

(12) **United States Patent**
Al-Ali

(10) **Patent No.:** **US 9,113,832 B2**
(45) **Date of Patent:** **Aug. 25, 2015**

(54) **WRIST-MOUNTED PHYSIOLOGICAL MEASUREMENT DEVICE**

(71) Applicant: **MASIMO CORPORATION**, Irvine, CA (US)

(72) Inventor: **Ammar Al-Ali**, San Juan Capistrano, CA (US)

(73) Assignee: **Masimo Corporation**, Irvine, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/217,788**

(22) Filed: **Mar. 18, 2014**

(65) **Prior Publication Data**

US 2014/0200420 A1 Jul. 17, 2014

Related U.S. Application Data

(63) Continuation of application No. 14/037,137, filed on Sep. 25, 2013, which is a continuation of application No. 12/955,826, filed on Nov. 29, 2010, now Pat. No. 8,548,548, which is a continuation of application No.

(Continued)

(51) **Int. Cl.**

A61B 5/1455 (2006.01)

A61B 5/00 (2006.01)

A61B 5/024 (2006.01)

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

CPC **A61B 5/14552** (2013.01); **A61B 5/002** (2013.01); **A61B 5/0026** (2013.01); **A61B 5/02427** (2013.01); **A61B 5/6826** (2013.01); **A61B 5/6838** (2013.01); **A61B 5/02438** (2013.01); **A61B 5/1455** (2013.01); **Y10S 128/903** (2013.01)

(58) **Field of Classification Search**

CPC **A61B 5/1455**; **A61B 5/14551**; **A61B 5/14552**; **A61B 5/681**; **A61B 5/6824**; **A61B 5/0002**; **A61B 5/001**; **A61B 5/002**

USPC **600/300**, **322**, **323**; **128/903**
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,690,313 A 9/1972 Weber et al.
3,978,849 A 9/1976 Geneen
4,108,166 A 8/1978 Schmid
4,231,354 A 11/1980 Kurtz et al.

(Continued)

FOREIGN PATENT DOCUMENTS

EP 735499 A1 10/1996
EP 2 335 569 A2 6/2011

(Continued)

OTHER PUBLICATIONS

Extended European Search Report for European Application No. 10195398.2 dated Jul. 5, 2012.

(Continued)

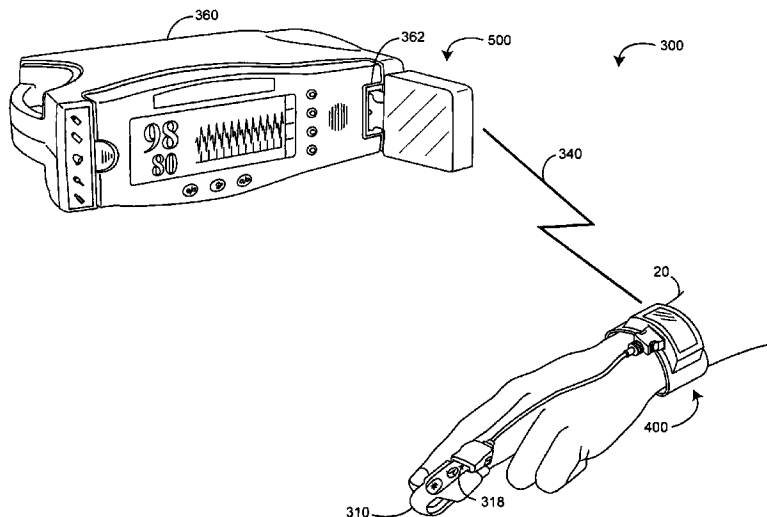
Primary Examiner — Eric Winakur

(74) *Attorney, Agent, or Firm* — Knobbe, Martens, Olson & Bear LLP

(57) **ABSTRACT**

A sensor interface is configured to receive a sensor signal. A transmitter generates a transmit signal. A receiver receives the signal corresponding to the transmit signal. Further, a monitor interface is configured to communicate a waveform to the monitor so that measurements derived by the monitor from the waveform are generally equivalent to measurements derivable from the sensor signal.

6 Claims, 17 Drawing Sheets



Related U.S. Application Data

11/417,006, filed on May 3, 2006, now Pat. No. 7,844,315, which is a continuation of application No. 11/048,330, filed on Feb. 1, 2005, now Pat. No. 7,844,314, which is a continuation of application No. 10/377,933, filed on Feb. 28, 2003, now Pat. No. 6,850,788.

(60) Provisional application No. 60/367,428, filed on Mar. 25, 2002.

(56) References Cited

U.S. PATENT DOCUMENTS

4,589,415 A	5/1986	Haaga	5,760,910 A	6/1998	Lepper, Jr. et al.
4,662,378 A	5/1987	Thomis	5,769,785 A	6/1998	Diab et al.
4,960,128 A	10/1990	Gordon et al.	5,694,020 A	7/1998	Meinzer et al.
4,964,408 A	10/1990	Hink et al.	5,782,757 A	7/1998	Diab et al.
5,041,187 A	8/1991	Hink et al.	5,785,659 A	7/1998	Caro et al.
5,069,213 A	12/1991	Polczynski	5,791,347 A	8/1998	Flaherty et al.
5,092,340 A	3/1992	Yamaguchi et al.	5,801,637 A	9/1998	Lomholt
5,140,519 A	8/1992	Friesdorf et al.	5,810,734 A	9/1998	Caro et al.
5,159,932 A	11/1992	Zanetti et al.	5,822,546 A	10/1998	George
5,161,539 A	11/1992	Evans et al.	5,823,950 A	10/1998	Diab et al.
5,163,438 A	11/1992	Gordon et al.	5,830,131 A	11/1998	Caro et al.
5,262,944 A	11/1993	Weisner et al.	5,833,618 A	11/1998	Caro et al.
5,277,189 A	1/1994	Jacobs	5,860,919 A	1/1999	Kiani-Azarbayjany et al.
5,278,627 A	1/1994	Aoyagi et al.	5,890,929 A	4/1999	Mills et al.
5,282,474 A	2/1994	Valdes Sosa et al.	5,904,654 A	5/1999	Wohltmann et al.
5,318,037 A	6/1994	Evans et al.	5,910,139 A	6/1999	Cochran et al.
5,319,355 A	6/1994	Russek	5,919,134 A	7/1999	Diab
5,333,106 A	7/1994	Lanpher et al.	5,921,920 A	7/1999	Marshall et al.
5,337,744 A	8/1994	Branigan	5,931,160 A	8/1999	Gilmore et al.
5,341,805 A	8/1994	Stavridi et al.	5,934,925 A	8/1999	Tobler et al.
5,358,519 A	10/1994	Grandjean	5,940,182 A	8/1999	Lepper, Jr. et al.
D353,195 S	12/1994	Savage et al.	5,995,855 A	11/1999	Kiani et al.
D353,196 S	12/1994	Savage et al.	5,997,343 A	12/1999	Mills et al.
5,375,599 A	12/1994	Shimizu	6,002,952 A	12/1999	Diab et al.
5,377,676 A	1/1995	Vari et al.	6,011,986 A	1/2000	Diab et al.
5,400,794 A	3/1995	Gorman	6,018,673 A	1/2000	Chin et al.
D359,546 S	6/1995	Savage et al.	6,027,452 A	2/2000	Flaherty et al.
5,431,170 A	7/1995	Mathews	6,032,678 A	3/2000	Rottem
D361,840 S	8/1995	Savage et al.	6,035,230 A	3/2000	Kang et al.
D362,063 S	9/1995	Savage et al.	6,036,642 A	3/2000	Diab et al.
5,452,717 A	9/1995	Branigan et al.	6,045,509 A	4/2000	Caro et al.
D363,120 S	10/1995	Savage et al.	6,067,462 A	5/2000	Diab et al.
5,456,252 A	10/1995	Vari et al.	6,081,735 A	6/2000	Diab et al.
5,479,934 A	1/1996	Imran	6,088,607 A	7/2000	Diab et al.
5,482,036 A	1/1996	Diab et al.	6,106,463 A	8/2000	Wilk
5,483,968 A	1/1996	Adam et al.	6,110,522 A	8/2000	Lepper, Jr. et al.
5,490,505 A	2/1996	Diab et al.	6,124,597 A	9/2000	Shehada
5,494,041 A	2/1996	Wilk	6,128,521 A	10/2000	Marro et al.
5,494,043 A	2/1996	O'Sullivan et al.	6,129,675 A	10/2000	Jay
5,503,149 A	4/1996	Beavin	6,132,218 A	10/2000	Benja-Athon
5,505,202 A	4/1996	Mogi et al.	6,144,868 A	11/2000	Parker
5,533,511 A	7/1996	Kaspari et al.	6,151,516 A	11/2000	Kiani-Azarbayjany et al.
5,534,851 A	7/1996	Russek	6,152,754 A	11/2000	Gerhardt et al.
5,561,275 A	10/1996	Savage et al.	6,157,850 A	12/2000	Diab et al.
5,562,002 A	10/1996	Lalin	6,165,005 A	12/2000	Mills et al.
5,566,676 A	10/1996	Rosenfeldt et al.	6,167,258 A	12/2000	Schmidt et al.
5,579,001 A	11/1996	Dempsey et al.	6,183,417 B1	2/2001	Geheb et al.
5,590,649 A	1/1997	Caro et al.	6,184,521 B1	2/2001	Coffin, IV et al.
5,602,924 A	2/1997	Durand et al.	6,185,448 B1	2/2001	Borovsky
5,632,272 A	5/1997	Diab et al.	6,195,576 B1	2/2001	John
5,638,816 A	6/1997	Kiani-Azarbayjany et al.	6,206,830 B1	3/2001	Diab et al.
5,638,818 A	6/1997	Diab et al.	6,221,012 B1	4/2001	Maschke et al.
5,640,967 A	6/1997	Fine et al.	6,224,553 B1	5/2001	Nevo
5,645,440 A	7/1997	Tobler et al.	6,229,856 B1	5/2001	Diab et al.
5,685,299 A	11/1997	Diab et al.	6,232,609 B1	5/2001	Snyder et al.
5,685,314 A	11/1997	Geheb et al.	6,236,872 B1	5/2001	Diab et al.
5,687,717 A	11/1997	Halpern et al.	6,241,683 B1	6/2001	Macklem et al.
5,724,983 A	3/1998	Selker et al.	6,253,097 B1	6/2001	Aronow et al.
5,725,308 A	3/1998	Smith et al.	6,256,523 B1	7/2001	Diab et al.
5,734,739 A	3/1998	Sheehan et al.	6,263,222 B1	7/2001	Diab et al.
D393,830 S	4/1998	Tobler et al.	6,267,723 B1	7/2001	Matsumura et al.
5,743,262 A	4/1998	Lepper, Jr. et al.	6,269,262 B1	7/2001	Kandori et al.
5,758,644 A	6/1998	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.
			6,301,493 B1	10/2001	Marro et al.
			6,317,627 B1	11/2001	Ennen et al.
			6,321,100 B1	11/2001	Parker
			6,325,761 B1	12/2001	Jay
			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.
			6,354,235 B1	3/2002	Davies
			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
			6,385,476 B1	5/2002	Osadchy et al.
			6,388,240 B2	5/2002	Schulz et al.

(56)

References Cited

U.S. PATENT DOCUMENTS

6,397,091 B2	5/2002	Diab et al.	6,897,788 B2	5/2005	Khair et al.
6,430,437 B1	8/2002	Marro	6,898,452 B2	5/2005	Al-Ali et al.
6,430,525 B1	8/2002	Weber et al.	6,907,237 B1	6/2005	Dorenbosch et al.
6,463,311 B1	10/2002	Diab	6,915,149 B2	7/2005	Ben-haim
6,470,199 B1	10/2002	Kopotic et al.	6,920,345 B2	7/2005	Al-Ali et al.
6,470,893 B1	10/2002	Boesen	6,931,268 B1	8/2005	Kiani-Azarbayjany et al.
6,501,975 B2	12/2002	Diab et al.	6,934,570 B2	8/2005	Kiani et al.
6,505,059 B1	1/2003	Kollias et al.	6,939,305 B2	9/2005	Flaherty et al.
6,515,273 B2	2/2003	Al-Ali	6,943,348 B1	9/2005	Coffin, IV
6,519,487 B1	2/2003	Parker	6,950,687 B2	9/2005	Al-Ali
6,524,240 B1	2/2003	Thede	6,952,340 B2	10/2005	Son et al.
6,525,386 B1	2/2003	Mills et al.	6,961,598 B2	11/2005	Diab
6,526,300 B1	2/2003	Kiani et al.	6,970,792 B1	11/2005	Diab
6,541,756 B2	4/2003	Schulz et al.	6,979,812 B2	12/2005	Al-Ali
6,542,764 B1	4/2003	Al-Ali et al.	6,980,419 B2	12/2005	Smith et al.
6,544,174 B2	4/2003	West et al.	6,983,179 B2	1/2006	Ben-haim
6,580,086 B1	6/2003	Schulz et al.	6,985,764 B2	1/2006	Mason et al.
6,584,336 B1	6/2003	Ali et al.	6,988,989 B2	1/2006	Weiner et al.
6,595,316 B2	7/2003	Cybulski et al.	6,990,087 B2	1/2006	Rao et al.
6,597,932 B2	7/2003	Tian et al.	6,993,371 B2	1/2006	Kiani et al.
6,597,933 B2	7/2003	Kiani et al.	6,996,427 B2	2/2006	Ali et al.
6,606,511 B1	8/2003	Ali et al.	6,997,884 B2	2/2006	Ulmsten et al.
6,616,606 B1	9/2003	Peterson et al.	6,999,904 B2	2/2006	Weber et al.
6,632,181 B2	10/2003	Flaherty et al.	7,003,338 B2	2/2006	Weber et al.
6,639,668 B1	10/2003	Trepagnier	7,003,339 B2	2/2006	Diab et al.
6,640,116 B2	10/2003	Diab	7,015,451 B2	3/2006	Dalke et al.
6,641,533 B2	11/2003	Causey et al.	7,024,233 B2	4/2006	Ali et al.
6,643,530 B2	11/2003	Diab et al.	7,025,729 B2	4/2006	De Chazal et al.
6,650,917 B2	11/2003	Diab et al.	7,027,849 B2	4/2006	Al-Ali
6,650,939 B2	11/2003	Taepke, II et al.	7,030,749 B2	4/2006	Al-Ali
6,654,624 B2	11/2003	Diab et al.	7,033,761 B2	4/2006	Shafer
6,658,276 B2	12/2003	Kiani et al.	7,035,686 B2	4/2006	Hogan
6,661,161 B1	12/2003	Lanzo et al.	7,039,449 B2	5/2006	Al-Ali
6,671,531 B2	12/2003	Al-Ali et al.	7,041,060 B2	5/2006	Flaherty et al.
6,678,543 B2	1/2004	Diab et al.	7,044,918 B2	5/2006	Diab
6,684,090 B2	1/2004	Ali et al.	7,063,666 B2	6/2006	Weng et al.
6,684,091 B2	1/2004	Parker	7,067,893 B2	6/2006	Mills et al.
6,694,180 B1	2/2004	Boesen	7,079,035 B2	7/2006	Bock et al.
6,697,656 B1	2/2004	Al-Ali	7,096,052 B2	8/2006	Mason et al.
6,697,657 B1	2/2004	Shehada et al.	7,096,054 B2	8/2006	Abdul-Hafiz et al.
6,697,658 B2	2/2004	Al-Ali	7,132,641 B2	11/2006	Schulz et al.
RE38,476 E	3/2004	Diab et al.	7,142,901 B2	11/2006	Kiani et al.
6,699,194 B1	3/2004	Diab et al.	7,149,561 B2	12/2006	Diab
6,714,804 B2	3/2004	Al-Ali et al.	7,186,966 B2	3/2007	Al-Ali
RE38,492 E	4/2004	Diab et al.	7,188,621 B2	3/2007	DeVries et al.
6,719,694 B2	4/2004	Weng et al.	7,190,261 B2	3/2007	Al-Ali
6,721,582 B2	4/2004	Trepagnier et al.	7,208,119 B1	4/2007	Kurtcock et al.
6,721,585 B1	4/2004	Parker	7,215,984 B2	5/2007	Diab
6,725,075 B2	4/2004	Al-Ali	7,215,986 B2	5/2007	Diab
6,728,560 B2	4/2004	Kollias et al.	7,221,971 B2	5/2007	Diab
6,735,459 B2	5/2004	Parker	7,225,006 B2	5/2007	Al-Ali et al.
6,745,060 B2	6/2004	Diab et al.	7,225,007 B2	5/2007	Al-Ali
6,751,492 B2	6/2004	Ben-haim	RE39,672 E	6/2007	Shehada et al.
6,760,607 B2	7/2004	Al-Ali	7,229,415 B2	6/2007	Schwartz
6,770,028 B1	8/2004	Ali et al.	7,239,905 B2	7/2007	Kiani-Azarbayjany et al.
6,771,994 B2	8/2004	Kiani et al.	7,241,287 B2	7/2007	Shehada et al.
6,783,492 B2	8/2004	Dominguez	7,244,251 B2	7/2007	Shehada et al.
6,790,178 B1	9/2004	Mault et al.	7,245,953 B1	7/2007	Parker
6,792,300 B1	9/2004	Diab et al.	7,252,659 B2	8/2007	Shehada et al.
6,795,724 B2	9/2004	Hogan	7,254,429 B2	8/2007	Schurman et al.
6,807,050 B1	10/2004	Whitehorn et al.	7,254,431 B2	8/2007	Al-Ali
6,813,511 B2	11/2004	Diab et al.	7,254,433 B2	8/2007	Diab et al.
6,816,741 B2	11/2004	Diab	7,254,434 B2	8/2007	Schulz et al.
6,817,979 B2	11/2004	Nihtila et al.	7,264,616 B2	9/2007	Shehada et al.
6,822,564 B2	11/2004	Al-Ali	7,267,671 B2	9/2007	Shehada et al.
6,826,419 B2	11/2004	Diab et al.	7,272,425 B2	9/2007	Al-Ali
6,830,711 B2	12/2004	Mills et al.	7,274,955 B2	9/2007	Kiani et al.
6,837,848 B2	1/2005	Bonner et al.	D554,263 S	10/2007	Al-Ali
6,841,535 B2	1/2005	Divita et al.	7,280,858 B2	10/2007	Al-Ali et al.
6,850,787 B2	2/2005	Weber et al.	7,285,090 B2	10/2007	Stivoric
6,850,788 B2	2/2005	Al-Ali	7,289,835 B2	10/2007	Mansfield et al.
6,852,083 B2	2/2005	Caro et al.	7,292,883 B2	11/2007	De Felice et al.
6,855,112 B2	2/2005	Kao et al.	7,295,866 B2	11/2007	Al-Ali
6,860,266 B2	3/2005	Blike	7,313,423 B2	12/2007	Griffin et al.
6,861,639 B2	3/2005	Al-Ali	7,314,446 B2	1/2008	Byrd et al.
			7,322,971 B2	1/2008	Shehada et al.
			7,328,053 B1	2/2008	Diab et al.
			7,332,784 B2	2/2008	Mills et al.
			7,340,287 B2	3/2008	Mason et al.

