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(54) **DELTA-SIGMA MODULATOR FOR OUTPUTTING ANALOG REPRESENTATION OF PHYSIOLOGICAL SIGNAL**

DELTA-SIGMA-MODULATOR ZUR AUSGABE EINER ANALOG-DARSTELLUNG EINES PHYSIOLOGISCHEN SIGNALS

MODULATEUR DELTA-SIGMA POUR RESTITUER UNE REPRESENTATION ANALOGIQUE D'UN SIGNAL PHYSIOLOGIQUE

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Description

[0001] The present invention relates to oximeters, and in particular to analog waveform displays in pulse oximeters.

[0002] Pulse oximetry is typically used to measure various blood chemistry characteristics including, but not limited to, the blood-oxygen saturation of hemoglobin in arterial blood, the volume of individual blood pulsations supplying the tissue, and the rate of blood pulsations corresponding to each heartbeat of a patient. Measurement of these characteristics has been accomplished by use of a non-invasive sensor which scatters light through a portion of the patient's tissue where blood perfuses the tissue, and photoelectrically senses the absorption of light in such tissue. The amount of light absorbed at various frequencies is then used to calculate the amount of blood constituent being measured.

[0003] The light scattered through the tissue is selected to be of one or more wavelengths that are absorbed by the blood in an amount representative of the amount of the blood constituent present in the blood. The amount of transmitted light scattered through the tissue will vary in accordance with the changing amount of blood constituent in the tissue and the related light absorption. For measuring blood oxygen level, such sensors have typically been provided with a light source that is adapted to generate light of at least two different wavelengths, and with photodetectors sensitive to both of those wavelengths, in accordance with known techniques for measuring blood oxygen saturation.

[0004] US 5,921,921 discloses an oximeter that detects the transillumination by red and infrared light of a portion of an in vivo subject and produces analog signals representative thereof on two channels. It has a delta-sigma modulator for conversion from analog into digital form.

[0005] Known non-invasive sensors include devices that are secured to a portion of the body, such as a finger, an ear or the scalp. In animals and humans, the tissue of these body portions is perfused with blood and the tissue surface is readily accessible to the sensor.

[0006] Pulse oximeters, after processing the sensor data and calculating oxygen saturation, present that information to a display. In some pulse oximeters, it is also desirable to display the analog waveform itself. For example, US Patent No. 6,188,470 shows a signal for a display reflecting the waveform. US Patent No. 6,385,471 also discusses a waveform display, and sets forth that the data is first digitized, prefiltered, and then reconstructed for the display.

[0007] Nellcor Puritan Bennett, the assignee of the present invention, provides analog outputs in a number of its products. The analog outputs are used for such purposes as synchronizing to other instruments (e.g., EKG, multi-parameter monitor) as well as for a display. The analog waveforms are sometimes provided from the hardware pre-processing circuitry, to insure the analog signal is close in time to the actual patient waveform.

[0008] A problem with providing an analog waveform to a display after processing is that the processing takes some time, and thus the signal provided is delayed and not real-time.

[0009] It is an object of the invention to provide a method and apparatus for generating a substantially real-time representation of an analog representation of a physiological signal. This object can be achieved by a method and apparatus as defined in the independent claims. Further enhancements are defined in the dependent claims. The present invention provides a method and apparatus for providing a substantially real-time representation of an analog representation of a physiological signal. The waveform signal from the sensor is converted into digital form. A delta-sigma modulator is used as a simple Digital-to-analog Converter (ADC). The output can then be provided through a simple hardware filter to give an analog output signal in nearly real-time, which can be used for other instruments, synchronization, display, etc.

[0010] The invention allows a waveform to be converted into digital form, and supplied to the software, while still allowing fast conversion back into hardware after initial processing in software. In particular, for a pulse oximeter that does demodulation in software, the digital IR signal can be obtained after this software demodulation, but before the much slower software filtering process used as part of the process to calculate oxygen saturation.

[0011] In one embodiment, in a first path the digital signal is processed, but a second path applies this digitized waveform to the delta-sigma modulator. The second path picks off the signal immediately after it is converted into digital form and demodulated. For a pulse oximeter, an IR signal is chosen for the analog output because it typically has less noise.

[0012] In one embodiment, the delta-sigma modulator is a software modulator which operates on the digitized version of the waveform. The delta-sigma modulator provides a single bit, serial output. This output is provided to a hardware RC filter, and then to the display.

[0013] For a further understanding of the nature and advantages of the invention, reference should be made to the following description taken in conjunction with the accompanying drawings.

