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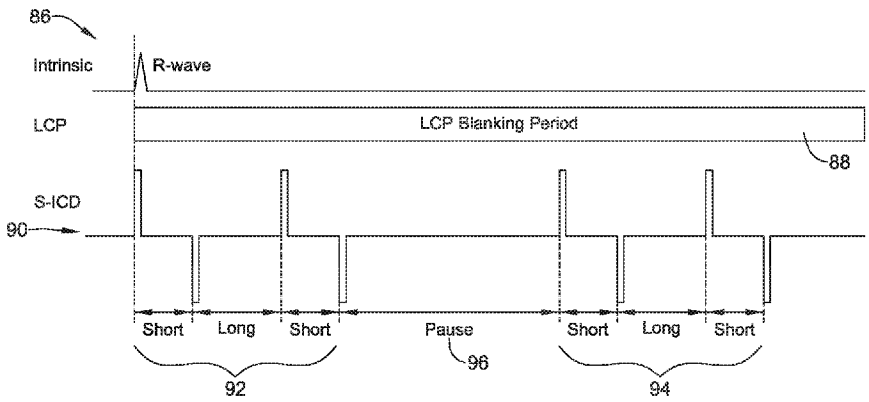

FIG. 6

(57) Abstract: Implantable medical devices (IMD), such as but not limited to leadless cardiac pacemakers (LCP), subcutaneous implantable cardioverter defibrillators (SICD), transvenous implantable cardioverter defibrillators, neuro-stimulators (NS), implantable monitors (IM), may be configured to communicate with each other. In some cases, a first IMD may transmit instructions to a second IMD. In order to improve the chances of a successfully received transmission, the first IMD may transmit the instructions several times during a particular time frame, such as during a single heartbeat. If the second IMD receives the message more than once, the second IMD recognizes that the messages were redundant and acts accordingly.

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[Continued on next page]

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INTRA-BODY DEVICE COMMUNICATION WITH REDUNDANT MESSAGE TRANSMISSION

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Patent Application Serial No. 62/450,833 filed on January 26, 2017, the disclosure of which is incorporated herein by reference.

TECHNICAL FIELD

[0002] The present disclosure pertains to medical devices, and more particularly to wireless intra-body communication between medical devices.

BACKGROUND

[0003] Implantable medical devices are commonly used today to monitor physiological or other parameters of a patient and/or deliver therapy to a patient. For example, to help patients with heart related conditions, various medical devices (e.g., pacemakers, defibrillators, etc.) can be implanted in a patient's body. Such devices may monitor and in some cases provide electrical stimulation (e.g. pacing, defibrillation, etc.) to the heart to help the heart operate in a more normal, efficient and/or safe manner. In another example, neuro stimulators can be used to stimulate tissue of a patient to help alleviate pain and/or other condition. In yet another example, an implantable medical device may simply be an implantable monitor that monitors one or more physiological or other parameters of the patient, and communicates the sensed parameters to another device such as another implanted medical device or an external device. In some cases, two or more devices cooperate to monitor and/or to provide therapy. In many of these examples, there is a desire to have such devices communicate with other devices when needed.

SUMMARY

[0004] The present disclosure pertains to medical devices, and more particularly to wireless intra-body communication between medical devices. The medical devices may include implantable medical devices (IMD), such as but not limited to leadless cardiac pacemakers (LCP), implantable cardioverter defibrillators (ICD), subcutaneous implantable cardioverter defibrillators (SICD), extracardiac implantable cardioverter defibrillators, transvenous

implantable cardioverter defibrillators, neuro-stimulators (NS), implantable monitors (IM), and/or the like. In some cases, the medical devices may include one or more external medical devices such as device programmers, wearable defibrillators and/or other external medical devices.

[0005] In one example, an implantable medical device (IMD) may be configured to pace a patient's heart and to be disposable within a chamber of the patient's heart. The IMD may include a housing and a plurality of electrodes. A controller may be housed by the housing and may be operably coupled to the plurality of electrodes. In some cases, the controller may be configured to generate and deliver pacing pulses via a pair of the plurality of electrodes, to receive messages transmitted by conducted communication from a remote implantable medical device (IMD) via a pair of the plurality of electrodes, and to receive cardiac signals via a pair of the plurality of electrodes. The controller may also be configured to receive at least one of a plurality of transmissions of the same message transmitted by conducted communication by the remote IMD during a cardiac cycle, and when more than one of the plurality of transmissions of the same message are received by the controller during the cardiac cycle, the controller may be configured to treat the more than one transmissions of the same messages as communication of one message.

[0006] Alternatively or additionally to any of the embodiments above, the controller may be configured to institute a blanking period during the cardiac cycle during which received cardiac signals are ignored by the controller.

[0007] Alternatively or additionally to any of the embodiments above, the controller may be configured to receive at least one of a plurality of transmissions of the same message during the blanking period.

[0008] Alternatively or additionally to any of the embodiments above, the controller may be configured to institute the blanking period at a predetermined time following a detected R-wave in the received cardiac signal.

[0009] Alternatively or additionally to any of the embodiments above, the blanking period may be configured to extend over at least 10 percent of a cardiac cycle, but less than an entire cardiac cycle.

[0010] Alternatively or additionally to any of the embodiments above, the blanking period may be configured to extend over at least 20 percent of a cardiac cycle, but less than an entire

cardiac cycle.

[0011] Alternatively or additionally to any of the embodiments above, the plurality of transmissions of the same message are received over a time duration that allows for physiological changes in the patient that result in differing communication vectors.

[0012] Alternatively or additionally to any of the embodiments above, the time duration may be selected to accommodate physiological changes in the patient resulting from the patient's heart beating.

[0013] Alternatively or additionally to any of the embodiments above, the time duration may be selected to accommodate physiological changes in the patient resulting from the patient breathing.

[0014] Alternatively or additionally to any of the embodiments above, the time duration may be shorter than a cardiac cycle.

[0015] Alternatively or additionally to any of the embodiments above, the time duration may span more than one cardiac cycle.

[0016] Alternatively or additionally to any of the embodiments above, the controller may be configured to institute a blanking period in response to receiving a message.

[0017] Alternatively or additionally to any of the embodiments above, the controller may be configured to generate and deliver pacing pulses via a first pair of the plurality of electrodes, to receive messages transmitted from the remote IMD via a second pair of the plurality of electrodes and to receive cardiac signals via a third pair of the plurality of electrodes, where the first pair of electrodes, the second pair of electrodes and the third pair of electrodes correspond to the same pair of electrodes.

[0018] Alternatively or additionally to any of the embodiments above, the message may be a command.

[0019] Alternatively or additionally to any of the embodiments above, the command may be an ATP command that instructs the controller to deliver Anti-Tachycardia Pacing (ATP) therapy to the patient's heart via a pair of the plurality of electrodes.

[0020] In another example, an implantable medical device (IMD) may be configured to sense electrical cardiac activity of a patient's heart and to deliver therapy to the patient's heart. The IMD may include a housing, a plurality of electrodes, and a controller that is housed by the housing and operably coupled to the plurality of electrodes. The controller may be configured to

sense cardiac electrical activity via two or more of the plurality of electrodes and to deliver therapy via two or more of the plurality of electrodes. In some cases, the controller may be configured to analyze the sensed cardiac electrical activity and to make a determination as to whether to provide a message to a remote implantable medical device (IMD) secured to the patient's heart. When the controller makes a determination to provide a message to the remote IMD, the controller may be configured to transmit a plurality of transmissions of the message by conducted communication during a cardiac cycle of the patient's heart.

[0021] Alternatively or additionally to any of the embodiments above, the controller may be configured to add a tracking number to each of the plurality of transmissions of the message.

[0022] Alternatively or additionally to any of the embodiments above, the IMD may be incapable of receiving a conducted communication messages from the remote IMD.

[0023] Alternatively or additionally to any of the embodiments above, each of the plurality of redundant transmissions of the message may include a command to the remote IMD to deliver one or more pacing pulses, and the controller of the IMD may be configured to monitor cardiac electrical activity for an indication that the remote IMD delivered the one or more pacing pulses.

[0024] Alternatively or additionally to any of the embodiments above, after the controller makes a determination to provide a message to the remote IMD, the controller may be configured to transmit the plurality of redundant transmissions of the message within a communication time period, wherein the communication time period has a time duration is sufficiently long to allows the remote IMD to change orientations relative to the IMD as a result of physiological changes in the patient to result in a substantially different signal strength at the remote IMD.

[0025] In another example, a medical system for sensing and regulating cardiac activity of a patient may include an implantable cardioverter defibrillator (ICD) that is configured to sense electrical cardiac activity of a patient's heart and to deliver therapy to the patient's heart, and a leadless cardiac pacemaker (LCP) that is configured to pace a patient's heart. The ICD may include a housing, a plurality of electrodes and an ICD controller that is housed by the housing of the ICD and operably coupled to the plurality of electrodes of the ICD. The ICD controller may be configured to sense cardiac electrical activity via two or more of the plurality of electrodes of the ICD and to deliver therapy via two or more of the plurality of electrodes of the ICD. In some cases, the ICD controller may be further configured to analyze the sensed cardiac electrical

activity and to make a determination as to whether to instruct a leadless cardiac pacemaker (LCP) to provide therapy to the patient's heart. When the ICD controller makes a determination to instruct the LCP to provide therapy to the patient's heart, the ICD controller may be configured to transmit a plurality of transmissions of an instruction during a single cardiac cycle of the patient's heart.

[0026] The LCP may include a housing, a plurality of electrodes that are exposed external to the housing of the LCP, and an LCP controller that is housed by the housing of the LCP and is operably coupled to the plurality of electrodes of the LCP. In some cases, the LCP controller may be configured to generate and deliver pacing pulses via two or more of the plurality of electrodes of the LCP, receive messages transmitted via two or more of the plurality of electrodes of the LCP, and receive cardiac signals via two or more of the plurality of electrodes of the LCP. The LCP controller may be further configured to receive at least one of the plurality of redundant transmissions of the instruction transmitted by the SICD during the single cardiac cycle, and when more than one of the plurality of redundant transmissions of the instruction are received by the LCP controller during the single cardiac cycle, the LCP controller may be configured to treat the more than one redundant transmissions of the instruction as one instruction, and only executes the one instruction and not each of the plurality of redundant transmissions of the instruction.