(56)

References Cited

U.S. PATENT DOCUMENTS

7,341,559 B2	3/2008	Schulz et al.	7,774,060 B2	8/2010	Westenskow et al.
7,343,186 B2	3/2008	Lamego et al.	7,778,851 B2	8/2010	Schoenberg et al.
D566,282 S	4/2008	Al-Ali et al.	7,791,155 B2	9/2010	Diab
7,355,512 B1	4/2008	Al-Ali	7,794,407 B2	9/2010	Rothenberg
7,356,178 B2	4/2008	Ziel et al.	7,801,581 B2	9/2010	Diab
7,356,365 B2	4/2008	Schurman	7,820,184 B2	10/2010	Stritzker et al.
7,371,981 B2	5/2008	Abdul-Hafiz	7,822,452 B2	10/2010	Schurman et al.
7,373,193 B2	5/2008	Al-Ali et al.	RE41,912 E	11/2010	Parker
7,373,194 B2	5/2008	Weber et al.	7,841,986 B2	11/2010	He et al.
7,376,453 B1	5/2008	Diab et al.	7,844,313 B2	11/2010	Kiani et al.
7,377,794 B2	5/2008	Al-Ali et al.	7,844,314 B2	11/2010	Al-Ali
7,377,899 B2	5/2008	Weber et al.	7,844,315 B2	11/2010	Al-Ali
7,382,247 B2	6/2008	Welch et al.	7,858,322 B2	12/2010	Tymianski et al.
7,383,070 B2	6/2008	Diab et al.	7,865,222 B2	1/2011	Weber et al.
7,413,546 B2	8/2008	Agutter et al.	7,865,232 B1	1/2011	Krishnaswamy et al.
7,415,297 B2	8/2008	Al-Ali et al.	7,873,497 B2	1/2011	Weber et al.
7,419,483 B2	9/2008	Shehada	7,880,606 B2	2/2011	Al-Ali
7,428,432 B2	9/2008	Ali et al.	7,880,626 B2	2/2011	Al-Ali et al.
7,438,683 B2	10/2008	Al-Ali et al.	7,890,156 B2	2/2011	Ooi et al.
7,439,856 B2	10/2008	Weiner et al.	7,891,355 B2	2/2011	Al-Ali et al.
7,440,787 B2	10/2008	Diab	7,894,868 B2	2/2011	Al-Ali et al.
7,454,240 B2	11/2008	Diab et al.	7,899,507 B2	3/2011	Al-Ali et al.
7,462,151 B2	12/2008	Childre et al.	7,899,518 B2	3/2011	Trepagnier et al.
7,467,002 B2	12/2008	Weber et al.	7,904,132 B2	3/2011	Weber et al.
7,469,157 B2	12/2008	Diab et al.	7,909,772 B2	3/2011	Popov et al.
7,471,969 B2	12/2008	Diab et al.	7,910,875 B2	3/2011	Al-Ali
7,471,971 B2	12/2008	Diab et al.	7,914,514 B2	3/2011	Calderon
7,483,729 B2	1/2009	Al-Ali et al.	7,919,713 B2	4/2011	Al-Ali et al.
7,483,730 B2	1/2009	Diab et al.	7,937,128 B2	5/2011	Al-Ali
7,489,250 B2	2/2009	Bock et al.	7,937,129 B2	5/2011	Mason et al.
7,489,958 B2	2/2009	Diab et al.	7,937,130 B2	5/2011	Diab et al.
7,496,391 B2	2/2009	Diab et al.	7,941,199 B2	5/2011	Kiani
7,496,393 B2	2/2009	Diab et al.	7,951,086 B2	5/2011	Flaherty et al.
D587,657 S	3/2009	Al-Ali et al.	7,957,780 B2	6/2011	Lamego et al.
7,497,828 B1	3/2009	Wilk et al.	7,962,188 B2	6/2011	Kiani et al.
7,499,741 B2	3/2009	Diab et al.	7,962,190 B1	6/2011	Diab et al.
7,499,835 B2	3/2009	Weber et al.	7,963,927 B2	6/2011	Kelleher et al.
7,500,950 B2	3/2009	Al-Ali et al.	7,967,749 B2	6/2011	Hutchinson et al.
7,509,154 B2	3/2009	Diab et al.	7,976,472 B2	7/2011	Kiani
7,509,494 B2	3/2009	Al-Ali	7,988,637 B2	8/2011	Diab
7,510,849 B2	3/2009	Schurman et al.	7,988,639 B2	8/2011	Starks
7,526,328 B2	4/2009	Diab et al.	7,990,382 B2	8/2011	Kiani
7,530,942 B1	5/2009	Diab	7,991,446 B2	8/2011	Al-Ali et al.
7,530,949 B2	5/2009	Al Ali et al.	7,991,463 B2	8/2011	Kelleher et al.
7,530,955 B2	5/2009	Diab et al.	8,000,761 B2	8/2011	Al-Ali
7,549,961 B1	6/2009	Hwang	8,008,088 B2	8/2011	Bellott et al.
7,551,717 B2	6/2009	Tome et al.	RE42,753 E	9/2011	Kiani-Azarbayjany et al.
7,559,520 B2	7/2009	Quijano et al.	8,019,400 B2	9/2011	Diab et al.
7,563,110 B2	7/2009	Al-Ali et al.	8,028,701 B2	10/2011	Al-Ali et al.
7,577,475 B2	8/2009	Cosentino et al.	8,029,765 B2	10/2011	Bellott et al.
7,590,950 B2	9/2009	Collins et al.	8,033,996 B2	10/2011	Behar
7,596,398 B2	9/2009	Al-Ali et al.	8,036,727 B2	10/2011	Schurman et al.
7,597,665 B2	10/2009	Wilk et al.	8,036,728 B2	10/2011	Diab et al.
7,612,999 B2	11/2009	Clark et al.	8,036,736 B2	10/2011	Snyder et al.
7,618,375 B2	11/2009	Flaherty	8,038,625 B2	10/2011	Afonso et al.
D606,659 S	12/2009	Kiani et al.	8,046,040 B2	10/2011	Ali et al.
7,639,145 B2	12/2009	Lawson et al.	8,046,041 B2	10/2011	Diab et al.
7,647,083 B2	1/2010	Al-Ali et al.	8,046,042 B2	10/2011	Diab et al.
D609,193 S	2/2010	Al-Ali et al.	8,048,040 B2	11/2011	Kiani
7,654,966 B2	2/2010	Westinskow et al.	8,050,728 B2	11/2011	Al-Ali et al.
7,684,845 B2	3/2010	Juan	8,068,104 B2	11/2011	Rampersad
7,689,437 B1	3/2010	Teller et al.	8,073,707 B2	12/2011	Teller et al.
RE41,236 E	4/2010	Seely	RE43,169 E	2/2012	Parker
D614,305 S	4/2010	Al-Ali et al.	8,118,620 B2	2/2012	Al-Ali et al.
7,693,697 B2	4/2010	Westinskow et al.	8,126,528 B2	2/2012	Diab et al.
RE41,317 E	5/2010	Parker	8,128,572 B2	3/2012	Diab et al.
7,729,733 B2	6/2010	Al-Ali et al.	8,130,105 B2	3/2012	Al-Ali et al.
7,734,320 B2	6/2010	Al-Ali	8,145,287 B2	3/2012	Diab et al.
7,736,318 B2	6/2010	Cosentino et al.	8,150,487 B2	4/2012	Diab et al.
7,761,127 B2	7/2010	Al-Ali et al.	8,175,672 B2	5/2012	Parker
7,761,128 B2	7/2010	Al-Ali et al.	8,180,420 B2	5/2012	Diab et al.
7,763,420 B2	7/2010	Stritzker et al.	8,182,443 B1	5/2012	Kiani
7,764,982 B2	7/2010	Dalke et al.	8,185,180 B2	5/2012	Diab et al.
D621,516 S	8/2010	Kiani et al.	8,190,223 B2	5/2012	Al-Ali et al.
7,766,818 B2	8/2010	Iketani et al.	8,190,227 B2	5/2012	Diab et al.
			8,203,438 B2	6/2012	Kiani et al.
			8,203,704 B2	6/2012	Merritt et al.
			8,204,566 B2	6/2012	Schurman et al.
			8,206,312 B2	6/2012	Farquhar

(56)

References Cited**U.S. PATENT DOCUMENTS**

8,219,172 B2	7/2012	Schurman et al.	8,571,617 B2	10/2013	Reichgott et al.
8,224,411 B2	7/2012	Al-Ali et al.	8,571,618 B1	10/2013	Lamego et al.
8,228,181 B2	7/2012	Al-Ali	8,571,619 B2	10/2013	Al-Ali et al.
8,229,533 B2	7/2012	Diab et al.	8,577,431 B2	11/2013	Lamego et al.
8,233,955 B2	7/2012	Al-Ali et al.	8,579,813 B2	11/2013	Causey
8,235,907 B2	8/2012	Wilk et al.	8,581,732 B2	11/2013	Al-Ali et al.
8,239,780 B2	8/2012	Manetta et al.	8,584,345 B2	11/2013	Al-Ali et al.
8,241,213 B2	8/2012	Lynn et al.	8,588,880 B2	11/2013	Abdul-Hafiz et al.
8,244,325 B2	8/2012	Al-Ali et al.	8,588,924 B2	11/2013	Dion
8,249,815 B2	8/2012	Taylor	8,600,467 B2	12/2013	Al-Ali et al.
8,255,026 B1	8/2012	Al-Ali	8,606,342 B2	12/2013	Diab
8,255,027 B2	8/2012	Al-Ali et al.	8,626,255 B2	1/2014	Al-Ali et al.
8,255,028 B2	8/2012	Al-Ali et al.	8,630,691 B2	1/2014	Lamego et al.
8,260,577 B2	9/2012	Weber et al.	8,634,889 B2	1/2014	Al-Ali et al.
8,265,723 B1	9/2012	McHale et al.	8,641,631 B2	2/2014	Sierra et al.
8,274,360 B2	9/2012	Sampath et al.	8,652,060 B2	2/2014	Al-Ali
8,294,716 B2	10/2012	Lord et al.	8,663,107 B2	3/2014	Kiani
8,301,217 B2	10/2012	Al-Ali et al.	8,666,468 B1	3/2014	Al-Ali
8,306,596 B2	11/2012	Schurman et al.	8,667,967 B2	3/2014	Al-Ali et al.
8,310,336 B2	11/2012	Muhsin et al.	8,670,811 B2	3/2014	O'Reilly
8,311,747 B2	11/2012	Taylor	8,670,814 B2	3/2014	Diab et al.
8,311,748 B2	11/2012	Taylor et al.	8,676,286 B2	3/2014	Weber et al.
8,315,683 B2	11/2012	Al-Ali et al.	8,682,407 B2	3/2014	Al-Ali
8,315,812 B2	11/2012	Taylor	RE44,823 E	4/2014	Parker
8,315,813 B2	11/2012	Taylor et al.	RE44,875 E	4/2014	Kiani et al.
8,315,814 B2	11/2012	Taylor et al.	8,690,799 B2	4/2014	Telfort et al.
8,321,150 B2	11/2012	Taylor	8,700,112 B2	4/2014	Kiani
RE43,860 E	12/2012	Parker	8,702,627 B2	4/2014	Telfort et al.
8,337,403 B2	12/2012	Al-Ali et al.	8,706,179 B2	4/2014	Parker
8,346,330 B2	1/2013	Lamego	8,712,494 B1	4/2014	MaNeish, III et al.
8,353,842 B2	1/2013	Al-Ali et al.	8,715,206 B2	5/2014	Telfort et al.
8,355,766 B2	1/2013	MacNeish, III et al.	8,718,735 B2	5/2014	Lamego et al.
8,359,080 B2	1/2013	Diab et al.	8,718,737 B2	5/2014	Diab et al.
8,360,936 B2	1/2013	Dibenedetto et al.	8,718,738 B2	5/2014	Blank et al.
8,364,223 B2	1/2013	Al-Ali et al.	8,720,249 B2	5/2014	Al-Ali
8,364,226 B2	1/2013	Diab et al.	8,721,541 B2	5/2014	Al-Ali et al.
8,374,665 B2	2/2013	Lamego	8,721,542 B2	5/2014	Al-Ali et al.
8,385,995 B2	2/2013	Al-Ali et al.	8,723,677 B1	5/2014	Kiani
8,385,996 B2	2/2013	Smith et al.	8,740,792 B1	6/2014	Kiani et al.
8,388,353 B2	3/2013	Kiani et al.	8,754,776 B2	6/2014	Poeze et al.
8,399,822 B2	3/2013	Al-Ali	8,755,535 B2	6/2014	Telfort et al.
8,401,602 B2	3/2013	Kiani	8,755,856 B2	6/2014	Diab et al.
8,405,608 B2	3/2013	Al-Ali et al.	8,755,872 B1	6/2014	Marinow
8,414,499 B2	4/2013	Al-Ali et al.	8,761,850 B2	6/2014	Lamego
8,418,524 B2	4/2013	Al-Ali	8,764,671 B2	7/2014	Kiani
8,423,106 B2	4/2013	Lamego et al.	8,768,423 B2	7/2014	Shakespeare et al.
8,428,967 B2	4/2013	Olsen et al.	8,771,204 B2	7/2014	Telfort et al.
8,430,817 B1	4/2013	Al-Ali et al.	8,777,634 B2	7/2014	Kiani et al.
8,437,825 B2	5/2013	Dalvi et al.	8,781,543 B2	7/2014	Diab et al.
8,455,290 B2	6/2013	Siskavich	8,781,544 B2	7/2014	Al-Ali et al.
8,457,703 B2	6/2013	Al-Ali	8,781,549 B2	7/2014	Al-Ali et al.
8,457,707 B2	6/2013	Kiani	8,788,003 B2	7/2014	Schurman et al.
8,463,349 B2	6/2013	Diab et al.	8,790,268 B2	7/2014	Al-Ali
8,466,286 B2	6/2013	Bellott et al.	8,801,613 B2	8/2014	Al-Ali et al.
8,471,713 B2	6/2013	Poeze et al.	8,821,397 B2	9/2014	Al-Ali et al.
8,473,020 B2	6/2013	Kiani et al.	8,821,415 B2	9/2014	Al-Ali et al.
8,483,787 B2	7/2013	Al-Ali et al.	8,830,449 B1	9/2014	Lamego et al.
8,489,364 B2	7/2013	Weber et al.	8,831,700 B2	9/2014	Schurman et al.
8,498,684 B2	7/2013	Weber et al.	8,840,549 B2	9/2014	Al-Ali
8,504,128 B2	8/2013	Blank et al.	8,847,740 B2	9/2014	Kiani et al.
8,509,867 B2	8/2013	Workman et al.	8,849,365 B2	9/2014	Smith et al.
8,515,509 B2	8/2013	Bruinsma et al.	8,852,094 B2	10/2014	Al-Ali et al.
8,523,781 B2	9/2013	Al-Ali	8,852,994 B2	10/2014	Wojtczuk et al.
8,529,301 B2	9/2013	Al-Ali et al.	8,868,147 B2	10/2014	Stippick et al.
8,532,727 B2	9/2013	Ali et al.	8,868,150 B2	10/2014	Al-Ali et al.
8,532,728 B2	9/2013	Diab et al.	8,870,792 B2	10/2014	Al-Ali et al.
D692,145 S	10/2013	Al-Ali et al.	8,886,271 B2	11/2014	Kiani et al.
8,547,209 B2	10/2013	Kiani et al.	8,888,539 B2	11/2014	Al-Ali et al.
8,548,548 B2	10/2013	Al-Ali	8,888,708 B2	11/2014	Diab et al.
8,548,549 B2	10/2013	Schurman et al.	8,892,180 B2	11/2014	Weber et al.
8,548,550 B2	10/2013	Al-Ali et al.	8,897,847 B2	11/2014	Al-Ali
8,560,032 B2	10/2013	Al-Ali et al.	8,909,310 B2	12/2014	Lamego et al.
8,560,034 B1	10/2013	Diab et al.	2001/0011355 A1	8/2001	Kawai
8,570,167 B2	10/2013	Al-Ali	2001/0031922 A1	10/2001	Weng et al.
8,570,503 B2	10/2013	Vo et al.	2002/0045836 A1	4/2002	Alkawwas
			2002/0052311 A1	5/2002	Solomon et al.
			2002/0063690 A1	5/2002	Chung et al.
			2002/0140675 A1	10/2002	Ali et al.
			2002/0198445 A1	12/2002	Dominguez et al.

