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Bar-Tal et al.

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(45) **Date of Patent: Jun. 11, 2019**

(54) **IDENTIFICATION OF FRACTIONATED SIGNALS**

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(73) Assignee: **Biosense Webster (Israel) Ltd.**, Yokneam (IL)

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(65) **Prior Publication Data**

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Related U.S. Application Data

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(51) **Int. Cl.**
A61B 5/00 (2006.01)
A61B 5/044 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***A61B 5/6852*** (2013.01); ***A61B 5/0402*** (2013.01); ***A61B 5/044*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC A61B 5/6852; A61B 5/046; A61B 5/0422; A61B 5/04012; A61B 5/0402; A61B 5/04525; A61B 5/0452; A61B 5/044
See application file for complete search history.

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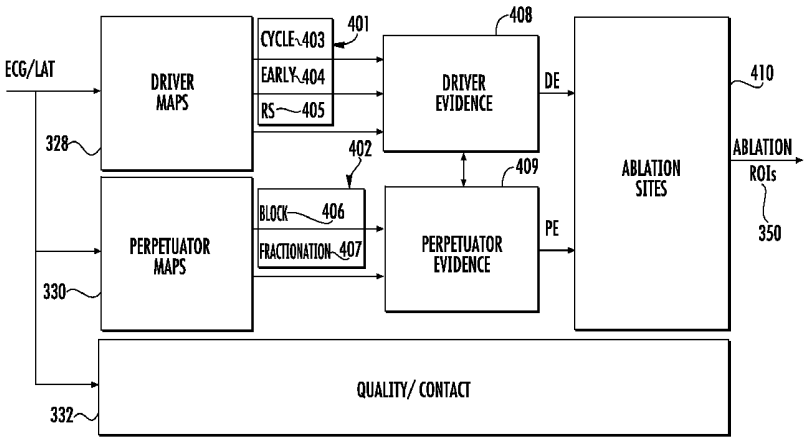
(Continued)

Primary Examiner — Mark Bockelman
(74) *Attorney, Agent, or Firm* — Volpe and Koenig, P.C.

(57) **ABSTRACT**

A system and method of determining regions of interest for heart ablation using fractionation. The method can comprise detecting, via sensors, electro-cardiogram (ECG) signals, each ECG signal detected via one of the sensors and indicating electrical activity of a heart, determining, for each of the ECG signals, activation times (LATs) each indicating a time of activation of a corresponding ECG signal, generating, based on the determined LATs of each of the ECG signals, one or more driver maps and one or more perpetuator maps, each representing the electrical activity of the heart, deriving parameters from the driver and perpetuator maps, using at least fractionation, processing and combining the derived parameters into driver evidence and perpetuator evidence, and determining the regions of interest for heart ablation in accordance with the fractionation used to derive the driver evidence and the perpetuator evidence.

14 Claims, 30 Drawing Sheets



(51) **Int. Cl.**

A61B 5/0402	(2006.01)
A61B 5/0452	(2006.01)
A61B 5/04	(2006.01)
A61B 5/042	(2006.01)
A61B 5/046	(2006.01)

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

CPC ***A61B 5/046*** (2013.01); ***A61B 5/04012*** (2013.01); ***A61B 5/0422*** (2013.01); ***A61B 5/0452*** (2013.01); ***A61B 5/04525*** (2013.01)

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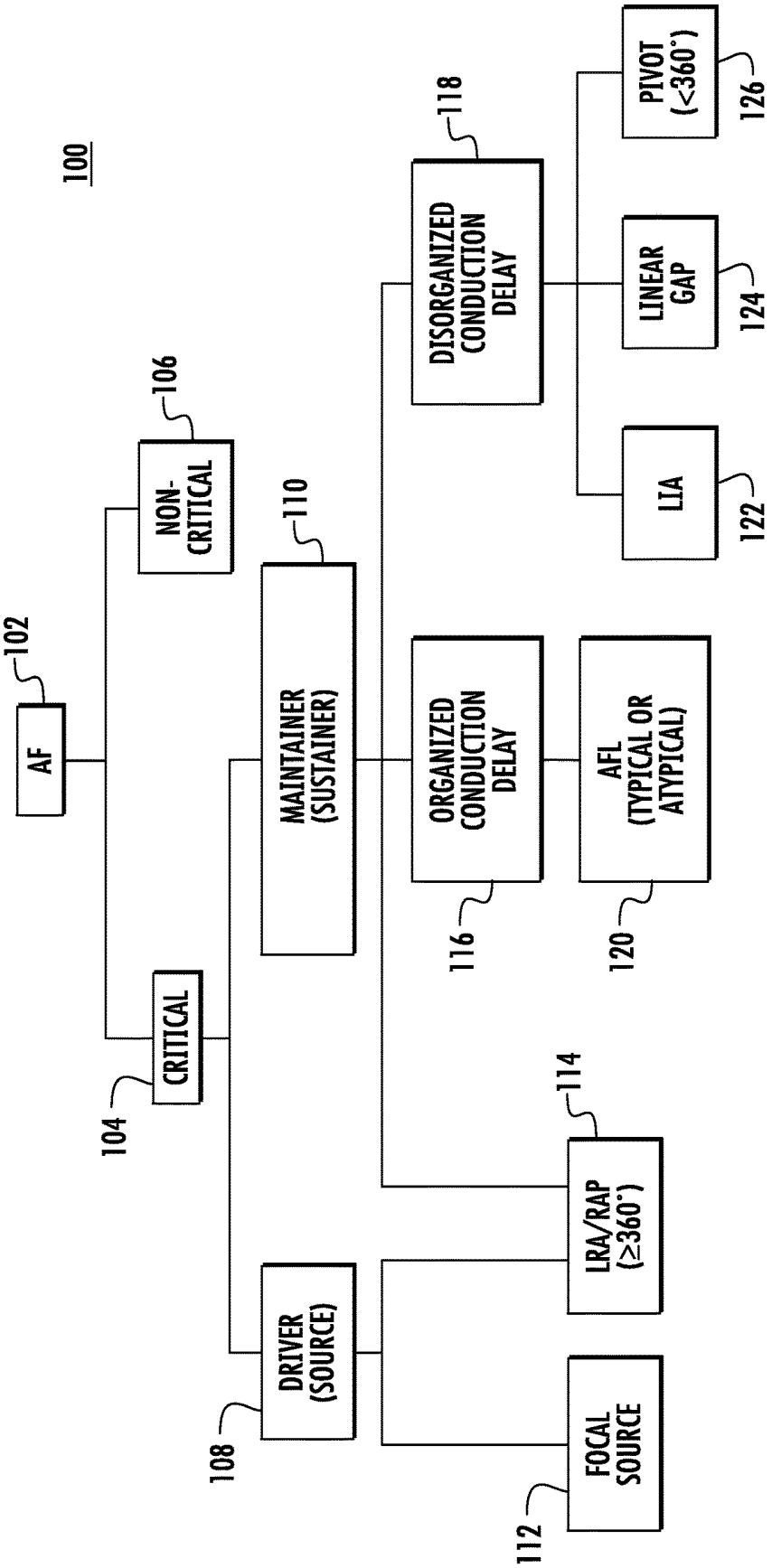

100
AF
102
NON-CRITICAL
106
CRITICAL
104
MAINTAINER (SUSTAINER)
110
DRIVER (SOURCE)
108
LRA/RAP (≥360°)
114
FOCAL SOURCE
112
ORGANIZED CONDUCTION DELAY
116
AFL (TYPICAL OR ATYPICAL)
120
DISORGANIZED CONDUCTION DELAY
118
PIVOT (<360°)
126
LINEAR GAP
124
LIA
122

FIG. 1

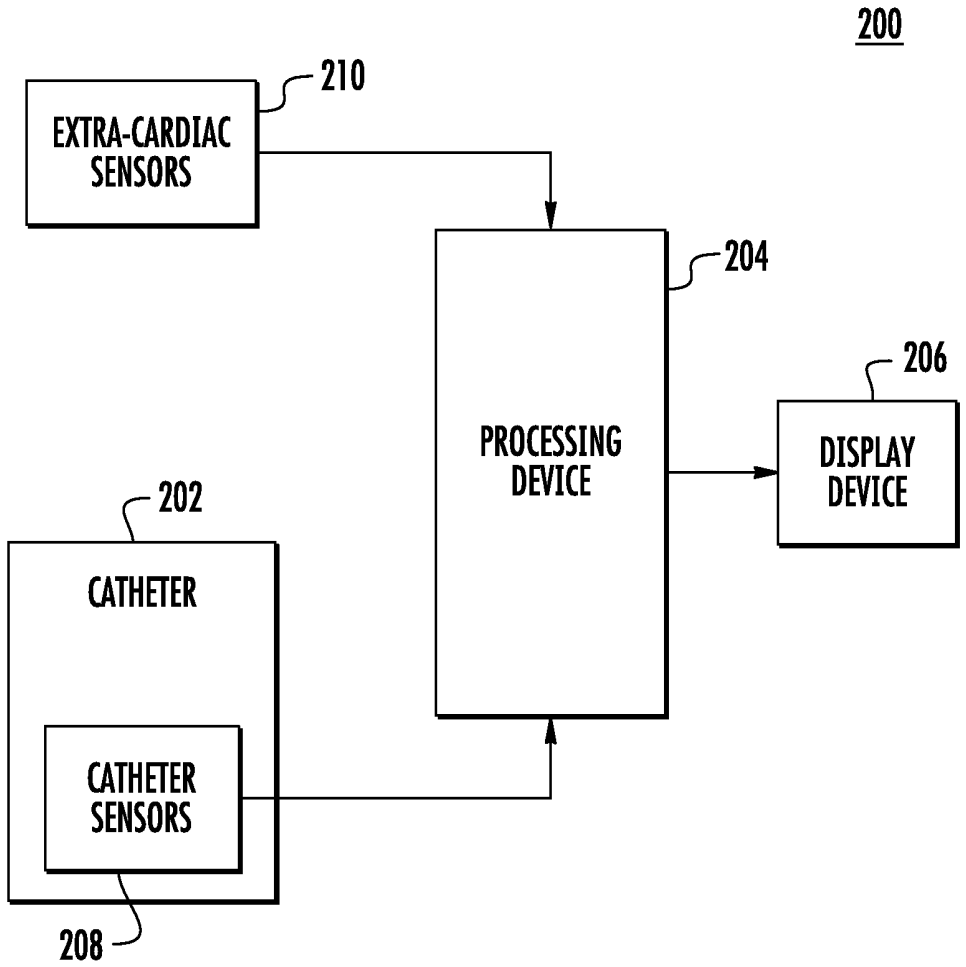

200
210
EXTRA-CARDIAC SENSORS
204
PROCESSING DEVICE
206
DISPLAY DEVICE
202
CATHETER
CATHETER SENSORS
208

FIG. 2

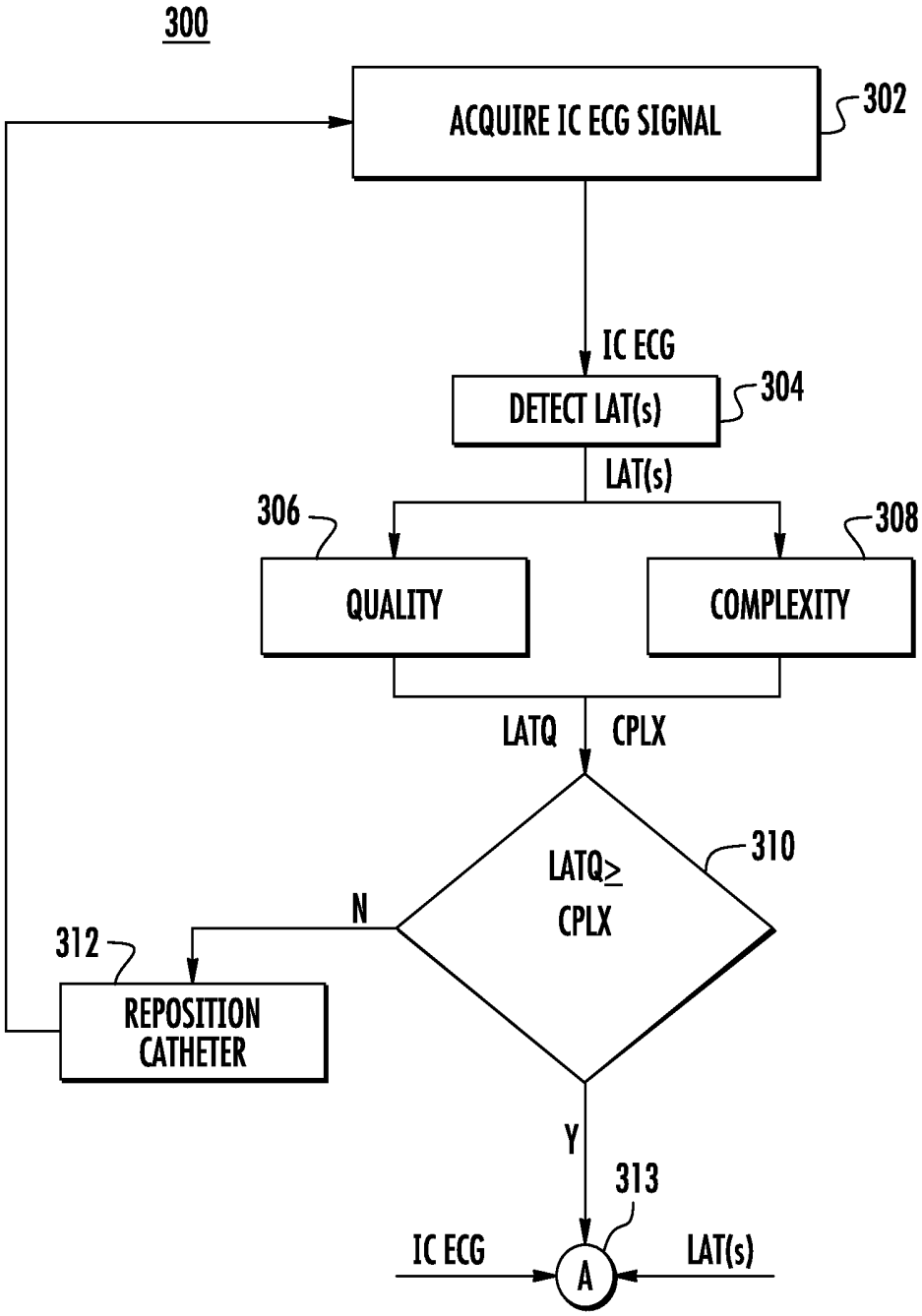

300
ACQUIRE IC ECG SIGNAL
302
IC ECG
DETECT LAT(s)
304
LAT(s)
306
QUALITY
308
COMPLEXITY
LATQ
CPLX
LATQ≥ CPLX
310
N
312
REPOSITION CATHETER
Y
313
IC ECG
A
LAT(s)

FIG. 3A

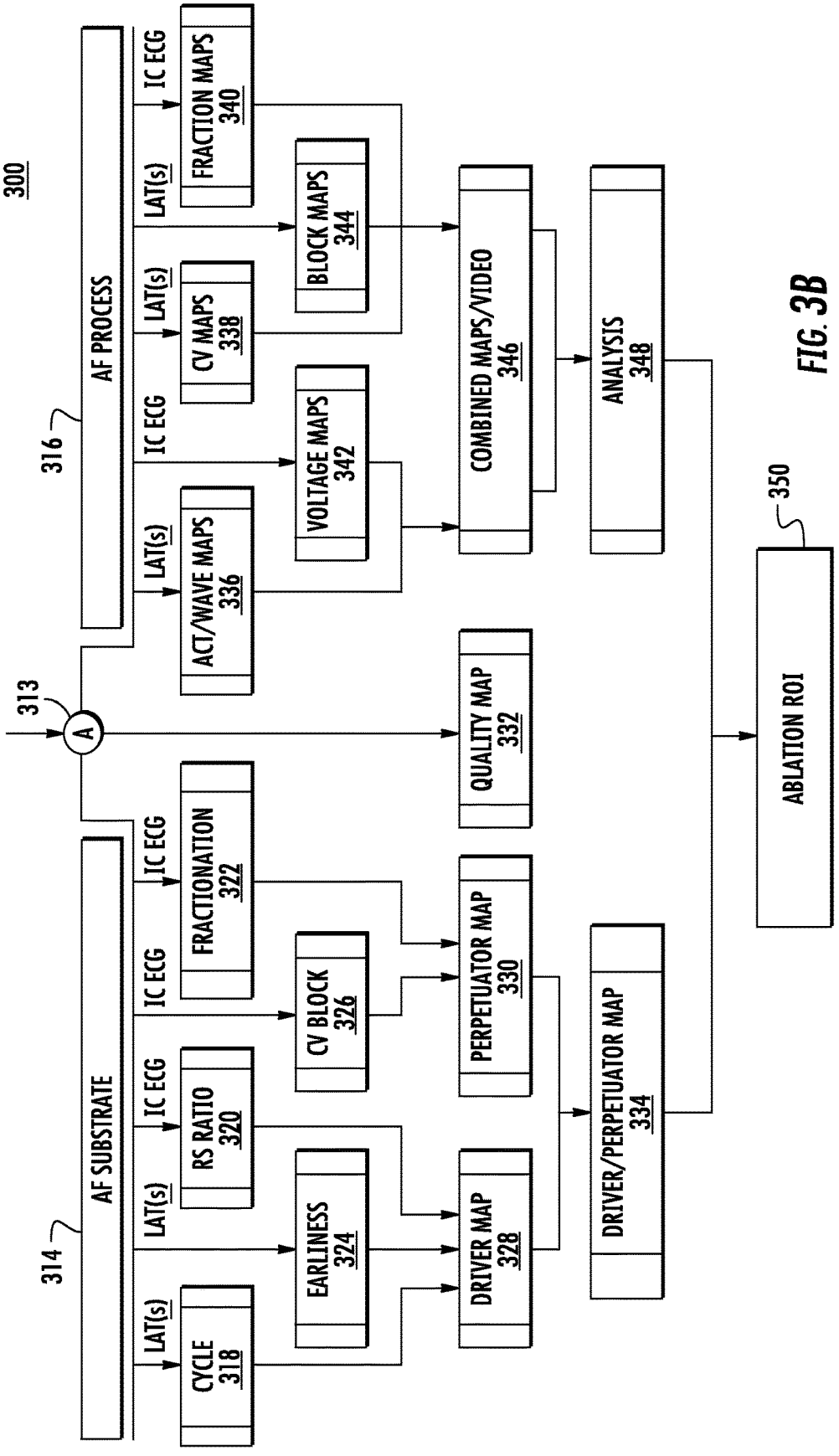

300
316
AF PROCESS
313
A
314
AF SUBSTRATE
LAT(s)
IC ECG
ACT/WAVE MAPS 336
VOLTAGE MAPS 342
FRACTION MAPS 340
CV MAPS 338
BLOCK MAPS 344
COMBINED MAPS/VIDEO 346
ANALYSIS 348
350
ABLATION ROI
QUALITY MAP 332
FRACTIONATION 322
CV BLOCK 326
PERPETUATOR MAP 330
RS RATIO 320
EARLINESS 324
DRIVER MAP 328
DRIVER/PERPETUATOR MAP 334
CYCLE 318