Fig. 1 is a block diagram of an oximeter incorporating the present invention.
Fig. 2 is a block diagram of a prior art circuit for generating an analog output signal.
Fig. 3 is a block diagram of an embodiment of a circuit for generating an analog output signal according to the present invention.
Fig. 4 is a block diagram of the software delta-sigma modulator according to an embodiment of the present invention.

Fig. 5 is a circuit diagram of an embodiment of the hardware RC filter according to an embodiment of the present invention.

Fig. 6 is a front view of a monitor showing an analog display according to an embodiment of the present invention.

Overall System

[0014] Fig. 1 illustrates an embodiment of an oximetry system incorporating the present invention. A sensor 10 includes red and infrared LEDs and a photodetector. These are connected by a cable 12 to a board 14. LED drive current is provided by an LED drive interface 16. The received photocurrent from the sensor is provided to an I-V interface 18. The IR and red voltages are then provided to a sigma-delta interface 20 incorporating the present invention. The output of sigma-delta interface 20 is provided to a microcontroller 22. Microcontroller 22 includes flash memory for a program, and RAM memory for data. The oximeter also includes a microprocessor chip 24 connected to a flash memory 26. Finally, a clock 28 is used and an interface 30 to a digital calibration in the sensor 10 is provided. A separate host 32 receives the processed information, as well as receiving an analog signal on a line 34 for providing an analog display.

Prior Art Demodulation in Hardware

[0015] Fig. 2 shows an example of a prior art circuit for generating an analog output signal. A signal from a patient sensor is processed in hardware through a current-to-voltage converter (I-V) 36, and a filter 37. The red and IR signals are then demodulated in a demodulator 38. A red signal is provided through a first channel of a filter 39 and an amplifier 40 to an ADC 41. Similarly, the IR signal is provided through a second channel of filter 42, amplifier 43 and ADC 44. The analog output is obtained from the IR signal at the input of ADC 44.

Demodulation in Software in the Present Invention

[0016] Fig. 3 shows an embodiment of the present invention where demodulation isn't done in hardware, rather in software, so an analog IR signal simply is not available in hardware. A signal from a patient sensor is processed in hardware through a current-to-voltage converter 45 and a filter 46, then is supplied to an ADC 47. In software, a demodulator separates the red and IR signals. The red signal is then provided to a software filter 49 and further processing not shown. The IR signal is similarly provided through a software filter 50 and further processing not shown. Since the software filtering can cause a significant time delay, the IR signal before the filter 50 is converted back into analog form. A sigma-delta modulator 51 is used as a simple Digital-to-analog Converter (ADC). By using a sigma-delta modulator, the conversion process is simple and can be done quickly. The resulting analog signal then only needs to be filtered in a simple RC filter 52.

Sigma-delta Modulator and Filter for Simple DAC

[0017] Fig. 4 is a block diagram of a delta-sigma modulator 51 of Fig. 3 according to an embodiment of the invention. This modulator is preferably implemented in software running on microcontroller 22 of Fig. 1. An input on line 52 is the digitized sensor signal. In a preferred embodiment this signal is the infrared (IR) signal as opposed to the red signal. The infrared is chosen because it is typically a cleaner signal than the red signal. Fig. 4 is a graphical representation of the difference equations implemented to create the second order noise shaping for the quintile signal. In one implementation, pseudocode that implements the difference equations is:

X is the input on line 52

Y is the output on line 54

A, B, and C are intermediate variables that store data from one iteration to the next loop every 206μS

```
A = X - C + (2 * B)
C = B
if A > 1/2 then
       Y=1
else

       Y=0
```

```
end if
B=A-Y

end loop
```

This code is executed in a loop that executes every 206μS, so the output (Y) is a 4845 bits/sec bit stream with an average value that is equal to the input (X).

[0018] The output on line 54 is preferably a 4845 Hz bitstream. This is provided to the input 60 of a hardware filter as shown in Fig. 5. This filter includes resistors 62 and 64 and capacitors 66 and 68. This filter acts on the digital output signal to convert it into analog form to produce an output on line 70 that can be provided to a display. The filter is a passive, second order RC filter, without a buffer on the output. Any buffering could be done by the host system before displaying, if required.

[0019] Fig. 6 shows an example of an analog display 72 on a pulse oximeter monitor 74. The signal for this display is provided from line 70 of Fig. 5.