(56)

References Cited**U.S. PATENT DOCUMENTS**

2003/0027326	A1	2/2003	Ulmsten et al.	2008/0228077	A1	9/2008	Wilk et al.
2004/0013647	A1	1/2004	Solomon et al.	2008/0275309	A1	11/2008	Stivoric et al.
2004/0073095	A1	4/2004	Causey et al.	2008/0281167	A1	11/2008	Soderberg et al.
2004/0090742	A1	5/2004	Son et al.	2008/0281168	A1	11/2008	Gibson et al.
2004/0122787	A1	6/2004	Avinash et al.	2008/0281181	A1	11/2008	Manziona et al.
2004/0126007	A1	7/2004	Ziel et al.	2008/0287751	A1	11/2008	Stivoric et al.
2004/0147818	A1	7/2004	Levy et al.	2008/0292172	A1	11/2008	Assmann et al.
2004/0152957	A1	8/2004	Stivoric et al.	2008/0300020	A1	12/2008	Nishizawa et al.
2004/0179332	A1	9/2004	Smith et al.	2008/0319275	A1	12/2008	Chiu et al.
2004/0186357	A1	9/2004	Soderberg et al.	2008/0319354	A1	12/2008	Bell et al.
2004/0230118	A1	11/2004	Shehada et al.	2009/0005651	A1	1/2009	Ward et al.
2004/0230132	A1	11/2004	Shehada et al.	2009/0018808	A1	1/2009	Bronstein et al.
2004/0230179	A1	11/2004	Shehada et al.	2009/0024008	A1	1/2009	Brunner et al.
2004/0243017	A1	12/2004	Causevic	2009/0052623	A1	2/2009	Tome et al.
2004/0254431	A1	12/2004	Shehada et al.	2009/0054735	A1	2/2009	Higgins et al.
2004/0254432	A1	12/2004	Shehada et al.	2009/0054743	A1	2/2009	Stewart
2005/0020918	A1	1/2005	Wilk et al.	2009/0062682	A1	3/2009	Bland et al.
2005/0038332	A1	2/2005	Saidara et al.	2009/0069642	A1	3/2009	Gao et al.
2005/0038680	A1	2/2005	McMahon	2009/0119330	A1	5/2009	Sampath et al.
2005/0065417	A1	3/2005	Ali et al.	2009/0124867	A1	5/2009	Hirsh et al.
2005/0080336	A1	4/2005	Byrd et al.	2009/0131759	A1	5/2009	Sims et al.
2005/0096542	A1	5/2005	Weng et al.	2009/0143832	A1	6/2009	Saba
2005/0113653	A1	5/2005	Fox et al.	2009/0157058	A1	6/2009	Ferren et al.
2005/0164933	A1	7/2005	Tymianski et al.	2009/0171225	A1	7/2009	Gadodia et al.
2005/0191294	A1	9/2005	Arap et al.	2009/0177090	A1	7/2009	Grunwald et al.
2005/0277872	A1	12/2005	Colby et al.	2009/0182287	A1	7/2009	Kassab
2006/0058647	A1	3/2006	Strommer et al.	2009/0226372	A1	9/2009	Ruoslathi et al.
2006/0089543	A1	4/2006	Kim et al.	2009/0247984	A1	10/2009	Lamego et al.
2006/0094936	A1	5/2006	Russ	2009/0264778	A1	10/2009	Markowitz et al.
2006/0149393	A1	7/2006	Calderon	2009/0275844	A1	11/2009	Al-Ali
2006/0155175	A1	7/2006	Ogino et al.	2009/0281462	A1	11/2009	Heliot et al.
2006/0200009	A1	9/2006	Wekell et al.	2009/0299157	A1	12/2009	Telfort et al.
2006/0217684	A1	9/2006	Shehada et al.	2009/0309755	A1	12/2009	Williamson et al.
2006/0217685	A1	9/2006	Shehada et al.	2010/0004518	A1	1/2010	Vo et al.
2006/0224413	A1	10/2006	Kim et al.	2010/0030040	A1	2/2010	Poeze et al.
2006/0235300	A1	10/2006	Weng et al.	2010/0030094	A1	2/2010	Lundback
2006/0253042	A1	11/2006	Stahmann et al.	2010/0036209	A1	2/2010	Ferren et al.
2007/0000490	A1	1/2007	DeVries et al.	2010/0069725	A1	3/2010	Al-Ali
2007/0021675	A1	1/2007	Childre et al.	2010/0125217	A1	5/2010	Kuo et al.
2007/0027368	A1	2/2007	Collins et al.	2010/0144627	A1	6/2010	Vitek et al.
2007/0032733	A1	2/2007	Burton et al.	2010/0185101	A1	7/2010	Sakai et al.
2007/0055116	A1	3/2007	Clark et al.	2010/0198622	A1	8/2010	Gajic et al.
2007/0055544	A1	3/2007	Jung et al.	2010/0210958	A1	8/2010	Manwaring et al.
2007/0060798	A1	3/2007	Krupnik et al.	2010/0261979	A1	10/2010	Kiani
2007/0088406	A1	4/2007	Bennett et al.	2010/0298659	A1	11/2010	Mccombie et al.
2007/0096897	A1	5/2007	Weiner	2010/0298661	A1	11/2010	Mccombie et al.
2007/0118399	A1	5/2007	Avinash et al.	2010/0305412	A1	12/2010	Darrah et al.
2007/0140475	A1	6/2007	Kurtock et al.	2010/0312103	A1	12/2010	Gorek et al.
2007/0156033	A1	7/2007	Causey et al.	2010/0317936	A1	12/2010	Al-Ali et al.
2007/0163589	A1	7/2007	DeVries et al.	2010/0317951	A1	12/2010	Rutkowski et al.
2007/0185390	A1	8/2007	Perkins et al.	2011/0001605	A1	1/2011	Kiani et al.
2007/0232941	A1	10/2007	Rabinovich	2011/0021930	A1	1/2011	Mazzeo et al.
2007/0244724	A1	10/2007	Pendergast et al.	2011/0023130	A1	1/2011	Gudgel et al.
2007/0254593	A1	11/2007	Jollota et al.	2011/0028809	A1	2/2011	Goodman
2007/0255114	A1	11/2007	Ackermann et al.	2011/0046495	A1	2/2011	Osypka
2007/0255116	A1	11/2007	Mehta et al.	2011/0080294	A1	4/2011	Tanishima et al.
2007/0255250	A1	11/2007	Moeborg et al.	2011/0082711	A1	4/2011	Poeze et al.
2008/0000479	A1	1/2008	Elaz et al.	2011/0087084	A1	4/2011	Jeong et al.
2008/0003200	A1	1/2008	Arap et al.	2011/0087117	A1	4/2011	Tremper et al.
2008/0021854	A1	1/2008	Jung et al.	2011/0087756	A1	4/2011	Biondi
2008/0033661	A1	2/2008	Syroid et al.	2011/0098583	A1	4/2011	Pandia et al.
2008/0053438	A1	3/2008	DeVries et al.	2011/0105854	A1	5/2011	Kiani et al.
2008/0058657	A1	3/2008	Schwartz et al.	2011/0118573	A1	5/2011	Mckenna
2008/0090626	A1	4/2008	Griffin et al.	2011/0172967	A1	7/2011	Al-Ali et al.
2008/0091089	A1	4/2008	Guillory et al.	2011/0184252	A1	7/2011	Archer et al.
2008/0091090	A1	4/2008	Guillory et al.	2011/0184253	A1	7/2011	Archer et al.
2008/0091471	A1	4/2008	Michon et al.	2011/0208015	A1	8/2011	Welch et al.
2008/0097167	A1	4/2008	Yudkovitch et al.	2011/0208018	A1	8/2011	Kiani
2008/0099366	A1	5/2008	Niemiec et al.	2011/0208073	A1	8/2011	Matsukawa et al.
2008/0108884	A1	5/2008	Kiani	2011/0209915	A1	9/2011	Telfort et al.
2008/0119412	A1	5/2008	Tymianski et al.	2011/0212090	A1	9/2011	Pedersen et al.
2008/0138278	A1	6/2008	Scherz et al.	2011/0213212	A1	9/2011	Al-Ali
2008/0171919	A1	7/2008	Stivoric et al.	2011/0230733	A1	9/2011	Al-Ali
2008/0208912	A1	8/2008	Garibaldi	2011/0237911	A1	9/2011	Lamego et al.
2008/0221396	A1	9/2008	Garces et al.	2011/0257544	A1	10/2011	Kaasinen et al.
				2011/0295094	A1	12/2011	Doyle et al.
				2012/0004579	A1	1/2012	Luo et al.
				2012/0059230	A1	3/2012	Teller et al.
				2012/0059267	A1	3/2012	Lamego et al.

(56)

References Cited**U.S. PATENT DOCUMENTS**

2012/0071771 A1 3/2012 Behar
 2012/0101353 A1 4/2012 Reggiardo et al.
 2012/0116175 A1 5/2012 Al-Ali et al.
 2012/0123799 A1 5/2012 Nolen et al.
 2012/0136221 A1 5/2012 Killen et al.
 2012/0179006 A1 7/2012 Jansen et al.
 2012/0197619 A1 8/2012 Namer Yelin et al.
 2012/0209082 A1 8/2012 Al-Ali
 2012/0209084 A1 8/2012 Olsen et al.
 2012/0226160 A1 9/2012 Kudoh
 2012/0227739 A1 9/2012 Kiani
 2012/0239434 A1 9/2012 Breslow et al.
 2012/0265039 A1 10/2012 Kiani
 2012/0282583 A1 11/2012 Thaler et al.
 2012/0283524 A1 11/2012 Kiani et al.
 2012/0286955 A1 11/2012 Welch et al.
 2012/0294801 A1 11/2012 Scherz et al.
 2012/0296178 A1 11/2012 Lamego et al.
 2012/0319816 A1 12/2012 Al-Ali
 2012/0330112 A1 12/2012 Lamego et al.
 2013/0006131 A1 1/2013 Narayan et al.
 2013/0006151 A1 1/2013 Main et al.
 2013/0023775 A1 1/2013 Lamego et al.
 2013/0035603 A1 2/2013 Jarausch et al.
 2013/0041591 A1 2/2013 Lamego
 2013/0045685 A1 2/2013 Kiani
 2013/0046204 A1 2/2013 Lamego et al.
 2013/0060108 A1 3/2013 Schurman et al.
 2013/0060147 A1 3/2013 Welch et al.
 2013/0079610 A1 3/2013 Al-Ali
 2013/0096405 A1 4/2013 Garfio
 2013/0096936 A1 4/2013 Sampath et al.
 2013/0109935 A1 5/2013 Al-Ali et al.
 2013/0162433 A1 6/2013 Muhsin et al.
 2013/0178749 A1 7/2013 Lamego
 2013/0190581 A1 7/2013 Al-Ali et al.
 2013/0197328 A1 8/2013 Diab et al.
 2013/0211214 A1 8/2013 Olsen
 2013/0243021 A1 9/2013 Siskavich
 2013/0253334 A1 9/2013 Al-Ali et al.
 2013/0262730 A1 10/2013 Al-Ali et al.
 2013/0274571 A1 10/2013 Diab et al.
 2013/0296672 A1 11/2013 O'Neil et al.
 2013/0317327 A1 11/2013 Al-Ali et al.
 2013/0317370 A1 11/2013 Dalvi et al.
 2013/0324808 A1 12/2013 Al-Ali et al.
 2013/0324817 A1 12/2013 Diab
 2013/0331670 A1 12/2013 Kiani
 2013/0338461 A1 12/2013 Lamego et al.
 2014/0012100 A1 1/2014 Al-Ali et al.
 2014/0025306 A1 1/2014 Weber et al.
 2014/0034353 A1 2/2014 Al-Ali et al.
 2014/0051952 A1 2/2014 Reichgott et al.
 2014/0051953 A1 2/2014 Lamego et al.
 2014/0051954 A1 2/2014 Al-Ali et al.
 2014/0058230 A1 2/2014 Abdul-Hafiz et al.
 2014/0066783 A1 3/2014 Kiani et al.
 2014/0077956 A1 3/2014 Sampath et al.
 2014/0081097 A1 3/2014 Al-Ali et al.
 2014/0081100 A1 3/2014 Muhsin et al.
 2014/0081175 A1 3/2014 Telfort
 2014/0094667 A1 4/2014 Schurman et al.
 2014/0100434 A1 4/2014 Diab et al.
 2014/0114199 A1 4/2014 Lamego et al.
 2014/0120564 A1 5/2014 Workman et al.
 2014/0121482 A1 5/2014 Merritt et al.
 2014/0121483 A1 5/2014 Kiani
 2014/0125495 A1 5/2014 Al-Ali

2014/0127137 A1 5/2014 Bellott et al.
 2014/0128696 A1 5/2014 Al-Ali
 2014/0128699 A1 5/2014 Al-Ali et al.
 2014/0129702 A1 5/2014 Lamego et al.
 2014/0135588 A1 5/2014 Al-Ali et al.
 2014/0142399 A1 5/2014 Al-Ali et al.
 2014/0142401 A1 5/2014 Al-Ali et al.
 2014/0142402 A1 5/2014 Al-Ali et al.
 2014/0163344 A1 6/2014 Al-Ali
 2014/0163402 A1 6/2014 Lamego et al.
 2014/0166076 A1 6/2014 Kiani et al.
 2014/0171763 A1 6/2014 Diab
 2014/0180038 A1 6/2014 Kiani
 2014/0180154 A1 6/2014 Sierra et al.
 2014/0194709 A1 7/2014 Al-Ali et al.
 2014/0194711 A1 7/2014 Al-Ali
 2014/0194766 A1 7/2014 Al-Ali et al.
 2014/0200420 A1 7/2014 Al-Ali
 2014/0200422 A1 7/2014 Weber et al.
 2014/0206963 A1 7/2014 Al-Ali
 2014/0213864 A1 7/2014 Abdul-Hafiz et al.
 2014/0243627 A1 8/2014 Diab et al.
 2014/0266790 A1 9/2014 Al-Ali et al.
 2014/0275808 A1 9/2014 Poeze et al.
 2014/0275835 A1 9/2014 Lamego et al.
 2014/0275871 A1 9/2014 Lamego et al.
 2014/0275872 A1 9/2014 Merritt et al.
 2014/0275881 A1 9/2014 Lamego et al.
 2014/0288400 A1 9/2014 Diab et al.
 2014/0296664 A1 10/2014 Bruinsma et al.
 2014/0303520 A1 10/2014 Telfort et al.
 2014/0309506 A1 10/2014 Lamego et al.
 2014/0309559 A1 10/2014 Telfort et al.
 2014/0316228 A1 10/2014 Blank et al.
 2014/0323825 A1 10/2014 Al-Ali et al.
 2014/0330092 A1 11/2014 Al-Ali et al.
 2014/0330098 A1 11/2014 Merritt et al.
 2014/0330099 A1 11/2014 Al-Ali et al.
 2014/0333440 A1 11/2014 Kiani
 2014/0336481 A1 11/2014 Shakespeare et al.
 2014/0343436 A1 11/2014 Kiani
 2014/0357966 A1 12/2014 Al-Ali

FOREIGN PATENT DOCUMENTS

EP 2 766 834 8/2014
 JP 2014/533997 12/2014
 WO WO 2004/056266 7/2004
 WO WO 2004/059551 7/2004
 WO WO 2013/056160 4/2013
 WO WO 2013/119982 8/2013

OTHER PUBLICATIONS

PCT International Search Report & Written Opinion, App. No. PCT/US2012/060109, dated Jun. 5, 2013.
 PCT International Preliminary Report on Patentability for Application No. PCT/US2012/060109, dated Apr. 24, 2014.
 PCT International Search Report & Written Opinion, App. No. PCT/US2014/060177, dated Dec. 19, 2014.
 PCT International Search Report and Written Opinion, App. No. PCT/US2013/025384, dated Aug. 6, 2013.
 Elmer-Dewitt, Philip, Apple's iWatch: The killer apps may be in hospitals, not health clubs, Fortune.com, Feb. 3, 2014, <http://fortune.com/2014/02/03/apples-iwatch-the-killer-apps-may-be-in-hospitals-not-health-clubs/>, in 4 pages.
 Wachter, S. Blake; Journal of the American Medical Informatics Association; The Employment of an Iterative Design Process to Develop a Pulmonary Graphical Display; vol. 10, No. 4, Jul./Aug. 2003; pp. 363-372.
 US 8,845,543, 09/2014, Diab et al. (withdrawn)

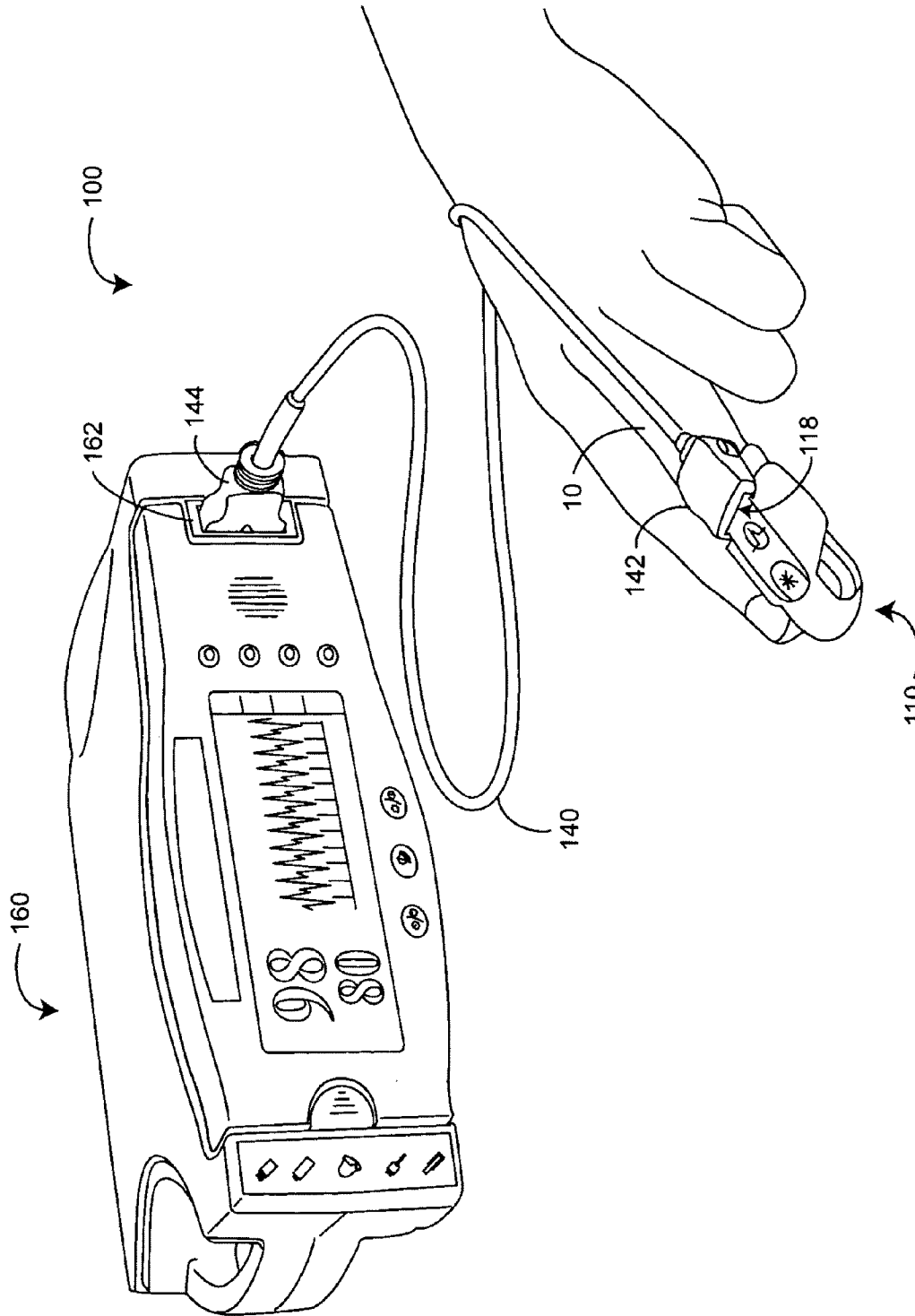


FIG. 1 (Prior Art)