FIG. 3B

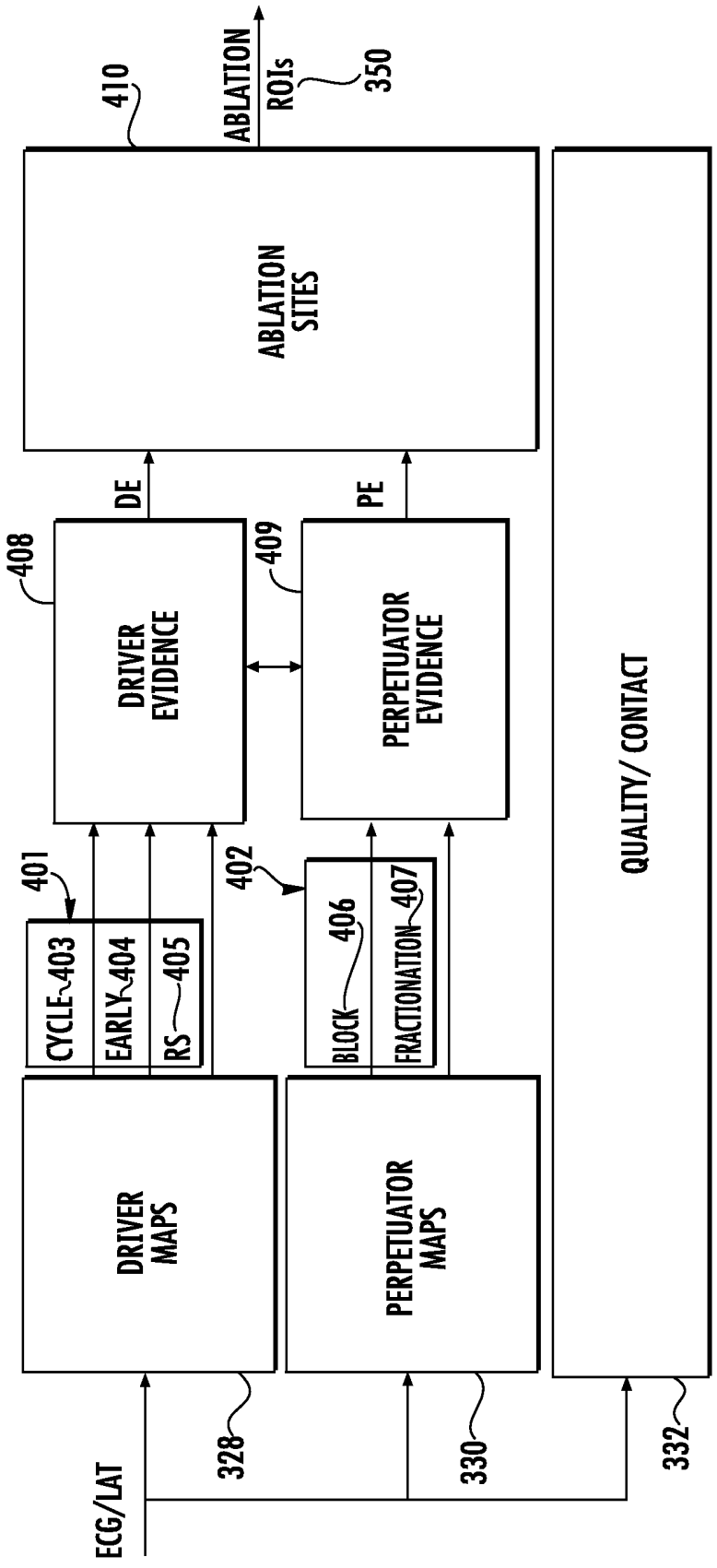

ECG/LAT
328
330
332
DRIVER MAPS
PERPETUATOR MAPS
QUALITY/ CONTACT
401
CYCLE 403
EARLY 404
RS 405
402
BLOCK 406
FRACTIONATION 407
408
DRIVER EVIDENCE
409
PERPETUATOR EVIDENCE
DE
PE
410
ABLATION SITES
ABLATION ROIs
350

FIG. 4

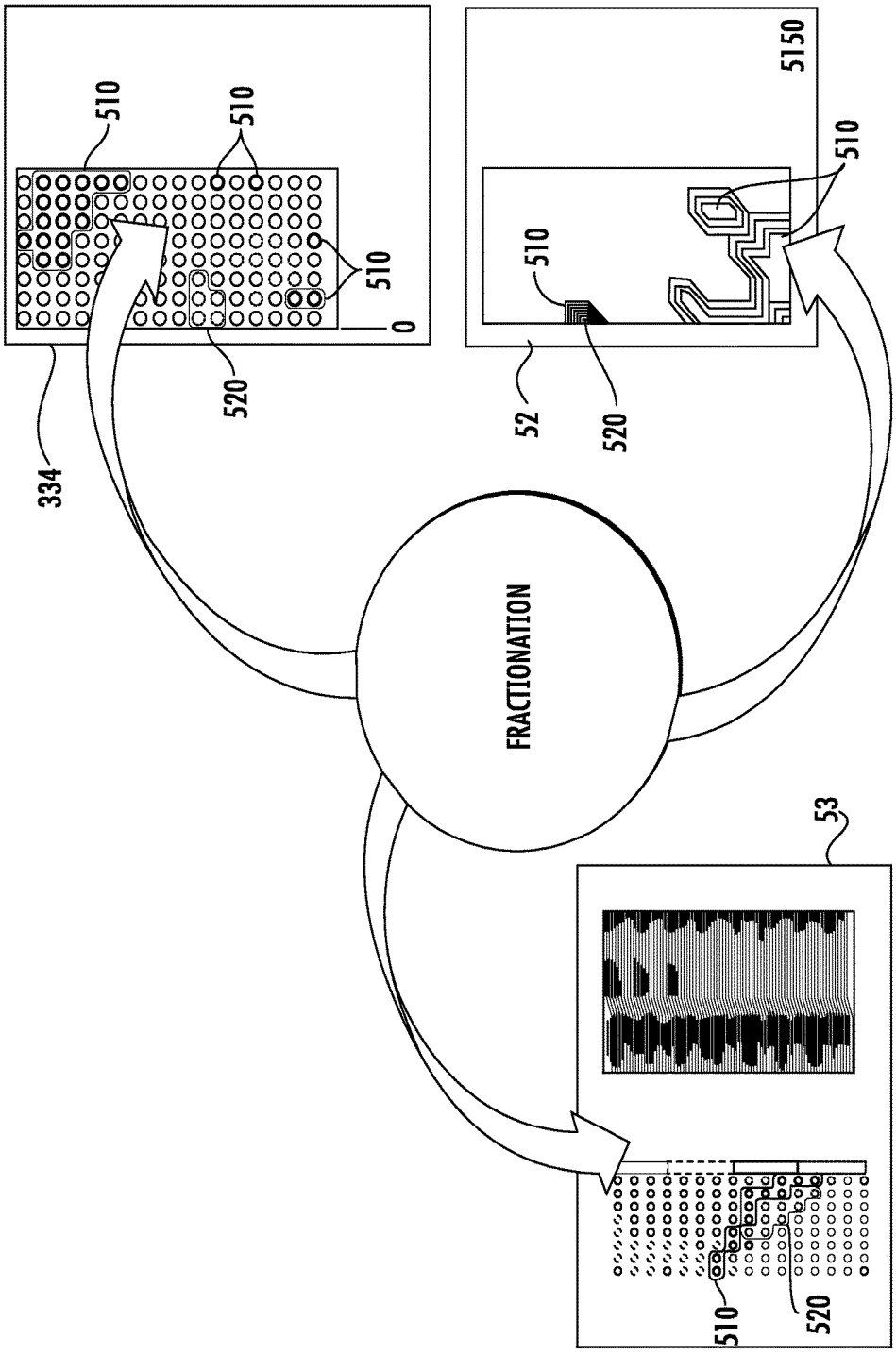

510
510
510
0
520
334
5150
510
510
52
520
FRACTIONATION
53
510
520

FIG. 5

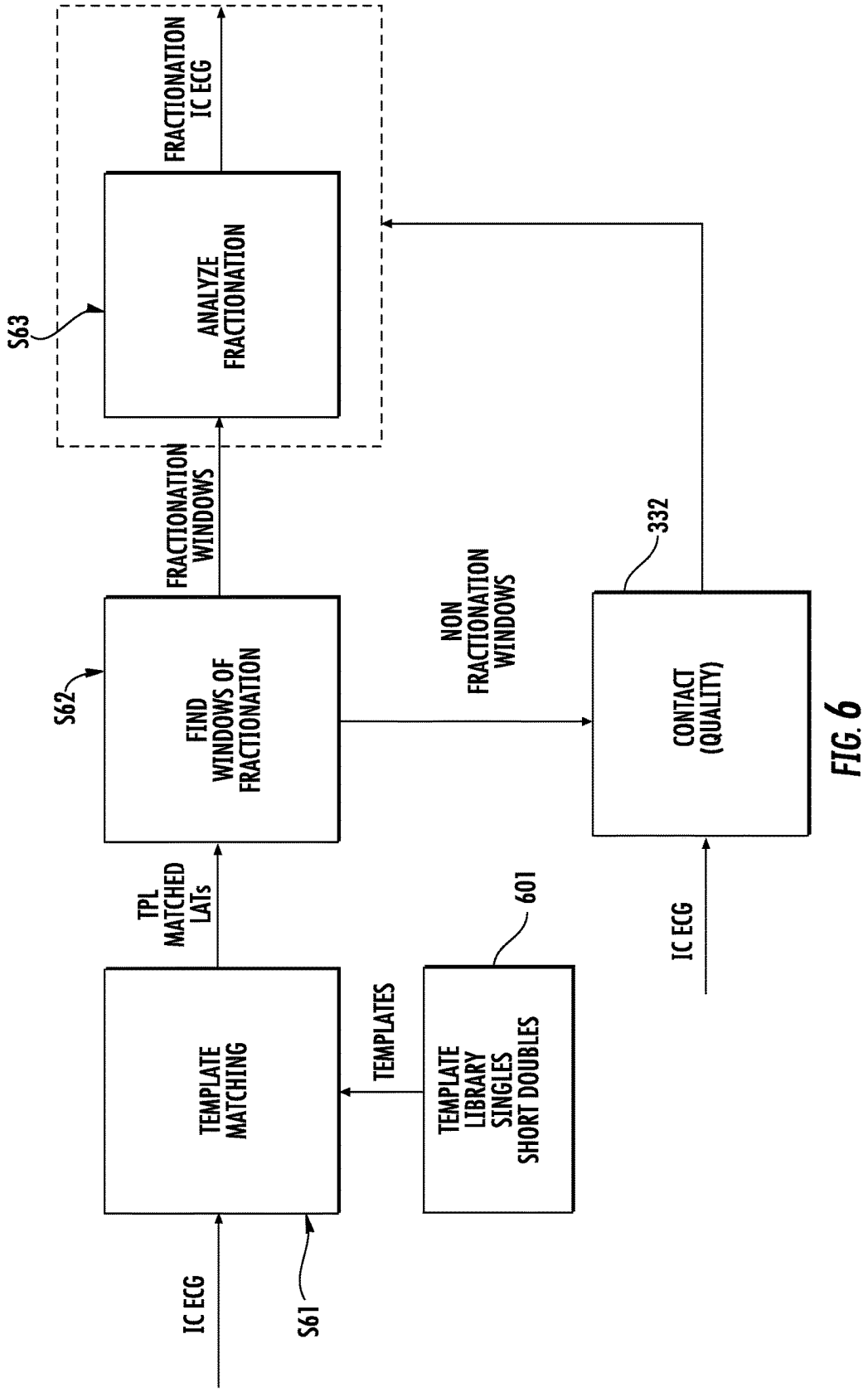

IC ECG
S61
TEMPLATE MATCHING
TEMPLATES
TEMPLATE LIBRARY SINGLES SHORT DOUBLES
601
TPL MATCHED LATs
IC ECG
S62
FIND WINDOWS OF FRACTIONATION
NON FRACTIONATION WINDOWS
332
CONTACT (QUALITY)
FRACTIONATION WINDOWS
S63
ANALYZE FRACTIONATION
FRACTIONATION IC ECG

FIG. 6

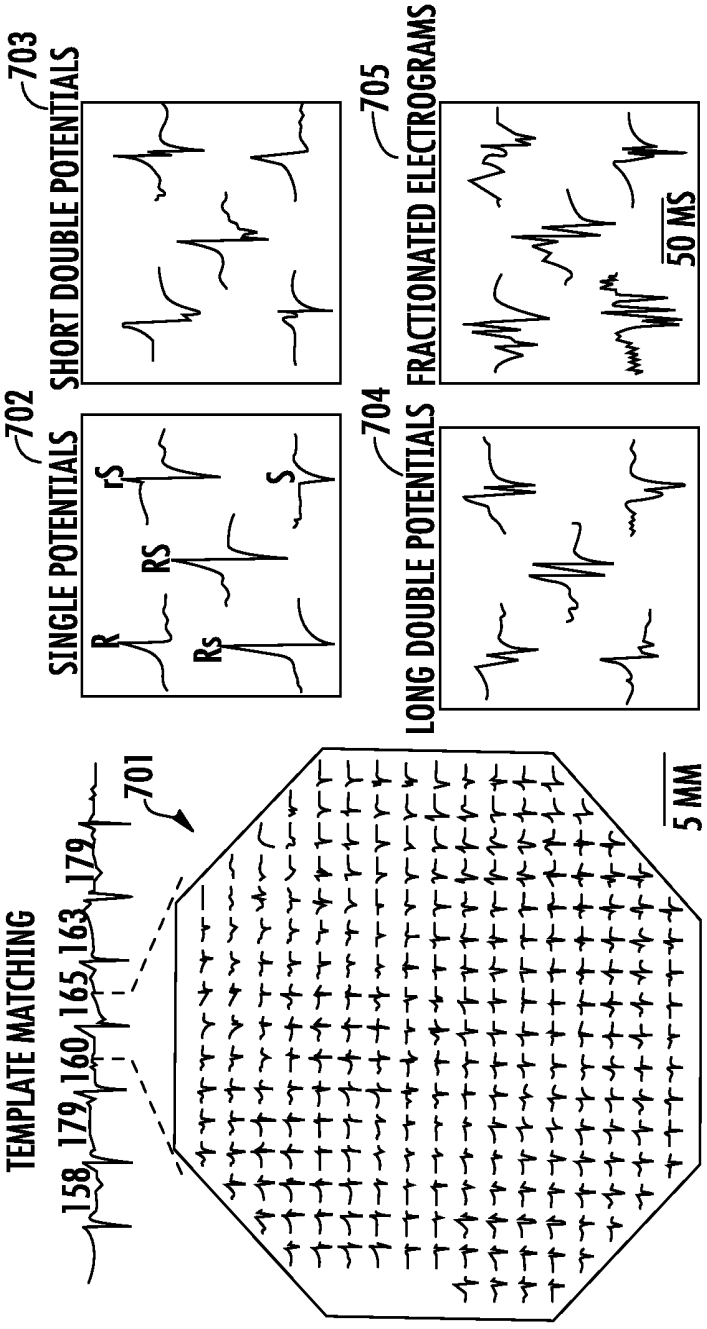

TEMPLATE MATCHING
158
179
160
165
163
179
701
5 MM
SINGLE POTENTIALS
702
R
Rs
RS
rS
S
SHORT DOUBLE POTENTIALS
703
LONG DOUBLE POTENTIALS
704
FRACTIONATED ELECTROGRAMS
705
50 MS

FIG. 7

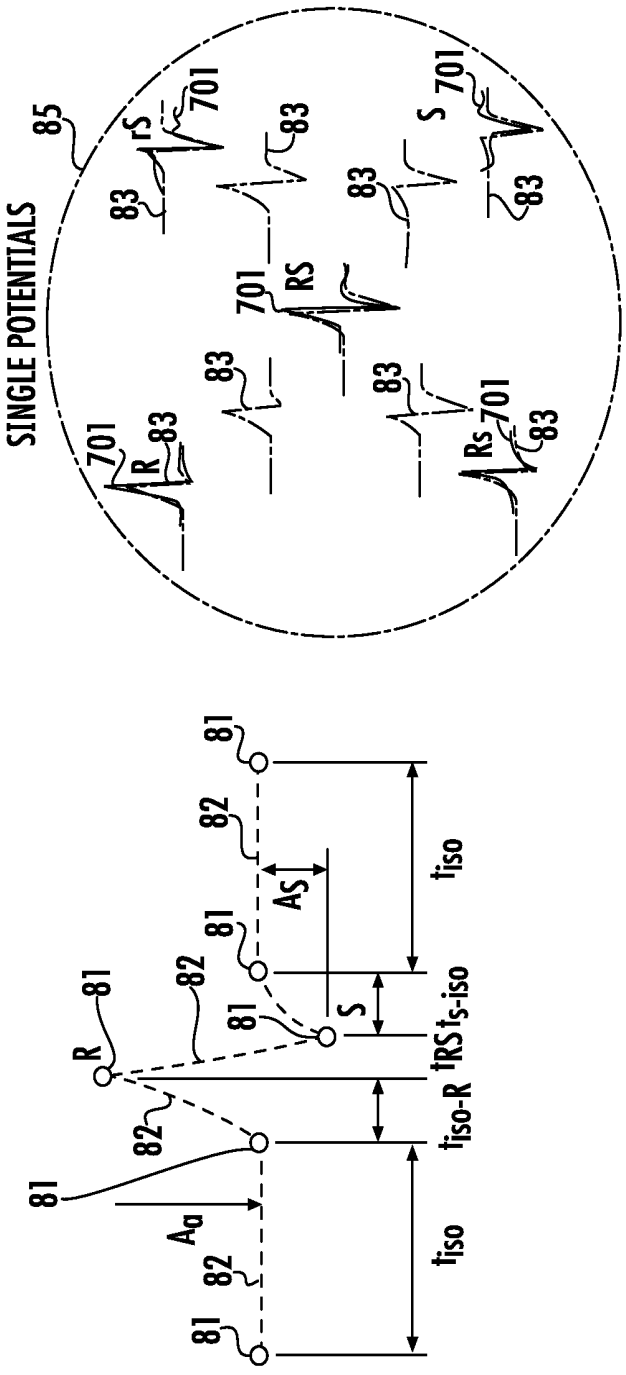

SINGLE POTENTIALS
85
701
83
rS
S
RS
R
Rs
81
82
AS
S
R
Aa
tiso
tS-iso
tRS
tiso-R

FIG. 8

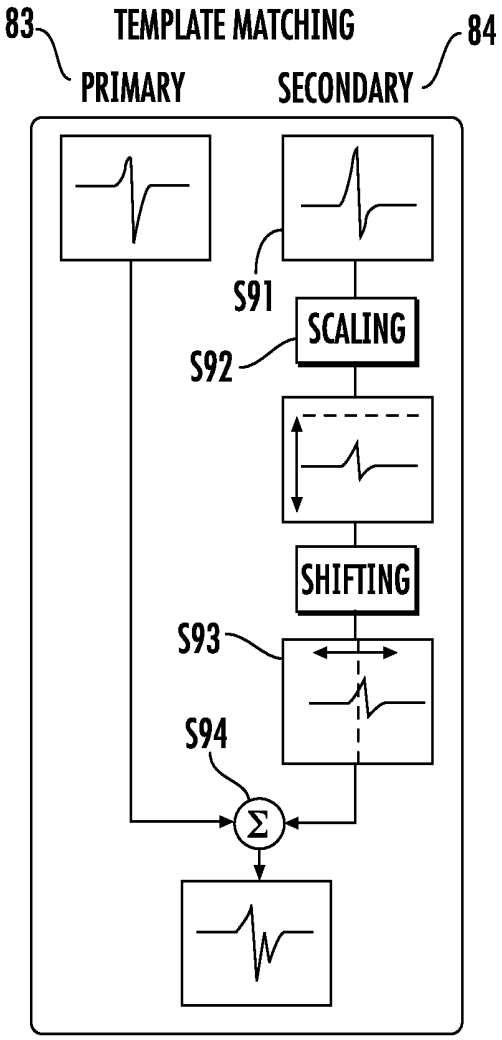

83
TEMPLATE MATCHING
84
PRIMARY
SECONDARY
S91
SCALING
S92
SHIFTING
S93
S94
Σ

FIG. 9

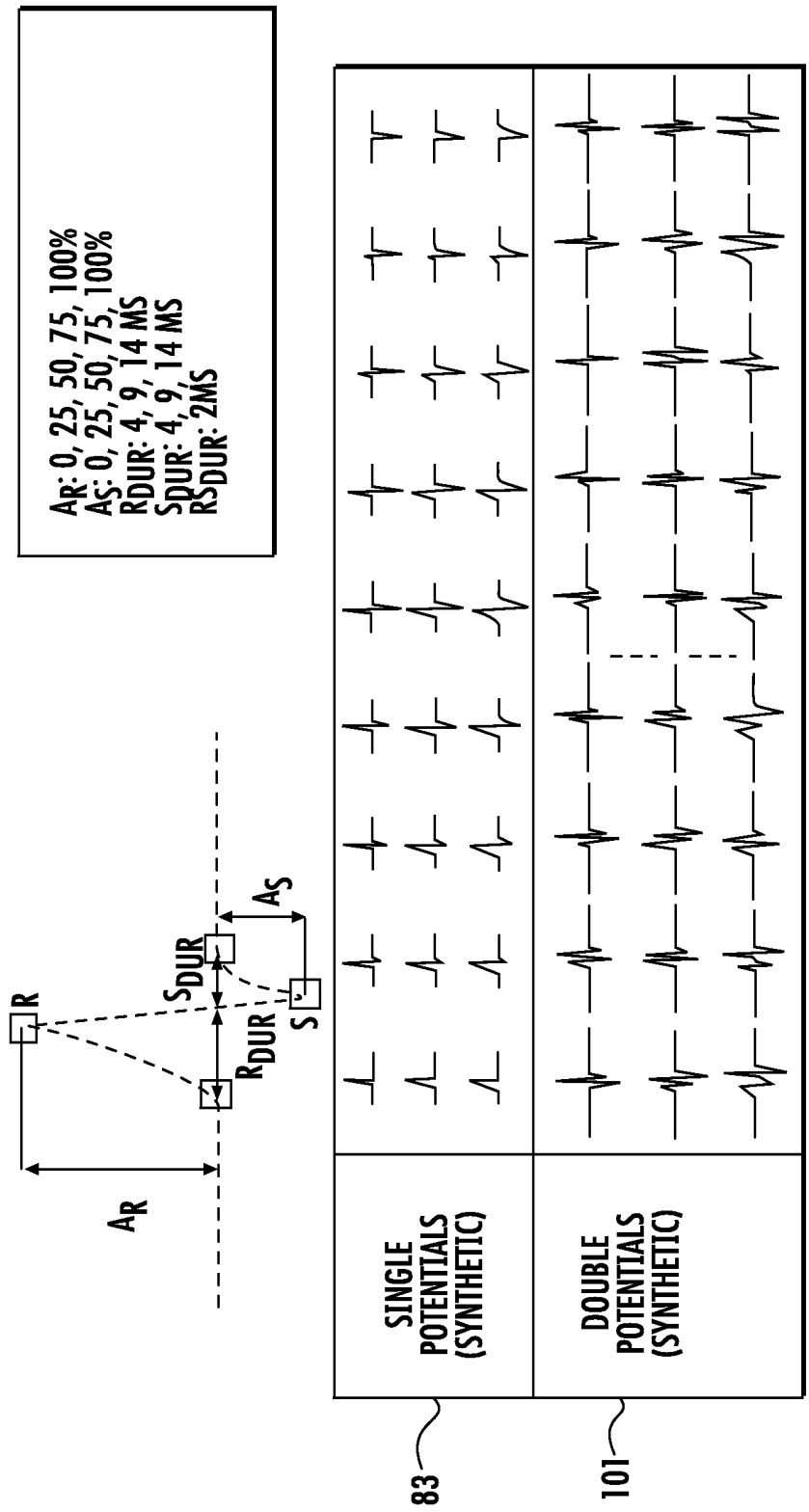

AR: 0, 25, 50, 75, 100%
AS: 0, 25, 50, 75, 100%
RDUR: 4, 9, 14 MS
SDUR: 4, 9, 14 MS
RSDUR: 2MS
R
SDUR
RDUR
S
AS
AR
SINGLE POTENTIALS (SYNTHETIC)
DOUBLE POTENTIALS (SYNTHETIC)
83
101