[0020] As will be understood by those of skill in the art, the present invention may be embodied in other specific forms without departing from the essential characteristics thereof. For example, the delta-sigma modulator could be of a different order than a second order. Some filtering could be done in software prior to the hardware filter, and a different configuration of the hardware filter could be used. Accordingly, the foregoing description is intended to be illustrative, but not limiting, of the scope of the invention which is set forth in the following claims.

Claims

1. A method for operating a physiological monitor comprising:

detecting an analog signal from a patient, wherein the analog signal comprises a physiological waveform;
converting the analog signal into a digital signal;
demodulating the digital signal to produce at least two demodulated physiological signals;
applying one of the demodulated physiological signals to a delta-sigma modulator (51) to provide an output signal; and
filtering said output signal to provide a real-time analog filtered physiological waveform output.

2. The method of claim 1, wherein said filtering is performed by a hardware filter (52) coupled to an output of said delta-sigma modulator (51).

3. The method of claim 1 or 2, wherein said delta-sigma modulator (51) provides a single bit output.

4. The method of one of the preceding claims, wherein the physiological waveform comprises a representation of an IR signal returned from a physiological sensor and a red signal returned from a physiological sensor.

5. The method of one of the preceding claims, wherein the demodulated waveform comprises a representation of an IR signal received from a physiological sensor.

6. The method of one of the preceding claims, wherein the delta-sigma modulator (51) is configured to provide second order noise shaping of the demodulated physiological signals.

7. The method of one of the preceding claims, wherein the delta-sigma modulator (51) is configured to output a serial bit stream (54) having a given frequency.

8. The method of claim 2, wherein the hardware filter (52) comprises an RC filter (62, 66, 64,68).

9. The method of one of the preceding claims, further comprising digitally filtering (49) of one of the demodulated physiological signals to provide a first digital output signal.

10. The method of one of the preceding claims, further comprising digitally filtering (50) of the other one of the demodulated physiological signals to provide a second digital output signal.

11. A physiological monitor apparatus comprising:

an input for receiving from a patient an analog signal including a physiological waveform;
an analog-to-digital converter (47) for converting said analog signal into a digital signal;
a demodulator for demodulating the digital signal to produce at least two demodulated physiological signals;
a delta-sigma modulator (51) configured to convert one of said demodulated physiological signals from digital into analog form;
a filter (52) coupled to an output of said delta-sigma modulator (51).

12. The physiological monitor apparatus of claim 11, wherein said delta-sigma modulator (51) is a software modulator that produces a serial, single bit output.

13. The physiological monitor apparatus of claim 11, wherein said filter (52) is a hardware RC filter (62, 64, 66, 68).

14. The physiological monitor apparatus of claim 11, further comprising a first digital filter (49) for filtering the at least other one of the demodulated physiological signals and/or a second digital filter (50) for filtering the at least one of the demodulated physiological signals.

15. The physiological monitor apparatus according to one of the preceding claims 11-14, wherein the physiological monitor apparatus is an oximeter apparatus; the physiological waveform is a pulse oximetry waveform; the processor includes a demodulator (48) for separating said waveform into red and IR signals, wherein the delta-sigma modulator (51) is a software delta-sigma modulator being configured to convert one of said red and IR signals in digital form back into an analog signal by producing a serial, single bit output; and wherein the filter (52) is a hardware RC filter (62, 64, 66, 68) coupled to an output of said delta-sigma modulator (51) for filtering said waveform.

Patentansprüche

1. Verfahren zum Betreiben einer physiologischen Überwachungseinrichtung, umfassend:

Detektieren eines analogen Signals von einem Patienten, wobei das analoge Signal eine physiologische Wellenform umfasst;
Umsetzen des analogen Signals in ein digitales Signal;
Demodulieren des digitalen Signals, um zumindest zwei demodulierte physiologische Signale zu erzeugen;
Anlegen eines der demodulierten physiologischen Signale an einen Delta-Sigma-Modulator (51), um ein Ausgangssignal bereitzustellen; und
Filtern des Ausgangssignals, um eine analoge gefilterte physiologische Echtzeit-Wellenformausgangsgröße bereitzustellen.

2. Verfahren nach Anspruch 1, wobei die Filterung mit einem Hardware-Filter (52) durchgeführt wird, das mit einem Ausgang des Delta-Sigma-Modulators (51) gekoppelt ist.

3. Verfahren nach Anspruch 1 oder 2, wobei der Delta-Sigma-Modulator (51) eine Einzelbitausgangsgröße bereitstellt.

4. Verfahren nach einem der vorhergehenden Ansprüche, wobei die physiologische Wellenform eine Darstellung eines von einem physiologischen Sensor zurückgegebenes IR-Signals und ein von einem physiologischen Sensor zurückgegebenes Rotsignal umfasst.

