



US010213108B2

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

(10) **Patent No.:** **US 10,213,108 B2**

(45) **Date of Patent:** ***Feb. 26, 2019**

(54) **ARM MOUNTABLE PORTABLE PATIENT MONITOR**

(56) **References Cited**

U.S. PATENT DOCUMENTS

(71) Applicant: **Masimo Corporation**, Irvine, CA (US)

3,646,606 A 2/1972 Buxton et al.
3,690,313 A 9/1972 Weppner et al.
(Continued)

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

FOREIGN PATENT DOCUMENTS

(73) Assignee: **MASIMO CORPORATION**, Irvine, CA (US)

EP 0 602 459 6/1994
EP 0602459 6/1994
(Continued)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 169 days.

This patent is subject to a terminal disclaimer.

OTHER PUBLICATIONS

US 8,845,543, 09/2014, Diab et al. (withdrawn)
(Continued)

(21) Appl. No.: **15/448,989**

Primary Examiner — Eric F Winakur

(22) Filed: **Mar. 3, 2017**

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

(65) **Prior Publication Data**

US 2017/0224262 A1 Aug. 10, 2017

Related U.S. Application Data

(63) Continuation of application No. 14/815,232, filed on Jul. 31, 2015, which is a continuation of application
(Continued)

(51) **Int. Cl.**

A61B 5/1455 (2006.01)

A61B 5/00 (2006.01)

(Continued)

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

CPC **A61B 5/0024** (2013.01); **A61B 5/002**
(2013.01); **A61B 5/0004** (2013.01);
(Continued)

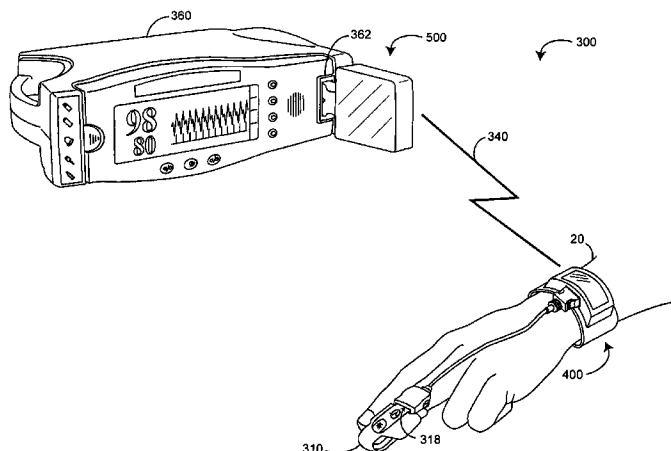
(58) **Field of Classification Search**

CPC ... A61B 5/0002; A61B 5/0004; A61B 5/0024;
A61B 5/02; A61B 5/0205; A61B 5/0402;
(Continued)

(57) **ABSTRACT**

An arm mountable portable patient monitoring device configured to receive physiological information from a plurality of sensors attached to a patient via wired connections for on-patient monitoring of parameter measurements and wireless transmission of parameter measurements to separate monitoring devices. The arm mountable portable patient monitoring device includes a housing, a strap, a display, a first sensor port positioned on a first side of the housing configured to face toward a hand of the patient when the housing is secured to the arm of the patient, second and third sensor ports configured to receive signals from additional sensor arrangements via a wired connections, one or more signal processing arrangements configured to cause to be displayed measurements of oxygen saturation and pulse rate, and a transmitter configured to wirelessly transmit information indicative of the measurements of oxygen saturation and pulse rate to a separate monitoring device.

22 Claims, 17 Drawing Sheets



Related U.S. Application Data

No. 14/217,788, filed on Mar. 18, 2014, now Pat. No. 9,113,832, which is a continuation of application No. 14/037,137, filed on Sep. 25, 2013, now Pat. No. 9,113,831, 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. 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.

(51) Int. Cl.

A61B 5/0205 (2006.01)
A61B 5/024 (2006.01)
A61B 5/021 (2006.01)
A61B 5/0404 (2006.01)
A61B 5/0428 (2006.01)
G08B 21/04 (2006.01)
A61B 5/0402 (2006.01)
H04W 4/70 (2018.01)

(52) U.S. Cl.

CPC **A61B 5/0015** (2013.01); **A61B 5/0026** (2013.01); **A61B 5/021** (2013.01); **A61B 5/0205** (2013.01); **A61B 5/02427** (2013.01); **A61B 5/02438** (2013.01); **A61B 5/0404** (2013.01); **A61B 5/0428** (2013.01); **A61B 5/14552** (2013.01); **A61B 5/6824** (2013.01); **A61B 5/6826** (2013.01); **A61B 5/6831** (2013.01); **A61B 5/6838** (2013.01); **A61B 5/72** (2013.01); **A61B 5/7228** (2013.01); **A61B 5/7271** (2013.01); **A61B 5/742** (2013.01); **A61B 5/7425** (2013.01); **A61B 5/7445** (2013.01); **A61B 5/7475** (2013.01); **G08B 21/0453** (2013.01); **A61B 5/0402** (2013.01); **A61B 5/1455** (2013.01); **A61B 2560/0214** (2013.01); **A61B 2562/222** (2013.01); **A61B 2562/227** (2013.01); **H04W 4/70** (2018.02); **Y10S 128/903** (2013.01)

(58) Field of Classification Search

CPC . A61B 5/1455; A61B 5/14551; A61B 5/6825; A61B 5/6826; A61B 5/6831; A61B 5/72; A61B 2560/0043; A61B 2562/06
 See application file for complete search history.

(56) References Cited**U.S. PATENT DOCUMENTS**

3,810,102 A	5/1974	Parks, III et al.
3,815,583 A	6/1974	Scheidt
3,972,320 A	8/1976	Kalman
3,978,849 A	9/1976	Geneen
4,013,067 A	3/1977	Kresse et al.
4,108,166 A	8/1978	Schmid
4,231,354 A	11/1980	Kurtz et al.
4,589,415 A	5/1986	Haaga
4,662,378 A	5/1987	Thomis
4,773,422 A	9/1988	Isaacson et al.
4,838,275 A	6/1989	Lee
4,852,570 A	8/1989	Levine
4,960,128 A	10/1990	Gordon et al.
4,964,408 A	10/1990	Hink et al.
RE33,643 E	7/1991	Isaacson et al.
5,041,187 A	8/1991	Hink et al.
5,069,213 A	12/1991	Polczynski
5,090,410 A	2/1992	Saper et al.
5,092,340 A	3/1992	Yamaguchi et al.
5,140,519 A	8/1992	Friesdorf et al.
5,159,932 A	11/1992	Zanetti et al.
5,161,539 A	11/1992	Evans et al.
5,163,438 A	11/1992	Gordon et al.
5,203,342 A	4/1993	Sakai
5,262,944 A	11/1993	Weisner et al.
5,277,189 A	1/1994	Jacobs
5,278,627 A	1/1994	Aoyagi et al.
5,282,474 A	2/1994	Valdes Sosa et al.
5,296,688 A	3/1994	Hamilton et al.
5,309,918 A	5/1994	Schraag
5,318,037 A	6/1994	Evans et al.
5,319,355 A	6/1994	Russek
5,331,549 A	7/1994	Crawford, Jr.
5,333,106 A	7/1994	Lanpher et al.
5,337,744 A	8/1994	Branigan
5,341,805 A	8/1994	Stavridi et al.
5,348,008 A	9/1994	Bornn et al.
5,358,519 A	10/1994	Grandjean
D353,195 S	12/1994	Savage et al.
D353,196 S	12/1994	Savage et al.
5,375,599 A	12/1994	Shimizu
5,375,604 A	12/1994	Kelly et al.
5,377,676 A	1/1995	Vari et al.
5,392,777 A	2/1995	Swedlow et al.
5,400,794 A	3/1995	Gorman
D357,982 S	5/1995	Dahl et al.
5,416,695 A	5/1995	Stutman et al.
5,417,222 A	5/1995	Dempsey et al.
D359,546 S	6/1995	Savage et al.
5,431,170 A	7/1995	Mathews
5,434,611 A	7/1995	Tamura
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	

US 10,213,108 B2

Page 3

(56)

References Cited

U.S. PATENT DOCUMENTS

5,724,580	A	3/1998	Levin et al.	6,110,522	A	8/2000	Lepper, Jr. et al.
5,724,983	A	3/1998	Selker et al.	6,124,597	A	9/2000	Shehada
5,725,308	A	3/1998	Smith et al.	6,128,521	A	10/2000	Marro et al.
5,734,739	A	3/1998	Sheehan et al.	6,129,675	A	10/2000	Jay
D393,830	S	4/1998	Tobler et al.	6,132,218	A	10/2000	Benja-Athon
5,743,262	A	4/1998	Lepper, Jr. et al.	6,139,494	A	10/2000	Cairnes
5,746,697	A	5/1998	Swedlow et al.	6,144,868	A	11/2000	Parker
5,754,111	A	5/1998	Garcia	6,151,516	A	11/2000	Kiani-Azarbayjany et al.
5,758,079	A	5/1998	Ludwig et al.	6,152,754	A	11/2000	Gerhardt et al.
5,758,644	A	6/1998	Diab et al.	6,154,667	A	11/2000	Miura et al.
5,760,910	A	6/1998	Lepper, Jr. et al.	6,157,850	A	12/2000	Diab et al.
5,769,785	A	6/1998	Diab et al.	6,165,005	A	12/2000	Mills et al.
5,772,585	A	6/1998	Lavin et al.	6,167,258	A	12/2000	Schmidt et al.
5,779,631	A	7/1998	Chance	D437,058	S	1/2001	Gozani
5,782,757	A	7/1998	Diab et al.	6,168,563	B1	1/2001	Brown
5,782,805	A	7/1998	Meinzer	6,171,237	B1	1/2001	Avitall et al.
5,785,659	A	7/1998	Caro et al.	6,175,752	B1	1/2001	Say et al.
5,791,347	A	8/1998	Flaherty et al.	6,178,343	B1	1/2001	Bindzus et al.
5,792,052	A	8/1998	Isaacson et al.	6,183,417	B1	2/2001	Gehab et al.
5,800,349	A	9/1998	Isaacson et al.	6,184,521	B1	2/2001	Coffin, IV et al.
5,801,637	A	9/1998	Lomholt	6,185,448	B1	2/2001	Borovsky
5,810,734	A	9/1998	Caro et al.	6,190,327	B1	2/2001	Isaacson et al.
5,813,403	A	9/1998	Soller et al.	6,195,576	B1	2/2001	John
5,822,544	A	10/1998	Chaco et al.	6,206,830	B1	3/2001	Diab et al.
5,822,546	A	10/1998	George	6,215,403	B1	4/2001	Chan et al.
5,823,950	A	10/1998	Diab et al.	6,221,012	B1	4/2001	Maschke et al.
5,829,723	A	11/1998	Brunner	6,224,553	B1	5/2001	Nevo
5,830,131	A	11/1998	Caro et al.	6,229,856	B1	5/2001	Diab et al.
5,830,137	A	11/1998	Scharf	6,230,142	B1	5/2001	Benigno et al.
5,833,618	A	11/1998	Caro et al.	6,232,609	B1	5/2001	Snyder et al.
RE36,000	E	12/1998	Swedlow et al.	6,236,872	B1	5/2001	Diab et al.
5,855,550	A	1/1999	Lai et al.	6,241,683	B1	6/2001	Macklem et al.
5,860,919	A	1/1999	Kiani-Azarbayjany et al.	6,241,684	B1 *	6/2001	Amano A61B 5/02438 600/503
5,865,736	A	2/1999	Baker et al.	6,251,113	B1	6/2001	Appelbaum
5,876,351	A	3/1999	Rohde	6,253,097	B1	6/2001	Aronow et al.
5,879,292	A	3/1999	Sternberg et al.	6,256,523	B1	7/2001	Diab et al.
5,885,214	A	3/1999	Monroe et al.	6,263,222	B1	7/2001	Diab et al.
5,890,929	A	4/1999	Mills et al.	6,267,723	B1	7/2001	Matsumura et al.
5,904,654	A	5/1999	Wohlmann et al.	6,269,262	B1	7/2001	Kandori et al.
5,910,139	A	6/1999	Cochran et al.	6,278,522	B1	8/2001	Lepper, Jr. et al.
5,919,134	A	7/1999	Diab	6,280,213	B1	8/2001	Tobler et al.
5,921,920	A	7/1999	Marshall et al.	6,285,896	B1	9/2001	Tobler et al.
5,924,074	A	7/1999	Evans	6,289,238	B1	9/2001	Besson et al.
5,931,160	A	8/1999	Gilmore et al.	6,301,493	B1	10/2001	Marro et al.
5,931,791	A	8/1999	Saltzstein et al.	6,304,767	B1	10/2001	Soller et al.
5,934,925	A	8/1999	Tobler et al.	6,308,089	B1	10/2001	von der Ruhr et al.
5,940,182	A	8/1999	Lepper, Jr. et al.	6,312,378	B1	11/2001	Bardy
5,942,986	A	8/1999	Shabot et al.	6,317,627	B1	11/2001	Ennen et al.
5,957,854	A	9/1999					

(56)

References Cited

U.S. PATENT DOCUMENTS

6,470,893	B1	10/2002	Boesen	6,795,724	B2	9/2004	Hogan
6,491,647	B1	12/2002	Bridger et al.	6,796,186	B2	9/2004	Lia et al.
6,501,975	B2	12/2002	Diab et al.	6,804,656	B1	10/2004	Rosenfeld
6,505,059	B1	1/2003	Kollias et al.	6,807,050	B1	10/2004	Whitehorn et al.
6,515,273	B2	2/2003	Al-Ali	6,813,511	B2	11/2004	Diab et al.
6,516,289	B2 *	2/2003	David A61B 5/6822 600/300	6,816,741	B2	11/2004	Diab
6,519,487	B1	2/2003	Parker	6,817,979	B2	11/2004	Nihtila et al.
6,524,240	B1	2/2003	Thede	6,822,564	B2	11/2004	Al-Ali
6,525,386	B1	2/2003	Mills et al.	6,826,419	B2	11/2004	Diab et al.
6,526,300	B1	2/2003	Kiani et al.	6,830,711	B2	12/2004	Mills et al.
6,541,756	B2	4/2003	Schulz et al.	6,837,848	B2	1/2005	Bonner et al.
6,542,764	B1	4/2003	Al-Ali et al.	6,841,535	B2	1/2005	Divita et al.
6,544,173	B2	4/2003	West et al.	6,845,256	B2	1/2005	Chin et al.
6,544,174	B2	4/2003	West et al.	6,850,787	B2	2/2005	Weber et al.
6,551,243	B2	4/2003	Bocionek et al.	6,850,788	B2	2/2005	Al-Ali
6,553,242	B1	4/2003	Sarussi	6,852,083	B2	2/2005	Caro et al.
6,570,592	B1	5/2003	Sajdak et al.	6,855,112	B2	2/2005	Kao et al.
6,577,893	B1	6/2003	Besson et al.	6,860,266	B2	3/2005	Blike
6,578,428	B1	6/2003	Dromms et al.	6,861,639	B2	3/2005	Al-Ali
6,580,086	B1	6/2003	Schulz et al.	6,897,788	B2	5/2005	Khair et al.
6,584,336	B1	6/2003	Ali et al.	6,898,452	B2	5/2005	Al-Ali et al.
6,595,316	B2	7/2003	Cybulski et al.	6,907,237	B1	6/2005	Dorenbosch et al.
6,597,932	B2	7/2003	Tian et al.	6,915,149	B2	7/2005	Ben-haim
6,597,933	B2	7/2003	Kiani et al.	6,920,345	B2	7/2005	Al-Ali et al.
6,606,511	B1	8/2003	Ali et al.	6,931,268	B1	8/2005	Kiani-Azarbayjany et al.
6,612,984	B1	9/2003	Kerr, II	6,934,570	B2	8/2005	Kiani et al.
6,616,606	B1	9/2003	Peterson et al.	6,939,305	B2	9/2005	Flaherty et al.
6,632,181	B2	10/2003	Flaherty et al.	6,942,616	B2	9/2005	Kerr, II
6,639,668	B1	10/2003	Trepagnier	6,943,348	B1	9/2005	Coffin, IV
6,640,116	B2	10/2003	Diab	6,950,687	B2	9/2005	Al-Ali
6,641,533	B2	11/2003	Causey et al.	6,952,340	B2	10/2005	Son
6,643,530	B2	11/2003	Diab et al.	6,961,598	B2	11/2005	Diab
6,646,556	B1	11/2003	Smith et al.	6,970,792	B1	11/2005	Diab
6,650,917	B2	11/2003	Diab et al.	6,979,812	B2	12/2005	Al-Ali
6,650,939	B2	11/2003	Takpke, II et al.	6,980,419	B2	12/2005	Smith et al.
6,654,624	B2	11/2003	Diab et al.	6,983,179	B2	1/2006	Ben-haim
D483,872	S	12/2003	Cruz et al.	6,985,764	B2	1/2006	Mason et al.
6,658,276	B2	12/2003	Kianl et al.	6,988,989	B2	1/2006	Weiner et al.
6,661,161	B1	12/2003	Lanzo et al.	6,990,087	B2	1/2006	Rao et al.
6,663,570	B2	12/2003	Mott et al.	6,993,371	B2	1/2006	Kiani et al.
6,671,531	B2	12/2003	Al-Ali et al.	6,996,427	B2	2/2006	Ali et al.
6,678,543	B2	1/2004	Diab et al.	6,997,884	B2	2/2006	Ulmsten
6,684,090	B2	1/2004	Ali et al.	6,999,904	B2	2/2006	Weber et al.
6,684,091	B2	1/2004	Parker	7,003,338	B2	2/2006	Weber et al.
6,694,160	B2	2/2004	Chin	7,003,339	B2	2/2006	Diab et al.
6,694,180	B1	2/2004	Boesen	7,015,451	B2	3/2006	Dalke et al.
6,697,656	B1	2/2004	Al-Ali	7,024,233	B2	4/2006	Ali et al.
6,697,657	B1	2/2004	Shehada et al.	7,025,729	B2	4/2006	De Chazal et al.
6,697,658	B2	2/2004	Al-Ali				

