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**Cao et al.**

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(54) **ATRIAL ARRHYTHMIA DETECTION DURING INTERMITTENT INSTANCES OF VENTRICULAR PACING IN A CARDIAC MEDICAL DEVICE**

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(51) **Int. Cl.**

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| ***A61B 5/0456*** | (2006.01) |
| ***A61B 5/00*** | (2006.01) |
| *A61N 1/39* | (2006.01) |

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(58) **Field of Classification Search**

None

See application file for complete search history.

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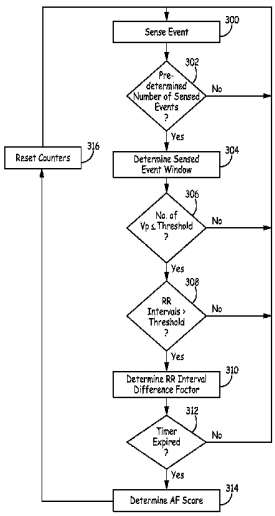
*Primary Examiner* — Erica Lee

(57) **ABSTRACT**

A method and medical device for determining a cardiac event that includes sensing a cardiac signal, determining a predetermined number of sensed cardiac events in response to the sensed cardiac signal, determining a plurality of sensed event windows in response to the predetermined number of the sensed cardiac events, determining, for each of the plurality of sensed event windows, whether a number of paced events is less than a paced event threshold, determining whether intervals within the sensed event windows having a number of paced events less than the paced event threshold are greater than an interval threshold, determining an interval difference factor for each of the plurality of windows having intervals less than the interval threshold, and determining the cardiac event in response to the interval difference factors determined for each of the plurality of windows.

**21 Claims, 6 Drawing Sheets**



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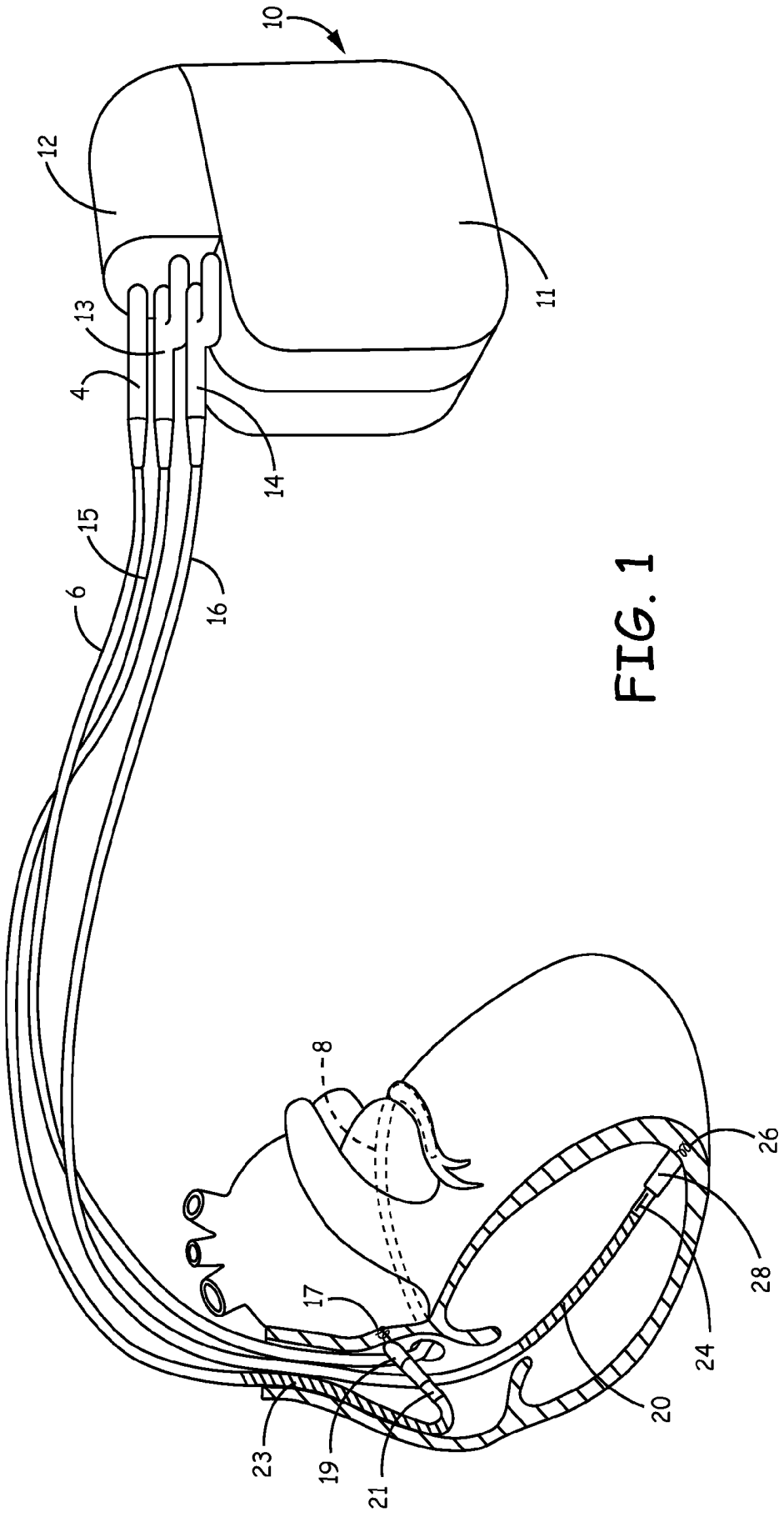
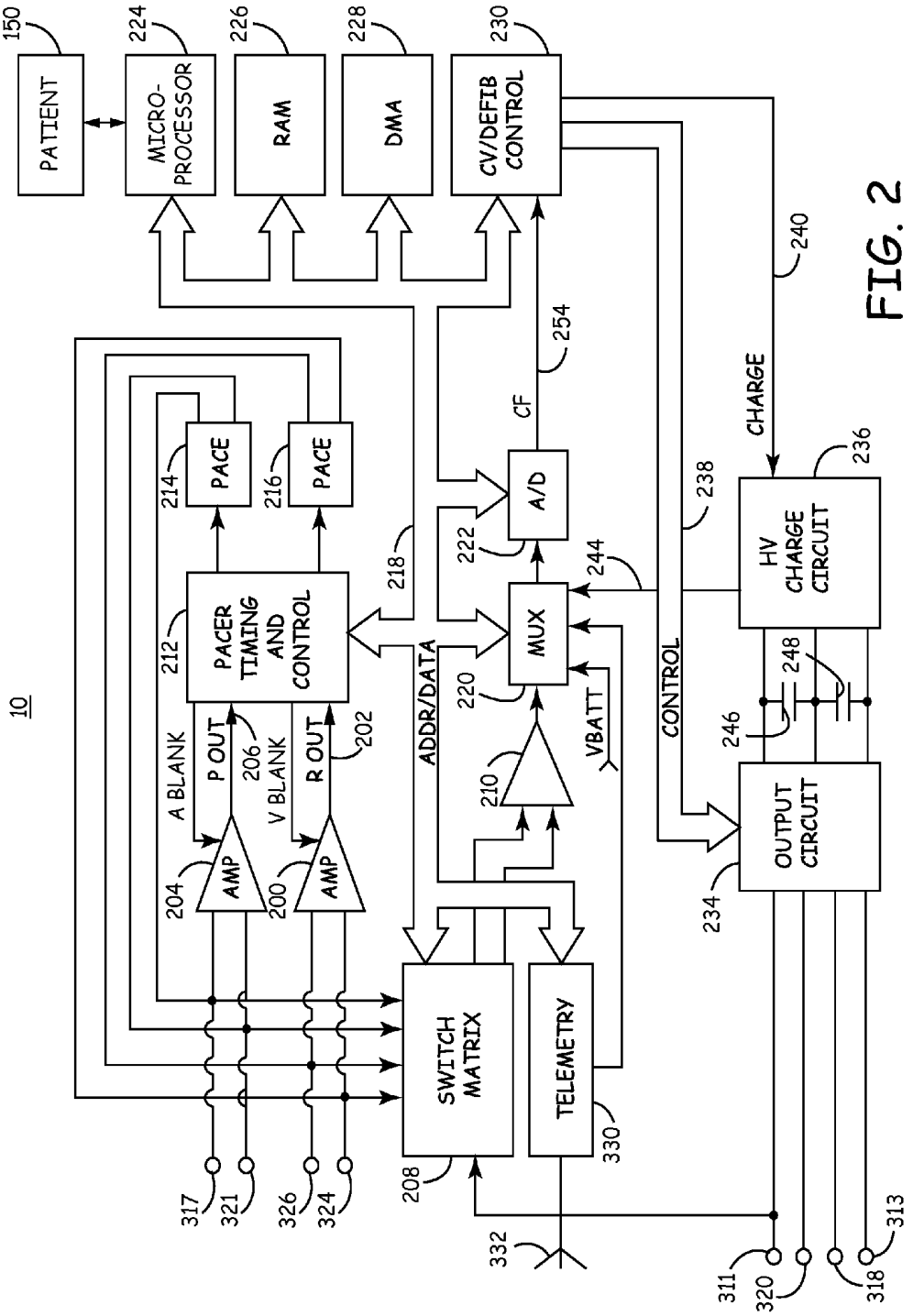