5. Verfahren nach einem der vorhergehenden Ansprüche, wobei die demodulierte Wellenform eine Darstellung eines von einem physiologischen Sensor empfangenen IR-Signals umfasst.

6. Verfahren nach einem der vorhergehenden Ansprüche, wobei der Delta-Sigma-Modulator (51) entsprechend konfiguriert ist, um Rauschformung zweiter Ordnung der demodulierten physiologischen Signale bereitzustellen.

7. Verfahren nach einem der vorhergehenden Ansprüche, wobei der Delta-Sigma-Modulator (51) entsprechend konfiguriert ist, um einen seriellen Bitstrom (54) mit einer gegebenen Frequenz auszugeben.

8. Verfahren nach Anspruch 2, wobei das Hardware-Filter (52) ein RC-Filter (62, 66, 64, 68) umfasst.

9. Verfahren nach einem der vorhergehenden Ansprüche, ferner umfassend: digitales Filtern (49) eines der demodulierten physiologischen Signale, um ein erstes digitales Ausgangssignal bereitzustellen.

10. Verfahren nach einem der vorhergehenden Ansprüche, ferner umfassend: digitales Filtern (50) des anderen der demodulierten physiologischen Signale, um ein zweites digitales Ausgangssignal bereitzustellen.

11. Physiologische Überwachungsvorrichtung, umfassend:

einen Eingang zum Empfangen eines analogen Signals mit einer physiologischen Wellenform von einem Patienten;
einen Analog-Digital-Umsetzer (47) zum Umsetzen des analogen Signals in ein digitales Signal;
einen Demodulator zum Demodulieren des digitalen Signals, um zumindest zwei demodulierte physiologische Signale zu erzeugen;
einen Delta-Sigma-Modulator (51), der entsprechend konfiguriert ist, um eines der demodulierten physiologischen Signale aus der digitalen in die analoge Form umzusetzen;
ein Filter (52), das mit einem Ausgang des Delta-Sigma-Modulators (51) gekoppelt ist.

12. Physiologische Überwachungsvorrichtung nach Anspruch 11, wobei der Delta-Sigma-Modulator (51) ein Software-Modulator ist, der eine serielle Einzelbitausgangsgröße erzeugt.

13. Physiologische Überwachungsvorrichtung nach Anspruch 11, wobei das Filter (52) ein Hardware-RC-Filter (62, 64, 66, 68) ist.

14. Physiologische Überwachungsvorrichtung nach Anspruch 11, ferner umfassend ein erstes digitales Filter (49) zum Filtern das zumindest anderen der demodulierten physiologischen Signale und/oder ein zweites digitales Filter (50) zum Filtern des zumindest einen der demodulierten physiologischen Signale.

15. Physiologische Überwachungsvorrichtung nach einem der vorhergehenden Ansprüche 11 bis 14, wobei die physiologische Überwachungsvorrichtung eine Oximetervorrichtung ist; die physiologische Wellenform ist eine Pulsoximetrie-Wellenform ist; der Prozessor einen Demodulator (48) zum Trennen der Wellenform in ein Rot- und ein IR-Signal aufweist, wobei der Delta-Sigma-Modulator (51) ein Software-Delta-Sigma-Modulator ist, der entsprechend konfiguriert ist, um eines der Rot- und IR-Signale in digitaler Form durch Erzeugung einer seriellen Einzelbitausgangsgröße wieder in ein analoges Signal umzusetzen; und wobei das Filter (52) ein Hardware-RC-Filter (62, 64, 66, 68) ist, das mit einem Ausgang des Delta-Sigma-Modulators (51) zum Filtern der Wellenform gekoppelt ist.

Revendications

1. Procédé de fonctionnement d'un moniteur physiologique consistant à :

détecter un signal analogique provenant d'un patient, le signal analogique ayant une forme d'onde physiologique ;
convertir le signal analogique en un signal numérique ;
démoduler le signal numérique pour produire au moins deux signaux physiologiques démodulés ;
appliquer un des signaux physiologiques démodulés à un modulateur delta-sigma (51) pour fournir un signal de sortie ; et
filtrer ledit signal de sortie pour fournir une sortie de forme d'onde physiologique filtrée analogique en temps réel.

2. Procédé selon la revendication 1, dans lequel ledit filtrage est effectué par un filtre matériel (52) couplé à une sortie dudit modulateur delta-sigma (51).

