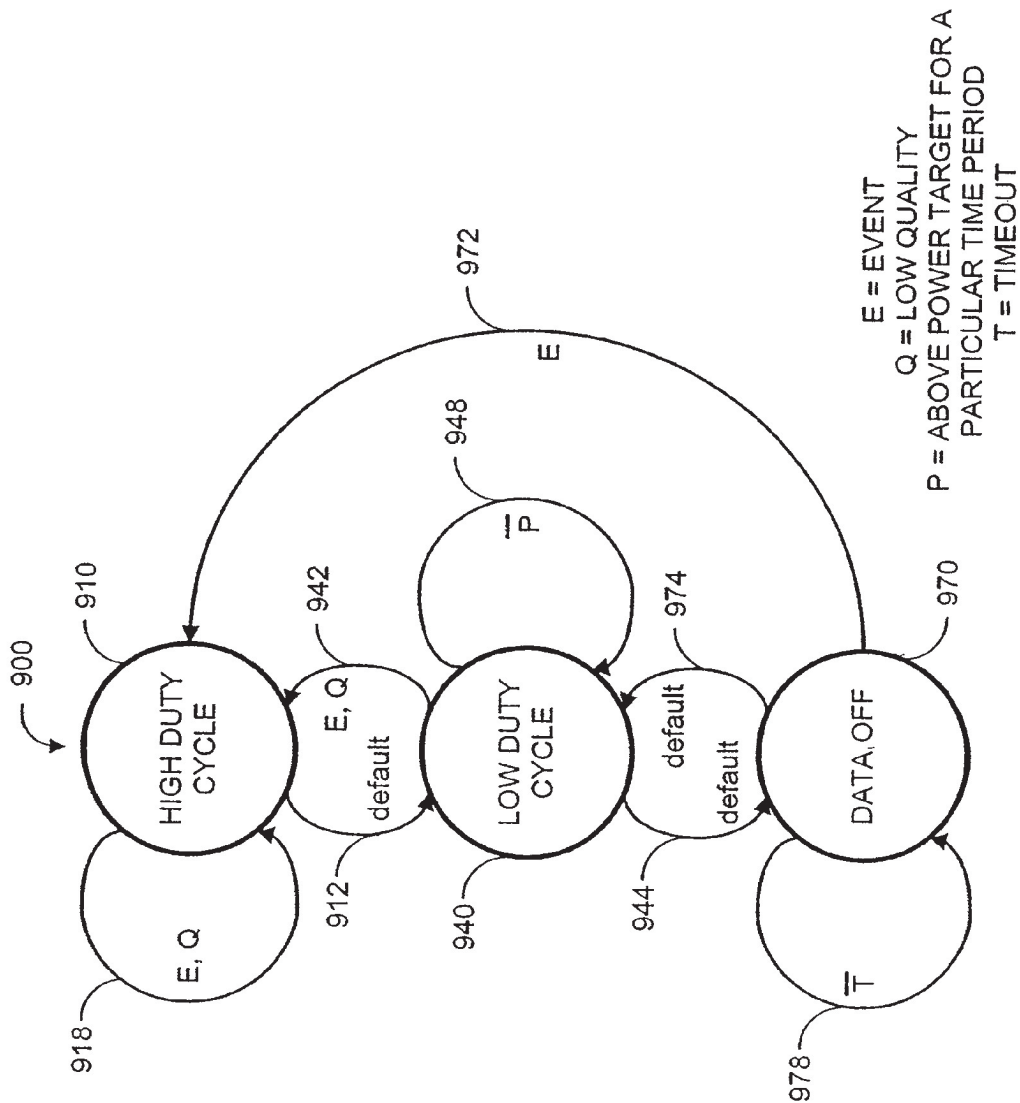E = EVENT
