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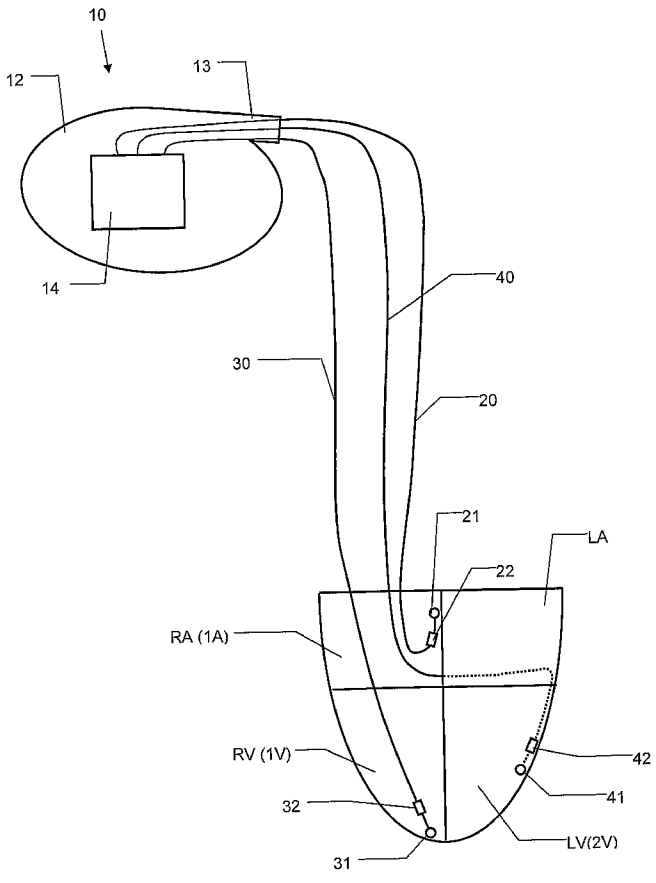
(54) Title: AN IMPLANTABLE HEART STIMULATING DEVICE, SYSTEM AND METHOD



(57) Abstract: The invention concerns an implantable bi- ventricular heart stimulating device (10) including a control circuit (14) comprising a first atrial sensing and/or pacing circuit (25, 27) and ventricular sensing (35, 45) and pacing (37, 47) circuits for a first (IV) and a second (2V) ventricle. The device (10) is arranged to normally operate with a time VV between a pacing pulse delivered, or inhibited, by a first ventricular pacing circuit (37) and a pacing pulse delivered, or inhibited, by a second ventricular pacing circuit (47). The device (10) is arranged to determine a particular time VV_{cts} that is to be used instead of VV during a capture threshold search. The invention also concerns a system including such a device (10) and a method of, in a human or animal being, performing a capture threshold search.

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An implantable heart stimulating device, system and method

BACKGROUND OF THE INVENTION

1. Field of the invention

The present invention relates to an implantable heart stimulating device with which it is possible to stimulate both the ventricles of a heart, i.e. a bi-ventricular pacer.

The invention also relates to a system including such a device and to a method of, in a human or animal being, performing a capture threshold search.

2. Description of the prior art

Several different implantable devices for stimulating a heart are known. The devices are normally able to sense the electrical activity of the heart. Some implantable devices are able to deliver stimulation pulses to and/or sense the right atrium (in some case even the left atrium) and also to deliver stimulation pulses to and sense both the left and right ventricle.

Devices that are able to deliver stimulation pulses to both the left and right ventricle can be called bi-ventricular pacers. Such devices can be used to treat patients who suffer from different severe cardiac problems, e.g. patients suffering from congestive heart failure (CHF). CHF is defined generally as the inability of the heart to deliver a sufficient amount of blood to the body. CHF can have different causes. It can for example be caused by a left bundle branch block (LBBB) or a right bundle branch block (RBBB). By using bi-ventricular pacing, the contraction of the ventricles can be controlled in order to improve the ability of the heart to pump blood. The stimulation pulses to the two ventricles can be delivered simultaneously but it is also known that the stimulation pulses to the two ventricles are delivered with a short time delay between them in order to optimise the pumping performance of the heart.

US-A-5 720 768 describes different possible electrode positions in order to stimulate or sense the different chambers of the heart.

US-A-6 070 100 describes that electrodes may be positioned in both the left and the right atrium as well as in the left and the right ventricles.

In connection with implantable pacers, it is known to detect the capture of the heart, i.e. to detect whether the heart actually reacts to a delivered stimulation pulse. If the heart is not captured, it is possible to arrange the pacer to deliver a back-up pulse with a higher pulse energy than the first pulse. It is also possible to increase the pulse energy in future stimulation pulses if capture is not detected. In order to save battery it is important that the stimulation pulses are not delivered with an unnecessarily high energy. In order to determine a suitable pulse energy, it is known to perform an automatic threshold/capture search. By varying the energy of the stimulation pulses, and by detecting whether capture occurs, it is thus possible to find a threshold value for the stimulation pulse energy. Based on the threshold value, a suitable stimulation pulse energy can be determined.

