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El Haddad et al.

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(54) **CARDIAC ACTIVATION TIME DETECTION**

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A61B 5/04	(2006.01)
A61B 5/042	(2006.01)
A61B 5/0452	(2006.01)
A61B 5/00	(2006.01)

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

CPC ***A61B 5/04012*** (2013.01); ***A61B 5/042*** (2013.01); ***A61B 5/0422*** (2013.01); ***A61B 5/0452*** (2013.01); *A61B 5/7203* (2013.01); *A61B 5/7239* (2013.01)

(58) **Field of Classification Search**

None

See application file for complete search history.

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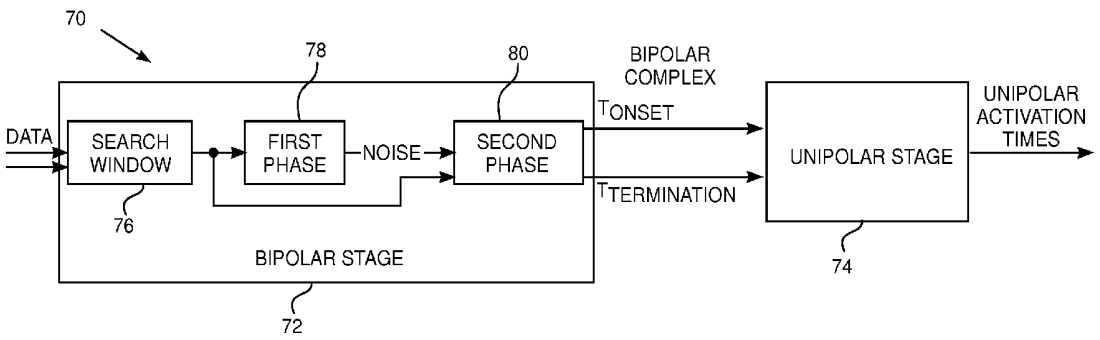
(57) **ABSTRACT**

A method for characterizing an electrocardiogram, including receiving a first unipolar signal from a first location of a heart and a second unipolar signal from a second location of the heart. The method further includes generating a bipolar signal from the first and second unipolar signals, and analyzing the bipolar signal to delineate a time period during which the first and second locations generate a bipolar complex. The method also includes analyzing the first unipolar signal within the time period to determine an activation time of the first location.

15 Claims, 11 Drawing Sheets



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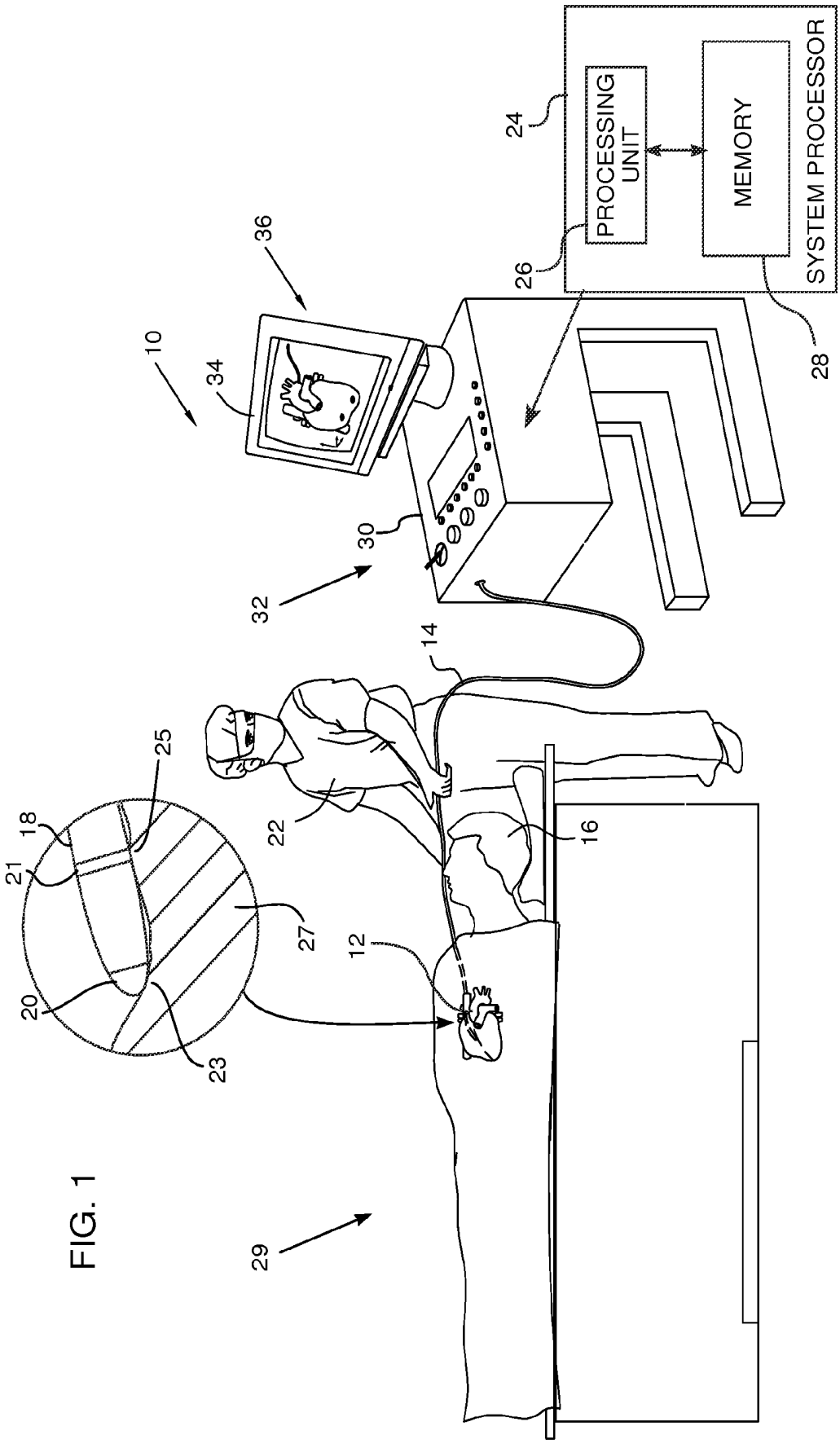

SYSTEM PROCESSOR
PROCESSING UNIT
MEMORY
24
26
28
36
34
10
30
32
14
25
18
21
22
16
27
12
20
23
29

FIG. 1

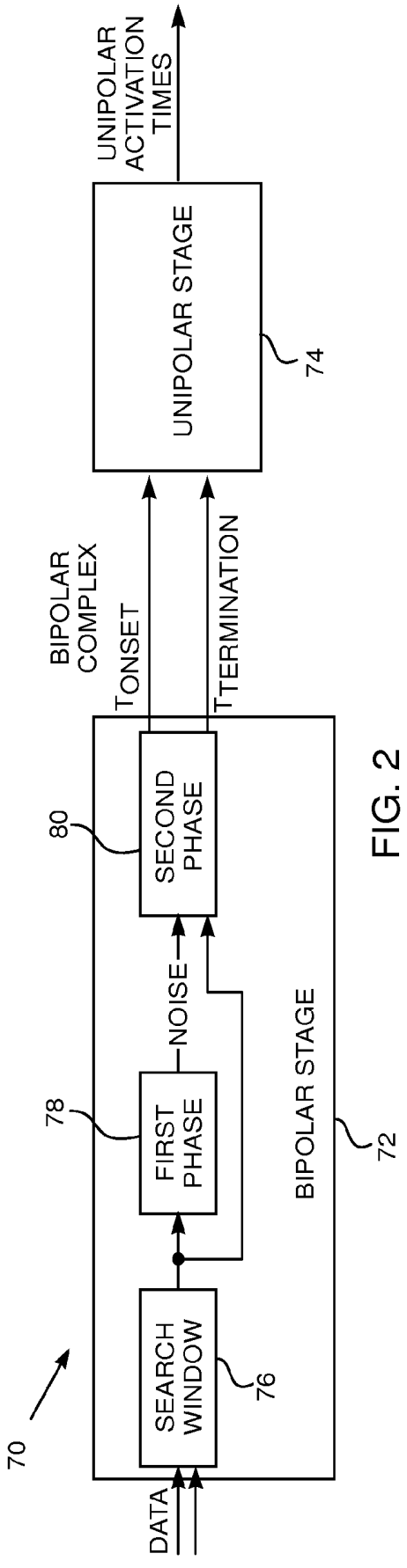

70
DATA
SEARCH WINDOW
76
FIRST PHASE
78
NOISE
SECOND PHASE
80
BIPOLAR STAGE
72
BIPOLAR COMPLEX
TONSET
TTERMINATION
UNIPOLAR STAGE
74
UNIPOLAR ACTIVATION TIMES

FIG. 2

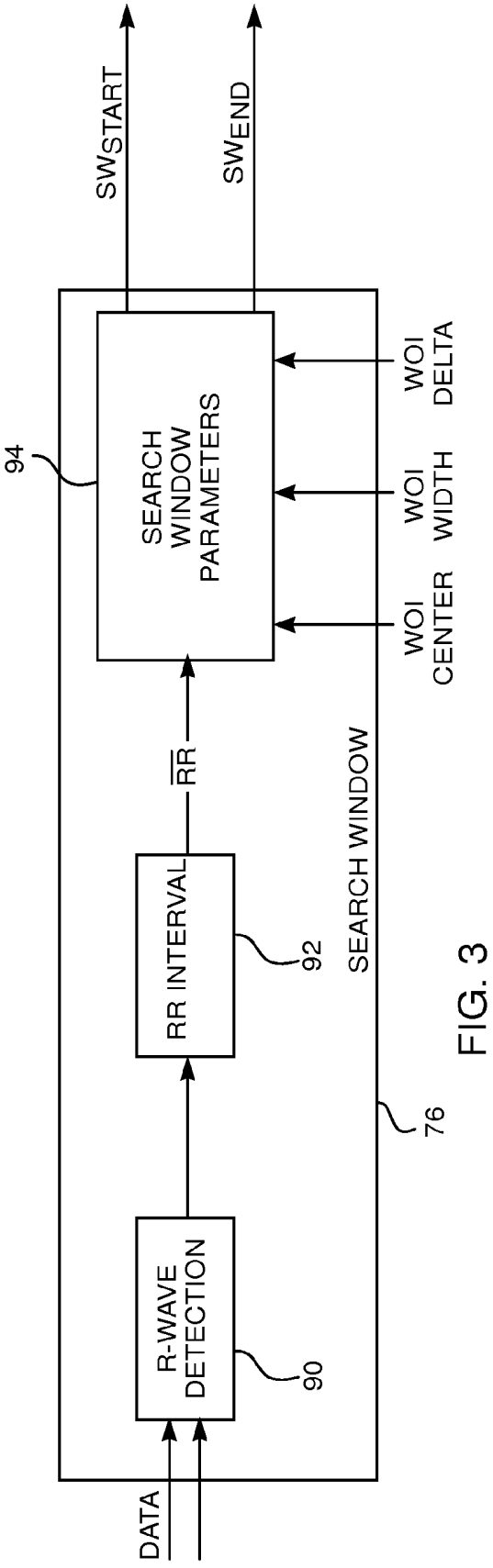

DATA
R-WAVE DETECTION
90
RR INTERVAL
92
RR
SEARCH WINDOW
76
SEARCH WINDOW PARAMETERS
94
WOI CENTER
WOI WIDTH
WOI DELTA
SWEND
SWSTART