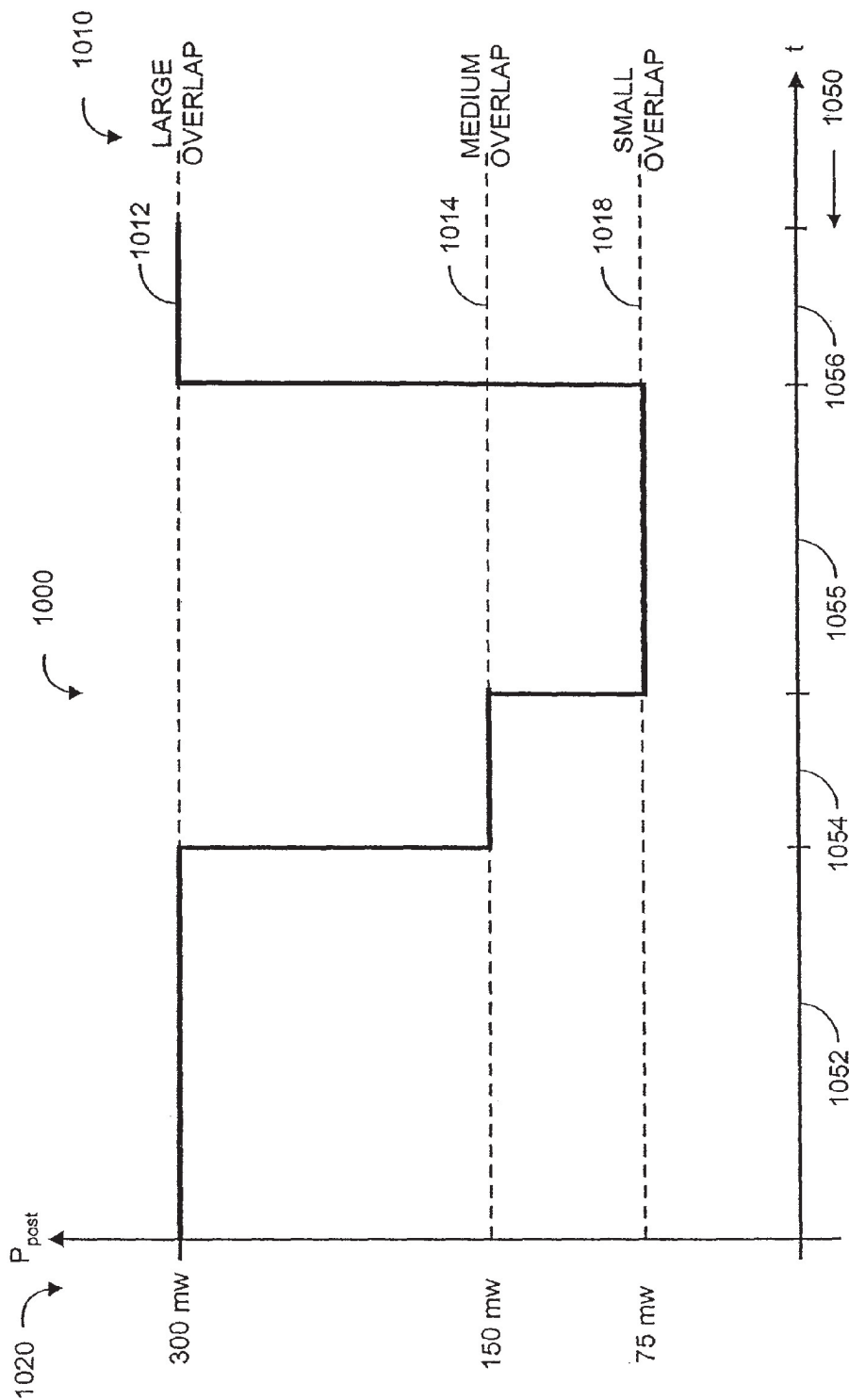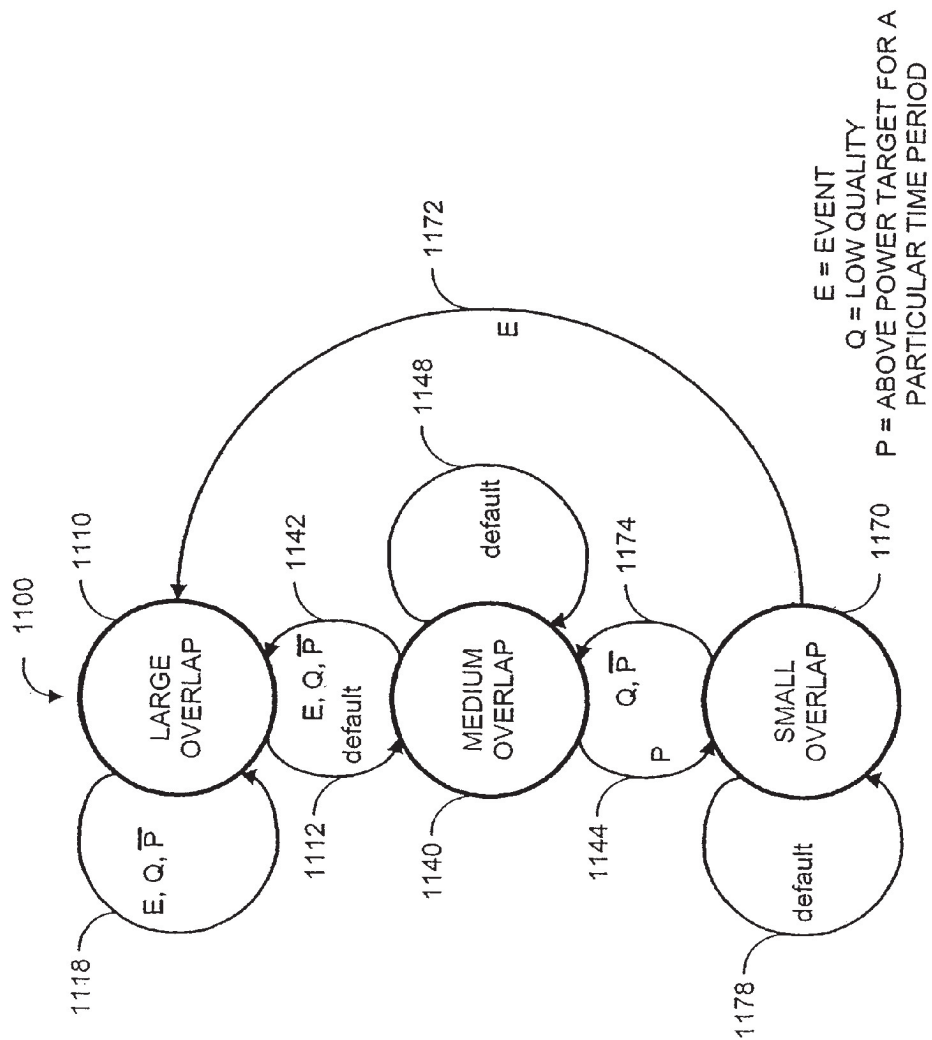Q = LOW QUALITY