[0027] The above summary of some illustrative embodiments is not intended to describe each disclosed embodiment or every implementation of the present disclosure. The Figures, and Detailed Description, which follow, more particularly exemplify some of these embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

[0028] The disclosure may be more completely understood in consideration of the following detailed description in connection with the accompanying drawings, in which:

[0029] Figure 1 is a highly schematic diagram of an illustrative system in accordance with an example of the disclosure;

[0030] Figure 2 is a high schematic diagram of an illustrative system in accordance with an example of the disclosure;

[0031] Figure 3 is a schematic block diagram of an illustrative leadless cardiac pacemaker (LCP) useable in the systems of Figures 1 and 2;

[0032] Figure 4 is a schematic block diagram of an illustrative implantable cardioverter defibrillator (ICD) useable in the systems of Figures 1 and 2;

[0033] Figure 5A and 5B are schematic illustrations of illustrative blanking periods relative to an electrocardiogram (ECG);

[0034] Figure 6 is a schematic illustration of a communication of redundant messages within a blanking period;

[0035] Figure 7 is a more detailed schematic block diagram of an illustrative LCP in accordance with an example of the disclosure;

[0036] Figure 8 is a schematic block diagram of another illustrative medical device that may be used in conjunction with the LCP of Figure 7;

[0037] Figure 9 is a schematic diagram of an exemplary medical system that includes multiple LCPs and/or other devices in communication with one another; and

[0038] Figure 10 is a schematic diagram of a system including an LCP and another medical device, in accordance with an example of the disclosure.

[0039] While the disclosure is amenable to various modifications and alternative forms, specifics thereof have been shown by way of example in the drawings and will be described in detail. It should be understood, however, that the intention is not to limit the disclosure to the particular embodiments described. On the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the disclosure.

DESCRIPTION

[0040] For the following defined terms, these definitions shall be applied, unless a different definition is given in the claims or elsewhere in this specification.

[0041] All numeric values are herein assumed to be modified by the term "about," whether or not explicitly indicated. The term "about" generally refers to a range of numbers that one of skill in the art would consider equivalent to the recited value (i.e., having the same function or result). In many instances, the terms "about" may include numbers that are rounded to the nearest significant figure.

[0042] The recitation of numerical ranges by endpoints includes all numbers within that range (e.g. 1 to 5 includes 1, 1.5, 2, 2.75, 3, 3.80, 4, and 5).

[0043] As used in this specification and the appended claims, the singular forms "a", "an",

and "the" include plural referents unless the content clearly dictates otherwise. As used in this specification and the appended claims, the term "or" is generally employed in its sense including "and/or" unless the content clearly dictates otherwise.

[0044] It is noted that references in the specification to "an embodiment", "some embodiments", "other embodiments", etc., indicate that the embodiment described may include one or more particular features, structures, and/or characteristics. However, such recitations do not necessarily mean that all embodiments include the particular features, structures, and/or characteristics. Additionally, when particular features, structures, and/or characteristics are described in connection with one embodiment, it should be understood that such features, structures, and/or characteristics may also be used connection with other embodiments whether or not explicitly described unless clearly stated to the contrary.

[0045] The following detailed description should be read with reference to the drawings in which similar structures in different drawings are numbered the same. The drawings, which are not necessarily to scale, depict illustrative embodiments and are not intended to limit the scope of the disclosure. While the present disclosure is applicable to any suitable implantable medical device (IMD), the description below often uses pacemakers and more particularly leadless cardiac pacemakers (LCP) as particular examples.

[0046] Figure 1 is a schematic diagram showing an illustrative system 10 that may be used to sense and/or pace a heart H. In some cases, the system 10 may also be configured to shock the heart H. The heart H includes a right atrium RA and a right ventricle RV. The heart H also includes a left atrium LA and a left ventricle LV. In some cases, the system 10 may include a medical device that provides anti-arrhythmic therapy to the heart H. In some cases, the system 10 may include a first medical device 12 and a second medical device 14. In some instances, the first medical device 12 may be implantable within the patient at a position near or even within the heart H. In some cases, the second medical device 14 may be implanted within the patient but at a location that is exterior to the heart H. For example, in some cases, the second medical device 14 may be implanted at a subcutaneous position within the patient's chest. In some cases, the second medical device 14 may be exterior to the patient.

[0047] In some cases, the second medical device 14 may be configured to maintain and/or trend pace settings and capture data for the first medical device 12 for the purposes of long-term optimization of pace settings. In some cases, the second medical device 14 may utilize

additional inputs, such as posture, time of day, intrinsic heart rate, and the like, as inputs to a capture algorithm. The second medical device 14 may, for example, be configured to correlate changes in a pace threshold resulting from the other inputs, and proactively adjust pace settings. In some cases, the second medical device 14 may be utilized to optimize the AV delay utilized by the first medical device 12. For example, the second medical device 14 may be able to monitor ECG morphology and/or acceleration data, such as RV or LV pace timing.

[0048] If the second medical device 14 is implanted prior to implanting the first medical device 12, the second medical device 14 may be used to guide optimal placement of the first medical device 12 by, for example, monitoring the QRS width, morphology, Heart Rate Variability (HRV), accelerometer signals, etc. In some cases, the second medical device 14 could provide feedback of the attempted first medical device 12's location prior to fixation or untethering of the first medical device 12. Minimizing QRS width, HRV and/or certain morphological parameters would be a possible goal of the clinician to obtain such an optimal implantation site, for example. In some cases, the second medical device 14 may be able to monitor the impedance and or heart sounds to possibly detect myocardial functional improvements as indicated by hypertrophy, or dilated cardiomyopathy. For example, these diseases generally have increased left ventricles, thus possibly lower impedance and/or contraction changes. These are just examples.

[0049] Figure 2 is a schematic diagram showing an illustrative system 16 that may be used to sense and/or pace a heart H. In some cases, the system 16 may be considered as being an example of the system 10 shown in Figure 1. In some cases, the system 16 may include a leadless cardiac pacemaker (LCP) 18 and an implantable cardioverter defibrillator (ICD) 20. In some cases, the ICD 20 may be a subcutaneous implantable cardioverter defibrillator (SICD), an extracardiac implantable cardioverter defibrillator and/or a transvenous implantable cardioverter defibrillator. In some cases, as illustrated, the ICD 20 may be an SICD. The LCP 18 may be considered as being an illustrative but non-limiting example of the first medical device 12 and the ICD 20 may be considered as being an illustrative but non-limiting example of the second medical device 14 described with respect to Figure 1.

[0050] In some cases, the LCP 18 may be intracardially implanted. While a single LCP 18 is shown in Figure 2, it will be appreciated that two or more LCPs 18 may be implanted in or on the heart H. The LCP 18 may be implanted into any chamber of the heart, such as the right

atrium RA, the left atrium LA, the right ventricle RV and the left ventricle LV. When more than one LCP is provided, each LCP may be implanted in a different chamber. In some cases, multiple LCP's may be implanted within a single chamber of the heart H.

[0051] In some cases, the ICD 20 may be extracardially implanted. While not shown in Figure 2, in some cases the ICD 20 may include a lead/electrode that may be configured to be placed subcutaneously and outside of a patient's sternum. In other cases, the lead/electrode may extend around or through the sternum and may be fixed adjacent an inner surface of the sternum. In both cases, the lead/electrode is positioned extracardially (outside of the patient's heart). The ICD 20 may be configured to sense electrical activity generated by the heart H as well as provide electrical energy to the heart H in order to shock the heart H from an undesired heart rhythm to a desired heart rhythm.

[0052] In some cases, the LCP 18 and the ICD 20 may be implanted at the same time. In some instances, depending on the cardiac deficiencies of a particular patient, the ICD 20 may be implanted first, and one or more LCPs 18 may be implanted at a later date if/when the patient develops indications for receiving cardiac resynchronization therapy and/or it becomes necessary to pace the heart H. In some cases, it is contemplated that one or more LCPs 18 may be implanted first, in order to sense and pace the heart H. When a need for possible defibrillation becomes evident, the ICD 20 may subsequently be implanted. Regardless of implantation order or sequence, it will be appreciated that the LCP 18 and the ICD 20 may communicate with each other using any desired communications modality, such as conducted communication, inductive communication, acoustic communication, RF communication, optical communication and/or using any other suitable communication modality.

[0053] In some cases, the LCP 18 and the ICD 20 may work together in delivering therapy to the heart H. For example, in some cases, the ICD 20 may sense cardiac electrical activity of the heart H and may analyze the sensed cardiac electrical activity in order to determine whether the ICD 20 itself should deliver therapy such as shocking therapy to the heart H or if it would be appropriate for the ICD 20 to instruct the LCP 18 to deliver pacing therapy to the heart H. In some cases, the pacing therapy may be anti-tachycardia pacing (ATP) therapy, but this is just an example. When the ICD 20 determines that it would be appropriate to have the LCP 18 deliver pacing therapy, the ICD 20 may transmit a message to the LCP 18 instructing the LCP 18 to delivery pacing therapy.

[0054] In some cases, it will be appreciated that communication vectors between the ICD 20 and the LCP 18 may be at least somewhat time-dependent, particularly as the LCP 18 may be moving as a result of physiological changes in the patient, such as but not limited to the heart H beating and/or the patient breathing. For example, as the heart H beats, it will be appreciated that an LCP 18, if anchored at its distal end to a heart wall of the heart H, can change orientation in response to the heart wall moving, blood flowing through the heart, and the like. In some cases, communication from the ICD 20 to the LCP 18 may be one-way communication, wherein the ICD 20 is not able to receive confirmation messages from the LCP 18, and/or the LCP 18 is not able to transmit confirmation messages back to the ICD 20, either as a result of hardware limitations or poor communication vectors, for example.