3. Procédé selon la revendication 1 ou 2, dans lequel ledit modulateur delta-sigma (51) fournit une sortie à un seul bit.

4. Procédé selon une des revendications précédentes, dans lequel la forme d'onde physiologique est constituée d'une représentation d'un signal IR renvoyé par un capteur physiologique et d'un signal rouge renvoyé par un capteur physiologique.

5. Procédé selon une des revendications précédentes, dans lequel la forme d'onde démodulée est constituée d'une représentation d'un signal IR reçu d'un capteur physiologique.

6. Procédé selon une des revendications précédentes, dans lequel le modulateur delta-sigma (51) est configuré pour fournir une mise en forme de bruit de second ordre des signaux physiologiques démodulés.

7. Procédé selon une des revendications précédentes, dans lequel le modulateur delta-sigma (51) est configuré pour produire un train de bits en série (54) ayant une fréquence donnée.

8. Procédé selon la revendication 2, dans lequel le filtre matériel (52) est constitué d'un filtre RC (62, 66, 64, 68).

9. Procédé selon une des revendications précédentes, consistant en outre à filtrer numériquement (49) un des signaux physiologiques démodulés pour fournir un premier signal de sortie numérique.

10. Procédé selon une des revendications précédentes, consistant en outre à filtrer numériquement (50) l'autre des signaux physiologiques démodulés pour fournir un second signal de sortie numérique.

11. Appareil de monitorage physiologique comprenant :

une entrée pour recevoir d'un patient un signal analogique incluant une forme d'onde physiologique ;
un convertisseur analogique-numérique (47) pour convertir ledit signal analogique en un signal numérique ;
un démodulateur pour démoduler le signal numérique pour produire au moins deux signaux physiologiques démodulés ;
un modulateur delta-sigma (51) configuré pour convertir un desdits signaux physiologiques démodulés de la forme numérique à analogique ;
un filtre (52) couplé à une sortie dudit modulateur delta-sigma (51).

12. Appareil de monitorage physiologique selon la revendication 11, dans lequel ledit modulateur delta-sigma (51) est un modulateur logiciel qui produit une sortie à un seul bit en série.

13. Appareil de monitorage physiologique selon la revendication 11, dans lequel ledit filtre (52) est un filtre RC matériel (62, 64, 66, 68).

14. Appareil de monitorage physiologique selon la revendication 11, comprenant en outre un premier filtre numérique (49) pour filtrer l'au moins un autre des signaux physiologiques démodulés et/ou un second filtre numérique (50) pour filtrer l'au moins un des signaux physiologiques démodulés.

15. Appareil de monitorage physiologique selon une des revendications 11 à 14 précédentes, dans lequel l'appareil de monitorage physiologique est un appareil d'oxymétrie ; la forme d'onde physiologique est une forme d'onde d'oxymétrie pulsée ; le processeur inclut un démodulateur (48) pour séparer ladite forme d'onde en des signaux rouge et IR, dans lequel le modulateur delta-sigma (51) est un modulateur delta-sigma logiciel étant configuré pour reconvertir un desdits signaux rouge et IR de forme numérique en un signal analogique en produisant une sortie à un seul bit en série ; et dans lequel le filtre (52) est un filtre RC matériel (62, 64, 66, 68) couplé à une sortie dudit modulateur delta-sigma (51) pour filtrer ladite forme d'onde.