FIG. 3

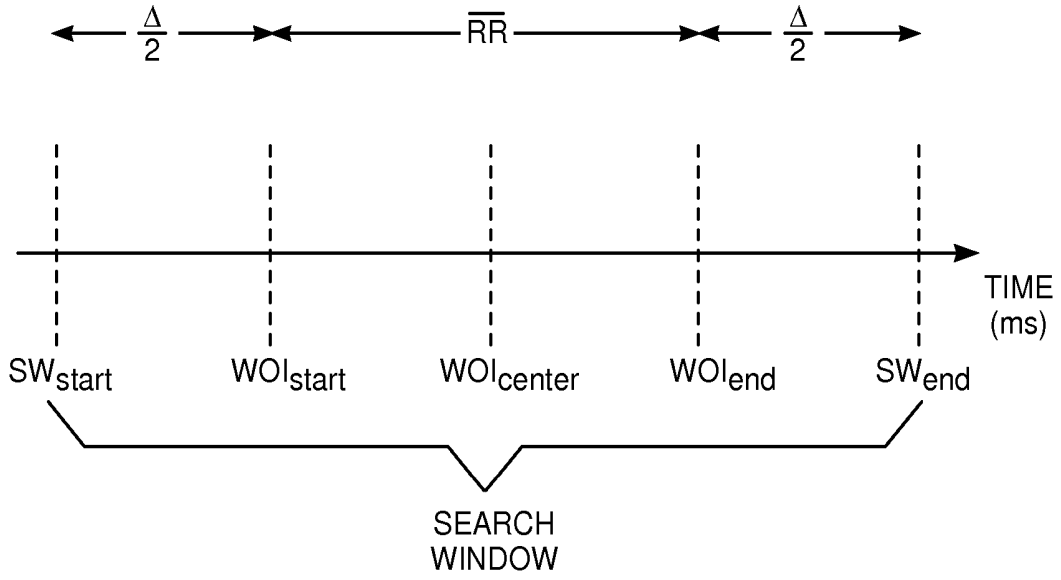

Δ/2
RR
Δ/2
TIME (ms)
SWstart
WOIstart
WOIcenter
WOIend
SWend
SEARCH WINDOW

FIG. 4

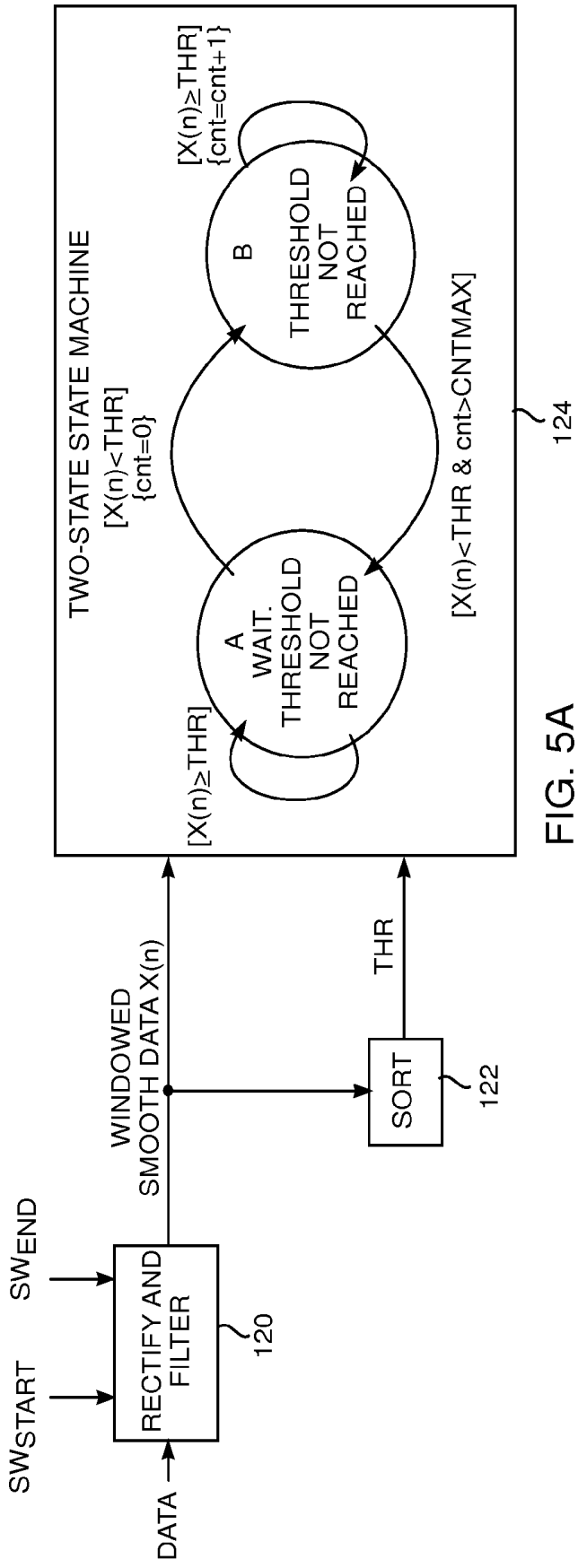


FIG. 5A

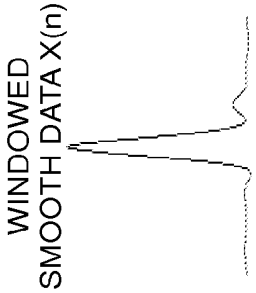


FIG. 5C

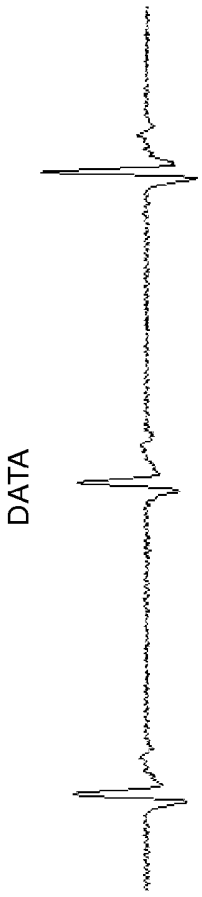
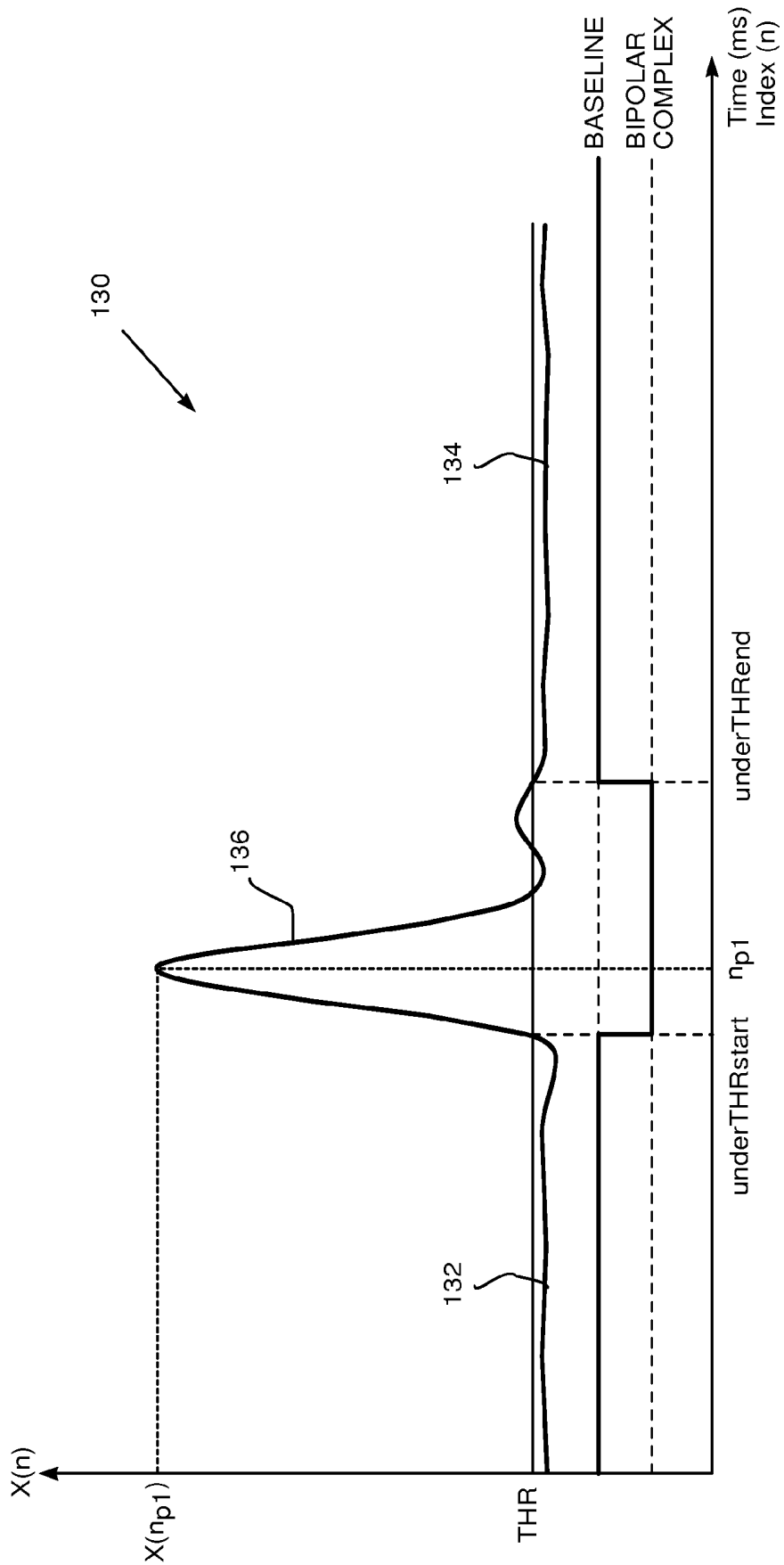