(56)

References Cited

U.S. PATENT DOCUMENTS

7,241,287 B2	7/2007	Shehada et al.	7,496,393 B2	2/2009	Diab et al.
7,244,251 B2	7/2007	Shehada et al.	D587,657 S	3/2009	Al-Ali et al.
7,245,373 B2	7/2007	Soller et al.	7,497,828 B1	3/2009	Wilk et al.
7,245,953 B1	7/2007	Parker	7,499,739 B2	3/2009	Sweitzer et al.
7,252,659 B2	8/2007	Shehada et al.	7,499,741 B2	3/2009	Diab et al.
7,254,429 B2	8/2007	Schurman et al.	7,499,835 B2	3/2009	Weber et al.
7,254,431 B2	8/2007	Al-Ali	7,500,950 B2	3/2009	Al-Ali et al.
7,254,433 B2	8/2007	Diab et al.	7,509,154 B2	3/2009	Diab et al.
7,254,434 B2	8/2007	Schulz et al.	7,509,494 B2	3/2009	Al-Ali
7,256,708 B2	8/2007	Rosenfeld	7,510,849 B2	3/2009	Schurman et al.
7,257,438 B2	8/2007	Kinast	7,515,043 B2	4/2009	Welch et al.
7,261,697 B2	8/2007	Berstein	7,515,044 B2	4/2009	Welch et al.
7,264,616 B2	9/2007	Shehada et al.	7,526,328 B2	4/2009	Diab et al.
7,267,671 B2	9/2007	Shehada et al.	7,530,942 B1	5/2009	Diab
7,272,425 B2	9/2007	Al-Ali	7,530,949 B2	5/2009	Al Ali et al.
7,274,955 B2	9/2007	Kiani et al.	7,530,955 B2	5/2009	Diab et al.
D554,263 S	10/2007	Al-Ali	7,532,919 B2	5/2009	Soyemi et al.
7,280,858 B2	10/2007	Al-Ali et al.	7,549,961 B1	6/2009	Hwang
7,285,090 B2	10/2007	Stivorovic	7,551,717 B2	6/2009	Tome et al.
7,289,835 B2	10/2007	Mansfield et al.	7,559,520 B2	7/2009	Quijano et al.
7,292,883 B2	11/2007	De Felice et al.	7,563,110 B2	7/2009	Al-Ali et al.
7,295,866 B2	11/2007	Al-Ali	7,577,475 B2	8/2009	Consentino et al.
7,307,543 B2	12/2007	Rosenfeld	7,590,950 B2	9/2009	Collins et al.
7,313,423 B2	12/2007	Griffin et al.	7,596,398 B2	9/2009	Al-Ali et al.
7,314,446 B2	1/2008	Byrd et al.	7,597,665 B2	10/2009	Wilk et al.
7,315,825 B2	1/2008	Rosenfeld	7,612,999 B2	11/2009	Clark et al.
7,321,862 B2	1/2008	Rosenfeld	7,616,303 B2	11/2009	Yang et al.
7,322,971 B2	1/2008	Shehada et al.	7,618,375 B2	11/2009	Flaherty
7,328,053 B1	2/2008	Diab et al.	D606,659 S	12/2009	Kiani et al.
7,332,784 B2	2/2008	Mills et al.	7,639,145 B2	12/2009	Lawson et al.
7,340,287 B2	3/2008	Mason et al.	7,647,083 B2	1/2010	Al-Ali et al.
7,341,559 B2	3/2008	Schulz et al.	7,650,291 B2	1/2010	Rosenfeld
7,343,186 B2	3/2008	Lamego et al.	D609,193 S	2/2010	Al-Ali et al.
D566,282 S	4/2008	Al-Ali et al.	7,654,966 B2	2/2010	Westinskow et al.
7,355,512 B1	4/2008	Al-Ali	7,684,845 B2	3/2010	Juan
7,356,178 B2	4/2008	Ziel et al.	7,689,437 B1	3/2010	Teller et al.
7,356,365 B2	4/2008	Schurman	RE41,236 E	4/2010	Seely
7,359,742 B2	4/2008	Maser et al.	D614,305 S	4/2010	Al-Ali et al.
7,371,981 B2	5/2008	Abdul-Hafiz	7,693,697 B2	4/2010	Westinskow et al.
7,373,193 B2	5/2008	Al-Ali et al.	RE41,317 E	5/2010	Parker
7,373,194 B2	5/2008	Weber et al.	D615,655 S	5/2010	Maser et al.
7,376,453 B1	5/2008	Diab et al.	7,722,542 B2	5/2010	Lia et al.
7,377,794 B2	5/2008	Al Ali et al.	7,729,733 B2	6/2010	Al-Ali et al.
7,377,899 B2	5/2008	Weber et al.	7,734,320 B2	6/2010	Al-Ali
7,378,975 B1	5/2008	Smith et al.	7,736,318 B2	6/2010	Consentino et al.
7,382,247 B2	6/2008	Welch et al.	7,740,590 B2	6/2010	Bernstein
7,383,070 B2	6/2008	Diab et al.	7,761,127 B2	7/2010	Al-Ali et al.
7,390,299 B2	6/2008	Weiner et al.	7,761,128 B2	7/2010	Al-Ali et al.
7,392,074 B2	6/2008	Isaacson et al.	7,763,420 B2	7/2010	Strizker et al.
7,395,216 B2	7/2008	Rosenfeld	7,764,982 B2	7/2010	Dalke et al.
7,411,509 B2	8/2008	Rosenfeld	D621,515 S	8/2010	Chua et al.
7,413,546 B2	8/2008	Agutter et al.	D621,516 S	8/2010	Kiani et al.
7,415,297 B2	8/2008	Al-Ali et al.	7,766,818 B2	8/2010	Iketani et al.
7,419,483 B2	9/2008	Shehada	7,772		

(56)

References Cited

U.S. PATENT DOCUMENTS

7,891,355 B2	2/2011	Al-Ali et al.	8,233,955 B2	7/2012	Al-Ali et al.
7,894,868 B2	2/2011	Al-Ali et al.	8,235,907 B2	8/2012	Wilk et al.
7,899,507 B2	3/2011	Al-Ali et al.	8,239,780 B2	8/2012	Manetta et al.
7,899,518 B2	3/2011	Trepagnier et al.	8,241,213 B2	8/2012	Lynn et al.
7,904,132 B2	3/2011	Weber et al.	8,244,325 B2	8/2012	Al-Ali et al.
7,909,772 B2	3/2011	Popov et al.	8,249,815 B2	8/2012	Taylor
7,910,875 B2	3/2011	Al-Ali	8,255,026 B1	8/2012	Al-Ali
7,914,514 B2	3/2011	Calderon	8,255,027 B2	8/2012	Al-Ali et al.
7,919,713 B2	4/2011	Al-Ali et al.	8,255,028 B2	8/2012	Al-Ali et al.
7,937,128 B2	5/2011	Al-Ali	8,260,577 B2	9/2012	Weber et al.
7,937,129 B2	5/2011	Mason et al.	8,265,723 B1	9/2012	McHale et al.
7,937,130 B2	5/2011	Diab et al.	8,274,360 B2	9/2012	Sampath et al.
7,941,199 B2	5/2011	Kiani	8,280,473 B2	10/2012	Al-Ali
7,951,086 B2	5/2011	Flaherty et al.	8,294,588 B2	10/2012	Fisher et al.
7,957,780 B2	6/2011	Lamego et al.	8,294,716 B2	10/2012	Lord et al.
7,962,188 B2	6/2011	Kiani et al.	8,301,217 B2	10/2012	Al-Ali et al.
7,962,190 B1	6/2011	Diab et al.	8,306,596 B2	11/2012	Schurman et al.
7,963,927 B2	6/2011	Kelleher et al.	8,310,336 B2	11/2012	Muhsein et al.
7,967,749 B2	6/2011	Hutchinson et al.	8,311,747 B2	11/2012	Taylor
7,970,450 B2	6/2011	Kroecker	8,311,748 B2	11/2012	Taylor et al.
7,976,472 B2	7/2011	Kiani	8,315,683 B2	11/2012	Al-Ali et al.
7,988,637 B2	8/2011	Diab	8,315,812 B2	11/2012	Taylor
7,988,639 B2	8/2011	Starks	8,315,813 B2	11/2012	Taylor et al.
7,990,382 B2	8/2011	Kiani	8,315,814 B2	11/2012	Taylor et al.
7,991,446 B2	8/2011	Ali et al.	8,321,150 B2	11/2012	Taylor
7,991,463 B2	8/2011	Kelleher et al.	RE43,860 E	12/2012	Parker
7,991,625 B2	8/2011	Rosenfeld	8,326,392 B2	12/2012	Grubac et al.
8,000,761 B2	8/2011	Al-Ali	8,326,649 B2	12/2012	Rosenfeld
8,008,088 B2	8/2011	Bellott et al.	8,328,793 B2	12/2012	Birkenbach et al.
RE42,753 E	9/2011	Kiani-Azarbayjany et al.	8,337,403 B2	12/2012	Al-Ali et al.
8,019,400 B2	9/2011	Diab et al.	8,346,330 B2	1/2013	Lamego
8,027,846 B2	9/2011	Schoenberg	8,353,842 B2	1/2013	Al-Ali et al.
8,028,701 B2	10/2011	Al-Ali et al.	8,355,766 B2	1/2013	MacNeish, III et al.
8,029,765 B2	10/2011	Bellott et al.	8,359,080 B2	1/2013	Diab et al.
8,033,996 B2	10/2011	Behar	8,360,936 B2	1/2013	Dibenedetto et al.
8,036,727 B2	10/2011	Schurman et al.	8,364,223 B2	1/2013	Al-Ali et al.
8,036,728 B2	10/2011	Diab et al.	8,364,226 B2	1/2013	Diab et al.
8,036,736 B2	10/2011	Snyder et al.	8,374,665 B2	2/2013	Lamego
8,038,625 B2	10/2011	Afonso et al.	8,385,972 B2	2/2013	Bochenko et al.
8,046,040 B2	10/2011	Ali et al.	8,385,995 B2	2/2013	Al-Ali et al.
8,046,041 B2	10/2011	Diab et al.	8,385,996 B2	2/2013	Smith et al.
8,046,042 B2	10/2011	Diab et al.	D679,018 S	3/2013	Fullerton et al.
8,048,040 B2	11/2011	Kiani	8,388,353 B2	3/2013	Kiani et al.
8,050,728 B2	11/2011	Al-Ali et al.	8,399,822 B2	3/2013	Al-Ali
8,068,104 B2	11/2011	Rampersad	8,401,602 B2	3/2013	Kiani
8,073,707 B2	12/2011	Teller et al.	8,401,874 B2	3/2013	Rosenfeld
8,094,013 B1	1/2012	Lee et al.	8,405,608 B2	3/2013	Al-Ali et al.
8,107,397 B1	1/2012	Bagchi et al.	8,414,499 B2	4/2013	Al-Ali et al.
RE43,169 E	2/2012	Parker	8,418,524 B2	4/2013	Al-Ali
8,118,620 B2	2/2012	Al-Ali et al.	8,423,106 B2	4/2013	Lamego et al.
8,126,528 B2	2/2012	Diab et al.	8,428,967 B2	4/2013	Olsen et al.
8,128,572 B2	3/2012	Diab et al.	8,430,817 B1	4/2013	Al-Ali et al.
8,130,105 B2	3/2012	Al-Ali et al.	8,437,825 B2	5/2013	Dalvi et al.
8,145,2					

(56)

References Cited

U.S. PATENT DOCUMENTS

8,548,550 B2	10/2013	Al-Ali et al.	8,792,950 B2	7/2014	Larsen et al.
8,560,032 B2	10/2013	Al-Ali et al.	8,801,613 B2	8/2014	Al-Ali et al.
8,560,034 B1	10/2013	Diab et al.	8,814,822 B2	8/2014	Yodfat et al.
8,564,613 B2	10/2013	Prior et al.	8,818,477 B2	8/2014	Soller
8,565,847 B2	10/2013	Buxton et al.	8,821,397 B2	9/2014	Al-Ali et al.
8,568,361 B2	10/2013	Yodfat et al.	8,821,415 B2	9/2014	Al-Ali et al.
8,570,167 B2	10/2013	Al-Ali	8,830,449 B1	9/2014	Lamego et al.
8,570,503 B2	10/2013	Vo et al.	8,831,700 B2	9/2014	Schurman et al.
8,571,617 B2	10/2013	Reichgott et al.	8,840,549 B2	9/2014	Al-Ali et al.
8,571,618 B1	10/2013	Lamego et al.	8,845,530 B2	9/2014	Bruce et al.
8,571,619 B2	10/2013	Al-Ali et al.	8,847,740 B2	9/2014	Kiani et al.
8,577,431 B2	11/2013	Lamego et al.	8,849,365 B2	9/2014	Smith et al.
8,578,082 B2	11/2013	Medina et al.	8,852,094 B2	10/2014	Al-Ali et al.
8,579,813 B2	11/2013	Causey, III et al.	8,852,994 B2	10/2014	Wojtczuk et al.
8,581,732 B2	11/2013	Al-Ali et al.	8,866,620 B2	10/2014	Amir
8,584,345 B2	11/2013	Al-Ali et al.	8,868,147 B2	10/2014	Stippick et al.
8,588,880 B2	11/2013	Abdul-Hafiz et al.	8,868,150 B2	10/2014	Al-Ali et al.
8,588,924 B2	11/2013	Dion	8,870,792 B2	10/2014	Al-Ali et al.
8,597,287 B2	12/2013	Benamou et al.	8,873,035 B2	10/2014	Yang et al.
8,600,467 B2	12/2013	Al-Ali et al.	D718,455 S	11/2014	Maser et al.
8,600,777 B2	12/2013	Schoenberg	8,878,888 B2	11/2014	Rosenfeld
8,606,342 B2	12/2013	Diab	8,886,271 B2	11/2014	Kiani et al.
8,615,281 B2	12/2013	Yodfat et al.	8,888,539 B2	11/2014	Al-Ali et al.
8,620,678 B2	12/2013	Gotlib	8,888,708 B2	11/2014	Diab et al.
8,626,255 B2	1/2014	Al-Ali et al.	8,892,180 B2	11/2014	Weber et al.
8,630,691 B2	1/2014	Lamego et al.	8,897,847 B2	11/2014	Al-Ali
8,634,889 B2	1/2014	Al-Ali et al.	8,903,467 B2	12/2014	Sweitzer et al.
8,641,631 B2	2/2014	Sierra et al.	8,907,287 B2	12/2014	Vanderpohl
8,641,670 B2	2/2014	Yodfat et al.	8,909,310 B2	12/2014	Lamego et al.
8,652,060 B2	2/2014	Al-Ali	8,909,330 B2	12/2014	McCombie et al.
8,663,107 B2	3/2014	Kiani	8,911,377 B2	12/2014	Al-Ali
8,666,468 B1	3/2014	Al-Ali	8,912,909 B2	12/2014	Al-Ali et al.
8,667,967 B2	3/2014	Al-Ali et al.	8,920,317 B2	12/2014	Al-Ali et al.
8,670,810 B2	3/2014	Isaacson	8,921,699 B2	12/2014	Al-Ali et al.
8,670,811 B2	3/2014	O'Reilly	8,922,382 B2	12/2014	Al-Ali et al.
8,670,814 B2	3/2014	Diab et al.	8,929,964 B2	1/2015	Al-Ali et al.
8,676,286 B2	3/2014	Weber et al.	8,939,914 B2	1/2015	Turnquist et al.
8,682,407 B2	3/2014	Al-Ali	8,942,777 B2	1/2015	Diab et al.
RE44,823 E	4/2014	Parker	8,948,834 B2	2/2015	Diab et al.
RE44,875 E	4/2014	Kiani et al.	8,948,835 B2	2/2015	Diab
8,690,771 B2	4/2014	Wekell et al.	8,951,248 B2	2/2015	Messerly et al.
8,690,799 B2	4/2014	Telfort et al.	8,956,292 B2	2/2015	Wekell et al.
8,695,206 B2	4/2014	Isaacson et al.	8,956,294 B2	2/2015	McCombie et al.
8,700,112 B2	4/2014	Kiani	8,962,170 B2	2/2015	Frey et al.
8,702,627 B2	4/2014	Telfort et al.	8,965,471 B2	2/2015	Lamego
8,706,179 B2	4/2014	Parker	8,977,351 B2	3/2015	Kivisto
8,712,494 B1	4/2014	MacNeish, III et al.	8,983,564 B2	3/2015	Al-Ali
8,715,206 B2	5/2014	Telfort et al.	8,989,831 B2	3/2015	Al-Ali et al.
8,718,735 B2	5/2014	Lamego et al.	8,996,085 B2	3/2015	Kiani et al.
8,718,737 B2	5/2014	Diab et al.	8,998,809 B2	4/2015	Kiani
8,718,738 B2	5/2014	Blank et al.	9,014,778 B2	4/2015	Datta et al.
8,720,249 B2	5/2014	Al-Ali	9,017,355 B2	4/2015	Smith et al.
8,721,541 B2	5/2014	Al-Ali et al.	9,028,407 B1	5/201	