FIG. 1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226
RAM
228
DMA
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CV/DEFIB CONTROL
240
CHARGE
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CF
A/D
222
MUX
220
244
238
CONTROL
HV CHARGE CIRCUIT
236
248
246
OUTPUT CIRCUIT
234
VBATT
210
ADDR/DATA
218
PACER TIMING AND CONTROL
212
PACE
214
PACE
216
A BLANK
P OUT
206
V BLANK
R OUT
202
AMP
204
AMP
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SWITCH MATRIX
208
TELEMETRY
330
317
321
326
324
332
311
320
318
313

FIG. 2

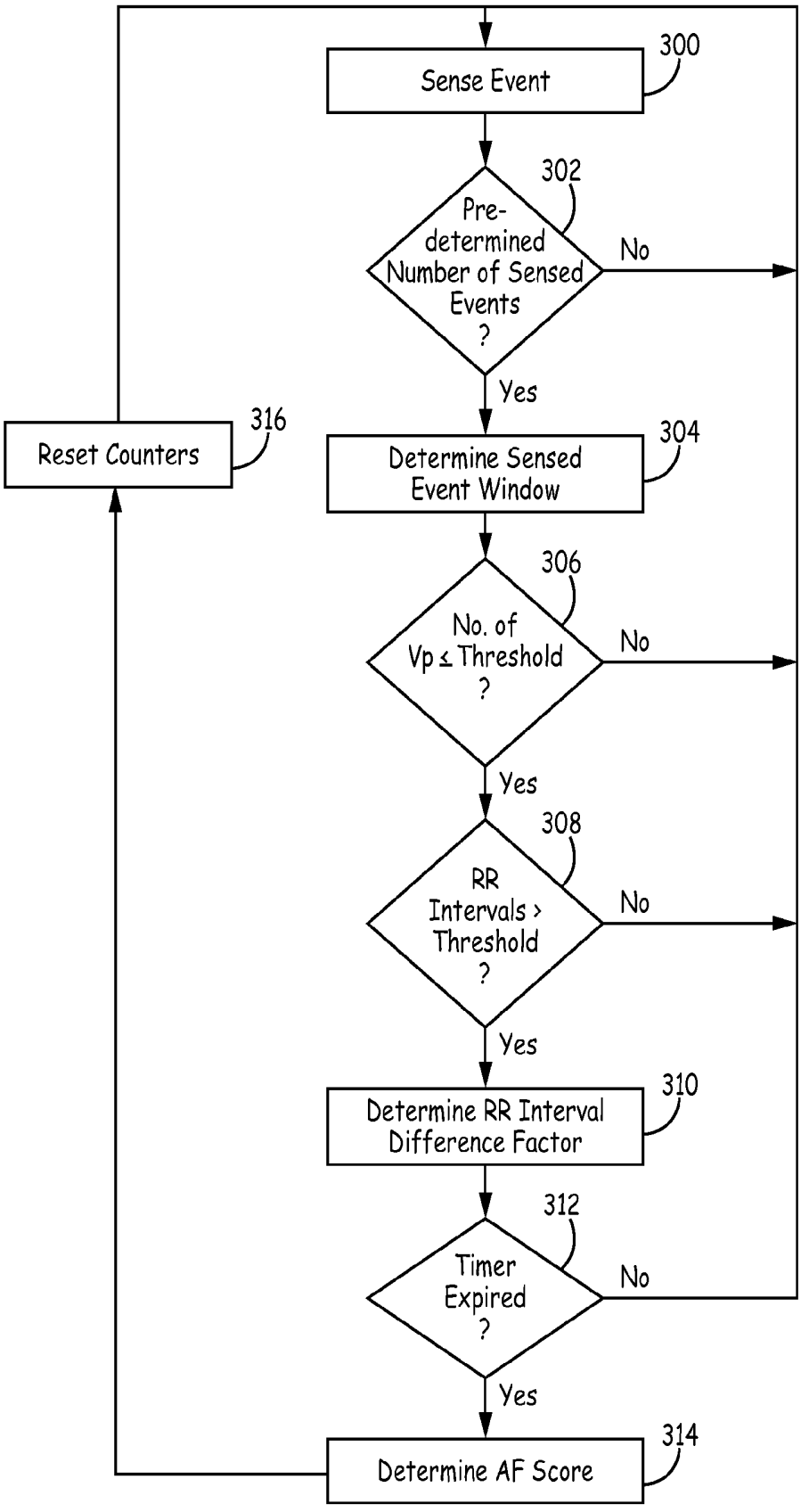
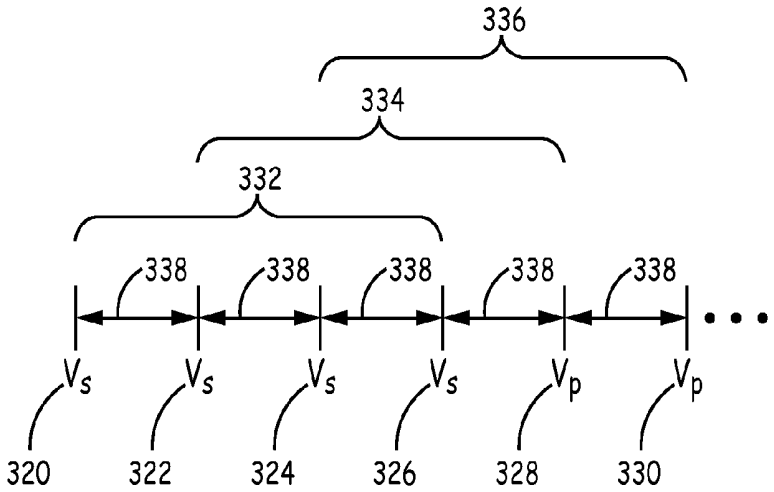

Sense Event
300
Pre-determined Number of Sensed Events ?
302
No
Yes
Determine Sensed Event Window
304
No. of Vp ≤ Threshold ?
306
No
Yes
RR Intervals > Threshold ?
308
No
Yes
Determine RR Interval Difference Factor
310
Timer Expired ?
312
No
Yes
Determine AF Score
314
Reset Counters
316

FIG. 3


336
334
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322
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326
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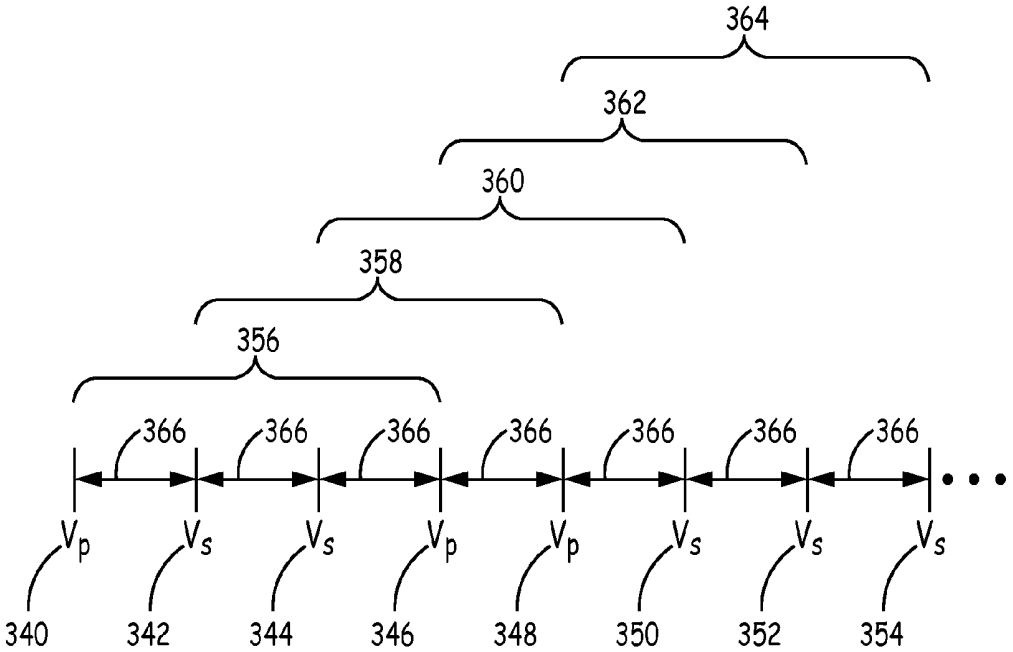
330