[0055] In some instances, and to help improve the robustness and/or reliability of the one-way communication channel, the ICD 20 may transmit a plurality of redundant transmissions of an instruction or other message to the LCP 18. As a non-limiting example, the ICD 20 may be configured to transmit the same instruction three times. As long as at least one of the three redundant messages is successfully received by the LCP 18, the LCP 18 is able to carry out the instruction received from the ICD 20. In some cases, the plurality of redundant transmissions from the ICD 20 may be transmitted within a single cardiac cycle. Since the orientation of the LCP 18 relative to the ICD 20 may change over the course of a heartbeat, the communication vector between the LCP 18 and the ICD 20 may change over the course of a heartbeat. By transmitting redundant messages, the chance that the LCP 18 is not located along a null of the transmission field generated by the ICD 20 is increased for at least one of the messages, thereby potentially increasing the robustness and/or reliability of the communication channel. In some cases, the plurality of redundant transmissions from the ICD 20 are transmitted within a portion of a single cardiac cycle, such as in 10 percent, 20 percent, 30 percent, 40 percent, 60 percent, or more or less.

[0056] Similarly, the LCP 18 may be configured to receive one or more of the redundant messages transmitted by the ICD 20 and to recognize that any of the received messages are in fact redundant and represent repetition of a single instruction and/or message, rather than multiple instructions and/or messages. Accordingly, the LCP 18 may be configured to treat the more than one redundant instruction, if the LCP 18 successfully receives more than one redundant instruction, as a single instruction. As a result, the LCP 18 may only execute one

instruction, and not each of the received redundant instructions. In some cases, particularly if the LCP 18 is not able to confirm receipt of instructions, or the ICD 20 is not able to receive such confirmatory or acknowledgement messages, the ICD 20 may monitor cardiac electrical activity for indications that the LCP 18 carried out the desired instruction(s). For example, the ICD 20 may monitor cardiac electrical activity for indications of an Anti-Tachycardia Pacing (ATP) therapy if the ICD 20 instructed the LCP 18 to carry out an ATP therapy.

[0057] Figure 3 is a schematic diagram of an illustrative leadless cardiac pacemaker (LCP) 30 that may be considered as being an example of the LCP 18 (Figure 2). In some cases, the LCP 30 may include a housing 32 and a plurality of electrodes that are exposed external to the housing 32. As illustrated, the LCP 30 includes a pair of electrodes 34, 36 that are secured relative to the housing 32. While two electrodes 34, 36 are illustrated, it will be appreciated that in some cases the LCP 30 may include three or more electrodes. A controller 38 is disposed within the housing 32 and may be operably coupled to the pair of electrodes 34, 36 via electrical connectors 35 and 37, respectively. A power supply 40 is operably coupled to the controller 38 and provides power for operation of the controller 38 as well as providing power for generating pacing pulses that can be delivered via the pair of electrodes 34, 36 via the controller 38. In some cases, the controller 38 may be considered as being configured to generate and deliver a plurality of pacing pulses via the pair of electrodes 34, 36. In some cases, the LCP 30 may include one or more other sensors such as an accelerometer or a gyro, for example.

[0058] In some cases, the LCP 30 may include a communications module 42 that is operably coupled to the controller 38 and may be configured to receive messages from other devices, and in some cases send messages to other devices. In some cases, the communications module 42 may enable the LCP 30 to receive messages from another implanted device, such as but not limited to an SICD such as the ICD 20 (Figure 2). In some cases, the controller 38 may be configured to receive, via the communications module 42, messages communicated via conducted communication that may be picked up by the electrodes 34, 36. In some cases, the messages received by the LCP 18 may represent a command from a remote device such as the ICD 20. In some instances, the command may be an ATP command that instructs the controller 38 to deliver Anti-Tachycardia Pacing (ATP) therapy to the patient's heart H via a pair of the plurality of electrodes.

[0059] In some cases, the controller 38 may be configured to receive at least one of a

plurality of redundant transmissions of the same message transmitted by conducted communication by a remote device such as the ICD 20 during a cardiac cycle. When more than one of the plurality of redundant transmissions of the same message are received by the controller 38 during the cardiac cycle, the controller 38 may be configured to treat the more than one redundant transmissions of the same messages as one message. In some cases, the controller 38 may be configured to institute a blanking period during the cardiac cycle during which cardiac signals sensed by the electrodes 34 and 36 are ignored by the controller 38, meaning that the controller 38 is only listening for transmitted messages, and is ignoring cardiac electrical activity during the blanking period. In some cases, the controller 38 may be configured to institute a blanking period in response to receiving a message, possibly to see if additional messages are to be transmitted, for example. In some cases, the controller 38 may be configured to receive at least one of a plurality of redundant transmissions of the same message during the blanking period, and in some cases, may receive two or more of the plurality of redundant transmissions. In some cases, the controller 38 may be configured to institute a blanking period at a predetermined time following a detected R-wave in the received cardiac signal.

[0060] In some cases, the plurality of redundant transmissions of the same message may be received over a time duration that allows for physiological changes in the patient that result in differing communication vectors for each of the redundant messages. When a blanking period is provided, this time duration may correspond to the blanking period, or may lie at least partially outside the blanking period. In some cases, the time duration may be selected to accommodate physiological changes in the patient resulting from the patient's heart beating. In some cases, the time duration may be selected to accommodate physiological changes in the patient resulting from the patient breathing. In some instances, the time duration may be shorter than a cardiac cycle. In some cases, the time duration may span more than one cardiac cycle.

[0061] In some cases, the controller 38 of the LCP 30 may be configured to generate and deliver pacing pulses via a first pair of the plurality of electrodes, to receive messages transmitted from the implantable medical device (IMD) remote from the LCP via a second pair of the plurality of electrodes, and to receive cardiac signals via a third pair of the plurality of electrodes. In some cases, the first pair of electrodes, the second pair of electrodes and the third pair of electrodes correspond to the same pair of electrodes, while in others, different electrodes may be used.

[0062] Figure 4 is a schematic diagram of an illustrative subcutaneous implantable cardioverter defibrillator (SICD) 50 that may, for example, be considered as being an example of the ICD 20 (Figure 2). The illustrative SICD 50 includes a housing 52 and an electrode support 54 that is operably coupled to the housing 52. In some cases, the electrode support 54 may be configured to place one or more electrodes in a position, such as subcutaneous or sub-sternal, that enables the one or more electrodes to detect cardiac electrical activity as well as to deliver electrical shocks to the heart H when appropriate. In the example shown, the housing 52 may house a controller 56, a power supply 58 and a communications module 60. As illustrated, the electrode support 54 includes a first electrode 62, a second electrode 64 and a third electrode 66. In some cases, the electrode support 54 may include fewer or more electrodes. In some cases, the SICD 50 may include one or more other sensors such as an accelerometer or a gyro, for example.

[0063] In some cases, the controller 56 may be configured to analyze cardiac electrical activity sensed by two or more of the electrodes 62, 64, 66 and to make a determination as to whether to provide a message and/or instruction to a leadless cardiac pacemaker (LCP), such as but not limited to the LCP 18, 30 implanted remote from the SICD 50 and secured to the patient's heart H. In some cases, when the controller 56 makes a determination to provide a message and/or instruction to the LCP 18, 30, the controller 56 may be configured to transmit a plurality of redundant transmissions of the message and/or instruction by conducted communication during a cardiac cycle of the patient's heart. In some cases, the controller 56 may be configured to add a tracking number to each of the plurality of redundant transmissions of the message and/or instruction. For example, the tracking number could be as simple as "1 of 3", "2 of 3" and "3 of 3" of three sequentially transmitted redundant messages. When such tracking numbers are added, the receiving LCP 18, 30 may more easily recognize the messages as being repeated or redundant copies of the same message. In other cases, the LCP 18, 30 may simply treat all messages received during a predetermined time period (e.g. during a blanking period) as redundant messages of the same message.

[0064] In some cases, the ICD 20, 50 may not be capable of receiving acknowledge messages such as but not limited to conducted communication messages from the LCP 18, 30, due to either hardware limitations or poor communication vectors. In some cases, each of the plurality of redundant transmissions of a message may include a command or instruction to the

LCP 18, 30 to deliver one or more pacing pulses, and the controller 56 of the SICD 50 may be configured to monitor cardiac electrical activity for an indication that the LCP 18, 30 delivered the one or more pacing pulses. In some instances, after the controller 56 makes a determination to provide a message to the LCP 18, 30, the controller 56 may be configured to transmit the plurality of redundant transmissions of the message within a communication time period having a time duration that is sufficiently long to allows the LCP 18, 30 to change orientations relative to the SICD 50 as a result of physiological changes in the patient to result in a substantially different vector and/or signal strength at the LCP 18, 30.

[0065] As noted, a blanking period may correspond to a portion of a cardiac cycle or may even extend over more than one cardiac cycle. Figure 5A shows an illustrative electrocardiogram (ECG) 70 with several blanking periods indicated thereon. In the example shown, a first blanking period 72 follows an R-wave 74. A second blanking period 76 follows an R-wave 78. A third blanking period 80 follows an R-wave 82. Each of the first blanking period 72, the second blanking period 76 and the third blanking period 80 are illustrated as being shorter than one cardiac cycle, with a cardiac cycle being defined as a time period between successive R-waves. In some instances, it is contemplated that the duration of a particular blanking period may be adjusted. In some cases, each blanking period 72, 76, 80 may have the same time duration. In some cases, for example, the blanking period 72, 76, 80 may each extend over at least 10 percent of a cardiac cycle, but less than an entire cardiac cycle. Each of the blanking period 72, 76, 80 may extend over at least 20 percent of a cardiac cycle, but less than an entire cardiac cycle. Each of the blanking period 72, 76, 80 may extend over at least 30 percent, 40 percent, 60 percent or more or less of a cardiac cycle. In some cases, as illustrated in Figure 5B, a blanking period 84 follows the R-wave 74 and extends to a point beyond the next successive R-wave 78.