FIG. 10

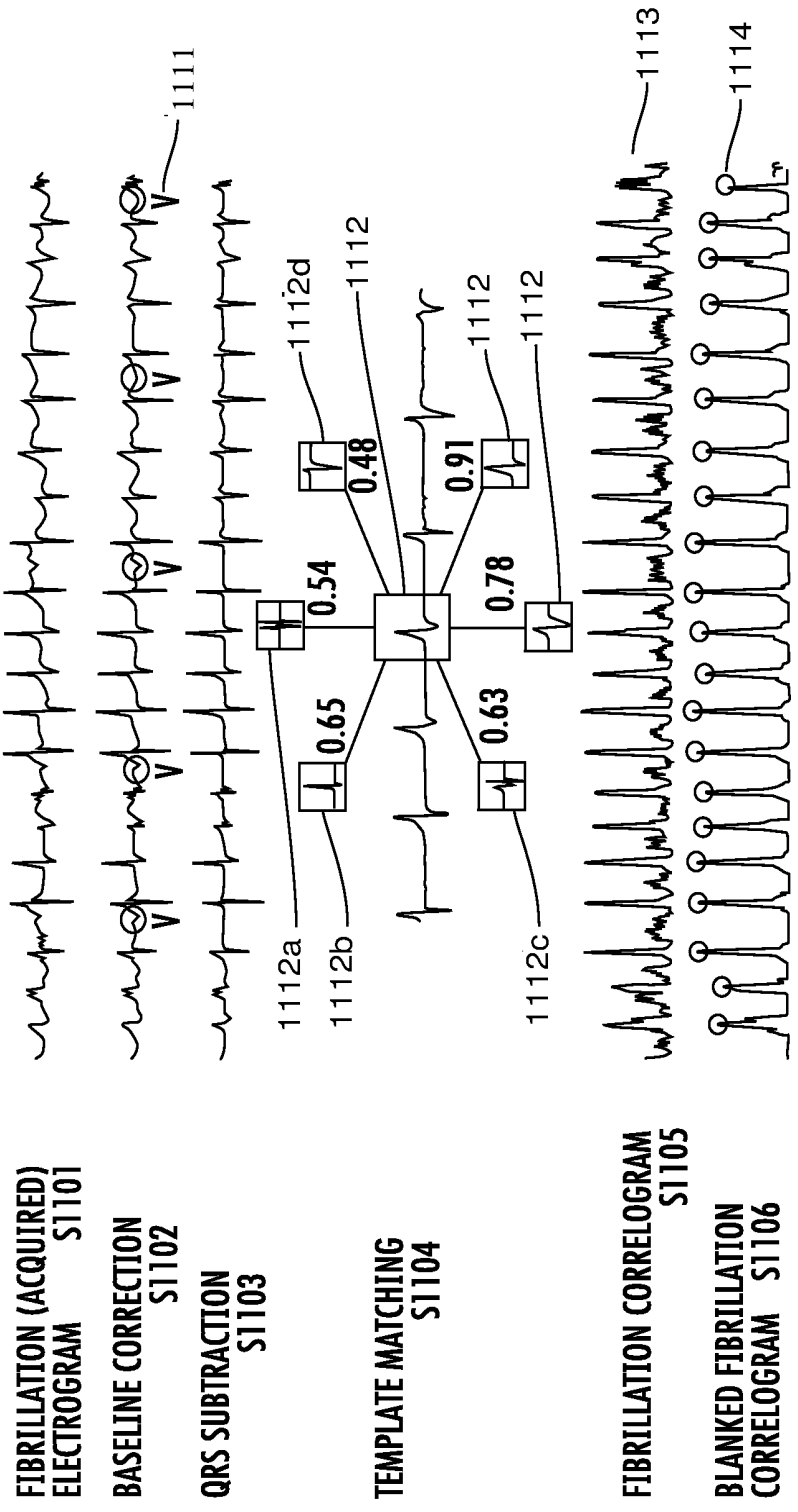

FIBRILLATION (ACQUIRED) ELECTROGRAM S1101
BASELINE CORRECTION S1102
QRS SUBTRACTION S1103
TEMPLATE MATCHING S1104
FIBRILLATION CORRELOGRAM S1105
BLANKED FIBRILLATION CORRELOGRAM S1106
1111
1112a
1112b
1112c
1112d
1112
1112
1112
0.54
0.65
0.63
0.48
0.91
0.78
1113
1114

FIG. 11

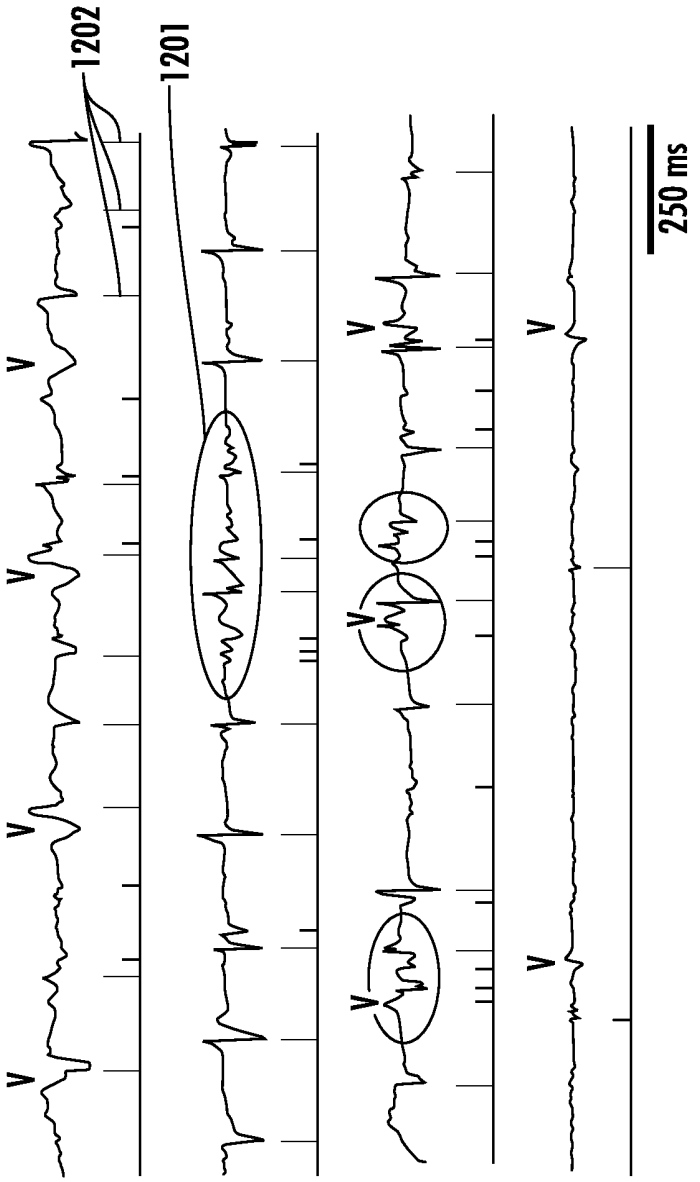


FIG. 12

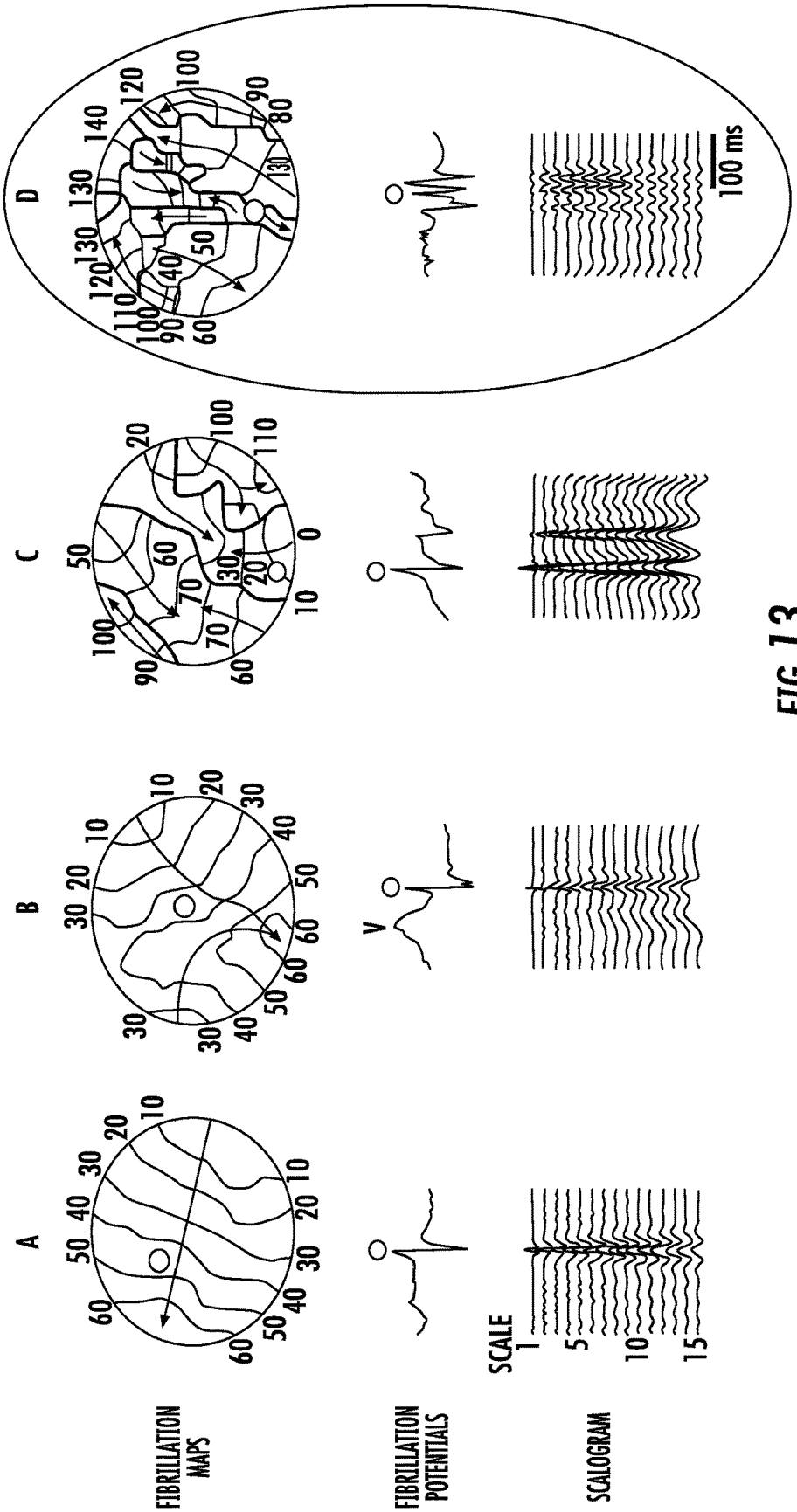

A
B
C
D
V
100 ms
SCALE
1
5
10
15
FIBRILLATION MAPS
FIBRILLATION POTENTIALS
SCALOGRAM

FIG. 13

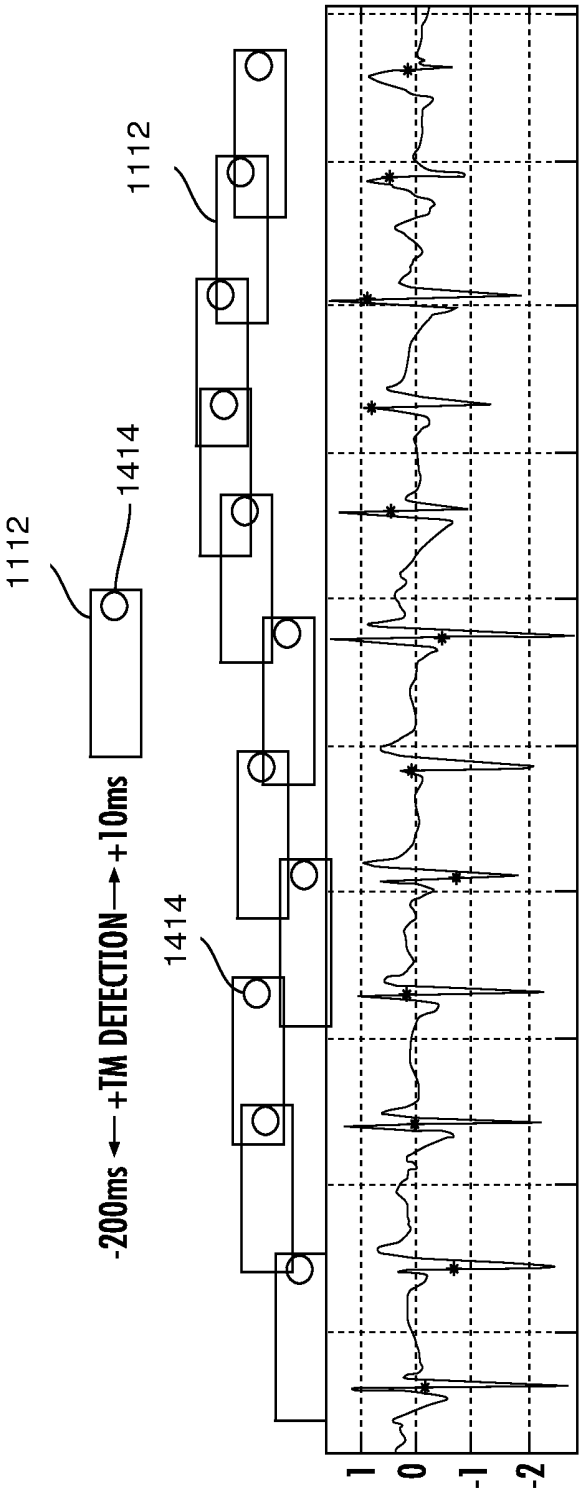


FIG. 14

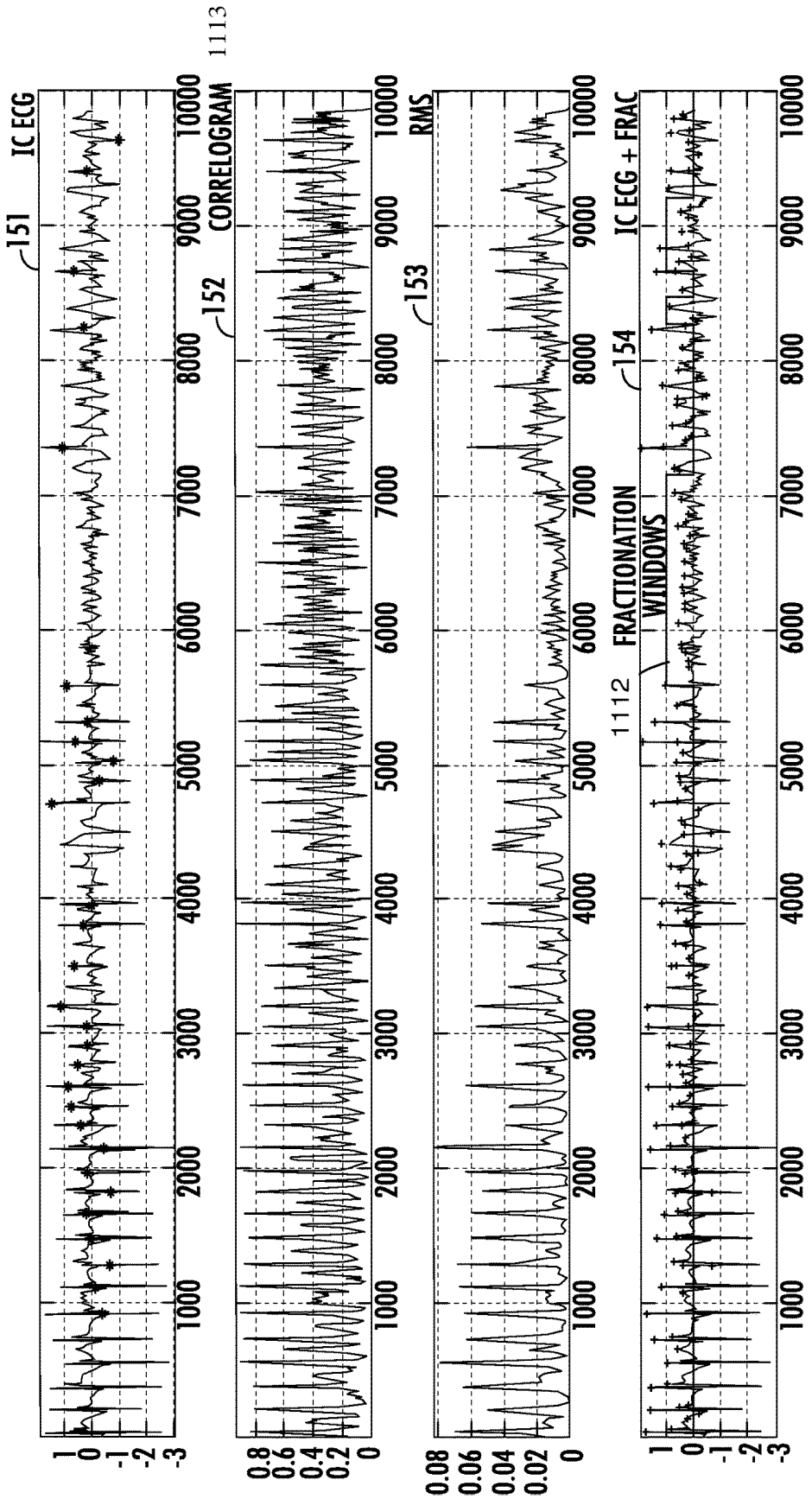

IC ECG
151
CORRELOGRAM
152
RMS
153
IC ECG + FRAC
154
1113
1112
FRACTIONATION
WINDOWS
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
1
0
-1
-2
-3
0.8
0.6
0.4
0.2
0
0.08
0.06
0.04
0.02
0