FIG. 4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350
352
354

FIG. 5

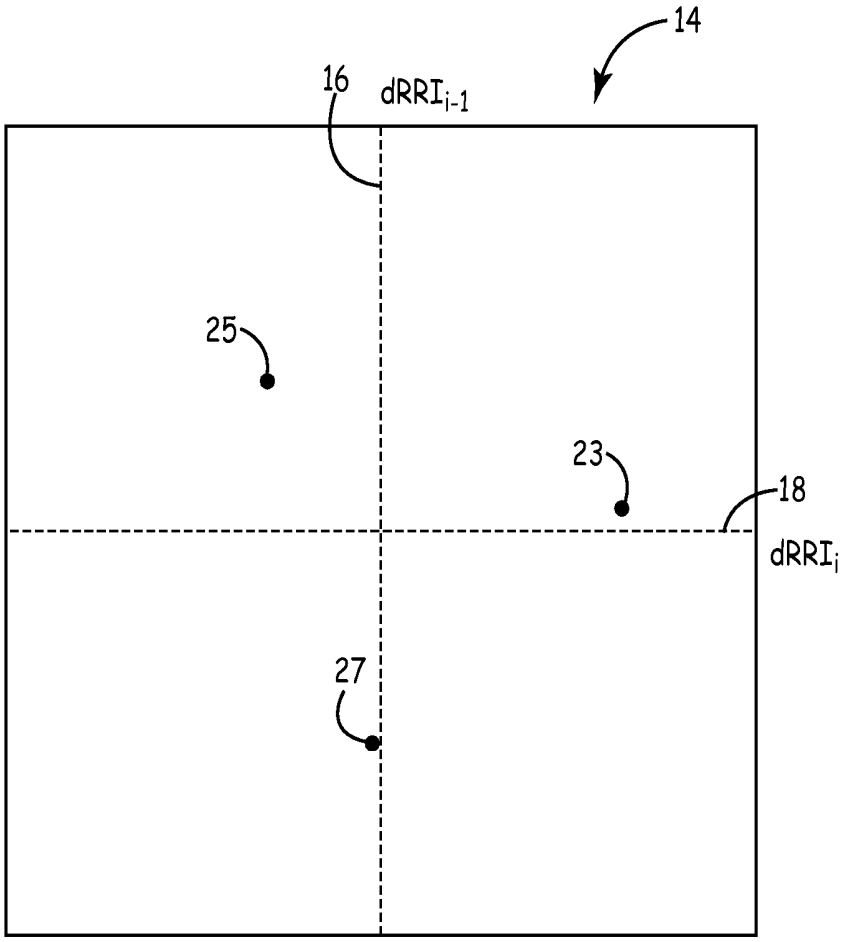


FIG. 6

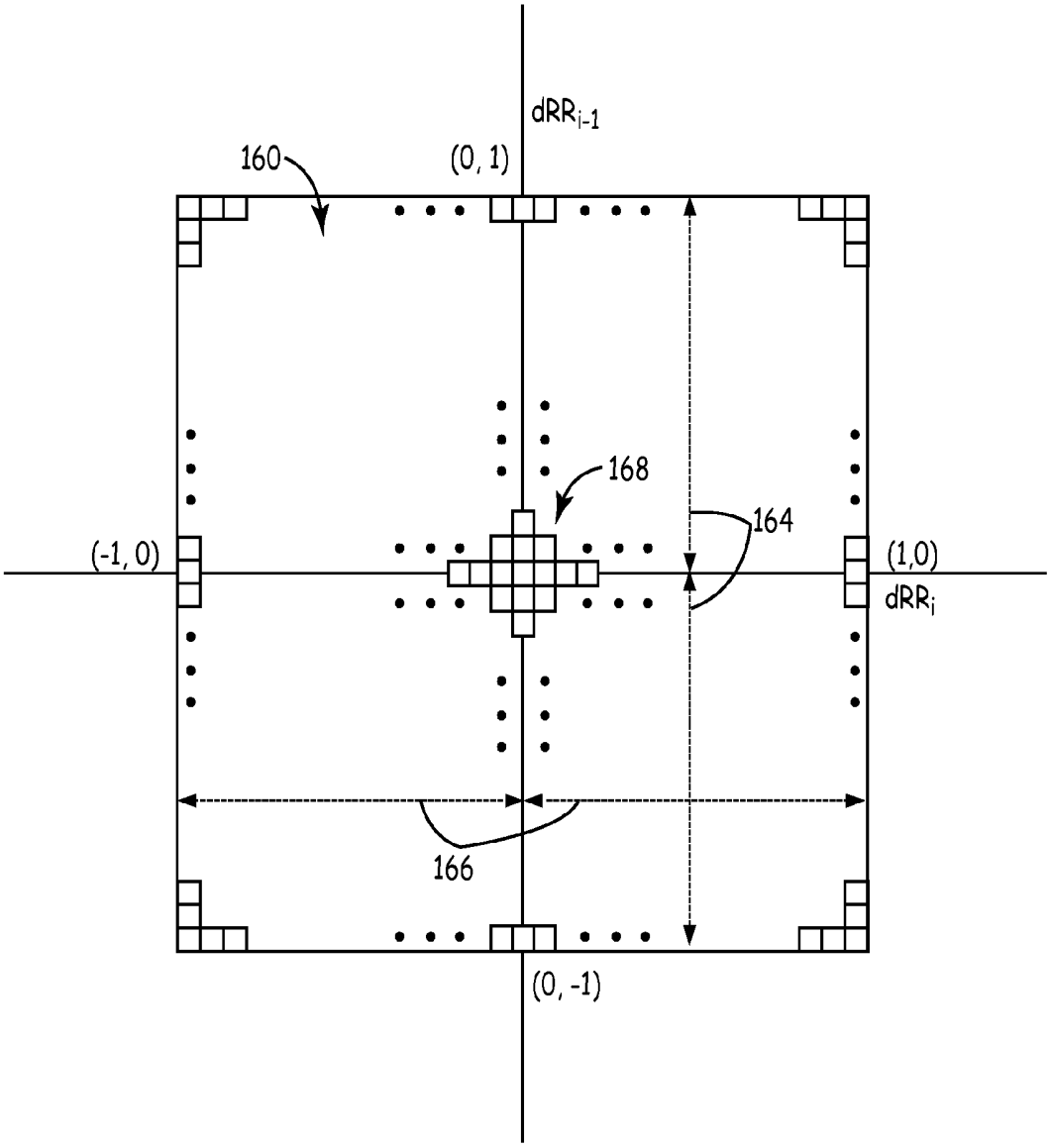


FIG. 7

# ATRIAL ARRHYTHMIA DETECTION DURING INTERMITTENT INSTANCES OF VENTRICULAR PACING IN A CARDIAC MEDICAL DEVICE

## TECHNICAL FIELD

The disclosure relates generally to cardiac medical devices and, in particular, to methods for detecting atrial arrhythmias during intermittent instances of ventricular pacing in a cardiac medical device.

## BACKGROUND

During normal sinus rhythm (NSR), the heart beat is regulated by electrical signals produced by the sino-atrial (SA) node located in the right atrial wall. Each atrial depolarization signal produced by the SA node spreads across the atria, causing the depolarization and contraction of the atria, and arrives at the atrioventricular (A-V) node. The A-V node responds by propagating a ventricular depolarization signal through the bundle of His of the ventricular septum and thereafter to the bundle branches and the Purkinje muscle fibers of the right and left ventricles.

Atrial tachyarrhythmia includes the disorganized form of atrial fibrillation (AF) and varying degrees of organized atrial tachycardia, including atrial flutter. Atrial fibrillation (AF) occurs because of multiple focal triggers in the atrium or because of changes in the substrate of the atrium causing heterogeneities in conduction through different regions of the atria. The ectopic triggers can originate anywhere in the left or right atrium or pulmonary veins. The AV node will be bombarded by frequent and irregular atrial activations but will only conduct a depolarization signal when the AV node is not refractory. The ventricular cycle lengths will be irregular and will depend on the different states of refractoriness of the AV-node.

As more serious consequences of persistent atrial arrhythmias have come to be understood, such as an associated risk of relatively more serious ventricular arrhythmias and stroke, there is a growing interest in monitoring and treating atrial arrhythmias.

Methods for discriminating arrhythmias that are atrial in origin from arrhythmias originating in the ventricles have been developed for use in dual chamber implantable devices wherein both an atrial EGM signal and a ventricular EGM signal are available. Discrimination of arrhythmias can rely on event intervals (PP intervals and RR intervals), event patterns, and EGM morphology. Such methods have been shown to reliably discriminate ventricular arrhythmias from supra-ventricular arrhythmias. In addition, such methods have been developed for use in single chamber implantable devices, subcutaneous implantable devices, and external monitoring devices, where an adequate atrial EGM signal having acceptable signal-to-noise ratio is not always available for use in detecting and discriminating atrial arrhythmias. However, such single chamber devices have been designed to monitor AF during non-paced ventricular rhythm. What is needed, therefore, is a method for monitoring atrial arrhythmias during an intermittent ventricular paced rhythm.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic diagram of an exemplary medical device for detecting arrhythmia during ventricular pacing according to an embodiment of the present disclosure.



FIG. **2** is a functional block diagram of an IMD according to one embodiment.

FIG. **3** is flowchart of a method for detecting atrial arrhythmias during intermittent instances of ventricular pacing in a cardiac medical device according to an embodiment of the present disclosure.

FIG. **4** is a schematic diagram illustrating detecting atrial arrhythmias during intermittent instances of ventricular pacing in a cardiac medical device according to an embodiment of the present disclosure.

FIG. **5** is a schematic diagram illustrating detecting atrial arrhythmias during intermittent instances of ventricular pacing in a cardiac medical device according to another embodiment of the present disclosure.

FIG. **6** is a schematic diagram of classifying of cardiac events in a cardiac medical device according to an embodiment of the present disclosure.