[0066] Figure 6 provides a schematic illustration of a redundant message that may be transmitted to the LCP 18, 30 by the ICD 20, 50. In the example shown, a R-wave 86 indicates a start of an LCP blanking period 88. The duration of the LCP blanking period 88 may fall within a portion of a cardiac cycle or may extend over more than one cardiac cycle. The SICD may be seen as providing a redundant transmission 90 of a message and/or instruction to the LCP. The redundant transmission 90 may be seen as having a first message 92 and a second message 94 separated by a pause 96. As illustrated, each of the first message 92 and the second message 94

include a series of pulses, pings, or chirps defining a short time frame, a long time frame, a short time frame therebetween. It will be appreciated that this is merely illustrative, as the message may include any number of pulses, pings or chirps, defining any number of short, long or other time frames therebetween. As can be seen, the second message 94 is the same as the first message 92, and has the same pattern of pulses, pings or chirps. That is, the second message 94 is redundant to the first message 92.

[0067] In some cases, and as shown in Figure 5A, the same message(s) may be re-broadcast during each of two (or more) heat beats. This may help increase the time between redundant messages, and thus may allow for physiological changes that occur over longer time periods than just one heartbeat.

[0068] Figure 7 depicts another illustrative leadless cardiac pacemaker (LCP) that may be implanted into a patient and may operate to deliver appropriate therapy to the heart, such as to deliver anti-tachycardia pacing (ATP) therapy, cardiac resynchronization therapy (CRT), bradycardia therapy, and/or the like. As can be seen in Figure 7, the LCP 100 may be a compact device with all components housed within the or directly on a housing 120. In some cases, the LCP 100 may be considered as being an example of the LCP 18 (Figure 2) or the LCP 30 (Figure 3). In the example shown in Figure 7, the LCP 100 may include a communication module 102, a pulse generator module 104, an electrical sensing module 106, a mechanical sensing module 108, a processing module 110, a battery 112, and an electrode arrangement 114. The LCP 100 may include more or less modules, depending on the application.

[0069] The communication module 102 may be configured to communicate with devices such as sensors, other medical devices such as an SICD, and/or the like, that are located externally to the LCP 100. Such devices may be located either external or internal to the patient's body. Irrespective of the location, external devices (i.e. external to the LCP 100 but not necessarily external to the patient's body) can communicate with the LCP 100 via communication module 102 to accomplish one or more desired functions. For example, the LCP 100 may communicate information, such as sensed electrical signals, data, instructions, messages, R-wave detection markers, etc., to an external medical device (e.g. SICD and/or programmer) through the communication module 102. The external medical device may use the communicated signals, data, instructions, messages, R-wave detection markers, etc., to perform various functions, such as determining occurrences of arrhythmias, delivering electrical

stimulation therapy, storing received data, and/or performing any other suitable function. The LCP 100 may additionally receive information such as signals, data, instructions and/or messages from the external medical device through the communication module 102, and the LCP 100 may use the received signals, data, instructions and/or messages to perform various functions, such as determining occurrences of arrhythmias, delivering electrical stimulation therapy, storing received data, and/or performing any other suitable function. The communication module 102 may be configured to use one or more methods for communicating with external devices. For example, the communication module 102 may communicate via radiofrequency (RF) signals, inductive coupling, optical signals, acoustic signals, conducted communication signals, and/or any other signals suitable for communication.

[0070] In the example shown in Figure 7, the pulse generator module 104 may be electrically connected to the electrodes 114. In some examples, the LCP 100 may additionally include electrodes 114'. In such examples, the pulse generator 104 may also be electrically connected to the electrodes 114'. The pulse generator module 104 may be configured to generate electrical stimulation signals. For example, the pulse generator module 104 may generate and deliver electrical stimulation signals by using energy stored in the battery 112 within the LCP 100 and deliver the generated electrical stimulation signals via the electrodes 114 and/or 114'. Alternatively, or additionally, the pulse generator 104 may include one or more capacitors, and the pulse generator 104 may charge the one or more capacitors by drawing energy from the battery 112. The pulse generator 104 may then use the energy of the one or more capacitors to deliver the generated electrical stimulation signals via the electrodes 114 and/or 114'. In at least some examples, the pulse generator 104 of the LCP 100 may include switching circuitry to selectively connect one or more of the electrodes 114 and/or 114' to the pulse generator 104 in order to select which of the electrodes 114/114' (and/or other electrodes) the pulse generator 104 delivers the electrical stimulation therapy. The pulse generator module 104 may generate and deliver electrical stimulation signals with particular features or in particular sequences in order to provide one or multiple of a number of different stimulation therapies. For example, the pulse generator module 104 may be configured to generate electrical stimulation signals to provide electrical stimulation therapy to combat bradycardia, tachycardia, cardiac synchronization, bradycardia arrhythmias, tachycardia arrhythmias, fibrillation arrhythmias, cardiac synchronization arrhythmias and/or to produce any other suitable electrical

stimulation therapy. Some more common electrical stimulation therapies include anti-tachycardia pacing (ATP) therapy, cardiac resynchronization therapy (CRT), and cardioversion/defibrillation therapy. In some cases, the pulse generator 104 may provide a controllable pulse energy. In some cases, the pulse generator 104 may allow the controller to control the pulse voltage, pulse width, pulse shape or morphology, and/or any other suitable pulse characteristic.

[0071] In some examples, the LCP 100 may include an electrical sensing module 106, and in some cases, a mechanical sensing module 108. The electrical sensing module 106 may be configured to sense the cardiac electrical activity of the heart. For example, the electrical sensing module 106 may be connected to the electrodes 114/114', and the electrical sensing module 106 may be configured to receive cardiac electrical signals conducted through the electrodes 114/114'. The cardiac electrical signals may represent local information from the chamber in which the LCP 100 is implanted. For instance, if the LCP 100 is implanted within a ventricle of the heart (e.g. RV, LV), cardiac electrical signals sensed by the LCP 100 through the electrodes 114/114' may represent ventricular cardiac electrical signals. In some cases, the LCP 100 may be configured to detect cardiac electrical signals from other chambers (e.g. far field), such as the P-wave from the atrium.

[0072] The mechanical sensing module 108 may include one or more sensors, such as an accelerometer, a pressure sensor, a heart sound sensor, a blood-oxygen sensor, a chemical sensor, a temperature sensor, a flow sensor and/or any other suitable sensors that are configured to measure one or more mechanical/chemical parameters of the patient. Both the electrical sensing module 106 and the mechanical sensing module 108 may be connected to a processing module 110, which may provide signals representative of the sensed mechanical parameters. Although described with respect to Figure 7 as separate sensing modules, in some cases, the electrical sensing module 106 and the mechanical sensing module 108 may be combined into a single sensing module, as desired.

[0073] The electrodes 114/114' can be secured relative to the housing 120 but exposed to the tissue and/or blood surrounding the LCP 100. In some cases, the electrodes 114 may be generally disposed on either end of the LCP 100 and may be in electrical communication with one or more of the modules 102, 104, 106, 108, and 110. The electrodes 114/114' may be supported by the housing 120, although in some examples, the electrodes 114/114' may be

connected to the housing 120 through short connecting wires such that the electrodes 114/114' are not directly secured relative to the housing 120. In examples where the LCP 100 includes one or more electrodes 114', the electrodes 114' may in some cases be disposed on the sides of the LCP 100, which may increase the number of electrodes by which the LCP 100 may sense cardiac electrical activity, deliver electrical stimulation and/or communicate with an external medical device. The electrodes 114/114' can be made up of one or more biocompatible conductive materials such as various metals or alloys that are known to be safe for implantation within a human body. In some instances, the electrodes 114/114' connected to the LCP 100 may have an insulative portion that electrically isolates the electrodes 114/114' from adjacent electrodes, the housing 120, and/or other parts of the LCP 100. In some cases, one or more of the electrodes 114/114' may be provided on a tail (not shown) that extends away from the housing 120.

[0074] The processing module 110 can be configured to control the operation of the LCP 100. For example, the processing module 110 may be configured to receive electrical signals from the electrical sensing module 106 and/or the mechanical sensing module 108. Based on the received signals, the processing module 110 may determine, for example, abnormalities in the operation of the heart H. Based on any determined abnormalities, the processing module 110 may control the pulse generator module 104 to generate and deliver electrical stimulation in accordance with one or more therapies to treat the determined abnormalities. The processing module 110 may further receive information from the communication module 102. In some examples, the processing module 110 may use such received information to help determine whether an abnormality is occurring, determine a type of abnormality, and/or to take particular action in response to the information. The processing module 110 may additionally control the communication module 102 to send/receive information to/from other devices.

[0075] In some examples, the processing module 110 may include a pre-programmed chip, such as a very-large-scale integration (VLSI) chip and/or an application specific integrated circuit (ASIC). In such embodiments, the chip may be pre-programmed with control logic in order to control the operation of the LCP 100. By using a pre-programmed chip, the processing module 110 may use less power than other programmable circuits (e.g. general purpose programmable microprocessors) while still being able to maintain basic functionality, thereby potentially increasing the battery life of the LCP 100. In other examples, the processing module

110 may include a programmable microprocessor. Such a programmable microprocessor may allow a user to modify the control logic of the LCP 100 even after implantation, thereby allowing for greater flexibility of the LCP 100 than when using a pre-programmed ASIC. In some examples, the processing module 110 may further include a memory, and the processing module 110 may store information on and read information from the memory. In other examples, the LCP 100 may include a separate memory (not shown) that is in communication with the processing module 110, such that the processing module 110 may read and write information to and from the separate memory.

[0076] The battery 112 may provide power to the LCP 100 for its operations. In some examples, the battery 112 may be a non-rechargeable lithium-based battery. In other examples, a non-rechargeable battery may be made from other suitable materials, as desired. Because the LCP 100 is an implantable device, access to the LCP 100 may be limited after implantation. Accordingly, it is desirable to have sufficient battery capacity to deliver therapy over a period of treatment such as days, weeks, months, years or even decades. In some instances, the battery 112 may a rechargeable battery, which may help increase the useable lifespan of the LCP 100. In still other examples, the battery 112 may be some other type of power source, as desired.

