United States Patent [19]

Diab et al.

[11] Patent Number: 5,632,272

[45] Date of Patent: May 27, 1997

[54] SIGNAL PROCESSING APPARATUS

[75] Inventors: **Mohamed K. Diab; Esmaiel Kiani-Azarbayjany; Ibrahim M. Elfadel**, all of Laguna Niguel; **Rex J. McCarthy**, Mission Viejo; **Walter M. Weber**, Los Angeles; **Robert A. Smith**, Corona, all of Calif.

[73] Assignee: **Masimo Corporation**, Mission Viejo, Calif.

[21] Appl. No.: **320,154**

[22] Filed: **Oct. 7, 1994**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 132,812, Oct. 6, 1993, Pat. No. 5,490,505, and a continuation-in-part of Ser. No. 249,690, May 26, 1994, Pat. No. 5,482,036, which is a continuation of Ser. No. 666,060, Mar. 7, 1991, abandoned.

[51] Int. Cl.^{6} **A61B 5/00**

[52] U.S. Cl. **128/633**; 128/666

[58] Field of Search 128/633–634, 128/664–667, 672, 687–688, 716; 356/39–41

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,647,299	3/1972	Lavallee .
3,704,706	12/1972	Herczfeld et al. .
4,063,551	12/1977	Sweeney .
4,086,915	5/1978	Kofsky et al. .
4,095,117	6/1978	Nagy .
4,407,290	10/1983	Wilber .
4,537,200	8/1985	Widrow .
4,649,505	3/1987	Zinser, Jr. et al. .
4,773,422	9/1988	Isaacson et al. .
4,799,493	1/1989	DeFault .
4,800,495	1/1989	Smith .
4,824,242	4/1989	Frick et al. .
4,848,901	7/1989	Hood, Jr. .
4,860,759	8/1989	Kahn et al. .
4,863,265	9/1989	Flower et al. .
4,867,571	9/1989	Frick et al. .
4,869,253	9/1989	Craig, Jr. et al. .
4,869,254	9/1989	Stone et al. .
4,883,353	11/1989	Hausman .
4,892,101	1/1990	Cheung et al. .
4,907,594	3/1990	Muz .
4,911,167	3/1990	Corenman et al. .
4,927,264	5/1990	Shiga et al. .
4,928,692	5/1990	Goodman et al. .
4,948,248	8/1990	Lehman .
4,955,379	9/1990	Hall .
4,956,867	9/1990	Zurek et al. .
5,057,695	10/1991	Hirao et al. .
5,273,036	12/1993	Kronberg et al. .
5,458,128	10/1995	Polanyi et al. .... 128/633 X

OTHER PUBLICATIONS

Rabiner, Lawrence et al. *Theory and Application of Digital Signal Processing*, p. 260, 1975.

Tremper, Kevin et al., *Advances in Oxygen Monitoring*, pp. 137–153, 1987.

Harris, Fred et al., "Digital Signal Processing with Efficient Polyphase Recursive All–Pass Filters", Presented at International Conference on Signal Processing, Florence, Italy, Sep. 4–6, 1991, 6 pages.

(List continued on next page.)

Primary Examiner—Angela D. Sykes
Attorney, Agent, or Firm—Knobbe, Martens, Olson & Bear, LLP.

[57] **ABSTRACT**

The present invention involves method and apparatus for analyzing two measured signals that are modeled as containing primary and secondary portions. Coefficients relate the two signals according to a model defined in accordance with the present invention. In one embodiment, the present invention involves utilizing a transformation which evaluates a plurality of possible signal coefficients in order to find appropriate coefficients. Alternatively, the present invention involves using statistical functions or Fourier transform and windowing techniques to determine the coefficients relating to two measured signals. Use of this invention is described in particular detail with respect to blood oximetry measurements.

23 Claims, 37 Drawing Sheets
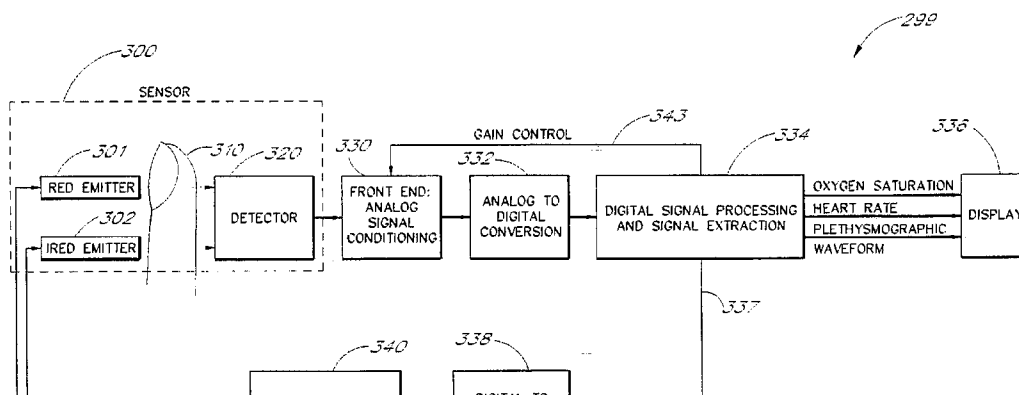
OTHER PUBLICATIONS

Haykin, Simon, *Adaptive Filter Theory,* Prentice Hall, Englewood Cliffs, NJ, 1985.