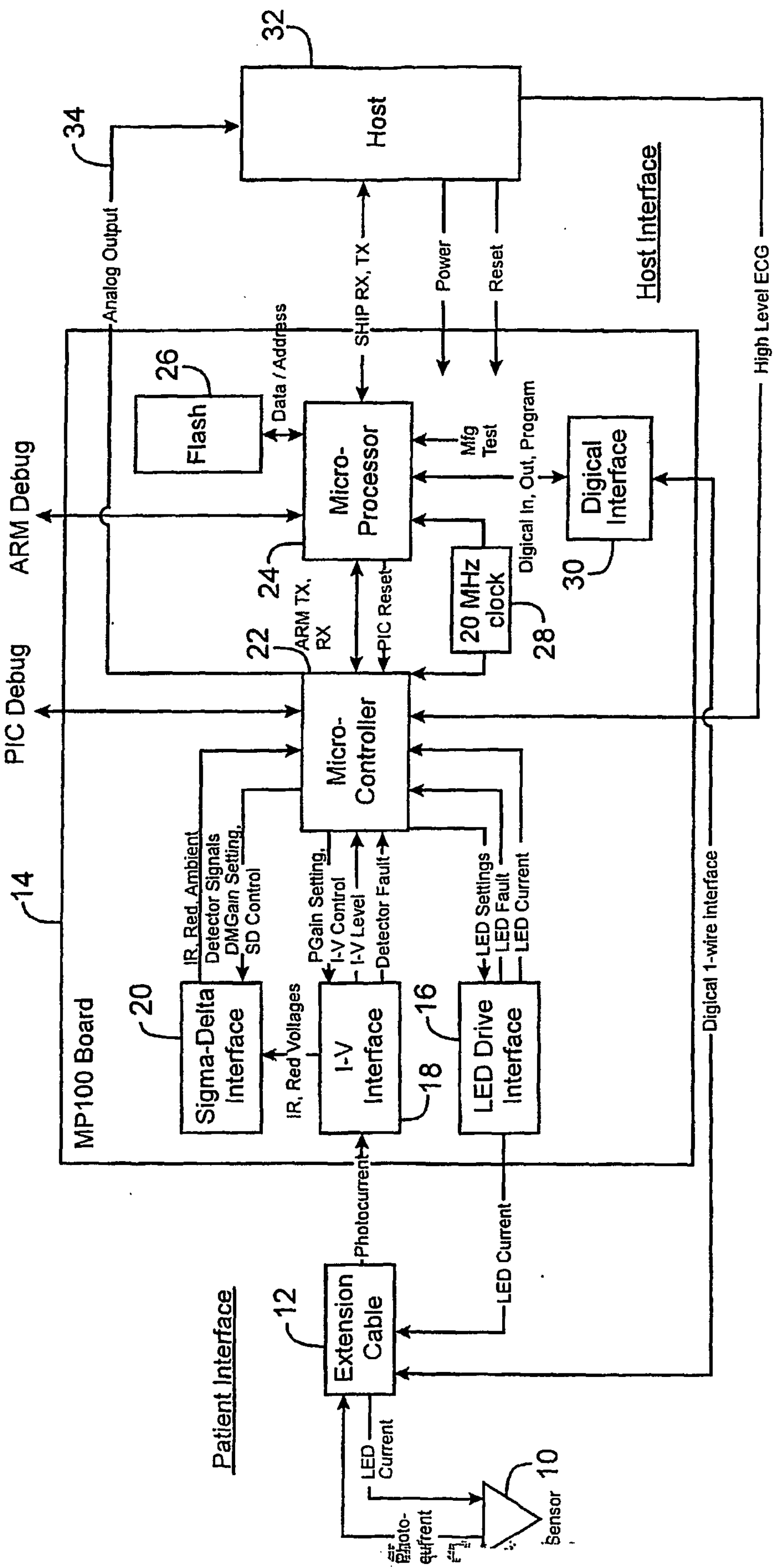
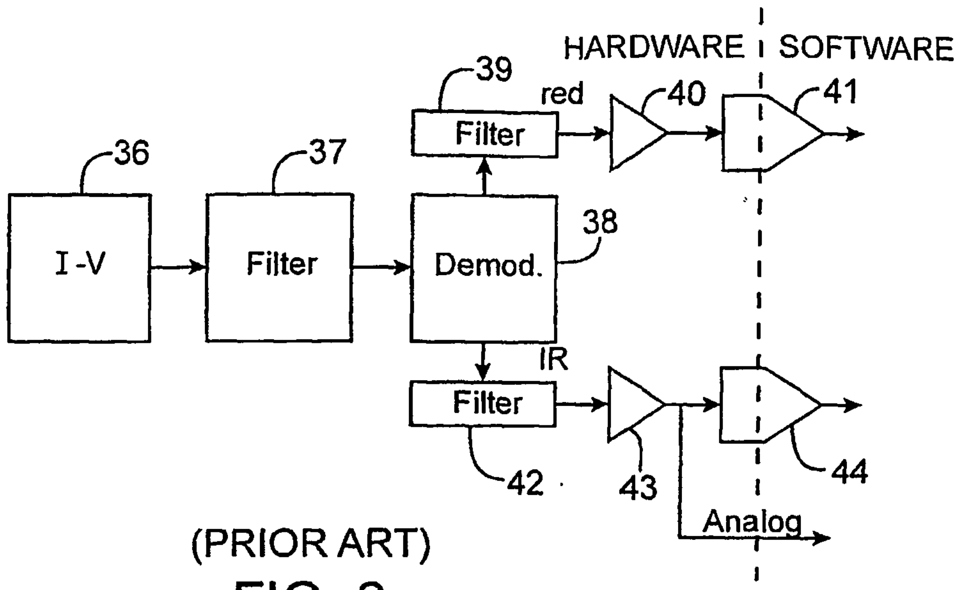