FIG. 5B

FIG. 6


130
134
136
132
BASELINE
BIPOLAR COMPLEX
Time (ms)
Index (n)
underTHRend
underTHRstart
n_{p1}
X(n)
X(n_{p1})
THR

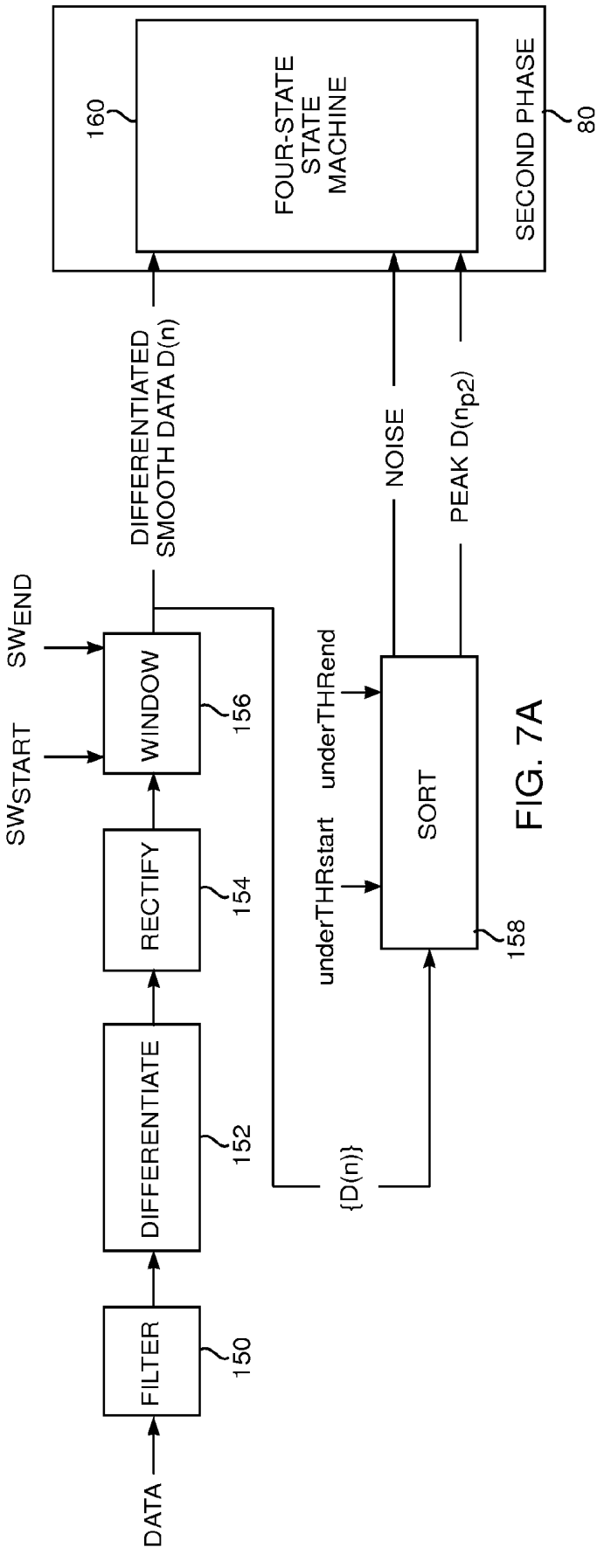

DATA
FILTER
150
DIFFERENTIATE
152
RECTIFY
154
WINDOW
156
SORT
158
SECOND PHASE
80
FOUR-STATE STATE MACHINE
160
SWSTART
SWEND
underTHRstart
underTHRend
{D(n)}
DIFFERENTIATED SMOOTH DATA D(n)
NOISE
PEAK D(np2)

FIG. 7A

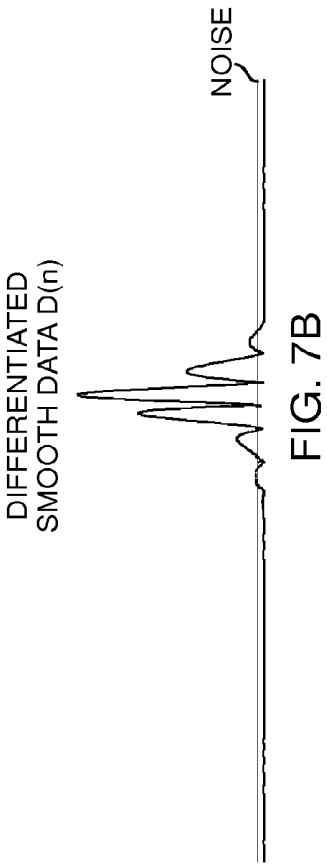

DIFFERENTIATED SMOOTH DATA D(n)
NOISE

FIG. 7B

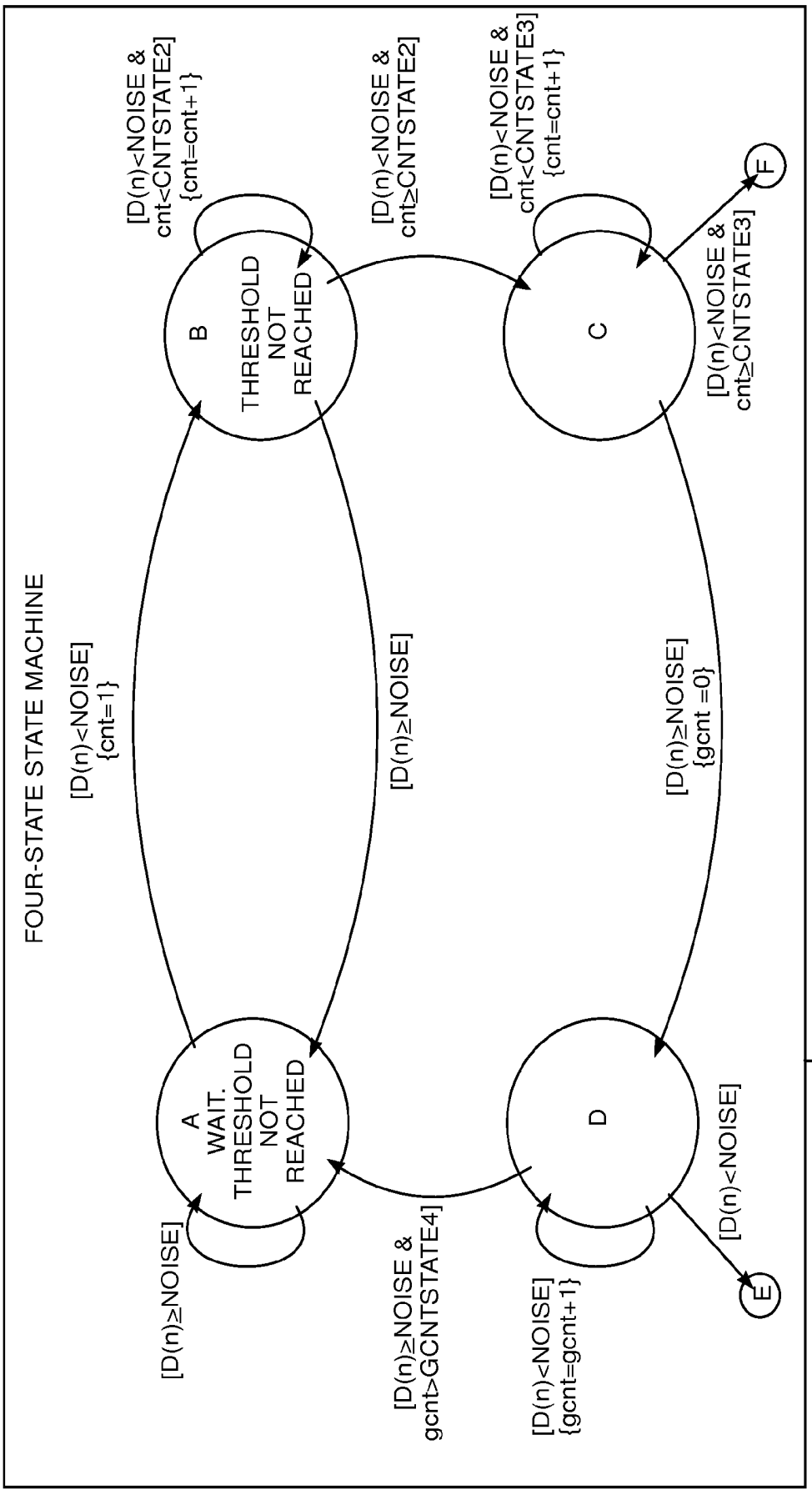

FOUR-STATE STATE MACHINE
A
WAIT.
THRESHOLD
NOT
REACHED
B
THRESHOLD
NOT
REACHED
C
D
E
F
[D(n)<NOISE]
{cnt=1}
[D(n)≥NOISE]
[D(n)<NOISE &
cnt<CNTSTATE2]
{cnt=cnt+1}
[D(n)<NOISE &
cnt≥CNTSTATE2]
[D(n)<NOISE &
cnt<CNTSTATE3]
{cnt=cnt+1}
[D(n)<NOISE &
cnt≥CNTSTATE3]
[D(n)≥NOISE]
{gcnt =0}
[D(n)≥NOISE]
[D(n)≥NOISE &
gcnt>GCNTSTATE4]
[D(n)<NOISE]
{gcnt=gcnt+1}
[D(n)<NOISE]
160