Widrow, Bernard, *Adaptive Signal Processing,* Prentice Hall, Englewood Cliffs, NJ 1985.

Brown, David P., "Evaluation of Pulse Oximeters using Theoretical Models and Experimental Studies", Master's thesis, University of Washington, Nov. 25, 1987, pp. 1–142.

Cohen, Arnon, "Volume I Time and Frequency Domains Analysis", *Biomedical Signal Processing,* CRC Press, Inc., jBoca Raton, Florida, pp. 152–159.

Severinghaus, J.W., "Pulse Oximetry Uses and Limitations", pp. 1–4, ASA Convention, New Orleans, 1989.

Mook, G.A., et al., "Spectrophotometirc determination of Oxygen saturation of blood independent of the presence of indocyanine green", *Cardiovascular Research,* vol. 13, pp. 233–237, 1979.

Neuman, Michael R., "Pulse Oximetry: Physical Principles, Technical Realization and Present Limitations", *Continuous Transcutaneous Monitoring,* Plenum Press, New York, 1987, pp. 135–144.

Mook, G.A., et al., "Wavelength dependency of the spectrophotometric determination of blood oxygen saturation", *Clinical Chemistry Acta,* vol. 26, pp. 170–173, 1969.

Klimasauskas, Casey, "Neural Nets and Noise Filtering", *Dr. Dobb's Journal,* Jan. 1989, p. 32.

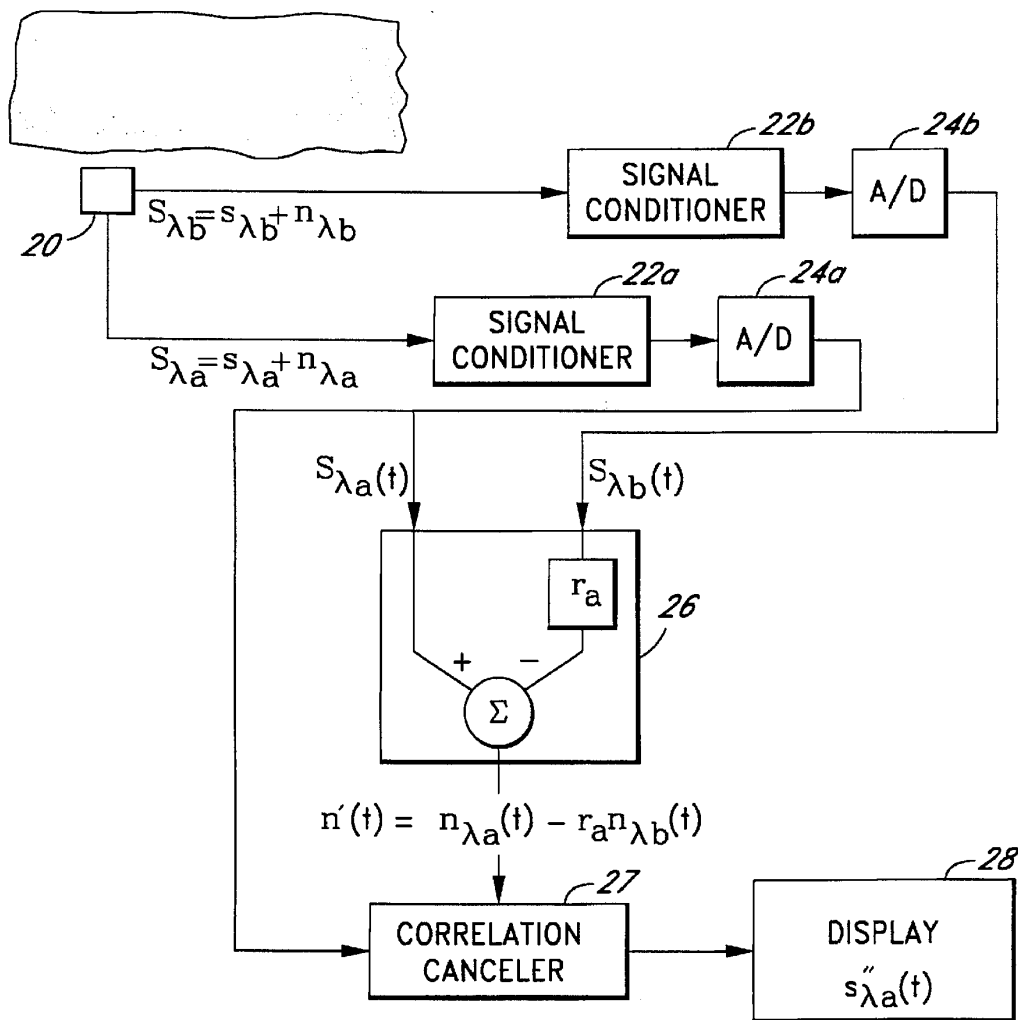Melnikof, S. "Neural Networks for Signal Processing: A Case Study", *Dr. Dobbs Journal,* Jan. 1989. pp. 36–37.

