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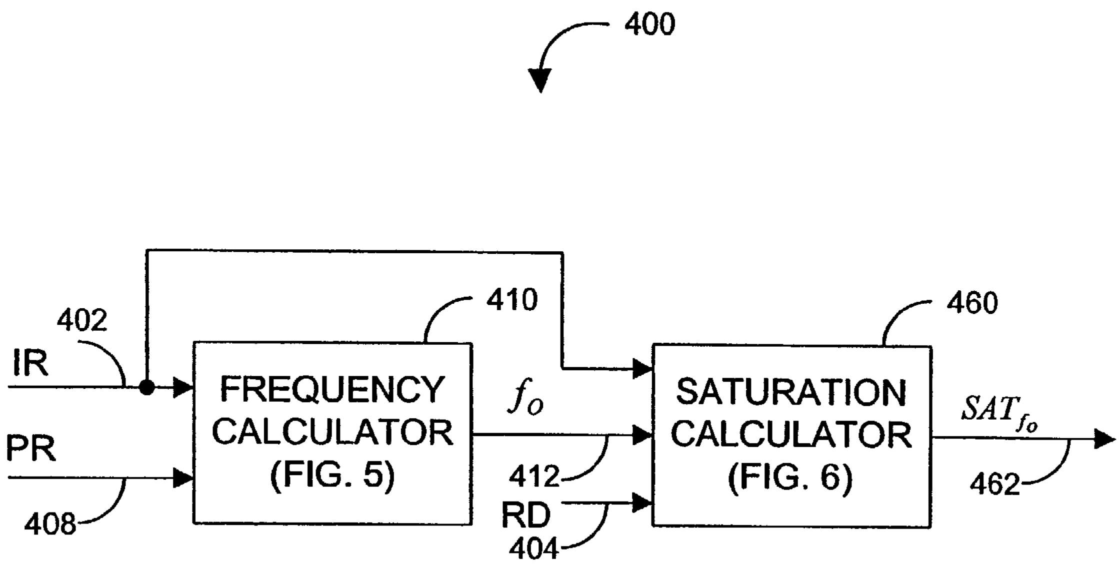
(54) Title: SIGNAL COMPONENT PROCESSOR



(57) Abstract: A signal processor generates basis functions and identifies at least one basis function component of a sensor signal in order to calculate a physiological measurement. The signal processor is advantageously applied to pulse oximetry so as to directly calculate oxygen saturation and so as to calculate a robust oxygen saturation measurement. In particular, a signal component transform may be calculated within a window around a derived pulse rate estimate. A signal component transform may also utilize sinusoidal basis functions, and an optimization of a signal component transform may occur at a particular frequency or a set of frequencies. A sinusoidal waveform or waveforms at that frequency or set of frequencies is generated to select associated red and infrared components of the sensor signal, and an oxygen saturation is calculated from a magnitude ratio of these components.

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SIGNAL COMPONENT PROCESSOR

Background of the Invention

Early detection of low blood oxygen is critical in the medical field, for example in critical care and surgical applications, because an insufficient supply of oxygen can result in brain damage and death in a matter of minutes. Pulse oximetry is a widely accepted noninvasive procedure for measuring the oxygen saturation level of arterial blood, an indicator of oxygen supply. A pulse oximeter typically provides a numerical readout of the patient's oxygen saturation and pulse rate. A pulse oximetry system consists of a sensor attached to a patient, a monitor, and a cable connecting the sensor and monitor. Conventionally, a pulse oximetry sensor has both red (RD) and infrared (IR) light-emitting diode (LED) emitters and a photodiode detector. The pulse oximeter measurements are based upon the absorption by arterial blood of the two wavelengths emitted by the sensor. The pulse oximeter alternately activates the RD and IR sensor emitters and reads the resulting RD and IR sensor signals, i.e. the current generated by the photodiode in proportion to the detected RD and IR light intensity, in order to derive an arterial oxygen saturation value, as is well-known in the art. A pulse oximeter contains circuitry for controlling the sensor, processing the sensor signals and displaying the patient's oxygen saturation and pulse rate.

Summary of the Invention

FIG. **1A** illustrates a plethysmograph waveform **110**, which is a display of blood volume, shown along the ordinate **101**, over time, shown along the abscissa **102**. The shape of the plethysmograph waveform **110** is a function of heart stroke volume, pressure gradient, arterial elasticity and peripheral resistance. Ideally, the waveform **110** displays a short, steep inflow phase **111** during ventricular systole followed by a typically three to four times longer outflow phase **112** during diastole. A dicrotic notch **116** is generally attributed to closure of the aortic valve at the end of ventricular systole.

FIG. **1B** illustrates a corresponding RD or IR sensor signal $s(t)$ **130**, such as described above. The typical plethysmograph waveform **110** (FIG. **1A**), being a function of blood volume, also provides a light absorption profile. A pulse oximeter, however, does not directly detect light absorption and, hence, does not directly measure the plethysmograph waveform **110**. However, IR or RD sensor signals are 180° out-of-phase versions of the waveform **110**. That is, peak detected intensity **134** occurs at minimum absorption **114** and minimum detected intensity **138** occurs at maximum absorption **118**.

FIG. **1C** illustrates the corresponding spectrum of $s(t)$, which is a display of signal spectral magnitude $|S(\omega)|$, shown along the ordinate **105**, versus frequency, shown along the abscissa **106**. The plethysmograph spectrum is depicted under both high signal quality **150** and low signal quality **160** conditions. Low signal quality can result when a pulse oximeter sensor signal is distorted by motion-artifact and noise. Signal processing technologies such as described in U.S. Patent 5,632,272, assigned to the assignee of the present invention and incorporated by reference herein, allow pulse oximetry to function through patient motion and other low signal quality conditions.

Ideally, plethysmograph energy is concentrated at the pulse rate frequency **172** and associated harmonics **174, 176.** Accordingly, motion-artifact and noise may be reduced and pulse oximetry measurements improved by filtering out sensor signal frequencies that are not related to the pulse rate. Under low signal quality conditions, however, the frequency spectrum is corrupted and the pulse rate fundamental **152** and harmonics **154**, **156** can be obscured or masked, resulting in errors in the computed pulse rate. In addition, a pulse rate, physiologically, is dynamic, potentially varying significantly between different measurement periods. Hence, maximum plethysmograph energy may not correspond to the computed pulse rate except under high signal quality conditions and stable pulse rates. Further, an oxygen saturation value calculated from an optical density ratio, such as a normalized red over infrared ratio, at the pulse rate frequency can be sensitive to computed pulse rate errors. In order to increase the robustness of oxygen saturation measurements, therefore, it is desirable to improve pulse rate based measurements by identifying sensor signal components that correspond to an optimization, such as maximum signal energy.

One aspect of a signal component processor comprises a physiological signal, a basis function index determined from the signal, a basis function waveform generated according to the index, a component derived from the sensor signal and the waveform, and a physiological measurement responsive to the component. In one embodiment, the component is responsive to the inner product of the sensor signal and the waveform. In another embodiment, the index is a frequency and the waveform is a sinusoid at the frequency. In that embodiment, the signal processor may further comprise a pulse rate estimate derived from the signal wherein the frequency is selected from a window including the pulse rate estimate. The physiological measurement may be an oxygen saturation value responsive to a magnitude of the component.

Another aspect of a signal component processor comprises a signal input, a basis function indicator derived from the signal input, a plurality of basis functions generated according to the indicator, a plurality of characteristics of the signal input corresponding to the basis functions and an optimization of the characteristics so as to identify at least one of said basis functions. In one embodiment, the indicator is a pulse rate estimate and the processor further comprises a window configured to include the pulse rate estimate, and a plurality of frequencies selected from within the window. In another embodiment, the characteristic comprises a plurality of signal remainders corresponding to the basis functions and a plurality of magnitudes of the signal remainders. In that embodiment, the optimization comprises a minima of the magnitudes. In a further embodiment, the characteristic comprises a plurality of components corresponding to the basis functions and a plurality of magnitudes of the components. In this embodiment, the optimization comprises a maxima of the magnitudes.

An aspect of a signal component processing method comprises the steps of receiving a sensor signal, calculating an estimated pulse rate, determining an optimization of the sensor signal proximate the estimated pulse rate, defining a frequency corresponding to the optimization, and outputting a physiological measurement responsive to a component of the sensor signal at the frequency. In one embodiment the determining step comprises the substeps of transforming the sensor signal to a frequency spectrum encompassing the estimated pulse rate and detecting an extrema of the spectrum indicative of the frequency. The transforming step may comprise the substeps of defining a window including the estimated pulse rate, defining a plurality of selected frequencies within the window, canceling the selected frequencies, individually, from the sensor signal to generate a plurality of remainder signals and calculating a plurality of magnitudes of the remainder signals. The detecting step may comprise the substep of locating a minima of the magnitudes.

In another embodiment, the outputting step comprises the substeps of inputting a red (RD) portion and an infrared (IR) portion of the sensor signal, deriving a RD component of the RD portion and an IR component of the IR portion corresponding to the frequency and computing an oxygen saturation based upon a magnitude ratio of the RD component and the IR component. The deriving step may comprise the substeps of generating a sinusoidal waveform at the frequency and selecting the RD component and the IR component utilizing the waveform. The selecting step may comprise the substep of calculating the inner product between the waveform and the RD portion and the inner product between the waveform and the IR portion. The selecting step may comprise the substeps of canceling the waveform from the RD portion and the IR portion, leaving a RD remainder and an IR remainder, and subtracting the RD remainder from the RD portion and the IR remainder from the IR portion.

A further aspect of a signal component processor comprises a first calculator means for deriving an optimization frequency from a pulse rate estimate input and a sensor signal, and a second calculator means for deriving a physiological measurement responsive to a sensor signal component at the frequency. In one embodiment, the first calculator means comprises a signal component transform means for determining a plurality of signal values corresponding to a plurality of selected frequencies within a window including the pulse rate estimate, and a detection means for determining a particular one of the selected frequencies corresponding to an optimization of the sensor signal. The second calculator means may comprise a waveform means for generating a sinusoidal signal at the frequency, a frequency selection means for determining a component of the sensor signal from the sinusoidal signal and a calculator means for deriving a ratio responsive to the component.

Brief Description of the Drawings

FIGS. **1A-C** are graphical representations of a pulse oximetry sensor signal;

FIG. **1A** is a typical plethysmograph illustrating blood volume versus time;

FIG. **1B** is a pulse oximetry sensor signal illustrating detected light intensity versus time;

FIG. **1C** is a pulse oximetry sensor signal spectrum illustrating both high signal quality and low signal quality conditions;

FIGS. **2-3** are magnitude versus frequency graphs for a pulse oximetry sensor signal illustrating an example of signal component processing;

FIG. **2** illustrates a frequency window around an estimated pulse rate; and

FIG. **3** illustrates an associated signal component transform;

FIGS. **4-7** are functional block diagrams of one embodiment of a signal component processor;

FIG. **4** is a top-level functional block diagram of a signal component processor;

FIG. **5** is a functional block diagram of a frequency calculator;

FIG. **6** is a functional block diagram of a saturation calculator; and

FIG. **7** is a functional block diagram of one embodiment of a frequency selection;

FIGS. **8A-B** are flowcharts of an iterative embodiment of a frequency calculator; and

FIGS. **9-11** are functional block diagrams of another embodiment of a signal component processor;

FIG. **9** is a top-level functional block diagram of a signal component processor;

FIG. **10** is a functional block diagram of an index calculator; and

FIG. **11** is a functional block diagram of a measurement calculator.