The detection of capture involves several problems. Different signals from the heart or generated by the pacemaker may interfere with each other, which may make the detection of capture difficult. The evoked response that it is intended to detect may thus be hidden because of other electrical phenomena. It is particularly difficult to detect capture in a bi-ventricular pacer, since in such a pacer there are more delivered and detected signals which may interfere with each other.

A concept used in this technical field is the concept "fusion". A fusion may occur when an intrinsic depolarisation of the heart takes place simultaneously, or at least almost simultaneously, with a stimulation pulse from the heart stimulating device. Fusion should be avoided when performing a threshold/capture search. In order to avoid such fusion, it is known to temporarily, during such a threshold/capture search, shorten the AV-delay and the PV-delay. Typically, these delays are shortened such that they are set at a predetermined fixed value (e.g. 50ms and 25ms, respectively) during such a search.

US 6 498 950 B1 describes a device and method for performing automatic capture/threshold determination in a mono-ventricular pacer. The document describes a method and a device that instead of using the mentioned fixed AV-delay and the PV-delay during a threshold/capture search, use delays adapted to the particular patient. According to this document, the device periodically measures the AR/PR conduction

times and tabulate and/or otherwise process this data. When an automatic capture/threshold determination occurs, this measured conduction data, which corresponds to the particular patient, is used to adjust the AV/PV delays while minimizing patient discomfort and adverse hemodynamic effects.

SUMMARY OF THE INVENTION

One object of the present invention is to provide an implantable bi-ventricular heart stimulating device with which a threshold/capture search can be carried in an hemodynamically optimal manner. Another object is to provide such a device with which it is possible to adjust certain timing parameters in an optimal manner when performing such a threshold/capture search. A further object it to provide such a device with which it is possible to deliver ventricular pacing pulses to both ventricles even during the time cycles when such a threshold/capture search is carried out. Further objects or advantages of the invention will become clear from the following description and claims.

The above objects are achieved by an implantable heart stimulating device including a control circuit comprising:

at least one memory;

a first atrial sensing and/or pacing circuit, adapted to communicate with a first atrial sensing and/or pacing electrode suited to be positioned in an atrium of a heart, wherein said first atrial sensing and/or pacing circuit is adapted to enable sensing and/or pacing of such an atrium;

a first ventricular sensing circuit, adapted to communicate with a first ventricular sensing electrode suited to be positioned in or at a first ventricle of a heart, wherein said first ventricular sensing circuit is adapted to enable sensing of such a ventricle;

a first ventricular pacing circuit, adapted to communicate with a first ventricular pacing electrode suited to be positioned in or at a first ventricle of a heart, wherein said first ventricular pacing circuit is adapted to enable pacing of such a ventricle;

a second ventricular sensing circuit, adapted to communicate with a second ventricular sensing electrode suited to be positioned in or at a second ventricle of a heart, wherein said second ventricular sensing circuit is adapted to enable sensing of such a ventricle;

a second ventricular pacing circuit, adapted to communicate with a second ventricular pacing electrode suited to be positioned in or at a second ventricle of a heart, wherein said second ventricular pacing circuit is adapted to enable pacing of such a ventricle;

said control circuit being arranged to be able to detect an evoked response to a pacing pulse delivered by said first ventricular pacing circuit by sensing, with said first ventricular sensing circuit, within a first time window that follows after a pacing pulse delivered by said first ventricular pacing circuit;

said control circuit being arranged to be able to detect an evoked response to a pacing pulse delivered by said second ventricular pacing circuit by sensing, with said second ventricular sensing circuit, within a second time window that follows after a pacing pulse delivered by said second ventricular pacing circuit;

said control circuit being arranged to be able to operate with time cycles corresponding to normal heart cycles;

said control circuit being arranged to be able to operate, during the normal operation of the device, with a value PV and/or AV, where PV is the time between the sensing with said first atrial sensing and/or pacing circuit and a subsequent pacing pulse, which may also be inhibited, of said first ventricular pacing circuit and AV is the time between the pacing with said first atrial sensing and/or pacing circuit and a subsequent pacing pulse, which may also be inhibited, of said first ventricular pacing circuit;

said control circuit being arranged to, within a time cycle, be able to deliver pacing pules with both said first ventricular pacing circuit and said second ventricular pacing circuit with a time gap VV, during the normal operation of the device, between a pacing pulse delivered, or inhibited, by said first ventricular pacing circuit and a pacing pulse delivered, or inhibited, by said second ventricular pacing circuit, wherein said time gap VV is ≥ 0;

said control circuit being arranged to be able to carry out a capture threshold search, by, during a plurality of time cycles, vary the energy of the pacing pulses delivered by said first ventricular pacing circuit and said second ventricular pacing circuit and to detect, with said first ventricular sensing circuit and said second ventricular sensing circuit, respectively, possible evoked responses during said first time window and said second time window, respectively, such that a suitable pulse energy for the pacing pulses delivered by said first ventricular pacing circuit and said second ventricular pacing circuit, respectively, is determined;

wherein said control circuit is arranged to determine a time gap VV_{cts}, that is to be used instead of VV during said capture threshold search, wherein the determination of said time gap VV_{cts} involves the calculation of a value