FIG. 15

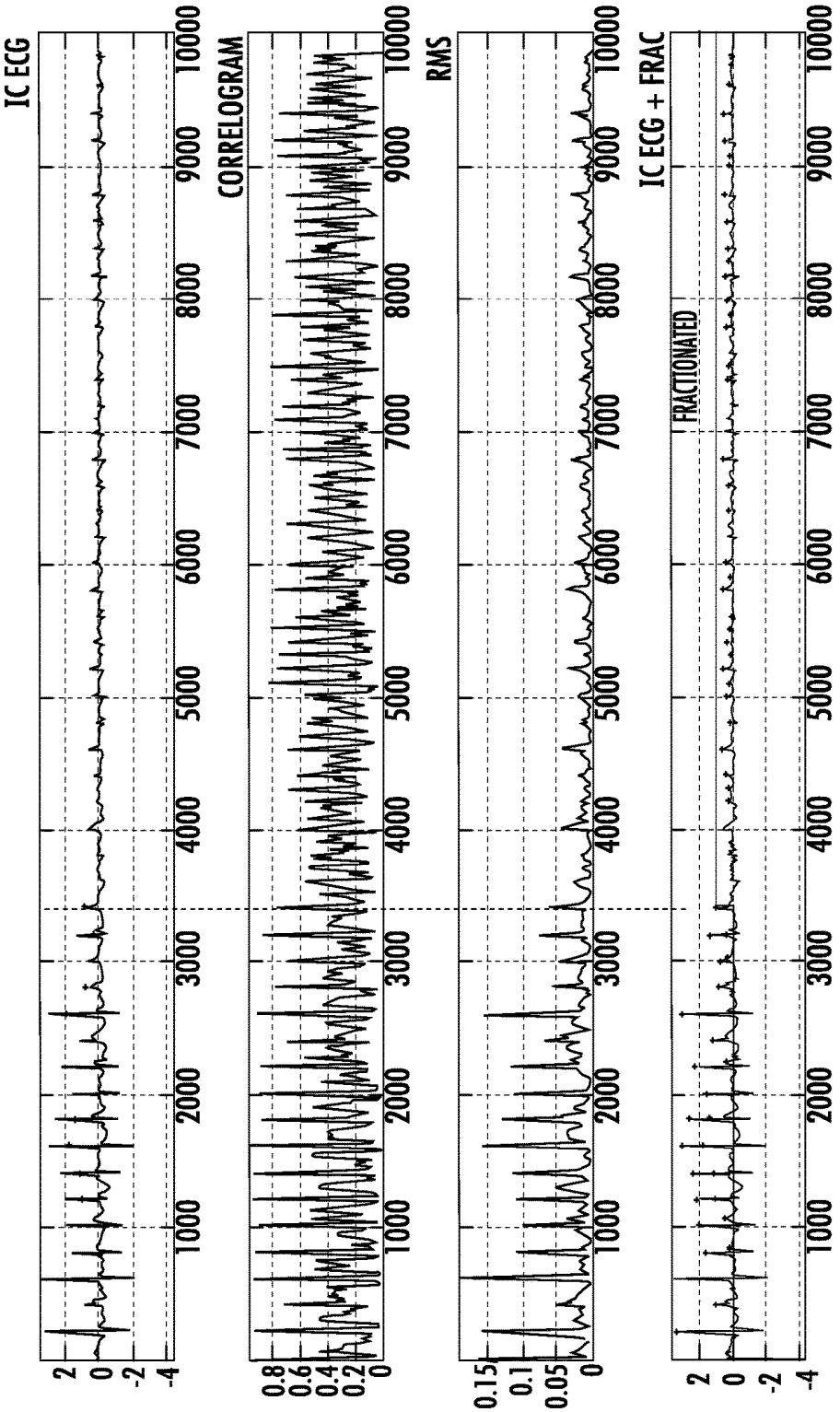

IC ECG
CORRELOGRAM
RMS
IC ECG + FRAC
FRACTIONATED
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000

FIG. 16

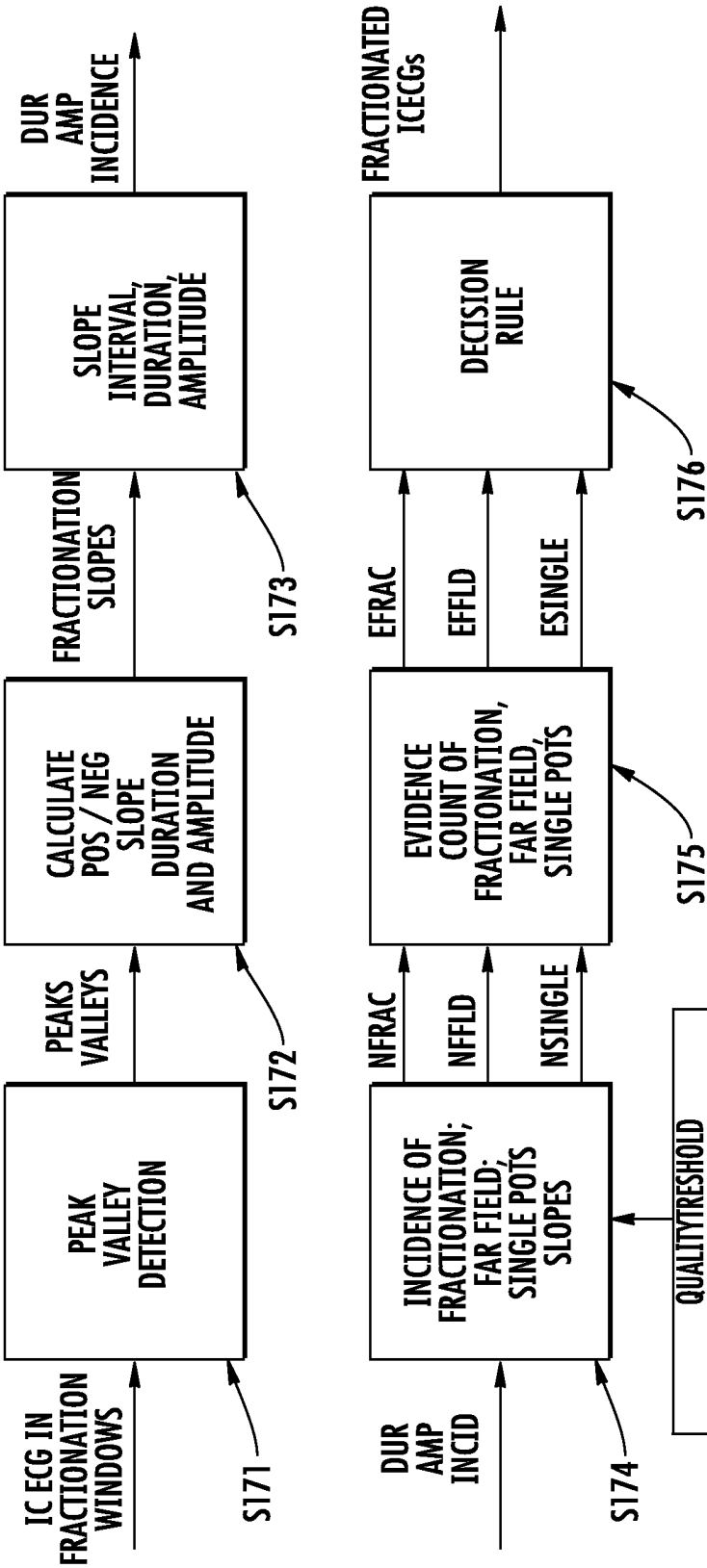

IC ECG IN FRACTIONATION WINDOWS
S171
PEAK VALLEY DETECTION
PEAKS VALLEYS
S172
CALCULATE POS / NEG SLOPE DURATION AND AMPLITUDE
FRACTIONATION SLOPES
S173
SLOPE INTERVAL, DURATION, AMPLITUDE
DUR AMP INCIDENCE
DUR AMP INCID
S174
INCIDENCE OF FRACTIONATION; FAR FIELD; SINGLE POTS SLOPES
NFRAC
NFFLD
NSINGLE
QUALITYTRESHOLD SLOPEAMPLOW {FRAC, FFLD, SINGLE} SLOPEAMPHIGH {FRAC, SLOPEDUR{FRAC,FFLD,SINGLE}
S175
EVIDENCE COUNT OF FRACTIONATION, FAR FIELD, SINGLE POTS
EFRAC
EFFLD
ESINGLE
S176
DECISION RULE
FRACTIONATED ICECGs

FIG. 17

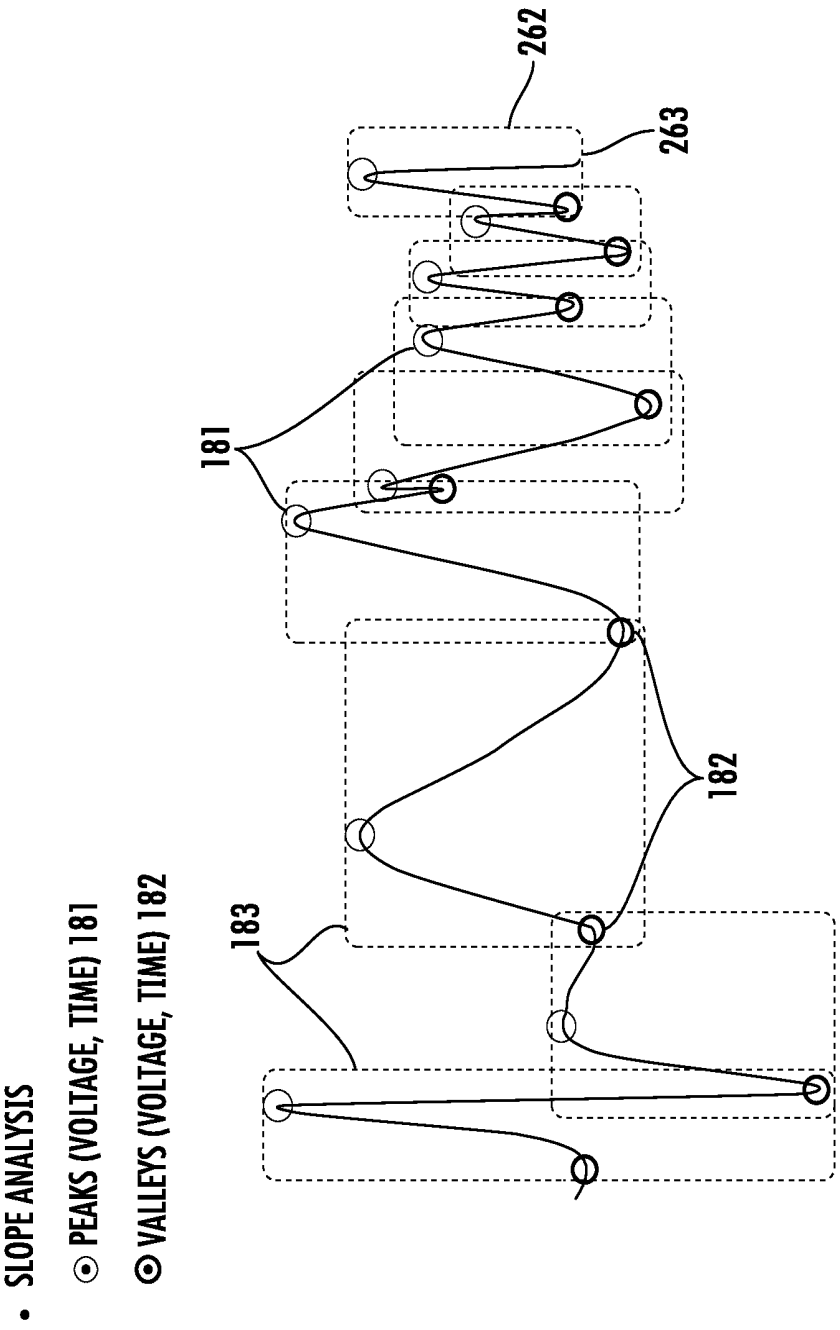

• SLOPE ANALYSIS
⊙ PEAKS (VOLTAGE, TIME) 181
⊙ VALLEYS (VOLTAGE, TIME) 182
181
182
183
262
263

FIG. 18

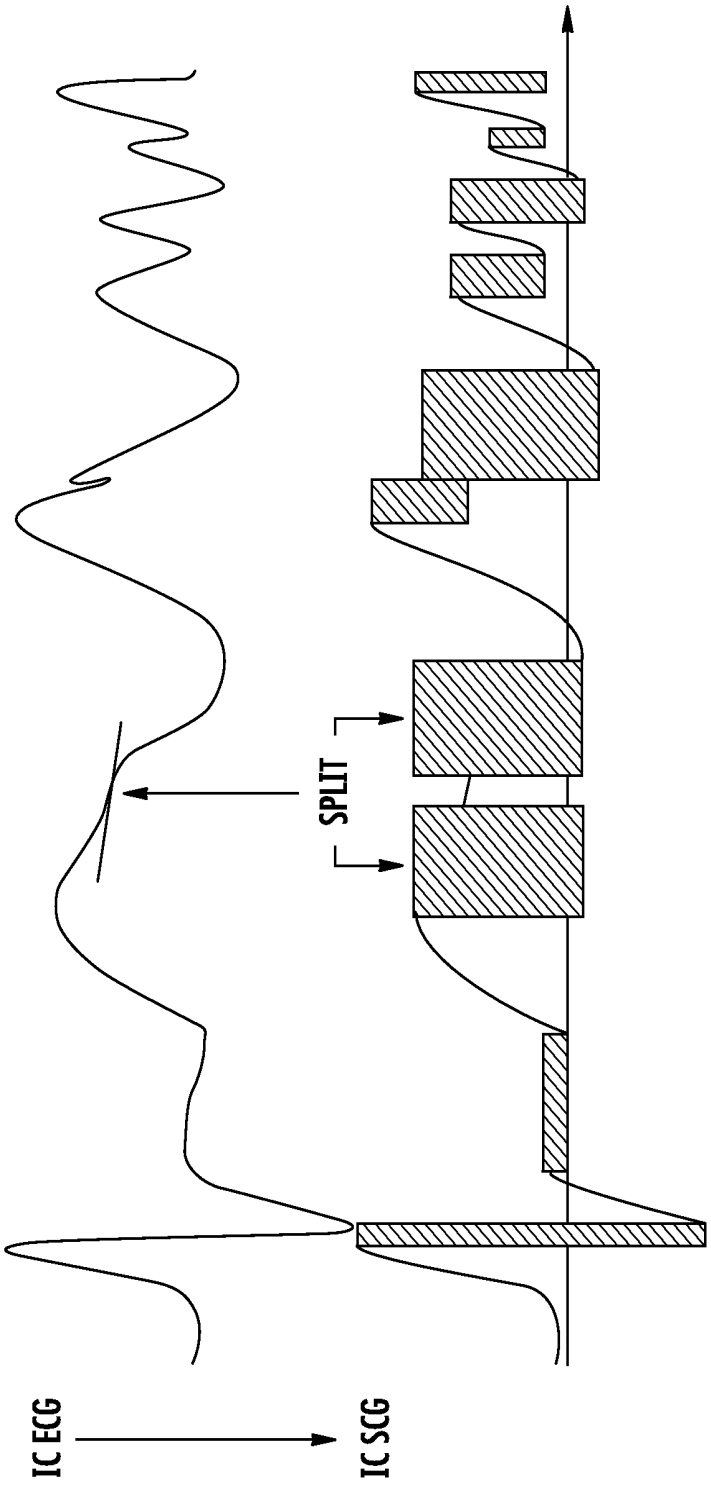


FIG. 19

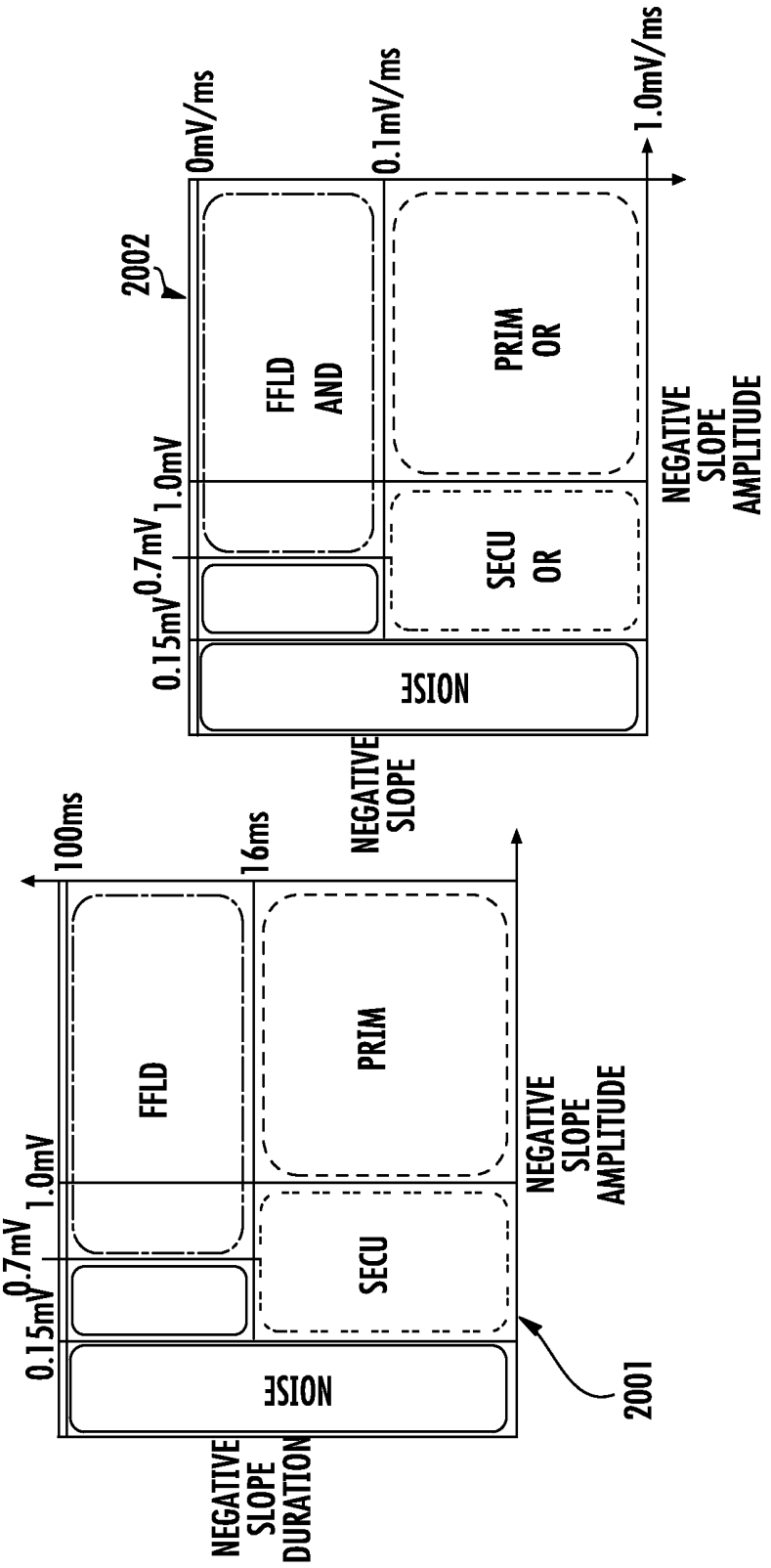

0mV/ms
0.1mV/ms
1.0mV/ms
2002
FFLD AND
PRIM OR
NEGATIVE SLOPE AMPLITUDE
1.0mV
0.7mV
0.15mV
SECU OR
NOISE
NEGATIVE SLOPE
100ms
16ms
FFLD
PRIM
NEGATIVE SLOPE AMPLITUDE
1.0mV
0.7mV
0.15mV
SECU
NOISE
2001
NEGATIVE SLOPE DURATION