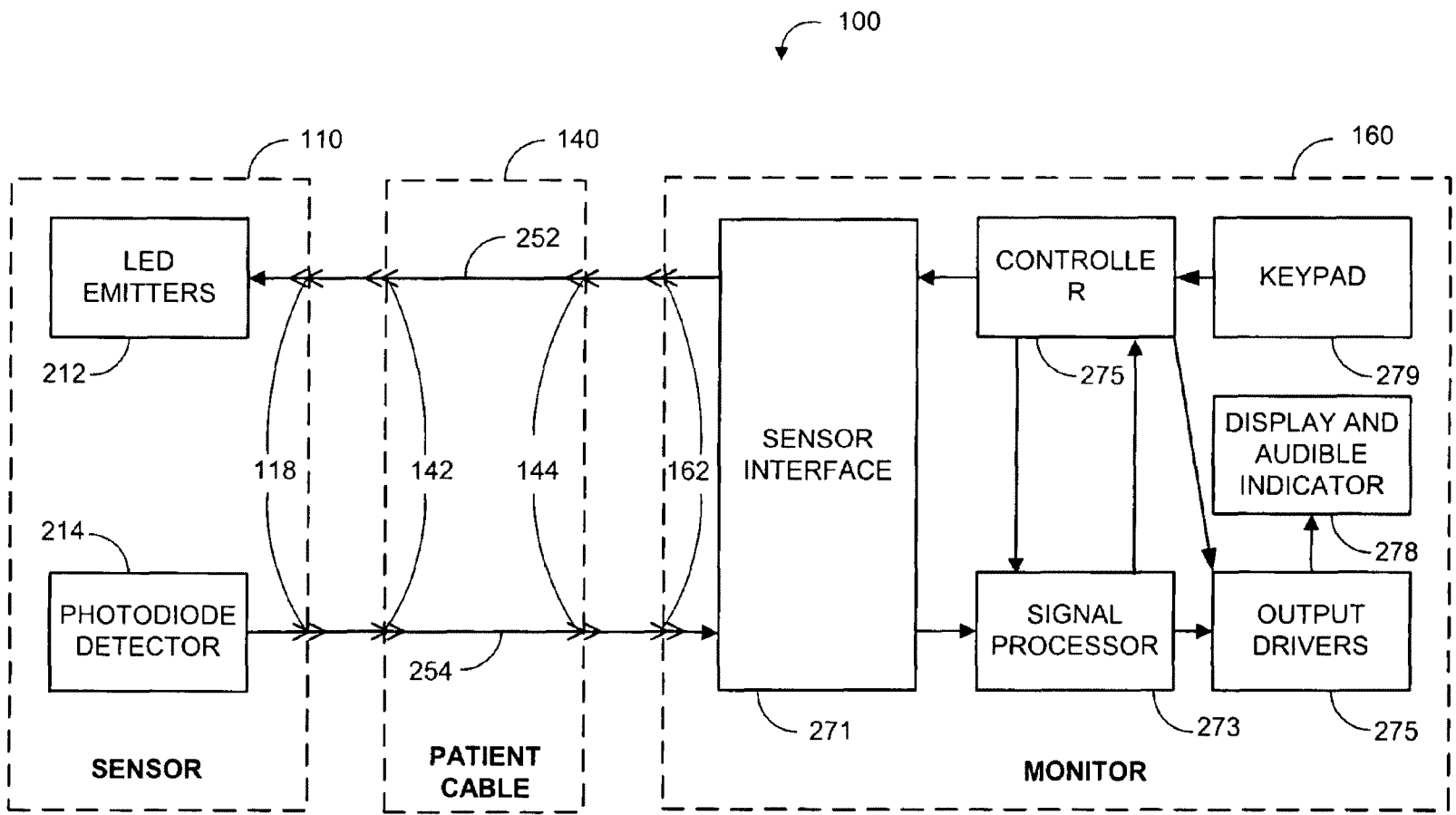


FIG. 2 (Prior Art)