32
Host
34
Analog Output
Host Interface
SHIP RX, TX
Power
Reset
High Level ECG
Data / Address
26
Flash
Micro-
Processor
Mfg
Test
Digical In, Out, Program
Digical
Interface
30
ARM Debug
24
ARM TX,
RX
PIC Reset
20 MHz
clock
28
22
PIC Debug
Micro-
Controller
14
IR, Red, Ambient
Detector Signals
DMGain Setting,
SD Control
PGain Setting,
I-V Control
I-V Level
Detector Fault
LED Settings
LED Fault
LED Current
20
Sigma-Delta
Interface
IR, Red Voltages
I-V
Interface
18
16
LED Drive
Interface
MP100 Board
Digical 1-wire Interface
Photocurrent
LED Current
12
Extension
Cable
Patient Interface
LED
Current
Photo-
current
10
Sensor

FIG. 1



(PRIOR ART)
FIG. 2

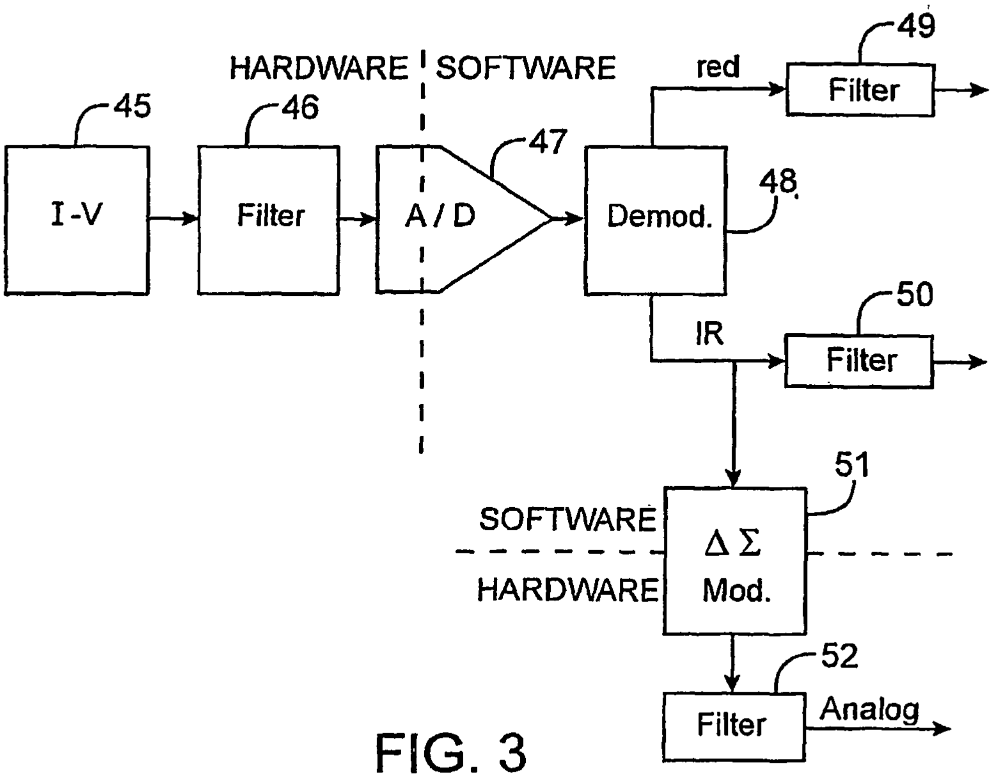


FIG. 3

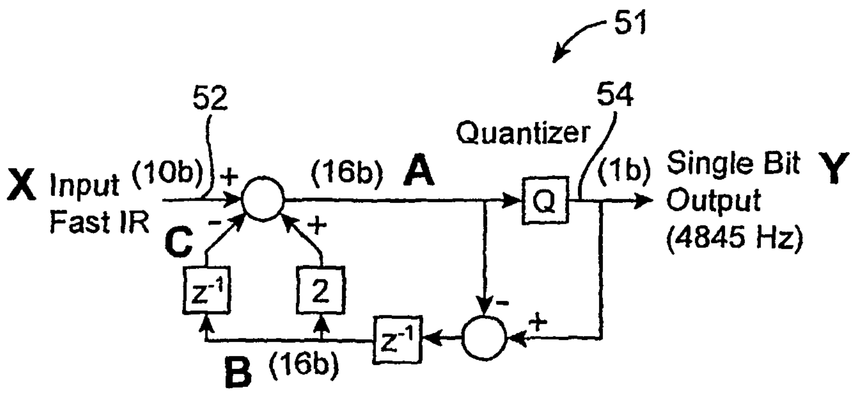


FIG. 4

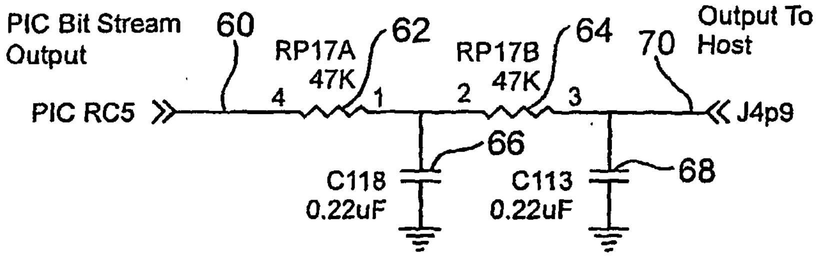


FIG. 5

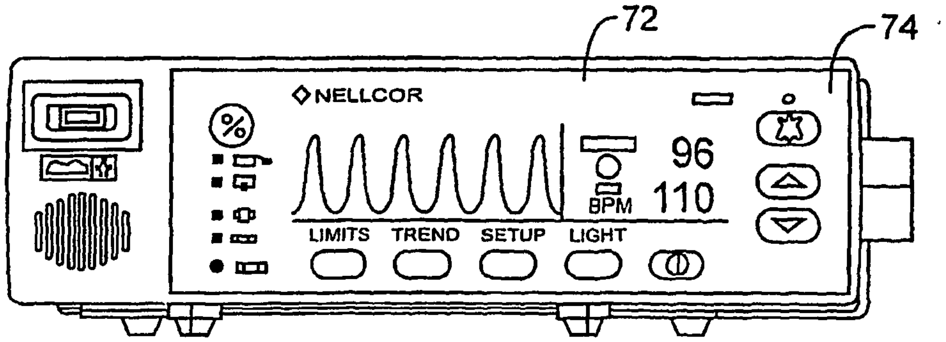