FIG. **7** is a diagram of an exemplary two-dimensional histogram representing a Lorenz plot area for identifying cardiac events.

## DETAILED DESCRIPTION

In the following description, references are made to illustrative embodiments for carrying out the methods described herein. It is understood that other embodiments may be utilized without departing from the scope of the disclosure.

In various embodiments, ventricular signals are used for determining successive ventricular cycle lengths for use in detecting atrial arrhythmias. The atrial arrhythmia detection methods do not require an atrial signal source. The methods presented herein may be embodied in software, hardware or firmware in implantable or external medical devices. Such devices include implantable monitoring devices having cardiac EGM/ECG monitoring capabilities and associated EGM/ECG sense electrodes, which may be intracardiac, epicardial, or subcutaneous electrodes.

The methods described herein can also be incorporated in implantable medical devices having therapy delivery capabilities, such as single chamber or bi-ventricular pacing systems or ICDs that sense the R-waves in the ventricles and deliver an electrical stimulation therapy to the ventricles. The atrial arrhythmia detection methods presently disclosed may also be incorporated in external monitors having ECG electrodes coupled to the patient's skin to detect R-waves, e.g. Holter monitors, or within computerized systems that analyze pre-recorded ECG or EGM data. Embodiments may further be implemented in a patient monitoring system, such as a centralized computer system which processes data sent to it by implantable or wearable monitoring devices.

FIG. **1** is a schematic diagram of an exemplary medical device for detecting arrhythmia during ventricular pacing according to an embodiment of the present disclosure. As illustrated in FIG. **1**, a medical device according to an embodiment of the present disclosure may be in the form of an implantable cardioverter defibrillator (ICD) **10** a connector block **12** that receives the proximal ends of a right ventricular lead **16**, a right atrial lead **15** and a coronary sinus lead **6**, used for positioning electrodes for sensing and stimulation in three or four heart chambers. Right ventricular lead **16** is positioned such that its distal end is in the right ventricle for sensing right ventricular cardiac signals and delivering pacing or shocking pulses in the right ventricle. For these purposes, right ventricular lead **16** is equipped with a ring electrode **24**, an extendable helix electrode **26** mounted retractably within an electrode head **28**, and a coil

electrode **20**, each of which are connected to an insulated conductor within the body of lead **16**. The proximal end of the insulated conductors are coupled to corresponding connectors carried by bifurcated connector **14** at the proximal end of lead **16** for providing electrical connection to the ICD **10**. It is understood that although the device illustrated in FIG. **1** is a dual chamber device, other devices such as single chamber devices may be utilized to perform the technique of the present disclosure described herein.

The right atrial lead **15** is positioned such that its distal end is in the vicinity of the right atrium and the superior vena cava. Lead **15** is equipped with a ring electrode **21** and an extendable helix electrode **17**, mounted retractably within electrode head **19**, for sensing and pacing in the right atrium. Lead **15** is further equipped with a coil electrode **23** for delivering high-energy shock therapy. The ring electrode **21**, the helix electrode **17** and the coil electrode **23** are each connected to an insulated conductor with the body of the right atrial lead **15**. Each insulated conductor is coupled at its proximal end to a connector carried by bifurcated connector **13**.

The coronary sinus lead **6** is advanced within the vasculature of the left side of the heart via the coronary sinus and great cardiac vein. The coronary sinus lead **6** is shown in the embodiment of FIG. **1** as having a defibrillation coil electrode **8** that may be used in combination with either the coil electrode **20** or the coil electrode **23** for delivering electrical shocks for cardioversion and defibrillation therapies. In other embodiments, coronary sinus lead **6** may also be equipped with a distal tip electrode and ring electrode for pacing and sensing functions in the left chambers of the heart. The coil electrode **8** is coupled to an insulated conductor within the body of lead **6**, which provides connection to the proximal connector **4**.

The electrodes **17** and **21** or **24** and **26** may be used as true bipolar pairs, commonly referred to as a "tip-to-ring" configuration. Further, electrode **17** and coil electrode **20** or electrode **24** and coil electrode **23** may be used as integrated bipolar pairs, commonly referred to as a "tip-to-coil" configuration. In accordance with the invention, ICD **10** may, for example, adjust the electrode configuration from a tip-to-ring configuration, e.g., true bipolar sensing, to a tip-to-coil configuration, e.g., integrated bipolar sensing, upon detection of oversensing in order to reduce the likelihood of future oversensing. In other words, the electrode polarities can be reselected in response to detection of oversensing in an effort to reduce susceptibility of oversensing. In some cases, electrodes **17**, **21**, **24**, and **26** may be used individually in a unipolar configuration with the device housing **11** serving as the indifferent electrode, commonly referred to as the "can" or "case" electrode.

The device housing **11** may also serve as a subcutaneous defibrillation electrode in combination with one or more of the defibrillation coil electrodes **8**, **20** or **23** for defibrillation of the atria or ventricles. It is recognized that alternate lead systems may be substituted for the three lead system illustrated in FIG. **1**. While a particular multi-chamber ICD and lead system is illustrated in FIG. **1**, methodologies included in the present invention may adapted for use with any single chamber, dual chamber, or multi-chamber ICD or pacemaker system, subcutaneous implantable device, or other internal or external cardiac monitoring device.

FIG. **2** is a functional schematic diagram of the medical device of FIG. **1**. This diagram should be taken as exemplary of the type of device with which the invention may be embodied and not as limiting. The disclosed embodiment shown in FIG. **2** is a microprocessor-controlled device, but the methods of the present invention may also be practiced with other types of devices such as those employing dedicated digital circuitry.

With regard to the electrode system illustrated in FIG. **1**, ICD **10** is provided with a number of connection terminals for achieving electrical connection to the leads **6**, **15**, and **16** and their respective electrodes. A connection terminal **311** provides electrical connection to the housing **11** for use as the indifferent electrode during unipolar stimulation or sensing. The connection terminals **320**, **313**, and **318** provide electrical connection to coil electrodes **20**, **8** and **23** respectively. Each of these connection terminals **311**, **320**, **313**, and **318** are coupled to the high voltage output circuit **234** to facilitate the delivery of high energy shocking pulses to the heart using one or more of the coil electrodes **8**, **20**, and **23** and optionally the housing **11**.

The connection terminals **317** and **321** provide electrical connection to the helix electrode **17** and the ring electrode **21** positioned in the right atrium. The connection terminals **317** and **321** are further coupled to an atrial sense amplifier **204** for sensing atrial signals such as P-waves. The connection terminals **326** and **324** provide electrical connection to the helix electrode **26** and the ring electrode **24** positioned in the right ventricle. The connection terminals **326** and **324** are further coupled to a ventricular sense amplifier **200** for sensing ventricular signals. The atrial sense amplifier **204** and the ventricular sense amplifier **200** preferably take the form of automatic gain controlled amplifiers with adjustable sensitivity. In accordance with the invention, ICD **10** and, more specifically, microprocessor **224** automatically adjusts the sensitivity of atrial sense amplifier **204**, ventricular sense amplifier **200** or both in response to detection of oversensing in order to reduce the likelihood of oversensing. Ventricular sense amplifier **200** and atrial sense amplifier **204** operate in accordance with originally programmed sensing parameters for a plurality of cardiac cycles, and upon detecting oversensing, automatically provides the corrective action to avoid future oversensing. In this manner, the adjustments provided by ICD **10** to amplifiers **200** and **204** to avoid future oversensing are dynamic in nature. Particularly, microprocessor **224** increases a sensitivity value of the amplifiers, thus reducing the sensitivity, when oversensing is detected. Atrial sense amplifier **204** and ventricular sense amplifier **200** receive timing information from pacer timing and control circuitry **212**.

Specifically, atrial sense amplifier **204** and ventricular sense amplifier **200** receive blanking period input, e.g., ABLANK and VBLANK, respectively, which indicates the amount of time the electrodes are "turned off" in order to prevent saturation due to an applied pacing pulse or defibrillation shock. As will be described, the blanking periods of atrial sense amplifier **204** and ventricular sense amplifier **200** and, in turn, the blanking periods of sensing electrodes associated with the respective amplifiers may be automatically adjusted by ICD **10** to reduce the likelihood of oversensing. The general operation of the ventricular sense amplifier **200** and the atrial sense amplifier **204** may correspond to that disclosed in U.S. Pat. No. 5,117,824, by Keimel, et al., incorporated herein by reference in its entirety. Whenever a signal received by atrial sense amplifier **204** exceeds an atrial sensitivity, a signal is generated on the P-out signal line **206**. Whenever a signal received by the ventricular sense amplifier **200** exceeds a ventricular sensitivity, a signal is generated on the R-out signal line **202**.

Switch matrix **208** is used to select which of the available electrodes are coupled to a wide band amplifier **210** for use in digital signal analysis. Selection of the electrodes is

controlled by the microprocessor **224** via data/address bus **218**. The selected electrode configuration may be varied as desired for the various sensing, pacing, cardioversion and defibrillation functions of the ICD **10**. Specifically, microprocessor **224** may modify the electrode configurations based on detection of oversensing due to cardiac or non-cardiac origins. Upon detection of R-wave oversensing, for example, microprocessor **224** may modify the electrode configuration of the right ventricle from true bipolar sensing, e.g., tip-to-ring, to integrated bipolar sensing, e.g., tip-to-coil.