(56)

References Cited

U.S. PATENT DOCUMENTS

9,138,192 B2	9/2015	Weber et al.	9,566,019 B2	2/2017	Al-Ali et al.
9,142,117 B2	9/2015	Muhsin et al.	9,579,039 B2	2/2017	Jansen et al.
9,149,228 B2	10/2015	Kinast	9,591,975 B2	3/2017	Dalvi et al.
9,153,112 B1	10/2015	Kiani et al.	9,622,692 B2	4/2017	Lamego et al.
9,153,121 B2	10/2015	Kiani et al.	9,622,693 B2	4/2017	Diab
9,161,696 B2	10/2015	Al-Ali et al.	D788,312 S	5/2017	Al-Ali et al.
9,161,713 B2	10/2015	Al-Ali et al.	9,636,055 B2	5/2017	Al-Ali et al.
9,167,995 B2	10/2015	Lamego et al.	9,636,056 B2	5/2017	Al-Ali
9,173,993 B2	11/2015	Yodfat et al.	9,649,054 B2	5/2017	Lamego et al.
9,176,141 B2	11/2015	Al-Ali et al.	9,662,052 B2	5/2017	Al-Ali et al.
9,183,738 B1	11/2015	Allen, Sr. et al.	9,668,679 B2	6/2017	Schurman et al.
9,186,102 B2	11/2015	Bruinsma et al.	9,668,680 B2	6/2017	Bruinsma et al.
9,192,312 B2	11/2015	Al-Ali	9,668,703 B2	6/2017	Al-Ali
9,192,329 B2	11/2015	Al-Ali	9,675,286 B2	6/2017	Diab
9,192,351 B1	11/2015	Telfort et al.	9,687,160 B2	6/2017	Kiani
9,195,385 B2	11/2015	Al-Ali et al.	9,693,719 B2	7/2017	Al-Ali et al.
D745,167 S	12/2015	Canas et al.	9,693,737 B2	7/2017	Al-Ali
9,211,072 B2	12/2015	Kiani	9,697,928 B2	7/2017	Al-Ali et al.
9,211,095 B1	12/2015	Al-Ali	9,717,425 B2	8/2017	Kiani et al.
9,218,454 B2	12/2015	Kiani et al.	9,717,458 B2	8/2017	Lamego et al.
9,226,696 B2	1/2016	Kiani	9,724,016 B1	8/2017	Al-Ali et al.
9,241,662 B2	1/2016	Al-Ali et al.	9,724,024 B2	8/2017	Al-Ali
9,245,668 B1	1/2016	Vo et al.	9,724,025 B1	8/2017	Kiani et al.
9,254,087 B2	2/2016	Isaacson et al.	9,730,640 B2	8/2017	Diab et al.
9,259,185 B2	2/2016	Abdul-Hafiz et al.	9,743,887 B2	8/2017	Al-Ali et al.
9,262,586 B2	2/2016	Steiger et al.	9,749,232 B2	8/2017	Sampath et al.
9,267,572 B2	2/2016	Barker et al.	9,750,442 B2	9/2017	Olsen
9,277,864 B2	3/2016	Yang et al.	9,750,443 B2	9/2017	Smith et al.
9,277,880 B2	3/2016	Poeze et al.	9,750,461 B1	9/2017	Telfort
9,289,167 B2	3/2016	Diab et al.	9,775,545 B2	10/2017	Al-Ali et al.
9,295,421 B2	3/2016	Kiani et al.	9,775,546 B2	10/2017	Diab et al.
9,307,928 B1	4/2016	Al-Ali et al.	9,775,570 B2	10/2017	Al-Ali
9,323,894 B2	4/2016	Kiani	9,778,079 B1	10/2017	Al-Ali et al.
D755,392 S	5/2016	Hwang et al.	9,782,077 B2	10/2017	Lamego et al.
9,326,712 B1	5/2016	Kiani	9,782,110 B2	10/2017	Kiani
9,333,316 B2	5/2016	Kiani	9,787,568 B2	10/2017	Lamego et al.
9,339,220 B2	5/2016	Lamego et al.	9,788,735 B2	10/2017	Al-Ali
9,341,565 B2	5/2016	Lamego et al.	9,788,768 B2	10/2017	Al-Ali et al.
9,351,673 B2	5/2016	Diab et al.	9,795,300 B2	10/2017	Al-Ali
9,351,675 B2	5/2016	Al-Ali et al.	9,795,310 B2	10/2017	Al-Ali
9,364,155 B2	6/2016	Bardy et al.	9,795,358 B2	10/2017	Telfort et al.
9,364,181 B2	6/2016	Kiani et al.	9,795,739 B2	10/2017	Al-Ali et al.
9,368,671 B2	6/2016	Wojtczuk et al.	9,801,556 B2	10/2017	Kiani
9,370,325 B2	6/2016	Al-Ali et al.	9,801,588 B2	10/2017	Weber et al.
9,370,326 B2	6/2016	McHale et al.	9,808,188 B1	11/2017	Perea et al.
9,370,335 B2	6/2016	Al-Ali et al.	9,814,418 B2	11/2017	Weber et al.
9,375,179 B2	6/2016	Schultz et al.	9,820,691 B2	11/2017	Kiani
9,375,185 B2	6/2016	Ali et al.	9,833,152 B2	12/2017	Kiani et al.
9,386,953 B2	7/2016	Al-Ali	9,833,180 B2	12/2017	Shakespeare et al.
9,386,961 B2	7/2016	Al-Ali et al.	9,839,379 B2	12/2017	Al-Ali et al.
9,392,945 B2	7/2016	Al-Ali et al.	9,839,381 B1	12/2017	Weber et al.
9,397,448 B2	7/2016	Al-Ali et al.	9,847,002 B2	12/2017	Kiani et al.
9,402,544 B2	8/2016	Yee et al.	9,847,749 B2	12/2017	Kiani et al.
9,408,542					

(56)

References Cited

U.S. PATENT DOCUMENTS

9,993,207	B2	6/2018	Al-Ali et al.	2005/0113655	A1	5/2005	Hull
10,007,758	B2	6/2018	Al-Ali et al.	2005/0119580	A1	6/2005	Eveland
D822,215	S	7/2018	Al-Ali et al.	2005/0124864	A1	6/2005	Mack et al.
D822,216	S	7/2018	Barker et al.	2005/0125256	A1	6/2005	Schoenberg
10,010,276	B2	7/2018	Al-Ali et al.	2005/0131288	A1	6/2005	Turner et al.
10,032,002	B2	7/2018	Kiani et al.	2005/0164933	A1	7/2005	Tymianski et al.
10,039,482	B2	8/2018	Al-Ali et al.	2005/0191294	A1	9/2005	Arap et al.
10,052,037	B2	8/2018	Kinast et al.	2005/0197550	A1	9/2005	Al-Ali et al.
10,058,275	B2	8/2018	Al-Ali et al.	2005/0228298	A1	10/2005	Banet et al.
10,064,562	B2	9/2018	Al-Ali	2005/0228299	A1	10/2005	Banet
10,086,138	B1	10/2018	Novak, Jr.	2005/0234317	A1	10/2005	Kiani
10,092,200	B2	10/2018	Al-Ali et al.	2005/0245839	A1	11/2005	Stivoric et al.
10,092,249	B2	10/2018	Kiani et al.	2005/0268401	A1	12/2005	Dixon et al.
10,098,550	B2	10/2018	Al-Ali et al.	2005/0277872	A1	12/2005	Colby, Jr. et al.
10,098,591	B2	10/2018	Al-Ali et al.	2006/0049936	A1	3/2006	Collins, Jr. et al.
10,098,610	B2	10/2018	Al-Ali et al.	2006/0058647	A1	3/2006	Strommer et al.
2001/0011355	A1	8/2001	Kawai	2006/0089543	A1	4/2006	Kim et al.
2001/0031922	A1	10/2001	Weng et al.	2006/0089546	A1	4/2006	Mahony et al.
2001/0039199	A1	11/2001	Shinzaki	2006/0094936	A1	5/2006	Russ
2001/0046366	A1	11/2001	Susskind	2006/0106294	A1	5/2006	Maser et al.
2001/0046862	A1	11/2001	Coppinger et al.	2006/0149393	A1	7/2006	Calderon
2001/0055978	A1	12/2001	Herrod et al.	2006/0155175	A1	7/2006	Ogino et al.
2002/0038392	A1	3/2002	De La Hueraga	2006/0161054	A1	7/2006	Reuss et al.
2002/0045836	A1	4/2002	Alkawwas	2006/0167351	A1	7/2006	Isaacson et al.
2002/0052311	A1	5/2002	Solomon et al.	2006/0217684	A1	9/2006	Shehada et al.
2002/0063690	A1	5/2002	Chung et al.	2006/0217685	A1	9/2006	Shehada et al.
2002/0099277	A1	7/2002	Harry et al.	2006/0224413	A1	10/2006	Kim et al.
2002/0107436	A1	8/2002	Barton	2006/0235300	A1	10/2006	Weng et al.
2002/0140675	A1	10/2002	Ali et al.	2006/0253042	A1	11/2006	Stahmann et al.
2002/0165462	A1	11/2002	Westbrook et al.	2006/0276714	A1	12/2006	Holt et al.
2002/0177758	A1	11/2002	Schoenberg	2007/0000490	A1	1/2007	DeVries et al.
2002/0198445	A1	12/2002	Dominguez et al.	2007/0002533	A1	1/2007	Kogan et al.
2003/0027326	A1	2/2003	Ulmsten et al.	2007/0021675	A1	1/2007	Childre et al.
2003/0033102	A1	2/2003	Dietiker	2007/0027368	A1	2/2007	Collins et al.
2003/0052787	A1	3/2003	Zerhusen et al.	2007/0032733	A1	2/2007	Burton et al.
2003/0058838	A1	3/2003	Wengrovitz	2007/0055116	A1	3/2007	Clark et al.
2003/0149349	A1	8/2003	Jensen	2007/0055544	A1	3/2007	Jung et al.
2003/0158466	A1	8/2003	Lynn et al.	2007/0060798	A1	3/2007	Krupnik et al.
2003/0181798	A1	9/2003	Al-Ali	2007/0088406	A1	4/2007	Bennett et al.
2003/0181817	A1	9/2003	Mori	2007/0096897	A1	5/2007	Weiner
2003/0214408	A1	11/2003	Grajales et al.	2007/0100222	A1	5/2007	Mastrototaro et al.
2003/0216670	A1	11/2003	Beggs	2007/0118399	A1	5/2007	Avinash et al.
2003/0229276	A1	12/2003	Sarussi et al.	2007/0140475	A1	6/2007	Kurtock et al.
2004/0000713	A1	1/2004	Yamashita et al.	2007/0156033	A1	7/2007	Causey et al.
2004/0013647	A1	1/2004	Solomon et al.	2007/0157285	A1	7/2007	Frank et

(56)

References Cited

U.S. PATENT DOCUMENTS

2008/0215627	A1	9/2008	Higgins et al.	2011/0021930	A1	1/2011	Mazzeo et al.
2008/0221396	A1	9/2008	Garces et al.	2011/0023130	A1	1/2011	Gudgel et al.
2008/0221420	A1	9/2008	Grubac et al.	2011/0028809	A1	2/2011	Goodman
2008/0222251	A1	9/2008	Parthasarathy	2011/0046495	A1	2/2011	Osycka
2008/0228077	A1	9/2008	Wilk et al.	2011/0066051	A1	3/2011	Moon et al.
2008/0275309	A1	11/2008	Stivoric et al.	2011/0077473	A1	3/2011	Lisogurski
2008/0281167	A1	11/2008	Soderberg et al.	2011/0078596	A1	3/2011	Rawlins et al.
2008/0281168	A1	11/2008	Gibson et al.	2011/0080294	A1	4/2011	Tanishima et al.
2008/0281181	A1	11/2008	Manziona et al.	2011/0082711	A1	4/2011	Poeze et al.
2008/0287751	A1	11/2008	Stivoric et al.	2011/0087083	A1	4/2011	Poeze et al.
2008/0292172	A1	11/2008	Assmann et al.	2011/0087084	A1	4/2011	Jeong et al.
2008/0300020	A1	12/2008	Nishizawa et al.	2011/0087117	A1	4/2011	Tremper et al.
2008/0319275	A1	12/2008	Chiu et al.	2011/0087756	A1	4/2011	Biondi
2008/0319354	A1	12/2008	Bell et al.	2011/0098583	A1	4/2011	Pandia et al.
2009/0005651	A1	1/2009	Ward et al.	2011/0105854	A1	5/2011	Kiani et al.
2009/0018808	A1	1/2009	Bronstein et al.	2011/0105956	A1	5/2011	Hirth
2009/0024008	A1	1/2009	Brunner et al.	2011/0118573	A1	5/2011	Mckenna
2009/0043172	A1	2/2009	Zagorchev et al.	2011/0125060	A1	5/2011	Telfort et al.
2009/0043180	A1	2/2009	Tschautscher et al.	2011/0152629	A1	6/2011	Eaton et al.
2009/0052623	A1	2/2009	Tome et al.	2011/0172967	A1	7/2011	Al-Ali et al.
2009/0054735	A1	2/2009	Higgins et al.	2011/0184252	A1	7/2011	Archer et al.
2009/0062682	A1	3/2009	Bland et al.	2011/0184253	A1	7/2011	Archer et al.
2009/0069642	A1	3/2009	Gao et al.	2011/0208015	A1	8/2011	Welch et al.
2009/0099480	A1	4/2009	Salgo et al.	2011/0208018	A1	8/2011	Kiani
2009/0119330	A1	5/2009	Sampath et al.	2011/0208073	A1	8/2011	Matsukawa et al.
2009/0119843	A1	5/2009	Rodgers et al.	2011/0209915	A1	9/2011	Telfort et al.
2009/0124867	A1	5/2009	Hirsch et al.	2011/0212090	A1	9/2011	Pedersen et al.
2009/0131759	A1	5/2009	Sims et al.	2011/0213212	A1	9/2011	Al-Ali
2009/0143832	A1	6/2009	Saba	2011/0227739	A1	9/2011	Gilham et al.
2009/0157058	A1	6/2009	Ferren et al.	2011/0230733	A1	9/2011	Al-Ali
2009/0171170	A1	7/2009	Li et al.	2011/0237911	A1	9/2011	Lamego et al.
2009/0171225	A1	7/2009	Gadodia et al.	2011/0237969	A1	9/2011	Eckerbom et al.
2009/0177090	A1	7/2009	Grunwald et al.	2011/0257544	A1	10/2011	Kaasinen et al.
2009/0182287	A1	7/2009	Kassab	2011/0257554	A1	10/2011	Banet et al.
2009/0226372	A1	9/2009	Ruoslahti et al.	2011/0263203	A1	10/2011	Parthasarathy
2009/0247984	A1	10/2009	Lamego et al.	2011/0263950	A1	10/2011	Larson et al.
2009/0259114	A1	10/2009	Johnson et al.	2011/0288383	A1	11/2011	Diab
2009/0264778	A1	10/2009	Markowitz et al.	2011/0295094	A1	12/2011	Doyle et al.
2009/0275813	A1	11/2009	Davis	2011/0301444	A1	12/2011	Al-Ali
2009/0275844	A1	11/2009	Al-Ali	2012/0004579	A1	1/2012	Luo et al.
2009/0281462	A1	11/2009	Heliot et al.	2012/0029300	A1	2/2012	Paquet
2009/0299157	A1	12/2009	Telfort et al.	2012/0029879	A1	2/2012	Sing et al.
2009/0299675	A1	12/2009	Isaacson et al.	2012/0041316	A1	2/2012	Al-Ali et al.
2009/0309645	A1	12/2009	Isaacson et al.	2012/0046557	A1	2/2012	Kiani
2009/0309755	A1	12/2009	William				