[0077] To implant the LCP 100 inside a patient's body, an operator (e.g., a physician, clinician, etc.), may fix the LCP 100 to the cardiac tissue of the patient's heart. To facilitate fixation, the LCP 100 may include one or more anchors 116. The anchor 116 may include any one of a number of fixation or anchoring mechanisms. For example, the anchor 116 may include one or more pins, staples, threads, screws, helix, tines, and/or the like. In some examples, although not shown, the anchor 116 may include threads on its external surface that may run along at least a partial length of the anchor 116. The threads may provide friction between the cardiac tissue and the anchor to help fix the anchor 116 within the cardiac tissue. In other examples, the anchor 116 may include other structures such as barbs, spikes, or the like to facilitate engagement with the surrounding cardiac tissue.

[0078] Figure 8 depicts an example of another or second medical device (MD) 200, which may be used in conjunction with the LCP 100 (Figure 7) in order to detect and/or treat cardiac abnormalities. In some cases, the MD 200 may be considered as an example of the ICD 20 (Figure 2) or the SICD 50 (Figure 4). In the example shown, the MD 200 may include a communication module 202, a pulse generator module 204, an electrical sensing module 206, a

mechanical sensing module 208, a processing module 210, and a battery 218. Each of these modules may be similar to the modules 102, 104, 106, 108, and 110 of LCP 100. Additionally, the battery 218 may be similar to the battery 112 of the LCP 100. In some examples, however, the MD 200 may have a larger volume within the housing 220. In such examples, the MD 200 may include a larger battery and/or a larger processing module 210 capable of handling more complex operations than the processing module 110 of the LCP 100.

[0079] While it is contemplated that the MD 200 may be another leadless device such as shown in Figure 7, in some instances the MD 200 may include leads such as leads 212. The leads 212 may include electrical wires that conduct electrical signals between the electrodes 214 and one or more modules located within the housing 220. In some cases, the leads 212 may be connected to and extend away from the housing 220 of the MD 200. In some examples, the leads 212 are implanted on, within, or adjacent to a heart of a patient. The leads 212 may contain one or more electrodes 214 positioned at various locations on the leads 212, and in some cases at various distances from the housing 220. Some leads 212 may only include a single electrode 214, while other leads 212 may include multiple electrodes 214. Generally, the electrodes 214 are positioned on the leads 212 such that when the leads 212 are implanted within the patient, one or more of the electrodes 214 are positioned to perform a desired function. In some cases, the one or more of the electrodes 214 may be in contact with the patient's cardiac tissue. In some cases, the one or more of the electrodes 214 may be positioned subcutaneously and outside of the patient's heart. In some cases, the electrodes 214 may conduct intrinsically generated electrical signals to the leads 212, e.g. signals representative of intrinsic cardiac electrical activity. The leads 212 may, in turn, conduct the received electrical signals to one or more of the modules 202, 204, 206, and 208 of the MD 200. In some cases, the MD 200 may generate electrical stimulation signals, and the leads 212 may conduct the generated electrical stimulation signals to the electrodes 214. The electrodes 214 may then conduct the electrical signals and delivery the signals to the patient's heart (either directly or indirectly).

[0080] The mechanical sensing module 208, as with the mechanical sensing module 108, may contain or be electrically connected to one or more sensors, such as accelerometers, acoustic sensors, blood pressure sensors, heart sound sensors, blood-oxygen sensors, and/or other sensors which are configured to measure one or more mechanical/chemical parameters of the heart and/or patient. In some examples, one or more of the sensors may be located on the leads 212,

but this is not required. In some examples, one or more of the sensors may be located in the housing 220.

[0081] While not required, in some examples, the MD 200 may be an implantable medical device. In such examples, the housing 220 of the MD 200 may be implanted in, for example, a transthoracic region of the patient. The housing 220 may generally include any of a number of known materials that are safe for implantation in a human body and may, when implanted, hermetically seal the various components of the MD 200 from fluids and tissues of the patient's body.

[0082] In some cases, the MD 200 may be an implantable cardiac pacemaker (ICP). In this example, the MD 200 may have one or more leads, for example the leads 212, which are implanted on or within the patient's heart. The one or more leads 212 may include one or more electrodes 214 that are in contact with cardiac tissue and/or blood of the patient's heart. The MD 200 may be configured to sense intrinsically generated cardiac electrical signals and determine, for example, one or more cardiac arrhythmias based on analysis of the sensed signals. The MD 200 may be configured to deliver CRT, ATP therapy, bradycardia therapy, and/or other therapy types via the leads 212 implanted within the heart. In some examples, the MD 200 may additionally be configured provide defibrillation therapy.

[0083] In some instances, the MD 200 may be an implantable cardioverter-defibrillator (ICD). In such examples, the MD 200 may include one or more leads implanted within a patient's heart. The MD 200 may also be configured to sense cardiac electrical signals, determine occurrences of tachyarrhythmias based on the sensed signals, and may be configured to deliver defibrillation therapy in response to determining an occurrence of a tachyarrhythmia. In other examples, the MD 200 may be a subcutaneous implantable cardioverter-defibrillator (S-ICD). In examples where the MD 200 is an S-ICD, one of the leads 212 may be a subcutaneously implanted lead. In at least some examples where the MD 200 is an S-ICD, the MD 200 may include only a single lead which is implanted subcutaneously, but this is not required. In some instances, the lead(s) may have one or more electrodes that are placed subcutaneously and outside of the chest cavity. In other examples, the lead(s) may have one or more electrodes that are placed inside of the chest cavity, such as just interior of the sternum but outside of the heart H.

[0084] In some examples, the MD 200 may not be an implantable medical device. Rather,

the MD 200 may be a device external to the patient's body, and may include skin-electrodes that are placed on a patient's body. In such examples, the MD 200 may be able to sense surface electrical signals (e.g. cardiac electrical signals that are generated by the heart or electrical signals generated by a device implanted within a patient's body and conducted through the body to the skin). In such examples, the MD 200 may be configured to deliver various types of electrical stimulation therapy, including, for example, defibrillation therapy.

[0085] Figure 9 illustrates an example of a medical device system and a communication pathway through which multiple medical devices 302, 304, 306, and/or 310 may communicate. In the example shown, the medical device system 300 may include LCPs 302 and 304, external medical device 306, and other sensors/devices 310. The external device 306 may be any of the devices described previously with respect to the MD 200. Other sensors/devices 310 may also be any of the devices described previously with respect to the MD 200. In some instances, other sensors/devices 310 may include a sensor, such as an accelerometer, an acoustic sensor, a blood pressure sensor, or the like. In some cases, other sensors/devices 310 may include an external programmer device that may be used to program one or more devices of the system 300.

[0086] Various devices of the system 300 may communicate via communication pathway 308. The communication pathway 308 may include one or a number of different communication paths and/or a number of different communication modes. The communication pathway 308 may also include one or more distinct communication vectors. In some cases, for example, the LCPs 302 and/or 304 may sense intrinsic cardiac electrical signals and may communicate such signals to one or more other devices 302/304, 306, and 310 of the system 300 via communication pathway 308. In one example, one or more of the devices 302/304 may receive such signals and, based on the received signals, determine an occurrence of an arrhythmia. In some cases, the device or devices 302/304 may communicate such determinations to one or more other devices 306 and 310 of the system 300. In some cases, one or more of the devices 302/304, 306, and 310 of the system 300 may take action based on the communicated determination of an arrhythmia, such as by delivering a suitable electrical stimulation to the heart of the patient. It is contemplated that the communication pathway 308 may communicate using RF signals, inductive coupling, optical signals, acoustic signals, or any other signals suitable for communication. Additionally, in at least some examples, device communication pathway 308 may include multiple signal types. For instance, other sensors/device 310 may communicate

with the external device 306 using a first signal type (e.g. RF communication) but communicate with the LCPs 302/304 using a second signal type (e.g. conducted communication). Further, in some examples, communication between devices may be limited. For instance, as described above, in some examples, the LCPs 302/304 may communicate with the external device 306 only through other sensors/devices 310, where the LCPs 302/304 send signals to other sensors/devices 310, and other sensors/devices 310 relay the received signals to the external device 306.

[0087] In some cases, the communication pathway 308 may include conducted communication. Accordingly, devices of the system 300 may have components that allow for such conducted communication. For instance, the devices of system 300 may be configured to transmit conducted communication signals (e.g. current and/or voltage pulses) into the patient's body via one or more electrodes of a transmitting device, and may receive the conducted communication signals (e.g. pulses) via one or more electrodes of a receiving device. The patient's body may "conduct" the conducted communication signals (e.g. pulses) from the one or more electrodes of the transmitting device to the electrodes of the receiving device in the system 300. In such examples, the delivered conducted communication signals (e.g. pulses) may differ from pacing or other therapy signals. For example, the devices of the system 300 may deliver electrical communication pulses at an amplitude /pulse width that is sub-capture threshold to the heart. Although, in some cases, the amplitude/pulse width of the delivered electrical communication pulses may be above the capture threshold of the heart, but may be delivered during a blanking period of the heart (e.g. refractory period) and/or may be incorporated in or modulated onto a pacing pulse, if desired.

[0088] Delivered electrical communication pulses may be modulated in any suitable manner to encode communicated information. In some cases, the communication pulses may be pulse width modulated or amplitude modulated. Alternatively, or in addition, the time between pulses may be modulated to encode desired information. In some cases, conducted communication pulses may be voltage pulses, current pulses, biphasic voltage pulses, biphasic current pulses, or any other suitable electrical pulse as desired.