Detailed Description of the Preferred Embodiments

FIGS. **2** and **3** provide graphical illustration examples of signal component processing. Advantageously, signal component processing provides a direct method for the calculation of saturation based on pulse rate. For example, it is not necessary to compute a frequency transform, such as an FFT, which derives an entire frequency spectrum. Rather, signal component processing singles out specific signal components, as described in more detail below. Further, signal component processing advantageously provides a method of refinement for the calculation of saturation based on pulse rate.

FIG. **2** illustrates high and low signal quality sensor signal spectrums **150, 160** as described with respect to FIG. **1C**, above. A frequency window **220** is created, including a pulse rate estimate PR **210**. A pulse rate estimate can be calculated as disclosed in US Patent No. 6,002,952, entitled "Signal Processing Apparatus and Method," assigned to the assignee of the present invention and incorporated by reference herein. A search is conducted within this window **220** for a component frequency f_o at an optimization. In particular, selected frequencies **230**, which include PR, are defined within the window **220**. The components of a signal $s(t)$ at each of these frequencies **230** are then examined for an optimization indicative of an extrema of energy, power or other signal characteristic. In an alternative embodiment, the components of the signal $s(t)$ are examined for an optimization over a continuous range of frequencies within the window **220**.

FIG. **3** illustrates an expanded portion of the graph described with respect to FIG. **2**, above. Superimposed on the high signal quality **150** and low signal quality **160** spectrums is a signal component transform **310**. In one embodiment, a signal component transform **310** is indicative of sensor signal energy and is calculated at selected signal frequencies **230** within the window **220**. A signal component transform **310** has an extrema **320** that indicates, in this embodiment, energy optimization at a particular one **330** of the selected frequencies **230**. The extrema **320** can be, for example, a maxima, minima or inflection point. In the embodiment illustrated, each point of the transform **310** is the magnitude of the signal remaining after canceling a sensor signal component at one of the selected frequencies. The extrema **320** is a minima, which indicates that canceling the corresponding frequency **330** removes the most signal energy. In an alternative embodiment, not illustrated, the transform **310** is calculated as the magnitude of signal components at each of the selected frequencies **230**. In that embodiment, the extrema is a maxima, which indicates the largest energy signal at the corresponding frequency. The result of a signal component transform **310** is identification of a frequency f_O **330** determined from the frequency of a signal component transform extrema **320**. Frequency f_O **330** is then used to calculate an oxygen saturation. A signal component transform and corresponding oxygen saturation calculations are described in additional detail with respect to FIGS. **4-8**, below. Although signal component processing is described above with respect to identifying a particular frequency within a window including a pulse rate estimate PR, a similar procedure could be performed on 2PR, 3PR etc. resulting in the identification of multiple frequencies f_{O1}, f_{O2}, etc., which could be used for the calculation of oxygen saturation as well.

Advantageously, a signal component transform **310** is calculated over any set of selected frequencies, unrestricted by the number or spacing of these frequencies. In this manner, a signal component transform **310** differs from a FFT or other standard frequency transforms. For example, a FFT is limited to *N* evenly-distributed frequencies spaced at a resolution of f_s/N, where *N* is the number of signal samples and f_s is the sampling frequency. That is, for a FFT, a relatively high sampling rate or a relatively large record length or both are needed to achieve a relatively high resolution in frequency. Signal component processing, as described herein, is not so limited. Further, a signal component transform **310** is advantageously calculated only over a range of frequencies of interest. A FFT or similar frequency transformation may be computationally more burdensome than signal component processing, in part because such a transform is computed over all frequencies within a range determined by the sampling frequency, f_s.

FIGS. **4-7** illustrate one embodiment of a signal component processor. FIG. **4** is a top-level functional block diagram of a signal component processor **400**. The signal component processor **400** has a frequency calculator **410** and a saturation calculator **460**. The frequency calculator **410** has an IR signal input **402**, a pulse rate estimate signal PR input **408** and a component frequency f_O output **412**. The frequency calculator **410** performs a signal component transform based upon the PR input **408** and determines the f_O output **412**, as described with respect to FIGS. **2-3**, above. The frequency calculator **410** is described in further detail with respect to FIG. **5**, below.

In an alternative embodiment, the frequency calculator **410** determines f_O **412** based upon a RD signal input substituted for, or in addition to, the IR signal input **402**. Similarly, one of ordinary skill in the art will recognize that f_O can be determined by the frequency calculator **410** based upon one or more inputs responsive to a variety of sensor wavelengths.

The saturation calculator **460** has an IR signal input **402**, a RD signal input **404**, a component frequency f_O input **412** and an oxygen saturation output, SAT_{f_O} **462**. The saturation calculator **460** determines values of the IR signal input **402** and the RD signal input **404** at the component frequency f_O **412** and computes a ratio of those values to determine SAT_{f_O} **462**, as described with respect to FIG. **6**, below. The IR signal input **402** and RD signal input **404** can be expressed as:

$$IR = \begin{bmatrix} IR_0 \\ \vdots \\ IR_{N-1} \end{bmatrix}; \qquad RD = \begin{bmatrix} RD_0 \\ \vdots \\ RD_{N-1} \end{bmatrix} \tag{1}$$

where N is the number of samples of each signal input.

FIG. **5** shows one embodiment of the frequency calculator **410**. In this particular embodiment, the frequency calculator functions are window generation **520**, frequency cancellation **540**, magnitude calculation **560** and minima determination **580**. Window generation **520**, frequency cancellation **540** and magnitude calculation **560** combine to create a signal component transform **310** (FIG. **3**), as described with respect to FIG. **3**, above. Minima determination **580** locates the signal component transform extrema **320** (FIG. **3**), which identifies f_O **412**, also described with respect to FIG. **3**, above.

As shown in FIG. **5**, window generation **520** has a PR input **408** and defines a window **220** (FIG. **3**) about PR **210** (FIG. **3**) including a set of selected frequencies **230** (FIG. **3**)

$$\{f_m; m = 0, \cdots M-1\}; \qquad f = \begin{bmatrix} f_0 \\ \vdots \\ f_{M-1} \end{bmatrix} \tag{2}$$

where M is the number of selected frequencies **230** (FIG. **3**) within the window **220** (FIG. **3**). Window generation **520** has a sinusoidal output X_f, Y_f **522**, which is a set of sinusoidal waveforms $x_{n,f}$, $y_{n,f}$ each corresponding to one of the set of selected frequencies **230** (FIG. **3**). Specifically

$$X_f = \begin{bmatrix} x_{0,f} \\ \vdots \\ x_{N-1,f} \end{bmatrix}; \qquad Y_f = \begin{bmatrix} y_{0,f} \\ \vdots \\ y_{N-1,f} \end{bmatrix} \tag{3a}$$

$$x_{n,f} = \sin(2\pi fn); \qquad y_{n,f} = \cos(2\pi fn) \tag{3b}$$

Also shown in FIG. **5**, the frequency cancellation **540** has IR **402** and X_f, Y_f **522** inputs and a remainder output R_f **542**, which is a set of remainder signals $r_{n,f}$ each corresponding to one of the sinusoidal waveforms $x_{n,f}$, $y_{n,f}$. For each selected frequency f **230** (FIG. **3**), frequency cancellation **540** cancels that frequency component from the input signal IR **402** to generate a remainder signal $r_{n,f}$. In particular, frequency cancellation **540** generates a remainder R_f **542**

$$R_f = \begin{bmatrix} r_{0,f} \\ \vdots \\ r_{N-1,f} \end{bmatrix} \tag{4a}$$

$$R_f = IR - \frac{IR \bullet X_f}{|X_f|^2} X_f - \frac{IR \bullet Y_f}{|Y_f|^2} Y_f \tag{4b}$$

Additionally, as shown in FIG. **5**, the magnitude calculation **560** has a remainder input R_f **542** and generates a magnitude output W_f **562**, where

$$W_f = |R_f| = \sqrt{\sum_{n=0}^{N-1} r_{n,f}^2} \tag{5}$$

Further shown in FIG. **5**, the minima determination **580** has the magnitude values W_f **562** as inputs and generates a component frequency f_o output. Frequency f_o is the particular frequency associated with the minimum magnitude value

$$W_{fo} = \min \{W_f\} \tag{6}$$

FIG. **6** shows that the saturation calculator **460** functions are sinusoid generation **610**, frequency selection **620**, **640** and ratio calculation **670**. Sinusoid generation has a component frequency f_o input **208** and a sinusoidal waveform X_{fo}, Y_{fo} output **612**, which has a frequency of f_o. Frequency selection **620, 640** has a sensor signal input, which is either an IR signal **202** or a RD signal **204** and a sinusoid waveform X_{fo}, Y_{fo} input **612**. Frequency selection **620**, **640** provides magnitude outputs $z_{IR,fo}$ **622** and $z_{RD,fo}$ **642** which are the frequency components of the IR **202** and RD **204** sensor signals at the f_o frequency. Specifically, from equation 3(a)

$$X_{fo} = \begin{bmatrix} x_{0,fo} \\ \vdots \\ x_{N-1,fo} \end{bmatrix}; \qquad Y_{fo} = \begin{bmatrix} y_{0,fo} \\ \vdots \\ y_{N-1,fo} \end{bmatrix} \tag{7}$$

Then, referring to equation 1

$$z_{IR,fo} = \left| \frac{IR \bullet X_{fo}}{|X_{fo}|^2} X_{fo} + \frac{IR \bullet Y_{fo}}{|Y_{fo}|^2} Y_{fo} \right| = \sqrt{\frac{(IR \bullet X_{fo})^2}{|X_{fo}|^2} + \frac{(IR \bullet Y_{fo})^2}{|Y_{fo}|^2}} \tag{8a}$$

$$z_{RD,fo} = \left| \frac{RD \bullet X_{fo}}{|X_{fo}|^2} X_{fo} + \frac{RD \bullet Y_{fo}}{|Y_{fo}|^2} Y_{fo} \right| = \sqrt{\frac{(RD \bullet X_{fo})^2}{|X_{fo}|^2} + \frac{(RD \bullet Y_{fo})^2}{|Y_{fo}|^2}} \tag{8b}$$

For simplicity of illustration, EQS. **8a-b** assume that the cross-product of X_{fo} and Y_{fo} is zero, although generally this is not the case. The ratio calculation and mapping **670** has $z_{IR,fo}$ **622** and $z_{RD,fo}$ **642** as inputs and provides SAT_{fo} **262** as an output. That is

$$SAT_{f_o} = g\{z_{RD,fo} / z_{IR,fo}\} \tag{9}$$

where g is a mapping of the red-over-IR ratio to oxygen saturation, which may be an empirically derived lookup table, for example.