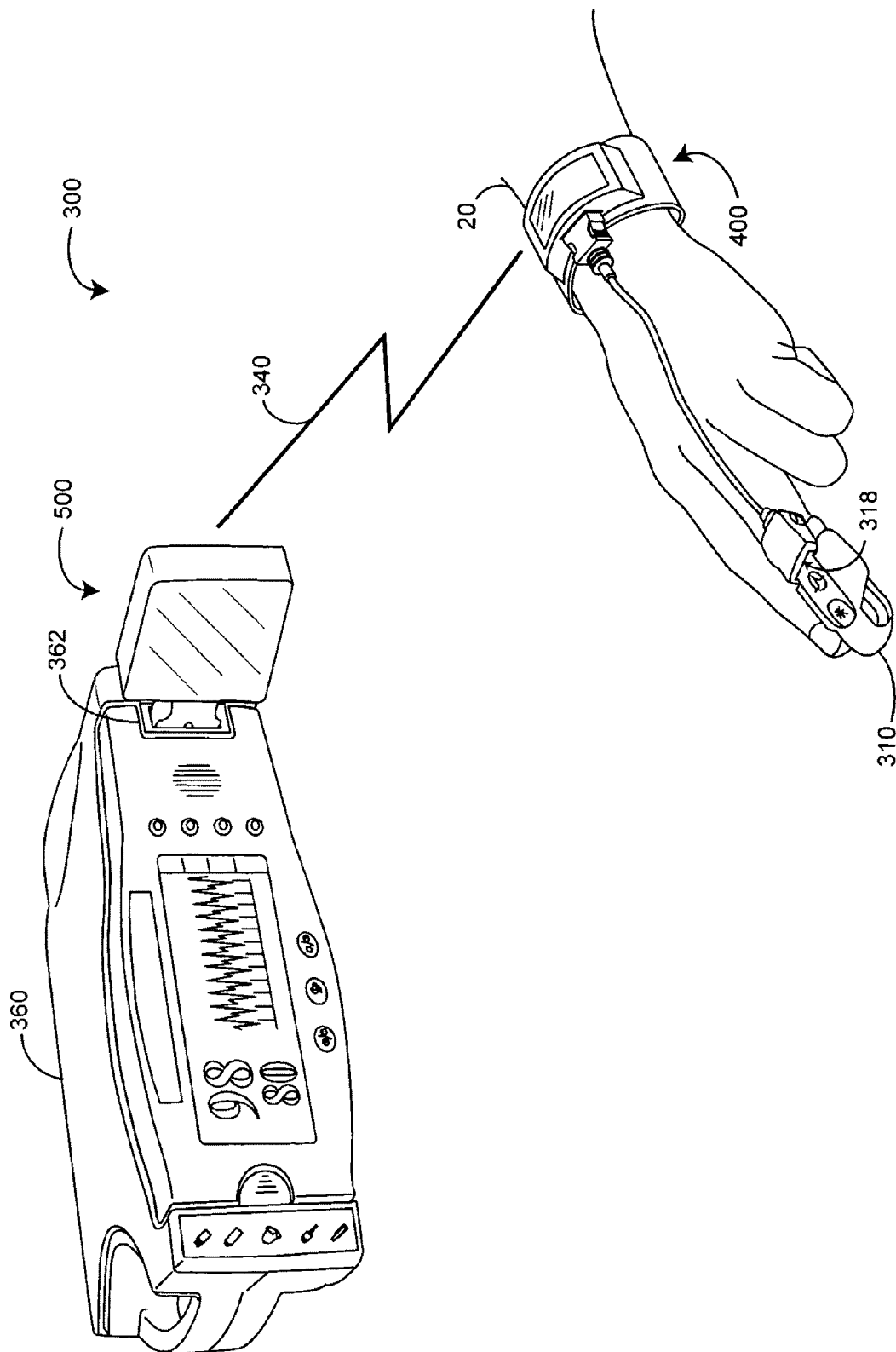


FIG. 3

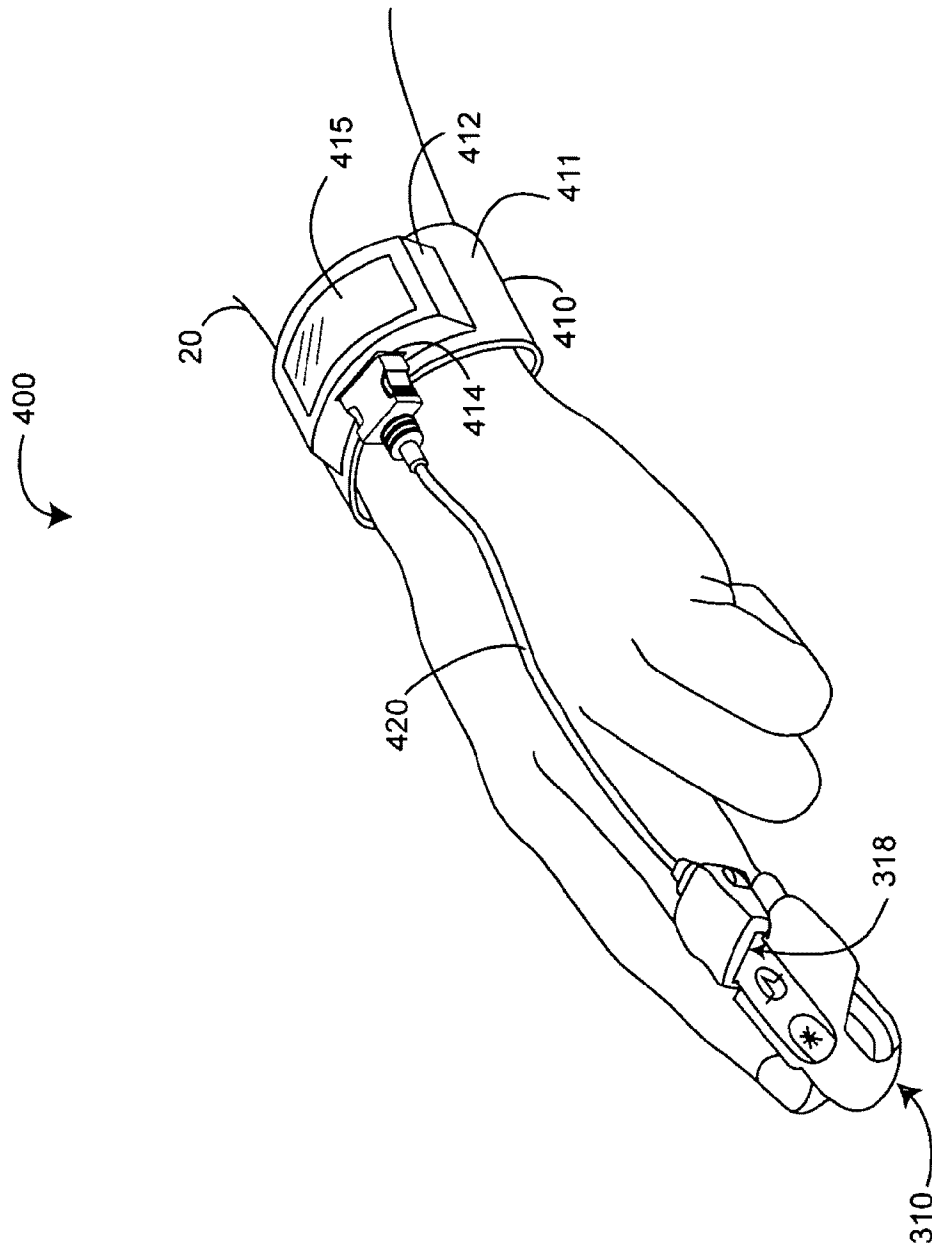


FIG. 4A

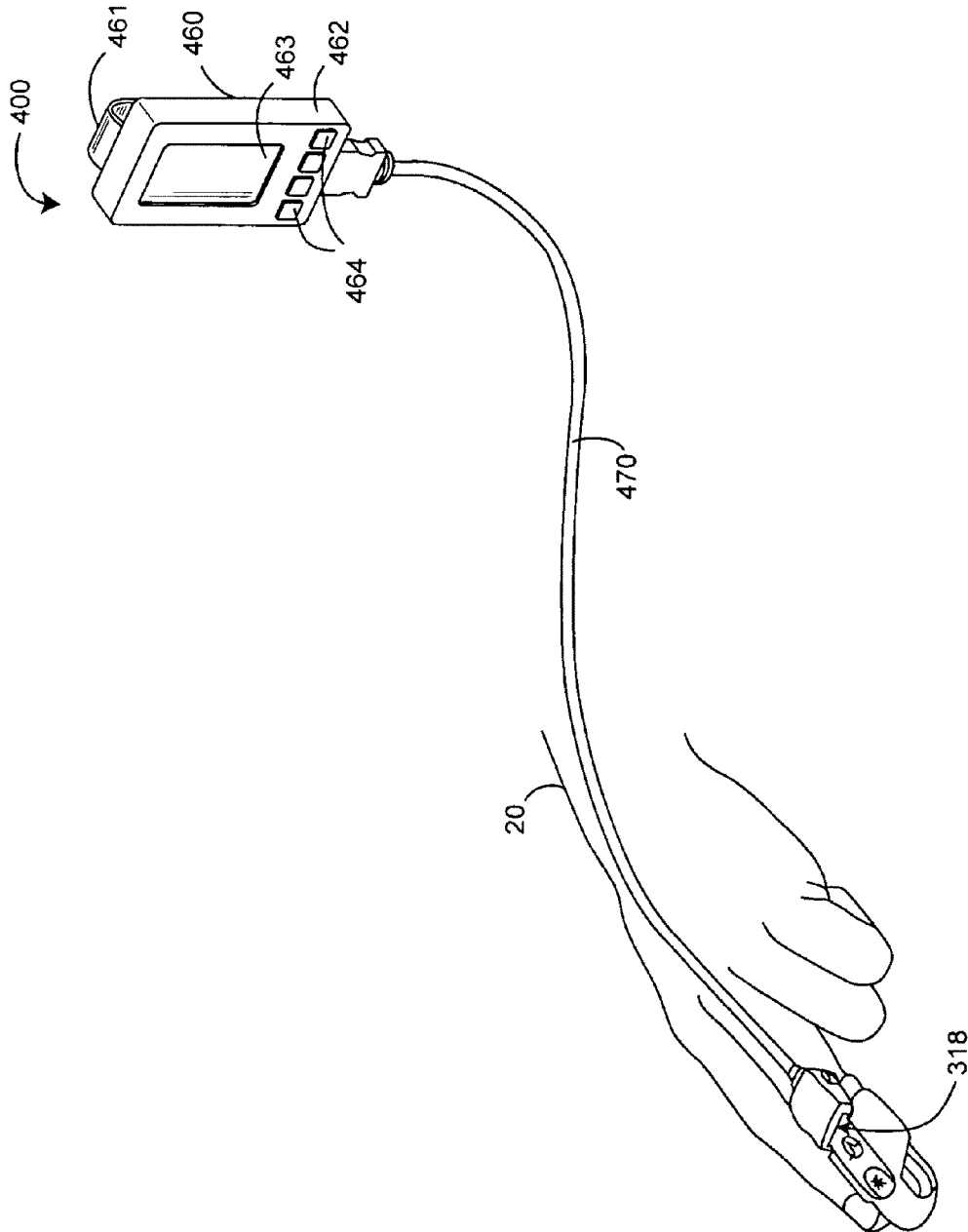


FIG. 4B

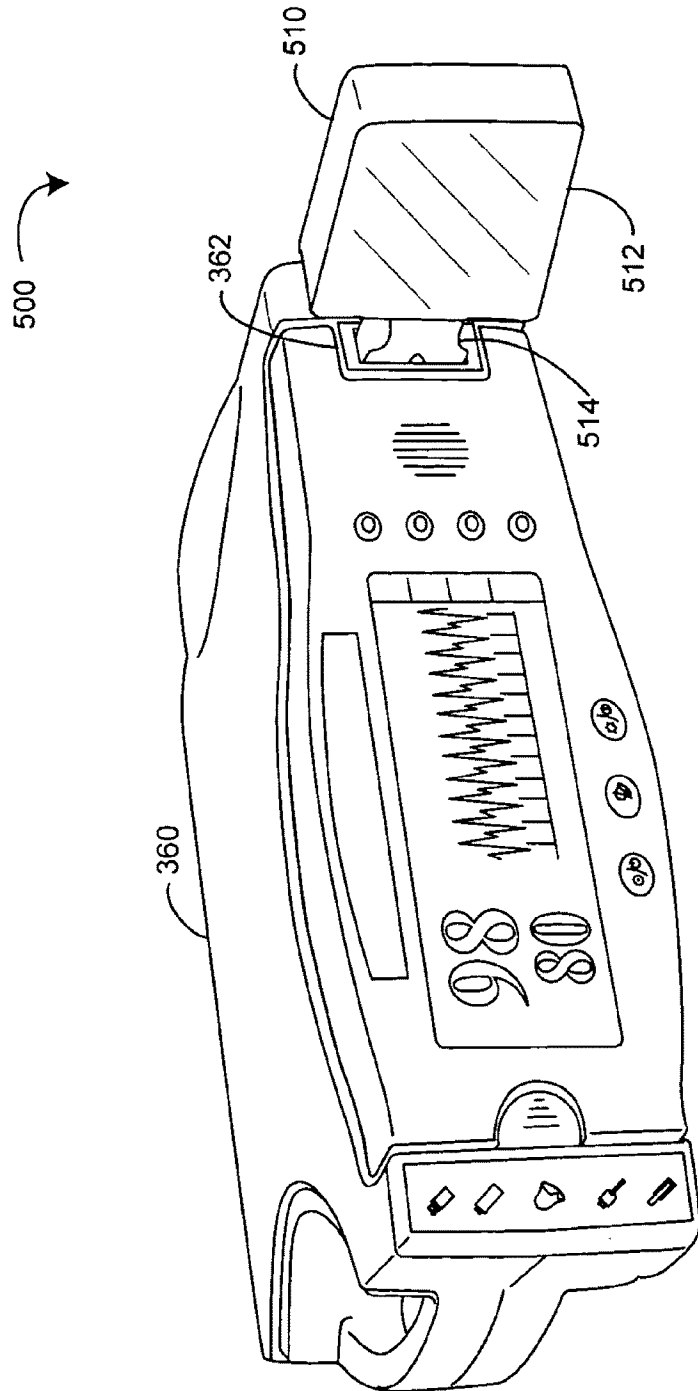


FIG. 5A

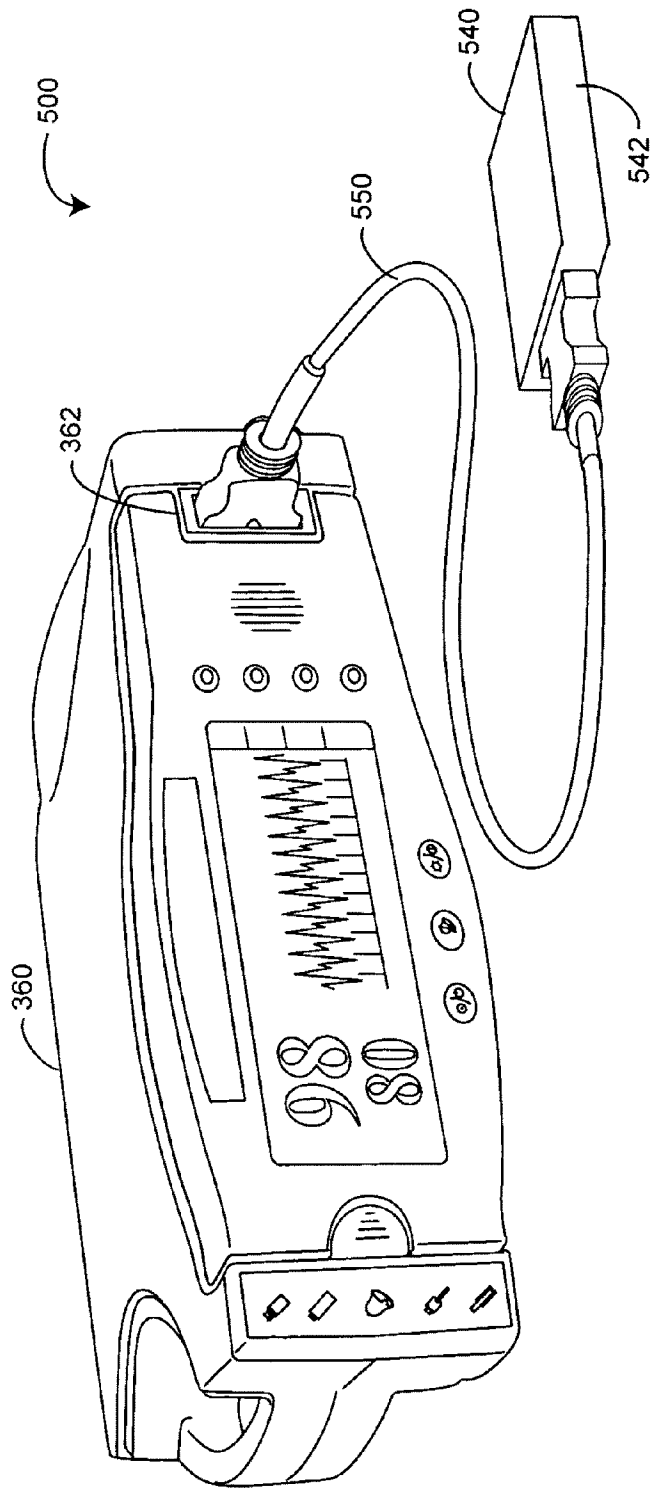


FIG. 5B

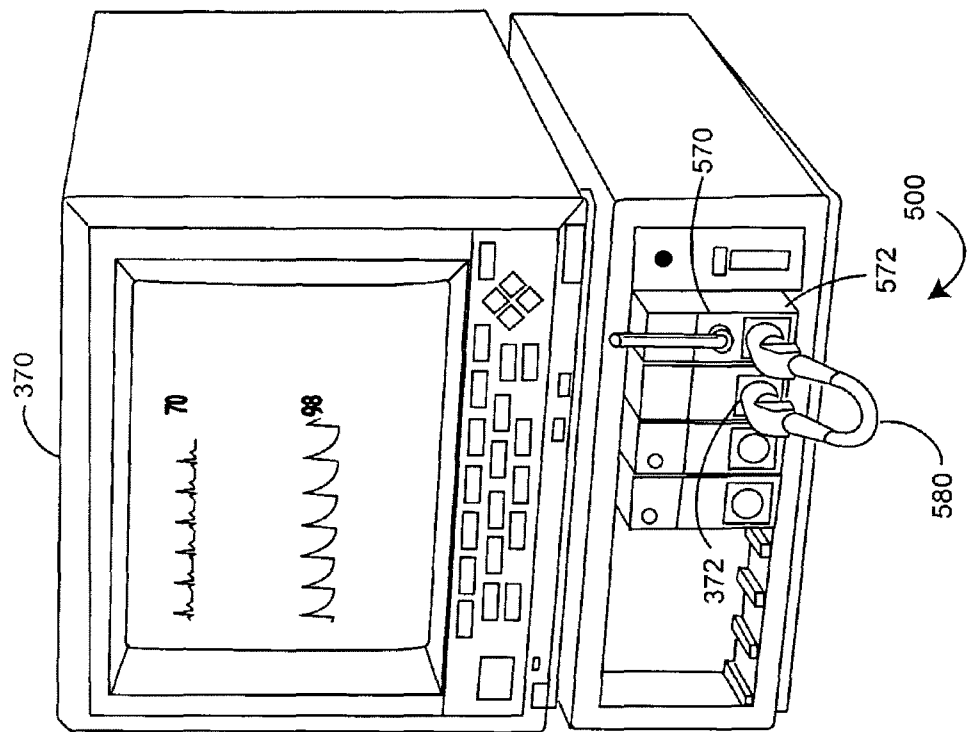


FIG. 5C

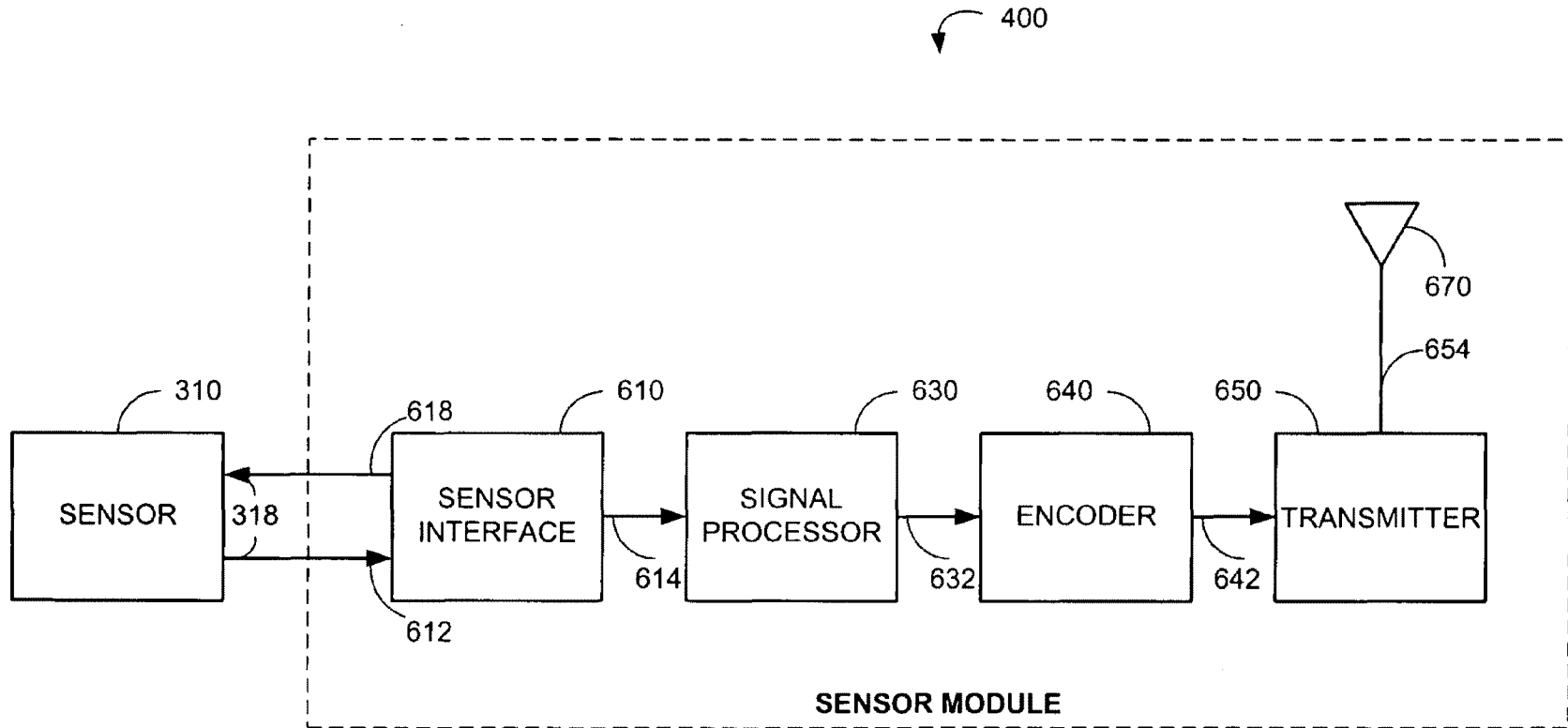


FIG. 6

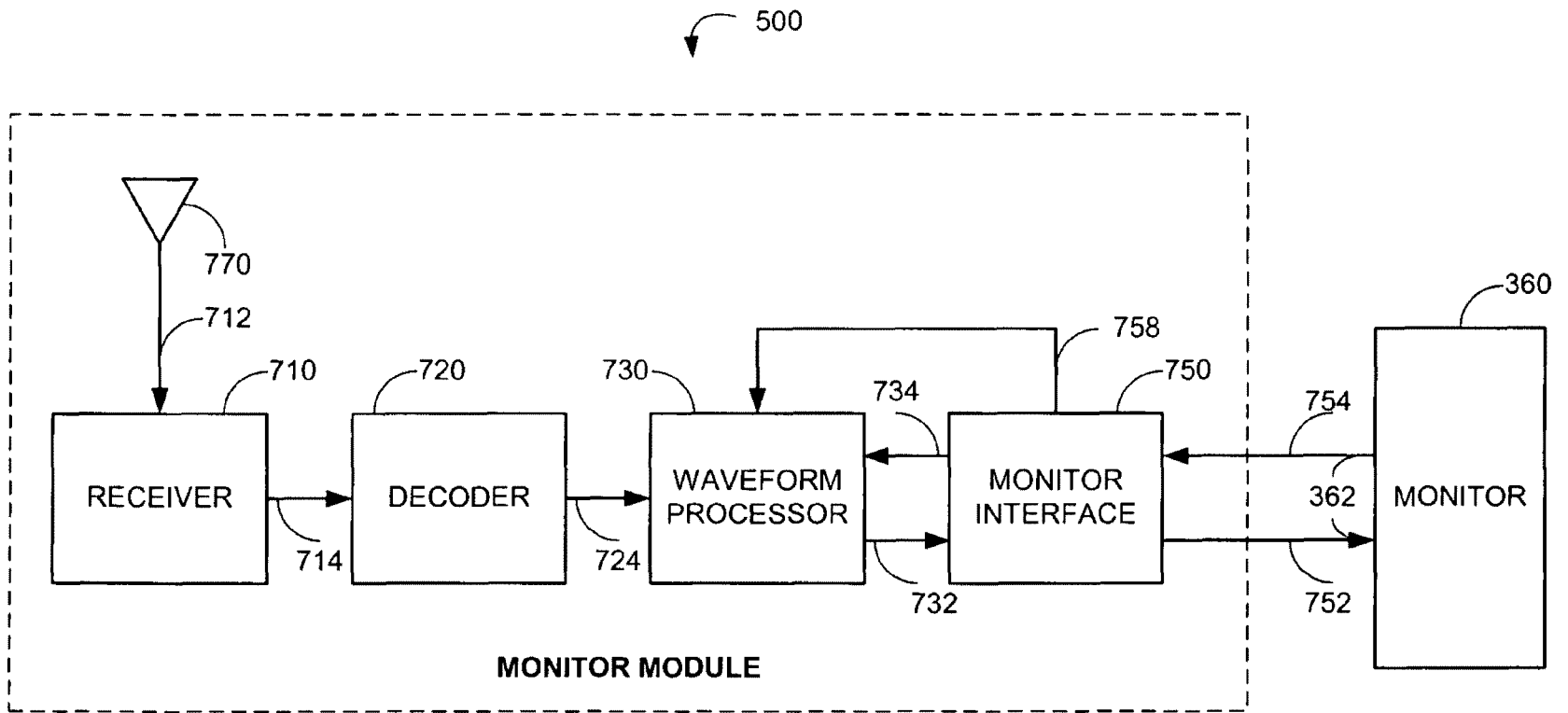


FIG. 7

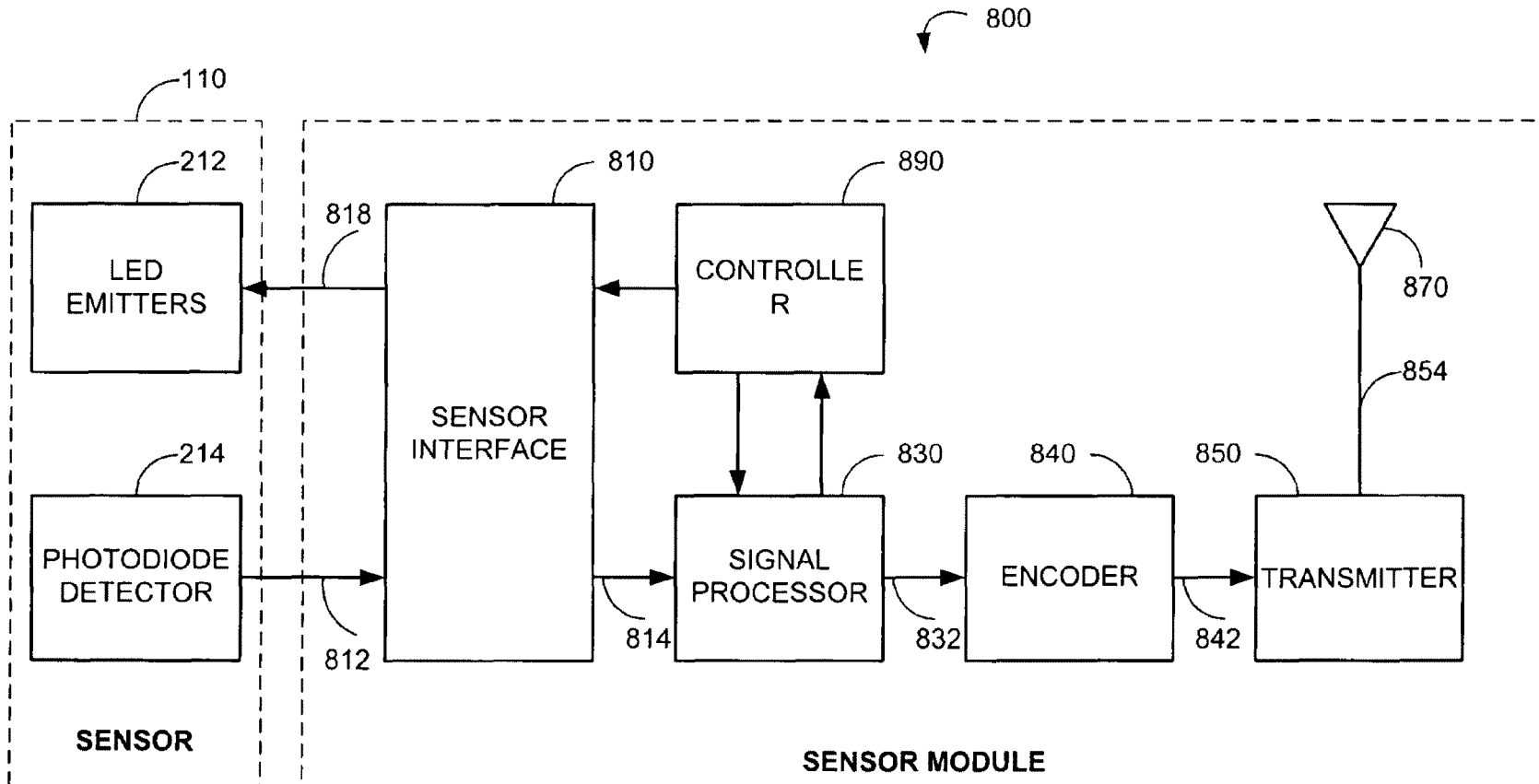


FIG. 8

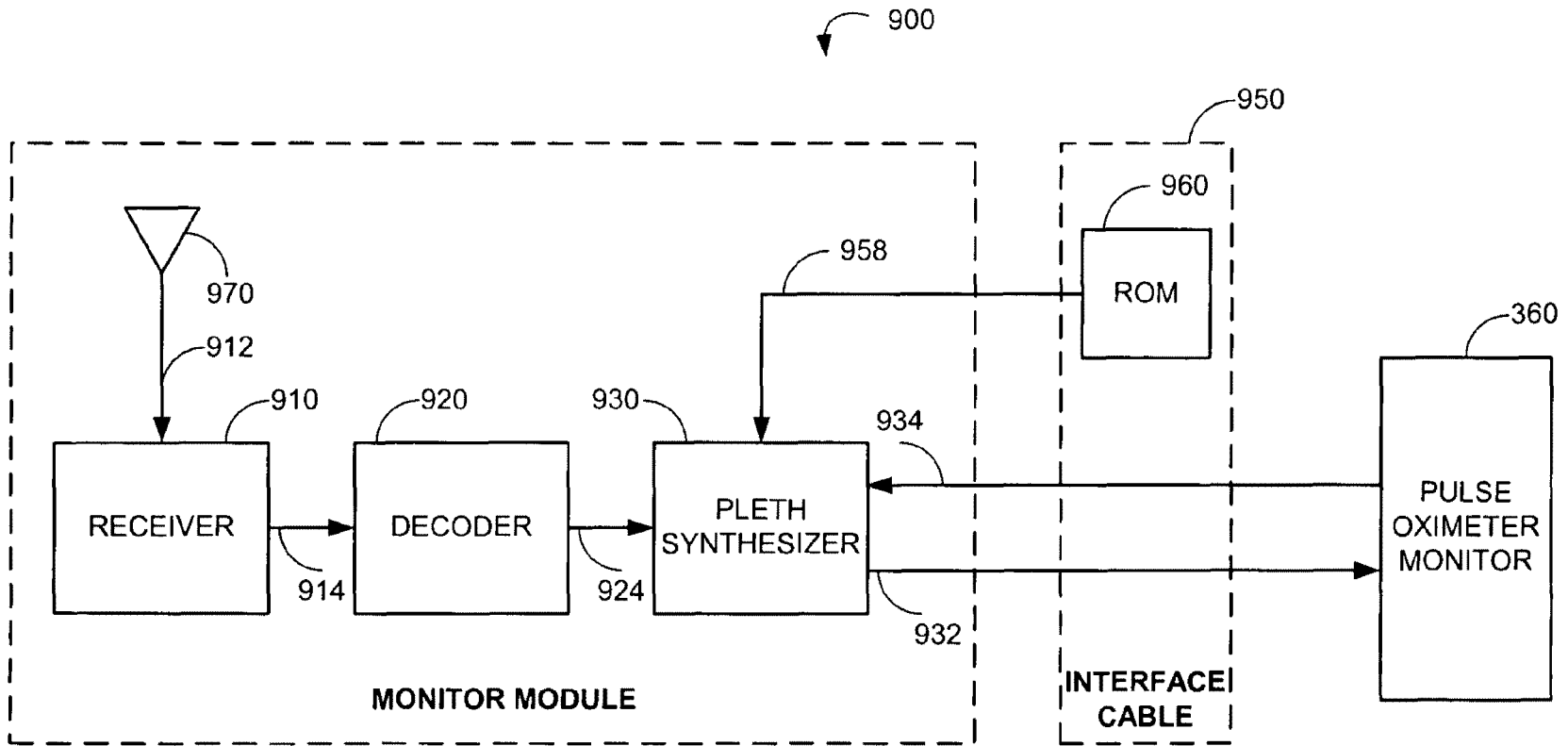


FIG. 9

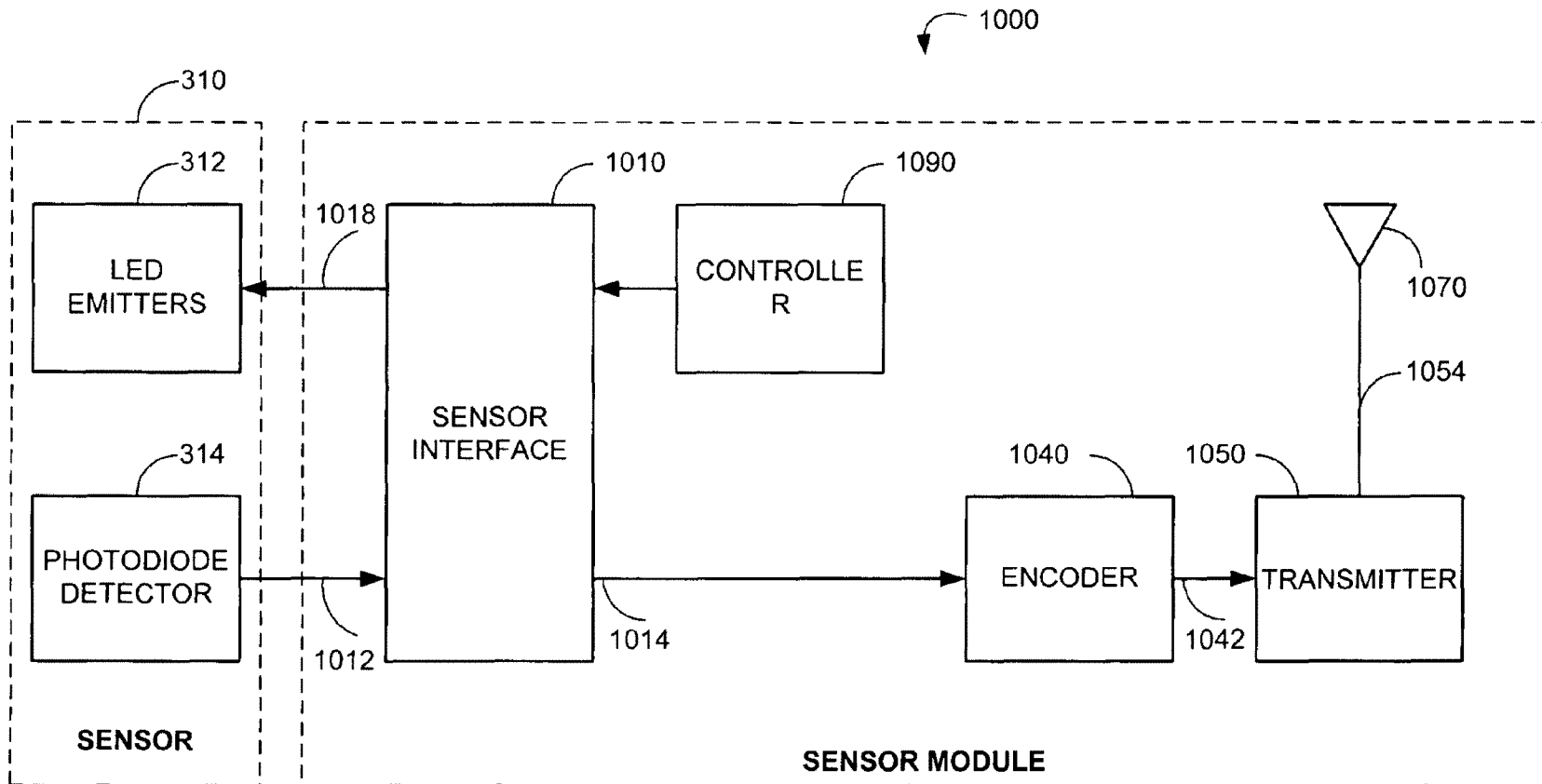


FIG. 10

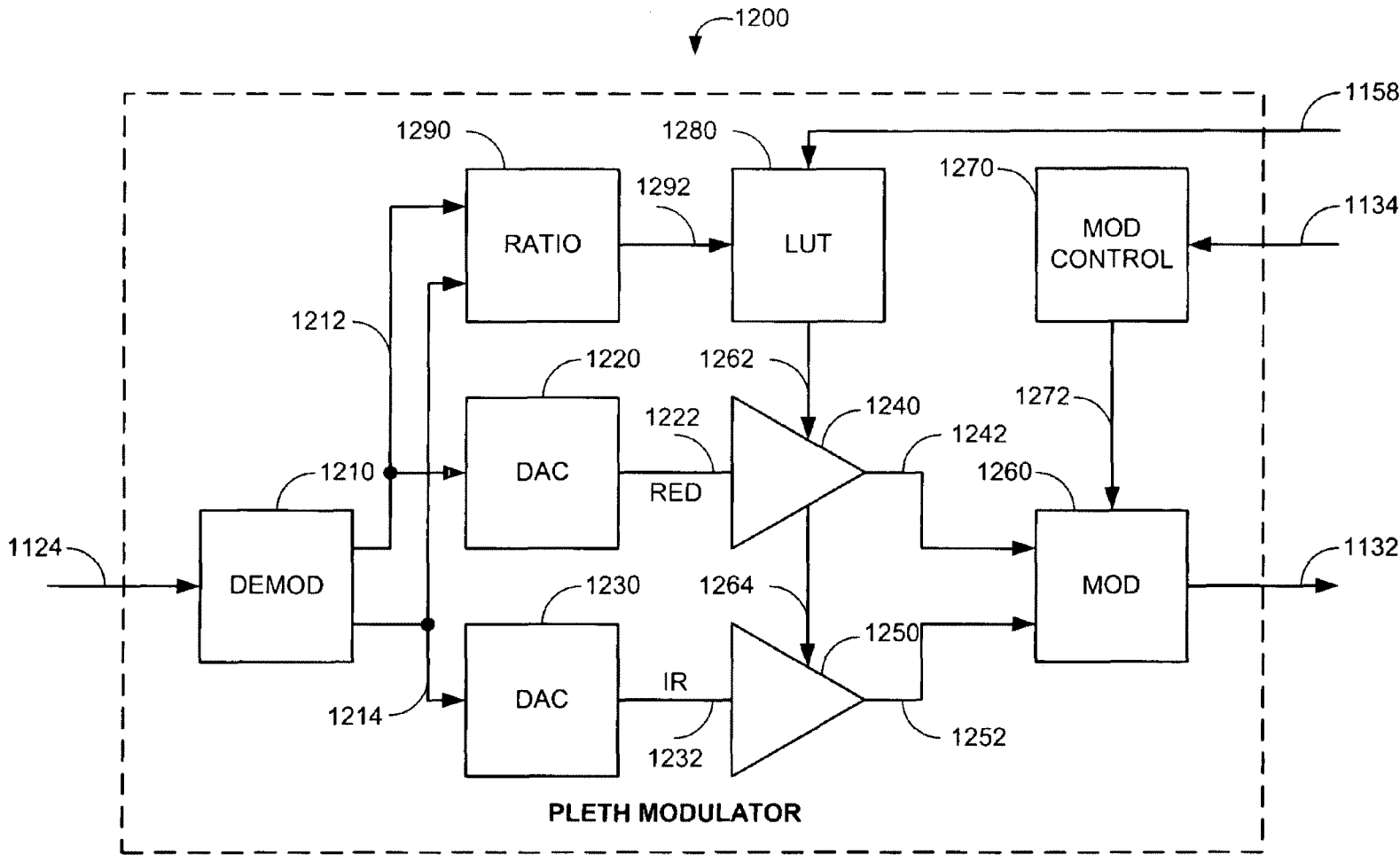


FIG. 12

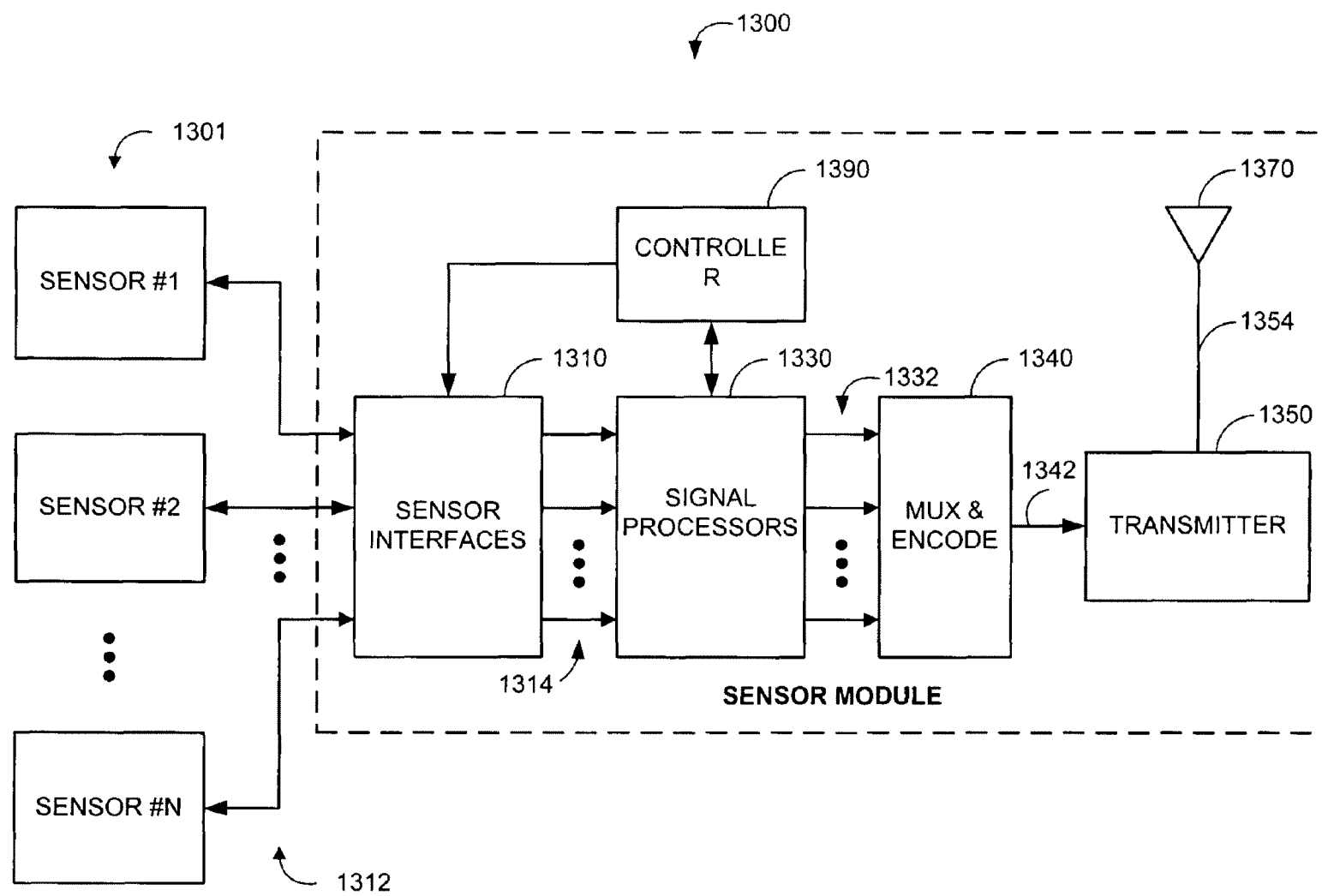


FIG. 13

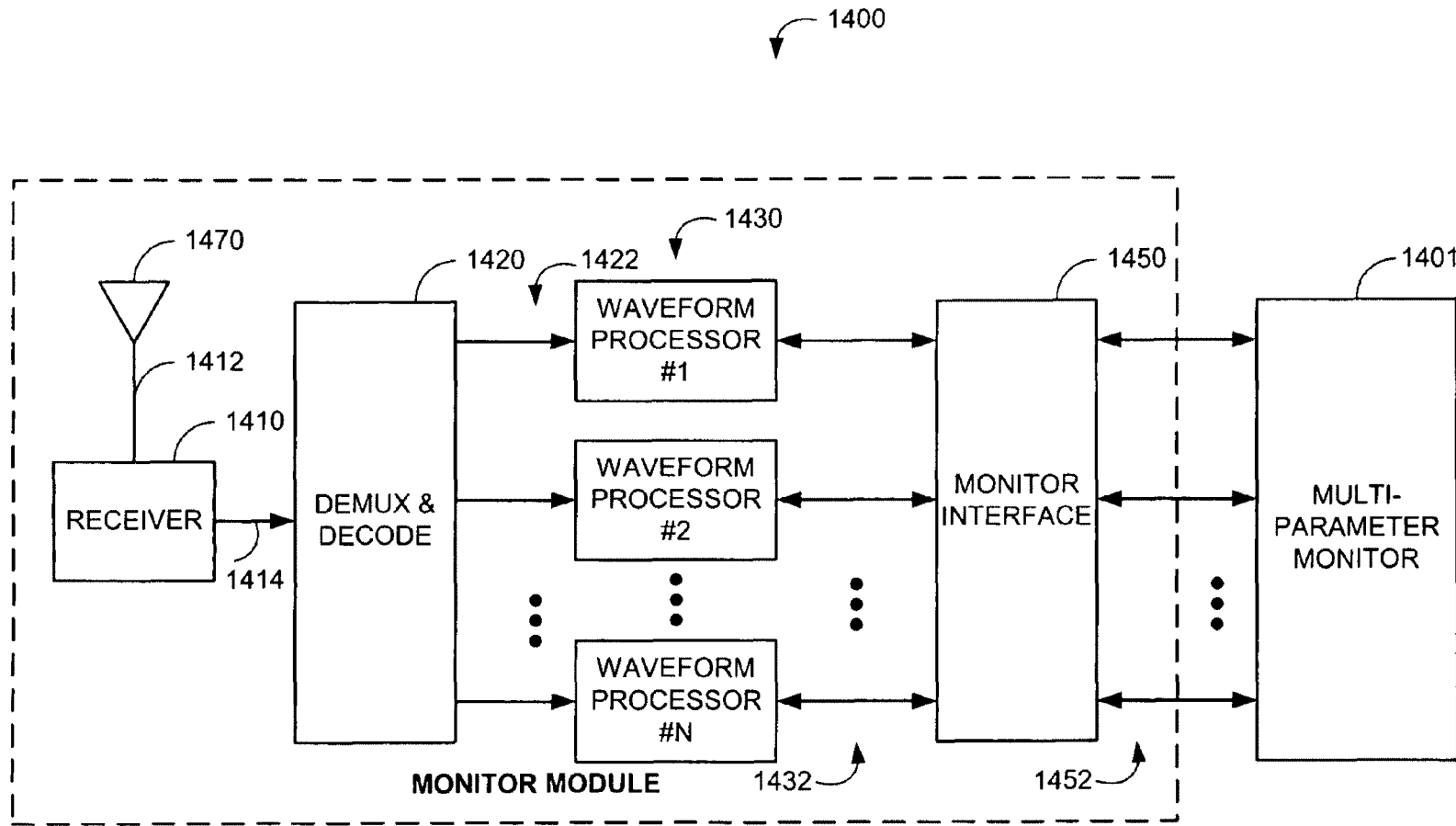


FIG. 14

1

WRIST-MOUNTED PHYSIOLOGICAL MEASUREMENT DEVICE

REFERENCE TO RELATED APPLICATION

The present application is a continuation of U.S. patent application Ser. No. 14/037,137, filed on Sep. 25, 2013, entitled "Physiological Measurement Communications Adapter," which is a continuation of U.S. patent application Ser. No. 12/955,826, filed on Nov. 29, 2010, entitled "Physiological Measurement Communications Adapter," which is a continuation of U.S. patent application Ser. No. 11/417,006, filed on May 3, 2006, entitled "Physiological Measurement Communications Adapter," now U.S. Pat. No. 7,844,315, which claims priority benefit under 35 U.S.C. § 120 to, and is a continuation of, U.S. patent application Ser. No. 11/048,330, filed Feb. 1, 2005, entitled "Physiological Measurement Communications Adapter," now U.S. Pat. No. 7,844,314, which is a continuation of U.S. patent application Ser. No. 10/377,933, entitled "Physiological Measurement Communications Adapter," now U.S. Pat. No. 6,850,788, which claims priority benefit under 35 U.S.C. § 119(e) from U.S. Provisional Application No. 60/367,428, filed Mar. 25, 2002, entitled "physiological Measurement Communications Adapter." The present application also incorporates the foregoing utility disclosures herein by reference.