$V1R2 - ER2 - \Delta_{V1R2}$,

where V1R2 is a value which is stored in said memory and which represents the time between a pacing pulse delivered by said first ventricular pacing circuit and a

subsequent event sensed by said second ventricular sensing circuit during a time cycle when no pacing pulse is delivered by said second ventricular pacing circuit, ER2 is said second time window and Δ_{V1R2} is a predetermined value that takes expected variations in V1R2 into account,
and wherein VV_{cts} is determined such that
$VV_{cts} \leq V1R2 - ER2 - \Delta_{V1R2}$ but with the additional condition that VV_{cts} shall not be less than 0 even if $V1R2 - ER2 - \Delta_{V1R2}$ is less than 0.

The device is thus arranged to calculate a particular time gap VV_{cts}. VV_{cts} can thus be used when performing a capture threshold search. If this time gap VV_{cts} is used instead of VV during the capture threshold search, then it is avoided that an R-wave that is being transferred to the second ventricle from the first ventricle interferes with the capture threshold search. Furthermore, this particular VV_{cts} is calculated in order to only reduce VV as much as is necessary in order to perform the capture threshold search. This means that this search can be carried out in a hemodynamically optimal manner. Moreover, it is possible to perform this capture threshold search in the second ventricle even if pacing pulses are delivered by the first ventricular pacing circuit during the same time cycle.

It can be noted that VV_{cts} is never less than 0, i.e. the order in which ventricular pulses are emitted by the first and second ventricular pacing circuits is not reversed.

It should be noted that when it is said that for example a certain circuit is adapted to enable sensing and pacing of an atrium or ventricle, this does not mean that the circuit actually is connected to an atrium or a ventricle. Instead it means that if the heart stimulating device, in which the circuit in question is included, is actually implanted in a body with suitably located electrodes, then the circuit in question would be able to sense and pace an atrium or a ventricle. Similarly, the expressions relating to atrial or ventricular pacing and sensing circuits or the like only means that these circuits are adapted to be able to sense typical atrial or ventricular events and that they are able to deliver pulses which are of the kind that is typical for stimulating atria or ventricles. A "pacing pulse" or the like is thus a pulse with an energy and morphology which would make it suitable to pace the relevant heart chamber.

It should be noted that the capture threshold search can be performed either simultaneously, i.e. during the same time cycles, for both the first and second ventricles or, alternatively, for one ventricle at a time.

According to one embodiment of the invention, the control circuit is arranged such that VV_{cts} is selected as the smallest of the following values:
VV and
V1R2 - ER2 - Δ_{V1R2},
but if V1R2 - ER2 - Δ_{V1R2} is less than 0, then VV_{cts} is selected to be 0.

By selecting VV_{cts} in this manner, an optimal VV_{cts} for use during the capture threshold search is determined. VV is thus only reduced if this is necessary in order to avoid the above discussed problem concerning a transferred R-wave to the second ventricle.

According to a further embodiment of the invention, the control circuit is arranged to determine a time AV_{cts}, that is to be used instead of AV during said capture threshold search, wherein the determination of said time AV_{cts} involves the calculation of a value
AR1 - ER1 - Δ_{AR1},
where AR1 is a value which is stored in said memory and which represents the time between a pacing pulse delivered by said first atrial sensing and/or pacing circuit and a subsequent event sensed by said first ventricular sensing circuit during a time cycle when no pacing pulse is delivered by said first ventricular pacing circuit, ER1 is said first time window and Δ_{AR1} is a predetermined value that takes expected variations in AR1 into account,
and wherein AV_{cts} is determined such that
$AV_{cts} \leq$ AR1 - ER1 - Δ_{AR1} but with the additional condition that AV_{cts} shall not be less than a predetermined minimum value for AV_{cts}, wherein said minimum value is ≥ 0, even if AR1 - ER1 - Δ_{AR1} is less than said minimum value.

The device thus determines a value AV_{cts} that can be used instead of AV during a capture threshold search. It is thereby avoided that an R-wave in the first ventricle, as a result of a delivered pacing pulse in the atrium, interferes with the capture threshold search.