FIG. **7** illustrates an alternative embodiment of frequency selection **620** (FIG. **6**), as described above. In this embodiment, frequency cancellation **540** and magnitude calculation **560**, as described with respect to FIG. **5**, can also be used, advantageously, to perform frequency selection. Specifically, frequency cancellation **540** has IR **202** and X_{fo}, Y_{fo} **612** as inputs and generates a remainder signal R_{fo} **712** as an output, where

$$R_{fo} = IR - \frac{IR \bullet X_{fo}}{\left|X_{fo}\right|^2} X_{fo} - \frac{IR \bullet Y_{fo}}{\left|Y_{fo}\right|^2} Y_{fo} \tag{10}$$

The remainder R_{fo} **712** is subtracted **720** from IR **202** to yield

$$Z_{f_o} = IR - \left[IR - \frac{IR \bullet X_{fo}}{\left|X_{f_o}\right|^2} X_{f_o} - \frac{IR \bullet Y_{fo}}{\left|Y_{f_o}\right|^2} Y_{f_o} \right] = \frac{IR \bullet X_{fo}}{\left|X_{f_o}\right|^2} X_{f_o} + \frac{IR \bullet Y_{fo}}{\left|Y_{f_o}\right|^2} Y_{f_o} \tag{11}$$

where z_{fo} **722** is the component of IR **202** at the f_o frequency. The magnitude calculation **560** has z_{fo} **722** as an input and calculates

$$\left|Z_{f_o}\right| = \left| \frac{IR \bullet X_{fo}}{\left|X_{f_o}\right|^2} X_{f_o} + \frac{IR \bullet Y_{fo}}{\left|Y_{f_o}\right|^2} Y_{f_o} \right| = \sqrt{\frac{(IR \bullet X_{f_o})^2}{\left|X_{f_o}\right|^2} + \frac{(IR \bullet Y_{f_o})^2}{\left|Y_{f_o}\right|^2}} \tag{12}$$

which is equivalent to equation **8a**, above.

FIGS. **8A-B** illustrate an iterative embodiment of the frequency calculator **410** (FIG. **4**) described above. An iterative frequency calculator **410** has an initialization **810**, a signal component transform **820**, an extrema detection **850**, a resolution decision **860** and a resolution refinement **880** and provides a component frequency f_o **870**. Initialization **810** defines a window around the pulse rate estimate PR and a frequency resolution within that window.

As shown in FIG. **8A**, a signal component transform **820** has an initial frequency selection **822**, a frequency cancellation **824** and an magnitude calculation **828**. A decision block **830** determines if the magnitude calculation **828** has been performed at each frequency within the window. If not, the loop of frequency cancellation **824** and magnitude calculation **828** is repeated for another selected frequency in the window. The frequency cancellation **824** removes a frequency component from the IR sensor signal, as described with respect to FIG. **5**, above. The magnitude calculation **828** determines the magnitude of the remainder signal, also described with respect to FIG. **5**, above. If the decision block **830** determines that the remainder signal magnitudes have been calculated at each of the selected frequencies, then the signal component transform loop **820** is exited to the steps described with respect to FIG. **8B**.

As shown in FIG. **8B**, the extrema detector **850** finds a minima of a signal component transform **820** and a resolution decision block **860** determines if the final frequency resolution of a signal component transform is achieved. If not, resolution refinement **880** is performed. If the final resolution is achieved, the component frequency output f_o is equated to the frequency of the minima **870**, i.e. a signal component transform minima determined by the extrema detector **850**.

Further shown in FIG. **8B**, the resolution refinement **880** has a set frequency estimate **882**, a window decrease **884** and a frequency resolution increase **888**. Specifically, the frequency estimate **882** is set to a signal component transform minima, as determined by the extrema detector **850**. The window decrease **884** defines a new and narrower window around the frequency estimate, and the frequency resolution increase **888** reduces the spacing of the selected frequencies within that window prior to the next iteration of a signal component transform **820**. In this manner, a signal component transform **820** and the resulting frequency estimate are refined to a higher resolution with each iteration of signal component transform **820**, extrema detection **850**, and resolution refinement **880**.

In a particular embodiment, the component calculation requires three iterations. A frequency resolution of 4 beats per minute or 4 BPM is used initially and a window of five or seven selected frequencies, including that of the initial pulse rate estimate PR, is defined. That is, a window of either 16 BPM or 24 BPM centered on PR is defined, and a signal component transform is computed for a set of 5 or 7 selected frequencies evenly spaced at 4 BPM. The result is a frequency estimate f_1. Next, the frequency resolution is reduced from 4 BPM to 2 BPM and a 4 BPM window centered on f_1 is defined with three selected frequencies, i.e. f_1-2 BPM, f_1, and f_1+2 BPM. The result is a higher resolution frequency estimate f_2. On the final iteration, the frequency resolution is reduced to 1BPM and a 2 BPM window centered on f_2 is defined with three selected frequencies, i.e. f_2-1 BPM, f_2, and f_2+1 BPM. The final result is the component frequency f_o determined by a signal component transform to within a 1BPM resolution. This component frequency f_o is then used to calculate the oxygen saturation, SAT_{f_o}, as described above.

The signal component processor has been described above with respect to pulse oximetry and oxygen saturation measurements based upon a frequency component that optimizes signal energy. The signal component processor, however, is applicable to other physiological measurements, such as blood glucose, carboxy-hemoglobin, respiration rate and blood pressure to name a few. Further, the signal component processor is generally applicable to identifying, selecting and processing any basis function signal components, of which single frequency components are one embodiment, as described in further detail with respect to FIG. **9**, below.

FIGS. **9-11** illustrate another embodiment of a signal component processor **900**. As shown in FIG. **9**, the processor **900** has an index calculator **910** and a measurement calculator **960**. The index calculator has a sensor signal input S **902** and outputs a basis function index κ_O **912**, as described with respect to FIG. **10**, below. The measurement calculator **960** inputs the basis function index κ_O **912** and outputs a physiological measurement U_{κ_O} **962**, as described with respect to FIG. **11**, below. The processor **900** also has a basis function indicator **980**, which is responsive to the sensor signal input S **902** and provides a parameter ε **982** that indicates a set of basis functions to be utilized by the index calculator **910**, as described with respect to FIG. **10**, below.

As shown in FIG. **10**, the functions of the index calculator **910** are basis subset generation **1020**, component cancellation **1040** and optimization calculation **1060**. The basis subset generation **1020** outputs a subset Φ_κ **1022** of basis function waveforms corresponding to a set of selected basis function indices κ . The basis functions can be any complete set of functions such that

$$S = \sum_{\kappa} a_\kappa \Phi_\kappa \tag{13}$$

For simplicity of illustration purposes, these basis functions are assumed to be orthogonal

$$\left\langle \vec{\Phi}_\gamma, \vec{\Phi}_\eta \right\rangle = 0; \gamma \neq \eta \tag{14}$$

where $\langle\ \rangle$ denotes an inner product. As such

$$a_\kappa = \left\langle S, \Phi_\kappa \right\rangle / \left\langle \Phi_\kappa, \Phi_\kappa \right\rangle \tag{15}$$

$$S_\kappa = a_\kappa \Phi_\kappa \tag{16}$$

In general, the basis functions may be non-orthogonal. The subset of basis functions generated is determined by an input parameter ε **982**. In the embodiment described with respect to FIG. **5**, above, the basis functions are sinusoids, the indices are the sinusoid frequencies and the input parameter ε **982** is a pulse rate estimate that determines a frequency window.

As shown in FIG. **10**, the component cancellation **1040** generates a remainder output R_κ **1042**, which is a set of remainder signals corresponding to the subset of basis function waveforms Φ_κ **1022**. For each basis function waveform generated, component cancellation removes the corresponding basis function component from the sensor signal S **902** to generate a remainder signal. In an alternative embodiment, component cancellation **1040** is replaced with a component selection that generates a corresponding basis function component of the sensor signal S **902** for each basis function generated. The optimization calculation **1060** generates a particular index κ_O **912** associated with an optimization of the remainders R_κ **1042** or, alternatively, an optimization of the selected basis function signal components.

As shown in FIG. **11**, the functions of the measurement calculator **960** are basis function generation **1120**, component selection **1140**, and physiological measurement calculation **1170**. The component selection **1140** inputs the sensor signal S **902** and a particular basis function waveform Φ_{κ_O} **1122** and outputs a sensor signal component S_{κ_O} **1142**. The physiological measurement **1170** inputs the sensor signal component S_{κ_O} **1142** and outputs the physiological measurement U_{κ_O} **962**, which is responsive to the sensor signal component S_{κ_O} **1142**. In the embodiment described with respect to FIG. **6**, above, the basis functions Φ_κ are sinusoids and the index κ_O is a particular sinusoid frequency. The basis function generation **1120** creates sine and cosine waveforms at this frequency. The component selection **1140** selects corresponding frequency components of the sensor signal portions, RD and IR. Also, the physiological measurement **1170** computes an oxygen saturation based upon a magnitude ratio of these RD and IR frequency components.

The signal component processor has been disclosed in detail in connection with various embodiments. These embodiments are disclosed by way of examples only and are not to limit the scope of the claims that follow. One of ordinary skill in the art will appreciate many variations and modifications.

WHAT IS CLAIMED IS:

1. A signal processor comprising:

a physiological signal;

a basis function index determined from said signal;

a basis function waveform generated according to said index;

a component derived from said sensor signal and said waveform; and

a physiological measurement responsive to said component.

2. The signal processor according to claim 1 wherein said component is responsive to the inner product of said sensor signal and said waveform.

3. The signal processor according to claim 1 wherein:

said index is a frequency; and

said waveform is a sinusoid at said frequency.

4. The signal processor according to claim 3 further comprising a pulse rate estimate derived from said signal wherein said frequency is selected from a window including said pulse rate estimate.

5. The signal processor according to claim 3 wherein said physiological measurement is an oxygen saturation value responsive to a magnitude of said component.

6. A signal processor comprising:

a signal input;

a basis function indicator derived from said signal input;

a plurality of basis functions generated according to said indicator;

a plurality of characteristics of said signal input corresponding to said basis functions; and

an optimization of said characteristics so as to identify at least one of said basis functions.

7. The signal processor according to claim 6 wherein said indicator is a pulse rate estimate and said processor further comprises:

a window configured to include said pulse rate estimate; and

a plurality of frequencies selected from within said window.

8. The signal processor according to claim 6 wherein said characteristic comprises:

a plurality of signal remainders corresponding to said basis functions; and

a plurality of magnitudes of said signal remainders;

and wherein said optimization comprises a minima of said magnitudes.

9. The signal processor according to claim 7 wherein said characteristic comprises:

a plurality of signal components corresponding to said basis functions; and

a plurality of magnitudes of said components;

and wherein said optimization comprises a maxima of said magnitudes.

10. A signal processing method comprising the steps of:

receiving a sensor signal;

calculating an estimated pulse rate;

determining an optimization of said sensor signal proximate said estimated pulse rate;

defining a frequency corresponding to said optimization; and

outputting a physiological measurement responsive to a component of said sensor signal at said frequency.

11. The signal processing method according to claim 10 wherein said determining step comprises the substeps of:

transforming said sensor signal to a frequency spectrum encompassing said estimated pulse rate; and

detecting an extrema of said spectrum indicative of said frequency.

12. The signal processing method according to claim 11 wherein said transforming step comprises the substeps of:

defining a window including said estimated pulse rate;

defining a plurality of selected frequencies within said window;

canceling said selected frequencies, individually, from said sensor signal to generate a plurality of remainder signals; and

calculating a plurality of magnitudes of said remainder signals.