P = ABOVE POWER TARGET FOR A
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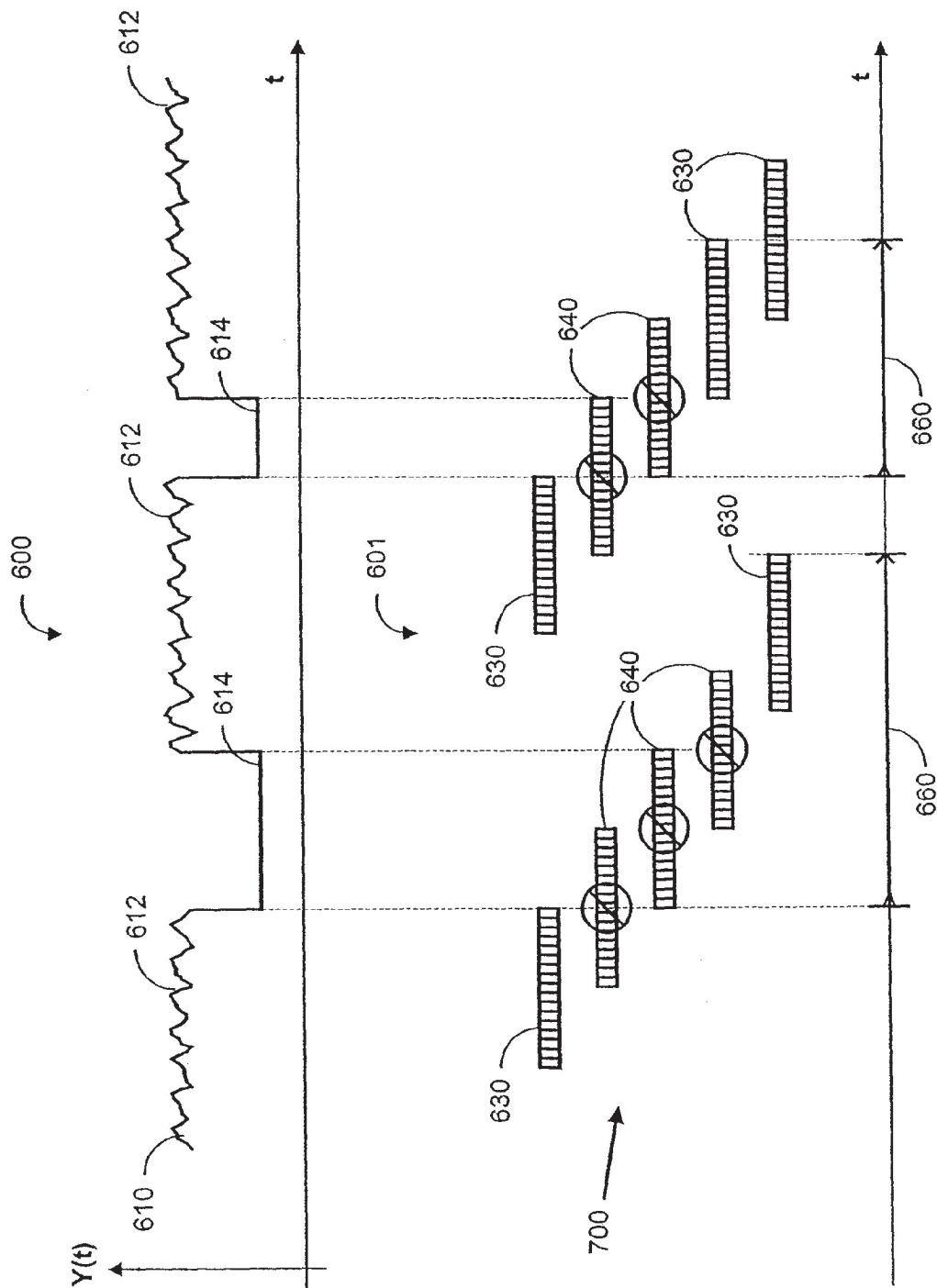