FIG. 6

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- US 5921921 A **[0004]**
- US 6188470 B **[0006]**
- US 6385471 B **[0006]**

专利名称(译)	Delta-sigma调制器，用于输出生理信号的模拟表示		
公开(公告)号	EP1729630B1	公开(公告)日	2010-05-26
申请号	EP2005714036	申请日	2005-02-24
[标]申请(专利权)人(译)	内尔科尔普里坦贝内特公司		
申请(专利权)人(译)	NELLCOR PURITAN BENNETT INCORPORATED		
当前申请(专利权)人(译)	NELLCOR PURITAN BENNETT LLC		
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发明人	PETERSEN, ETHAN SHEA, WILLIAM CHEW, BRADFORD, B.		
IPC分类号	A61B5/00 H03M7/32		
CPC分类号	A61B5/14551 H03M7/3028 H03M7/3042		
代理机构(译)	LAMP，西格玛		
优先权	10/787853 2004-02-25 US		
其他公开文献	EP1729630A1		
外部链接	Espacenet		

摘要(译)

一种用于提供生理信号的模拟表示的基本上实时表示的方法和设备。来自传感器的波形信号被转换为数字形式。 Δ-Σ调制器用作简单的数模转换器（ADC）。然后可以通过简单的硬件滤波器提供输出，几乎实时地提供模拟输出信号，可用于其他仪器，同步，显示等。

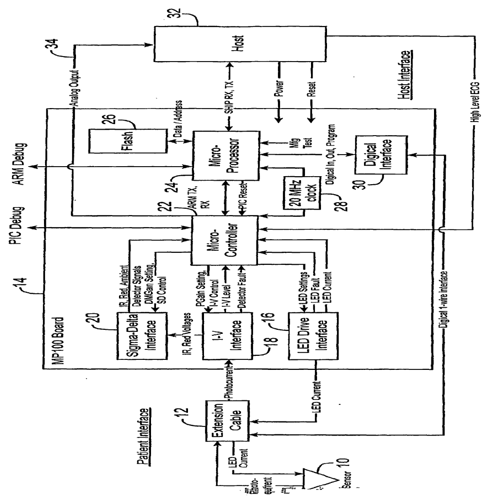

FIG. 1