13. The signal processing method according to claim 12 wherein said detecting step comprises the substep of locating a minima of said magnitudes.

14. The signal processing method according to claim 10 wherein said outputting step comprises the substeps of:

inputting a red (RD) portion and an infrared (IR) portion of said sensor signal;

deriving a RD component of said RD portion and an IR component of said IR portion corresponding to said frequency; and

computing an oxygen saturation based upon a magnitude ratio of said RD component and said IR component.

15. The signal processing method according to claim 14 wherein said deriving step comprises the substeps of:

generating a sinusoidal waveform at said frequency; and

selecting said RD component and said IR component utilizing said waveform.

16. The signal processing method according to claim 15 wherein said selecting step comprises the substep of calculating the inner product between said waveform and said RD portion and the inner product between said waveform and said IR portion.

17. The signal processing method according to claim 16 wherein said selecting step comprises the substeps of:

canceling said waveform from said RD portion and said IR portion, leaving a RD remainder and an IR remainder; and

subtracting said RD remainder from said RD portion and said IR remainder from said IR portion.

18. A signal processor comprising:

a first calculator means for deriving an optimization frequency from a pulse rate estimate and a sensor signal; and

a second calculator means for deriving a physiological measurement responsive to a sensor signal component at said frequency.

19. The signal processor according to claim 18 wherein said first calculator means comprises:

a signal component transform means for determining a plurality of signal values corresponding to a plurality of selected frequencies within a window including said pulse rate estimate; and

a detection means for determining a particular one of said selected frequencies corresponding to an optimization of said sensor signal.

20. The signal processor according to claim 19 wherein said second calculator means comprises:

a waveform means for generating a sinusoidal signal at said frequency;

a frequency selection means for determining a component of said sensor signal from said sinusoidal signal; and

a calculator means for deriving a ratio responsive to said component.

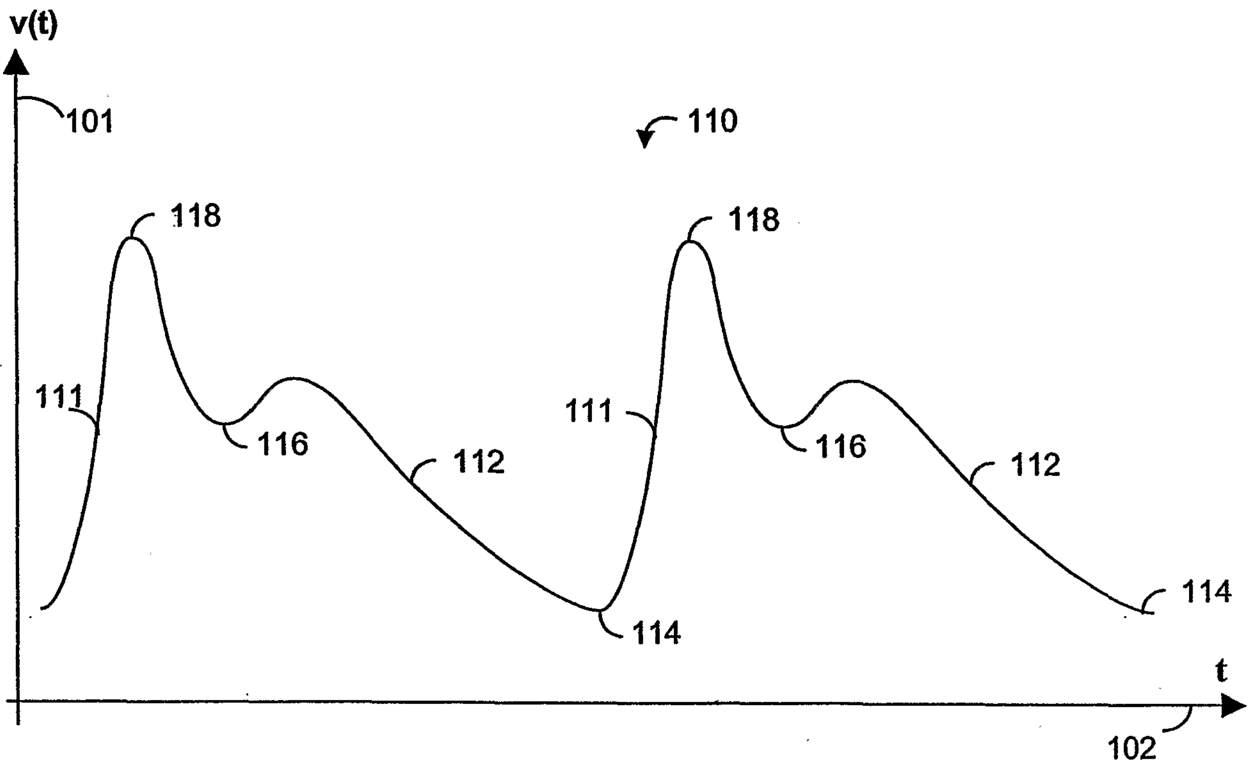


FIG. 1A

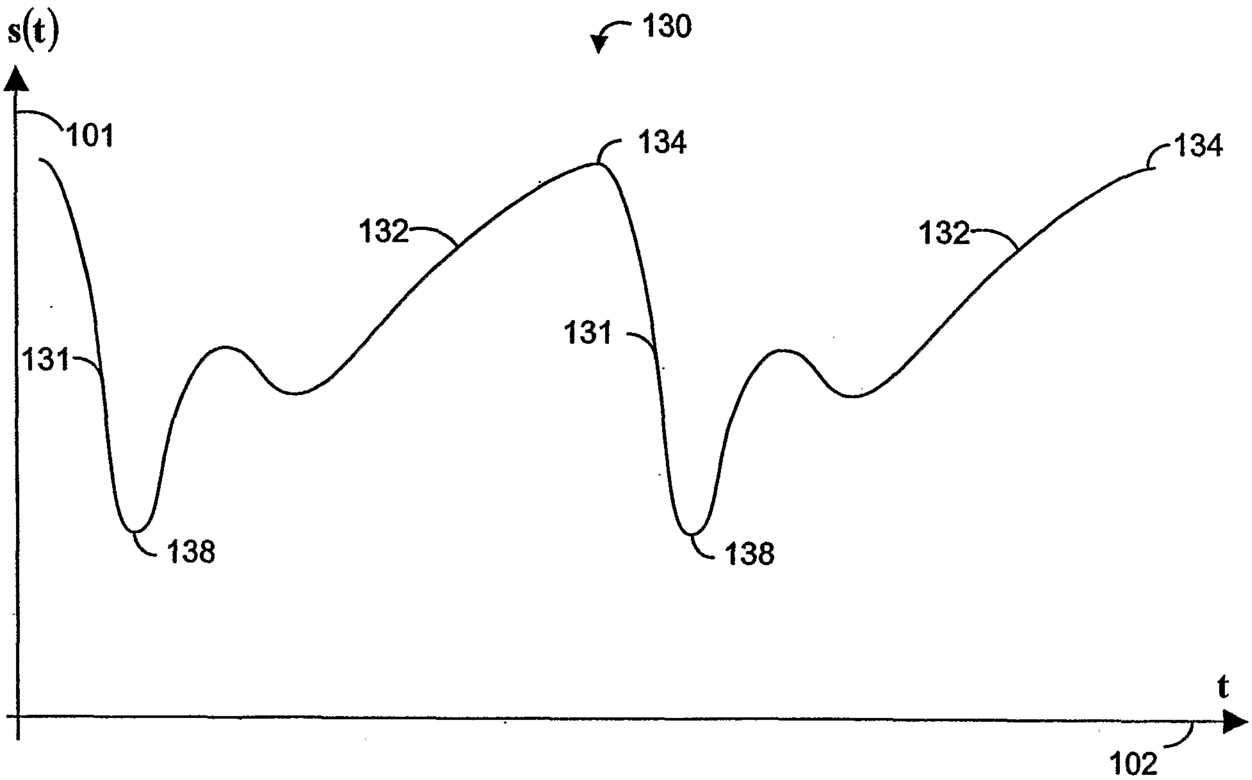
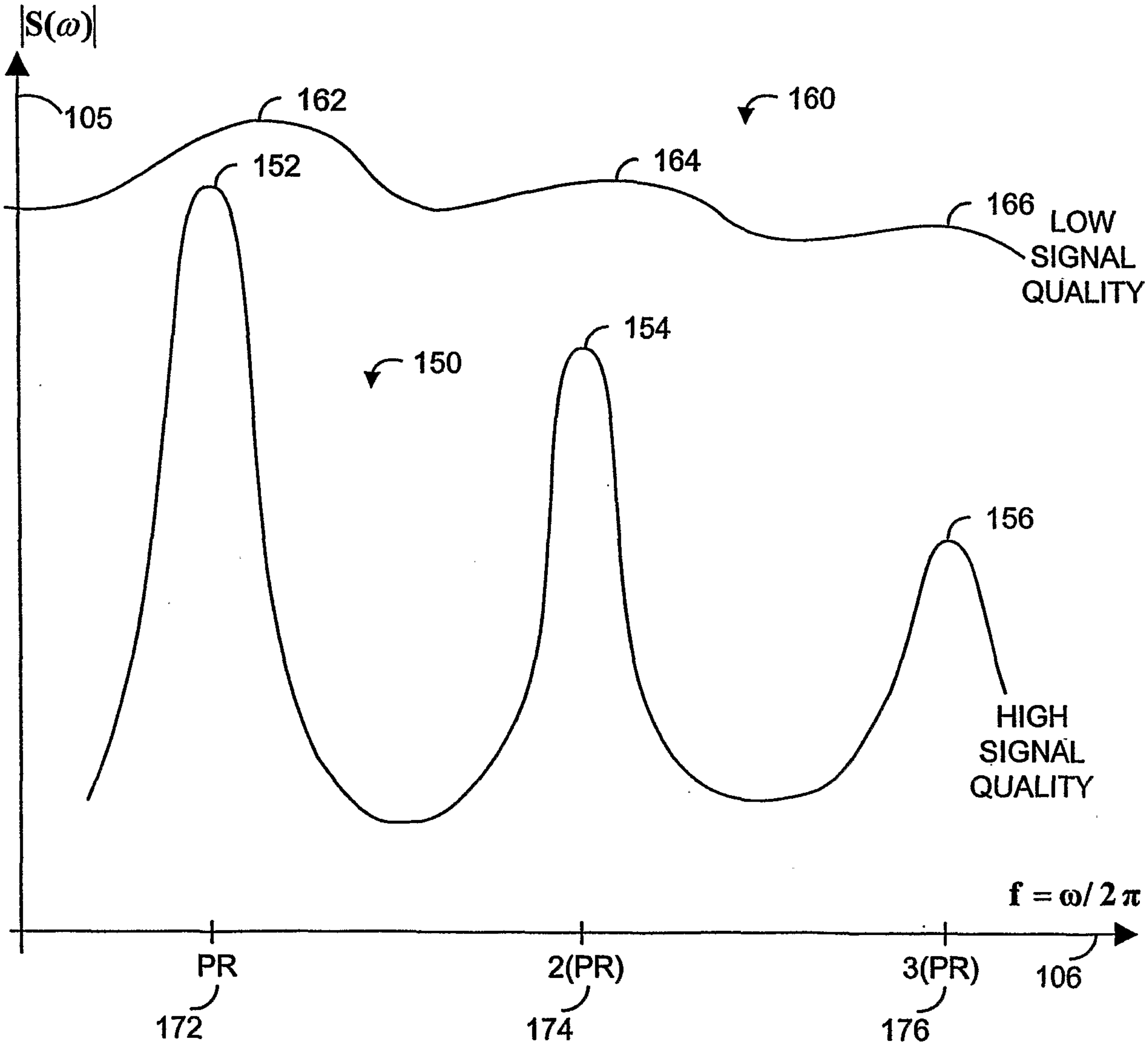