(56)

References Cited

U.S. PATENT DOCUMENTS

2013/0006131	A1	1/2013	Narayan et al.	2014/0155712	A1	6/2014	Lamego et al.
2013/0006151	A1	1/2013	Main et al.	2014/0163344	A1	6/2014	Al-Ali
2013/0023775	A1	1/2013	Lamego et al.	2014/0163402	A1	6/2014	Lamego et al.
2013/0035603	A1	2/2013	Jarausch et al.	2014/0166076	A1	6/2014	Kiani et al.
2013/0041591	A1	2/2013	Lamego	2014/0171763	A1	6/2014	Diab
2013/0046197	A1	2/2013	Dlugos, Jr. et al.	2014/0180038	A1	6/2014	Kiani
2013/0046204	A1	2/2013	Lamego et al.	2014/0180154	A1	6/2014	Sierra et al.
2013/0060108	A1	3/2013	Schurman et al.	2014/0180160	A1	6/2014	Brown et al.
2013/0060147	A1	3/2013	Welch et al.	2014/0187973	A1	7/2014	Brown et al.
2013/0079610	A1	3/2013	Al-Ali	2014/0188516	A1	7/2014	Kamen
2013/0092805	A1	4/2013	Funk et al.	2014/0194709	A1	7/2014	Al-Ali et al.
2013/0096405	A1	4/2013	Garfio	2014/0194711	A1	7/2014	Al-Ali
2013/0096936	A1	4/2013	Sampath et al.	2014/0194766	A1	7/2014	Al-Ali et al.
2013/0109929	A1	5/2013	Menzel	2014/0200422	A1	7/2014	Weber et al.
2013/0109935	A1	5/2013	Al-Ali et al.	2014/0206963	A1	7/2014	Al-Ali
2013/0123616	A1	5/2013	Merritt et al.	2014/0213864	A1	7/2014	Abdul-Hafiz et al.
2013/0162433	A1	6/2013	Muhsin et al.	2014/0221798	A1	8/2014	Isaacson
2013/0178749	A1	7/2013	Lamego	2014/0243627	A1	8/2014	Diab et al.
2013/0190581	A1	7/2013	Al-Ali et al.	2014/0243632	A1	8/2014	Ulrich et al.
2013/0197328	A1	8/2013	Diab et al.	2014/0257057	A1	9/2014	Reis Cunha et al.
2013/0197364	A1	8/2013	Han	2014/0266787	A1	9/2014	Tran
2013/0211214	A1	8/2013	Olsen	2014/0266790	A1	9/2014	Al-Ali et al.
2013/0243021	A1	9/2013	Siskavich	2014/0275808	A1	9/2014	Poeze et al.
2013/0253334	A1	9/2013	Al-Ali et al.	2014/0275816	A1	9/2014	Sandmore
2013/0261494	A1	10/2013	Bloom et al.	2014/0275835	A1	9/2014	Lamego et al.
2013/0267804	A1	10/2013	Al-Ali	2014/0275871	A1	9/2014	Lamego et al.
2013/0274571	A1	10/2013	Diab et al.	2014/0275872	A1	9/2014	Merritt et al.
2013/0274572	A1	10/2013	Al-Ali et al.	2014/0275881	A1	9/2014	Lamego et al.
2013/0279109	A1	10/2013	Lindblad et al.	2014/0275883	A1	9/2014	Haisley et al.
2013/0296672	A1	11/2013	O'Neil et al.	2014/0275885	A1	9/2014	Isaacson et al.
2013/0296713	A1	11/2013	Al-Ali et al.	2014/0275932	A1	9/2014	Zadig
2013/0310667	A1	11/2013	Grubac et al.	2014/0276115	A1	9/2014	Dalvi et al.
2013/0317327	A1	11/2013	Al-Ali et al.	2014/0288388	A1	9/2014	Isaacson et al.
2013/0317370	A1	11/2013	Dalvi et al.	2014/0288400	A1	9/2014	Diab et al.
2013/0317393	A1	11/2013	Weiss et al.	2014/0296664	A1	10/2014	Bruinsma et al.
2013/0324804	A1	12/2013	McKeown et al.	2014/0303520	A1	10/2014	Telfort et al.
2013/0324808	A1	12/2013	Al-Ali et al.	2014/0309506	A1	10/2014	Lamego et al.
2013/0324817	A1	12/2013	Diab	2014/0309559	A1	10/2014	Telfort et al.
2013/0331660	A1	12/2013	Al-Ali et al.	2014/0316217	A1	10/2014	Purdon et al.
2013/0331670	A1	12/2013	Kiani	2014/0316218	A1	10/2014	Purdon et al.
2013/0338461	A1	12/2013	Lamego et al.	2014/0316228	A1	10/2014	Blank et al.
2013/0340176	A1	12/2013	Stevens et al.	2014/0323825	A1	10/2014	Al-Ali et al.
2014/0012100	A1	1/2014	Al-Ali et al.	2014/0323897	A1	10/2014	Brown et al.
2014/0022081	A1	1/2014	Ribble et al.	2014/0323898	A1	10/2014	Purdon et al.
2014/0025306	A1	1/2014	Weber et al.	2014/0330092	A1		

(56)

References Cited

U.S. PATENT DOCUMENTS

2015/0106121	A1	4/2015	Muhsin et al.	2016/0324486	A1	11/2016	Al-Ali et al.
2015/0112151	A1	4/2015	Muhsin et al.	2016/0324488	A1	11/2016	Olsen
2015/0116076	A1	4/2015	Al-Ali et al.	2016/0327984	A1	11/2016	Al-Ali et al.
2015/0126830	A1	5/2015	Schurman et al.	2016/0328528	A1	11/2016	Al-Ali et al.
2015/0133755	A1	5/2015	Smith et al.	2016/0331332	A1	11/2016	Al-Ali
2015/0140863	A1	5/2015	Al-Ali et al.	2016/0359150	A1	12/2016	Martin et al.
2015/0141779	A1	5/2015	Johnson et al.	2016/0367164	A1	12/2016	Felix
2015/0141780	A1	5/2015	Meyer et al.	2016/0367173	A1	12/2016	Dalvi et al.
2015/0141781	A1	5/2015	Weber et al.	2017/0000394	A1	1/2017	Al-Ali et al.
2015/0165312	A1	6/2015	Kiani	2017/0007134	A1	1/2017	Al-Ali et al.
2015/0196237	A1	7/2015	Lamego	2017/0007198	A1	1/2017	Al-Ali et al.
2015/0196249	A1	7/2015	Brown et al.	2017/0014083	A1	1/2017	Diab et al.
2015/0201874	A1	7/2015	Diab	2017/0014084	A1	1/2017	Al-Ali et al.
2015/0208966	A1	7/2015	Al-Ali	2017/0027456	A1	2/2017	Kinast et al.
2015/0216459	A1	8/2015	Al-Ali et al.	2017/0042488	A1	2/2017	Muhsin
2015/0230755	A1	8/2015	Al-Ali et al.	2017/0055851	A1	3/2017	Al-Ali
2015/0238094	A1	8/2015	Lai et al.	2017/0055882	A1	3/2017	Al-Ali et al.
2015/0238722	A1	8/2015	Al-Ali	2017/0055887	A1	3/2017	Al-Ali
2015/0245773	A1	9/2015	Lamego et al.	2017/0055896	A1	3/2017	Al-Ali et al.
2015/0245794	A1	9/2015	Al-Ali	2017/0079594	A1	3/2017	Telfort et al.
2015/0257689	A1	9/2015	Al-Ali et al.	2017/0086723	A1	3/2017	Al-Ali et al.
2015/0272514	A1	10/2015	Kiani et al.	2017/0143281	A1	5/2017	Olsen
2015/0289814	A1	10/2015	Magar et al.	2017/0147774	A1	5/2017	Kiani
2015/0351697	A1	12/2015	Weber et al.	2017/0156620	A1	6/2017	Al-Ali et al.
2015/0351704	A1	12/2015	Kiani et al.	2017/0173632	A1	6/2017	Al-Ali
2015/0359429	A1	12/2015	Al-Ali et al.	2017/0187146	A1	6/2017	Kiani et al.
2015/0366472	A1	12/2015	Kiani	2017/0188919	A1	7/2017	Al-Ali et al.
2015/0366507	A1	12/2015	Blank	2017/0196464	A1	7/2017	Jansen et al.
2015/0374298	A1	12/2015	Al-Ali et al.	2017/0196470	A1	7/2017	Lamego et al.
2015/0374905	A1	12/2015	Yodfat et al.	2017/0202490	A1	7/2017	Al-Ali et al.
2015/0380875	A1	12/2015	Coverston et al.	2017/0224216	A1	8/2017	Al-Ali
2016/0000362	A1	1/2016	Diab et al.	2017/0224231	A1	8/2017	Al-Ali
2016/0007930	A1	1/2016	Weber et al.	2017/0224233	A1	8/2017	Al-Ali
2016/0029932	A1	2/2016	Al-Ali	2017/0228516	A1	8/2017	Sampath et al.
2016/0029933	A1	2/2016	Al-Ali et al.	2017/0245790	A1	8/2017	Al-Ali et al.
2016/0045118	A1	2/2016	Kiani	2017/0251974	A1	9/2017	Shreim et al.
2016/0051205	A1	2/2016	Al-Ali et al.	2017/0251975	A1	9/2017	Shreim et al.
2016/0058338	A1	3/2016	Schurman et al.	2017/0258403	A1	9/2017	Abdul-Hafiz et al.
2016/0058347	A1	3/2016	Reichgott et al.	2017/0311851	A1	11/2017	Schurman et al.
2016/0066823	A1	3/2016	Al-Ali et al.	2017/0311891	A1	11/2017	Kiani et al.
2016/0066824	A1	3/2016	Al-Ali et al.	2017/0325728	A1	11/2017	Al-Ali et al.
2016/0066879	A1	3/2016	Telfort et al.	2017/0332976	A1	11/2017	Al-Ali et al.
2016/0072429	A1	3/2016	Kiani et al.	2017/0340293	A1	11/2017	Al-Ali et al.
2016/0073967	A1	3/2016	Lamego et al.	2017/0360310	A1	12/2017	Kiani et al.
2016/0081552	A1	3/2016	Wojtczuk et al.	2017/0367632	A1	12	

(56)

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

2018/0192953	A1	7/2018	Shreim et al.
2018/0192955	A1	7/2018	Al-Ali et al.
2018/0199871	A1	7/2018	Pauley et al.
2018/0206795	A1	7/2018	Al-Ali
2018/0206815	A1	7/2018	Telfort
2018/0213583	A1	7/2018	Al-Ali
2018/0214031	A1	8/2018	Kiani et al.
2018/0214090	A1	8/2018	Al-Ali et al.
2018/0218792	A1	8/2018	Muhsin et al.
2018/0225960	A1	8/2018	Al-Ali et al.
2018/0238718	A1	8/2018	Dalvi
2018/0242853	A1	8/2018	Al-Ali
2018/0242921	A1	8/2018	Muhsin et al.
2018/0242923	A1	8/2018	Al-Ali et al.
2018/0242926	A1	8/2018	Muhsin et al.
2018/0247353	A1	8/2018	Al-Ali et al.
2018/0247712	A1	8/2018	Muhsin et al.
2018/0249933	A1	9/2018	Schurman et al.
2018/0253947	A1	9/2018	Muhsin et al.
2018/0256087	A1	9/2018	Al-Ali et al.
2018/0256113	A1	9/2018	Weber et al.
2018/0285094	A1	10/2018	Housel et al.
2018/0289325	A1	10/2018	Poeze et al.
2018/0289337	A1	10/2018	Al-Ali et al.
2018/0296161	A1	10/2018	Shreim et al.
2018/0300919	A1	10/2018	Muhsin et al.
2018/0310822	A1	11/2018	Indorf et al.
2018/0310823	A1	11/2018	Al-Ali et al.

FOREIGN PATENT DOCUMENTS

EP	0 735 499	10/1996
EP	1 408 823	5/2010
EP	1408823	5/2010
EP	2 335 569	6/2011
EP	2 766 834	8/2014
EP	2 811 894	12/2014
JP	02-050694	2/1990
JP	09-187428	7/1997
JP	10-336064	12/1998
JP	2001-501847	2/2001
JP	2002-165764	6/2002
JP	2002-172096	6/2002
JP	2002-233512	8/2002
JP	2002-535026	10/2002
JP	2003-275183	9/2003
JP	2004-024551	1/2004
JP	2004-513732	5/2004
JP	2005-038417	2/2005
JP	2005-218036	8/2005
JP	2005-295375	10/2005
JP	2007-021213	2/2007
JP	2007-095365	4/2007
JP	2007-174051	7/2007
JP	2008-541045	11/2008
JP	2009-017959	1/2009
JP	2009-207836	9/2009
JP	2010-503134	1/2010
JP	2010-524510	7/2010
JP	2011-519607	7/2011
JP	2011-519684	7/2011
JP	2011-152261	8/2011
JP	2012-519547	8/2012
JP	2014-533997	12/2014
RU	2199723	2/2003
WO	WO 96/016591	6/1996
WO	WO 1996/016591	6/1996
WO	WO 97/000708	1/1997
WO	WO 1997/000708	1/1997
WO	WO 98/015224	4/1998
WO	WO 1998/015224	4/1998
WO	WO 98/029790	7/1998
WO	WO 98/039749	9/1998
WO	WO 1998/039749	9/1998
WO	WO 99/013766	3/1999

WO	WO 99/056613	11/1999
WO	WO 00/062665	10/2000
WO	WO 00/063713	10/2000
WO	WO 2000/062665	10/2000
WO	WO 00/069328	11/2000
WO	WO 2000/069328	11/2000
WO	WO 01/041634	6/2001
WO	WO 2001/041634	6/2001
WO	WO 03/065926	8/2003
WO	WO 2003/065926	8/2003
WO	WO 2004/056266	7/2004
WO	WO 2004/059551	7/2004
WO	WO 2005/048830	6/2005
WO	WO 2005/092177	10/2005
WO	WO 2006/051461	5/2006
WO	WO 2010/054409	5/2010
WO	WO 2011/001302	1/2011
WO	WO 2011/002904	1/2011
WO	WO 2011/021948	2/2011
WO	WO 2011/025549	3/2011
WO	WO 2011/041017	4/2011
WO	WO 2013/056160	4/2013
WO	WO 2013/119982	8/2013
WO	WO 2015/054665	4/2015

OTHER

(56)

References Cited

OTHER PUBLICATIONS

International Search Report & Written Opinion in PCT Application No. PCT/US2013/025384, dated Aug. 6, 2013.

International Search Report & Written Opinion in PCT Application No. PCT/US2012/060109, dated Jun. 5, 2013.

International Preliminary Report on Patentability in PCT Application No. PCT/US2012/060109, dated Apr. 24, 2014.

International Search Report & Written Opinion in PCT Application No. PCT/US2014/060177, dated Dec. 19, 2014.

Aitkenhead et al., "Textbook of Anaesthesiology", "Medicina" Publishing House, 1999, vol. 1, pp. 437-440.

Crilly et al., "An Integrated Pulse Oximeter System for Telemedicine Applications", IEEE Instrumentation and Measurement Technology Conference, May 19-21, 1997, pp. 102-104.

Sweitzer et al., "Reducing Health Care Costs and Improving Patient Care with the Uni-Ox Pulse Oximeter from Snap Medical Technologies", Dissertation thesis for an MBA class given by the inventor on Dec. 18, 2004, pp. 7.