FIG. 8

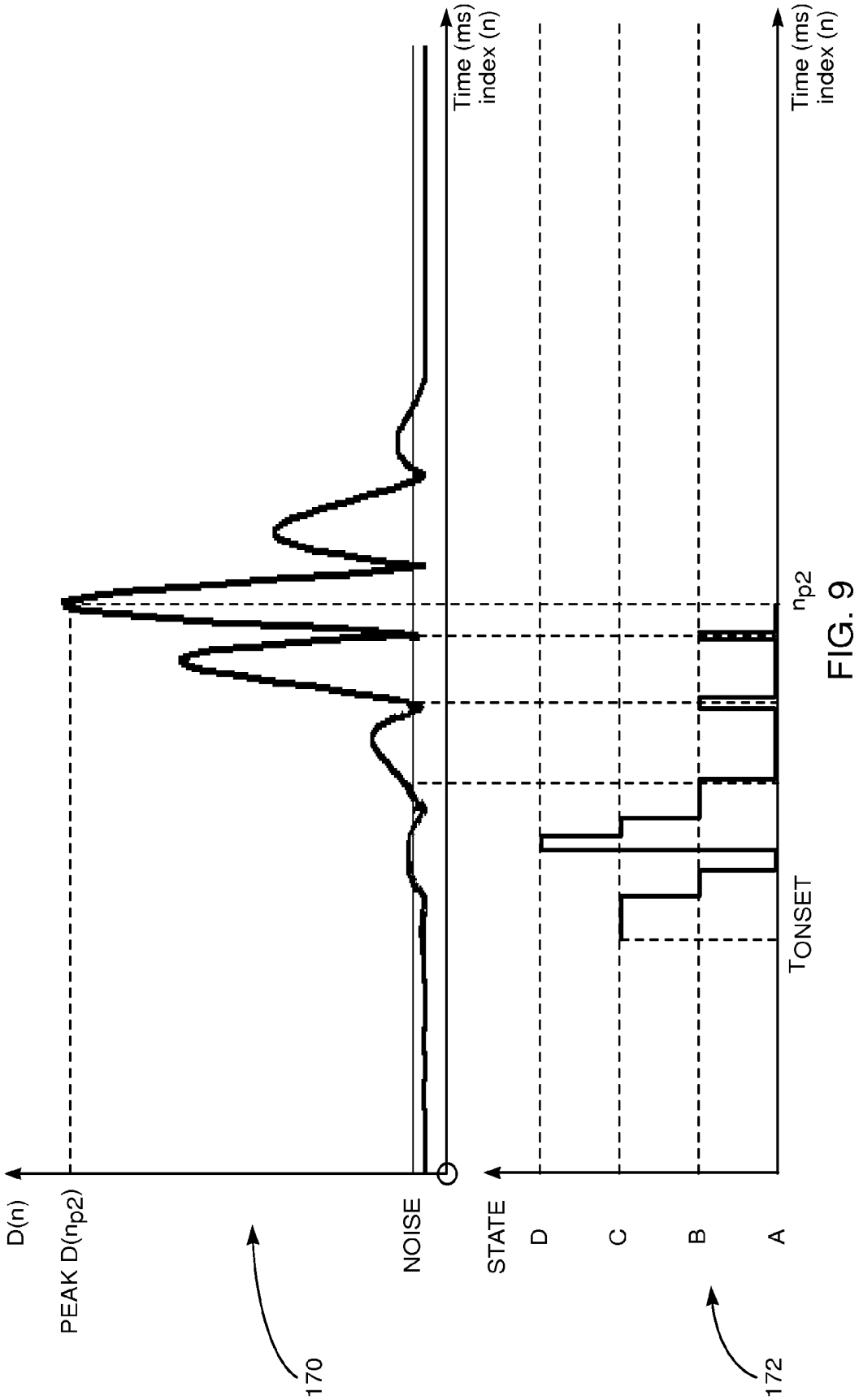

D(n)
PEAK D(np2)
NOISE
Time (ms)
index (n)
170
STATE
D
C
B
A
Time (ms)
index (n)
np2
TONSET
172