FIG. 1B



|S(ω)|
105
162
160
152
164
166
LOW SIGNAL QUALITY
154
150
156
HIGH SIGNAL QUALITY
f = ω/2π
PR
2(PR)
3(PR)
106
172
174
176

FIG. 1C

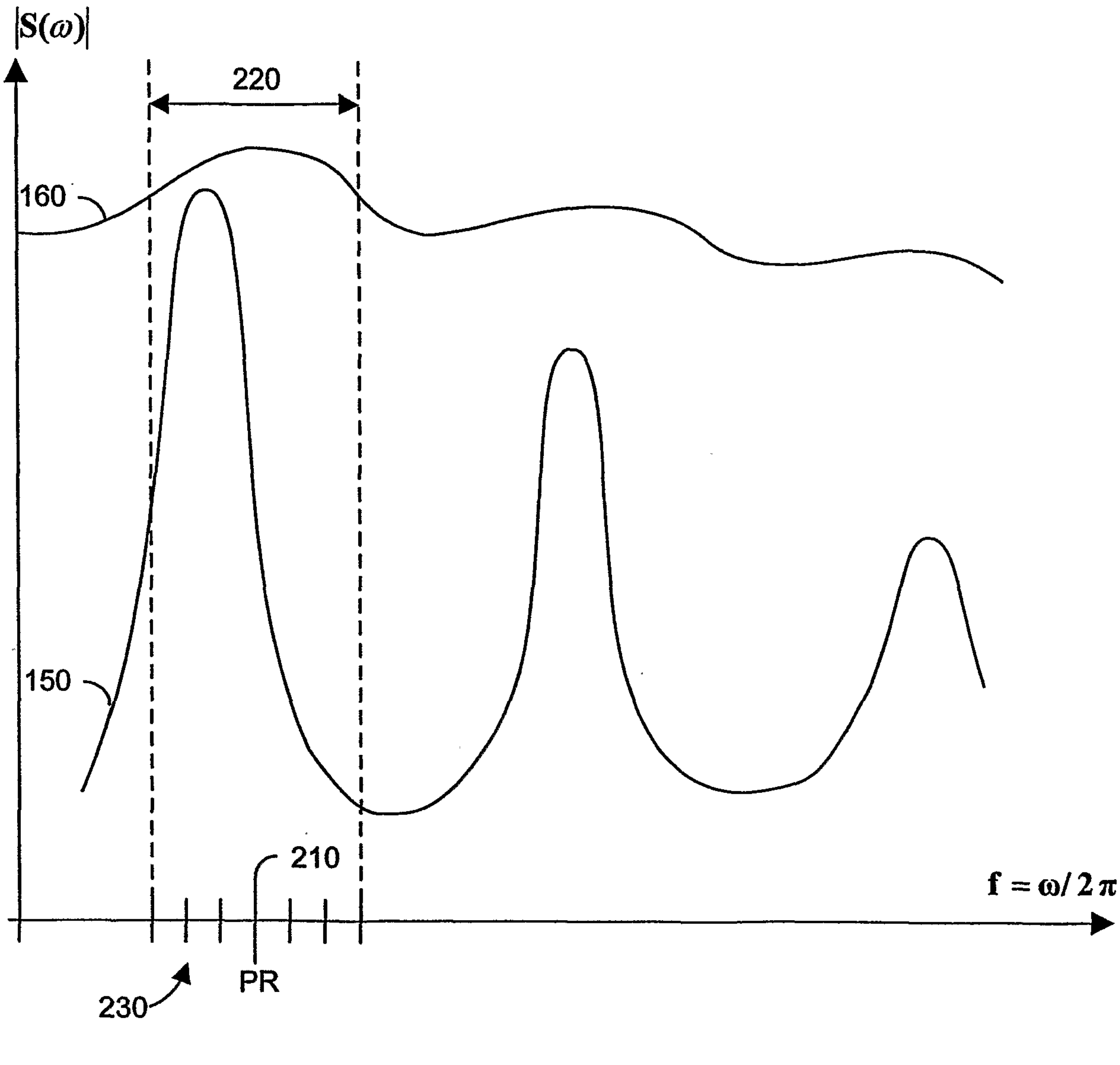


FIG. 2

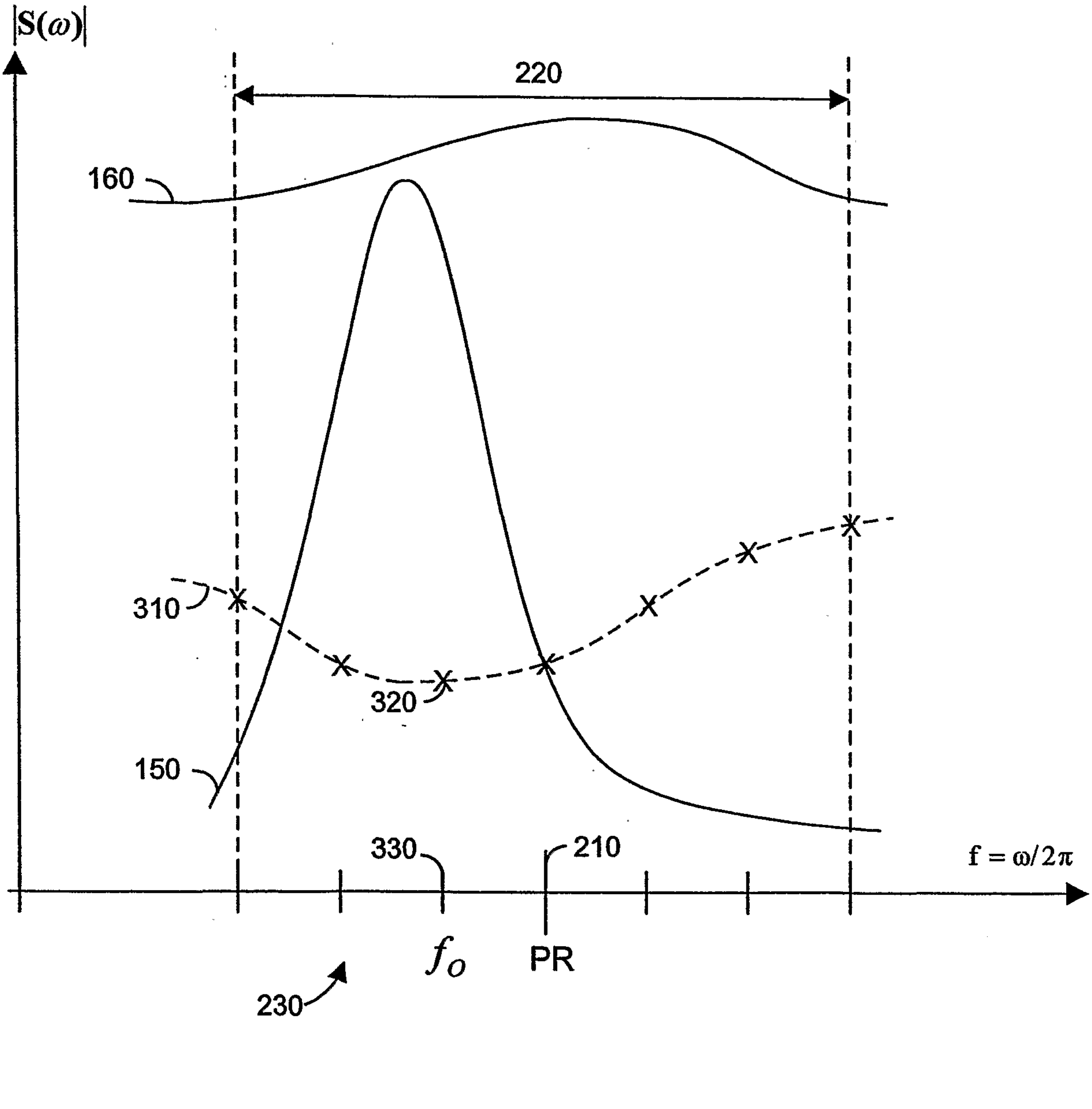


FIG. 3

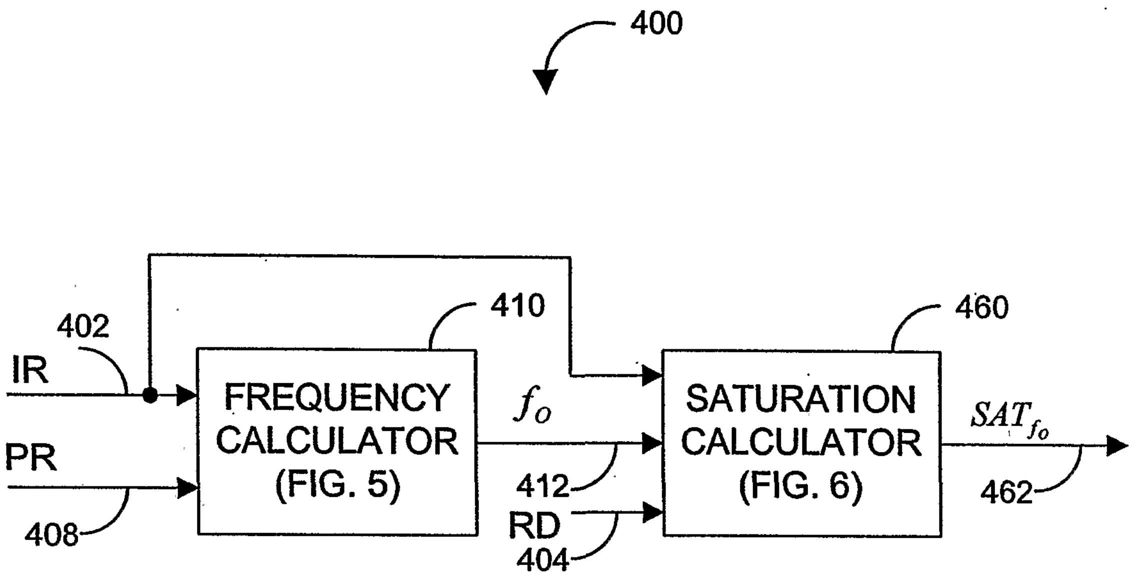

400
410
460
402
IR
PR
408
FREQUENCY
CALCULATOR
(FIG. 5)
f_o
412
RD
404
SATURATION
CALCULATOR
(FIG. 6)
SAT_{f_o}
462

FIG. 4

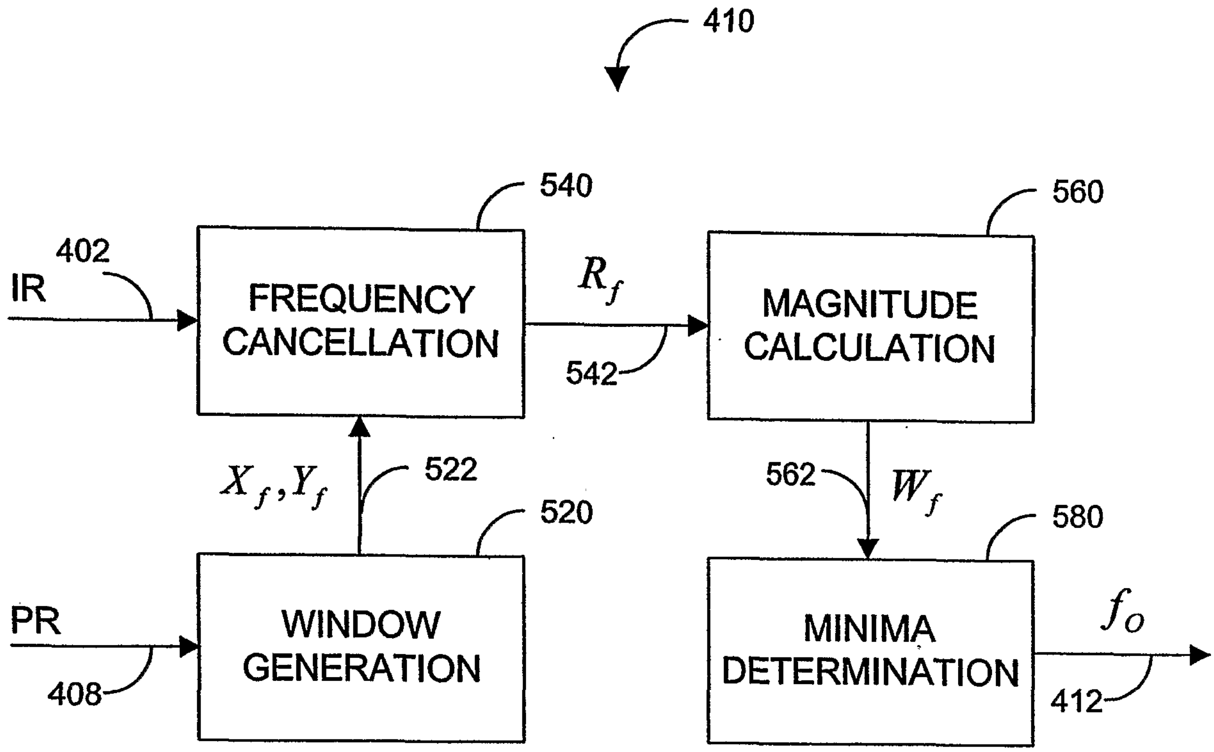

410
540
560
402
IR
FREQUENCY CANCELLATION
R_f
MAGNITUDE CALCULATION