[0089] Figure 10 shows an illustrative medical device system. In Figure 10, an LCP 402 is shown fixed to the interior of the left ventricle of the heart 410, and a pulse generator 406 is shown coupled to a lead 412 having one or more electrodes 408a-408c. In some cases, the pulse generator 406 may be part of a subcutaneous implantable cardioverter-defibrillator (S-ICD), and

the one or more electrodes 408a-408c may be positioned subcutaneously. In some cases, the one or more electrodes 408a-408c may be placed inside of the chest cavity but outside of the heart, such as just interior of the sternum. In some cases, the LCP 402 may communicate with the subcutaneous implantable cardioverter-defibrillator (S-ICD). In some cases, the lead 412 and/or pulse generator 406 may include an accelerometer 414 that may, for example, be configured to sense vibrations that may be indicative of heart sounds.

[0090] In some cases, the LCP 402 may be in the right ventricle, right atrium, left ventricle or left atrium of the heart, as desired. In some cases, more than one LCP 402 may be implanted. For example, one LCP may be implanted in the right ventricle and another may be implanted in the right atrium. In another example, one LCP may be implanted in the right ventricle and another may be implanted in the left ventricle. In yet another example, one LCP may be implanted in each of the chambers of the heart.

[0091] It should be understood that this disclosure is, in many respects, only illustrative. Changes may be made in details, particularly in matters of shape, size, and arrangement of steps without exceeding the scope of the disclosure. This may include, to the extent that it is appropriate, the use of any of the features of one example embodiment being used in other embodiments.

What is claimed is:

1. An implantable medical device (IMD) configured to pace a patient's heart, the IMD disposable within a chamber of the patient's heart, the IMD comprising:

a housing;

a plurality of electrodes;

a controller housed by the housing and operably coupled to the plurality of electrodes, the controller configured to:

generate and deliver electrical pulses via a pair of the plurality of electrodes;

receive messages transmitted by conducted communication from a remote implantable medical device (IMD) via a pair of the plurality of electrodes;

receive cardiac signals via a pair of the plurality of electrodes; and

the controller is configured to receive at least one of a plurality of transmissions of the same message transmitted by conducted communication by the remote IMD during a cardiac cycle, and when more than one of the plurality of transmissions of the same message are received by the controller during the cardiac cycle, the controller is configured to treat the more than one transmissions of the same messages as communication of one message.

2. The IMD of claim 1, wherein the controller is configured to institute a blanking period during the cardiac cycle during which received cardiac signals are ignored by the controller.

3. The IMD of claim 2, wherein the controller is configured to receive at least one of a plurality of redundant transmissions of the same message during the blanking period.

4. The IMD of any one of claims 2 or 3, wherein the controller is configured to institute the blanking period at a predetermined time following a detected R-wave in the received cardiac signal.

5. The IMD of any one of claims 2 to 4, wherein the blanking period is configured to extend over at least 10 percent of a cardiac cycle, or at least 20 percent of a cardiac cycle, but less than an entire cardiac cycle.

6. The IMD of any one of claims 1 to 5, wherein the plurality of redundant transmissions of the same message are received over a time duration that allows for physiological changes in the patient that result in differing communication vectors.

7. The IMD of any one of claims 1 to 6, wherein the controller is configured to:

generate and deliver pacing pulses via a first pair of the plurality of electrodes;

receive messages transmitted from the remote implantable medical device (IMD) via a second pair of the plurality of electrodes;

receive cardiac signals via a third pair of the plurality of electrodes; and

wherein the first pair of electrodes, the second pair of electrodes and the third pair of electrodes correspond to the same pair of electrodes.

8. The IMD of any one of claims 1 to 7, wherein the message is a command.

9. The IMD of claim 8, wherein the command is an ATP command that instructs the controller to deliver Anti-Tachycardia Pacing (ATP) therapy to the patient's heart via a pair of the plurality of electrodes.

10. An implantable medical device (IMD) configured to sense electrical cardiac activity of a patient's heart and to deliver therapy to the patient's heart, the IMD comprising:

a housing;

a plurality of electrodes;

a controller housed by the housing and operably coupled to the plurality of electrodes, the controller configured to sense cardiac electrical activity via two or more of the plurality of electrodes and to deliver therapy via two or more of the plurality of electrodes;

the controller configured to analyze the sensed cardiac electrical activity and to make a determination as to whether to provide a message to a remote implantable medical device (IMD) secured to the patient's heart; and

wherein, when the controller makes a determination to provide a message to the remote IMD, the controller is configured to transmit a plurality of transmissions of the message by conducted communication during a cardiac cycle of the patient's heart.

11. The IMD of claim 10, wherein the controller is configured to add a tracking number to each of the plurality of transmissions of the message.

12. The IMD of any one of claims 10 or 11, wherein the IMD is incapable of receiving a conducted communication messages from the remote IMD.

13. The IMD of any one of claims 10 to 12, wherein each of the plurality of transmissions of the message comprise a command to the remote IMD to deliver one or more pacing pulses, and the controller of the IMD is configured to monitor cardiac electrical activity for an indication that the remote IMD delivered the one or more pacing pulses.

14. The IMD of any one of claims 10 to 13, wherein after the controller makes a determination to provide a message to the remote IMD, the controller is configured to transmit the plurality of transmissions of the message within a communication time period, wherein the communication time period has a time duration sufficiently long to allow the remote IMD to change orientations relative to the IMD as a result of physiological changes in the patient to result in a substantially different signal strength at the remote IMD.

15. A medical system for sensing and regulating cardiac activity of a patient, the medical system comprising:

an implantable cardioverter defibrillator (ICD) configured to sense electrical cardiac activity of a patient's heart and to deliver therapy to the patient's heart, the ICD comprising:

a housing;

a plurality of electrodes;

an ICD controller housed by the housing of the ICD and operably coupled to the plurality of electrodes of the ICD, the ICD controller configured to sense cardiac electrical activity via two or more of the plurality of electrodes of the ICD and to deliver therapy via two or more of the plurality of electrodes of the ICD;

the ICD controller further configured to analyze the sensed cardiac electrical activity and to make a determination as to whether to instruct a leadless cardiac pacemaker (LCP) to provide therapy to the patient's heart;

wherein, when the ICD controller makes a determination to instruct the LCP to provide therapy to the patient's heart, the ICD controller is configured to transmit a plurality of transmissions of an instruction during a single cardiac cycle of the patient's heart;

a leadless cardiac pacemaker (LCP) configured to pace a patient's heart, the LCP disposable within a chamber of the patient's heart, the LCP comprising:

a housing;

a plurality of electrodes exposed external to the housing of the LCP;

an LCP controller housed by the housing of the LCP and operably coupled to the plurality of electrodes of the LCP, the LCP controller configured to:

generate and deliver pacing pulses via two or more of the plurality of electrodes of the LCP;

receive messages transmitted via two or more of the plurality of electrodes of the LCP;

receive cardiac signals via two or more of the plurality of electrodes of the LCP;

wherein the LCP controller is further configured to receive at least one of the plurality of transmissions of the instruction transmitted by the ICD during the single cardiac cycle, and when more than one of the plurality of transmissions of the instruction are received by the LCP controller during the single cardiac cycle, the LCP controller is configured to treat the more than one transmissions of the instruction as one instruction, and only

executes the one instruction and not each of the plurality of transmissions of the instruction.

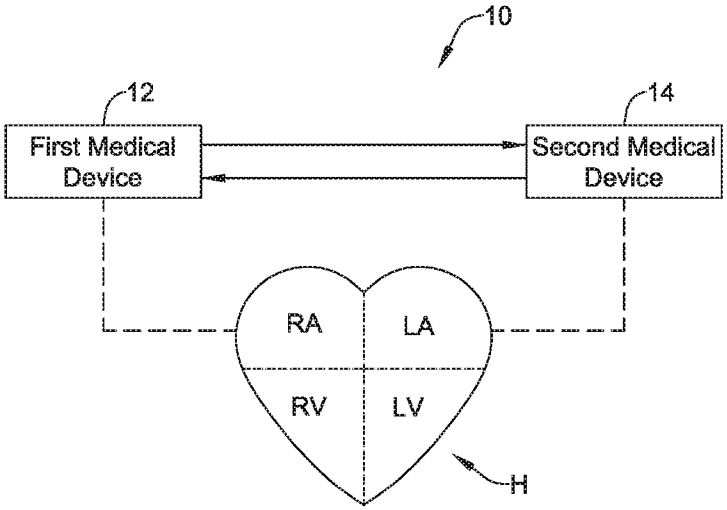
10
12
14
First Medical Device
Second Medical Device
RA
LA
RV
LV
H