Signals from the electrodes selected for coupling to bandpass amplifier **210** are provided to multiplexer **220**, and thereafter converted to multi-bit digital signals by A/D converter **222**, for storage in random access memory **226** under control of direct memory access circuit **228** via data/address bus **218**. Microprocessor **224** may employ digital signal analysis techniques to characterize the digitized signals stored in random access memory **226** to recognize and classify the patient's heart rhythm employing any of the numerous signal processing methodologies known in the art. An exemplary tachyarrhythmia recognition system is described in U.S. Pat. No. 5,545,186 issued to Olson et al, incorporated herein by reference in its entirety.

Upon detection of an arrhythmia, an episode of EGM data, along with sensed intervals and corresponding annotations of sensed events, are preferably stored in random access memory **226**. The EGM signals stored may be sensed from programmed near-field and/or far-field sensing electrode pairs. Typically, a near-field sensing electrode pair includes a tip electrode and a ring electrode located in the atrium or the ventricle, such as electrodes **17** and **21** or electrodes **26** and **24**. A far-field sensing electrode pair includes electrodes spaced further apart such as any of: the defibrillation coil electrodes **8**, **20** or **23** with housing **11**; a tip electrode **17** or **26** with housing **11**; a tip electrode **17** or **26** with a defibrillation coil electrode **20** or **23**; or atrial tip electrode **17** with ventricular ring electrode **24**. The use of near-field and far-field EGM sensing of arrhythmia episodes is described in U.S. Pat. No. 5,193,535, issued to Bardy, incorporated herein by reference in its entirety. Annotation of sensed events, which may be displayed and stored with EGM data, is described in U.S. Pat. No. 4,374,382 issued to Markowitz, incorporated herein by reference in its entirety.

The telemetry circuit **330** receives downlink telemetry from and sends uplink telemetry to an external programmer, as is conventional in implantable anti-arrhythmia devices, by means of an antenna **332**. Data to be uplinked to the programmer and control signals for the telemetry circuit are provided by microprocessor **224** via address/data bus **218**. EGM data that has been stored upon arrhythmia detection or as triggered by other monitoring algorithms may be uplinked to an external programmer using telemetry circuit **330**. Received telemetry is provided to microprocessor **224** via multiplexer **220**. Numerous types of telemetry systems known in the art for use in implantable devices may be used.

The remainder of the circuitry illustrated in FIG. **2** is an exemplary embodiment of circuitry dedicated to providing cardiac pacing, cardioversion and defibrillation therapies. The pacer timing and control circuitry **212** includes programmable digital counters which control the basic time intervals associated with various single, dual or multi-chamber pacing modes or anti-tachycardia pacing therapies delivered in the atria or ventricles. Pacer circuitry **212** also determines the amplitude of the cardiac pacing pulses under the control of microprocessor **224**.

During pacing, escape interval counters within pacer timing and control circuitry **212** are reset upon sensing of R-waves or P-waves as indicated by signals on lines **202** and **206**, respectively. In accordance with the selected mode of pacing, pacing pulses are generated by atrial pacer output circuit **214** and ventricular pacer output circuit **216**. The pacer output circuits **214** and **216** are coupled to the desired electrodes for pacing via switch matrix **208**. The escape interval counters are reset upon generation of pacing pulses, and thereby control the basic timing of cardiac pacing functions, including anti-tachycardia pacing.

The durations of the escape intervals are determined by microprocessor **224** via data/address bus **218**. The value of the count present in the escape interval counters when reset by sensed R-waves or P-waves can be used to measure R-R intervals and P-P intervals for detecting the occurrence of a variety of arrhythmias.

The microprocessor **224** includes associated read-only memory (ROM) in which stored programs controlling the operation of the microprocessor **224** reside. A portion of the random access memory (RAM) **226** may be configured as a number of recirculating buffers capable of holding a series of measured intervals for analysis by the microprocessor **224** for predicting or diagnosing an arrhythmia. In response to the detection of tachycardia, anti-tachycardia pacing therapy can be delivered by loading a regimen from microprocessor **224** into the pacer timing and control circuitry **212** according to the type of tachycardia detected. In the event that higher voltage cardioversion or defibrillation pulses are required, microprocessor **224** activates the cardioversion and defibrillation control circuitry **230** to initiate charging of the high voltage capacitors **246** and **248** via charging circuit **236** under the control of high voltage charging control line **240**. The voltage on the high voltage capacitors is monitored via a voltage capacitor (VCAP) line **244**, which is passed through the multiplexer **220**. When the voltage reaches a predetermined value set by microprocessor **224**, a logic signal is generated on the capacitor full (CF) line **254**, terminating charging. The defibrillation or cardioversion pulse is delivered to the heart under the control of the pacer timing and control circuitry **212** by an output circuit **234** via a control bus **238**. The output circuit **234** determines the electrodes used for delivering the cardioversion or defibrillation pulse and the pulse wave shape.

In one embodiment, the ICD **10** may be equipped with a patient notification system **150**. Any patient notification method known in the art may be used such as generating perceivable twitch stimulation or an audible sound. A patient notification system may include an audio transducer that emits audible sounds including voiced statements or musical tones stored in analog memory and correlated to a programming or interrogation operating algorithm or to a warning trigger event as generally described in U.S. Pat. No. 6,067,473 issued to Greeninger et al., incorporated herein by reference in its entirety.

FIG. **3** is flowchart of a method for detecting atrial arrhythmias during intermittent instances of ventricular pacing in a cardiac medical device according to an embodiment of the present disclosure. Flow chart **200** and other flow charts presented herein are intended to illustrate the functional operation of the device, and should not be construed as reflective of a specific form of software or hardware necessary to practice the invention. It is believed that the particular form of software will be determined primarily by the particular system architecture employed in the device and by the particular detection and therapy delivery methodologies employed by the device. Providing software to

accomplish the present invention in the context of any modern IMD, given the disclosure herein, is within the abilities of one of skill in the art.

Methods described in conjunction with flow charts presented herein may be implemented in a computer-readable medium that includes instructions for causing a programmable processor to carry out the methods described. A "computer-readable medium" includes but is not limited to any volatile or non-volatile media, such as a RAM, ROM, CD-ROM, NVRAM, EEPROM, flash memory, and the like. The instructions may be implemented as one or more software modules, which may be executed by themselves or in combination with other software.

As illustrated in FIG. **3**, during detection of atrial arrhythmias, the device senses events, such as ventricular events, for example, Block **300**, and identifies the sensed ventricular event as being either an intrinsic sensed event Vs or a paced event Vp resulting from pacing being delivered by the device. Depending upon the number of RR intervals chosen for determining RR interval differences, the device determines whether a predetermined number of sensed events, either a ventricular pacing event Vp or intrinsic ventricular sensed event VS, have been sensed, Block **302**. For example, according to one embodiment, if the desired number of RR intervals for RR interval differences is three, the predetermined number of sensed events utilized in Block **302** would be four sensed events, with the four sensed events forming a sensing window, as will be illustrated below. If the predetermined number of sensed events have not been sensed, the device determines the next sensed event, Block **300**, and the process is repeated.

Once the predetermined number of events are sensed, Yes in Block **302**, a sensed event window is identified based on the four events, Block **304**, and a determination is made as to whether the number of the sensed events in the sensed event window that are ventricular pace Vp events is less than or equal to a predetermined pacing event threshold, Block **306**. For example, according to one embodiment, the pacing event threshold is set as one so that the device determines whether one or less of the sensed events in the sensed event window are ventricular pace events. If the number of the sensed events in the sensed event window that are ventricular pace Vp events is not less than or equal to, i.e., is greater than the predetermined pacing event threshold, No in Block **306**, the device determines the next sensed event, Block **300**, and the process is repeated.

If the number of the sensed events in the sensed event window that are ventricular pace Vp events is less than or equal to the predetermined pacing event threshold, Yes in Block **306**, the device determines whether each of the RR intervals associated with the sensed events in the current sensed event window are greater than a predetermined interval threshold, Block **308**. For example, according to one embodiment the device determines whether each of the RR intervals associated with the sensed events in the sensed event window are greater than 220 milliseconds. If each of the RR intervals associated with the sensed events in the sensed event window are not greater than 220 milliseconds, No in Block **308**, the device determines the next sensed event, Block **300**, and the process is repeated using the next sensed event and the resulting next sensed event window.

If each of the RR intervals associated with the sensed events in the sensed event window are greater than 220 milliseconds, Yes in Block **308**, the device determines differences or variability of the RR intervals associated with the sensed events in the sensed event window, Block **310**, as will be described below. Once the RR intervals differences for the current sensed event window have been determined in Block **308**, the device determines whether a predetermined cardiac event timer has expired, Block **312**. If the event timer has not expired, No in Block **312**, the device determines the next sensed event, Block **300**, and the process is repeated using the next sensed event and the resulting next sensed event window. According to one embodiment, the cardiac event timer is set as two minutes so that once the event timer has expired, Yes in Block **312**, the device determines an atrial fibrillation AF score, Block **314**, based on the determined RR interval differences, Block **310**, resulting from multiple sensed event windows occurring during the predetermined time period, Block **312**, i.e., two minutes for example. The determination of the AF score is described below, with the device making a determining of either an atrial fibrillation AF event or a non-atrial fibrillation event occurring based on a comparison of the AF score to an AF detection threshold. The stored differences are then cleared, Block **316**, and the device determines the next sensed event, Block **300**, and the process is repeated for the next time period using the next sensed events and the resulting next sensed event windows.