542
X_f, Y_f
522
562
W_f
520
580
PR
WINDOW GENERATION
MINIMA DETERMINATION
f_O
408
412

FIG. 5

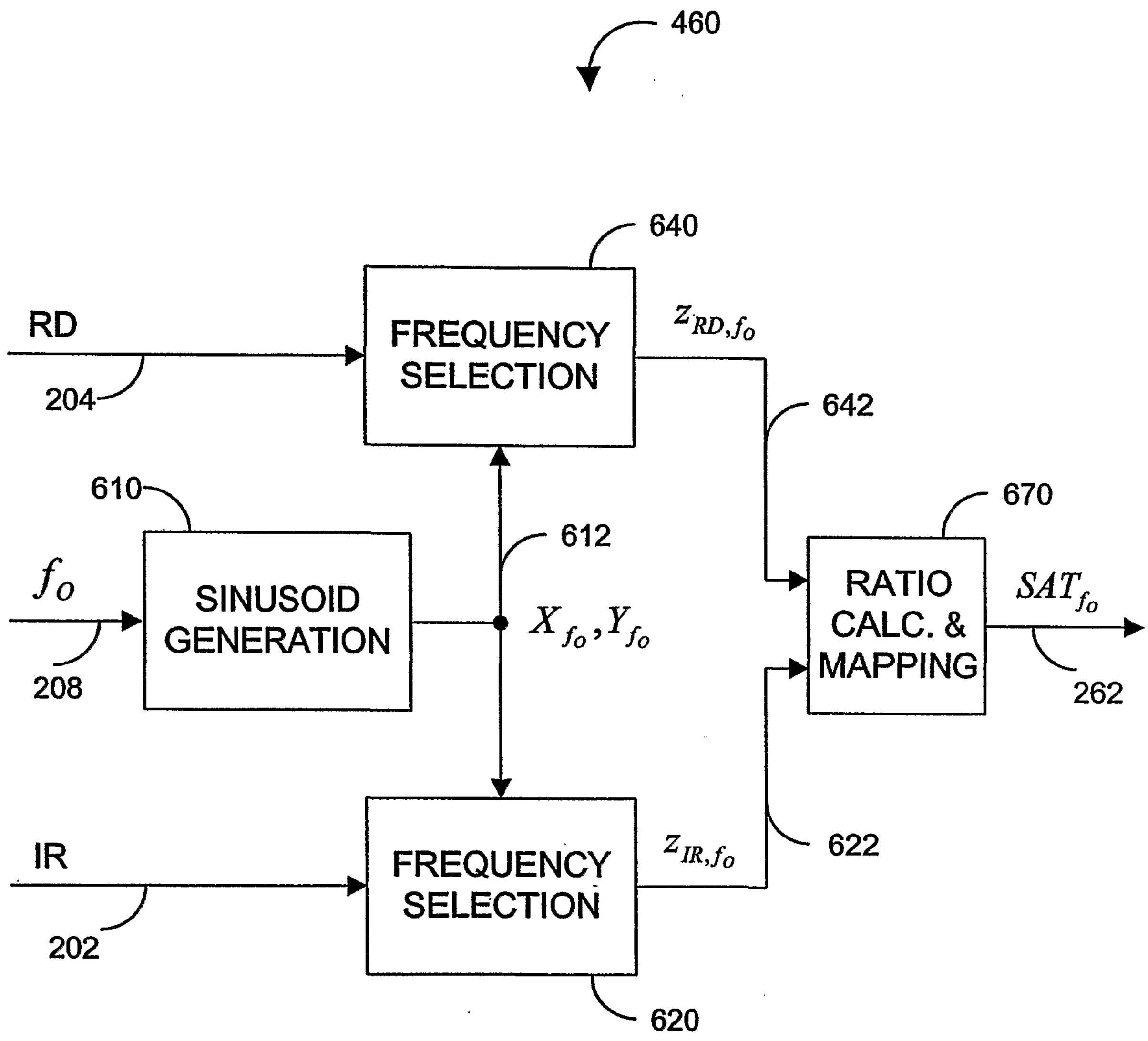

460
640
RD
FREQUENCY SELECTION
204
z_{RD,f_o}
642
610
612
670
f_o
SINUSOID GENERATION
X_{f_o}, Y_{f_o}
RATIO CALC. & MAPPING
SAT_{f_o}
208
262
IR
FREQUENCY SELECTION
z_{IR,f_o}
622
202
620

FIG. 6

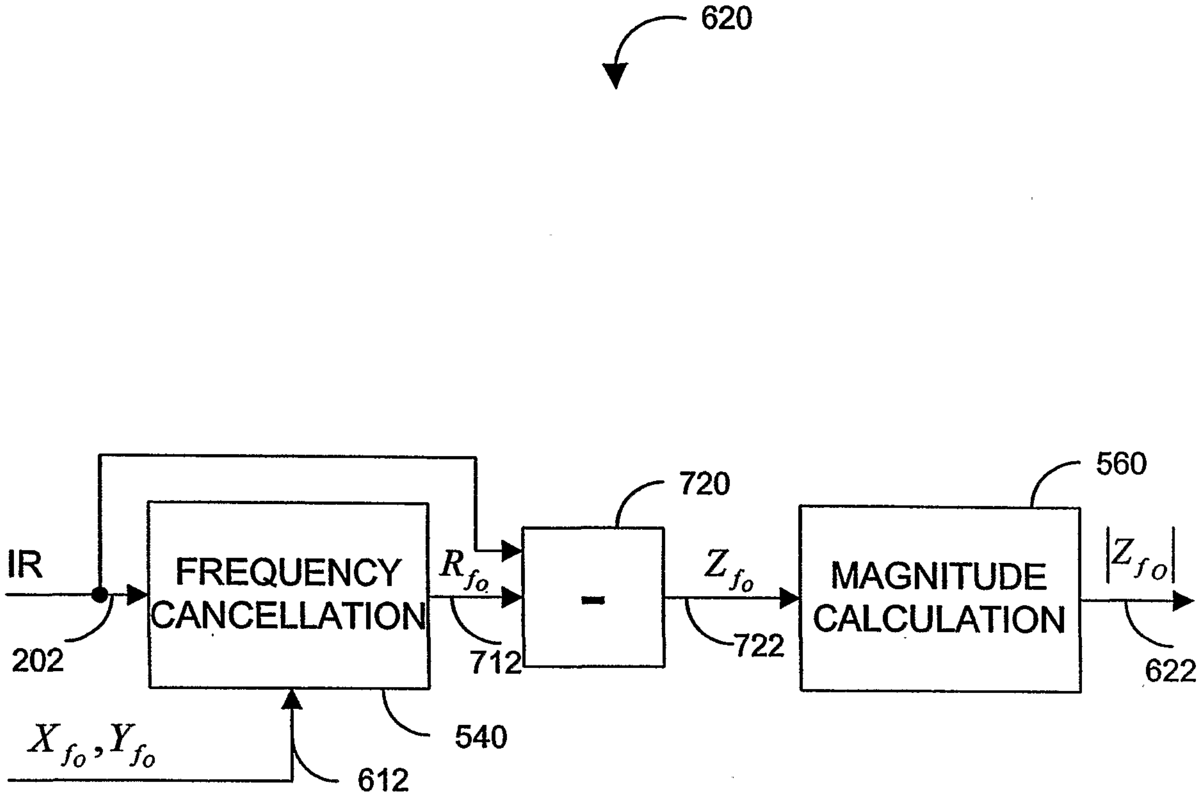

620
IR
202
FREQUENCY CANCELLATION
540
X_{fo}, Y_{fo}
612
R_{fo}
712
720
-
Z_{fo}
722
560
MAGNITUDE CALCULATION
$|Z_{fo}|$
622