BACKGROUND OF THE INVENTION

Patient vital sign monitoring may include measurements of blood oxygen, blood pressure, respiratory gas, and EKG among other parameters. Each of these physiological parameters typically requires a sensor in contact with a patient and a cable connecting the sensor to a monitoring device. For example, FIGS. 1-2 illustrate a conventional pulse oximetry system 100 used for the measurement of blood oxygen. As shown in FIG. 1, a pulse oximetry system has a sensor 110, a patient cable 140 and a monitor 160. The sensor 110 is typically attached to a finger 10 as shown. The sensor 110 has a plug 118 that inserts into a patient cable socket 142. The monitor 160 has a socket 162 that accepts a patient cable plug 144. The patient cable 140 transmits an LED drive signal 252 (FIG. 2) from the monitor 160 to the sensor 110 and a resulting detector signal 254 (FIG. 2) from the sensor 110 to the monitor 160. The monitor 160 processes the detector signal 254 (FIG. 2) to provide, typically, a numerical readout of the patient's oxygen saturation, a numerical readout of pulse rate, and an audible indicator or "beep" that occurs in response to each arterial pulse.

As shown in FIG. 2, the sensor 110 has both red and infrared LED emitters 212 and a photodiode detector 214. The monitor 160 has a sensor interface 271, a signal processor 273, a controller 275, output drivers 276, a display and audible indicator 278, and a keypad 279. The monitor 160 determines oxygen saturation by computing the differential absorption by arterial blood of the two wavelengths emitted by the sensor emitters 212, as is well-known in the art. The sensor interface 271 provides LED drive current 252 which alternately activates the red and IR LED emitters 212. The photodiode detector 214 generates a signal 254 corresponding to the red and infrared light energy attenuated from transmission through the patient finger 10 (FIG. 1). The sensor interface 271 also has input circuitry for amplification, filtering and digitization of the detector signal 254. The signal processor 273 calculates a ratio of detected red and infrared intensities, and an arterial oxygen saturation value is empirically determined based on that ratio. The controller 275 pro-

2

vides hardware and software interfaces for managing the display and audible indicator 278 and keypad 279. The display and audible indicator 278 shows the computed oxygen status, as described above, and provides the pulse beep as well as alarms indicating oxygen desaturation events. The keypad 279 provides a user interface for setting alarm thresholds, alarm enablement, and display options, to name a few.

SUMMARY OF THE INVENTION

Conventional physiological measurement systems are limited by the patient cable connection between sensor and monitor. A patient must be located in the immediate vicinity of the monitor. Also, patient relocation requires either disconnection of monitoring equipment and a corresponding loss of measurements or an awkward simultaneous movement of patient equipment and cables. Various devices have been proposed or implemented to provide wireless communication links between sensors and monitors, freeing patients from the patient cable tether. These devices, however, are incapable of working with the large installed base of existing monitors and sensors, requiring caregivers and medical institutions to suffer expensive wireless upgrades. It is desirable, therefore, to provide a communications adapter that is plug-compatible both with existing sensors and monitors and that implements a wireless link replacement for the patient cable.

An aspect of a physiological measurement communications adapter comprises a sensor interface configured to receive a sensor signal. A transmitter modulates a first baseband signal responsive to the sensor signal so as to generate a transmit signal. A receiver demodulates a receive signal corresponding to the transmit signal so as to generate a second baseband signal corresponding to the first baseband signal. Further, a monitor interface is configured to communicate a waveform responsive to the second baseband signal to a sensor port of a monitor. The waveform is adapted to the monitor so that measurements derived by the monitor from the waveform are generally equivalent to measurements derivable from the sensor signal. The communications adapter may further comprise a signal processor having an input in communications with the sensor interface, where the signal processor is operable to derive a parameter responsive to the sensor signal and where the first baseband signal is responsive to the parameter. The parameter may correspond to at least one of a measured oxygen saturation and a pulse rate.

One embodiment may further comprise a waveform generator that synthesizes the waveform from a predetermined shape. The waveform generator synthesizes the waveform at a frequency adjusted to be generally equivalent to the pulse rate. The waveform may have a first amplitude and a second amplitude, and the waveform generator may be configured to adjust the amplitudes so that measurements derived by the monitor are generally equivalent to a measured oxygen saturation.

In another embodiment, the sensor interface is operable on the sensor signal to provide a plethysmograph signal output, where the first baseband signal is responsive to the plethysmograph signal. This embodiment may further comprise a waveform modulator that modifies a decoded signal responsive to the second baseband signal to provide the waveform. The waveform modulator may comprise a demodulator that separates a first signal and a second signal from the decoded signal, an amplifier that adjusts amplitudes of the first and second signals to generate a first adjusted signal and a second adjusted signal, and a modulator that combines the first and second adjusted signals into the waveform. The amplitudes of

3

the first and second signals may be responsive to predetermined calibration data for the sensor and the monitor.

An aspect of a physiological measurement communications adapter method comprises the steps of inputting a sensor signal at a patient location, communicating patient data derived from the sensor signal between the patient location and a monitor location, constructing a waveform at the monitor location responsive to the sensor signal, and providing the waveform to a monitor via a sensor port. The waveform is constructed so that the monitor calculates a parameter generally equivalent to a measurement derivable from the sensor signal.

In one embodiment, the communicating step may comprise the substeps of deriving a conditioned signal from the sensor signal, calculating a parameter signal from the conditioned signal, and transmitting the parameter signal from the patient location to the monitor location. The constructing step may comprise the substep of synthesizing the waveform from the parameter signal. In an alternative embodiment, the communicating step may comprise the substeps of deriving a conditioned signal from said sensor signal and transmitting the conditioned signal from the patient location to the monitor location. The constructing step may comprise the substeps of demodulating the conditioned signal and re-modulating the conditioned signal to generate the waveform. The providing step may comprise the substeps of inputting a monitor signal from an LED drive output of the sensor port, modulating the waveform in response to the monitor signal, and outputting the waveform on a detector input of the sensor port.

Another aspect of a physiological measurement communications adapter comprises a sensor interface means for inputting a sensor signal and outputting a conditioned signal, a transmitter means for sending data responsive to the sensor signal, and a receiver means for receiving the data. The communications adapter further comprises a waveform processor means for constructing a waveform from the data so that measurements derived by a monitor from the waveform are generally equivalent to measurements derivable from the sensor signal, and a monitor interface means for communicating the waveform to a sensor port of the monitor. The communications adapter may further comprise a signal processor means for deriving a parameter signal from the conditioned signal, where the data comprises the parameter signal. The waveform processor means may comprise a means for synthesizing the waveform from the parameter signal. The data may comprise the conditioned signal, and the waveform processor means may comprise a means for modulating the conditioned signal in response to the monitor.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an illustration of a prior art pulse oximetry system;

FIG. 2 is a functional block diagram of a prior art pulse oximetry system;

FIG. 3 is an illustration of a physiological measurement communications adapter;

FIGS. 4A-B are illustrations of communications adapter sensor modules;

FIGS. 5A-C are illustrations of communications adapter monitor modules;

FIG. 6 is a functional block diagram of a communications adapter sensor module;

FIG. 7 is a functional block diagram of a communications adapter monitor module;

FIG. 8 is a functional block diagram of a sensor module configured to transmit measured pulse oximeter parameters;

4

FIG. 9 is a functional block diagram of a monitor module configured to receive measured pulse oximeter parameters;

FIG. 10 is a functional block diagram of a sensor module configured to transmit a plethysmograph;

FIG. 11 is a functional block diagram of a monitor module configured to receive a plethysmograph;

FIG. 12 is a functional block diagram of a waveform modulator;

FIG. 13 is a functional block diagram of a sensor module configured for multiple sensors; and

FIG. 14 is a functional block diagram of a monitor module configured for multiple sensors.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Overview

FIG. 3 illustrates one embodiment of a communications adapter. FIGS. 4-5 illustrate physical configurations for a communications adapter. In particular, FIGS. 4A-B illustrate sensor module configurations and FIGS. 5A-C illustrate monitor module configurations. FIGS. 6-14 illustrate communications adapter functions. In particular, FIGS. 6-7 illustrate general functions for a sensor module and a monitor module, respectively. FIGS. 8-9 functionally illustrate a communications adapter where derived pulse oximetry parameters, such as saturation and pulse rate are transmitted between a sensor module and a monitor module. Also, FIGS. 10-12 functionally illustrate a communications adapter where a plethysmograph is transmitted between a sensor module and a monitor module. FIGS. 13-14 functionally illustrate a multiple-parameter communications adapter.

FIG. 3 illustrates a communications adapter 300 having a sensor module 400 and a monitor module 500. The communications adapter 300 communicates patient data derived from a sensor 310 between the sensor module 400, which is located proximate a patient 20 and the monitor module 500, which is located proximate a monitor 360. A wireless link 340 is provided between the sensor module 400 and the monitor module 500, replacing the conventional patient cable, such as a pulse oximetry patient cable 140 (FIG. 1). Advantageously, the sensor module 400 is plug-compatible with a conventional sensor 310. In particular, the sensor connector 318 connects to the sensor module 400 in a similar manner as to a patient cable. Further, the sensor module 400 outputs a drive signal to the sensor 310 and inputs a sensor signal from the sensor 310 in an equivalent manner as a conventional monitor 360. The sensor module 400 may be battery powered or externally powered. External power may be for recharging internal batteries or for powering the sensor module during operation or both.

As shown in FIG. 3, the monitor module 500 is advantageously plug-compatible with a conventional monitor 360. In particular, the monitor's sensor port 362 connects to the monitor module 500 in a similar manner as to a patient cable, such as a pulse oximetry patient cable 140 (FIG. 1). Further, the monitor module 500 inputs a drive signal from the monitor 360 and outputs a corresponding sensor signal to the monitor 360 in an equivalent manner as a conventional sensor 310. As such, the combination sensor module 400 and monitor module 500 provide a plug-compatible wireless replacement for a patient cable, adapting an existing wired physiological measurement system into a wireless physiological measurement system. The monitor module 500 may be battery powered, powered from the monitor, such as by tapping current from a monitor's LED drive, or externally powered from an independent AC or DC power source.

5

Although a communications adapter **300** is described herein with respect to a pulse oximetry sensor and monitor, one of ordinary skill in the art will recognize that a communications adapter may provide a plug-compatible wireless replace for a patient cable that connects any physiological sensor and corresponding monitor. For example, a communications adapter **300** may be applied to a biopotential sensor, a non-invasive blood pressure (NIBP) sensor, a respiratory rate sensor, a glucose sensor and the corresponding monitors, to name a few.

Sensor Module Physical Configurations

FIGS. 4A-B illustrate physical embodiments of a sensor module **400**. FIG. 4A illustrates a wrist-mounted module **410** having a wrist strap **411**, a case **412** and an auxiliary cable **420**. The case **412** contains the sensor module electronics, which are functionally described with respect to FIG. 6, below. The case **412** is mounted to the wrist strap **411**, which attaches the wrist-mounted module **410** to a patient **20**. The auxiliary cable **420** mates to a sensor connector **318** and a module connector **414**, providing a wired link between a conventional sensor **310** and the wrist-mounted module **410**. Alternatively, the auxiliary cable **420** is directly wired to the sensor module **400**. The wrist-mounted module **410** may have a display **415** that shows sensor measurements, module status and other visual indicators, such as monitor status. The wrist-mounted module **410** may also have keys (not shown) or other input mechanisms to control its operational mode and characteristics. In an alternative embodiment, the sensor **310** may have a tail (not shown) that connects directly to the wrist-mounted module **410**, eliminating the auxiliary cable **420**.

FIG. 4B illustrates a clip-on module **460** having a clip **461**, a case **462** and an auxiliary cable **470**. The clip **461** attaches the clip-on module **460** to patient clothing or objects near a patient **20**, such as a bed frame. The auxiliary cable **470** mates to the sensor connector **318** and functions as for the auxiliary cable **420** (FIG. 4A) of the wrist-mounted module **410** (FIG. 4A), described above. The clip-on module **460** may have a display **463** and keys **464** as for the wrist-mounted module **410** (FIG. 4A). Either the wrist-mounted module **410** or the clip-on module **460** may have other input or output ports (not shown) that download software, configure the module, or provide a wired connection to other measurement instruments or computing devices, to name a few examples.

Monitor Module Physical Configurations

FIGS. 5A-C illustrate physical embodiments of a monitor module **500**. FIG. 5A illustrates a direct-connect module **510** having a case **512** and an integrated monitor connector **514**. The case **512** contains the monitor module electronics, which are functionally described with respect to FIG. 7, below. The monitor connector **514** mimics that of the monitor end of a patient cable, such as a pulse oximetry patient cable **140** (FIG. 1), and electrically and mechanically connects the monitor module **510** to the monitor **360** via the monitor's sensor port **362**.

FIG. 5B illustrates a cable-connect module **540** having a case **542** and an auxiliary cable **550**. The case **542** functions as for the direct-connect module **510** (FIG. 5A), described above. Instead of directly plugging into the monitor **360**, the cable-connect module **540** utilizes the auxiliary cable **550**, which mimics the monitor end of a patient cable, such as a pulse oximetry patient cable **140** (FIG. 1), and electrically connects the cable-connect module **540** to the monitor sensor port **362**.

FIG. 5C illustrates a plug-in module **570** having a plug-in case **572** and an auxiliary cable **580**. The plug-in case **572** is mechanically compatible with the plug-in chassis of a multiparameter monitor **370** and may or may not electrically con-

6

nect to the chassis backplane. The auxiliary cable **580** mimics a patient cable and electrically connects the plug-in module **570** to the sensor port **372** of another plug-in device. A direct-connect module **510** (FIG. 5A) or a cable-connect module **540** (FIG. 5B) may also be used with a multiparameter monitor **370**.

In a multiparameter embodiment, such as described with respect to FIGS. 13-14, below, a monitor module **500** may connect to multiple plug-in devices of a multiparameter monitor **370**. For example, a cable-connect module **540** (FIG. 5B) may have multiple auxiliary cables **550** (FIG. 5B) that connect to multiple plug-in devices installed within a multiparameter monitor chassis. Similarly, a plug-in module **570** may have one or more auxiliary cables **580** with multiple connectors for attaching to the sensor ports **372** of multiple plug-in devices.

Communications Adapter Functions

FIGS. 6-7 illustrate functional embodiments of a communications adapter. FIG. 6 illustrates a sensor module **400** having a sensor interface **610**, a signal processor **630**, an encoder **640**, a transmitter **650** and a transmitting antenna **670**. A physiological sensor **310** provides an input sensor signal **612** at the sensor connector **318**. Depending on the sensor **310**, the sensor module **400** may provide one or more drive signals **618** to the sensor **310**. The sensor interface **610** inputs the sensor signal **612** and outputs a conditioned signal **614**. The conditioned signal **614** may be coupled to the transmitter **650** or further processed by a signal processor **630**. If the sensor module configuration utilizes a signal processor **630**, it derives a parameter signal **632** responsive to the sensor signal **612**, which is then coupled to the transmitter **650**. Regardless, the transmitter **650** inputs a baseband signal **642** that is responsive to the sensor signal **612**. The transmitter **650** modulates the baseband signal **642** with a carrier to generate a transmit signal **654**. The transmit signal **654** may be derived by various amplitude, frequency or phase modulation schemes, as is well known in the art. The transmit signal **654** is coupled to the transmit antenna **670**, which provides wireless communications to a corresponding receive antenna **770** (FIG. 7), as described below.

As shown in FIG. 6, the sensor interface **610** conditions and digitizes the sensor signal **612** to generate the conditioned signal **614**. Sensor signal conditioning may be performed in the analog domain or digital domain or both and may include amplification and filtering in the analog domain and filtering, buffering and data rate modification in the digital domain, to name a few. The resulting conditioned signal **614** is responsive to the sensor signal **612** and may be used to calculate or derive a parameter signal **632**.

Further shown in FIG. 6, the signal processor **630** performs signal processing on the conditioned signal **614** to generate the parameter signal **632**. The signal processing may include buffering, digital filtering, smoothing, averaging, adaptive filtering and frequency transforms to name a few. The resulting parameter signal **632** may be a measurement calculated or derived from the conditioned signal, such as oxygen saturation, pulse rate, blood glucose, blood pressure and EKG to name a few. Also, the parameter signal **632** may be an intermediate result from which the above-stated measurements may be calculated or derived.

As described above, the sensor interface **610** performs mixed analog and digital pre-processing of an analog sensor signal and provides a digital output signal to the signal processor **630**. The signal processor **630** then performs digital post-processing of the front-end processor output. In alternative embodiments, the input sensor signal **612** and the output conditioned signal **614** may be either analog or digital, the

7

front-end processing may be purely analog or purely digital, and the back-end processing may be purely analog or mixed analog or digital.

In addition, FIG. 6 shows an encoder 640, which translates a digital word or serial bit stream, for example, into the baseband signal 642, as is well-known in the art. The baseband signal 642 comprises the symbol stream that drives the transmit signal 654 modulation, and may be a single signal or multiple related signal components, such as in-phase and quadrature signals. The encoder 640 may include data compression and redundancy, also well-known in the art.

FIG. 7 illustrates a monitor module 500 having a receive antenna 770, a receiver 710, a decoder 720, a waveform processor 730 and a monitor interface 750. A receive signal 712 is coupled from the receive antenna 770, which provides wireless communications to a corresponding transmit antenna 670 (FIG. 6), as described above. The receiver 710 inputs the receive signal 712, which corresponds to the transmit signal 654 (FIG. 6). The receiver 710 demodulates the receive signal to generate a baseband signal 714. The decoder 720 translates the symbols of the demodulated baseband signal 714 into a decoded signal 724, such as a digital word stream or bit stream. The waveform processor 730 inputs the decoded signal 724 and generates a constructed signal 732. The monitor interface 750 is configured to communicate the constructed signal 732 to a sensor port 362 of a monitor 360. The monitor 360 may output a sensor drive signal 754, which the monitor interface 750 inputs to the waveform processor 730 as a monitor drive signal 734. The waveform processor 730 may utilize the monitor drive signal 734 to generate the constructed signal 732. The monitor interface 750 may also provide characterization information 758 to the waveform processor 730, relating to the monitor 360, the sensor 310 or both, that the waveform processor 730 utilizes to generate the constructed signal 732.