FIG. **4** is a schematic diagram illustrating detecting atrial arrhythmias during ventricular pacing in a cardiac medical device according to an embodiment of the present disclosure. As illustrated in FIGS. **3** and **4**, according to one embodiment, once the device senses the predetermined number of sensed events **320-326**, Yes in Block **302**, a sensed event window **332** is formed, Block **304**, based on the current four sensed events **320-326**. The device determines whether only one or less of the sensed events **320-326** are ventricular paced events, Block **306**, and whether the RR intervals **338** formed between the sensed events **320-326** are greater than the interval threshold, Block **308**. In the example illustrated in FIG. **4**, all of sensed events **320-326** are ventricular sensed Vs events, and assuming all of the intervals **338** formed by the sensed events **320-326** are greater than the interval threshold, Yes in Block **308**, the device determines and stores an interval difference factor associated with the intervals **338** of the current sensed events **320-326**, Block **310**. If all of the intervals **338** formed by the sensed events **320-326** are not greater than the interval threshold, No in Block **308**, the device determines the next sensed event, Block **300**, and the process is repeated using the next sensed event and the resulting next sensed event window.

Assuming the cardiac event timer has not yet expired, No in Block **312**, the device senses the next event **328**, Block **300**, and a sensed event window **334** is formed, Block **304**, based on the current four sensed events **322-328**. The device determines whether only one or less of the sensed events **322-328** are ventricular paced events, Block **306**, and whether the RR intervals **338** formed between the sensed events **322-328** are greater than the interval threshold, Block **308**. In the example illustrated in FIG. **4**, since only one sensed event **338** of sensed events **322-328** is a ventricular paced Vp event, and assuming all of the intervals **338** formed by the sensed events **322-328** are greater than the interval threshold, Yes in Block **308**, the device determines and stores an interval difference factor associated with the intervals **338** of the current sensed events **322-328**, Block **310**.

Assuming the cardiac event timer has not yet expired, No in Block **312**, the device senses the next event **330**, Block **300**, and a sensed event window **336** is formed, Block **304**, based on the current four sensed events **324-330**. The device determines whether only one or less of the sensed events

324-330 are ventricular paced events, Block 306, and whether the RR intervals 338 formed between the sensed events 324-330 are greater than the interval threshold, Block 308. In the example illustrated in FIG. 4, since two sensed events 338 and 340 of sensed events 324-330 are ventricular paced Vp events, and therefore the number of sensed events in the sensed event window 336 that are ventricular paced Vp events is not less than or equal to the pacing event threshold, No in Block 306, an RR interval difference factor is not determined for that sensed event window 336, and the device determines the next sensed event, Block 300, and the process is repeated using the next sensed event and the resulting next sensed event window, and so on until the timer has expired, Yes in Block 312. Once the timer has expired, Yes in Block 312, the atrial fibrillation AF score for that time period is determined based on the currently stored interval difference factors, as described below.

FIG. 5 is a schematic diagram illustrating detecting atrial arrhythmias during ventricular pacing in a cardiac medical device according to another embodiment of the present disclosure. As illustrated in FIGS. 3 and 5, according to another embodiment, once the device senses the predetermined number of sensed events 340-346, Yes in Block 302, a sensed event window 356 is formed, Block 304, based on the current four sensed events 340-346. The device determines whether only one or less of the sensed events 340-346 are ventricular paced Vp events, Block 306, and whether the RR intervals 366 formed between the sensed events 340-346 are greater than the interval threshold, Block 308. In the exemplary embodiment illustrated in FIG. 5, during the determination as to whether only one or less of the sensed events 340-346 are ventricular paced Vp events, Block 306, rather than making the determination based on all of the sensed events 340-346 in the sensed event window 356, the device determines whether one or more of a predetermined number of the sensed events 340-346 are ventricular pace Vp events. For example, according to one embodiment, the device may determine whether only one or less of the most recent sensed event 346 in the sensed event window 356 and the previous two sensed events 342 and 344 are ventricular sensed Vp events, Block 306.

In the example illustrated in FIG. 5, the most recent sensed event 346 in the sensed event window 356 is a ventricular pace Vp event, and the two previous sensed events 342 and 344 are both ventricular sense VS events, resulting in there being only one ventricular pace Vp event. Therefore, the number of ventricular pace VP events is determined to be less than or equal to the ventricular pace Vp event threshold, i.e., one ventricular pace Vp event, Yes in Block 306. As a result, similar to above, the device determines whether the RR intervals 366 associated with the current sensed events 340-346 are greater than an interval threshold, Block 308, such as 220 milliseconds, for example. If the RR intervals 366 are not greater than the interval threshold, No in Block 308, the device does not store an interval difference factor, Block 310, for the intervals 366 associated with the current sensed events 340-346, and the process is repeated using the next sensed event 348 and the resulting next sensed event window 358.

If each of the RR intervals 366 are greater than the interval threshold, Yes in Block 308, the device stores an interval difference factor, Block 310, associated with the intervals 366 formed between the current sensed events 340-346, described below, and, assuming the timer has not expired, No in Block 312, the process is repeated using the next sensed event 348 and the resulting next sensed event window 360. If the timer has expired, Yes in Block 312, the device determines an atrial fibrillation AF score, Block 314, based on the determined RR interval difference factors, Block 310, resulting from multiple sensed event windows over the predetermined time period of Block 312, such as two minutes, for example. The determination of the AF score is described below, with the device making a determining of either an atrial fibrillation AF event or a non-atrial fibrillation event occurring based on a comparison of the AF score to an AF detection threshold. The current counters are then cleared, Block 316, and the device determines the next sensed event, Block 300, and the process is repeated for the next time period using the next sensed events and the resulting next sensed event windows.

As described above, if the RR intervals are not greater than the interval threshold, No in Block 310, or if the cardiac event timer has not yet expired, No in Block 312, the device senses the next cardiac event 348, Block 300, and a sensed event window 358 is formed, Block 304, based on the most current four sensed events 342-348. The device determines whether only one or less of the most recent sensed event 348 in the sensed event window 358 and the previous two sensed events 344 and 346 are ventricular sensed Vp events, Block 306. In the example illustrated in FIG. 5, the most recent sensed event 348 and one sensed event 346 of the two previous sensed events 344 and 346 are ventricular pace Vp events, and the other previous sensed event 344 is a ventricular sense VS event, resulting in there being two ventricular pace Vp events. Therefore, since the number of ventricular pace VP events is not less than or equal to the ventricular pace Vp event threshold, No in Block 306, the device does not determine and store an interval difference factor, Block 310, for the intervals 366 formed by the current sensed events 342-348, and the process is repeated using the next sensed event 350 and the resulting next sensed event window 360.

In particular, the device determines whether only one or less of the most recent sensed event 350 in the sensed event window 360 and the previous two sensed events 346 and 348 are ventricular sensed Vp events, Block 306. In the example illustrated in FIG. 5, the most recent sensed event 350 is a ventricular sense Vs event and both of the previous two sensed events 346 and 348 are ventricular pace Vp events, resulting in there being two ventricular pace Vp events occurring during the sensed event window 360. As a result, the number of ventricular pace Vp events is not less than or equal to the ventricular pace Vp event threshold, No in Block 306, and therefore the device does not store an interval difference factor associated with the intervals 366 formed by the current sensed events 344-350, and the process is repeated using the next sensed event 352 and the resulting next sensed event window 362.

In particular, the device determines whether only one or less of the most recent sensed event 352 in the sensed event window 362 and the previous two sensed events 348 and 350 are ventricular sensed Vp events, Block 306. In the example illustrated in FIG. 5, the most recent sensed event 352 and one sensed event 350 of the two previous sensed events 348 and 350 are ventricular sense Vs events, and the other previous sensed event 348 is a ventricular pace Vp event, resulting in only one ventricular pace Vp event occurring during the sensed event window 362. As a result, the number of ventricular pace VP events is less than or equal to the ventricular pace Vp event threshold, Yes in Block 306, and therefore the device determines whether the RR intervals 366 associated with the current sensed events 346-352 are greater than the interval threshold, Block 308. If the RR intervals 366 are not greater than the interval threshold, No

in Block **308**, the device does not store an interval difference factor, Block **310**, associated with the intervals **366** formed by the current sensed events **346-352**, and the process is repeated using the next sensed event **354** and the resulting next sensed event window **364**.

If each of the RR intervals **366** are greater than the interval threshold, Yes in Block **308**, the device stores an interval difference factor, Block **310**, associated with the intervals **366** formed between the current sensed events **346-352**, described below. Assuming the timer has not expired, No in Block **312**, the process is then repeated using the next sensed event **354** and the resulting next sensed event window **364**. If the timer has expired, Yes in Block **312**, the device determines an atrial fibrillation AF score, Block **314**, based on the determined RR interval difference factors, Block **310**, resulting from multiple sensed event windows over the predetermined time period of Block **312**, i.e., two minutes for example. The determination of the AF score is described below, with the device making a determining of either an atrial fibrillation AF event or a non-atrial fibrillation event occurring based on a comparison of the AF score to an AF detection threshold. The counters are then cleared, Block **316**, and the device determines the next sensed event, Block **300**, and the process is repeated for the next time period using the next sensed events and the resulting next sensed event windows, and so on.