FIG. 9

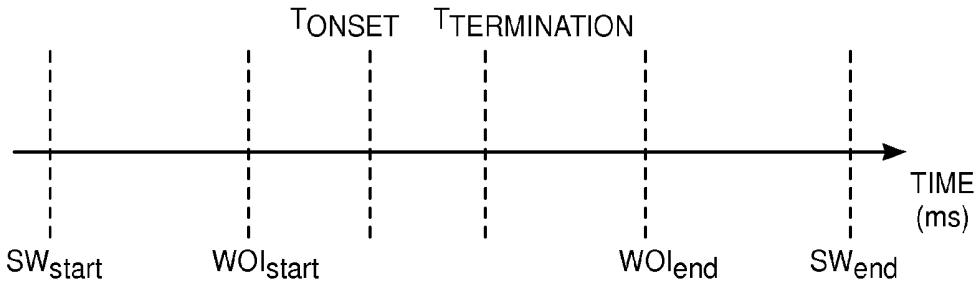


FIG. 10

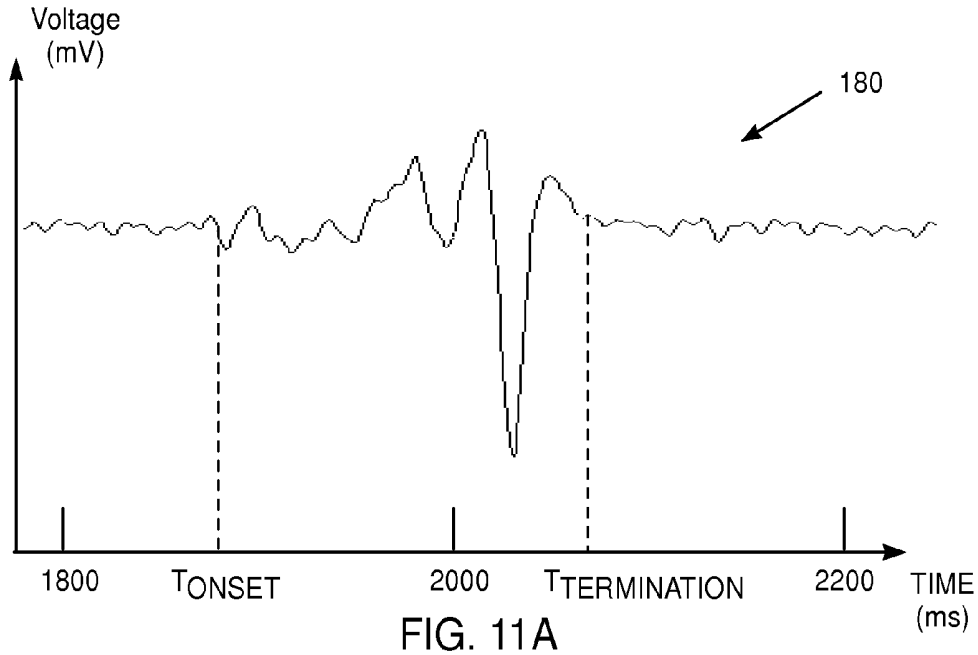


FIG. 11A

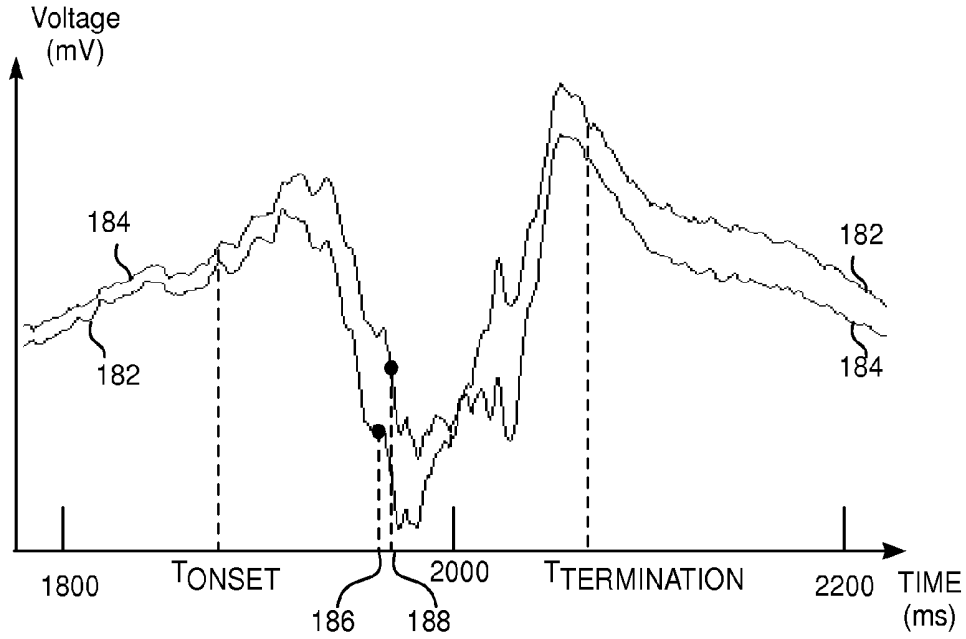


FIG. 11B

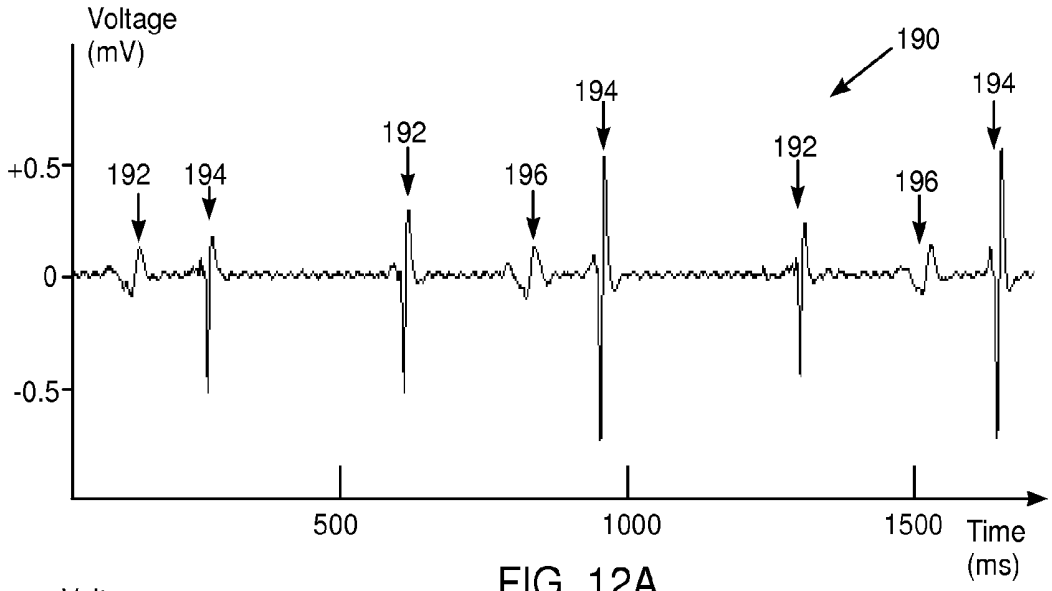


FIG. 12A

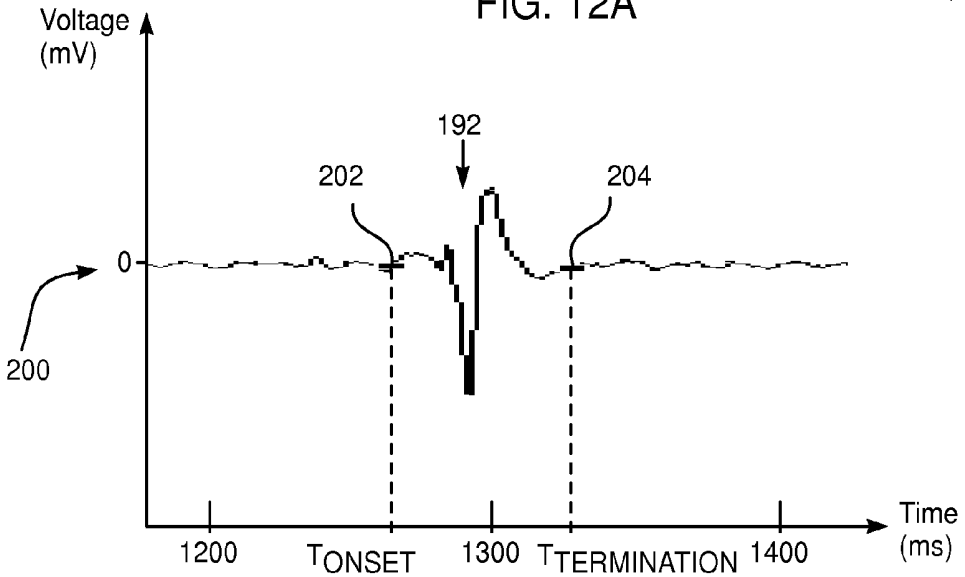


FIG. 12B

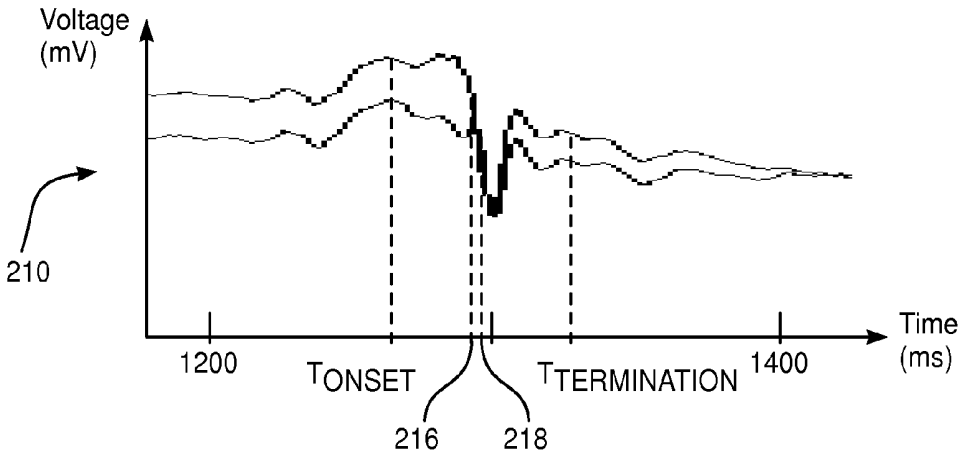


FIG. 12C

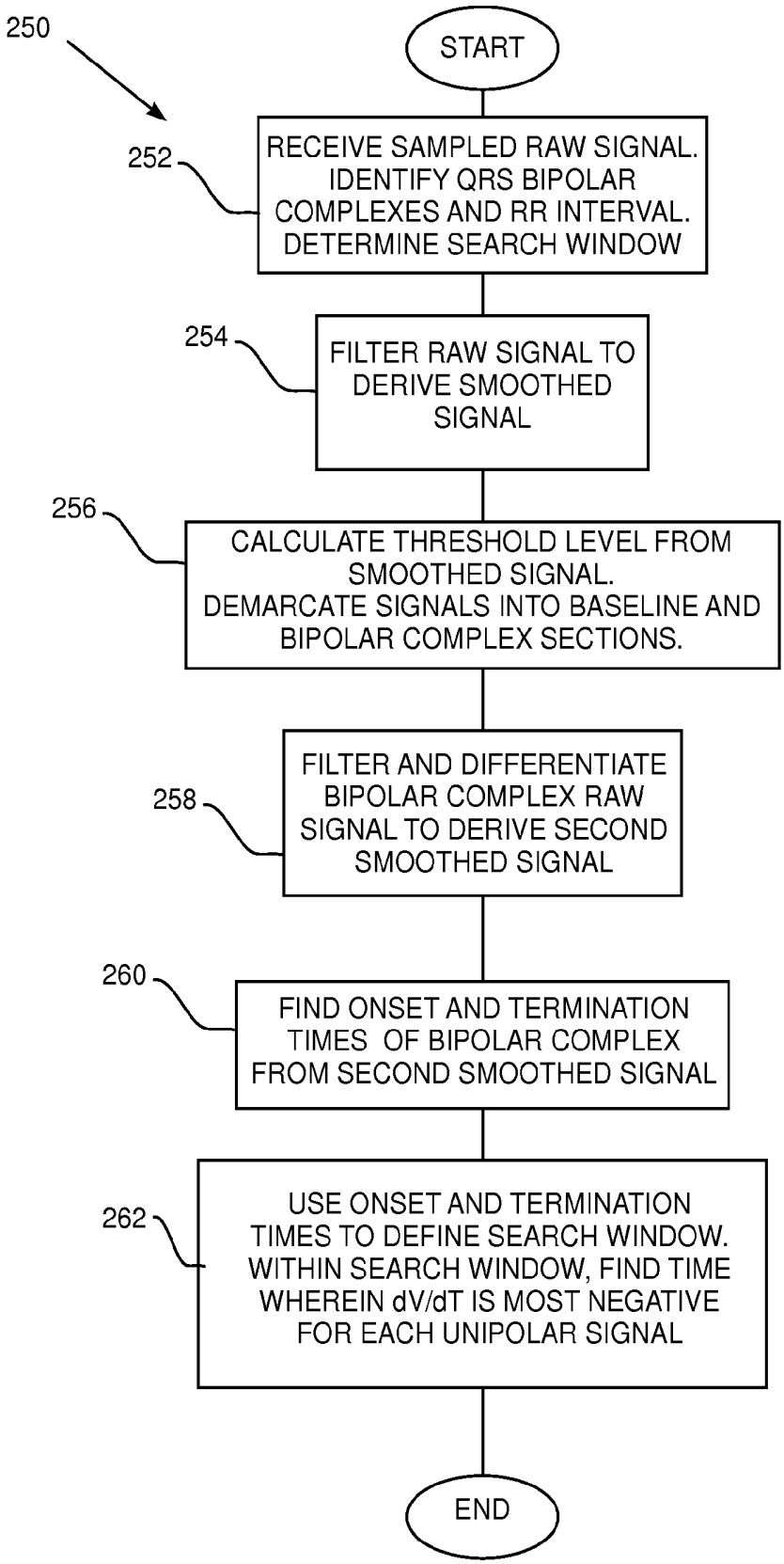

250
START
252
RECEIVE SAMPLED RAW SIGNAL. IDENTIFY QRS BIPOLAR COMPLEXES AND RR INTERVAL. DETERMINE SEARCH WINDOW
254
FILTER RAW SIGNAL TO DERIVE SMOOTHED SIGNAL
256
CALCULATE THRESHOLD LEVEL FROM SMOOTHED SIGNAL. DEMARCATE SIGNALS INTO BASELINE AND BIPOLAR COMPLEX SECTIONS.
258
FILTER AND DIFFERENTIATE BIPOLAR COMPLEX RAW SIGNAL TO DERIVE SECOND SMOOTHED SIGNAL
260
FIND ONSET AND TERMINATION TIMES OF BIPOLAR COMPLEX FROM SECOND SMOOTHED SIGNAL
262
USE ONSET AND TERMINATION TIMES TO DEFINE SEARCH WINDOW. WITHIN SEARCH WINDOW, FIND TIME WHEREIN dV/dT IS MOST NEGATIVE FOR EACH UNIPOLAR SIGNAL
END

FIG. 13

CARDIAC ACTIVATION TIME DETECTION

FIELD OF THE INVENTION

The present invention relates generally to signal analysis, and specifically to analysis of signals generated by a beating heart.

BACKGROUND OF THE INVENTION

One of the methods for characterizing cardiac activity relies on analyzing electrical signals generated by a heart as the heart beats. The signals typically have a relatively low level, of the order of millivolts, so that accurate analysis of the signals may be difficult. Notwithstanding the difficulties, accurate analysis can lead to improved characterization of heart activity, including determination of regions of the heart which may be defective.

Documents incorporated by reference in the present patent application are to be considered an integral part of the application except that to the extent any terms are defined in these incorporated documents in a manner that conflicts with the definitions made explicitly or implicitly in the present specification, only the definitions in the present specification should be considered.