FIG. 20

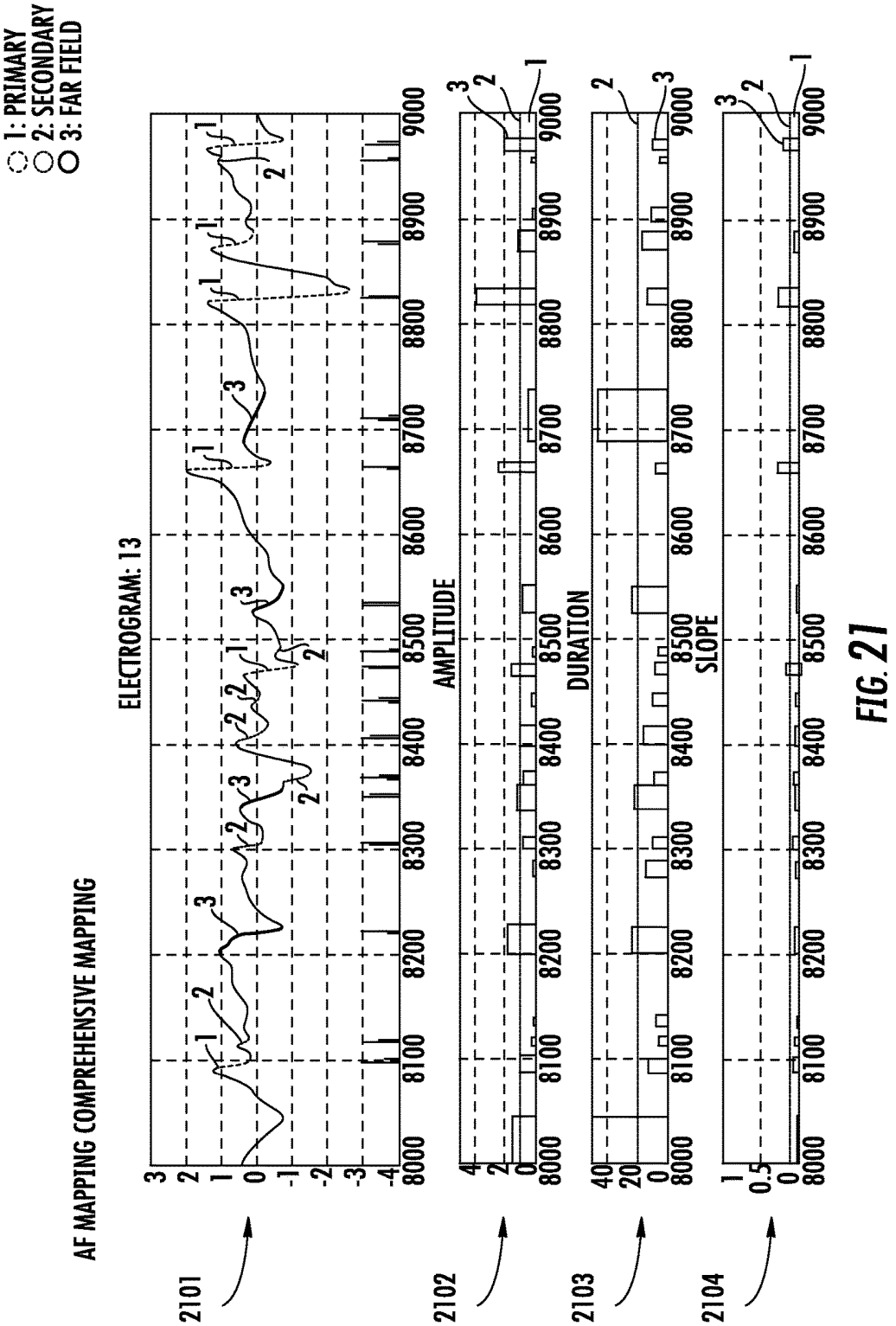

AF MAPPING COMPREHENSIVE MAPPING
1: PRIMARY
2: SECONDARY
3: FAR FIELD
ELECTROGRAM: 13
AMPLITUDE
DURATION
SLOPE
2101
2102
2103
2104

FIG. 21

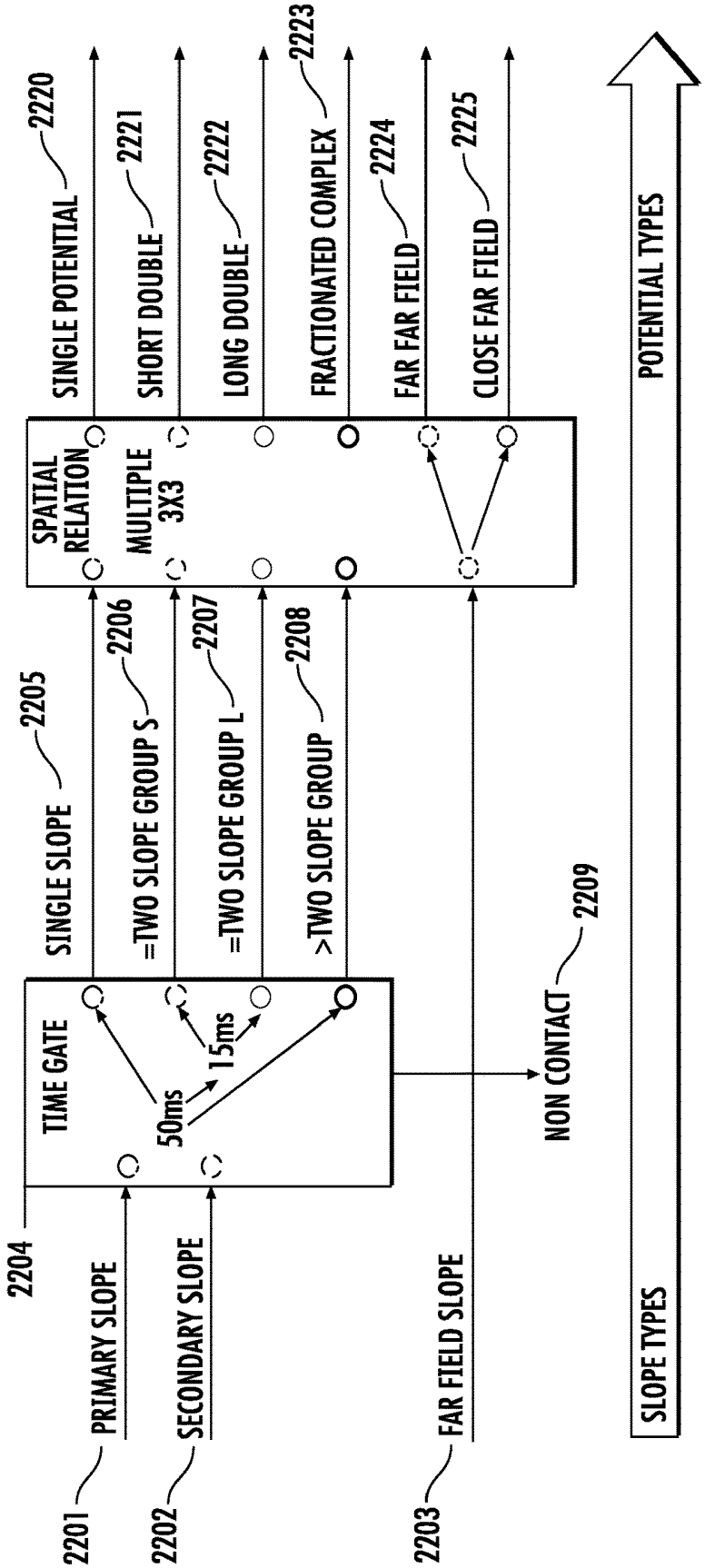

2220
SINGLE POTENTIAL
2221
SHORT DOUBLE
2222
LONG DOUBLE
2223
FRACTIONATED COMPLEX
2224
FAR FAR FIELD
2225
CLOSE FAR FIELD
POTENTIAL TYPES
SPATIAL RELATION
MULTIPLE 3X3
2205
SINGLE SLOPE
2206
=TWO SLOPE GROUP S
2207
=TWO SLOPE GROUP L
2208
>TWO SLOPE GROUP
2209
NON CONTACT
TIME GATE
50ms
15ms
2204
2201
PRIMARY SLOPE
2202
SECONDARY SLOPE
2203
FAR FIELD SLOPE
SLOPE TYPES

FIG. 22

TIME GATE: TEMPORAL GROUPING OF PRIMARY AND SECONDARY SLOPES

- NON CONTACT
  - ANALYZE 3X3 SPATIOTEMPORAL TIME WINDOW
  - FFLD SLOPE ANNOTATION
    - → FAR FIELD POTENTIAL
    - → NON-CONTACT
  - ANALYZE SLOPE ANNOTATION WITHIN WINDOW (t+/-W)
    - NO PRIMARY SLOPES FOUND IN CENTER ELECTRODE IC ECG
      - →NON CONTACT EVIDENCE ++
      - + ONLY FAR FIELD SLOPES FOUND IN NEIGHBORING ELECTRODES →NON CONTACT EVIDENCE ++
      - + PRIMARY SLOPES FOUND IN NEIGHBORING ELECTRODES→NON CONTACT EVIDENCE ++
    - PRIMARY SLOPES FOUND IN CENTER ELECTRODE IC ECG
      - →FF POTENTIAL EVIDENCE ++
      - + SYNCHRONOUS PRIMARY SLOPES FOUND IN NEIGHBORING ELECTRODES→NON CONTACT EVIDENCE ++

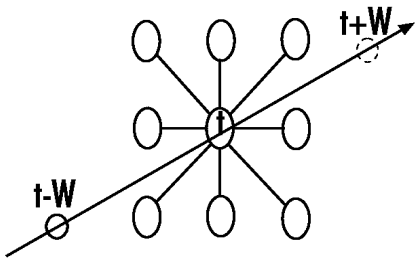


FIG. 23

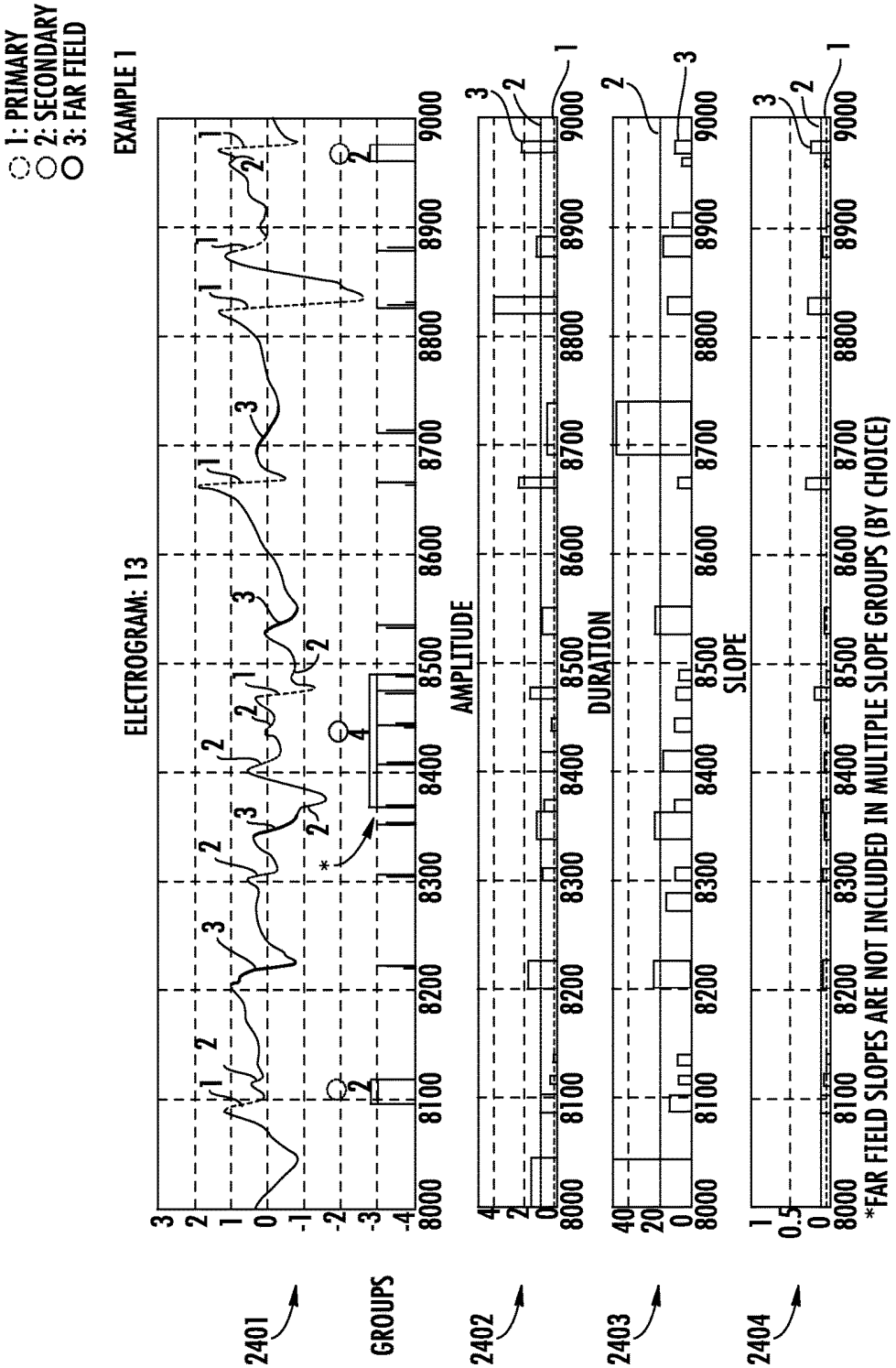

1: PRIMARY
2: SECONDARY
3: FAR FIELD
EXAMPLE 1
ELECTROGRAM: 13
2401
GROUPS
2402
AMPLITUDE
2403
DURATION
2404
SLOPE
8000 8100 8200 8300 8400 8500 8600 8700 8800 8900 9000
*FAR FIELD SLOPES ARE NOT INCLUDED IN MULTIPLE SLOPE GROUPS (BY CHOICE)

FIG. 24

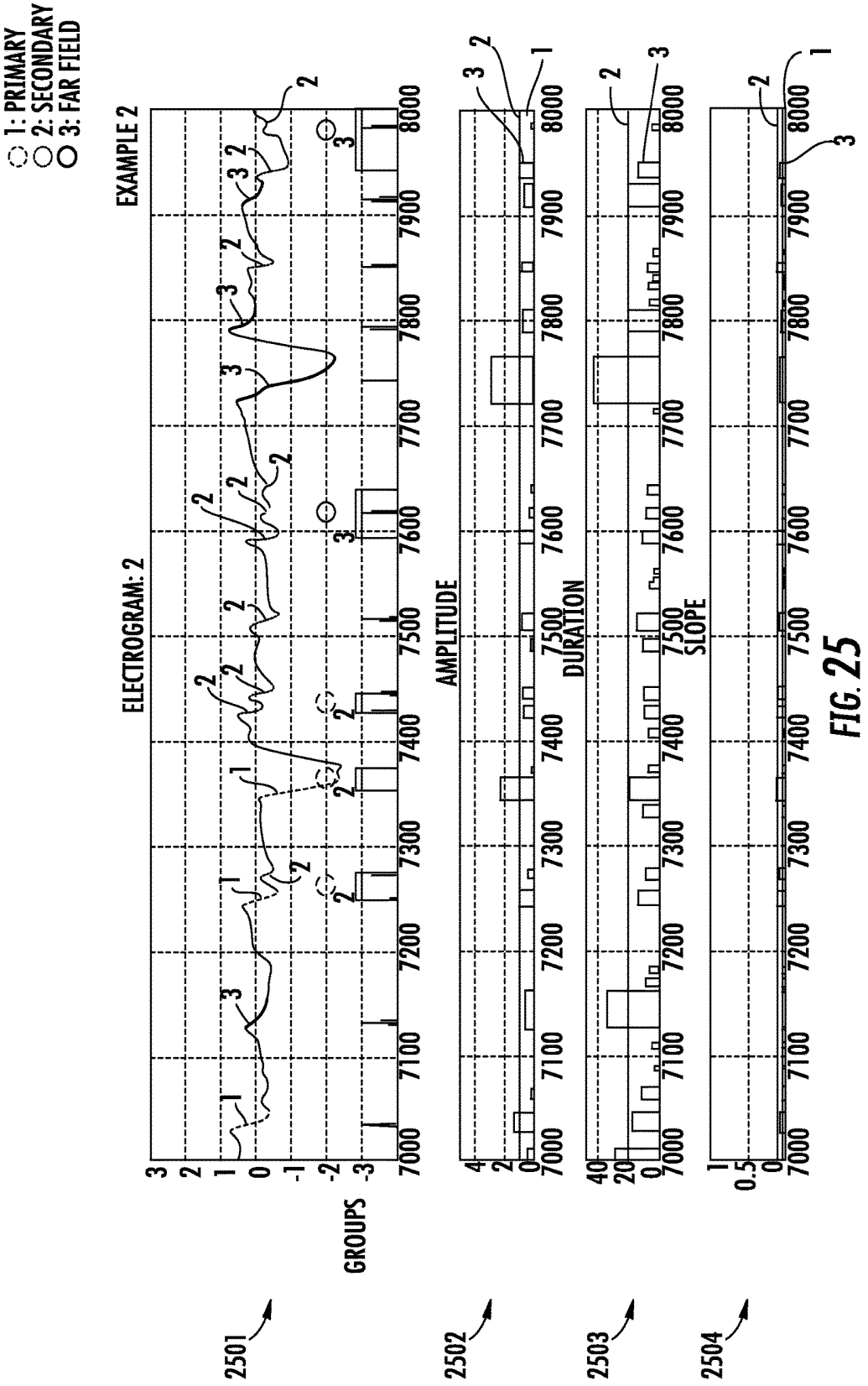

1: PRIMARY
2: SECONDARY
3: FAR FIELD
EXAMPLE 2
ELECTROGRAM: 2
GROUPS
AMPLITUDE
DURATION
SLOPE
2501
2502
2503
2504

FIG. 25

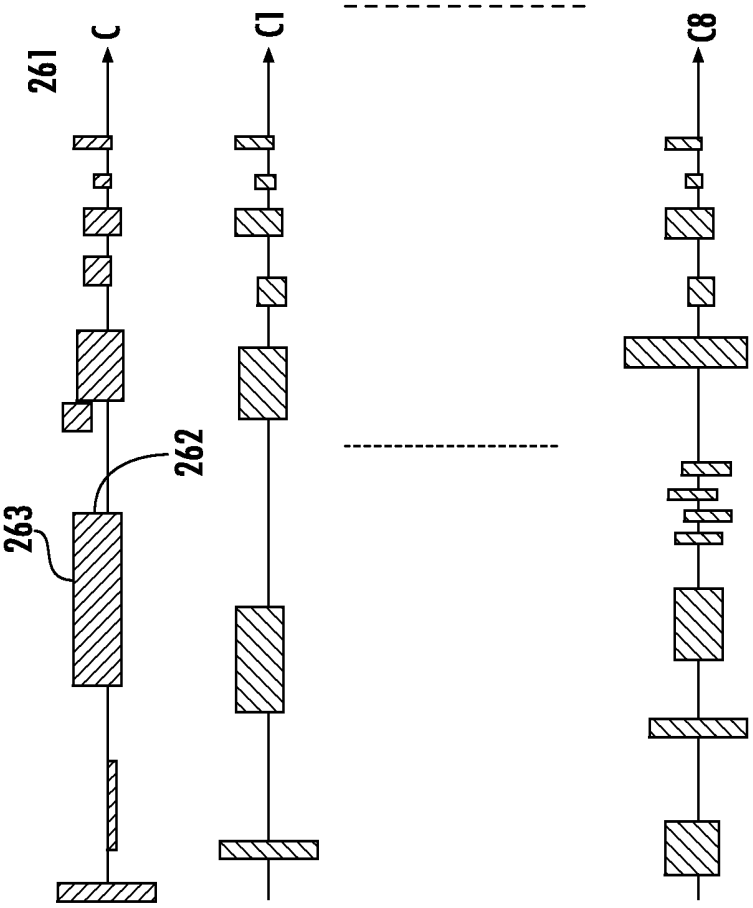
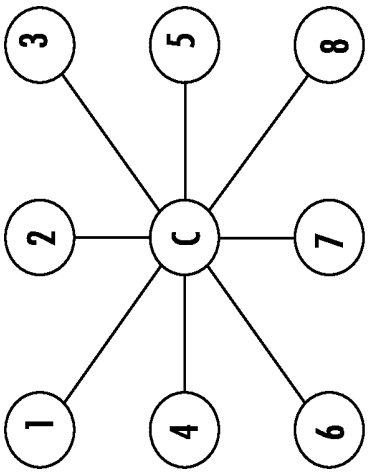