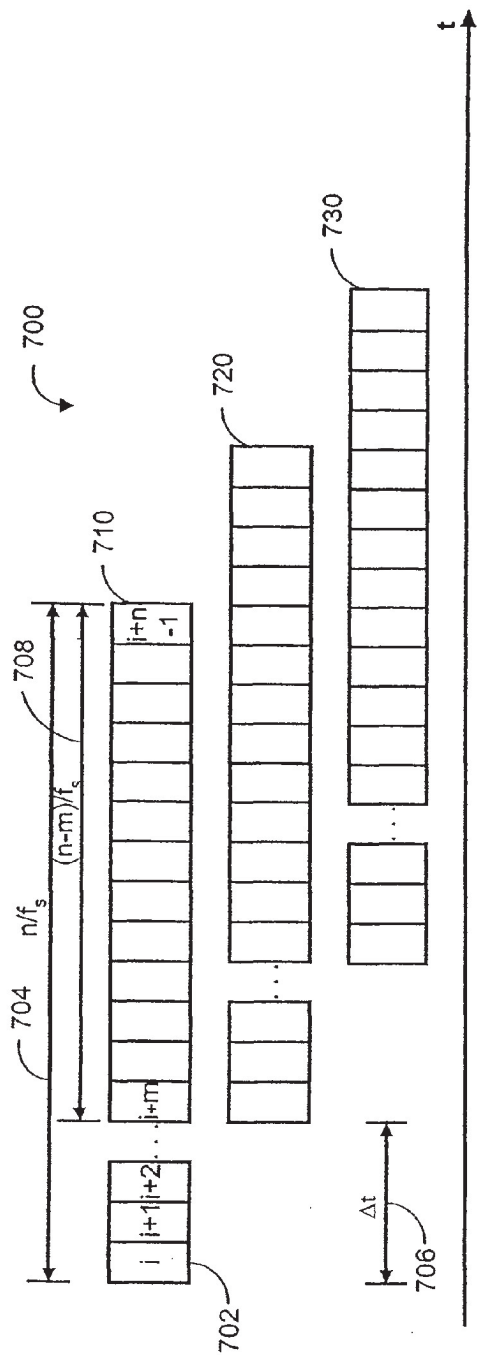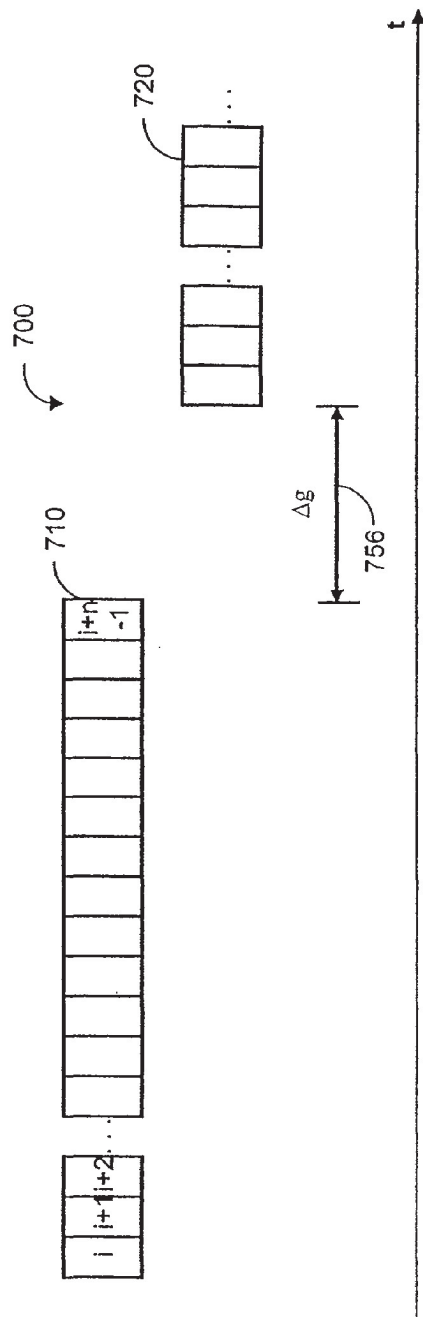