* cited by examiner

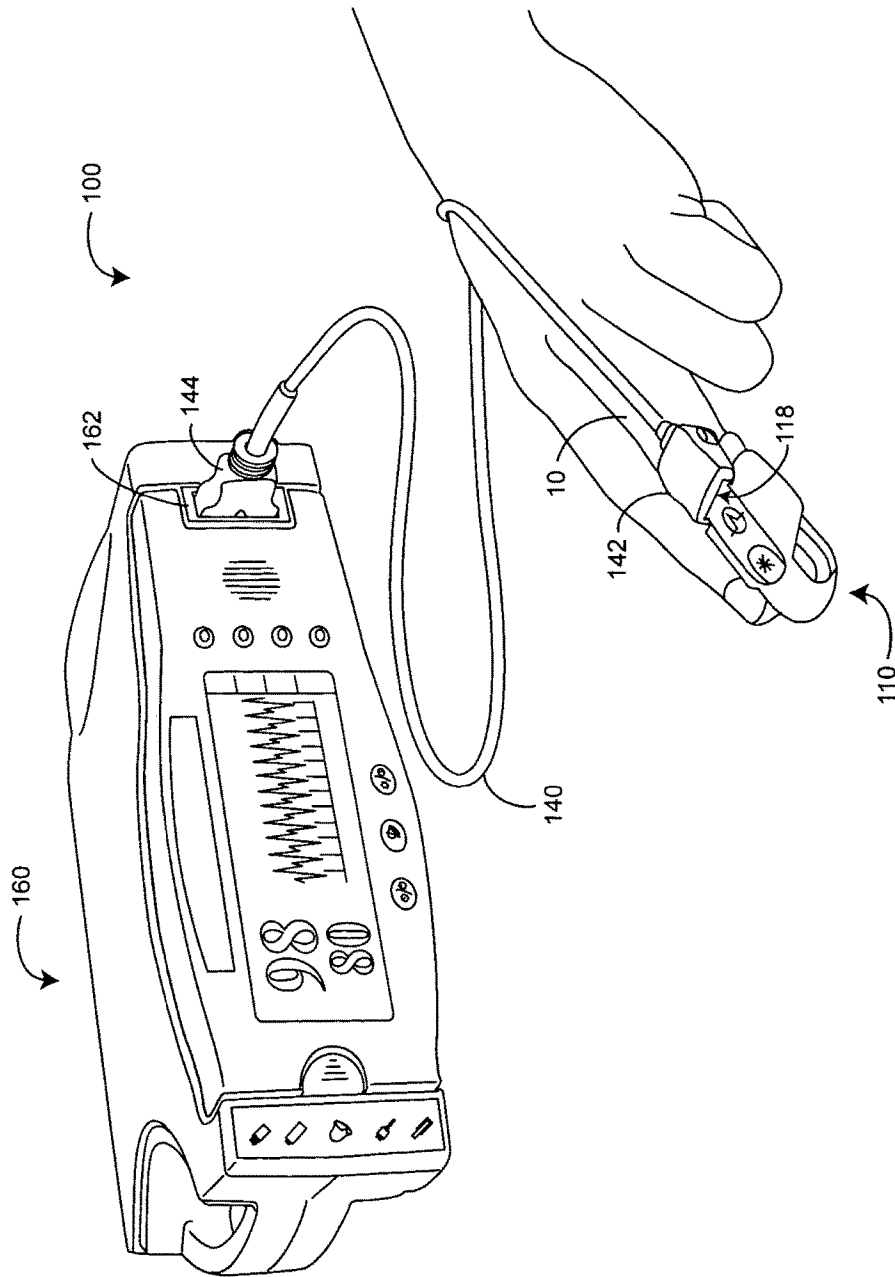


FIG. 1 (Prior Art)

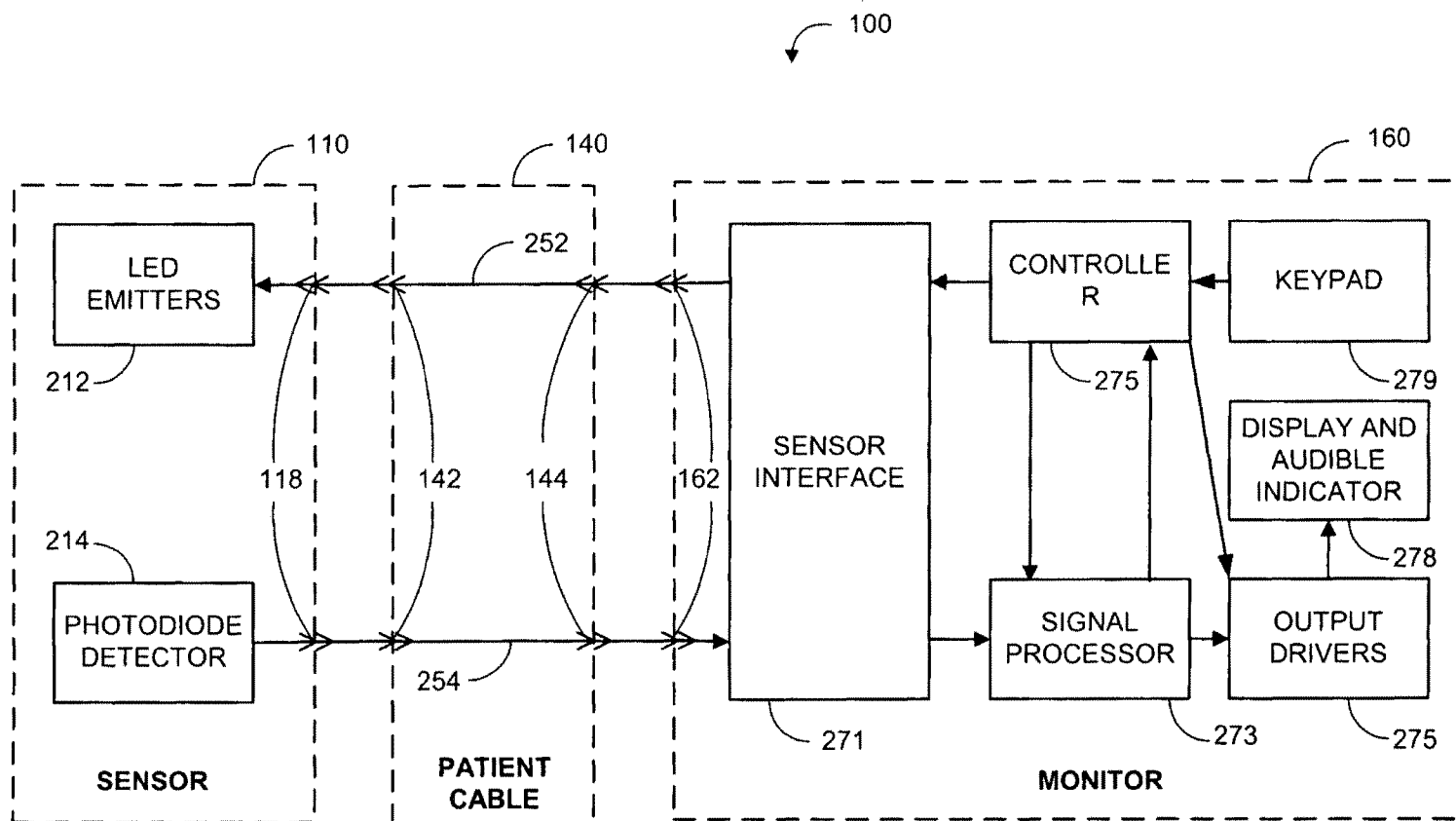


FIG. 2 (Prior Art)