SUMMARY OF THE INVENTION

An embodiment of the present invention provides a method for characterizing an electrocardiogram, including:

receiving a first unipolar signal from a first location of a heart and a second unipolar signal from a second location of the heart;

generating a bipolar signal from the first and second unipolar signals;

analyzing the bipolar signal to delineate a time period during which the first and second locations generate a bipolar complex; and

analyzing the first unipolar signal within the time period to determine an activation time of the first location.

Typically, analyzing the bipolar signal includes determining search window bounds to be applied to the bipolar signal. Analyzing the first unipolar signal may include applying the search window bounds to the first unipolar signal.

In a disclosed embodiment delineating the time period includes feeding data of the bipolar signal into a two-state state machine so as to determine bounds of the time period.

In a further disclosed embodiment analyzing the bipolar signal includes sorting data of the bipolar signal to determine a threshold level for the bipolar complex.

In a yet further disclosed embodiment analyzing the bipolar signal includes differentiating then rectifying data of the bipolar signal, so as to generate differentiated data. Delineating the time period may include feeding the differentiated data into a four-state state machine so as to determine bounds of the time period. Determining the activation time may include forming a first derivative of the first unipolar signal, and assigning a unipolar onset activation time as a time instant wherein the first derivative is a minimum value.

In an alternative embodiment the activation time includes a first activation time, and the method further includes analyzing the second unipolar signal within the time period to determine a second activation time of the second location.

In a further alternative embodiment the bipolar complex includes a first bipolar complex and a second bipolar complex, and the time period includes a first time period during which the first bipolar complex is generated and a second time period during which the second bipolar complex is generated, and analyzing the first unipolar signal includes determining first and second activation times respectively within the first and second time periods.

There is further provided, according to an embodiment of the present invention, apparatus for characterizing an electrocardiogram, including:

a probe which is configured to receive a first unipolar signal from a first location of a heart and a second unipolar signal from a second location of the heart; and

a processor which is configured to:

generate a bipolar signal from the first and second unipolar signals,

analyze the bipolar signal to delineate a time period during which the first and second locations generate a bipolar complex, and

analyze the first unipolar signal within the time period to determine an activation time of the first location.

There is further provided, according to an embodiment of the present invention, a computer software product for characterizing an electrocardiogram, including a tangible computer-readable medium in which computer program instructions are stored, which instructions, when read by a computer, cause the computer to:

receive a first unipolar signal from a first location of a heart and a second unipolar signal from a second location of the heart;

generate a bipolar signal from the first and second unipolar signals;

analyze the bipolar signal to delineate a time period during which the first and second locations generate a bipolar complex; and

analyze the first unipolar signal within the time period to determine an activation time of the first location.

The present disclosure will be more fully understood from the following detailed description of the embodiments thereof, taken together with the drawings, in which:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic illustration of an activation time detection system, according to an embodiment of the present invention;

FIG. **2** is a schematic block diagram illustrating an overall process in operating the system, according to an embodiment of the present invention;

FIG. **3** is a schematic block diagram illustrating a search window module, according to an embodiment of the present invention;

FIG. **4** is a time line illustrating a relationship between parameters used in a search window parameters block, according to an embodiment of the present invention;

FIG. **5**A is a schematic block diagram illustrating a first set of actions performed in a first phase block, and FIGS. **5**B and **5**C are schematic voltage vs. time graphs of data before and after the actions, according to embodiments of the present invention;

FIG. **6** illustrates windowed smoothed data output by a filter block, according to an embodiment of the present invention;

FIG. **7**A is a schematic block diagram illustrating a second set of actions performed in the first phase block, and FIG. **7**B is a schematic graph of data produced by the actions, according to embodiments of the present invention;

FIG. **8** is a schematic diagram of a four-state state machine, according to an embodiment of the present invention;

FIG. **9** illustrates the operation of the state machine, according to an embodiment of the present invention;

FIG. **10** illustrates values of time instances plotted on a time line, according to an embodiment of the present invention;

FIGS. **11**A and **11**B are schematic bipolar and unipolar graphs, according to an embodiment of the present invention;

FIGS. **12**A, **12**B, and **12**C are graphs of signals derived from multiple bipolar complexes occurring within one heart beat, according to embodiments of the present invention; and

FIG. **13** is a flowchart of steps followed to determine activation times, according to an embodiment of the present invention.

DETAILED DESCRIPTION OF EMBODIMENTS

Overview

An embodiment of the present invention provides a method for characterizing an electrocardiogram, by processing electrocardiogram data in two stages. The data is in the form of two unipolar signals from two different locations in the heart, and the characterization is able to determine activation times of locations in the heart providing the data.

In a first stage of the process, the data is analyzed as a bipolar signal, to determine time instances of the signal that delineate a bipolar complex within signal. In a second stage of the process, the time instances are used as bounds within which each of the unipolar signals may be separately analyzed.

In order to determine the activation times of the different locations, a first derivative of each of the unipolar signals is evaluated. The time at which the first derivative is a minimum is assumed to be an onset activation time, i.e., the time at which tissue generating the unipolar signal begins to activate. The method may be used to find the onset activation times of each of the two different locations.

The method may be used to analyze signals which have one bipolar complex per heart beat, and may also be used to analyze signals having more than one bipolar complex per heart beat.

The inventors have operated the method in real time, and have clinically verified that the method provides accurate results.

System Description

Reference is now made to FIG. **1**, which is a schematic illustration of an activation time detection system **10**, according to an embodiment of the present invention. System **10** analyzes electrocardiograph signals, in order to measure, inter alia, an onset point in time of a given signal. For simplicity and clarity, the following description, except where otherwise stated, assumes an investigative procedure wherein system **10** performs measurements on a heart **12**, herein assumed to comprise a human heart, using a probe **14**.

Typically, probe **14** comprises a catheter which is inserted into the body of a subject **16** during the investigative procedure. A distal tip **18** of the probe comprises a first electrode **20** and a second electrode **21** which receive electrocardiograph (ECG) signals from respective locations **23** and **25** in heart **12**. The locations are typically within tissue **27** of the heart. The signals from the two electrodes form a bipolar signal which is analyzed by system **10**, as described herein. The investigative procedure is performed by a user **22** of system **10**, and in the description herein user **22** is assumed, by way of example, to be a medical professional.

One or more other electrodes **29** are used during the procedure. The other electrodes may be attached to probe **14**, to another probe similar to probe **14** and located within the heart, and/or to the skin of subject **16**. The other electrodes are used as reference electrodes to provide a reference ground for the signals from electrodes **20** and **21**, in which case the two signals of the respective electrodes are unipolar signals.

System **10** is typically controlled by a system processor **24** which may be realized as a general purpose computer. The system processor comprises a processing unit **26** communicating with a memory **28**. Processor **24** may be mounted in a console **30**, comprising operating controls **32** that typically include a keypad and a pointing device such as a mouse or trackball that professional **22** uses to interact with the processor. Results of the operations performed by processor **24** are provided to the professional on a screen **34** which may display a diagram of the results of the analysis performed by the system. Alternatively or additionally, the results are used by system **10** in presenting other parameters to professional **22**, such as a map of local activation times (LATs) of heart **12**. Professional **22** is able to use controls **32** to input values of parameters used by processor **24** in the operation of system **10**

Processor **24** uses software stored in memory **28** to operate system **10**. The software may be downloaded to processor **24** in electronic form, over a network, for example, or it may, alternatively or additionally, be provided and/or stored on non-transitory tangible computer-readable media, such as magnetic, optical, or electronic memory.

System **10** can be realized as the CARTO XP EP Navigation and Ablation System, available from Biosense Webster, Inc., 3333 Diamond Canyon Road, Diamond Bar, Calif. 91765, suitably modified to execute the procedures described herein.

In some cases electrodes **20** and/or **21** may provide both ECG and other signals or the electrodes may be used for other purposes. For example, the CARTO system referenced above uses electrodes which detect ECG signals, measures impedances of the electrodes for tracking, as well as using the electrodes to provide radio-frequency ablation.

FIG. **2** is a schematic block diagram **70** illustrating an overall process followed by processor **24** in operating system **10**, according to an embodiment of the present invention. In a bipolar stage **72**, the processor receives raw unfiltered signals, as voltage levels, from electrodes **20** and **21** and operates on them to form bipolar signal data. The processor analyzes the bipolar data to determine a time period, or window, defining a bipolar complex. For simplicity and clarity, in the following description except where otherwise stated there is assumed to be one bipolar complex per heart beat.

The bipolar complex is bounded by an initial time instance T_{ONSET} and a final time instance $T_{TERMINATION}$. The processor uses the time bounds of the bipolar complex to define a window within which to perform unipolar analysis.

In a unipolar stage **74**, the processor considers each of the electrode **20** and **21** signals separately, as unipolar voltage vs. time signals, and analyzes the unipolar signals within the time window found in the bipolar stage. The analysis enables the processor to determine respective unipolar acti-

vation times at which the regions in contact with electrodes **20** and **21** activate. The activation times typically comprise times at which the derivative of the unipolar signal has a maximum negative value.

Bipolar stage **72** is formed of three modules: a search window module **76**, and two subsequent modules, a first phase module **78** and a second phase module **80**. The operations performed by the processor for each module are described below. In the description the signals from electrodes **20** and **21** are assumed to be sampled over a period of approximately 2.5 s at a rate of approximately 1 kHz, giving approximately 2,500 samples to be analyzed by system **10**. However, system **10** may operate with any convenient sample period and rate of sampling.

FIG. **3** is a schematic block diagram illustrating search window module **76** in more detail, according to an embodiment of the present invention. In an R-wave detection block **90** processor **24** analyzes the set of incoming sample values to identify times at which the R-waves in the sample occurs. Typically for a set of samples taken over 2.5 s there are approximately two to four R-waves, although subjects having tachycardia may have five or more R-waves within a 2.5 s time period. The identification is typically performed by finding the times at which the sample peaks.

In an RR interval block **92** the processor finds the mean time period $\overline{RR}$ between the peaks identified in block **92**.