FIG. 7

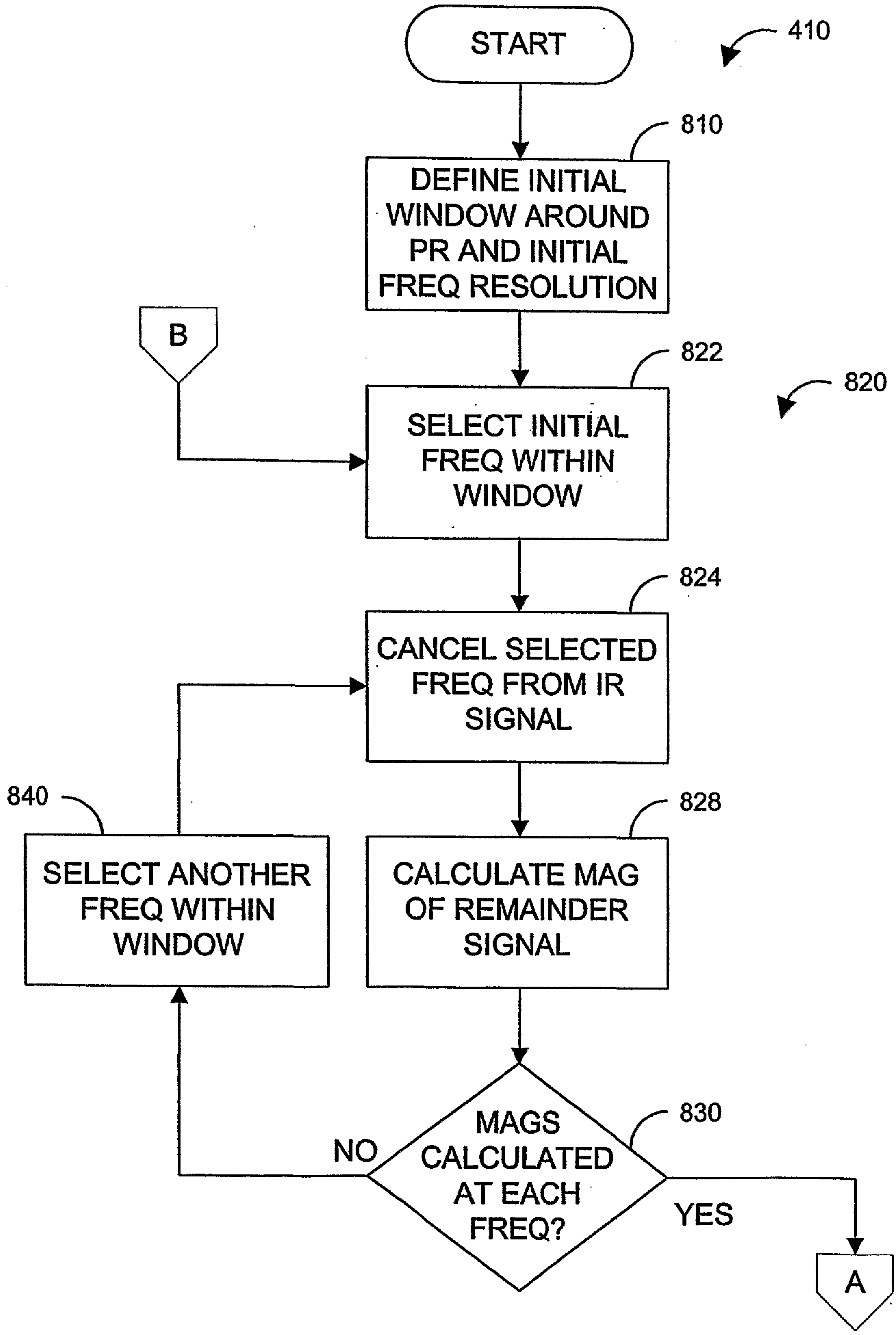

START
410
810
DEFINE INITIAL WINDOW AROUND PR AND INITIAL FREQ RESOLUTION
B
822
820
SELECT INITIAL FREQ WITHIN WINDOW
824
CANCEL SELECTED FREQ FROM IR SIGNAL
840
SELECT ANOTHER FREQ WITHIN WINDOW
828
CALCULATE MAG OF REMAINDER SIGNAL
830
MAGS CALCULATED AT EACH FREQ?
NO
YES
A

FIG. 8A

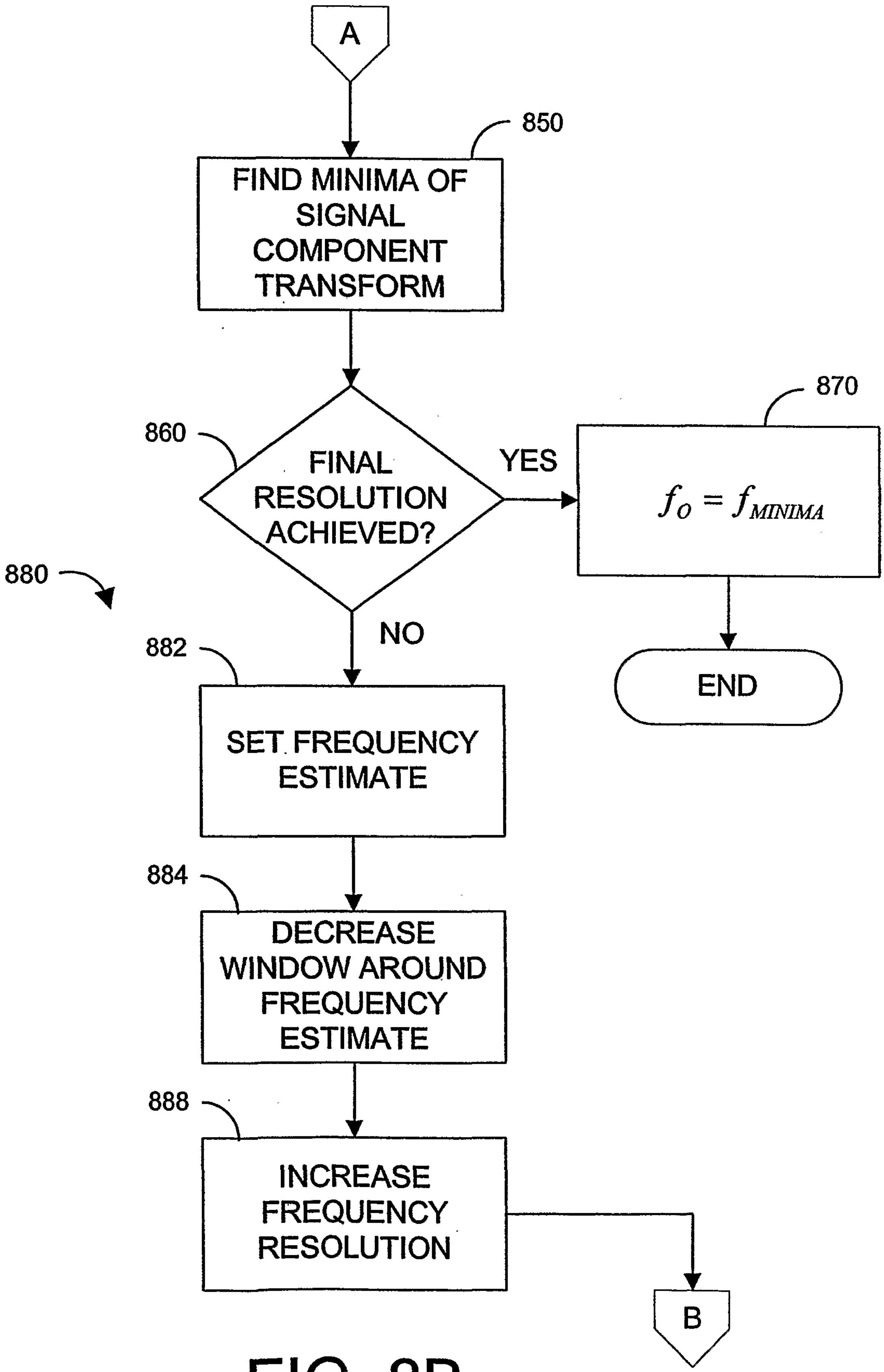

A
850
FIND MINIMA OF SIGNAL COMPONENT TRANSFORM
860
FINAL RESOLUTION ACHIEVED?
YES
870
$f_O = f_{MINIMA}$
END
880
NO
882
SET FREQUENCY ESTIMATE
884
DECREASE WINDOW AROUND FREQUENCY ESTIMATE
888
INCREASE FREQUENCY RESOLUTION
B

FIG. 8B

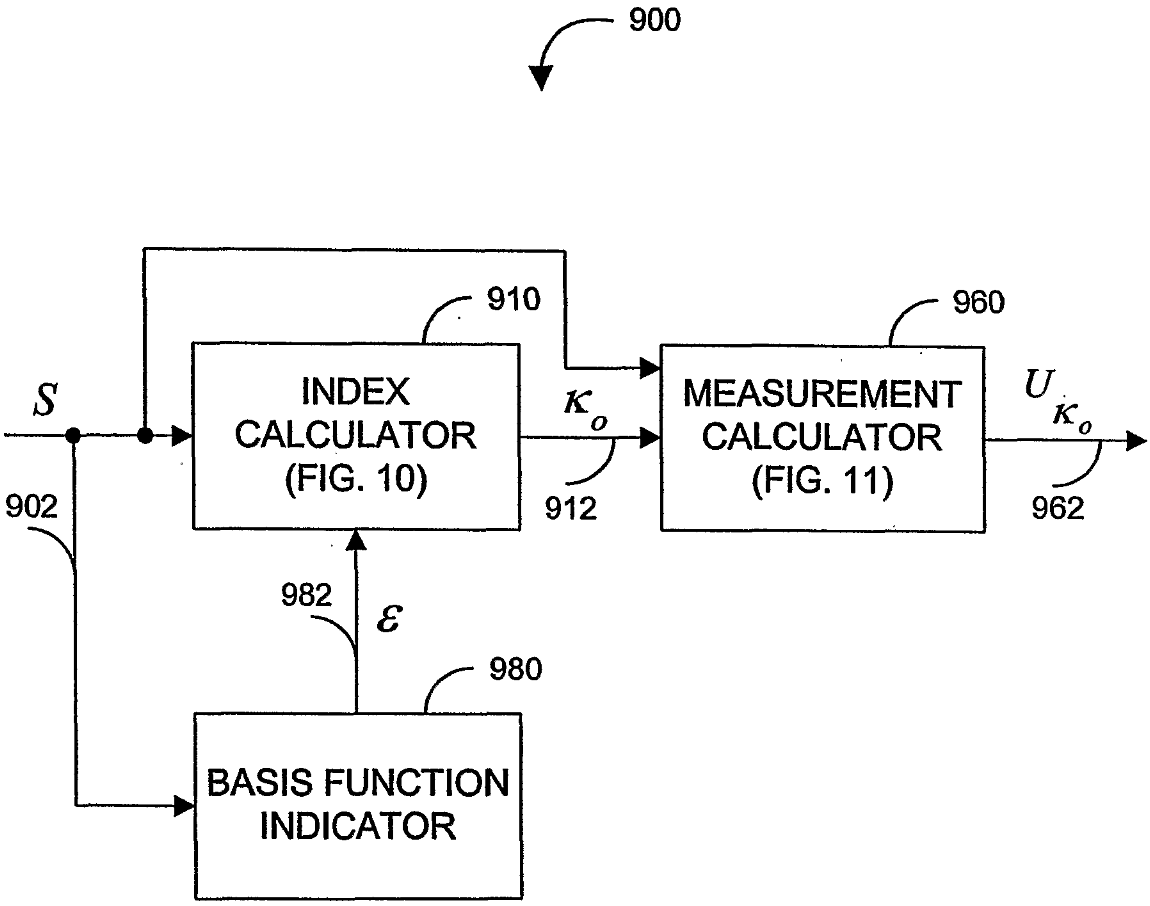

900
910
960
S
INDEX
CALCULATOR
(FIG. 10)
κ_o
MEASUREMENT
CALCULATOR
(FIG. 11)
U_{κ_o}
902
912
962
982
ε
980
BASIS FUNCTION
INDICATOR