The determination of said time AV_{cts} can also involve the calculation of a value
$AR2 - VV_{cts} - ER2 - \Delta_{AR2}$,
where AR2 is a value which is stored in said memory and which represents the time between a pacing pulse delivered by said first atrial sensing and/or pacing circuit and a subsequent event sensed by said second ventricular sensing circuit during a time cycle when no pacing pulse is delivered by said second ventricular pacing circuit, VV_{cts} is as previously defined, ER2 is said second time window and Δ_{AR2} is a predetermined value that takes expected variations in AR2 into account,
and wherein AV_{cts} is determined such that
$AV_{cts} \leq AR2 - VV_{cts} - ER2 - \Delta_{AR2}$ but with the additional condition that AV_{cts} shall not be less than a predetermined minimum value for AV_{cts}, wherein said minimum value is ≥ 0, even if $AR2 - VV_{cts} - ER2 - \Delta_{AR2}$ is less than said minimum value.

By using this calculation when determining AV_{cts}, it is also avoided that an R-wave in the second ventricle, caused by a previous pacing pulse delivered by the first atrial pacing circuit, interferes with the capture threshold search.

The AV_{cts} can be selected as the smallest of the following values:
AV,
$AR1 - ER1 - \Delta_{AR1}$, and
$AR2 - VV_{cts} - ER2 - \Delta_{AR2}$,
but with the additional condition that AV_{cts} shall not be less than a predetermined minimum value for AV_{cts}, wherein said minimum value is ≥ 0, even if $AR1 - ER1 - \Delta_{AR1}$ or $AR2 - VV_{cts} - ER2 - \Delta_{AR2}$ is less than said minimum value.

In this manner, an optimal AV_{cts} can be determined.

According to one embodiment of the invention, the minimum value for AV_{cts} can be larger than 0 but less than 90ms, for example, larger than 30ms but less than 70ms. Such minimum values for AV_{cts} have been found to be appropriate.

According to a further embodiment of the invention, the control circuit is arranged to determine a time PV_{cts}, that is to be used instead of PV during said capture threshold search, wherein the determination of said time PV_{cts} involves the calculation of a value
$PR1 - ER1 - \Delta_{PR1}$,

where PR1 is a value which is stored in said memory and which represents the time between an event sensed by said first atrial sensing and/or pacing circuit and a subsequent event sensed by said first ventricular sensing circuit during a time cycle when no pacing pulse is delivered by said first ventricular pacing circuit, ER1 is said first time window and Δ_{PR1} is a predetermined value that takes expected variations in PR1 into account,
and wherein PV_{cts} is determined such that
$PV_{cts} \leq PR1 - ER1 - \Delta_{PR1}$ but with the additional condition that PV_{cts} shall not be less than a predetermined minimum value for PV_{cts}, wherein said minimum value is ≥ 0, even if $PR1 - ER1 - \Delta_{PR1}$ is less than said minimum value.

In this manner, a suitable PV_{cts} can be determined such that it is prevented that an R-wave in the first ventricle, caused by a previous sensed atrial event, interferes with the capture threshold search.

In analogy with the above described embodiments in connection with AV_{cts} ,the determination of said time PV_{cts} can also involve the calculation of a value
$PR2 - VV_{cts} - ER2 - \Delta_{PR2}$,
where PR2 is a value which is stored in said memory and which represents the time between an event sensed by said first atrial sensing and/or pacing circuit and a subsequent event sensed by said second ventricular sensing circuit during a time cycle when no pacing pulse is delivered by said second ventricular pacing circuit, VV_{cts} is as previously defined, ER2 is said second time window and Δ_{PR2} is a predetermined value that takes expected variations in PR2 into account,
and wherein PV_{cts} is determined such that
$PV_{cts} \leq PR2 - VV_{cts} - ER2 - \Delta_{PR2}$ but with the additional condition that PV_{cts} shall not be less than a predetermined minimum value for PV_{cts}, wherein said minimum value is ≥ 0, even if $PR2 - VV_{cts} - ER2 - \Delta_{PR2}$ is less than said minimum value.

In this manner it is possible to determine PV_{cts} such that an R-wave in the second ventricle, caused by a previous sensed atrial event, does not interfere with the capture threshold search.

PV_{cts} can be selected as the smallest of the following values:
PV,
$PR1 - ER1 - \Delta_{PR1}$, and

$PR2 - VV_{cts} - ER2 - \Delta_{PR2}$,
but with the additional condition that PV_{cts} shall not be less than a predetermined minimum value for PV_{cts}, wherein said minimum value is ≥ 0, even if $PR1 - ER1 - \Delta_{PR1}$ or $PR2 - VV_{cts} - ER2 - \Delta_{PR2}$ is less than said minimum value.

In this manner an optimal PV_{cts} can be determined.