FIG. 1

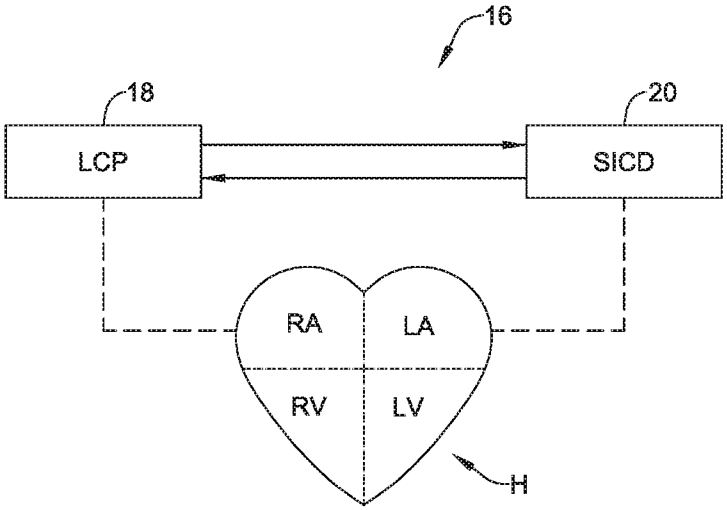

FIG. 2

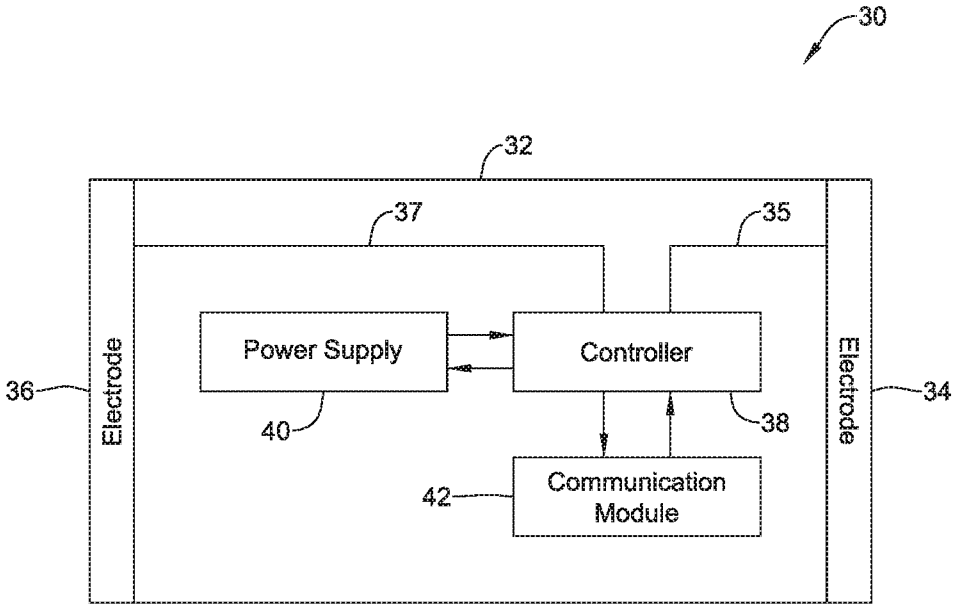
30
32
37
35
Power Supply
Controller
Electrode
Electrode
36
34
40
38
42
Communication Module

FIG. 3

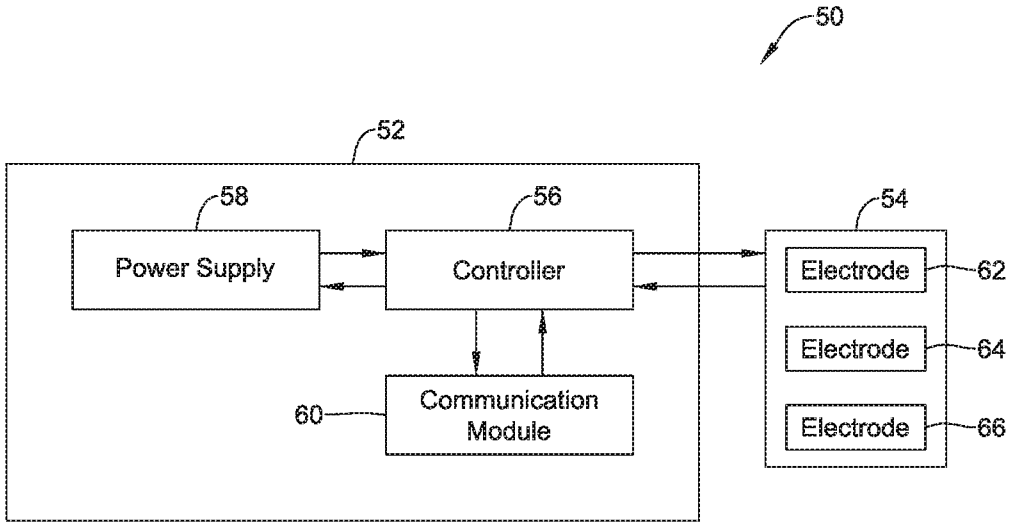
50
52
58
56
54
Power Supply
Controller
Electrode
62
Electrode
64
Electrode
66
60
Communication Module

FIG. 4

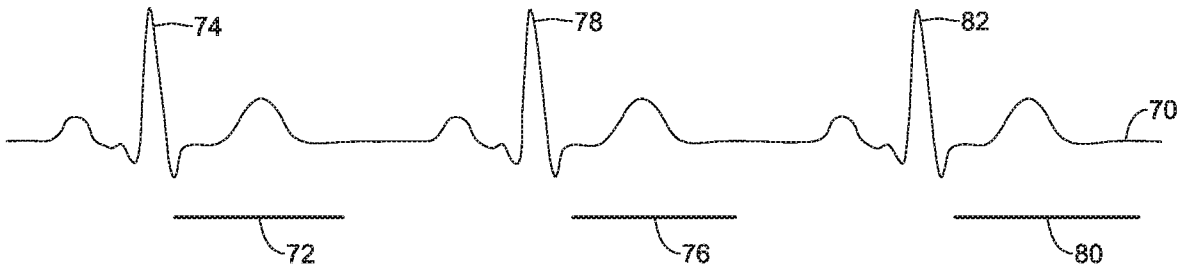

FIG. 5A

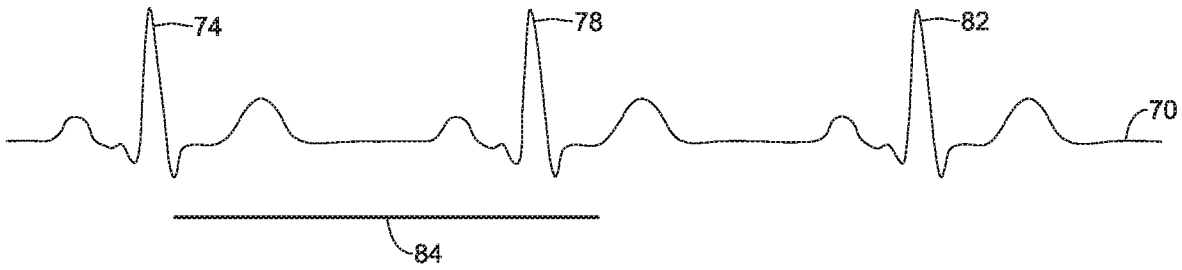

FIG. 5B

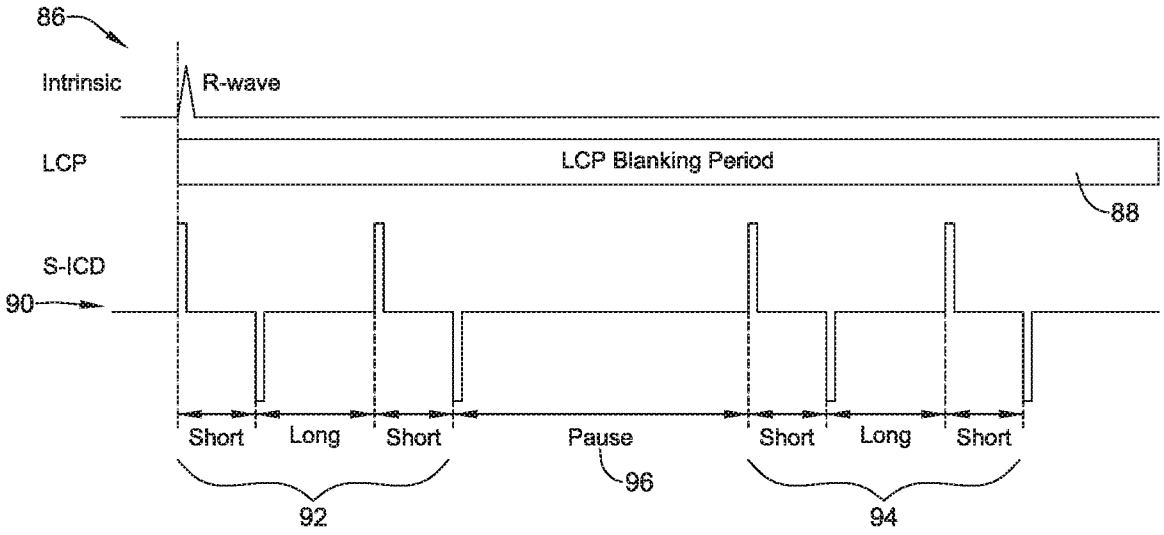
86
Intrinsic
R-wave
LCP
LCP Blanking Period
88
S-ICD
90
Short
Long
Short
Pause
96
Short
Long
Short
92
94

FIG. 6

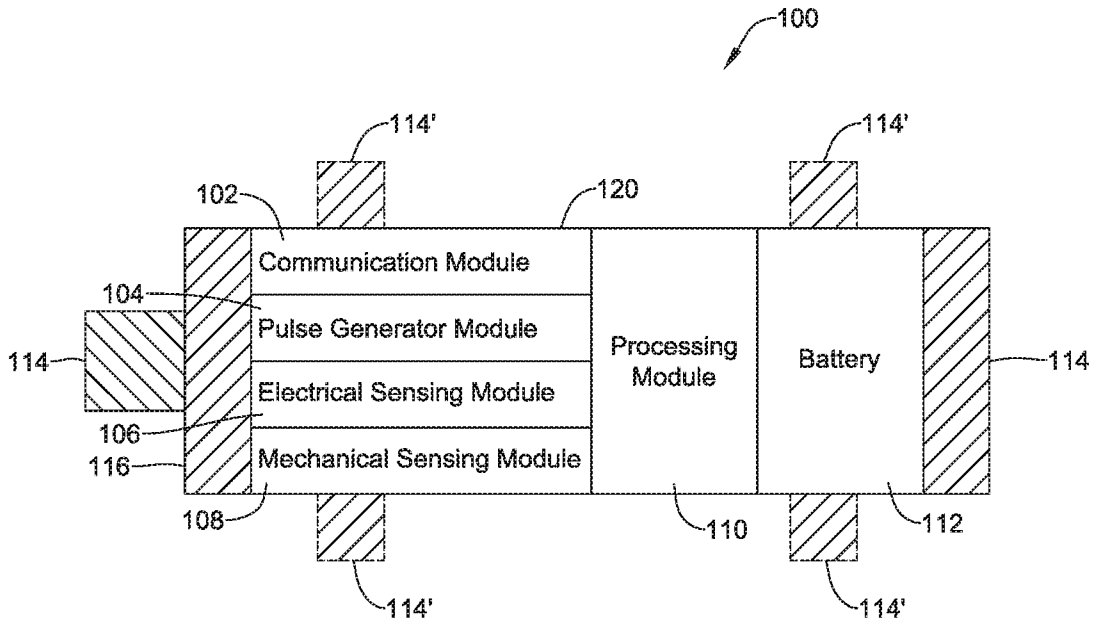
100
114'
114'
102
120
Communication Module
104
Pulse Generator Module
Processing Module
Battery
114
114
Electrical Sensing Module
106
116
Mechanical Sensing Module
108
110
112
114'
114'