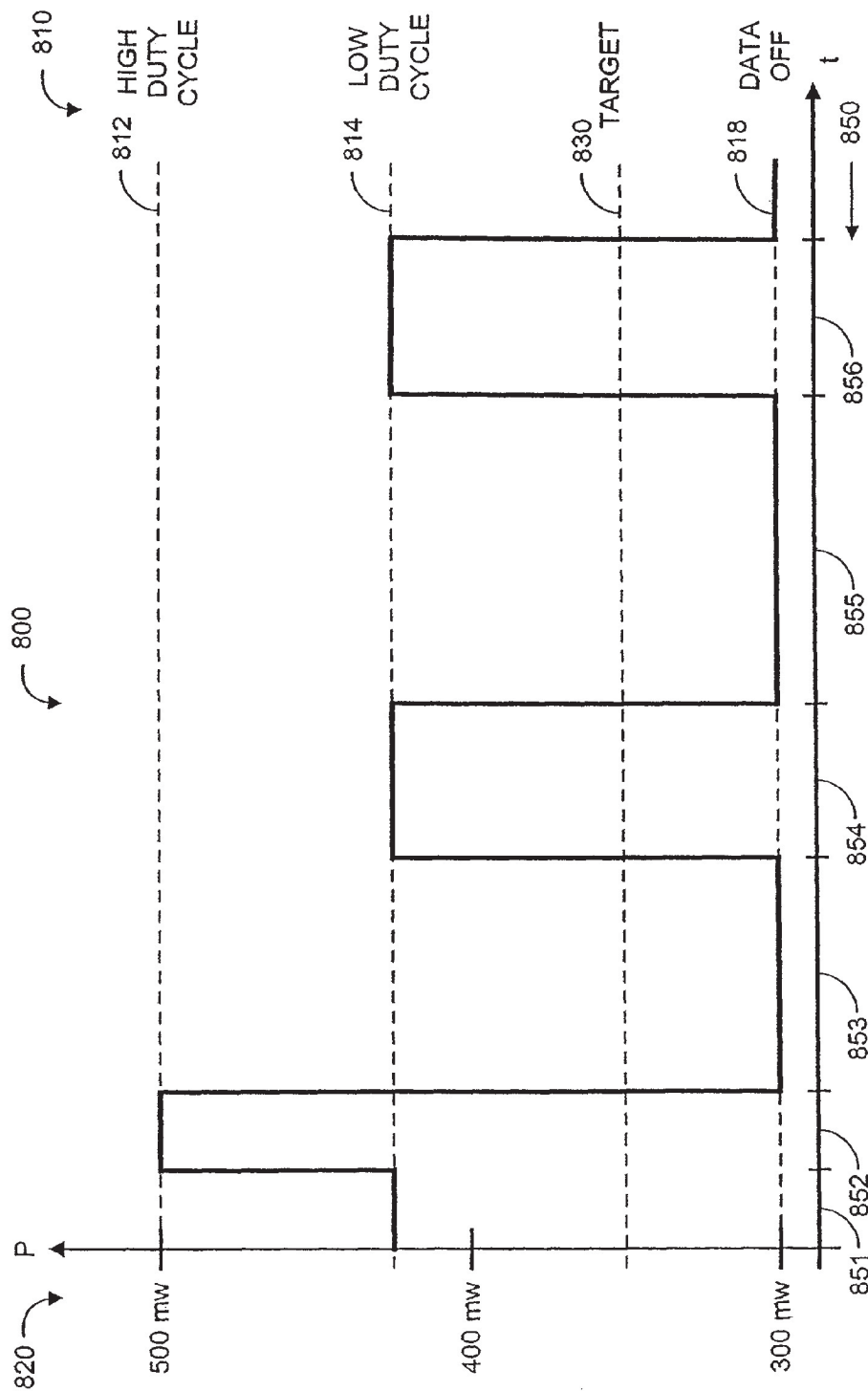
LOW POWER PULSE OXIMETER