According to one embodiment of the invention, the minimum value for PV_{cts} is larger than 0 but less than 60ms, for example larger than 10ms but less than 40ms. Such minimum values for PV_{cts} have been found to be appropriate.

According to a further embodiment of the invention, the control circuit is arranged to be able to carry out a search procedure for determining V1R2, and to store the determined value of V1R2 in said memory, such that this stored value can be used when determining VV_{cts} in accordance with any of the above described embodiments. According to this embodiment, the device is thus also arranged to be able to determine V1R2. The determined V1R2 can then be used when determining VV_{cts}.

The control circuit can be arranged such that the procedure for determining V1R2 also involves determining the variation in V1R2 and the determination of an appropriate value for Δ_{V1R2} and to store the determined value for Δ_{V1R2} in said memory, such that this stored value can be used when determining VV_{cts} in accordance with any of the above described embodiments. The device can thus also be arranged to automatically determine also Δ_{V1R2}. This determined value can then be used when determining VV_{cts}.

The control circuit can be arranged such that the procedure for determining V1R2 includes the delivery of a pacing pulse by said first ventricular pacing circuit and the sensing of a subsequent event by said second ventricular sensing circuit during the same time cycle, wherein the control circuit is arranged to carry out this procedure during a part of the time cycle when no atrial events are likely to be sensed by said second ventricular sensing circuit. The control circuit is thus set up to determine V1R2 during a portion of the time cycle when no atrial events are likely to cause sensing in the second ventricular sensing circuit. This means that the control circuit ensures that the detected R-wave actually is caused by a ventricular event in the first ventricle.

Analogously to the above determination of V1R2, the control circuit can be arranged to be able to carry out a search procedure for determining AR1, AR2, PR1, PR2, Δ_{AR1}, Δ_{AR2}, Δ_{PR1} and/or Δ_{PR2} and to store the determined values in said memory. How this is done is clear from the claims and from the description below. The device is thus arranged to be able to determine all the different values that are to be used when determining VV_{cts}, AV_{cts} and PV_{cts}.

According to another aspect of the invention, the invention provides an implantable heart stimulating system comprising:
an implantable heart stimulating device according to any of the preceding embodiments, and
said first atrial sensing and/or pacing electrode ,
said first ventricular sensing electrode ,
said first ventricular pacing electrode,
said second ventricular sensing electrode, and
said second ventricular pacing electrode ,
wherein said electrodes are operationally connected to said device.

The system can also comprise a plurality of leads, on which said electrodes are positioned, which leads are connected to said device. The first ventricular sensing electrode can be the same as the first ventricular pacing electrode and the second ventricular sensing electrode can be the same as the second ventricular pacing electrode.

Such a system is thus suitable to be used in a human or animal being.

Another aspect of the invention concerns a method of, in a human or animal being, performing a capture threshold search with the help of a heart stimulating device that, during the normal operation of the device, is set up to operate with times VV, AV and/or PV, ER1 and ER2, where VV is the time between a pacing pulse delivered, or inhibited, to a first ventricle and a pacing pulse delivered, or inhibited, during the same heart cycle, to a second ventricle, wherein said time gap VV is ≥ 0, where AV is the time between a pacing pulse to a first atrium and a subsequent pacing pulse, which may also be inhibited, to said first ventricle, where PV is the time between a sensed event in said first atrium and a subsequent pacing pulse, which may also be inhibited, to said first ventricle, where ER1 is the evoked response detection window for the first

ventricle and where ER2 is the evoked response detection window for the second ventricle. The method includes the following steps:
determine a value V1R2, where V1R2 represents the time between a pacing pulse to the first ventricule and a subsequent event in the second ventricle, during a heart cycle when no pacing pulse is delivered to the second ventricle;
determine Δ_{V1R2}, where Δ_{V1R2} is a value that takes expected variations in V1R2 into account;
determine a time gap VV_{cts}, that is to be used instead of VV during said capture threshold search, such that
$VV_{cts} \leq V1R2 - ER2 - \Delta_{V1R2}$ but with the additional condition that VV_{cts} shall not be less than 0 even if $V1R2 - ER2 - \Delta_{V1R2}$ is less than 0; and
perform a capture threshold search by using VV_{cts} instead of VV.

The method can involve the selection of VV_{cts} as the smallest of the following values:
VV and
$V1R2 - ER2 - \Delta_{V1R2}$,
but if $V1R2 - ER2 - \Delta_{V1R2}$ is less than 0, then VV_{cts} is selected to be 0.

With such a method, advantages corresponding to those described above in connection with the device are obtained.

In analogous manners, the method can also involve the determination of AR1, AR2, PR1, PR2, Δ_{AR1}, Δ_{AR2}, Δ_{PR1} and/or Δ_{PR2} and to use the determined values when determining AV_{cts} and PV_{cts}, and, furthermore, to perform a capture threshold search by using AV_{cts} and PV_{cts} instead of AV and PV.