FIG. 7

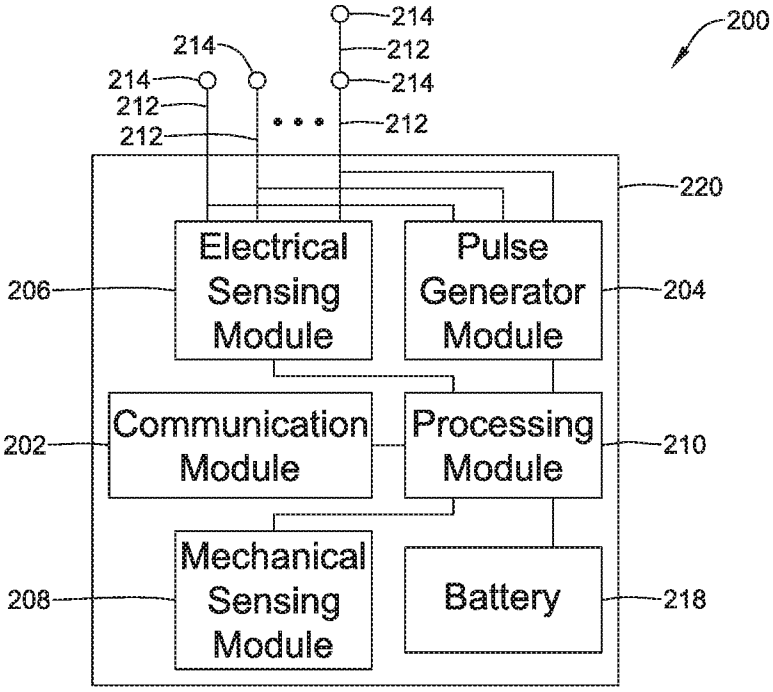
214
214
214
212
214
212
212
212
200
220
Electrical Sensing Module
206
Pulse Generator Module
204
Communication Module
202
Processing Module
210
Mechanical Sensing Module
208
Battery
218

FIG. 8

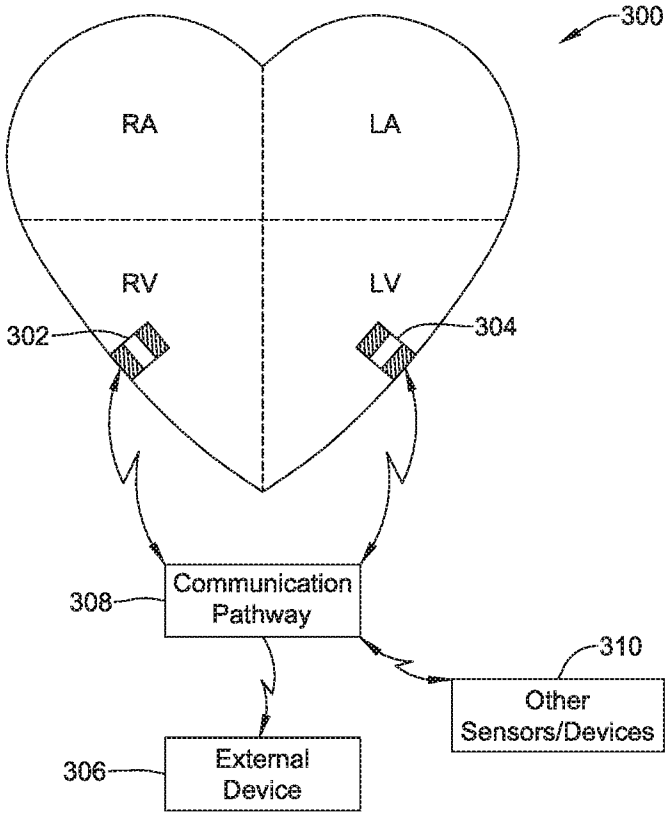
300
RA
LA
RV
LV
302
304
Communication Pathway
308
310
Other Sensors/Devices
External Device
306

FIG. 9

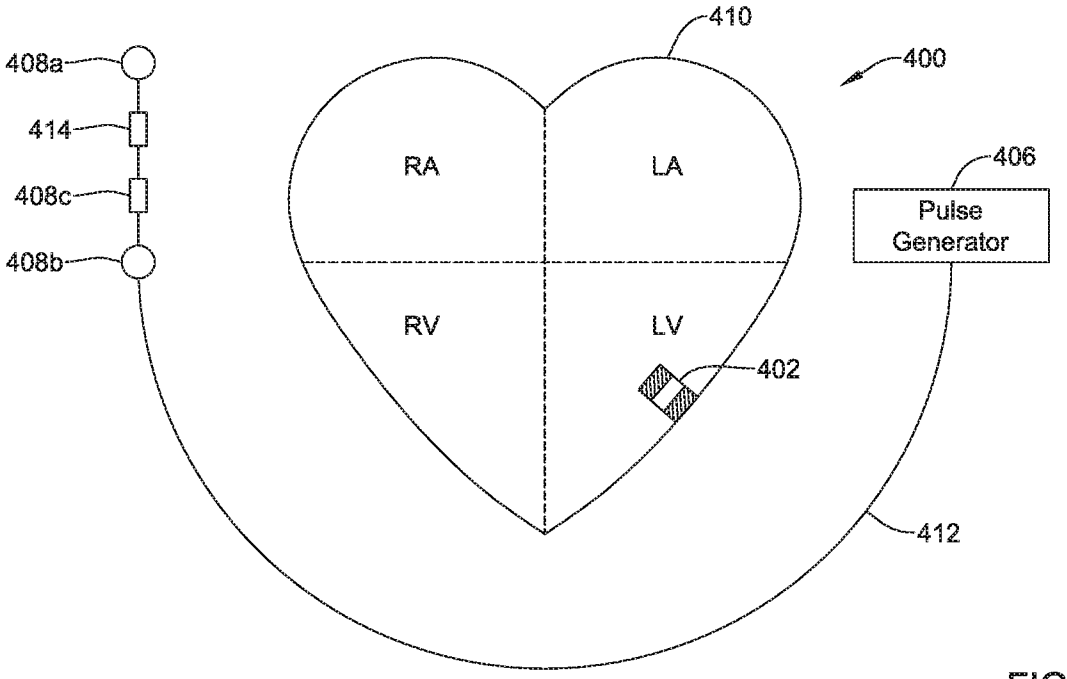
410
400
408a
414
408c
408b
RA
LA
406
Pulse Generator
RV
LV
402
412

FIG. 10

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2018/015268

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61N1/372 A61N1/375
ADD. A61N1/37 A61B5/00 H04B13/00 A61N1/39

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
A61N A61B H04B

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2016/121128 A1 (FISHLER MATTHEW G [US] ET AL) 5 May 2016 (2016-05-05) abstract; figures 1-20 paragraphs [0033] - [0193]	1-15
A	US 2016/121129 A1 (PERSSON BENJAMIN T [US] ET AL) 5 May 2016 (2016-05-05) abstract; figures 1-6 paragraphs [0026] - [0085]	1-15
A	WO 2016/022397 A1 (CARDIAC PACEMAKERS INC [US]) 11 February 2016 (2016-02-11) abstract; figures 1-16 pages 12-38	1-15

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

☒ See patent family annex.

* Special categories of cited documents :

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
29 May 2018	07/06/2018

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Mendelevitch, L

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2018/015268

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2016121128 A1	05-05-2016	NONE	
US 2016121129 A1	05-05-2016	NONE	
WO 2016022397 A1	11-02-2016	CN 106794350 A	31-05-2017
		EP 3177362 A1	14-06-2017
		JP 2017523002 A	17-08-2017
		US 2016038742 A1	11-02-2016
		US 2017136248 A1	18-05-2017
		US 2017281961 A1	05-10-2017
		WO 2016022397 A1	11-02-2016

专利名称(译)	带冗余消息传输的体内设备通信		
公开(公告)号	EP3573706A1	公开(公告)日	2019-12-04
申请号	EP2018704693	申请日	2018-01-25
[标]申请(专利权)人(译)	心脏起搏器股份公司		
申请(专利权)人(译)	心脏起搏器，INC.		
当前申请(专利权)人(译)	心脏起搏器，INC.		
[标]发明人	KOOP BRENDAN EARLY HUELSKAMP PAUL NELSON KYLE LEONARD MAILE KEITH R LUDWIG JACOB M		
发明人	KOOP, BRENDAN EARLY HUELSKAMP, PAUL JUFFER, LANCE ERIC NELSON, KYLE LEONARD MAILE, KEITH R. LUDWIG, JACOB M.		
IPC分类号	A61N1/372 A61N1/375 A61N1/37 A61B5/00 H04B13/00 A61N1/39		
CPC分类号	A61B5/0028 A61N1/3702 A61N1/37205 A61N1/37211 A61N1/37288 A61N1/3756 A61N1/395 A61N1/39622 H04B13/005 A61N1/3621 A61N1/365 A61N1/37252 A61N1/37518		
优先权	62/450833 2017-01-26 US		
外部链接	Espacenet		

摘要(译)

植入式医疗设备（IMD），例如但不限于无引线心脏起搏器（LCP），皮下植入式心律转复除颤器（SICD），经静脉植入式心律转复除颤器，神经刺激器（NS），植入式监护仪（IM），可配置为彼此沟通。在一些情况下，第一IMD可以将指令发送到第二IMD。为了提高成功接收传输的机会，第一IMD可以在特定时间帧期间多次传输指令，例如在单个心跳期间。如果第二IMD不止一次接收到该消息，则第二IMD识别出该消息是冗余的并且相应地起作用。