In a search window parameters block **94** the processor calculates times of a start and end times SW_{START}, SW_{END}, of a search window to be used in further analysis of the input data. In the CARTO system referenced above, professional **22** is able to program a window of interest (WOI) center time and width, WOI_{CENTER}, WOI_{WIDTH}. In order to perform the calculation in the CARTO system, block **94** uses values of parameters WOI_{CENTER}, WOI_{WIDTH}, together with an additional time period WOI_{DELTA}, also referred to herein using the symbol Δ, provided by professional **22**. WOI_{CENTER} is typically arbitrarily set by the professional to approximate an expected half-way point in time of mean time period $\overline{RR}$, but WOI_{CENTER} may be set to be any other convenient point in time. WOI_{WIDTH} is typically also arbitrarily set by the professional to approximate an expected mean time period $\overline{RR}$ but may also be set to any convenient time period. Using values of WOI_{CENTER}, WOI_{WIDTH}, and WOI_{DELTA}, block **94** calculates values of SW_{START}, SW_{END} for the search window.

FIG. **4** is a time line illustrating a relationship between the parameters used in search window parameters block **94**, according to an embodiment of the present invention. As is illustrated by the time line, the search window delineated by block **94** has a total width of $(\overline{RR}+\Delta)$, beginning at a time SW_{START} and ending at a time SW_{END}.

It will be understood that while the calculation of the start and end times of the search window generated by block **94** has been explained with reference to the CARTO system, professional **22** may use any convenient method known in the art to delineate an appropriate search window.

A typical value for Δ is approximately 20 ms. A typical value of $\overline{RR}$ depends on subject **16**. For a tachycardiac subject $\overline{RR}$ may be approximately 240 ms, in which case, with Δ=20 ms value, the search window is approximately 220 ms wide.

FIG. **5**A is a schematic block diagram illustrating a first set of actions performed by processor **24** in first phase block **78**, and FIGS. **5**B and **5**C are schematic voltage vs. time graphs of data before and after the actions, according to embodiments of the present invention. (For simplicity, voltage and time axes for the graphs are not shown.) In a rectify and filter block **120** bipolar raw data, from electrodes **20** and **21** and illustrated in FIG. **5**B, is first rectified, then low-pass filtered to remove high frequency components from the data and to produce smoothed data. In one embodiment the inventors use a second order Butterworth filter having a cut off frequency of approximately 20 Hz.

The filtered smoothed data is then windowed, using the search window times SW_{START} and SW_{END} from block **94** (FIG. **3**), to generate a set of sample data {X(n)} where n is an index of the data, and X is the data value. The set of smoothed data is schematically illustrated in FIG. **5**C. Assuming the example search window width given above for a tachycardiac subject, and a sample rate of approximately 1000 Hz, there are approximately 220 smoothed samples in the windowed data, so that in this case n is a positive integer between 1 and approximately 220.

In a sort block **122** the smoothed samples are sorted by value and arranged into a frequency distribution. From the frequency distribution a threshold voltage level THR, that is to be applied in analyzing the data, is extracted. Level THR is selected to be close to, but above, the level of the smoothed baseline data. In one embodiment, the level is selected as a base value corresponding to the 5th percentile of the frequency distribution, added with a factor of 5% of the amplitude of the smoothed signal. Alternatively, level THR may be selected by any other suitable method for defining a level close to, but above, the smoothed baseline data.

In addition, sort block **122** determines a peak sample $X(n_{p1})$ of the smoothed data.

The processor supplies level THR, and the sampled smoothed values X(n) to a two-state state machine **124**. Conditions for transitions between the two states A and B of the state machine are indicated in FIG. **5**A within square brackets [ ]; actions performed during the transitions are indicated within braces { }. Starting from the peak sample $X(n_{p1})$, data X(n) are sequentially fed backward in time until a first transition, at an index underTHRstart, occurs. In addition the data are fed forward in time, starting from the peak sample $X(n_{p1})$, until a second transition, at an index underTHRend, occurs. A parameter cnt counts the number of samples operated on by the state machine. A user-set variable CNTMAX, indicative of an acceptable number of samples between transitions underTHRstart and underTHRend, is typically set to be approximately 100, but may be set to be any other convenient number.

FIG. **6** illustrates the windowed smoothed data output by filter block **120** (as also shown schematically in FIG. **5**C), according to an embodiment of the present invention. A graph **130** represents the windowed smoothed samples X(n) output by the filter block. State machine **124** divides the samples into three sections: two baseline sections **132** and **134** that are below threshold THR, and a bipolar complex section **136**. The bipolar complex is bounded by the two transition indices underTHRstart and underTHRend generated by the state machine.

FIG. **7**A is a schematic block diagram illustrating a second set of actions performed by processor **24** in first phase block **78** (FIG. **2**), and FIG. **7**B is a schematic graph of data produced by the actions, according to embodiments of the present invention. In a filter block **150**, bipolar raw data from electrodes **20** and **21** is low-pass filtered to remove high frequency components and produce smoothed data. In one embodiment the inventors use a second order Butterworth filter having a cut off frequency of approximately 35 Hz. In

a differentiation block **152** the smoothed data is differentiated, and is then rectified in a rectify block **154** to produce rectified differentiated data.

The data from block **154** is windowed in a window block **156**, using the search window times SW_{START} and SW_{END} from block **94** (FIG. **3**). The windowing generates a set of differentiated smooth data {D(n)} where D is the data value. FIG. **7**B is a graphic illustration of the data output of block **154**, shown in more detail in FIG. **9**.

The set of differentiated smooth data transfers to a sort block **158**, as well as to a four-state state machine **160** in second phase **80** of the bipolar stage (FIG. **2**). In sort block **158** the indices, underTHRstart and underTHRend, determined by two-state state machine **124** and illustrated in FIG. **6**, are used to divide {D(n)} into a differentiated binary complex section and two noise sections. Processor **24** sorts the values in both noise sections into a frequency distribution, and from the distribution a differentiated noise level NOISE, that is to be applied in analyzing the differentiated smooth data, is extracted. Level NOISE is selected to be close to, but above, the level of both noise sections, and is shown schematically in FIG. **7**B. In one embodiment, the level is based on a 95th percentile of the frequency distribution.

Sort block **158** also determines a peak value $D(n_{p2})$ and an index n_{p2} of the differentiated binary complex, and transfers $D(n_{p2})$ to the four-state state machine.

FIG. **8** is a schematic diagram of four-state state machine **160**, according to an embodiment of the present invention. The state machine comprises four states A, B, C, and D, together with two exit states E end F. Conditions for transitions between the states are indicated in FIG. **8** within square brackets [ ]; actions performed during the transitions are indicated within braces { }. Starting from the peak sample $D(n_{p2})$, and with the state machine in state A, sample data D(n) are fed backward in time until exit state F is reached. The time, i.e., the index value, at which state F is reached is an onset time, T_{ONSET}, of the bipolar complex. In addition, a termination time, $T_{TERMINATION}$, of the bipolar complex is found by feeding sample data D(n) forward in time until exit state E is reached.

In the state machine, parameters cnt and gcnt count the number of samples operated on by the state machine. Variables CNTSTATE2, CNTSTATE3, and CNTSTATE4 may be set by professional **22**, as representative of acceptable numbers of samples between states of the state machine as transitions occur through the differentiated noise level NOISE. Typical values of CNTSTATE2, CNTSTATE3, and CNTSTATE4 are respectively 8, 18, and 4, but the values may be set by professional **22** to any suitable value.

FIG. **9** illustrates the operation of state machine **160**, according to an embodiment of the present invention. A graph **170** (similar to FIG. **7**B) represents the smoothed data D(n) transferred from window block **156** to the state machine. Values of noise level NOISE, and PEAK $D(n_{p2})$, transferred from sort block **158**, are also shown on graph **170**.

A graph **172** shows the states of the state machine, and the transitions between the states, in determining the value of T_{ONSET}. As shown in the graph, processor **24** (FIG. **1**) begins operating the state machine from the peak value $D(n_{p2})$, at sample n_{p2}, in state A. As succeeding backwards-in-time samples feed into the state machine, the machine, after initially alternating between states A and B, then transfers in turn to states C, D, A, B, and C. At the last state C, the machine transfers to exit state F (FIG. **8**). A similar set of transitions occurs for samples fed forwards-in-time from peak value $D(n_{p2})$ the transitions ending in state D and exit state E and determining the value of $T_{TERMINATION}$.

FIG. **10** illustrates values of T_{ONSET} and $T_{TERMINATION}$ plotted on a time line, according to an embodiment of the present invention. The time line illustrates a typical relationship between the values of T_{ONSET} and $T_{TERMINATION}$ and the time values used in investigating the bipolar complex and described above with reference to FIG. **4**.

From the values of T_{ONSET} and $T_{TERMINATION}$ system **10** is able to evaluate a signal-to-noise ratio (SNR) of the bipolar complex, according to equation (1):

$$SNR = 20 \cdot \log\left(\frac{S-N}{N}\right) \tag{1}$$

where S is the root mean square (RMS) value of the unfiltered bipolar data lying between T_{ONSET} and $T_{TERMINATION}$, and

N is the RMS value of the unfiltered bipolar data before T_{ONSET} and after $T_{TERMINATION}$.

Professional **22** is able to use the value of SNR in order to establish a confidence level for the evaluated values of T_{ONSET} and $T_{TERMINATION}$.

Returning to FIG. **2**, processor **24** transfers the values of T_{ONSET} and $T_{TERMINATION}$ to unipolar stage **74**. In stage **74**, the processor forms a time window, bounded by T_{ONSET} and $T_{TERMINATION}$, and analyzes the smoothed unipolar voltage (V) vs. time (t) signals from each of electrodes **20** and **21** within the window. Within the window the processor calculates values of the slopes of each unipolar signal, i.e., values of first derivative

$$\frac{dV}{dt}.$$

For each signal the processor selects the time at which the first derivative

$$\frac{dV}{dt}$$

has its most negative, i.e., its minimum, value, and this time is assumed to be the time at which the tissue generating the signal begins to activate.

FIGS. **11**A and **11**B are schematic bipolar and unipolar graphs, according to an embodiment of the present invention. A graph **180** is a voltage vs. time graph of a bipolar signal, and graphs **182** and **184** are voltage vs. time graphs of respective unipolar signals forming the bipolar signal. Both sets of graphs have times T_{ONSET} and $T_{TERMINATION}$, as determined above, marked on the graphs. In the case of graphs **182** and **184**, respective activation times **186** and **188**, being the times of the most negative derivative of the respective unipolar signals within the window defined by T_{ONSET} and $T_{TERMINATION}$, are shown. Activation times **186** and **188** are the times that the tissue generating the unipolar signals begins to activate, and are also herein termed unipolar onset activation times.