FIG. 9

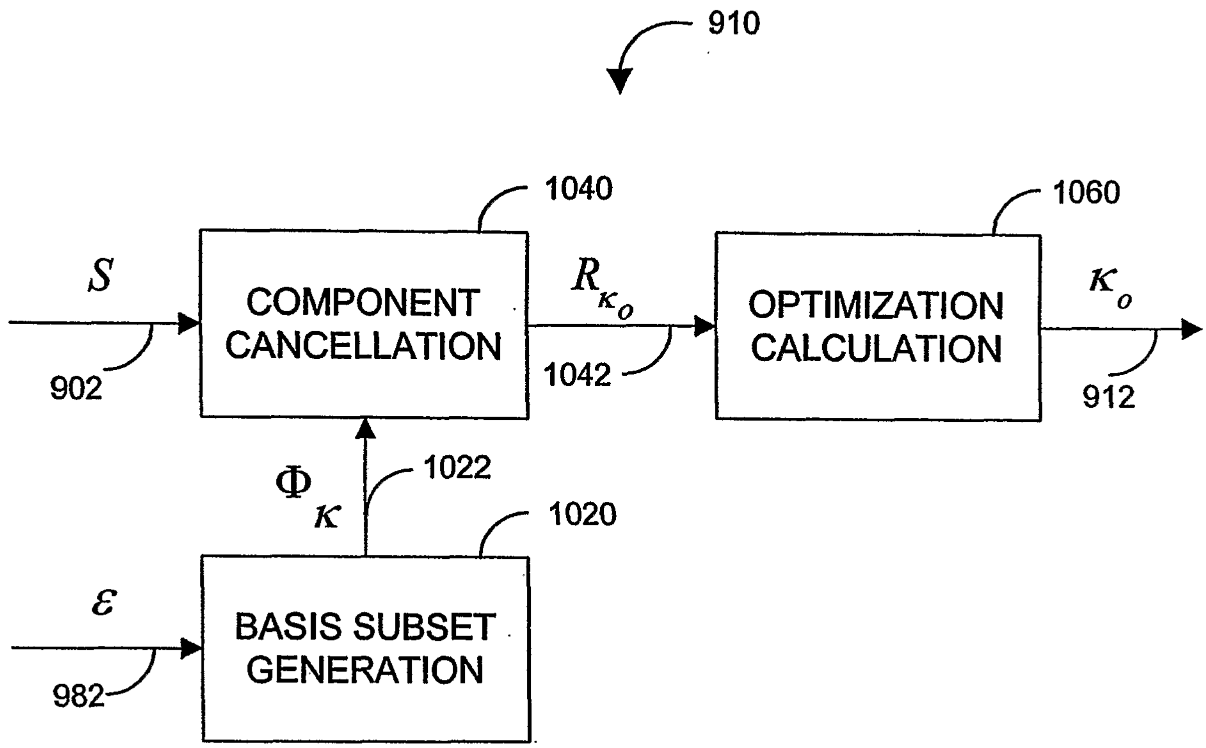

910
1040
1060
S
COMPONENT CANCELLATION
R
OPTIMIZATION CALCULATION
κ o
902
1042
912
Φ κ
1022
1020
ε
BASIS SUBSET GENERATION
982

FIG. 10

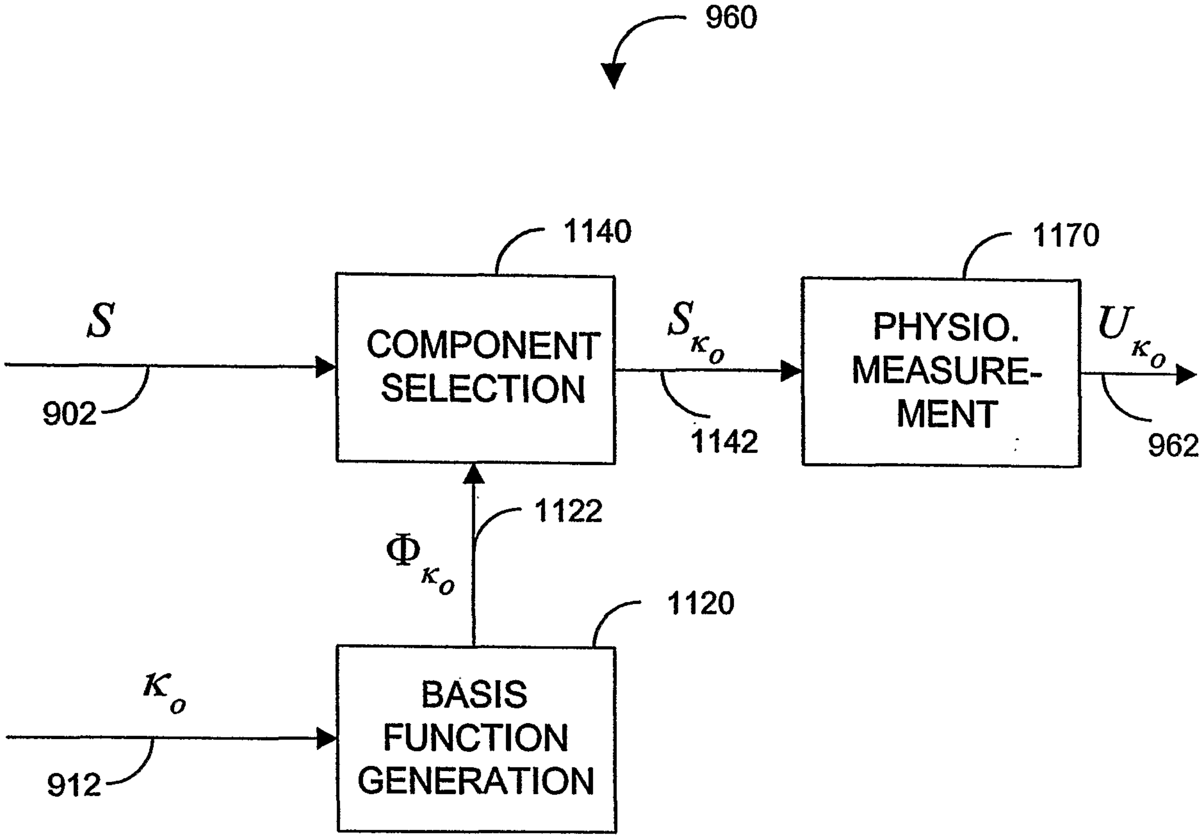

960
1140
1170
S
COMPONENT SELECTION
S_{κ_o}
PHYSIO. MEASUREMENT
U_{κ_o}
902
1142
962
1122
Φ_{κ_o}
1120
κ_o
BASIS FUNCTION GENERATION
912

FIG. 11

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 02/20674

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 A61B5/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 A61B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 98 42250 A (NELLCOR PURITAN BENNETT INC) 1 October 1998 (1998-10-01) page 2, line 1 - line 7 page 15, last paragraph -page 17, last paragraph ---	10-20
A	US 6 002 952 A (DIAB MOHAMED K ET AL) 14 December 1999 (1999-12-14) cited in the application column 17, line 7 -column 21, line 47 ---	10-20
A	US 5 995 858 A (KINAST ERIC) 30 November 1999 (1999-11-30) column 8, line 19 - line 41 -----	10-20

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
30 October 2002	06/11/2002

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Manschot, J

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 02/20674

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [ ] Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. [X] Claims Nos.: 1-9
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:
see FURTHER INFORMATION sheet PCT/ISA/210

3. [ ] Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. [ ] As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. [ ] As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

[ ] The additional search fees were accompanied by the applicant's protest.

[ ] No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

Continuation of Box I.2

Claims Nos.: 1-9

The present set of claims contains multiple independent claims, which render it difficult, if not impossible, to determine the matter for which protection is sought. The present application therefore fails to comply with the clarity and conciseness requirements of Article 6 PCT (see also Rule 6.1(a) PCT) to such an extent that a meaningful search is impossible.
Furthermore, claims 1 and 6 relate to an apparatus but fail to define any apparatus features. Instead they define abstract and non-constructional features like: a signal, an index, a waveform, a signal component, a measurement, etc. Therefore, it is obscure how the apparatus is restricted. Moreover, these claims use expressions like "basis function index" , "basis functions", etc., which expressions have no well known clear and definite meaning. Consequently, claims 1 and 6 are so unclear that no meaningful search can be carried out.

Therefore, and since (as far as clear from the description) clarification of claims 1 and 6 could only lead to claims defining subject-matter falling under the scope of claims 10 to 20, the search has been carried out for those parts of the application which do appear to be clear (and concise), namely claims 10 to 20.

The applicant's attention is drawn to the fact that claims, or parts of claims, relating to inventions in respect of which no international search report has been established need not be the subject of an international preliminary examination (Rule 66.1(e) PCT). The applicant is advised that the EPO policy when acting as an International Preliminary Examining Authority is normally not to carry out a preliminary examination on matter which has not been searched. This is the case irrespective of whether or not the claims are amended following receipt of the search report or during any Chapter II procedure.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 02/20674

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
WO 9842250	A	01-10-1998	WO	9842250	A1	01-10-1998
			AU	720609	B2	08-06-2000
			AU	2105197	A	20-10-1998
			EP	0975446	A1	02-02-2000
			JP	2001518822	T	16-10-2001
US 6002952	A	14-12-1999	AU	7109298	A	11-11-1998
			US	6067462	A	23-05-2000
			WO	9846126	A1	22-10-1998
US 5995858	A	30-11-1999	NONE			

patsnap

专利名称(译)	信号分量处理器		
公开(公告)号	EP1399058A1	公开(公告)日	2004-03-24
申请号	EP2002742353	申请日	2002-06-28
[标]申请(专利权)人(译)	梅西莫股份有限公司		
申请(专利权)人(译)	Masimo公司		
当前申请(专利权)人(译)	Masimo公司		
[标]发明人	WEBER WALTER M AL ALI AMMAR CAZZOLI LORENZO		
发明人	WEBER, WALTER, M. AL-ALI, AMMAR CAZZOLI, LORENZO		
IPC分类号	A61B5/02 A61B5/00 A61B5/145 A61B5/1455		
CPC分类号	A61B5/14552 A61B5/024 A61B5/02433 A61B5/14532 A61B5/1455 A61B5/14551 A61B5/7282		
代理机构(译)	法思博事务所		
优先权	60/302438 2001-06-29 US		
其他公开文献	EP1399058B1		
外部链接	Espacenet		

摘要(译)

信号处理器生成基函数并识别传感器信号的至少一个基函数分量，以便计算生理测量。信号处理器有利地应用于脉搏血氧测定法，以便直接计算氧饱和度并且以便计算稳健的氧饱和度测量值。特别地，可以在导出的脉搏率估计周围的窗口内计算信号分量变换。信号分量变换还可以利用正弦基函数，并且信号分量变换的优化可以在特定频率或一组频率处发生。产生该频率或频率组的正弦波形或波形以选择传感器信号的相关红色和红外分量，并根据这些分量的幅度比计算氧饱和度。