In the example illustrated in FIG. **5**, the most recent sensed event **354** and both of the two previous sensed events **350** and **352** are ventricular sense Vs events, resulting in the number of ventricular pace VP events being less than or equal to the ventricular pace Vp event threshold, Yes in Block **306**. Assuming that each of the RR intervals **366** are greater than the interval threshold, Yes in Block **308**, the device determines and stores an interval difference factor, Block **310**, associated with the intervals **366** formed between the current sensed events **348-354**, described below. In this way, assuming the timer has expired, Yes in Block **312**, in the example of FIG. **5**, the device determines and stores an interval difference factor, Block **310**, only for intervals formed in sensed event windows **356**, **362** and **364**, and not for intervals formed in sensed event windows **358** and **360**. The determination of the atrial fibrillation AF score, Block **314**, described below, is therefore made based on the interval difference factor, Block **310**, determined only for intervals formed in sensed event windows **356**, **362** and **364**, and therefore does not include intervals formed in sense event windows **358** and **360** having more than the predetermined number of ventricular pace Vp events therein.

FIG. **6** is a schematic diagram of classifying of cardiac events in a cardiac medical device according to an embodiment of the present disclosure. As illustrated in FIG. **6**, according to one embodiment, in order to determine the atrial fibrillation AF score based on the determined RR intervals difference factors resulting from multiple sensed event windows, described above, the determined RR interval difference factors calculated for the RR intervals formed by the sensed events for each sensed event window, described above, are used to plot single points on a Lorentz plot **14**.

The Lorenz plot **14** is a Cartesian coordinate system defined by $\delta RR_i$ along the x-axis **18** and $\delta RR_{i-1}$ along the y-axis **16**. As such, each plotted point in a Lorenz plot is defined by an x-coordinate equaling $\delta RR_i$ and a y-coordinate equaling $\delta RR_{i-1}$. $\delta RR_i$ is the difference between the $i^{th}$ RR interval and the previous RR interval, $RRI_{i-1}$. $\delta RR_{i-1}$ is the difference between $RRI_{i-1}$ and the previous RR interval, $RRI_{i-2}$. As such, each data point plotted on the Lorenz plot **14** represents a ventricular cycle length VCL pattern relating to three consecutive VCLs: $RRI_i$, and $RRI_{i-2}$, measured between the four consecutively sensed R-waves associated with a sensing event window.

In order to plot each point on the Lorenz plot area **14**, a ($\delta RR_i$, $\delta RR_{i-1}$) point is identified based on the RR interval difference determined for the intervals formed by the sensed events in each single sensed event window during the two minute time period having one or less ventricular pace Vp events, described above. The atrial fibrillation AF score for each two minute time period is then determined based on the relative position of the resulting plotted points on the plot area **14**. For example, using the example illustrated in FIG. **5**, a first data point **23** is plotted based on the RR interval difference factor determined for intervals **366** formed in sensed event window **356**, a second data point **25** is plotted based on the RR interval difference factor determined for intervals **366** formed in sensed event window **362**, and a third data point **27** is plotted based on the RR interval difference factor determined for intervals **366** formed in sensed event window **364**, and so forth.

In particular, for example, $\delta RR_i$ for the first data point **23** is determined as the difference between the RR interval **366** between sense **346** and sense **344** and the RR interval **366** between sense **344** and sense **342**, and $\delta RR_{i-1}$ is determined as the difference between the RR interval **366** between sense **344** and sense **342** and the RR interval **366** between sense **342** and sense **340**. In the same way, the corresponding ($\delta RR_i$, $\delta RR_{i-1}$) point is identified for sensed event windows **362** and **364**, and so on until the timer has expired.

The plotted ($\delta RR_i$, $\delta RR_{i-1}$) points over a two minute time period are then used to identify the event as either an atrial fibrillation event or a non-atrial fibrillation. Methods have been developed for detecting atrial arrhythmias based on the irregularity of ventricular cycles measured by RR intervals that exhibit discriminatory signatures when plotted in a Lorenz scatter plot such as the plot shown in FIG. **6**. One such method is generally disclosed by Ritscher et al. in U.S. Pat. No. 7,031,765, or in U.S. Pat. No. 8,639,316 to Sarkar, both incorporated herein by reference in their entireties. Other methods are generally disclosed by Sarkar, et al. in U.S. Pat. No. 7,623,911 and in U.S. Pat. No. 7,537,569 and by Houben in U.S. Pat. No. 7,627,368, all of which patents are also incorporated herein by reference in their entirety.

FIG. **7** is a diagram of an exemplary two-dimensional histogram representing a Lorenz plot area for identifying cardiac events. Generally, the Lorenz plot area **14** shown in FIG. **7** is numerically represented by a two-dimensional histogram **160** having predefined ranges **166** and **164** in both positive and negative directions for the $\delta RR_i$ and $\delta RR_{i-1}$ coordinates, respectively. The two-dimensional histogram is divided into bins **168** each having a predefined range of $\delta RR_i$ and $\delta RR_{i-1}$ values. In one example, the histogram range might extend from −1200 ms to +1200 ms for both $\delta RR_i$ and $\delta RR_{i-1}$ values, and the histogram range is divided into bins extending 7.5 ms in each of the two dimensions resulting in a 160 bin×160 bin histogram. The successive RRI differences determined over a detection time interval are used to populate the histogram **160**. Each bin stores a count of the number of ($\delta RR_i$, $\delta RR_{i-1}$) data points falling into the bin range. The bin counts may then be used in determining RRI variability metrics and patterns for determining a cardiac rhythm type.

An RRI variability metric is determined from the scatter plot. Generally, the more histogram bins that are occupied, i.e. the more sparse the distribution of ($\delta RR_i$, $\delta RR_{i-1}$) points, the more irregular the VCL during the data acquisition time period. As such, a metric of the RRI variability can be used

for detecting atrial fibrillation, which is associated with highly irregular VCL. In one embodiment, an RRI variability metric for detecting AF, referred to as an AF score is computed as generally described in the above-incorporated '911 patent. Briefly, the AF score may be defined by the equation:

AF Evidence=Irregularity Evidence−Origin Count−PAC Evidence

wherein Irregularity Evidence is the number of occupied histogram bins outside a Zero Segment defined around the origin of the Lorenz plot area. During normal sinus rhythm or highly organized atrial tachycardia, nearly all points will fall into the Zero Segment because of relatively small, consistent differences between consecutive RRIs. A high number of occupied histogram bins outside the Zero segment is therefore positive evidence for AF.

The Origin Count is the number of points in a "Zero Segment" defined around the Lorenz plot origin. A high Origin Count indicates regular RRIs, a negative indicator of atrial fibrillation, and is therefore subtracted from the Irregularity Evidence term. In addition, a regular PAC evidence score may be computed as generally described in the above-incorporated '911 patent. The regular PAC evidence score is computed based on a cluster signature pattern of data points that is particularly associated with PACs that occur at regular coupling intervals and present regular patterns of RRIs, e.g. associated with bigeminy (short-short-long RRIs) or trigeminy (short-short-short-long RRIs).

In other embodiments, an AF score or other RRI variability score for classifying an atrial rhythm may be computed as described in any of the above-incorporated '765, '316, '911, '569 and '368 patents.

The AF score is compared to an AF threshold for detecting atrial fibrillation to determine whether the AF score corresponds to an AF event. The AF threshold may be selected and optimized based on historical clinical data of selected patient populations or historical individual patient data, and the optimal threshold setting may vary from patient to patient. If the metric crosses a detection threshold, AF detection occurs. A response to AF detection is made, either in response to a classification of a single two second time interval as being AF, i.e., being greater than the AF threshold, or in response to a predetermined number of two second intervals being classified as being an AF event by each being greater than the AF threshold. Such response to the AF detection may include withholding or altering therapy, such as a ventricular therapy, for example, storing data that can be later retrieved by a clinician, triggering an alarm to the patient or that may be sent remotely to alert the clinician, delivering or adjusting a therapy, and triggering other signal acquisition or analysis.

The RRI measurements may continue to be performed after an AF detection to fill the histogram during the next detection time interval. After each detection time interval, the RRI variability metric is determined and the histogram bins are re-initialized to zero for the next detection time interval. The new RRI variability metric determined at the end of each data acquisition interval may be used to determine if the AF episode is sustained or terminated.

Thus, an apparatus and method have been presented in the foregoing description with reference to specific embodiments. It is appreciated that various modifications to the referenced embodiments may be made without departing from the scope of the invention as set forth in the following claims.