REFERENCE TO RELATED APPLICATIONS

The present application is a continuation of U.S. application Ser. No. 10/785,573, entitled "Low Power Pulse Oximeter," filed Feb. 24, 2004, 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. 7A-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 com-

promising 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. 7A-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. 7A-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. 7A, 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. 7B, 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 embodi-

ments 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 patient monitor, the method comprising:

driving one or more light sources configured to emit light into tissue of a monitored patient;

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

continuously operating a patient monitor at a lower power consumption level to determine measurement values for one or more physiological parameters of a patient;

comparing processing characteristics to a predetermined threshold; and

when said processing characteristics pass said threshold, transitioning to continuously operating said patient monitor at a higher power consumption level, wherein said continuously operating at said lower power consumption level comprises reducing activation of an attached sensor, said sensor positioning said light sources and said detectors proximate said tissue.

2. The method of claim **1**, wherein said reducing activation comprises reducing a duty cycle of said sensor.

3. The method of claim **1**, wherein during said operating at said higher power consumption level, monitoring when said processing characteristics recedes from said threshold; and when receded, transitioning to continuously operating said patient monitor at said lower power consumption level.

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

5. The method of claim **4**, wherein said signal characteristics comprise signal strength.

6. The method of claim **4**, wherein said signal characteristics comprise a presence of noise.

7. The method of claim **4**, wherein said signal characteristics comprise a presence of motion induced noise.

8. The method of claim **1**, wherein said processing characteristics include determining an estimate of current power consumption and comparing said estimate with a target power consumption.

9. A method of managing power consumption during continuous patient monitoring by adjusting behavior of a patient monitor, the method comprising:

driving one or more light sources configured to emit light into tissue of a monitored patient;

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

continuously operating a patient monitor at a lower power consumption level to determine measurement values for one or more physiological parameters of a patient;

comparing processing characteristics to a predetermined threshold; and

when said processing characteristics pass said threshold, transitioning to continuously operating said patient monitor at a higher power consumption level, wherein said continuously operating at said lower power consumption level comprises reducing an amount of processing by a signal processor.

10. The method of claim **9**, wherein said reducing comprises processing less data.

11. The method of claim **10**, wherein said processing less data comprises reducing an overlap in data blocks being processed.

12. A method of managing power consumption during continuous patient monitoring by adjusting behavior of a patient monitor, the method comprising:

driving one or more light sources configured to emit light into tissue of a monitored patient;

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

continuously operating a patient monitor at a lower power consumption level to determine measurement values for one or more physiological parameters of a patient;

comparing processing characteristics to a predetermined threshold; and

when said processing characteristics pass said threshold, transitioning to continuously operating said patient monitor at a higher power consumption level, wherein said processing characteristics include an override condition.

13. The method of claim **12**, wherein said override condition comprises measurements during a critical care environment.

14. The method of claim **12**, wherein said override condition comprises one or more monitored parameters exhibiting predefined behavior.

15. A patient monitor configured to manage power consumption during continuous patient monitoring, the monitor 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; and

one or more processors continuously operating at a lower power consumption level to determine measurement values for one or more physiological parameters of said patient, said processors comparing processing characteristics to a predetermined threshold, and when said processing characteristics pass said threshold, said processors transitioning to continuously operating at a higher power consumption level, wherein processors reduce activation of an attached sensor.

16. The monitor of claim **15**, wherein said processors reduce a duty cycle of said sensor.

17. The monitor of claim **15**, wherein during said operating at said higher power consumption level, said processors monitors when said processing characteristics recedes from said threshold; and when receded, said processors transition to continuously operating at said lower power consumption level.

18. The monitor of claim **15**, wherein said processing characteristics comprise signal characteristics from one or more light sensitive detectors.

19. The monitor of claim **15**, wherein said processing characteristics include determining an estimate of current power consumption and comparing said estimate with a target power consumption.

20. A patient monitor configured to manage power consumption during continuous patient monitoring, the monitor 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; and

one or more processors continuously operating at a lower power consumption level to determine measurement values for one or more physiological parameters of said patient, said processors comparing processing characteristics to a predetermined threshold, and when said processing characteristics pass said threshold, said processors transitioning to continuously operating at a

higher power consumption level, wherein said processors reduce an amount of processing by a signal processor.

21. The monitor of claim **20**, wherein said processors reduce an overlap in data blocks being processed.

22. A patient monitor configured to manage power consumption during continuous patient monitoring, the monitor 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; and

one or more processors continuously operating at a lower power consumption level to determine measurement values for one or more physiological parameters of said patient, said processors comparing processing characteristics to a predetermined threshold, and when said processing characteristics pass said threshold, said processors transitioning to continuously operating at a higher power consumption level, wherein said processing characteristics include an override condition.

23. The monitor of claim **22**, wherein said override condition comprises measurements during a critical care environment.

24. The monitor of claim **22**, wherein said override condition comprises one or more monitored parameters exhibiting predefined behavior.

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