FIG. 26



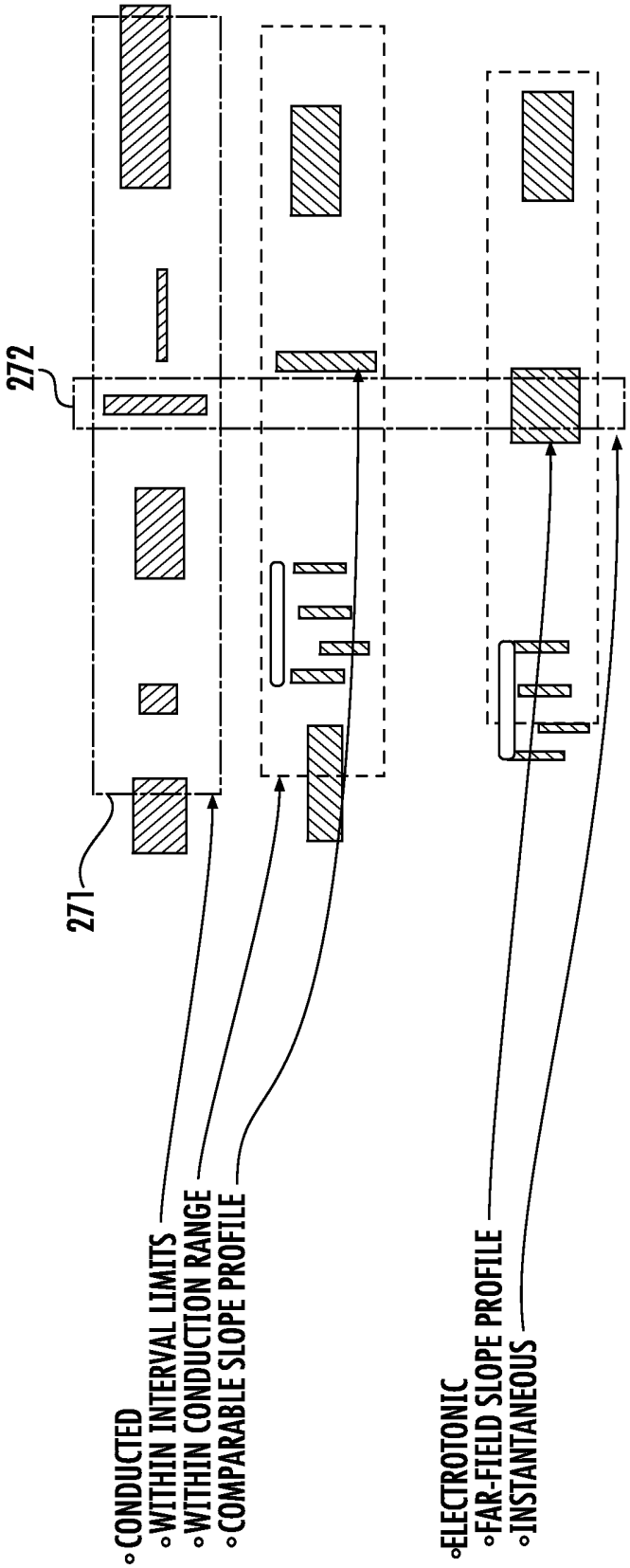

272
271
•CONDUCTED
•WITHIN INTERVAL LIMITS
•WITHIN CONDUCTION RANGE
•COMPARABLE SLOPE PROFILE
•ELECTROTONIC
•FAR-FIELD SLOPE PROFILE
•INSTANTANEOUS

FIG. 27

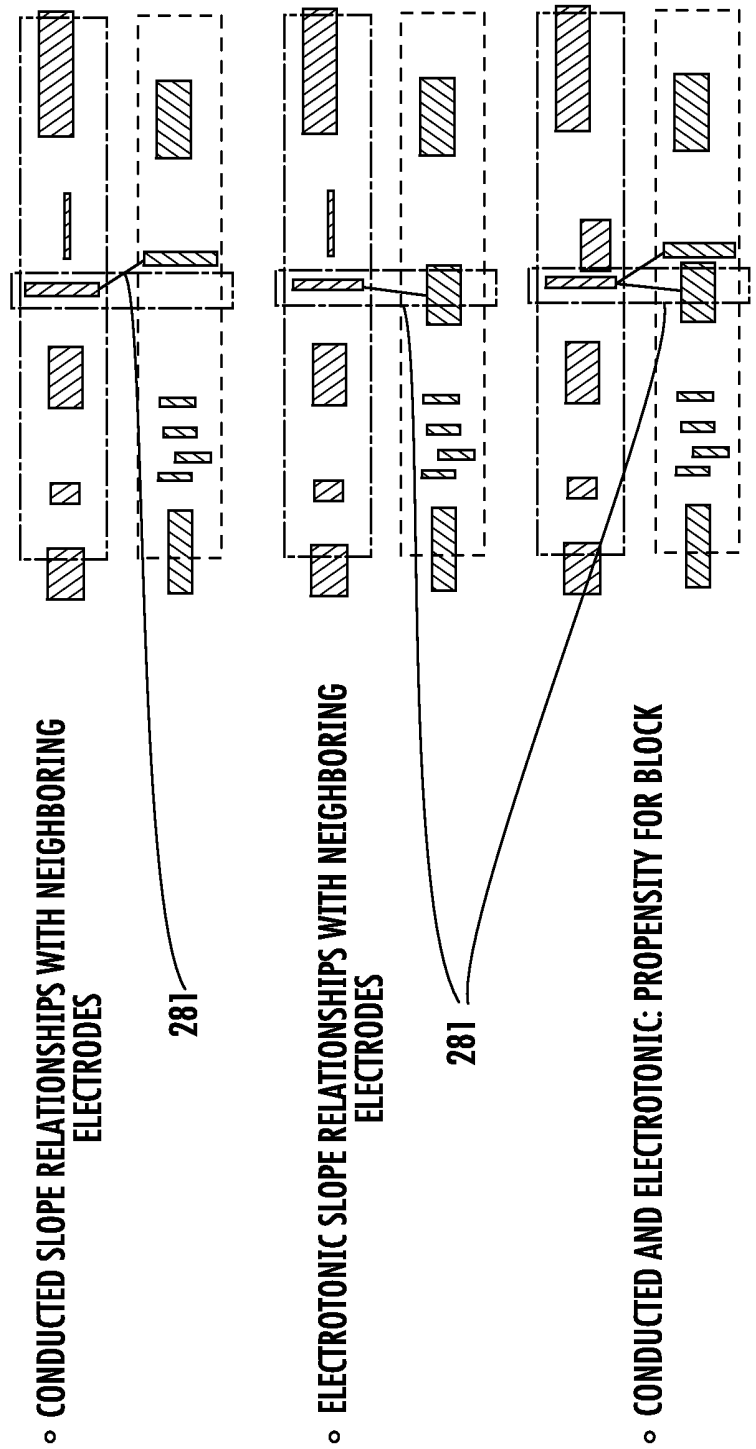

CONDUCTED SLOPE RELATIONSHIPS WITH NEIGHBORING ELECTRODES
281
ELECTROTONIC SLOPE RELATIONSHIPS WITH NEIGHBORING ELECTRODES
281
CONDUCTED AND ELECTROTONIC: PROPENSITY FOR BLOCK

FIG. 28

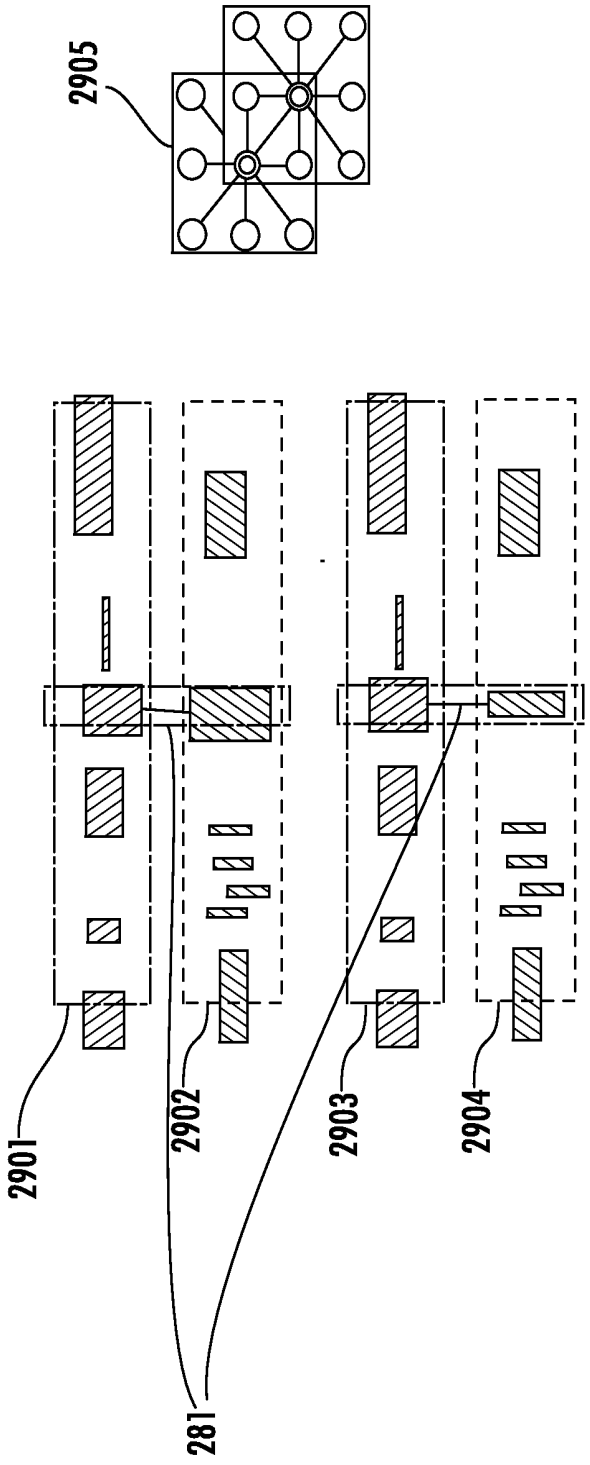


FIG. 29

IDENTIFICATION OF FRACTIONATED SIGNALS

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 62/278,676, filed Jan. 14, 2016, which is incorporated by reference as if fully set forth. This application incorporates by reference as if fully set forth U.S. patent application Ser. No. 15/404,228 titled "Region of Interest Focal Source Detection Using Comparisons of R-S Wave Magnitudes and LATs of RS Complexes," U.S. patent application Ser. No. 15/404,225 titled "Region of Interest Rotational Activity Pattern Detection," U.S. patent application Ser. No. 15/404,226 titled "Overall System and Method for Detecting Regions of Interest," U.S. patent application Ser. No. 15/404,231 titled "Non-Overlapping Loop-Type or Spline-Type Catheter To Determine Activation Source Direction and Activation Source Type," and U.S. patent application Ser. No. 15/404,266 titled "Region of Interest Focal Source Detection," all filed on Jan. 12, 2017.

FIELD OF THE INVENTION

The present invention relates to systems and methods for determining regions of interest to be ablated for treatment of cardiac arrhythmia, such as atrial fibrillation. More particularly, the invention relates to improvements in analysis of intracardiac electrocardiography (ECG) signals to improve activation maps and better determine regions of interest.

BACKGROUND

Cardiac arrhythmia includes different types of abnormal or irregular heart rhythms, such as, for example, atrial fibrillation (AF), which is characterized by rapid and irregular beating. Under normal heart conditions, a heartbeat is produced by electrical pulses (i.e., signals) which originate in the upper chambers (i.e., atria) of the heart and pass through the atria through the atrioventricular (AV) node to a pair of lower chambers (i.e., ventricles) of the heart. As the signals pass through the atria, the atria contract and pump blood through the AV node into the ventricles. This causes the ventricles to contract, pumping out blood from the heart to the body. During conditions of AF, however, the signals in the atria become chaotic and cause the heart to beat irregularly.

AF can negatively affect the physical, psychological and emotional quality of a person's life. AF can progressively increase in severity and frequency and, if left untreated, may lead to chronic fatigue, congestive heart failure or stroke. One type of AF treatment includes prescribed medications, such as rhythm control medications and medications used to manage the increased risk of stroke. These medications must be taken daily and indefinitely. Another type of AF treatment includes cardioversion, which attempts to restore a normal heart rhythm by providing electric shocks to the heart through electrodes placed on the chest. In some persistent types of AF, cardioversion is either ineffective or cannot be attempted.

Recent approaches for treating AF include minimally invasive ablation procedures (e.g., catheter ablation) in which the heart tissue is ablated to terminate electrical pathways and block faulty electrical impulses that can cause heart rhythm disorders.

SUMMARY

A method may be used to determine one or more regions of interest for cardiac ablation using fractionation. For example, the method may detect, using one or more sensors, electro-cardiogram (ECG) signals. Each detected ECG signal may indicate electrical activity of a heart. The method may next determine, for each of the plurality of ECG signals, one or more local activation times (LATs). Each LAT may indicate a time of activation of a corresponding ECG signal.

The method may then generate, based on the determined one or more LATs, one or more driver maps. In addition, the method may also generate one or more perpetuator maps, each representing the electrical activity of the heart. The driver map and/or perpetuator map may be used to derive parameter using at least fractionation. The the derived parameters may then be processed and combined into driver evidence and perpetuator evidence. Finally, the method may determine the regions of interest for cardiac ablation in accordance with the fractionation used to derive the driver evidence and the perpetuator evidence.

A system may be used to determine one or more regions of interest for cardiac ablation using fractionation. The system may include a plurality of sensors, each sensor configured to detect a plurality of electro-cardiogram (ECG) signals over time. Each ECG signal may indicate electrical activity of a heart.

The system may include a processing device comprising one or more processors. Each processor may be configured to determine, for each of the plurality of ECG signals, one or more local activation times (LATs). Each LAT may indicate a time of activation of a corresponding ECG signal. Each processor may generate, based on the determined one or more LATs of each of the plurality of ECG signals, one or more driver maps. Each processor may further generate one or more perpetuator maps, each representing the electrical activity of the heart.

Each processor may derive parameters from the driver and perpetuator maps, using at least fractionation. Each processor may then process and combine the derived parameters into driver evidence and perpetuator evidence. Each processor may then determine the regions of interest for cardiac ablation in accordance with the fractionation used to derive the driver evidence and the perpetuator evidence and display the regions of interest information on a display device.

A computer software product may include a non-transitory computer readable storage medium in which computer program instructions are stored. The instructions, when executed by a computer, may cause the computer to perform one or more steps.

For example, the computer may perform a detection step, via a plurality of sensors, electro-cardiogram (ECG) signals, each ECG signal detected via one of the plurality of sensors and indicating electrical activity of a heart. The computer may also perform a determining step, for each of the plurality of ECG signals, one or more local activation times (LATs) each indicating a time of activation of a corresponding ECG signal.

The computer software product may cause the computer to generate, based on the determined one or more LATs of each of the plurality of ECG signals, one or more driver maps. The computer software product may cause the computer to also generate one or more perpetuator maps, each representing the electrical activity of the heart.

The computer software product may cause the computer to derive parameters from the driver and perpetuator maps,

using at least fractionation. The computer software product may cause the computer to process and combine the derived parameters into driver evidence and perpetuator evidence. Finally, the computer software product may cause the computer to determine the regions of interest for cardiac ablation in accordance with the fractionation used to derive the driver evidence and the perpetuator evidence.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the present invention, reference is made to the detailed description of the invention, by way of example, which is to be read in conjunction with the following drawings, wherein like elements are given like reference numerals.

FIG. **1** is a block diagram illustrating an exemplary classification of AF used with embodiments disclosed herein.

FIG. **2** is a block diagram illustrating an exemplary system used to determine AF ROIs for ablation for use with embodiments disclosed herein.

FIGS. **3**A and **3**B are portions of a flow diagram illustrating an exemplary method of determining an AF ROI for ablation according to an embodiment.

FIG. **4** illustrates mapping to appoint ROIs for ablation.

FIG. **5** is an overview of AF Mapping Fractionation.

FIG. **6** is an overview of Fractionation Analysis in AF Mapping to Appoint ROIs for Ablation.

FIGS. **7-11** illustrate AF Mapping to Appoint Ablation ROIs.

FIG. **12** illustrates AF Mapping to Appoint Ablation ROIs Detect Fractionated IC ECG.

FIG. **13** illustrates AF Mapping to Appoint ROIs for Ablation.

FIG. **14** illustrates AF Mapping Detect Fractionated Episodes in IC ECG.

FIG. **15** illustrates AF Mapping Detect Fractionated Episodes in IC ECG.

FIGS. **16-17** illustrate AF Mapping Detect Fractionated Episodes in IC ECG.

FIG. **18** illustrates AF Mapping Detect Fractionated Episodes with increased specificity.

FIG. **19** illustrates AF Mapping Comprehensive Mapping.

FIG. **20** illustrates AF Mapping Comprehensive Mapping—Slope View.

FIG. **21** illustrates AF Mapping Comprehensive Mapping—characterize slopes.

FIG. **22** shows a progression from slope types to potential types.

FIG. **23** further illustrates time gate and temporal grouping of primary and secondary slopes.

FIGS. **24** and **25** provide two examples of groupings, further illustrating single slope, two slope group, long double slope group and >two slopes.

FIG. **26** illustrates the spatio-temporal analysis of identified slopes represented as rectangles.

FIGS. **27-29** show example AF mapping spatio-temporal slope analysis.

DETAILED DESCRIPTION OF THE INVENTION

Conventional methods and systems used for catheter ablation typically include inserting the catheter through an incision in the skin and guided up to the heart. Before ablation is performed, intra-cardiac electrocardiogram (IC ECG) signals of the heart are acquired via electrodes placed at different areas of the heart. The signals are monitored and used to provide information to determine whether one or more areas of the heart are causing the irregular heart rhythm. The conventional methods and systems used to determine these areas to be ablated, however, are time consuming (e.g., several hours) and rely on medical personnel with specific expertise and experience (typically requiring many hours of training).

Embodiments disclosed herein employ systems, apparatuses and methods of determining potential regions of interest (ROIs) to be targeted for ablation. Various mapping techniques are utilized to provide maps of the electrophysical conditions of the AF substrate and maps representing a spatio-temporal manifestation of the AF process to provide efficient and accurate determination of potential ablation ROIs. Mapping techniques utilize various parameters (e.g., cycle, earliness, R-S complex, conduction velocity (CV), block and fractionation) of acquired IC ECG signals and detected local activation times (LATs) to identify potential evidence of drivers and perpetuators of the AF substrate. Identification of the potential evidence of drivers and perpetuators is used to provide mapping (e.g., driver maps and perpetuator maps) of the AF substrate. Mapping techniques also include utilizing the various parameters of the acquired IC ECG signals and detected local activation times to provide mapping (e.g., activation/wave maps, CV maps, fractionation maps, voltage maps and block maps) which potentially represents the spatio-temporal manifestation of the AF process. The mapping of the spatio-temporal manifestation of the AF process can be used in addition to, or alternative to, the mapping of the AF substrate to identify potential ablation ROIs. The mapping techniques are used to potentially reduce AF map analysis training time, increase success rates resulting from ablation and facilitate efficient interpretation of AF maps. For simplification purposes, embodiments described herein refer to systems and methods used for the treatment of AF. It is noted however, embodiments may be used for the treatment of any type of cardiac arrhythmia including different types of abnormal or irregular heart rhythms.

FIG. **1** is a block diagram illustrating an exemplary classification of AF used with embodiments disclosed herein. The exemplary classification in FIG. **1** distinguishes between critical and non-critical AF as well as between drivers and perpetuators of AF and their relative spatio-temporal patterns.

For example, as shown in FIG. **1**, an irregular heart rhythm characterized as AF **102** is classified as critical **104** or non-critical **106**. Examples of non-critical AF **106** include paroxysmal (i.e., intermittent) irregular heart rhythm episodes in which the heartbeat often normalizes as quickly as within a few seconds or after a few hours, and persistent irregular heart rhythm episodes in which a normal heart may be restored by rhythm medical therapy or a procedure (e.g., cardioversion). Examples of critical AF **104** include long-standing persistent irregular heart rhythm episodes that continue for longer periods of time (e.g., more than a year) in which the heart is in a constant state of AF and the condition is considered permanent.

Critical AF can be classified according to characteristics (e.g., areas of activation) that can be derived from IC ECG signals. Areas of activation may be identified as potential contributing factors to AF. As shown in FIG. **1**, critical AF is classified according to different areas of activation, including a potential driver of AF (hereinafter "driver") or potential source of AF (hereinafter "source") **108** and a potential perpetuator **110** of AF (hereinafter "perpetuator"). A driver

108 is an area of activation (e.g., in the atria) where electrical pulses originate to stimulate the heart to contract and which can potentially contribute to AF, for example, by producing fibrillatory conduction to other areas of the atria. A perpetuator 110 is an area of sustained activation (e.g., electrophysiological process/substrate) which can also potentially contribute to AF.

Drivers 108 and perpetuators 110 may be represented (e.g., mapped) according to their spatio-temporal manifestation. As shown in FIG. 1, drivers 108 and perpetuators 110 are classified by exemplary spatio-temporal manifestation types, including focal sources (foci) 112 and localized rotational activation (LRA) sources or rotational activation patterns (RAPs) sources 114. A focal source is a type of driver originating at a small area of the atria which spreads centrifugally from a single point. A RAP 114 source is an irregular region of the heart where the electrical pulses rotate at least 360 degrees about a center area.