We claim:

**1**. A method of determining an atrial fibrillation event in a medical device, comprising:

sensing a cardiac signal;

detecting a plurality of sensed ventricular events in the sensed cardiac signal;

determining a plurality of sensed event windows, each of the plurality of sensed event windows including a predetermined number of the sensed ventricular events;

determining, for each of the plurality of sensed event windows, whether a number of sensed ventricular events corresponding to paced events is less than a paced event threshold;

determining whether RR intervals within the sensed event windows having a number of sensed ventricular events corresponding to paced events less than the paced event threshold are greater than an interval threshold;

determining RR interval differences for each of the plurality of sensed event windows in which each of the RR intervals are greater than the interval threshold; and

detecting an atrial fibrillation event based on at least the RR interval differences determined for each of the plurality of sensed event windows in which each of the RR intervals are greater than the interval threshold.

**2**. The method of claim **1**, wherein detecting the atrial fibrillation event based on at least the RR interval differences comprises determining a relative distribution of the RR interval differences.

**3**. The method of claim **1**, wherein the predetermined number of sensed ventricular events comprises four sensed ventricular events, the paced event threshold comprises one paced event, and the interval threshold comprises 220 milliseconds.

**4**. The method of claim **1**, further comprising determining, for each sensed event window of the plurality of sensed event windows, whether one or less of a most recent sensed ventricular event of the respective sensed event window and two sensed ventricular events occurring prior to the most recent sensed ventricular event are paced events.

**5**. The method of claim **1**, wherein each of the plurality of sensed event windows comprise four sensed ventricular events, and wherein all of the plurality of sensed event windows combined occur during a two minute time period.

**6**. The method of claim **5**, wherein the four sensed ventricular events comprise a first sensed ventricular event, a second sensed ventricular event subsequent to the first sensed event, a third sensed ventricular event subsequent to the second sensed ventricular event and a fourth sensed ventricular event subsequent to the third sensed ventricular event, and wherein determining the atrial fibrillation event based on at least the RR interval differences comprises:

populating a two dimensional histogram for the two minute time period with data points each having an x-coordinate and a y-coordinate, wherein the x-coordinate comprises the difference between a first RR interval and a second RR interval, the first RR interval being between the fourth sensed ventricular event and the third sensed ventricular event and the second RR interval being between the third sensed ventricular event and the second sensed ventricular event, and the y-coordinate comprises the difference between the second RR interval and a third RR interval, the third interval being between the second sensed ventricular event and the first sensed ventricular event;

determining an atrial fibrillation evidence score based on the populated histogram; and

identifying the atrial fibrillation event in response to the atrial fibrillation evidence score being greater than an atrial fibrillation threshold.

**7**. The method of claim **6**, further comprising determining, for each sensed event window of the plurality of sensed event windows, whether one or less of a most recent sensed ventricular event of the respective sensed event window and two sensed ventricular events occurring prior to the most recent sensed ventricular event are paced events.

**8**. The method of claim **6**, wherein one of the first ventricular sensed event, the second ventricular sensed event, the third ventricular sensed event and the fourth ventricular sensed event are paced events.

**9**. The method of claim **1**, wherein the sensed ventricular events comprise a first sensed ventricular event, a second sensed ventricular event subsequent to the first sensed ventricular event, a third sensed ventricular event subsequent to the second sensed ventricular event and a fourth sensed ventricular event subsequent to the third sensed ventricular event, and wherein determining an interval difference factor comprises determining a first RR interval difference between a first RR interval and a second RR interval, the first RR interval being between the fourth sensed ventricular event and the third sensed ventricular event and the second being interval between the third sensed event and the second sensed event, and determining a second RR interval difference between the second RR interval and a third RR interval, the third RR interval being between the second sensed ventricular event and the first sensed ventricular event.

**10**. The device of claim **9**, wherein the four sensed ventricular events comprise a first sensed ventricular event, a second sensed ventricular event subsequent to the first sensed ventricular event, a third sensed ventricular event subsequent to the second sensed ventricular event and a fourth sensed ventricular event subsequent to the third sensed ventricular event, and wherein the processor is configured to populate a two dimensional histogram for the two minute time period with data points each having an x-coordinate and a y-coordinate, wherein the x-coordinate comprises the difference between a first RR interval and a second RR interval, the first RR interval being between the fourth sensed ventricular event and the third sensed ventricular event and the second RR interval being between the third sensed ventricular event and the second sensed ventricular event, and the y-coordinate comprises the difference between the second RR interval and a third RR interval, the third RR interval being between the second sensed ventricular event and the first sensed ventricular event, determine an atrial fibrillation evidence score based on the populated histogram, and identify the atrial fibrillation event in response to the atrial fibrillation evidence score being greater than an atrial fibrillation threshold.

**11**. The device of claim **10**, wherein the processor is configured to determine, for each sensed event window of the plurality of sensed event windows, whether one or less of a most recent sensed ventricular event of the respective sensed event window and two sensed ventricular events occurring prior to the most recent sensed ventricular event are paced events.

**12**. The device of claim **10**, wherein one of the first ventricular sensed event, the second ventricular sensed event, the third ventricular sensed event and the fourth ventricular sensed event are paced events.

**13**. A medical device for determining an atrial fibrillation event, comprising:

a sensor sensing a cardiac signal; and

a processor configured to detecting a plurality of sensed ventricular events in the sensed cardiac signal, determine a plurality of sensed event windows, each of the plurality of sensed event windows including a predetermined number of the sensed ventricular events, determine, for each of the plurality of sensed event windows, whether a number of sensed ventricular events corresponding to paced events is less than a paced event threshold, determine whether RR intervals within the sensed event windows having a number of sensed ventricular events corresponding to paced events less than the paced event threshold are greater than an interval threshold, determine RR interval differences for each of the plurality of sensed event windows in which each of the RR intervals are greater than the interval threshold, and detecting an atrial fibrillation event based on the RR interval differences determined for each of the plurality of sensed event windows in which each of the RR intervals are greater than the interval threshold.

**14**. The device of claim **13**, wherein detecting the atrial fibrillation event based on at least the RR interval differences comprises determining a relative distribution of the RR interval differences.

**15**. The device of claim **13**, wherein the predetermined number of sensed ventricular events comprises four sensed ventricular events, the paced event threshold comprises one paced event, and the interval threshold comprises 220 milliseconds.

**16**. The device of claim **13**, wherein the processor is configured to determine, for each sensed event window of the plurality of sensed event windows, whether one or less of a most recent sensed ventricular event of the respective sensed event window and two sensed ventricular events occurring prior to the most recent sensed ventricular event are paced events.

**17**. The device of claim **13**, wherein each of the plurality of sensed event windows comprise four sensed ventricular events, and wherein all of the plurality of sensed event windows combined occur during a two minute time period.

**18**. The device of claim **13**, wherein the sensed ventricular events comprise a first sensed ventricular event, a second sensed ventricular event subsequent to the first sensed ventricular event, a third sensed ventricular event subsequent to the second sensed ventricular event and a fourth sensed ventricular event subsequent to the third sensed ventricular event, and wherein determining an interval difference factor comprises determining a first RR interval difference between a first RR interval and a second RR interval, the first RR interval being between the fourth sensed ventricular event and the third sensed ventricular event and the second being interval between the third sensed event and the second sensed event, and determining a second RR interval difference between the second RR interval and a third RR interval, the third RR interval being between the second sensed ventricular event and the first sensed ventricular event.

**19**. The device of claim **13**, wherein the device comprises a single-chamber implantable medical device that obtains the cardiac signal via electrodes within a ventricle of the heart.

**20**. A non-transitory computer-readable medium storing a set of instructions which cause a processor of an implantable medical device to perform a method comprising:

sensing a cardiac signal;

detecting a plurality of sensed ventricular events in the sensed cardiac signal;

determining a plurality of sensed event windows, each of the plurality of sensed event windows including a predetermined number of the sensed ventricular events;

determining, for each of the plurality of sensed event windows, whether a number of sensed ventricular events corresponding to paced events is less than a paced event threshold;

determining whether RR intervals within the sensed event windows having a number of sensed ventricular events corresponding to paced events less than the paced event threshold are greater than an interval threshold;

determining RR interval differences for each of the plurality of sensed event windows in which each of the RR intervals are greater than the interval threshold; and

detecting an atrial fibrillation event based on at least the RR interval differences determined for each of the plurality of sensed event windows in which each of the RR intervals are greater than the interval threshold.

**21**. The non-transitory computer-readable medium of claim **20**, the method further comprising determining, for each sensed event window of the plurality of sensed event windows, whether one or less of a most recent sensed ventricular event of the respective sensed event window and two sensed ventricular events occurring prior to the most recent sensed event are paced events.

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|---|---|---|---|
| 专利名称(译) | 在心脏医疗设备中间歇性心室起搏期间检测房性心律失常 | | |
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| 外部链接 | Espacenet USPTO | | |


摘要(译)

一种用于确定心脏事件的方法和医疗设备，包括感测心脏信号，响应于感测到的心脏信号确定预定数量的感测到的心脏事件，响应于感测到的心脏的预定数量确定多个感测到的事件窗口事件，为多个感测事件窗口中的每一个确定多个起搏事件是否小于起搏事件阈值，确定感测事件窗口内具有小于起搏事件阈值的多个起搏事件的间隔是否更大比间隔阈值确定具有小于间隔阈值的间隔的多个窗口中的每个窗口的间隔差异因子，并且响应于针对多个窗口中的每个窗口确定的间隔差异因子确定心脏事件。