For clarity, the description above considers embodiments of system **10** that evaluate signal parameters where there is one bipolar complex per heart beat. System **10** is not limited to such evaluations, and may be used to identify signals

where multiple bipolar complexes occur per heart beat, and furthermore, to evaluate signal parameters of the multiple bipolar complexes. The identification of the occurrence of multiple bipolar signals may typically be by measuring intervals between adjacent complexes, since, in contrast to signals having one bipolar complex per heart beat, the intervals change.

Those having ordinary skill in the art will be able to adapt the description above, mutatis mutandis, to evaluate parameters of unipolar signals generating multiple bipolar complexes occur per heart beat. Such parameters include, but are not limited to, evaluating respective unipolar onset activation times for each bipolar complex in a given heart beat.

FIGS. **12**A, **12**B, and **12**C are graphs of signals derived from multiple bipolar complexes occurring within one heart beat, according to embodiments of the present invention. A graph **190** (FIG. **12**A) is a bipolar signal exhibiting an atrial bipolar complex **194**, and ventricular bipolar complexes **192** and **196**. Each bipolar complex may be analyzed by initially defining a search window for a given complex. A method for defining the search window for each complex is substantially as described above with reference to FIG. **3**, mutatis mutandis, to allow for differing RR intervals within the bipolar signal.

A graph **200** (FIG. **12**B) is an enlarged graph of a specific ventricular bipolar complex **192**. Onset and termination times **202** and **204** for the complex have been marked on the graph. The times are evaluated substantially as described above with reference to FIG. **8**, by feeding smoothed data derived from the complex through state machine **160**.

A graph **210** (FIG. **12**C) illustrates unipolar signals **212** and **214** corresponding to bipolar complex **192** of FIG. **12**B. As described above, respective unipolar onset activation times **216** and **218** for each signal, occur at the times wherein the first derivative of each signal, measured between onset and termination times **202** and **204**, has its most negative value, i.e., is a minimum.

System **10** may also be used to evaluate other parameters relevant to signals having multiple bipolar complexes occurring within one heart beat, as will be apparent to those of ordinary skill in the art. Such parameters include, but are not limited to, a duration time between first and second atrial bipolar complexes, by measuring a mean RR interval between the complexes. All such parameters are assumed to be included within the scope of the present invention.

FIG. **13** is a flowchart **250** of steps followed by processor **24** in operating system **10** to determine activation times, according to an embodiment of the present invention. For simplicity and clarity, the description of the steps of the flowchart assumes that signals received have one bipolar complex per heart beat, except where otherwise stated. Those with ordinary skill in the art will be able to adapt the description for cases having multiple bipolar complexes per heart beat.

Steps **252**-**260** are actions performed in bipolar stage **72** and step **262** is performed in unipolar stage **74** (FIG. **2**).

In an initial step **252**, the processor receives signals as sampled data from electrodes **20** and **21**. The processor analyzes the signals to identify R waves, an $\overline{RR}$ value, and bounds of a search window, as described above with reference to FIGS. **3** and **4**.

In a first filtration step **254**, the sampled data are rectified, filtered, and windowed, and the resulting smoothed data is fed into two-state state machine **124**. In a demarcation step **256** the two-state state machine divides the data it receives into baseline sections and a bipolar complex section. Steps **254** and **256** are as described above with reference to FIGS. **5**A-**5**C and FIG. **6**.

In a second filtration step **258**, the sampled data of the bipolar complex are filtered, differentiated and windowed to derive a second smoothed signal, as described above with reference to FIGS. **7**A and **7**B.

In a bipolar complex analysis step **260**, the processor evaluates onset and termination times of the complex by feeding the second smoothed signal data into four-state state machine **160**, as described with reference to FIGS. **8** and **9**.

In an activation time step **262**, a time of activation of tissue in contact with electrodes **20** and **21** is determined by analyzing the unipolar signals from each electrode within a window defined by the bipolar onset and termination times of step **260**. Actions performed by the processor in step **262** are described with reference to FIGS. **11**A and **11**B, and also (for situations of multiple bipolar complexes in one heart beat) with reference to FIGS. **12**A-**12**C.

The analysis differentiates the unipolar signals within the window, and finds the respective times at which the first derivatives are most negative, i.e., are minima. These times correspond to an onset activation time of the tissue in contact with electrode **20**, and an onset activation time of the tissue in contact with electrode **21**.

It will be appreciated that the embodiments described above are cited by way of example, and that the present invention is not limited to what has been particularly shown and described hereinabove. Rather, the scope of the present invention includes both combinations and subcombinations of the various features described hereinabove, as well as variations and modifications thereof which would occur to persons skilled in the art upon reading the foregoing description and which are not disclosed in the prior art.

We claim:

1. A method for characterizing an electrocardiogram, comprising:

receiving a first unipolar signal from a first location of a heart and a second unipolar signal from a second location of the heart;

generating a bipolar signal from the first and second unipolar signals;

analyzing the bipolar signal to delineate a time period during which the first and second locations generate a bipolar complex and rectifying data of the bipolar signal and differentiating the rectified data of the bipolar signal, so as to generate differentiated data, wherein delineating the time period comprises feeding the differentiated data into a four-state state machine so as to determine bounds of the time period; and

analyzing the first unipolar signal within the time period to determine an activation time of the first location.

2. The method according to claim **1**, wherein analyzing the bipolar signal comprises determining search window bounds to be applied to the bipolar signal.

3. The method according to claim **2**, wherein analyzing the first unipolar signal comprises applying the search window bounds to the first unipolar signal.

4. The method according to claim **1**, wherein analyzing the bipolar signal comprises sorting data of the bipolar signal to determine a threshold level for the bipolar complex.

5. The method according to claim **1**, wherein analyzing the bipolar signal comprises rectifying data of the bipolar signal and differentiating the rectified data of the bipolar signal, so as to generate differentiated data.

6. The method according to claim **1**, wherein determining the activation time comprises forming a first derivative of

the first unipolar signal, and assigning a unipolar onset activation time as a time instant wherein the first derivative is a minimum value.

7. The method according to claim **1**, wherein the activation time comprises a first activation time, the method further comprising analyzing the second unipolar signal within the time period to determine a second activation time of the second location.

8. The method according to claim **1**, wherein the bipolar complex comprises a first bipolar complex and a second bipolar complex, and wherein the time period comprises a first time period during which the first bipolar complex is generated and a second time period during which the second bipolar complex is generated, and wherein analyzing the first unipolar signal comprises determining first and second activation times respectively within the first and second time periods.

9. Apparatus for characterizing an electrocardiogram, comprising:

a probe which is configured to receive a first unipolar signal from a first location of a heart and a second unipolar signal from a second location of the heart; and

a processor which is configured to:

generate a bipolar signal from the first and second unipolar signals,

analyze the bipolar signal to delineate a time period during which the first and second locations generate a bipolar complex and rectifying data of the bipolar signal and differentiating the rectified data of the bipolar signal, so as to generate differentiated data, wherein delineating the time period comprises feeding the differentiated data into a four-state state machine so as to determine bounds of the time period; and

analyze the first unipolar signal within the time period to determine an activation time of the first location.

10. The apparatus according to claim **9**, wherein analyzing the bipolar signal comprises determining search window bounds to be applied to the bipolar signal.

11. The apparatus according to claim **9**, wherein analyzing the bipolar signal comprises sorting data of the bipolar signal to determine a threshold level for the bipolar complex.

12. The apparatus according to claim **9**, wherein analyzing the bipolar signal comprises rectifying data of the bipolar signal and differentiating the rectified data of the bipolar signal, so as to generate differentiated data.

13. The apparatus according to claim **9**, wherein determining the activation time comprises forming a first derivative of the first unipolar signal, and assigning a unipolar onset activation time as a time instant wherein the first derivative is a minimum value.

14. The apparatus according to claim **9**, wherein the activation time comprises a first activation time, and further comprising analyzing the second unipolar signal within the time period to determine a second activation time of the second location.

15. The apparatus according to claim **9**, wherein the bipolar complex comprises a first bipolar complex and a second bipolar complex, and wherein the time period comprises a first time period during which the first bipolar complex is generated and a second time period during which the second bipolar complex is generated, and wherein analyzing the first unipolar signal comprises determining first and second activation times respectively within the first and second time periods.

* * * * *

专利名称(译)	心脏激动时间检测		
公开(公告)号	US9833157	公开(公告)日	2017-12-05
申请号	US13/453249	申请日	2012-04-23
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申请(专利权)人(译)	EL哈达德MILAD阿巴斯 Hayam酒店，GAL BAR-TAL，MEIR 胡本，RICHARD PETRUS MARIA DUYTSCHAEVER，马蒂亚斯FRANCIS		
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CPC分类号	A61B5/04012 A61B5/042 A61B5/0452 A61B5/0422 A61B5/7239 A61B5/7203		
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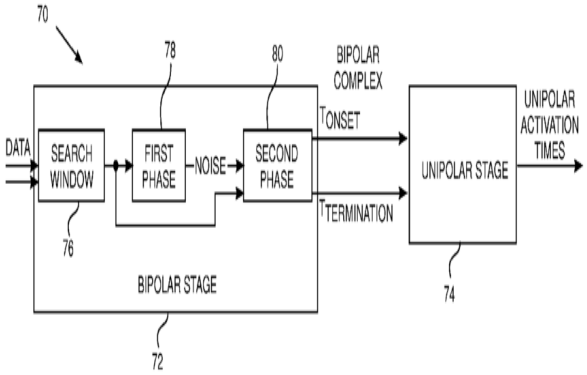
摘要(译)

一种用于表征心电图的方法，包括从心脏的第一位置接收第一单极信号和从心脏的第二位置接收第二单极信号。该方法还包括从第一和第二单极信号产生双极信号，并分析双极信号以描绘第一和第二位置产生双极复合波的时间段。该方法还包括在该时间段内分析第一单极信号以确定第一位置的激活时间。


70
78
80
BIPOLAR COMPLEX
DATA
SEARCH WINDOW
FIRST PHASE
NOISE
SECOND PHASE
TONSET
TTERMINATION
UNIPOLAR STAGE
UNIPOLAR ACTIVATION TIMES
76
BIPOLAR STAGE
74
72