FIG. 1

FIG. 2

BONE
MUSCLE
TISSUE
ARTERIAL BLOOD
VENOUS BLOOD
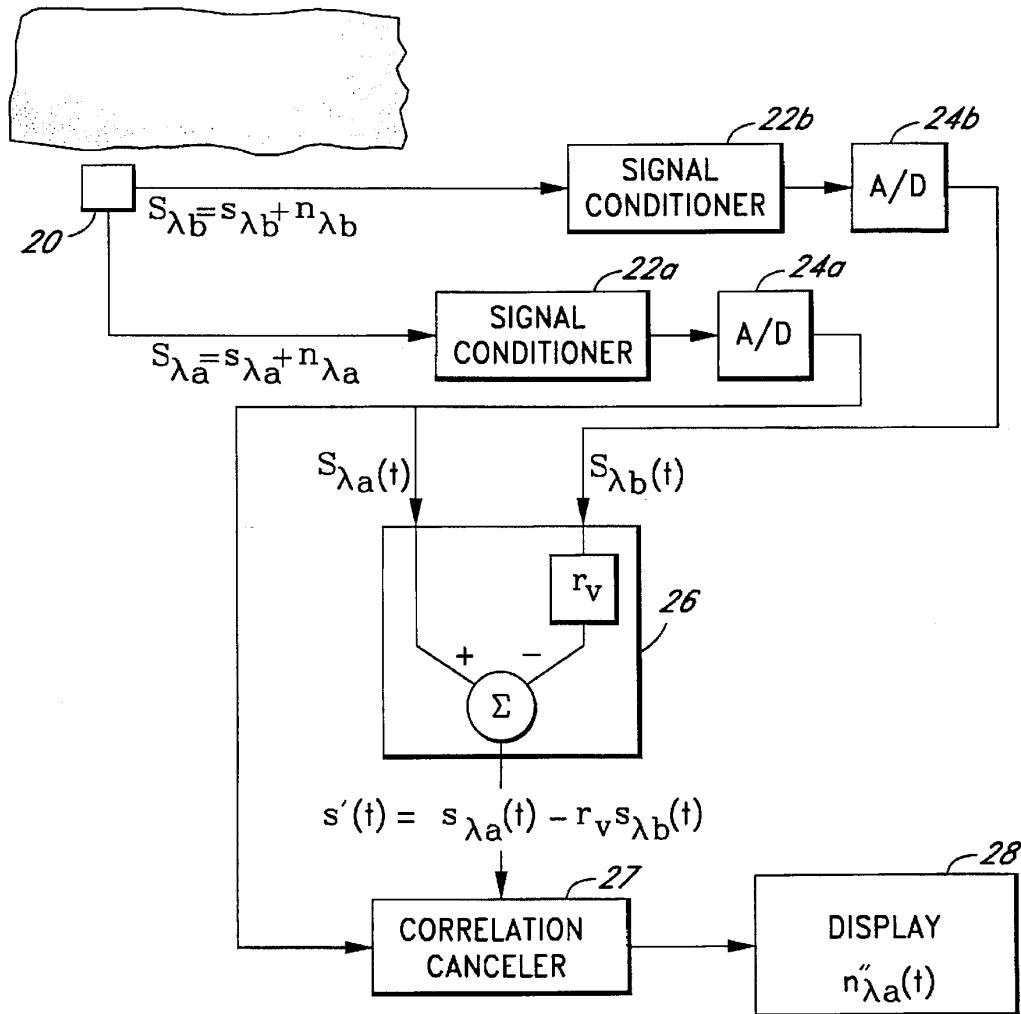
FIG. 3