By actually using the determined values for VV_{cts}, AV_{cts} and PV_{cts} during a capture threshold search, this search can be performed in an hemodynamically optimal manner.

The method can be performed on a human or animal being suffering from congestive heart failure, for example on a on a human or animal being suffering from a bundle branch block.

Further aspects and advantages of the present invention will become clear from the following description and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig 1 shows schematically a heart stimulating system with a heart stimulating device connected to leads with sensing and pacing electrodes positioned in a heart.

Fig 2 shows schematically a control circuit which may form part of the device.

Fig 3 shows schematically a somewhat more detailed illustration of part of the control circuit of Fig 2.

Fig 4 illustrates schematically a method according to the invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

Fig 1 shows schematically an implantable heart stimulating device 10 according to the invention. The device 10 comprises a housing 12. The housing 12 includes a control circuit 14. The device 10 comprises a connector portion 13. Via the connector portion 13, the device 10 can be connected to different leads. In Fig 1 the device 10 is connected to three leads 20, 30 and 40.

The lead 20 includes a pacing and sensing electrode 21, 22. In the shown example, this electrode 21, 22 is a bipolar electrode with a tip portion 21 and a ring portion 22. However, it is within of the scope of the invention that instead unipolar electrodes can be used, as is known to a person skilled in the art. Similarly to the lead 20, the lead 30 includes a pacing and sensing electrode 31, 32 and the lead 40 includes a pacing and sensing electrode 41, 42. The device 10 together with the leads 20, 30, 40 and the electrodes 21, 22; 31, 32; 41 42 constitutes an embodiment of an implantable heart stimulating system according to the invention.

Fig 1 also schematically illustrates a heart with a right atrium RA, a left atrium LA, a right ventricle RV and a left ventricle LV.

The electrode 21, 22 constitutes a first atrial sensing and/or pacing electrode 21, 22 which is positioned in a first atrium 1A of the heart, according to this embodiment the right atrium RA, in order to enable sensing and/or pacing of this atrium RA.

The electrode 31, 32 constitutes a first ventricular sensing and pacing electrode 31, 32, which is positioned in a first ventricle 1V of the heart, in this embodiment the right

ventricle RV. The first ventricular sensing and pacing electrode 31, 32 is adapted to enable sensing and pacing of this first ventricle 1V.

The electrode 41, 42 constitutes a second ventricular sensing and pacing electrode 41, 42, which is positioned at a second ventricle 2V of the heart, in this embodiment the left ventricle LV. The second ventricular sensing and pacing electrode 41, 42 is adapted to enable sensing and pacing of this second ventricle 2V. The lead 40 may for example be introduced via the right atrium RA and the coronary sinus such that the electrode 41, 42 is positioned in for example the middle or great cardiac vein of the heart. How to introduce the lead 40 in this manner is known to a person skilled in the art.

Although not shown in Fig 1, it is also possible that the system is connected to further leads and/or further electrodes, for example electrodes positioned in order to sense and/or pace the left atrium LA and electrodes designed to enable defibrillation.

Fig 2 shows schematically the control circuit 14 in some more detail. The control circuit 14 includes a memory 15 connected to a control portion 18. The control circuit 14 includes a first atrial sensing and/or pacing circuit 25, 27. In this embodiment, this circuit 25, 27 includes a sensing circuit 25 and a pacing circuit 27. The first atrial sensing and/or pacing circuit 25, 27 communicates with the first atrial sensing and/or pacing electrode 21, 22 via the lead 20. The first atrial sensing and/or pacing circuit 25, 27 is thus adapted to sense and/or pace an atrium 1A, in this case the right atrium RA.

The control circuit 14 also includes a first ventricular sensing circuit 35 and a first ventricular pacing circuit 37. These circuits 35, 37 communicate with the first ventricular sensing and pacing electrode 31, 32 via the lead 30. The circuits 35, 37 are thus adapted to sense and pace a first ventricle 1V, in this case the right ventricle RV.

The control circuit 14 also includes a second ventricular sensing circuit 45 and a second ventricular pacing circuit 47. These circuits 45, 47 communicate with the second ventricular sensing and pacing electrode 41, 42 via the lead 40. These circuits 45, 47 are adapted to sense and pace a second ventricle 2V, in this case the left ventricle LV.

The control circuit 14 is arranged, or programmed, to include several operational features. The control circuit is thus arranged to be able to detect an evoked response to a pacing pulse delivered by said first ventricular pacing circuit 37 by sensing, with said first ventricular sensing circuit 35, within a first time window ER1 that follows after a pacing pulse delivered by said first ventricular pacing circuit 37.