The constructed signal 732 is adapted to the monitor 360 so that measurements derived by the monitor 360 from the constructed signal 732 are generally equivalent to measurements derivable from the sensor signal 612 (FIG. 6). Note that the sensor 310 (FIG. 6) may or may not be directly compatible with the monitor 360. If the sensor 310 (FIG. 6) is compatible with the monitor 360, the constructed signal 732 is generated so that measurements derived by the monitor 360 from the constructed signal 732 are generally equivalent (within clinical significance) with those derivable directly from the sensor signal 612 (FIG. 6). If the sensor 310 (FIG. 6) is not compatible with the monitor 360, the constructed signal 732 is generated so that measurements derived by the monitor 360 from the constructed signal 732 are generally equivalent to those derivable directly from the sensor signal 612 (FIG. 6) using a compatible monitor.

Wireless Pulse Oximetry

FIGS. 8-11 illustrate pulse oximeter embodiments of a communications adapter. FIGS. 8-9 illustrate a sensor module and a monitor module, respectively, configured to communicate measured pulse oximeter parameters. FIG. 10-11 illustrate a sensor module and a monitor module, respectively, configured to communicate a plethysmograph signal. Parameter Transmission

FIG. 8 illustrates a pulse oximetry sensor module 800 having a sensor interface 810, signal processor 830, encoder 840, transmitter 850, transmitting antenna 870 and controller 890. The sensor interface 810, signal processor 830 and controller 890 function as described with respect to FIG. 2, above. The sensor interface 810 communicates with a standard pulse oximetry sensor 310, providing an LED drive signal 818 to the LED emitters 312 and receiving a sensor

8

signal 812 from the detector 314 in response. The sensor interface 810 provides front-end processing of the sensor signal 812, also described above, providing a plethysmograph signal 814 to the signal processor 830. The signal processor 830 then derives a parameter signal 832 that comprises a real time measurement of oxygen saturation and pulse rate. The parameter signal 832 may include other parameters, such as measurements of perfusion index and signal quality. In one embodiment, the signal processor is an MS-5 or MS-7 board available from Masimo Corporation, Irvine, Calif.

As shown in FIG. 8, the encoder 840, the transmitter 850 and the transmitting antenna 870 function as described with respect to FIG. 6, above. For example, the parameter signal 832 may be a digital word stream that is serialized into a bit stream and encoded into a baseband signal 842. The baseband signal 842 may be, for example, two bit symbols that drive a quadrature phase shift keyed (QPSK) modulator in the transmitter 850. Other encodings and modulations are also applicable, as described above. The transmitter 850 inputs the baseband signal 842 and generates a transmit signal 854 that is a modulated carrier having a frequency suitable for short-range transmission, such as within a hospital room, doctor's office, emergency vehicle or critical care ward, to name a few. The transmit signal 854 is coupled to the transmit antenna 870, which provides wireless communications to a corresponding receive antenna 970 (FIG. 9), as described below.

FIG. 9 illustrates a monitor module 900 having a receive antenna 970, a receiver 910, a decoder 920, a waveform generator 930 and an interface cable 950. The receive antenna 970, receiver 910 and decoder 920 function as described with respect to FIG. 7, above. In particular, the receive signal 912 is coupled from the receive antenna 970, which provides wireless communications to a corresponding transmit antenna 870 (FIG. 8). The receiver 910 inputs the receive signal 912, which corresponds to the transmit signal 854 (FIG. 8). The receiver 910 demodulates the receive signal 912 to generate a baseband signal 914. Not accounting for transmission errors, the baseband signal 914 corresponds to the sensor module baseband signal 842 (FIG. 8), for example a symbol stream of two bits each. The decoder 920 assembles the baseband signal 914 into a parameter signal 924, which, for example, may be a sequence of digital words corresponding to oxygen saturation and pulse rate. Again, not accounting for transmission errors, the monitor module parameter signal 924 corresponds to the sensor module parameter signal 832 (FIG. 8), derived by the signal processor 830 (FIG. 8).

Also shown in FIG. 9, the waveform generator 930 is a particular embodiment of the waveform processor 730 (FIG. 7) described above. The waveform generator 930 generates a synthesized waveform 932 that the pulse oximeter monitor 360 can process to calculate SpO_2 and pulse rate values or exception messages. In the present embodiment, the waveform generator output does not reflect a physiological waveform. In particular, the synthesized waveform is not physiological data from the sensor module 800, but is a waveform synthesized from predetermined stored waveform data to cause the monitor 360 to calculate oxygen saturation and pulse rate equivalent to or generally equivalent (within clinical significance) to that calculated by the signal processor 830 (FIG. 8). The actual intensity signal from the patient received by the detector 314 (FIG. 8) is not provided to the monitor 360 in the present embodiment. Indeed, the waveform provided to the monitor 360 will usually not resemble a plethysmographic waveform or other physiological data from the patient to whom the sensor module 800 (FIG. 8) is attached.

The synthesized waveform 932 is modulated according to the drive signal input 934. That is, the pulse oximeter monitor

360 expects to receive a red and IR modulated intensity signal originating from a detector, as described with respect to FIGS. 1-2, above. The waveform generator 930 generates the synthesized waveform 932 with a predetermined shape, such as a triangular or sawtooth waveform stored in waveform generator memory or derived by a waveform generator algorithm. The waveform is modulated synchronously with the drive input 934 with first and second amplitudes that are processed in the monitor 360 as red and IR portions of a sensor signal. The frequency and the first and second amplitudes are adjusted so that pulse rate and oxygen saturation measurements derived by the pulse oximeter monitor 360 are generally equivalent to the parameter measurements derived by the signal processor 830 (FIG. 8), as described above. One embodiment of a waveform generator 930 is described in U.S. Patent Application No. 60/117,097 entitled "Universal/Upgrading Pulse Oximeter," assigned to Masimo Corporation, Irvine, Calif. and incorporated by reference herein. Although the waveform generator 930 is described above as synthesizing a waveform that does not resemble a physiological signal, one of ordinary skill will recognize that another embodiment of the waveform generator 930 could incorporate, for example, a plethysmograph simulator or other physiological signal simulator.

Further shown in FIG. 9, the interface cable 950 functions in a manner similar to the monitor interface 750 (FIG. 7) described above. The interface cable 950 is configured to communicate the synthesized waveform 932 to the monitor 360 sensor port and to communicate the sensor drive signal 934 to the waveform generator 930. The interface cable 950 may include a ROM 960 that contains monitor and sensor characterization data. The ROM 960 is read by the waveform generator 930 so that the synthesized waveform 932 is adapted to a particular monitor 360. For example, the ROM 960 may contain calibration data of red/IR versus oxygen saturation, waveform amplitude and waveform shape information. An interface cable is described in U.S. Patent Application No. 60/117,092, referenced above. Monitor-specific SatShare™ brand interface cables are available from Masimo Corporation, Irvine, Calif. In an alternative embodiment, such as a direct connect monitor module as illustrated in FIG. 5A, an interface cable 950 is not used and the ROM 960 may be incorporated within the monitor module 900 itself.

Plethysmograph Transmission

FIG. 10 illustrates another pulse oximetry sensor module 1000 having a sensor interface 1010, encoder 1040, transmitter 1050, transmitting antenna 1070 and controller 1090, which have the corresponding functions as those described with respect to FIG. 8, above. The encoder 1040, however, inputs a plethysmograph signal 1014 rather than oxygen saturation and pulse rate measurements 832 (FIG. 8). Thus, the sensor module 1000 according to this embodiment encodes and transmits a plethysmograph signal 1014 to a corresponding monitor module 1100 (FIG. 11) in contrast to derived physiological parameters, such as oxygen saturation and pulse rate. The plethysmograph signal 1014 is illustrated in FIG. 10 as being a direct output from the sensor interface 1010. In another embodiment, the sensor module 1000 incorporates a decimation processor, not shown, after the sensor interface 1010 so as to provide a plethysmograph signal 1014 having a reduced sample rate.

FIG. 11 illustrates another pulse oximetry monitor module 1100 having a receive antenna 1170, a receiver 1110, a decoder 1120 and an interface cable 1150, which have the corresponding functions as those described with respect to FIG. 9, above. This monitor module embodiment 1100, however, has a waveform modulator 1200 rather than a waveform

generator 930 (FIG. 9), as described above. The waveform modulator 1200 inputs a plethysmograph signal from the decoder 1120 rather than oxygen saturation and pulse rate measurements, as described with respect to FIG. 9, above. Further, the waveform modulator 1200 provides an modulated waveform 1132 to the pulse oximeter monitor 360 rather than a synthesized waveform, as described with respect to FIG. 9. The modulated waveform 1132 is a plethysmographic waveform modulated according to the monitor drive signal input 1134. That is, the waveform modulator 1200 does not synthesize a waveform, but rather modifies the received plethysmograph signal 1124 to cause the monitor 360 to calculate oxygen saturation and pulse rate generally equivalent (within clinical significance) to that derivable by a compatible, calibrated pulse oximeter directly from the sensor signal 1012 (FIG. 10). The waveform modulator 1200 is described in further detail with respect to FIG. 12, below.

FIG. 12 shows a waveform modulator 1200 having a demodulator 1210, a red digital-to-analog converter (DAC) 1220, an IR DAC 1230, a red amplifier 1240, an IR amplifier 1250, a modulator 1260, a modulator control 1270, a look-up table (LUT) 1280 and a ratio calculator 1290. The waveform modulator 1200 demodulates red and IR plethysmographs ("pleths") from the decoder output 1124 into a separate red pleth 1222 and IR pleth 1232. The waveform modulator 1200 also adjusts the amplitudes of the pleths 1222, 1232 according to stored calibration curves for the sensor 310 (FIG. 10) and the monitor 360 (FIG. 11). Further, the waveform modulator 1200 re-modulates the adjusted red pleth 1242 and adjusted IR pleth 1252, generating a modulated waveform 1132 to the monitor 360 (FIG. 11).

As shown in FIG. 12, the demodulator 1210 performs the demodulation function described above, generating digital red and IR pleth signals 1212, 1214. The DACs 1220, 1230 convert the digital pleth signals 1212, 1214 to corresponding analog pleth signals 1222, 1232. The amplifiers 1240, 1250 have variable gain control inputs 1262, 1264 and perform the amplitude adjustment function described above, generating adjusted red and IR pleth signals 1242, 1252. The modulator 1260 performs the re-modulation function described above, combining the adjusted red and IR pleth signals 1242, 1252 according to a control signal 1272. The modulator control 1270 generates the control signal 1272 synchronously with the LED drive signal(s) 1134 from the monitor 360.

Also shown in FIG. 12, the ratio calculator 1290 derives a red/IR ratio from the demodulator outputs 1212, 1214. The LUT 1280 stores empirical calibration data for the sensor 310 (FIG. 10). The LUT 1280 also downloads monitor-specific calibration data from the ROM 1160 (FIG. 11) via the ROM output 1158. From this calibration data, the LUT 1280 determines a desired red/IR ratio for the modulated waveform 1132 and generates red and IR gain outputs 1262, 1264 to the corresponding amplifiers 1240, 1250, accordingly. A desired red/IR ratio is one that allows the monitor 360 (FIG. 11) to derive oxygen saturation measurements from the modulated waveform 1132 that are generally equivalent to that derivable directly from the sensor signal 1012 (FIG. 10).

One of ordinary skill in the art will recognize that some of the signal processing functions described with respect to FIGS. 8-11 may be performed either within a sensor module or within a monitor module. Signal processing functions performed within a sensor module may advantageously reduce the transmission bandwidth to a monitor module at a cost of increased sensor module size and power consumption. Likewise, signal processing functions performed within a monitor module may reduce sensor module size and power consumption at a cost of increase transmission bandwidth.

11

For example, a monitor module embodiment **900** (FIG. 9) described above receives measured pulse oximeter parameters, such as oxygen saturation and pulse rate, and generates a corresponding synthesized waveform. In that embodiment, the oxygen saturation and pulse rate computations are performed within a sensor module **800** (FIG. 8). Another monitor module embodiment **1100** (FIG. 11), also described above, receives a plethysmograph waveform and generates a remodulated waveform. In that embodiment, minimal signal processing is performed within a sensor module **1000** (FIG. 10). In yet another embodiment, not shown, a sensor module transmits a plethysmograph waveform or a decimated plethysmograph waveform having a reduced sample rate. A corresponding monitor module has a signal processor, such as described with respect to FIG. 8, in addition to a waveform generator, as described with respect to FIG. 9. The signal processor computes pulse oximeter parameters and the waveform generator generates a corresponding synthesized waveform, as described above. In this embodiment, minimal signal processing is performed within the sensor module, and the monitor module functions are performed on the pulse oximeter parameters computed within the monitor module.

Wireless Multiple Parameter Measurements

FIGS. 13-14 illustrate a multiple parameter communications adapter. FIG. 13 illustrates a multiple parameter sensor module **1300** having sensor interfaces **1310**, one or more signal processors **1330**, a multiplexer and encoder **1340**, a transmitter **1350**, a transmitting antenna **1370** and a controller **1390**. One or more physiological sensors **1301** provide input sensor signals **1312** to the sensor module **1300**. Depending on the particular sensors **1301**, the sensor module **1300** may provide one or more drive signals **1312** to the sensors **1301** as determined by the controller **1390**. The sensor interfaces **1310** input the sensor signals **1312** and output one or more conditioned signals **1314**. The conditioned signals **1314** may be coupled to the transmitter **1350** or further processed by the signal processors **1330**. If the sensor module configuration utilizes signal processors **1330**, it derives multiple parameter signals **1332** responsive to the sensor signals **1312**, which are then coupled to the transmitter **1350**. Regardless, the transmitter **1350** inputs a baseband signal **1342** that is responsive to the sensor signals **1312**. The transmitter **1350** modulates the baseband signal **1342** with a carrier to generate a transmit signal **1354**, which is coupled to the transmit antenna **1370** and communicated to a corresponding receive antenna **1470** (FIG. 14), as described with respect to FIG. 6, above. Alternatively, there may be multiple baseband signals **1342**, and the transmitter **1350** may transmit on multiple frequency channels, where each channel conveys data responsive to one or more of the sensor signals **1314**.

As shown in FIG. 13, the sensor interface **1310** conditions and digitizes the sensor signals **1312** as described for a single sensor with respect to FIG. 6, above. The resulting conditioned signals **1314** are responsive to the sensor signals **1312**. The signal processors **1330** perform signal processing on the conditioned signals **1314** to derive parameter signals **1332**, as described for a single conditioned signal with respect to FIG. 6, above. The parameter signals **1332** may be physiological measurements such as oxygen saturation, pulse rate, blood glucose, blood pressure, EKG, respiration rate and body temperature to name a few, or may be intermediate results from which the above-stated measurements may be calculated or derived. The multiplexer and encoder **1340**

combines multiple digital word or serial bit streams into a single digital word or bit stream. The multiplexer and encoder

12

also encodes the digital word or bit stream to generate the baseband signal **1342**, as described with respect to FIG. 6, above.

FIG. 14 illustrates a multiple parameter monitor module **1400** having a receive antenna **1470**, a receiver **1410**, a demultiplexer and decoder **1420**, one or more waveform processors **1430** and a monitor interface **1450**. The receiver **1410** inputs and demodulates the receive signal **1412** corresponding to the transmit signal **1354** (FIG. 13) to generate a baseband signal **1414** as described with respect to FIG. 7, above. The demultiplexer and decoder **1420** separates the symbol streams corresponding to the multiple conditioned signals **1314** (FIG. 13) and/or parameter signals **1332** (FIG. 13) and translates these symbol streams into multiple decoded signals **1422**, as described for a single symbol stream with respect to FIG. 7, above. Alternatively, multiple frequency channels are received to generate multiple baseband signals, each of which are decoded to yield multiple decoded signals **1422**. The waveform processors **1430** input the decoded signals **1422** and generate multiple constructed signals **1432**, as described for a single decoded signal with respect to FIGS. 7-12, above. The monitor interface **1450** is configured to communicate the constructed signals **1432** to the sensor ports of a multiple parameter monitor **1401** or multiple single parameter monitors, in a manner similar to that for a single constructed signal, as described with respect to FIGS. 7-12, above. In particular, the constructed signals **1432** are adapted to the monitor **1401** so that measurements derived by the monitor **1401** from the constructed signals **1432** are generally equivalent to measurements derivable directly from the sensor signals **1312** (FIG. 13).

A physiological measurement communications adapter is described above with respect to wireless communications and, in particular, radio frequency communications. A sensor module and monitor module, however, may also communicate via wired communications, such as telephone, Internet or fiberoptic cable to name a few. Further, wireless communications can also utilize light frequencies, such as IR or laser to name a few.

A physiological measurement communications adapter has been disclosed in detail in connection with various embodiments. These embodiments are disclosed by way of examples only. One of ordinary skill in the art will appreciate many variations and modifications of a physiological measurement communications adapter within the scope of the claims that follow.

What is claimed is:

1. A pulse oximetry system comprising:

a receiver configured to communicate with a monitor device; and

a wrist-mountable pulse oximetry device including:

a wrist mount usable to mount the wrist-mountable pulse oximetry device on a wrist of a user;

a housing coupled to the wrist mount;

a sensor interface housed by the housing and configured to receive a sensor signal from a pulse oximetry sensor, the sensor signal indicative of oxygen saturation and pulse rate of the user; and

a transmitter housed by the housing and configured to: modulate a first baseband signal responsive to said sensor signal so as to generate the transmit signal; and

wirelessly transmit the transmit signal to the receiver,

wherein the receiver is further configured to:

receive the wirelessly transmitted signal from the wrist-mountable pulse oximetry device; and

13

adapt the received wirelessly transmitted signal to a monitor-compatible signal utilizing characterization information specific to the monitor device, the monitor-compatible signal adapted for compatibility with the monitor device, the monitor-compatible signal 5 usable by the monitor device to provide physiological parameter measurements consistent with the sensor signal received from the pulse oximetry sensor.

2. The pulse oximetry system of claim 1, wherein the wrist mount comprises a wrist strap. 10

3. The pulse oximetry system of claim 1, wherein the wrist-mountable pulse oximetry device further includes: one or more input mechanisms useable by the user to affect at least one of the operational mode or characteristics of the wrist-mountable pulse oximetry device. 15

4. The pulse oximetry system of claim 3, wherein the one or more input mechanisms comprise keys.

5. The pulse oximetry system of claim 1, wherein adapting the received wirelessly transmitted signal further includes adapting the received wirelessly transmitted signal to the monitor-compatible signal such that the monitor-compatible signal is further usable by the monitor device to provide measurements of perfusion index and signal quality. 20

6. The pulse oximetry system of claim 1, wherein the physiological parameter measurements include at least oxygen saturation and pulse rate of the user. 25

* * * * *

14