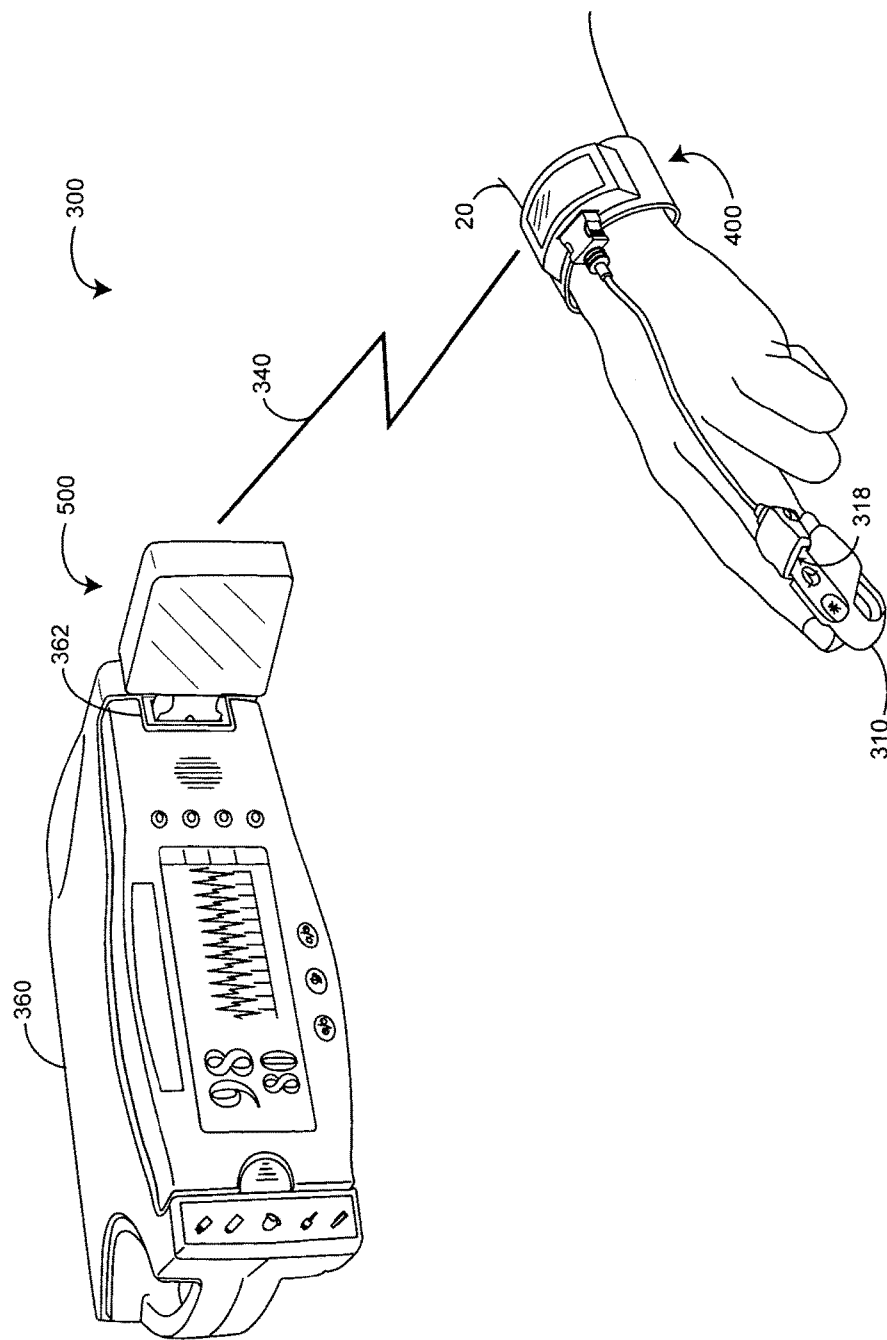


FIG. 3

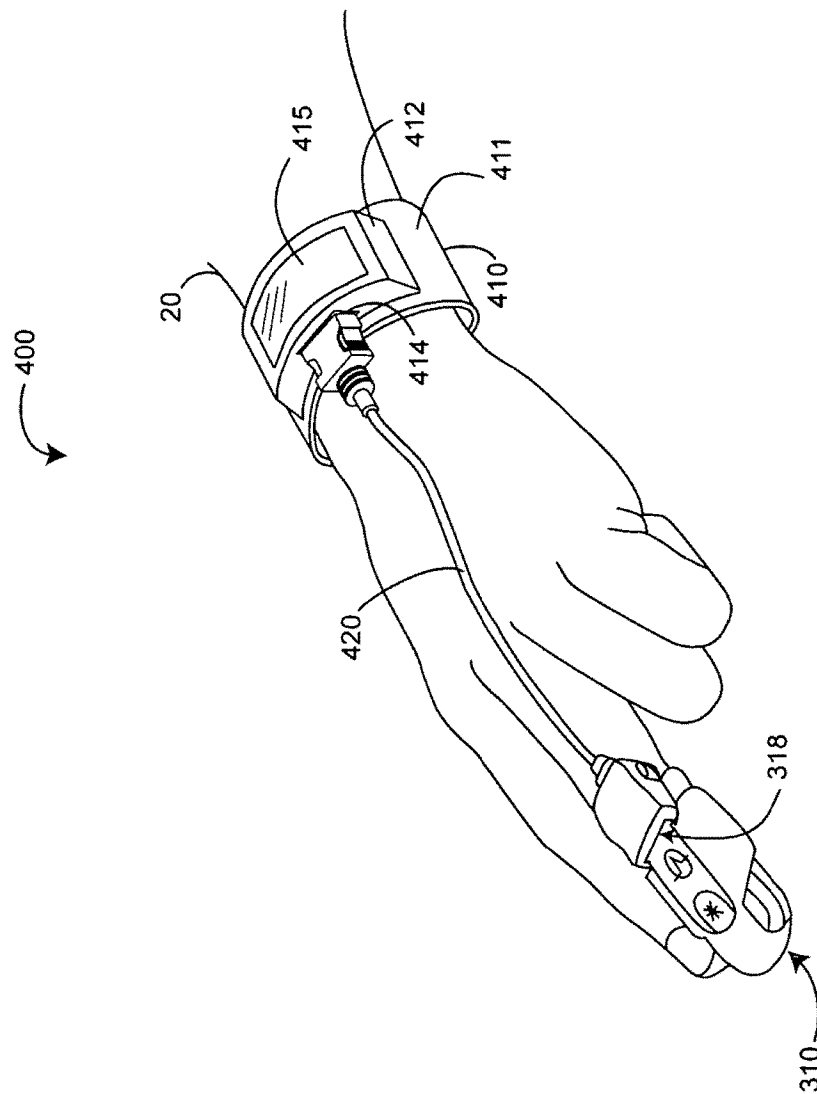


FIG. 4A

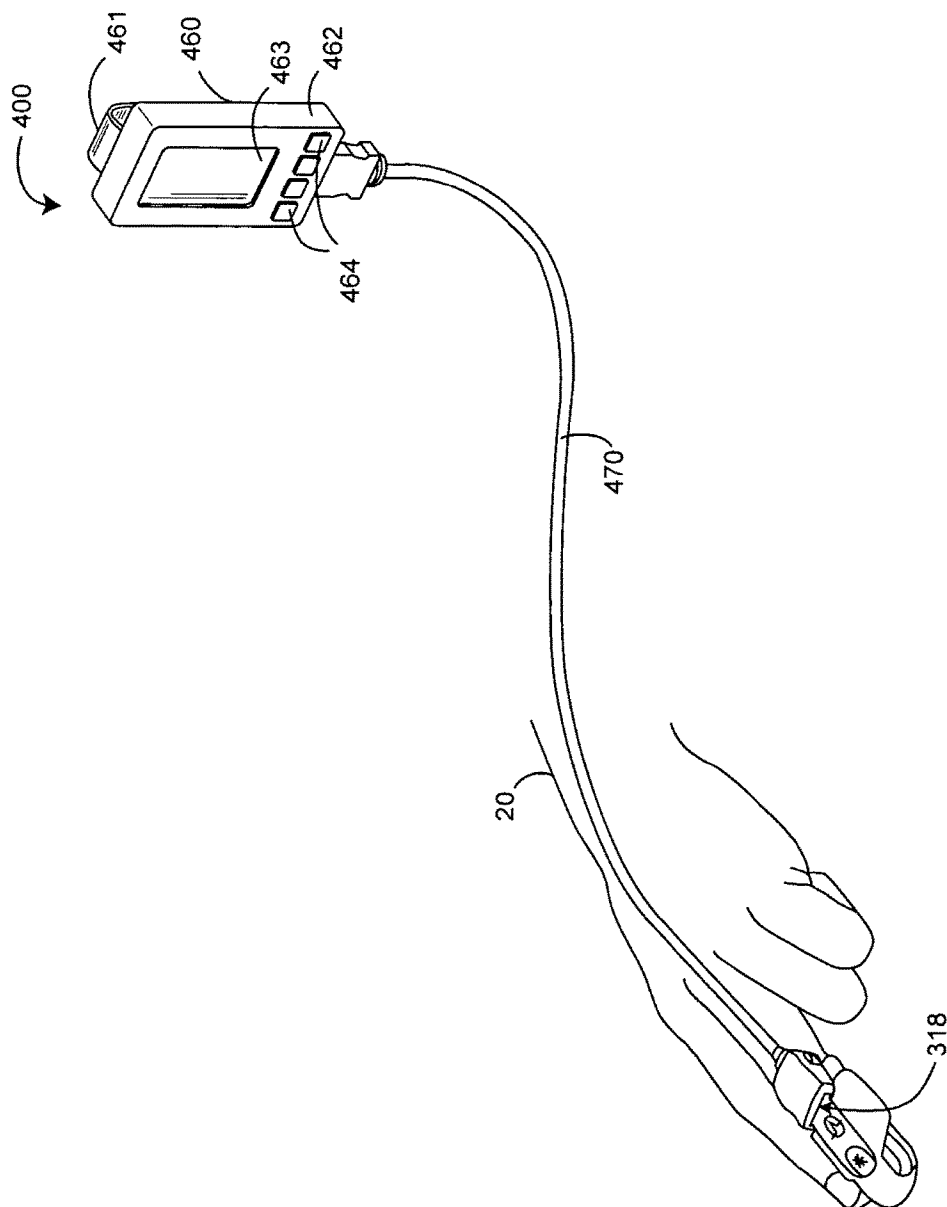


FIG. 4B

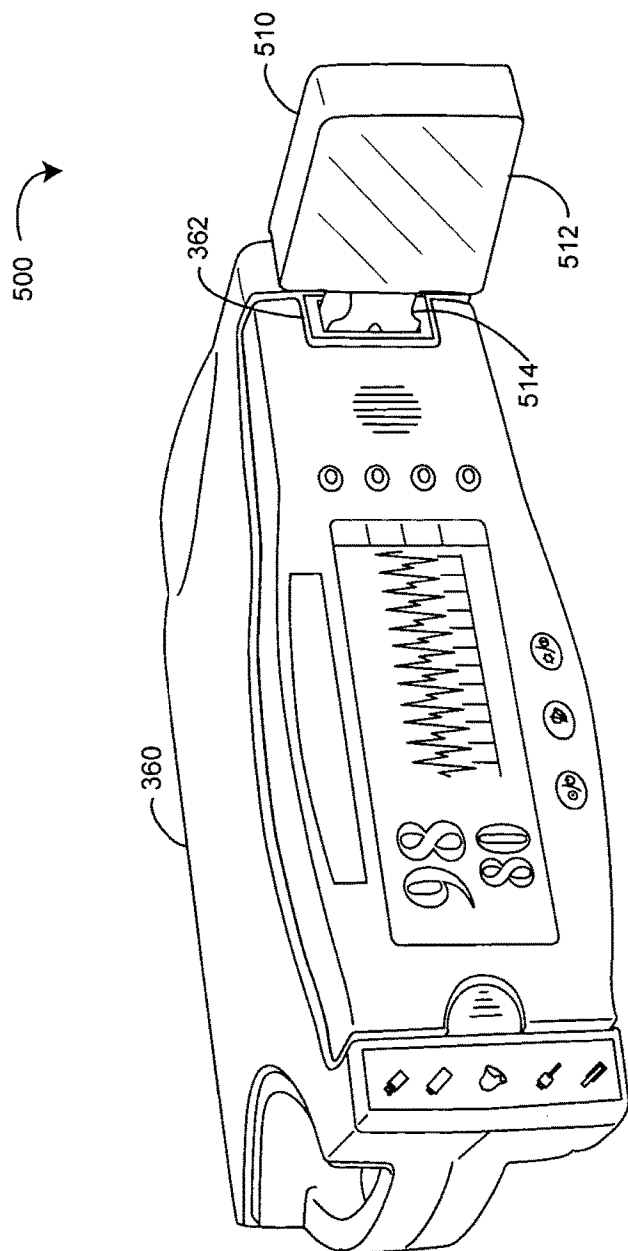


FIG. 5A

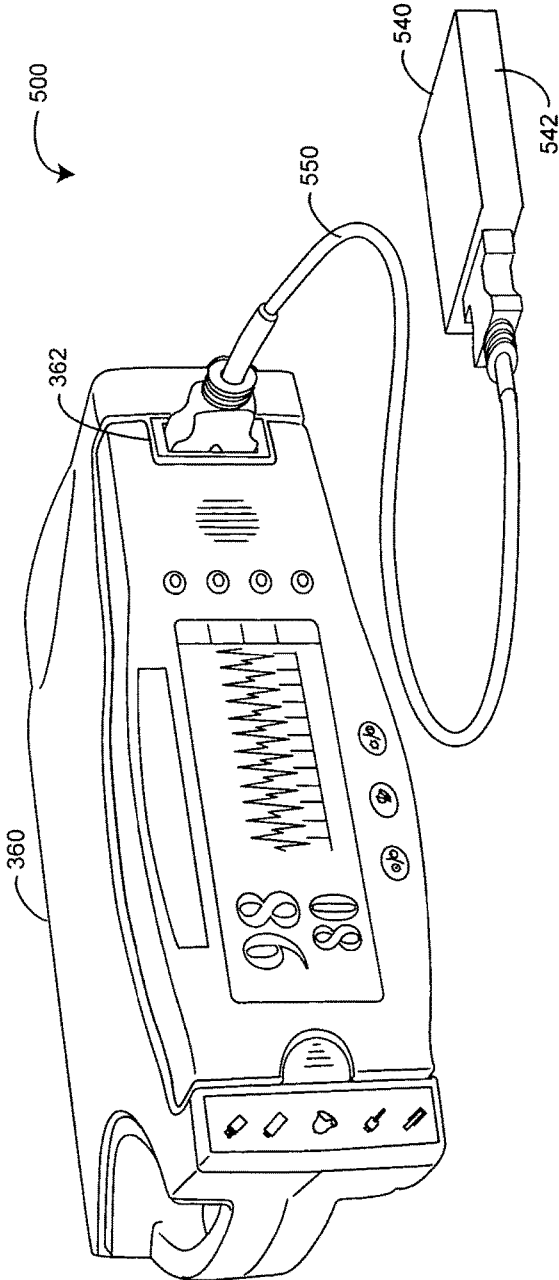


FIG. 5B

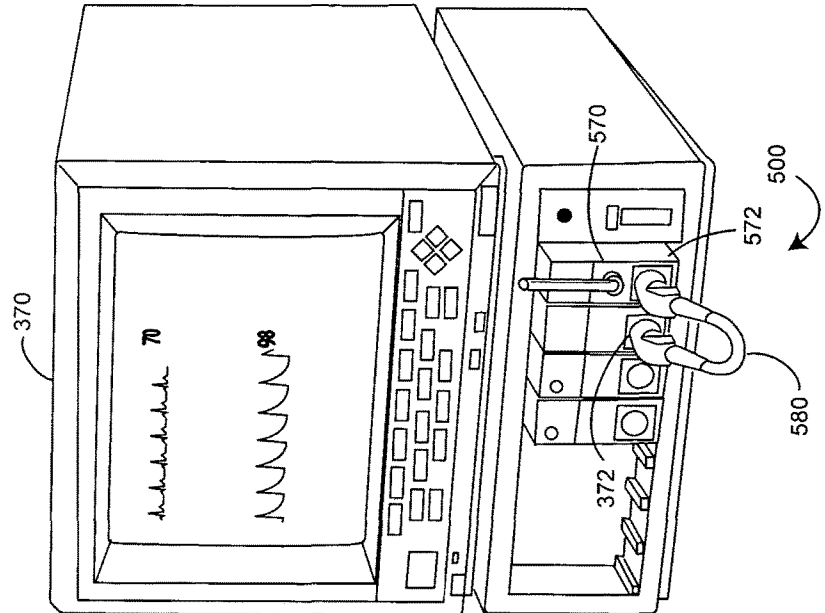


FIG. 5C

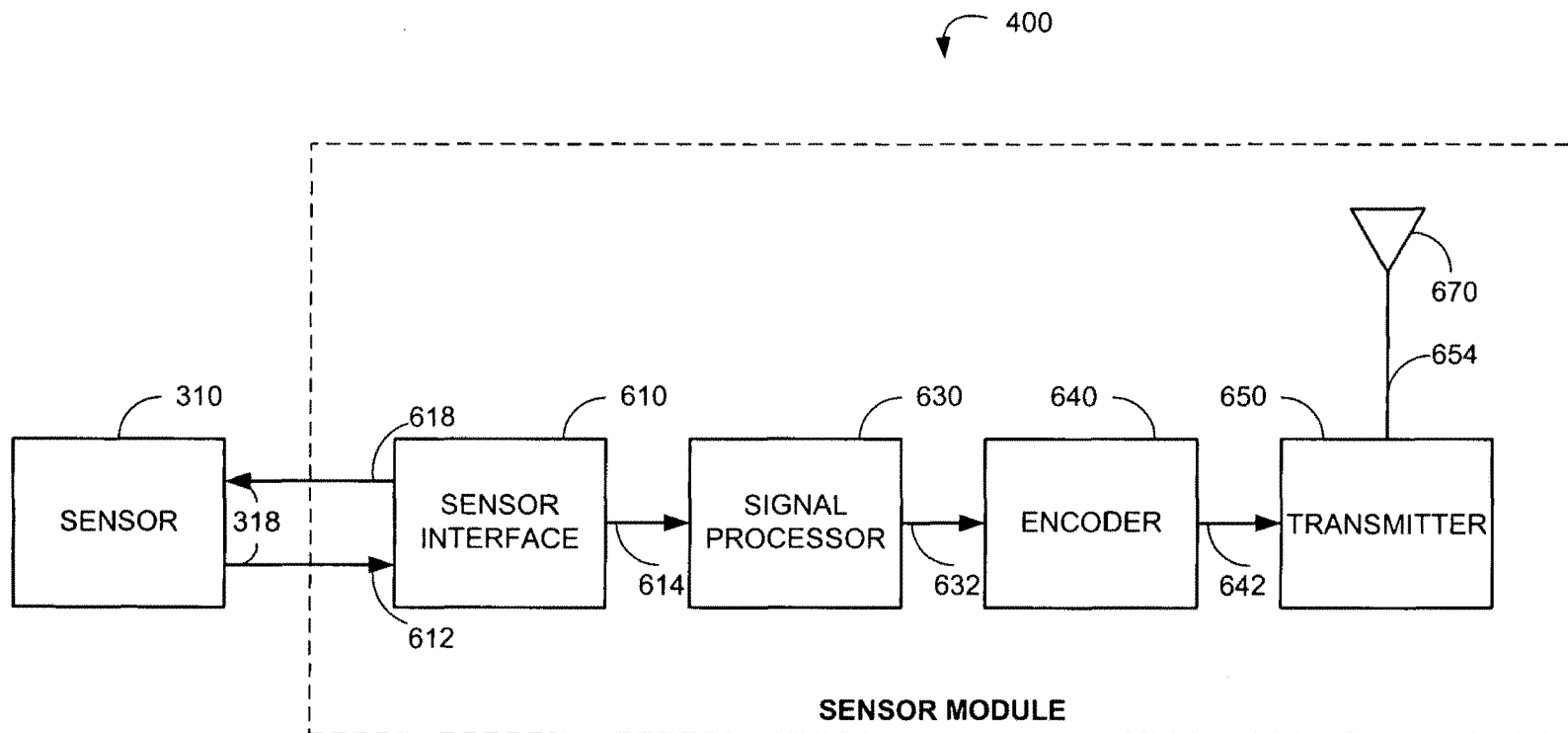


FIG. 6

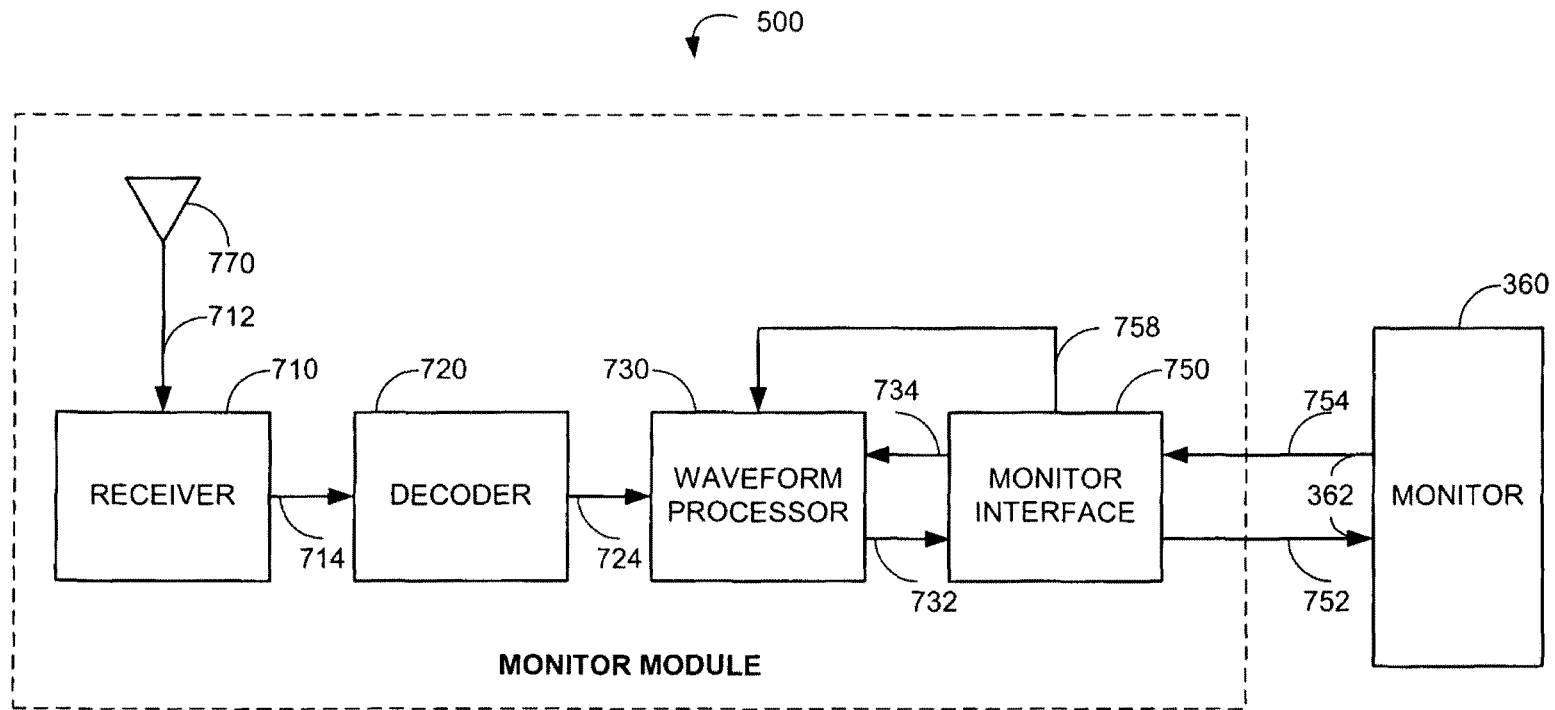


FIG. 7

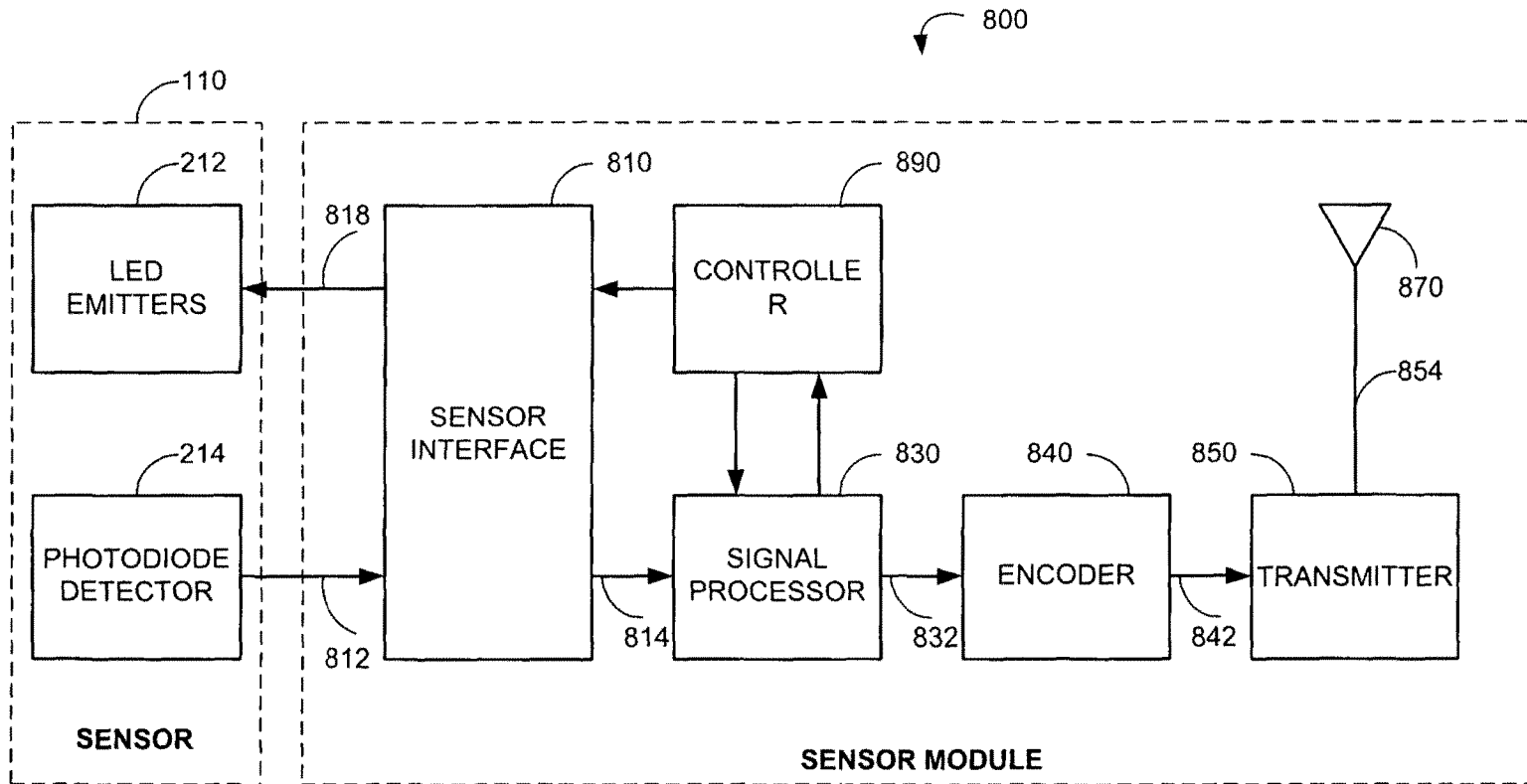


FIG. 8

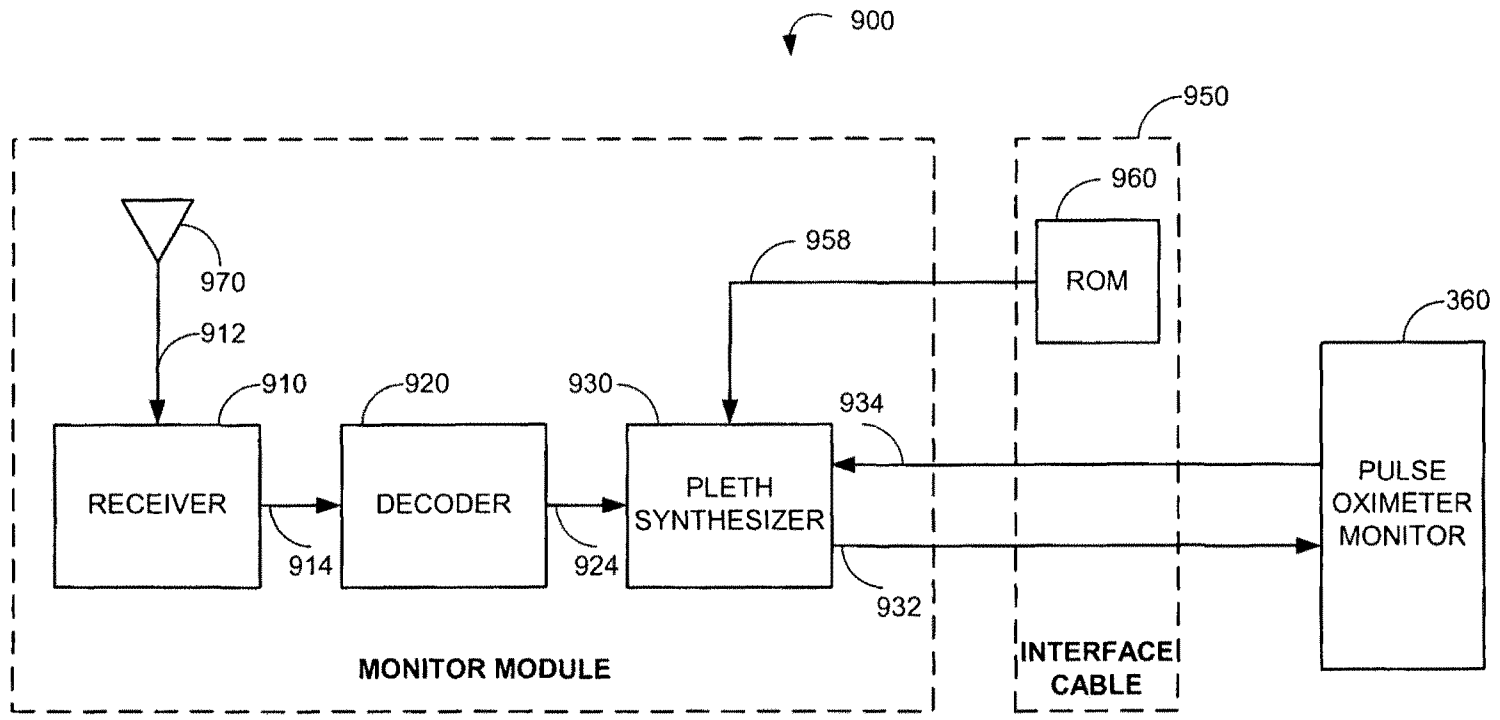


FIG. 9

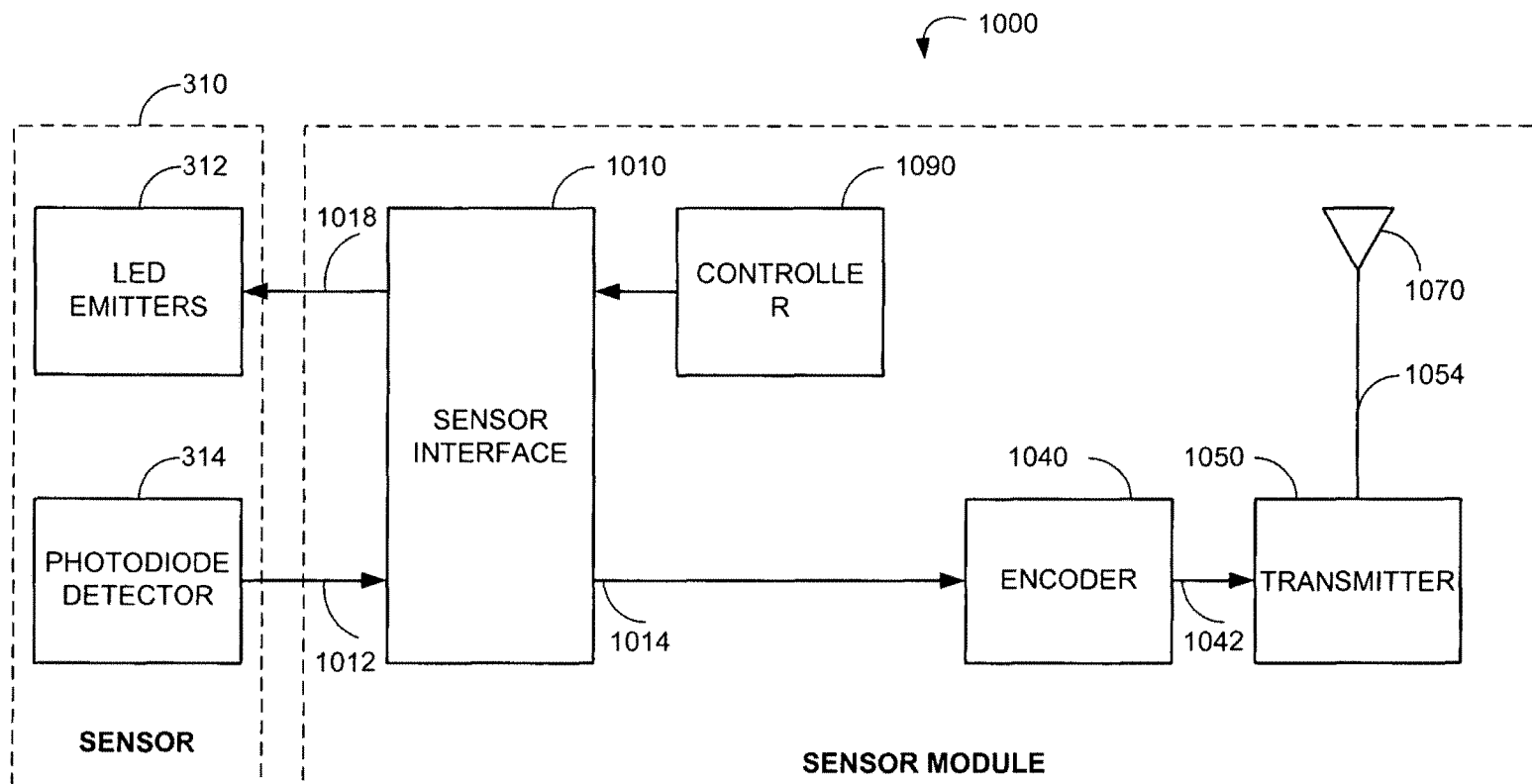


FIG. 10

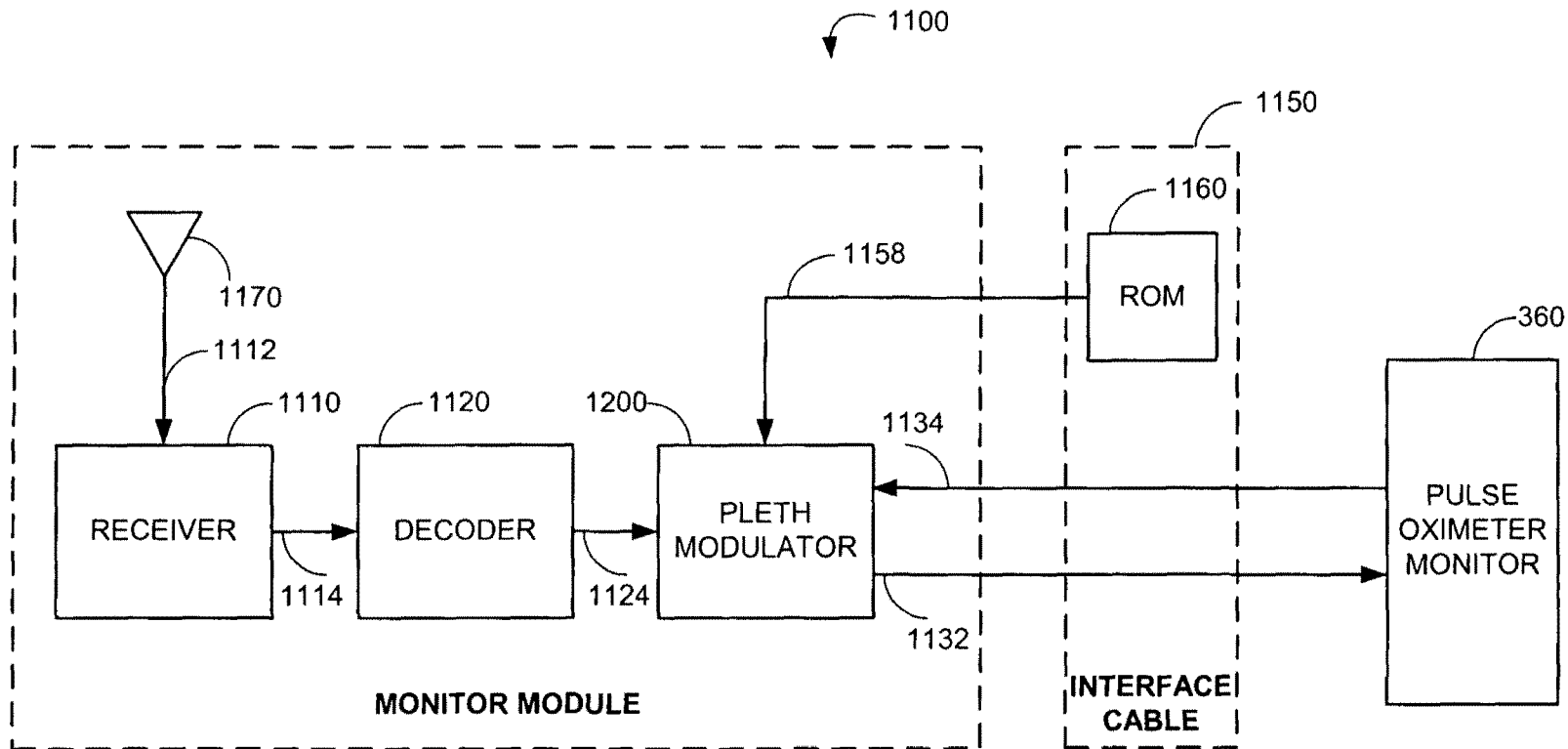


FIG. 11

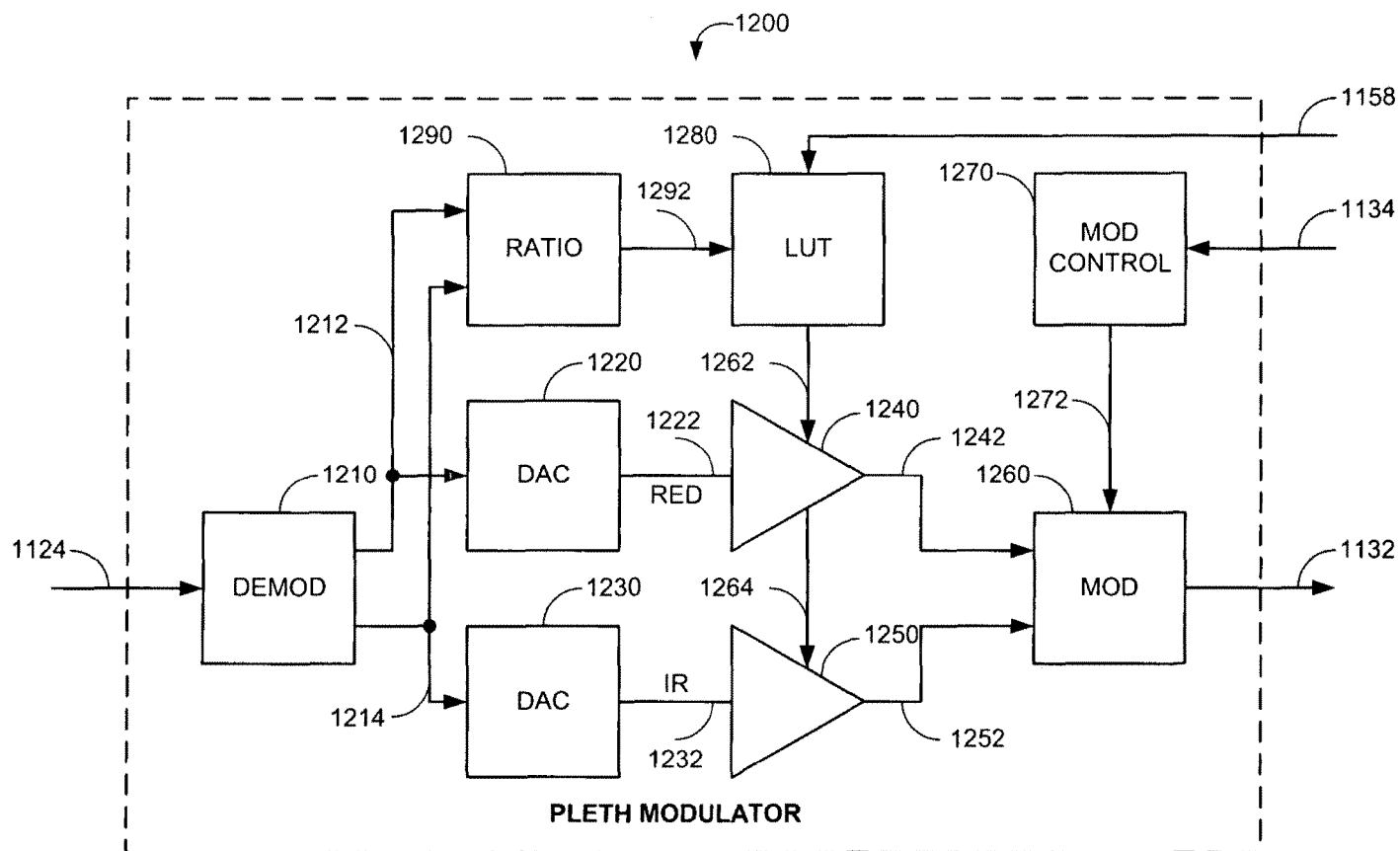


FIG. 12

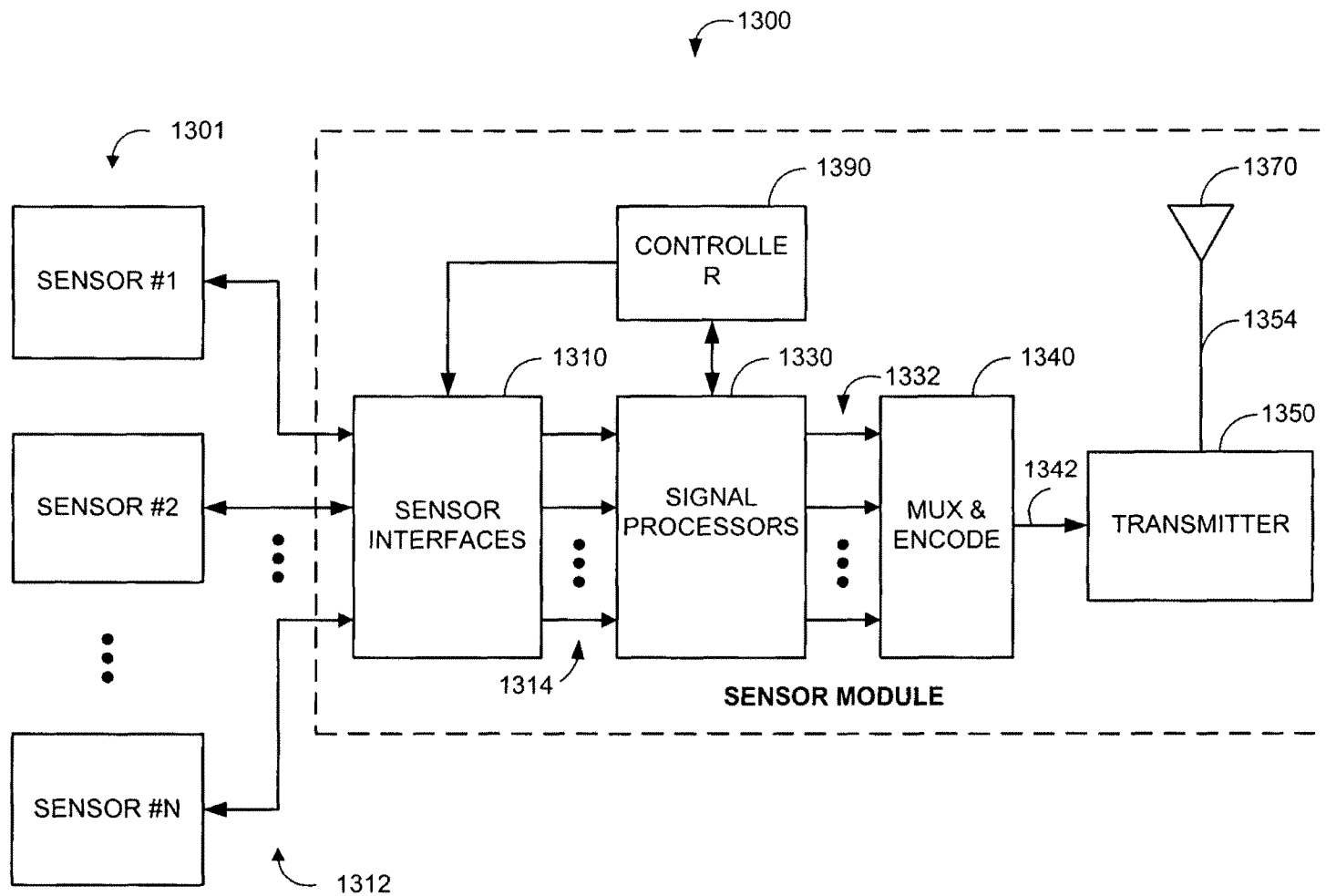


FIG. 13

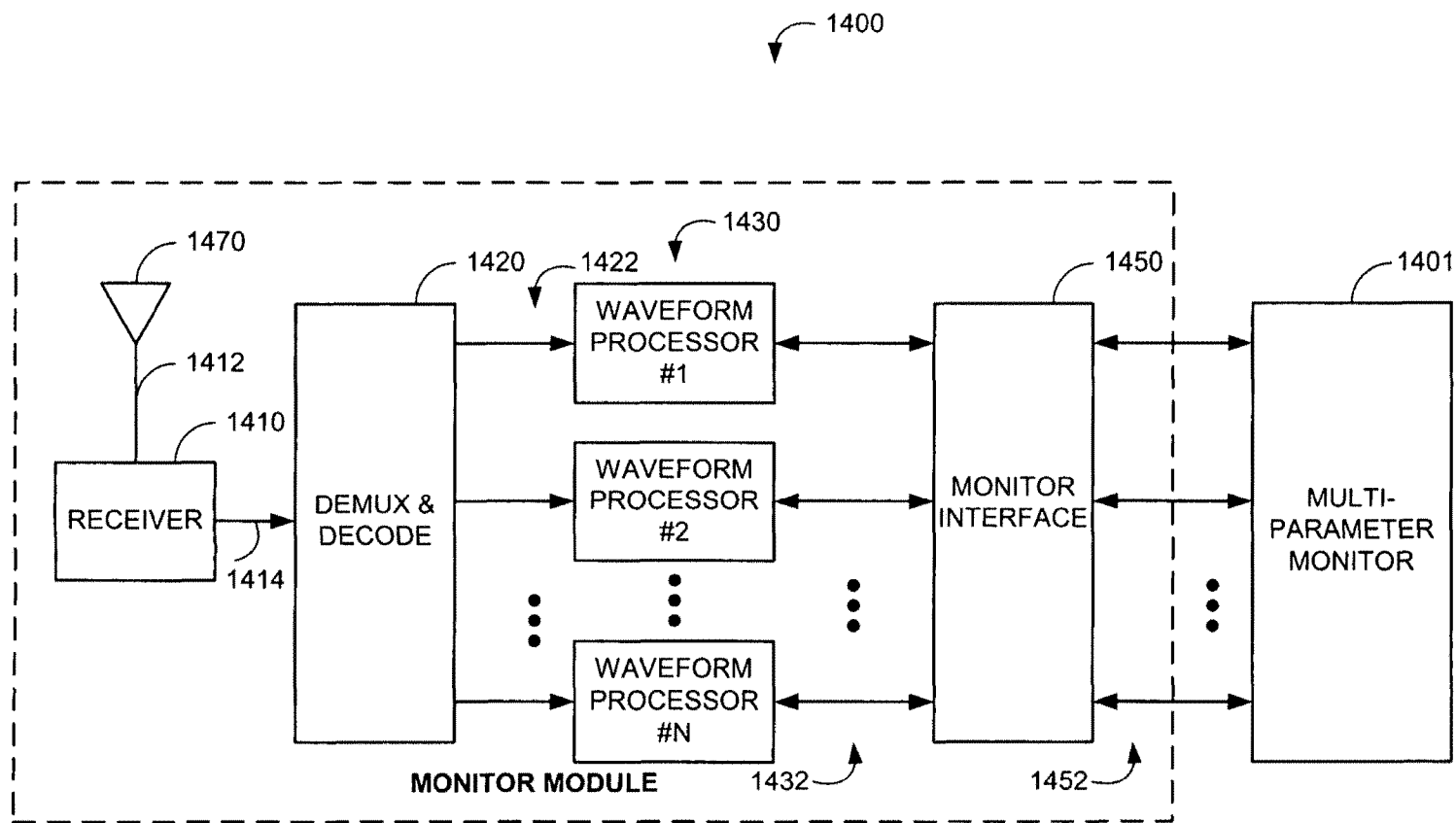


FIG. 14

1

**ARM MOUNTABLE PORTABLE PATIENT
MONITOR**

REFERENCE TO RELATED APPLICATION

The present application is a continuation of U.S. patent application Ser. No. 14/815,232, filed on Jul. 31, 2015, entitled "Physiological Measurement Communications Adapter," which is a continuation of U.S. patent application Ser. No. 14/217,788, filed on Mar. 18, 2014, entitled "Wrist-Mounted Physiological Measurement Device," now U.S. Pat. No. 9,113,832, which is a continuation of U.S. patent application Ser. No. 14/037,137, filed on Sep. 25, 2013, entitled "Physiological Measurement Communications Adapter," now U.S. Pat. No. 9,113,831, which is a continuation of U.S. patent application Ser. No. 12/955,826, filed on Nov. 29, 2010, entitled "Physiological Measurement Communications Adapter," now U.S. Pat. No. 8,548,548, 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** corre-

2

sponding 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** provides 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 adjusted 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

3

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 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;

4

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;

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

5

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.

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

6

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 connect 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 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 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 SpO₂ 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

11

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.

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**,

12

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 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.

13

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. An arm mountable portable patient monitoring device configured to receive physiological information from a plurality of sensors attached to a patient at at least two different measurement sites via wired connections for on-patient monitoring of parameter measurements and wireless transmission of parameter measurements to separate monitoring devices, the portable patient monitoring device comprising:
 - a housing configured to be secured to an arm of a patient under measurement;
 - a strap mountable to a back side of the housing and configured to secure the housing to the arm of the patient;
 - a display positioned on a front side of the housing, the display configured to show at least one status indicator of the portable patient monitoring device and one or more parameter measurements;
 - a first sensor port positioned on a first side of the housing, the first side of the housing configured to face toward a hand of the arm of the patient when the housing is secured to the arm of the patient, the first sensor port configured to electrically receive a signal from a pulse oximetry sensor via a wired connection from the pulse oximetry sensor to the first sensor port, the wired connection configured to extend from the first sensor port along a path substantially perpendicular to the first side of the housing;
 - a second sensor port positioned on the housing and configured to receive a signal from a second sensor arrangement via a wired connection;
 - a third sensor port positioned on the housing configured to receive a signal from a third sensor arrangement via a wired connection;
 - one or more signal processing arrangements configured to:
 - receive the signal from the pulse oximetry sensor; and
 - cause to be displayed, on the display, at least measurements of oxygen saturation and pulse rate derived from the signal; and
 - a transmitter configured to:
 - wirelessly transmit information indicative of the measurements of oxygen saturation and pulse rate to a separate monitoring device configured to receive the information indicative of the measurements of oxygen saturation and pulse rate.
2. The portable patient monitoring device of claim 1, wherein the wired connection from the pulse oximetry sensor to the first sensor port is provided at least in part via a tail of the pulse oximetry sensor.
3. The portable patient monitoring device of claim 2, wherein the wired connection is configured to run from the first sensor port, at least part way down the arm of the patient, and to a digit of the patient to which the pulse oximetry sensor is configured to be attached.
4. The portable patient monitoring device of claim 3, wherein the digit is a thumb of the patient.
5. The portable patient monitoring device of claim 1 further comprising:

14

- a cable providing the wired connection from the pulse oximetry sensor to the first sensor port.
6. The portable patient monitoring device of claim 5, wherein the cable is configured to be removably coupled to the housing via the first sensor port.
7. The portable patient monitoring device of claim 6, wherein the cable is configured to run from the first sensor port, at least part way down the arm of the patient, and to a digit of the patient to which the pulse oximetry sensor is configured to be attached, wherein the digit is on the hand of the arm of the patient.
8. The portable patient monitoring device of claim 7, wherein the digit is a thumb of the patient.
9. The portable patient monitoring device of claim 1, further comprising:
 - a battery configured to provide power to at least the display and the first sensor port.
10. The portable patient monitoring device of claim 1, wherein the front side of the housing comprises a single user interface.
11. The portable patient monitoring device of claim 10, wherein the single user interface comprises the display.
12. The portable patient monitoring device of claim 11, wherein the display is positioned centrally on the front side of the housing.
13. The portable patient monitoring device of claim 12, wherein the display positioned on the front side of the housing is sized such that the display covers most of a length of a shortest dimension of the front side of the housing.
14. The portable patient monitoring device of claim 1, wherein the one or more signal processing arrangements are further configured to:
 - receive signals from the second and third sensor arrangements; and
 - cause to be displayed, on the display, at least measurements of one or more additional physiological parameters based on the signals from the second and third sensor arrangements.
15. The portable patient monitoring device of claim 14, wherein the one or more signal processing arrangements are further configured to:
 - receive signals from the second and third sensor arrangements; and
 - cause to be displayed, on the display, measurements of all of the oxygen saturation, pulse rate, and the one or more additional physiological parameters.
16. The portable patient monitoring device of claim 15, wherein the transmitter is further configured to:
 - wirelessly transmit information indicative of the measurements of oxygen saturation, pulse rate, and the one or more additional physiological parameters to the separate monitoring device.
17. A method of portable patient monitoring comprising:
 - providing a portable patient monitoring device according to claim 1;
 - attaching the strap to the arm of the patient;
 - mounting the housing to the strap such that the first sensor port positioned on a first side of the housing faces toward the hand of the arm of the patient;
 - wrapping the pulse oximetry sensor around a digit of the hand of the patient;
 - attaching the wired connection from the pulse oximetry sensor to the first sensor port positioned on the first side of the housing; and
 - activating the portable patient monitoring device such that measurements of oxygen saturation and pulse rate are both:

15

displayed on the display of the portable patient monitoring device on the patient; and wirelessly transmitted to the separate monitoring device configured to receive the measurements of oxygen saturation and pulse rate.

18. The method of claim 17, further comprising:

attaching the second sensor arrangement to a second measurement site on the patient different from the hand of the patient;

attaching the wired connection from the second sensor arrangement to the second sensor port;