FIG. 1 also shows different types of perpetuators 110, including one type which exhibits organized conduction delay 116 and another which exhibits disorganized conduction delay 118. Another type of perpetuator 110 shown in FIG. 1 includes atrial flutter (AFL) 120 characterized by organized conduction delay 116 as well as localized irregular activation (LIA) 122, linear gaps 124 and pivots 126 (i.e., electrical pulses that rotate less than 360 degrees about a center area) characterized by disorganized conduction delay 118. Also, the RAP source 114 is shown as both a driver 108 and a perpetuator 110. Drivers 108 and perpetuators 110 are, for example, separately mapped to facilitate identification of driver types and/or perpetuator types and provide efficient and accurate determination of potential ablation ROIs.

Mapping and identification of drivers 108 and perpetuators 110 can also be based on one or more additional factors which may potentially contribute to AF or parameters which may potentially characterize the AF substrate (i.e., the AF process itself) and/or the manifestation of the AF process. For example, AF parameters or AF factors used to identify potential focal sources 108 include omnidirectional activation spread of activation from a point, earliness (e.g., focal source which starts after an excitable gap), triggers such as fast firing (e.g., short cycle-length and high dominant frequency) foci and breakthroughs (e.g., pulmonary veins (PV), free wall and transmural, endocardial and epicardial) and micro re-entry circuit which manifests as focal source and short-radius re-entry circuits which can manifest as a driver 108 depending on the specific anisotropic structure of the central obstacle.

AF parameters or AF factors used to map and identify RAP sources 114 include, for example, repetitive cycles, rotors which can manifest as a driver source 108, structural or functional anisotropy (e.g., localized or distributed), and short-radius re-entry circuits which can manifest as either a driver 108 or a perpetuator 110, depending on specific anisotropic structure of the central obstacle.

AF parameters or AF factors used to map and identify perpetuators 110 include, for example, extension (increased) path length, anatomical (pathological) block lines, fibrosis, stable functional block lines (e.g., areas of prolonged refractoriness), criticality (e.g., shortest path around block line>path length) and fibrillatory conduction factors (e.g., dissociated waves, re-entry circuit factors).

FIG. 2 is a block diagram illustrating an exemplary system 200 used to determine AF ROIs for ablation for use with embodiments disclosed herein. As shown in FIG. 2, the system 200 includes a catheter 202, a processing device 204 and a display device 206. Catheter 202 includes an array of catheter sensors (e.g., electrodes) each configured to detect electrical activity (electrical signals) of an area of the heart over time. When an IC ECG is performed, each electrode detects the electrical activity of an area of the heart in contact with the electrode. The system 200 also includes extra-cardiac sensors 210 (e.g., electrodes on the skin of a patient) configured to detect electrical activity of the heart via detection of electrical changes on the skin due to the electro-physiologic pattern of the heart.

The detected IC ECG signals and the detected extra-cardiac signals are processed (e.g., recorded over time, filtered, fractionated, mapped, combined, interpolated, etc.) by processing device 204 and displayed on display device 206.

Embodiments may include any number of sensors 210 used to detect ECG signals, including sensors used to detect IC ECG signals and extra-cardiac ECG signals. For simplification purposes, systems and methods described herein refer to the detection and use of IC ECG signals. It is noted, however, that embodiments may utilize IC ECG signals or extra-cardiac ECG signals or a combination of both IC ECG signals and extra-cardiac ECG signals.

Processing device 204 may include one or more processors each configured to process the ECG signals. Each processor of processing device 204 may be configured to record ECG signals over time, filter ECG signals, fractionate ECG signals into signal components (e.g., slopes, waves, complexes), map ECG signals, combine ECG signal information, map and interpolate mapping information, etc.

Display device 206 may include one or more displays each configured to display ECG signals, ECG signal information, maps of the AF process and maps representing a spatio-temporal manifestation of the AF process.

The catheter sensors 208 and the extra cardiac sensors 210 may be in wired or wireless communication with processing device 204. Display device 206 may also be in wired or wireless communication with processing device 204.

FIGS. 3A and 3B are portions of a flow diagram illustrating an exemplary method 300 of determining a potential ablation ROI. The method 300 employs a mapping taxonomy which includes, from its core moving outward, an IC ECG layer, a pre-processing layer, a LAT detection layer, a map segmentation layer, a map interpolation layer and a map interpretation layer.

FIG. 3A illustrates a portion of exemplary method 300. As shown in block 302 of FIG. 3A, the method 300 includes, as part of the IC ECG layer, acquiring an IC ECG signal which represents electrical activity of an area of the heart. The IC ECG signal acquired at block 302 is, for example, acquired from one of a number of electrodes in contact with different areas of the heart. After acquisition of the IC ECG (302), the method 300 includes, as part of the pre-processing layer, pre-processing of the acquired ECG signal, as shown in block 302 of FIG. 3A, The pre-processing may include execution of one or more algorithms, such as for example, cancellation of ventricular far field signals, baseline correction, and noise reduction. Ventricular far field detection may include, for example, a spatial averaging method (SAM), a temporal averaging method (TAM), a system identification method (SIM) and principal component analysis (PCA).

For each IC ECG signal acquired at block 302, one or more LATs of the corresponding pre-processed IC ECG signal is (are) detected at block 304. The LAT quality (shown as LATQ in FIG. 3A) of each signal is determined at block 306 as part of an exemplary LAT detection layer. The AF complexity (shown as CPLX in FIG. 3A) of the signal is determined at block 308.

As shown at decision point **310**, the method **300** includes determining whether to reposition the catheter based on the LAT quality of the signal and the AF complexity. A typical characteristic of high quality IC ECGs is little base line wander (e.g., low baseline vs. IC ECG RMS amplitude, limited ventricular far-field potentials vs. IC ECG RMS amplitude). IC ECG signals characteristics include discernable atrial complexes (e.g., confined (~50 ms) complexes separated by isoelectric segments repeating slopes, 50-200 ms interval; about 150 ms median) during AF. High quality complexes characteristic typically have considerable amplitudes and steep downward slopes (vs. upward slopes) within complexes. Characteristics of the IC ECG signals may be combined into a single measurable characteristic or parameter (e.g., having a measurable value of 0%-100%) to define LAT quality. The LAT quality may be compared to the AF complexity to determine whether to reposition the catheter.

In some embodiments, quality is defined by an ability to map AF for a level of AF complexity. Determining whether to reposition the catheter may include generating a map and determining whether the generated map can be used (e.g., is adequate) to map AF based on whether a level of coverage of a mapping electrode meets (e.g., matches) a level of AF complexity. The ability to map AF for a level of AF complexity may include meeting a map threshold level (e.g., adequate level, trustworthy level). A single parameter (i.e., mapping coverage) is used to define a level of coverage of the mapping electrode. Examples of characteristics that are combined to define the mapping coverage include: (1) contact of the mapping electrode (e.g., contact with active tissue (wall) related to covered area and LAT accuracy); (2) resolution of the electrodes (e.g., distances and electrode sensitivity radii between electrodes, including mean, minimum and maximum and distances); and (3) quality of the IC ECG and associated annotations provided by a detection algorithm.

AF complexity may include complexity of activation during AF creating wave dissociation (block lines), fusion and wave curvature. Accordingly, a map may be determined as a map which can be used (e.g., trustworthy or adequate) to map AF when, given a certain level of AF complexity (e.g., measured along y-axis), the mapping coverage (including signal and annotation quality measured along x-axis) is sufficient to map the AF complexity. If not, the trustworthiness of the map may become compromised or inadequate.

Signals may then be analyzed using the trustworthy or adequate maps to determine whether the catheter should be repositioned. If it is determined at decision point **310** to reposition the catheter, the catheter (e.g., catheter **202**) is repositioned at block **312** and a new IC ECG signal is acquired at block **302**. If it is determined at decision point **310** that the catheter should be repositioned, the method **300** continues to "point A" **313** (shown in FIG. **3**A and FIG. **3**B).

FIG. **3**A illustrates the acquiring of a single IC ECG signal for simplification purposes. In practice, however, multiple signals are acquired for each of the plurality of electrodes contacting the heart. Each IC ECG signal acquired at block **202** and the one or more LATs detected for each signal at block **204** are received at "point A" **313**.

FIG. **3**B illustrates exemplary methods which may be used to determine potential ablation ROIs. As shown FIG. **3**B, each acquired IC ECG signal and the one or more detected LATs for each signal are used to generate maps of the AF process that includes the electro-physical conditions of the AF substrate (indicated as the AF Substrate **314** in FIG. **3**B) and maps representing a spatio-temporal manifestation of the AF process (indicated as the AF Process **316** in FIG. **3**B) as part of an exemplary map segmentation layer.

For example, with regard to the AF Substrate **314** shown in FIG. **3**B, the one or more detected LATs are used to independently determine one or more factors or parameters which may contribute to AF. The left side of FIG. **3**B illustrates methods which characterize the AF substrate by collecting information over a predefined window of time while assessing a mean interval (e.g., cycle) based on a difference of subsequent LATs **318**, first activated (earliness) **324**, and morphological aspects of the IC ECG including RS-ratio **320** and fractionation **322** (e.g., fractionated electrograms). For example, the detected LATs are used to independently determine cycle information (e.g., cycle lengths) at block **318** and earliness information (e.g., earliest activation times, early drivers which start after an excitable gap) at block **324**. Each IC ECG signal is also used to independently determine R-S complex information **320** (e.g., ratio of R wave to S wave amplitude) and fractionation information **322** (e.g., slope information, information indicating an incidence of source behavior presented as the earliest activation from one of a plurality of electrodes, such as showing a percentage that the associated electrode was activated earlier than neighbouring electrodes) of the IC ECG signals and CV Block information **326** (e.g., information indicating slowed or blocked conduction (i.e., progression) of electrical impulses through the heart, such as the conduction time (CT) for the electrical pulse to travel a distance in the heart, the path length (i.e., the distance) and the CV of the electrical pulse).

As shown, a driver map **328** is generated from the cycle information **318**, the earliness information **324** and the R-S complex information **320**. A perpetuator map **330** is generated from the CV block information **326** and the fractionation information **322**. As shown, the information used to generate the driver map **328** and the information used to generate the perpetuator map **330** are combined (e.g., a single map, overlaid maps or adjacent maps in one display area) to generate a combined driver/perpetuator map **334**. The combined driver/perpetuator map **334** may then be used (e.g., interpolated as part of an exemplary map interpolation layer) to determine one or more ablation ROIs **350**.

With regard to the AF Process **316** shown in FIG. **3**B, the one or more detected LATs are used to independently generate activation/wave maps **336**, CV maps **338** (e.g., maps generated from the CT, the path length and/or the CV of the electrical pulse) and block maps **344** (e.g., maps generated from information indicating a block in the conduction of the signal).

Activation/wave maps **336** may, for example, include a map representing an incidence of source behavior presenting the earliest activation of one of a plurality of electrodes restricted by the same wave, such as indicating a percentage of activation waves detected by a corresponding electrode activated earlier than neighboring electrodes though restricted by neighbors activated by the same wave. Activation/wave maps **336** may, for example, also include a map representing the incidence of electrode positions associated with a fibrillation wave start.

Each IC ECG signal is used to independently generate voltage maps **342** and fraction maps **340**. The information used to generate maps **336**-**344** is combined to provide combined maps or video **346**. In some embodiments, the information used to generate the activation/wave maps **336** and voltage maps **342** is combined to generate a combined activation/wave/voltage map or video and the information used to generate the CV maps **338**, the block maps **344** and

the fraction maps **340** are combined to generate a combined CV/block/fraction map or video. The combined maps/video **346** are analyzed (e.g., interpreted by medical personnel as part of an exemplary map interpretation layer) at block **348** to determine ROIs to be ablated at block **350**. The combined maps/video **346** represent a spatio-temporal manifestation of the AF process which can be easily visualized and interpreted, facilitating an efficient and accurate process for determination of ROIs for ablation. Determined ROIs may be represented (e.g., displayed), for example, by color, by 3-D contour on a 4-D map, by icons (e.g., dynamically changing icons), etc.

In some embodiments, both the combined driver/perpetuator map **334** and the combined maps/video **346** are used to determine ROIs for ablation **350**. For example, the combined driver/perpetuator map **334** can be used to determine ROIs for ablation **350** without using (e.g., viewing, analyzing) the combined maps/video **346**.

In some embodiments, the quality map **332** is also used in combination with the combined driver/perpetuator map **334** and/or the combined maps/video **346** to determine ROIs for ablation **350**. The quality map **332** is used to determine the trustworthiness of the generated maps (e.g., driver map **328**, perpetuator map **330** and driver/perpetuator map **334**) related to AF substrate **314** and the generated maps (e.g., activation/wave maps **336**, CV maps **338**, fraction maps **340**, voltage maps **342** and block maps **344**) related to the AF process **316** parameters. If the quality of the quality map is low, the generated maps are less trusted and appointing an ablation ROI **350** must be regarded with an increase level of care (e.g., by a physician) compared to when the quality map indicates high quality signals (IC ECGs) as the basis for the generated maps.

In some embodiments, determining ROIs for ablation **350** includes appointing or selecting one or more ablation sites for use in determining one or more ROIs for ablation. For example, ablation sites may be appointed or selected from driver evidence and perpetuator evidence (e.g., determined from the driver map **328**, the perpetuator map **330** or the combined driver/perpetuator map **324**) and ablation ROIs **350** may be determined based on the appointed sites.

The maps and mapping techniques disclosed herein potentially: (i) reduce AF map analysis training time; (ii) reduce time to determine ROIs for ablation; (iii) facilitate efficient interpretation of AF maps; and (iv) increase ablation success rates for ablation aimed at isolation and extinguishing of drivers, path lengthening, slowing of re-entry circuits, fibrillatory conduction and fractionated potentials.

An inventive technique presented herein incorporates fractionation to efficiently determine accurate ROI to be targeted for ablation.

FIG. **4** shows a high level block schematic of the process of generating ablation ROIs (shown in FIG. **3**B) based on driver maps **328** (cycle, early, RS) and perpetuator maps **330** (block and fractionation). From these driver and perpetuator maps **328**, **330**, driver and perpetuator related parameters **401**, **402** are derived. Driver related parameters **401** include cycle length **403** (short cycle, fast repetition), earliness **404** (early activation driving the AF process), and RS ratio **405** (S-wave dominance). Perpetuator related parameters **402** include block **406** (block lines) and fractionated potentials **407** indicating non-uniform conduction. Both driver and perpetuator related parameters **401**, **402** are further processed and combined into driver evidence **408** (De) and perpetuator evidence **409** (Pe). Finally, driver and perpetuator evidence **408**, **409** are used (as two categories in Coumel's triangle of arrhythmogenicity) to derive potential ROIs for ablation **350**, either acting as driver or perpetuator process, or both.

FIG. **5** shows an example of a driver/perpetuator map **334** and temporal activation/fractionation maps (**52**, **53**). The upper right panel in FIG. **5** is a driver/perpetuator map **334** where dots **510** represent example areas with increased driver evidence (De **408**, as defined in FIG. **4**) exceeding a predefined threshold, and dots **520** represent example areas of increased perpetuator evidence (Pe>T), (Pe **409**, as defined in FIG. **4**).

FIG. **6** provides an overview of the inventive technique as a flow diagram illustrating AF mapping to appoint ROIs for ablation using fractionation analysis. As shown in FIG. **6**, in step S**61**, template matching is performed on an IC ECG, using templates from a template library **701** comprising synthetic singles and short doubles which are matched with an acquired IC ECG signal **302**. The creation of the template library **601** will be described in greater detail below with reference FIGS. **7-10**.

In step S**62**, windows of fractionation are found using the template matched LATs from step S**61**. This is discussed in detail below, see FIGS. **11** and **12**. Note that non-fractionation windows are not analyzed and are considered for contact **332** or quality analysis.

In step S**63**, fractionation is analyzed and fractionated IC ECG is produced using windows of fractionation, and also using non-fractionation windows as contact. One embodiment of this analysis will be described in greater detail hereinafter with reference to FIG. **13**.

Detection of fractionation is based on a filtering step, detecting and removing non-fractionated IC ECG potentials, including single, short double and long double potentials. FIGS. **7-11** illustrate AF mapping to appoint ablation ROIs showing detection of fractionated IC ECG.

FIG. **7** shows the distribution and exemplars **701** of various types of electrograms acquired from one of a number of electrodes in contact with different areas of the heart (see FIG. **3**A, block **302**). These may include single potentials **702**, short double potentials **703**, long double potentials **704** and fractionated electrograms **705**. All of the exemplars **701** are used as a basis for the creation of a template library **601** of synthetic single and short double potentials **801**, **802**.

In FIG. **8**, synthetic single potentials **801** are defined by six characteristic points **81** (e.g., the filled circles shown in the lower left side of FIG. **8**) connected by piecewise cubic spline interpolation **82** and bandwidth reduction (<250 Hz). In one embodiment, nine ratios between R- and S-wave amplitudes (from R to RS to S wave) are created as the synthetic single potentials **83**. In one embodiment, the different synthetic single potentials **83** are created by varying amplitude (A), duration (milliseconds) and further performing bandwidth reduction, such as a low pass filter (LPF) cut off of 250 Hz. This is described in more detail below. As shown in the circle **85** on the right of FIG. **8**, the synthetic potentials **83** can be overlaid on matching acquired single potentials **702**. As is shown, there is not necessarily a match for each synthetic potential.

FIG. **9** provides additional detail regarding template matching with respect to creating synthetic double potentials, such that selections of two synthetic potentials (primary potential **83** and secondary potential **84**) are used to create synthetic short double potentials. While the primary potential **83** is kept unchanged, the secondary potential **84** can be both scaled in amplitude (A) and time shifted (t) before addition with the primary potential **83** to create the short double potential. As shown in FIG. **9**, initially, to create

a synthetic set of short double potential templates, all combinations of two single potentials are selected (S91). The primary potential **83** components may be used without further manipulation. For the secondary potential **84** components, the following actions may be performed. Amplitude scaling of the secondary component (S92) is first performed. Next, a time shift (S93) is made with respect to relative time delay of the secondary component passing the recording electrode. Finally, the weighted and delayed singles, primary and secondary components, are summed (S94) to generate an entry in the set of 8,748 templates. In one embodiment, the template library specifications may include permutations of two templates from the set of single potentials, such that nine ratios are created, e.g., R, Rs, RS, fS, S, etc. In one embodiment, amplitude scaling, (e.g, zero (0) or fifty (50) percent amplitude reduction), may be used. In one embodiment, the secondary component time shift may be any of 4, 8, 12 16 ms as an example.

FIG. **10** shows a library of synthetic single potentials **83** and short double potentials **101** created using the amplitude (A_R, A_S) 0, 25, 50, 75 and 100%, durations (R_{Dur}, S_{Dur}) 4, 9, 15 ms and RS_{Dur} 2 ms parameters. As shown, twenty-seven single potentials **83** are created by varying the amplitude and then varying the duration; for example one single potential has A_R=0, A_S=0, R_{Dur}=4 ms, a second single potential has A_R=25%, A_S=0, R_{Dur}=9 ms, another single potential has A_R=50%, A_S=0, R_{Dur}=14 ms, yet another single potential has A_R=75%, A_R=0, R_{Dur}=4 ms, etc. These synthetic single and double potentials **83**, **101** are saved in the template library and used for the template matching portion of fractionation analysis.

FIG. **11** shows a method of template matching including a template library specification for a library of synthetic single potential **83** and short double potentials **84**. Initially, a fibrillation electrogram (IC ECG) is acquired (S**1101**). Next, a baseline correction is performed (S**1102**) in which the ventricular far field artifact **1111** is acquired. Next, QRS subtraction is performed (S**1103**), removing the ventricular far field artifact, and creating a simplified ECG. Next, template matching is performed on the simplified ECG as follows. A window of analysis is created and moved over the simplified ECG. FIG. **11** shows the window **1112** in the center of the simplified ECG, and also shows six "template-matching" templates, illustrating the templates from the template library being applied. As shown, the first template **1112***a* has a level of resemblance of 0.54 (approximately 54%). The second template **112***b* has a level of resemblance of 0.65 (approximately 65%). The third template **1112***c* has a level of resemblance of 0.63 (approximately 63%). The fourth template **1112***d* has 0.48 (approximately 48%), the fifth template **1112***e* has 0.91 (approximately 91%) and the sixth template **1112***f* has 0.78 (approximately 78%). Accordingly the window **1112** shows the "best match" of a level of resemblance of 0.91.

After the template matching has been performed, a fibrillation correlogram **1113** can be produced (S**1105**) using the "best match" template, e.g., 0.91 level of resemblance. This fibrillation correlogram **1113** can be created by calculating the correlation of the best fitting template (e.g., maximum correlation). Finally, the fibrillation correlogram **1113** is blanked for correlations less than a predefined maximum threshold (S**1106**), e.g., a threshold less than 0.4 or 0.5. Further, the blanked fibrillation correlogram **1113** shown in FIG. **11** includes a template number and detection point for each peak **1114**.