Similarly, the control circuit 14 is also arranged to be able to detect an evoked response to a pacing pulse delivered by said second ventricular pacing circuit 47 by sensing, with said second ventricular sensing circuit 45, within a second time window ER2 that follows after a pacing pulse delivered by said second ventricular pacing circuit 47.

How to design a pacer to sense evoked response is known to a person skilled in the art. The first time window ER1 may for example be set to begin 5ms to 30 ms, for example 15ms, after the delivery of a pacing pulse by the first ventricular pacing circuit 37. The length of the first time window ER1 may for example be 30ms to 70ms, for example 50ms. Analogously, the second time window ER2 can for example be set to begin 5ms to 30 ms, for example 15ms, after the delivery of a pacing pulse by the second ventricular pacing circuit 47. The length of the second time window ER2 may for example be 30ms to 70ms, for example 50ms. It should be noted that the first ER1 and second ER2 time windows do not necessarily have to have the same length and they do not necessarily have to start or end the same the time period after the respective delivered pacing pulse.

As is normal in a heart stimulating device, the first ventricular sensing circuit 35 and the second ventricular sensing circuit 45 are also able to sense events typical for an R-wave (QRS-complex) in the respective ventricle.

Fig 3 shows schematically a part of the control circuit 14 in some more detail. Fig 3 illustrates that the first ventricular sensing circuit 35 is connected to an evoked response detection logic 50 and an R-wave detection logic 51. The detection logics 50 and 51 can be seen to form part of the control portion 18 illustrated in Fig 2. Preferably, similar detection logics are of course arranged also for the second ventricular sensing circuit 45. The detection logic 50 is thus optimised to sense an evoked response and the detection logic 51 is optimised to detect an R-wave.

As is also normal in a heart stimulating device, the first atrial sensing and/or pacing circuit 25, 27 is also arranged to be able to detect events typical for a P-wave.

The control circuit 14 is arranged to be able to operate with time cycles corresponding to normal heart cycles. Such an operation is normal for an implantable heart stimulating device. The time cycles are determined by preset timer intervals which also may depend on detected signals

The control circuit 14 is also arranged to be able to operate, during the normal operation of the device 10, with a value PV and/or AV. PV is the time between the sensing with said first atrial sensing and/or pacing circuit 25, 27 and a subsequent pacing pulse, which may also be inhibited, of said first ventricular pacing circuit 37. AV is the time between the pacing with said first atrial sensing and/or pacing circuit 25, 27 and a subsequent pacing pulse, which may also be inhibited, of said first ventricular pacing circuit 37. It is well known to a person skilled in the art how an implantable heart stimulating device is set up in order to operate with PV and AV intervals. It is also known that the delivery of pacing pulses can be inhibited.

The control circuit 14 is also arranged to, within a time cycle, be able to deliver pacing pules with both said first ventricular pacing circuit 37 and said second ventricular pacing circuit 47 with a time gap VV, during the normal operation of the device 10, between a pacing pulse delivered, or inhibited, by said first ventricular pacing circuit 37 and a pacing pulse delivered, or inhibited, by said second ventricular pacing circuit 47, wherein said time gap VV is ≥ 0. A typical value of VV can be between 0ms and 80ms.

In the present case, the AV and PV intervals are thus defined in relation to the ventricular pacing circuit that is paced (or inhibited) first (if VV is not equal to 0; if VV is 0 then, of course, the first and second ventricular pacing circuits operate simultaneously). With this definition, VV cannot be less than 0. The ventrical that is referred to as the first ventricle 1V is thus, in the present document, the ventricle that is paced (or inhibited) first, if VV is not equal to 0. This ventricle can be either the left LV or the right RV ventricle depending on the particular case. However, the present invention is supposed to extend also to the situation where some other definition of the PV and AV intervals is used, e.g. if VV can be negative.

The control circuit 14 is also arranged to be able to carry out a capture threshold search, by during a plurality of time cycles, vary the energy of the pacing pulses delivered by said first ventricular pacing circuit 37 and said second ventricular pacing circuit 47 and to detect, with said first ventricular sensing circuit 35 and said second ventricular sensing circuit 45, respectively, possible evoked responses during said first time window ER1 and said second time window ER2, respectively, such that a suitable pulse energy for the pacing pulses delivered by said first ventricular pacing circuit 37 and said second ventricular pacing circuit 47, respectively, is determined. The suitable pulse energy can be selected somewhat higher than the actually measured threshold, in order to have a safety margin. According to the present invention, the capture threshold search can either be carried simultaneously (during the same time cycles) for both the first and second channels, or, alternatively, in one channel at a time. The device 10 can be arranged to perform a capture threshold search periodically, for example once a day, but it is also possible that the device 10 is set up to perform such a search when a predetermined number of lack of capture beats have been detected.