$S = s + n$
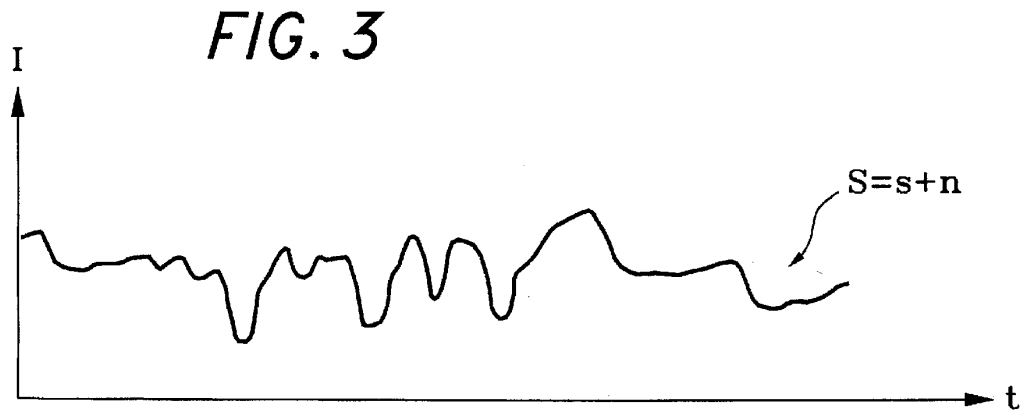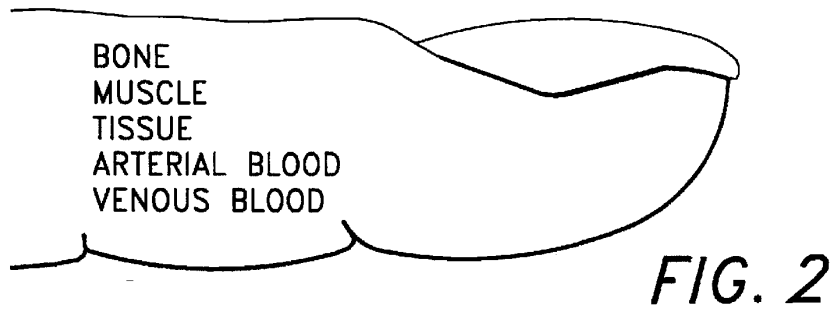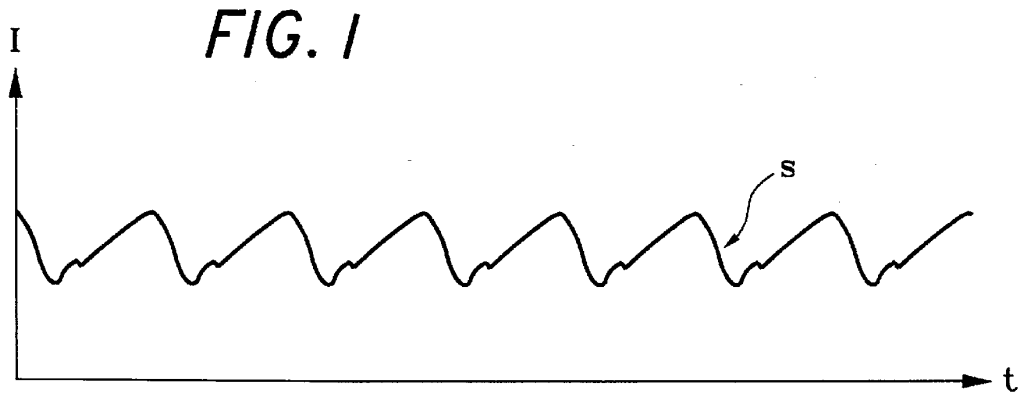
FIG. 4a

FIG. 4b

DOCKET ALARM

Explore Litigation Insights

Docket Alarm provides insights to develop a more informed litigation strategy and the peace of mind of knowing you're on top of things.

Real-Time Litigation Alerts

Keep your litigation team up-to-date with **real-time alerts** and advanced team management tools built for the enterprise, all while greatly reducing PACER spend.

Our comprehensive service means we can handle Federal, State, and Administrative courts across the country.

Advanced Docket Research

With over 230 million records, Docket Alarm's cloud-native docket research platform finds what other services can't. Coverage includes Federal, State, plus PTAB, TTAB, ITC and NLRB decisions, all in one place.

Identify arguments that have been successful in the past with full text, pinpoint searching. Link to case law cited within any court document via Fastcase.

Analytics At Your Fingertips

Learn what happened the last time a particular judge, opposing counsel or company faced cases similar to yours.

Advanced out-of-the-box PTAB and TTAB analytics are always at your fingertips.

API

Docket Alarm offers a powerful API (application programming interface) to developers that want to integrate case filings into their apps.

LAW FIRMS

Build custom dashboards for your attorneys and clients with live data direct from the court.

Automate many repetitive legal tasks like conflict checks, document management, and marketing.

FINANCIAL INSTITUTIONS

Litigation and bankruptcy checks for companies and debtors.

E-DISCOVERY AND LEGAL VENDORS

Sync your system to PACER to automate legal marketing.

fastcase®
Smarter legal research.