FIG. **12** shows a graph illustrating detection of a fractionated IC ECG. Fractionation episode detection can be performed using template matching to exclude single and short double potentials. For example, the detection process finds areas such as **1201** (row 2, indicated in the elliptical) where no match is detected. These non-matching areas **1201** are special and of interest when determining ablation ROIs **350**. Fractionation analysis may be aimed at identification of perpetuating areas during AF. Accordingly, combining fractionation and block can determine a perpetuator, shown as short lines **1202** (top row) in FIG. **12**.

FIG. **13** shows a graph illustrating different examples of AF mapping to appoint ROIs for ablation. The fibrillation maps (top row), fibrillation potentials (center row) and a scalogram (bottom row) resulting from wavelet decomposition of fibrillation potentials are shown in FIG. **13**. Example D displays multiple dissociated waves, epi-endo dissociation, and slow and/or staggered conduction which are used as tools or evidence to locate areas of fractionation.

FIG. **14** shows AF mapping to detect fractionated episodes in an IC ECG. As shown in FIG. **14**, multiple windows **1112** (−200 ms←+TM detection→+10 ms) are created around each detection point **1414** that result from template matching (i.e. TM detection). As long as subsequent windows overlap, no fractionation is detected. When a non-overlapping window has been detected, the fractionation signal is set to zero.

FIGS. **15** and **16** show examples of AF mapping to detect fractionated episodes in an IC ECG. The top graph (IC ECG) **151** shows an acquired ECG. The next graph **152** shows a correlogram **1113** derived in accordance with the procedure described above with respect to FIG. **11**. The next graph **153** shows root mean square (RMS) amplitude processing. The bottom graph **154** illustrates alternating episodes of non-fractionated and fractionated episodes; (i.e. fractionation windows **1112**). In other words, the bottom graph **154** indicates fractionated elements of the ECG signal

Referring to FIG. **16**, this shows a non-fractionated IC ECG followed by a fractionated IC ECG. The vertical dotted line shows the transition from a non-fractionated to fractionated IC ECG. In this manner, this change can be clearly observed in the IC ECG.

FIG. **17** is a more detailed flow diagram of a method for AF mapping to detect fractionated episodes in one embodiment using slope analysis. IC ECG fractionation windows are input and peak valley detection is performed (S**171**). Peak valleys are output and then positive/negative slope duration and amplitude are calculated (S**172**). Fractionation slopes are output from step S**172** and slope interval, duration and amplitude are used to calculate duration, amplitude and incidence (S**173**).

Duration, amplitude and incidence are then used to calculate the number of fractionation (NFRAC), far field (NFFLD) and single potential slopes (NSINGLE) (S**174**). NFRAC, NFFLD and NSINGLE are output from step S**174** into step S**175**. In step S**175**, evidence count of fractionation (EFRAC), far field (EFFLD), and single potentials (ESINGLE) are calculated. EFRAC, EFFLD and ESINGLE are output from step S**175** and input into step S**176**. In step S**176**, a decision rule is implemented and the fractionated IC ECGs are output. In one embodiment, a fractionated IC ECG may be identified if EFRAC is greater than a high predetermined threshold such as 90%. In another embodiment, a fractionated IC ECG may be identified if EFRAC is greater than another, lower predetermined threshold, such as 70%, and both EFFLD and ESINGLE are less than a third, low predetermined threshold.

In yet another embodiment, data such as a predetermined threshold (QUALITYTHRESHOLD), a low slope ampli-

tude with parameters, e.g., SLOPEAMPLOW {frac,ffld, single}, a high slop amplitude with paramenters (SLOPEAMPHIGH {frac}), and/or a duration of slope with paramenters (SLOPEDUR {frac,ffld,single}) can be input to step **S174**. In this embodiment, this data can be used to calculate the number or incidence of NFRAC, NFFLD, NSINGLE.

Fractionation maps can include two categories—amplitude and interval. A fractionation amplitude map illustrates incidence of electrode positions associated with a fractionated potentials. A fractionation interval map illustrates incidence of electrode positions associated with fractionated potentials.

FIG. **18** illustrates an embodiment of S**171** of FIG. **17**, that is, peak valley detection. As shown in FIG. **18**, slope analysis can include displaying peaks **181** and valleys **182** of an acquired ECG **302**. Each dotted-line rectangular box **183** comprises a "triplet" of slope values of valley **182**, peak **181**, and valley **182**. Further, each rectangular box **183** has as its height **262** the amplitude of the slope, and as its width **263** the duration of the slope. This is further described with respect to FIG. **26**.

FIG. **19** shows an embodiment of S**172** and S**173** regarding calculation of the positive/negative slope amplitude duration and amplitude. FIG. **26** shows the dotted-line rectangular boxes **183** of FIG. **18** as solid boxes **191**. As in FIG. **18**, the rectangular boxes of FIG. **19** indicate slope such that the height **262** of each box is the slope amplitude and the width **263** of each box is the slope duration. Note that for fractionation analysis, as discussed herein, downward slopes are of interest and upward slopes are generally ignored.

FIG. **20** is a diagram of an embodiment of S**174** regarding classification of the slope characteristics wherein two decision rectangles are presented. These are decision rectangles indicating slope information. As shown, each of the two rectangles **2001**, **2002**, comprise smaller rectangles illustrating slope classes such as far field (FFLD), noise, primary (PRIM) and secondary (SECU) components. Slope parameter(s) thresholds are defined to position the rectangles, relating negative slope duration vs. amplitude **2001** and relating negative slope to negative slope amplitude **2002** to obtain a non-ambiguous selection of one of the slope classes. For example, the slope duration can range from 0 ms to 100 ms, as shown in rectangle **2001**, while the slope can range from 0 to 1 mV/ms as shown in rectangle **2002**. Slope characteristics are discussed in more detail below.

FIG. **21** shows four graphs. From top to bottom they are Electrograms **2101**, Amplitudes **2102**, Duration **2103** and Slope **2104**. The upper graph **2101** shows the IC ECG and timing of slopes detected with their classification (PRIM, SECI or FFLD) based on the slope characteristics (slope amplitude, duration and slope) which are separately shown in the bottom three graphs **2102**, **2103**, **2104** along with their thresholds. The bottom graph **2104** illustrates the time stamp of the slope, (e.g. slope incidence). Each graph includes primary 1, secondary 2 and far field 3 slopes. This data is used to make decisions regarding the ECG and whether or not it includes fractionation, as discussed in more detail below.

FIG. **22** shows a progression from slope types to potential types. In one embodiment, primary slope **2201**, secondary slope **2202** and far field slope **2203** can progress to potential types of single potential **2220**, short double potential **2221**, long double potential **2222**, fractionated complex **2223**, far field **2224** and close far field **2225**. The progression from primary slope **2201** and secondary slope **2202** is initially performed using a time gate **2204**. The time gate **2204** processes slopes within time limits, which can be, for example, 15 ms and 50 ms as shown in FIG. **22**. However, these durations are merely an example and other timings may be used. Both primary slopes **2201** and secondary slopes **2202** are input into the time gate **2204** and an initial determination is made for converting the slopes into potentials based on these time limits. Primary and secondary slopes having a time limit of 50 ms, for example, can become one of two slope groups: single slope **2205** or >two slope group **2208** based on whether the slopes are singular or grouped. Also, primary and secondary slopes **2201**, **2202** having a time interval of 15 ms can be grouped into a long (>15 ms interval) group **2207** or a short group **2206** (<=15 ms interval), (e.g., two slope group S (short) **2206**, or two slope group L (long) **2207**. Groups with more than 2 slopes, and less than 50 ms intervals are grouped into the >Two slope group **2208**. After processing in the time gate **2204**, the slopes progress into potentials. As shown, single slopes are considered to have a special relation; they progress into single potentials **2220**. Two slope group S **2206** are typically a 3×3 multiple, and progress into short double potentials **2221**. Two slope group L **2227** progress into long double potentials **2222**, and >Two slope group **2208** progress into fractionated complex potentials **2223** which, as discussed herein, are special and receive special review. The potentials are grouped into consecutive slopes with an interval less than 50 ms, and are analyzed as slope types per group of slopes. Those potentials not within the group are output as non-contact **2209** and receive no additional analysis. Typically the group size is (2, >2).

FIG. **23** further illustrates time gate and temporal grouping of primary and secondary slopes. As shown in FIG. **23**, non-contact potentials produced by the time gate **2209** can be analyzed as follows. For the non-contact potentials, a 3×3 spatio-temporal time window is analyzed, and the FFLD slope annotation is performed. Evidence for non-contact is collected by searching the 3×3 neighborhood for far-field and additional non-contact potentials. Moreover, slope annotations within window (t+/−W) are analyzed for primary slopes. This analysis can reveal that either no primary slopes are found in center electrode IC ECG or that primary slopes are found in center electrode IC ECG. The finding of no primary slopes is based on the non-contact evidence and that only far field slopes are found in neighboring electrodes of the non-contact evidence, and further that primary slopes are found in neighboring electrodes of the non-contact evidence. The finding of primary slopes in center electrode IC ECG is based on far field potential evidence and synchronous primary slopes found in neighboring electrodes of the non-contact evidence.

FIGS. **24** and **25** provide two examples of groupings, further illustrating single slope **2205**, two slope group **2206**, long double slope group **2207** and >two slopes **2208** (as defined above). These figures show graphs of electrograms **2401**, **2501**, amplitude **2402**, **2502**, duration **2403**, **2503** and slope **2404**, **2504**, from top to bottom respectively. Each includes primary 1, secondary 2 and far field 3 slopes. FIGS. **24** and **25** further illustrate neighborhood groups which are discussed further below.

FIG. **26** illustrates the spatio-temporal analysis of identified slopes represented as rectangles. The matrix or set of circles on the left indicate the topological positions of eight (8) neighboring electrodes labeled **1-8** and C, i.e., center electrode. On the right of FIG. **26**, a series of slope traces is shown. The top trace **261** shows the slopes of the center electrode C as rectangles represent the amplitude and duration of the slopes. As aforementioned, the amplitude **262** of

the slope (A) is represented as height, and the duration **263** of the slope (D) is represented as width. The lower traces **1-8** show the same information for other eight (8) neighboring electrodes **1-8** that surround the center electrode C. For example, the output of electrodes **1** and **8** are shown in FIG. **26**.

FIGS. **27-29** show AF mapping spatio-temporal slope analysis which can be used to provide additional evidence regarding an acquired ECG **302** and whether or not portions of it are fractionated. Spatio-temporal relations are assessed between the slopes of center electrodes C and the slopes of neighboring electrodes **1-8**. Spatio-temporal relations are identified between the center electrode slope **261** and the slopes in each of the neighboring electrode IC ECGs **264**.

FIG. **27** shows the center electrode slopes **261** as graphs of conducted and electrotonic acquired ECG signals **302**. The dashed boxes represent the search windows for either conducted **271** (wide window) or electrotonic **272** (narrow window) relationships. Conducted relationships **271** comprise elements within interval limits, within conduction range and comparable slope profile. Electrotonic relationships **272** comprise far field slope profile and are instantaneous. Conducted window width **263** typically depends on conduction velocity and center-to-neighboring electrode distance. The more relations that can be made between the center electrode C and the eight neighboring electrodes **1-8**, the higher the evidence of correct annotation of the slope of the center electrode C will be.

FIGS. **28** and **29** show specific examples of conducted, electrotonic and combined electrotonic and conducted relationships between the center electrode slope profile **261** and one of the neighbors.

FIG. **28** shows graphs for determining the slope relationships of center electrode C versus neighbor electrodes **1-8**. Both conducted or electrotonic relationships found increased evidence that the primary slope being tested is related to a single potential. As shown in the graphs, single potential evidence increases in the case of: 1) conducted slope relationships with neighboring electrodes (top two graphs); 2) electronic slope relationships with neighboring electrodes (middle two graphs); and 3) the combination of conducted and electronic propensity for block (bottom two graphs). The line **281** indicates a time shift of the center neighboring slope within the window, indicating their conducted relationship.

FIG. **29**, shows a far field slope related to an electrotonic (top) or primary slope (bottom). Far field potential evidence can increase in the case of three factors as shown. A first factor can be electrotonic slope relationships with neighboring electrodes and maximum one single potential indicated slope. Note that this factor can either be based on slope initial characteristic (T*, E*) or as a result from slope type earlier assignment (T,E). A second factor can be either FF indicated, as shown in the top two graphs **2901**, **2902**, or only single potentials, as shown in the bottom two graphs **2903**, **2904**. Finally, if only electronic slope relationships are found, the propensity is for (temporary) non-contact electrode or far field (e.g. ventricular). The right side of FIG. **29** graphically illustrates a spatial difference between the measurements of 2 different electrode groups **2905**.

It should be understood that many variations are possible based on the disclosure herein. Although features and elements are described above in particular combinations, each feature or element can be used alone without the other features and elements or in various combinations with or without other features and elements.

The methods provided include implementation in a general purpose computer, a processor, or a processor core. Suitable processors include, by way of example, a general purpose processor, a special purpose processor, a conventional processor, a digital signal processor (DSP), a plurality of microprocessors, one or more microprocessors in association with a DSP core, a controller, a microcontroller, Application Specific Integrated Circuits (ASICs), Field Programmable Gate Arrays (FPGAs) circuits, any other type of integrated circuit (IC), and/or a state machine. Such processors can be manufactured by configuring a manufacturing process using the results of processed hardware description language (HDL) instructions and other intermediary data including netlists (such instructions capable of being stored on a computer readable media). The results of such processing can be maskworks that are then used in a semiconductor manufacturing process to manufacture a processor which implements methods described herein.

The methods or flow charts provided herein can be implemented in a computer program, software, or firmware incorporated in a non-transitory computer-readable storage medium for execution by a general purpose computer or a processor. Examples of non-transitory computer-readable storage mediums include a ROM, a random access memory (RAM), a register, cache memory, semiconductor memory devices, magnetic media such as internal hard disks and removable disks, magneto-optical media, and optical media such as CD-ROM disks, and digital versatile disks (DVDs).

What is claimed is:

1. A computer implemented method of determining regions of interest for cardiac ablation using fractionation which improves performance of a processing system, the method comprising:

detecting, via a plurality of sensors, electro-cardiogram (ECG) signals, each ECG signal detected via one of the plurality of sensors and indicating electrical activity of a heart;

determining, for each of the plurality of ECG signals, one or more local activation times (LATs) each indicating a time of activation of a corresponding ECG signal;

generating, based on the determined one or more LATs of each of the plurality of ECG signals, one or more driver maps and one or more perpetuator maps, each representing the electrical activity of the heart;

deriving parameters, comprising fractionated ECG signal potentials, from the perpetuator maps by:

comparing an ECG signal potential within a fractionation window to a plurality of stored signal potential templates;

selecting one of the stored signal potential templates according to a level of resemblance to the ECG signal within the fractionation window; and

displaying a mapping, using the derived parameters, which indicates driver evidence and perpetuator evidence of areas of fractionation,

wherein the regions of interest for cardiac ablation are determined in accordance with the areas of fractionation.

2. The method of claim **1**, further comprising:

deriving the parameters by:

filtering the LATs and removing non-fractionated LATs comprising non-fractionated single potentials, short double potentials and long double potentials.

3. The method of claim **1**, further comprising displaying, on a display device, the regions of interest.

4. A computer implemented method of determining regions of interest for cardiac ablation using fractionation which improves performance of a processing system, the method comprising:

detecting, via a plurality of sensors, electro-cardiogram (ECG) signals, each ECG signal detected via one of the plurality of sensors and indicating electrical activity of a heart;

determining, for each of the plurality of ECG signals, one or more local activation times (LATs) each indicating a time of activation of a corresponding ECG signal;

generating, based on the determined one or more LATs of each of the plurality of ECG signals, one or more driver maps and one or more perpetuator maps, each representing the electrical activity of the heart;

deriving parameters, comprising fractionated ECG signal potentials, from the perpetuator maps by:

determining peaks and valleys of an ECG signal within windows of fractionation;

calculating a number of fractionation slopes of the ECG signal between the peaks and valleys of the ECG ECG signal;

comparing the number of fractionation slopes to a predetermined threshold;

determining an ECG signal to be a fractionated signal if the number of fractionation slopes is greater than a predetermined threshold; and

displaying a fractionation map of the ECG signal,

wherein the regions of interest for cardiac ablation are determined from the fractionation map.

5. The method of claim 4, further comprising:

calculating incidence using the detected peak valleys;

calculating incidence fractionation far field for single potential slopes using the incidence.

6. The method of claim 4, further comprising:

converting slopes between the peaks and valleys into potentials using a time gate comprising temporal grouping of primary and secondary slopes;

grouping the potentials into groups of consecutive slopes within a predetermined interval; and

analyzing the potentials as slope types in accordance with the groupings.

7. The method of claim 6, wherein each group comprises one of a single slope group, a short double slope group, a long double slope group and a two slope group.

8. A system of determining regions of interest for cardiac ablation using fractionation which improves processing performance, the system comprising:

a plurality of sensors, each configured to detect one of a plurality of electro-cardiogram (ECG) signals over time, each ECG signal indicating electrical activity of a heart;

a processing device comprising one or more processor configured to:

determine, for each of the plurality of ECG signals, one or more local activation times (LATs) each indicating a time of activation of a corresponding ECG signal;

generate, based on the determined one or more LATs of each of the plurality of ECG signals, one or more driver maps and one or more perpetuator maps, each representing the electrical activity of the heart;

derive parameters, comprising fractionated ECG signal potentials, from the perpetuator maps by;

comparing an ECG signal potential within a fractionation window to a plurality of stored signal potential templates; and

selecting one of the stored signal potential templates according to a level of resemblance to the ECG signal within the fractionation window; and

a display device configured to display a mapping, using the derived parameters, which indicates driver evidence and perpetuator evidence of areas of fractionation,

wherein the regions of interest for cardiac ablation are determined in accordance with the areas of fractionation.

9. The system of claim 8, wherein the processing device is further configured to:

deriving the parameters by:

filtering the LATs and removing non-fractionated LATs comprising non-fractionated single potentials, short double potentials and long double potentials.

10. The system of claim 8, wherein the display device is configured to display the regions of interest.

11. A system of determining regions of interest for cardiac ablation using fractionation which improves processing performance, the system comprising:

a plurality of sensors, each configured to detect one of a plurality of electro-cardiogram (ECG) signals over time, each ECG signal indicating electrical activity of a heart;

a processing device configured to:

detect, via a plurality of sensors, electro-cardiogram (ECG) signals, each ECG signal detected via one of the plurality of sensors and indicating electrical activity of a heart;

determine, for each of the plurality of ECG signals, one or more local activation times (LATs) each indicating a time of activation of a corresponding ECG signal;

generate, based on the determined one or more LATs of each of the plurality of ECG signals, one or more driver maps and one or more perpetuator maps, each representing the electrical activity of the heart;

derive parameters, comprising fractionated ECG signal potentials, from the perpetuator maps by:

determining peaks and valleys of an ECG signal within windows of fractionation;

calculating a number of fractionation slopes of the ECG signal between the peaks and valleys of the ECG ECG signal;

comparing the number of fractionation slopes to a predetermined threshold;

determining an ECG signal to be a fractionated signal if the number of fractionation slopes is greater than a predetermined threshold; and

displaying a fractionation map of the ECG signal,

wherein the regions of interest for cardiac ablation are determined from the fractionation map.

12. The system of claim 11, wherein the processing device is further configured to:

calculate incidence using the detected peak valleys;

calculate incidence fractionation far field for single potential slopes using the incidence.

13. The system of claim 11, wherein the processing device is further configured to:

convert slopes between the peaks and valleys into potentials using a time gate comprising temporal grouping of primary and secondary slopes;

group the potentials into groups of consecutive slopes within a predetermined interval; and

analyze the potentials as slope types in accordance with the groupings.

14. The system of claim 13, wherein each group comprises one of a single slope group, a short double slope group, a long double slope group and a two slope group.

* * * * *

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外部链接	Espacenet		

摘要(译)

使用分馏确定用于心脏消融的感兴趣区域的系统和方法。该方法可以包括通过传感器检测心电图（ECG）信号，通过传感器之一检测到的每个ECG信号并指示心脏的电活动，为每个ECG信号确定每个指示的激活时间（LAT）。激活相应ECG信号的时间，基于所确定的每个ECG信号的LAT，生成一个或多个驾驶员地图和一个或多个永久性地图，每个地图代表心脏的电活动，从驾驶员获得参数和永久物图，至少使用分馏，处理并将衍生参数组合成驾驶员证据和永久证据，并根据用于推导驾驶员证据和永久证据的分馏来确定心脏消融的感兴趣区域。