attaching the third sensor arrangement to a third measurement site on the patient different from both the hand of the patient and the second measurement site; and

attaching the wired connection from the third sensor arrangement to the third sensor port,

wherein the portable patient monitoring device is further activated such that measurements of one or more additional physiological parameters are both:

displayed on the display of the portable patient monitoring device on the patient; and

wirelessly transmitted to the separate monitoring device.

19. An arm mountable portable patient monitoring device configured to receive physiological information from a plurality of sensors attached to a patient at at least two different measurement sites via wired connections for on-patient monitoring of parameter measurements and wireless transmission of parameter measurements to separate monitoring devices, the portable patient monitoring device comprising:

a housing configured to be secured to an arm of a patient under measurement, the housing comprising a front side including a single user interface, the single user interface comprising a display configured to show at least one or more parameter measurements;

a strap mountable to a back side of the housing and configured to secure the housing to the arm of the patient;

a first sensor port positioned on a first side of the housing, the first side of the housing configured to face toward a hand of the arm of the patient when the housing is secured to the arm of the patient, the first sensor port configured to electrically receive a signal from a pulse oximetry sensor via a wired connection from the pulse oximetry sensor to the first sensor port, the signal from the pulse oximetry sensor including analog information;

a second sensor port positioned on the housing and configured to receive a signal from a second sensor arrangement via a wired connection, the signal from the second sensor arrangement including digital information;

a third sensor port positioned on the housing configured to receive a signal from a third sensor arrangement via a wired connection;

16

one or more signal processing arrangements configured to:

receive the signal from the pulse oximetry sensor including the analog information;

receive the signal from the second sensor arrangement including the digital information;

determine digital transmit information based at least in part on: the analog information included in the signal from the pulse oximetry sensor, and the digital information included in the signal from the second sensor arrangement; and

cause to be displayed, on the display, at least measurements of oxygen saturation and pulse rate derived from the signal from the pulse oximetry sensor; and

a transmitter configured to:

wirelessly transmit the digital transmit information to a separate monitoring device configured to receive the digital transmit information, wherein the digital transmit information includes at least measurements of oxygen saturation and pulse rate derived from the signal from the pulse oximetry sensor, and wherein the digital transmit information further includes at least physiological measurements derived from the signal from the second sensor arrangement.

20. The portable patient monitoring device of claim 19, wherein the display is positioned centrally on the front side of the housing and sized such that, if measured along a shortest dimension of the front side of the housing, the display comprises most of a length of the shortest dimension.

21. A method of portable patient monitoring comprising: providing a portable patient monitoring device according to claim 19;

attaching the housing to the arm of the patient via the strap such that the first sensor port positioned on a first side of the housing faces toward the hand of the arm of the patient;

attaching the pulse oximetry sensor to a digit of the hand of the patient;

attaching the second sensor arrangement to the patient; attaching the wired connection from the pulse oximetry sensor to the first sensor port positioned on the first side of the housing;

attaching the wired connection from the second sensor arrangement to the second sensor port; and

activating the portable patient monitoring device such that measurements of oxygen saturation and pulse rate are displayed on the display of the portable patient monitoring device on the patient.

22. The method of claim 21, wherein activating the portable patient monitoring device further includes causing the digital transmit information to be wirelessly transmitted to the separate monitoring device configured to receive the digital transmit information.

* * * * *