As has been explained above, it may be necessary to reduce the different times AV, PV during a capture threshold search in order to avoid fusion. According to the present invention this is done in an optimal manner. Furthermore, according to the present invention, also VV is reduced, if necessary, in an optimal manner when a capture threshold search is being carried out.

When a capture threshold search is to be carried out, first some intrinsic conduction times have to be determined and stored in the memory. This can be done just before the capture threshold search is carried out. However, it is also possible to determine the intrinsic conduction times at an earlier stage.

First some abbreviations that are used below will be explained.

V1R2 is a value which represents the time between a pacing pulse delivered by said first ventricular pacing circuit 37 and a subsequent event sensed by said second ventricular sensing circuit 45 during a time cycle when no pacing pulse is delivered by said second ventricular pacing circuit 47. This time thus represents the time it takes for a paced R-wave in the first ventricle 1V to be transferred to the second ventricle 2V.

Δ_{V1R2} is a value that takes expected variations in V1R2 into account.

AR1 is a value which represents the time between a pacing pulse delivered by said first atrial sensing and/or pacing circuit 25, 27 and a subsequent event sensed by said first ventricular sensing circuit 35 during a time cycle when no pacing pulse is delivered by said first ventricular pacing circuit 37. AR1 thus represents the conduction time from a paced event in the atrium 1A to a detected R-wave in the first ventricle 1V.

Δ_{AR1} is a predetermined value that takes expected variations in AR1 into account.

AR2 is a value which represents the time between a pacing pulse delivered by said first atrial sensing and/or pacing circuit 25, 27 and a subsequent event sensed by said second ventricular sensing circuit 45 during a time cycle when no pacing pulse is delivered by said second ventricular pacing circuit 47. AR2 thus represents the conduction time from a paced event in the atrium 1A to a detected R-wave in the second ventricle 2V.

Δ_{AR2} is a predetermined value that takes expected variations in AR2 into account.

PR1 is a value which represents the time between an event sensed by said first atrial sensing and/or pacing circuit 25, 27 and a subsequent event sensed by said first ventricular sensing circuit 35 during a time cycle when no pacing pulse is delivered by said first ventricular pacing circuit 37. PR1 thus represents the conduction time from a sensed event in the atrium 1A to a detected R-wave in the first ventricle 1V.

Δ_{PR1} is a predetermined value that takes expected variations in PR1 into account.

PR2 is a value which represents the time between an event sensed by said first atrial sensing and/or pacing circuit 25, 27 and a subsequent event sensed by said second ventricular sensing circuit 45 during a time cycle when no pacing pulse is delivered by said second ventricular pacing circuit 47. PR2 thus represents the conduction time from a sensed event in the atrium 1A to a detected R-wave in the second ventricle 2V.

Δ_{PR2} is a predetermined value that takes expected variations in PR2 into account.

The device 10 is thus arranged to determine intrinsic conduction times.

The control circuit 14 is arranged to carry out a search procedure for determining V1R2, and to store the determined value of V1R2 in the memory 15. This procedure includes the delivery of a pacing pulse with the first ventricular pacing circuit 37 and the sensing of a subsequent event by the second ventricular sensing circuit 45 during the same time cycle. The control circuit 14 is arranged to carry out this procedure during a part of the time cycle when no atrial events are likely to be sensed by the second ventricular sensing circuit 45, i.e. the part of the time cycle when no sensing in the second ventricle 2V caused by a previous atrial event is likely to occur. This procedure also involves determining the variation in V1R2 and the determination of an appropriate value for Δ_{V1R2} and to store the determined value for Δ_{V1R2} in the memory 15. The determined value of V1R2 can thus for example represent the mean value of the conduction times V1R2 measured during a number of heart cycles, for example 10 heart cycles. Δ_{V1R2} can be determined statistically and can thus represent some measure of the variation in V1R2. For example, Δ_{V1R2} can be selected such that an expected value of V1R2 with a certain probability, for example 98% percent probability, will fall within the range V1R2 $\pm$ Δ_{V1R2}.

Analogously, the control circuit 14 is arranged to carry out a search procedure for determining AR1, and to store the determined value of AR1 in the memory 15. The procedure for determining AR1 includes the delivery of a pacing pulse with the first atrial sensing and/or pacing circuit 25, 27 and the sensing of a subsequent event with the first ventricular sensing circuit 35 during the same time cycle. The control circuit 14 is arranged such that no pacing pulse is delivered by the first ventricular pacing circuit 37 during this time cycle. The procedure for determining AR1 also involves determining the variation in AR1 and the determination of an appropriate value for Δ_{AR1} and to store the determined value for Δ_{AR1} in the memory 15.

Analogously, the control circuit 14 is arranged to carry out a search procedure for determining AR2, and to store the determined value of AR2 in the memory 15. The procedure for determining AR2 includes the delivery of a pacing pulse with the first atrial sensing and/or pacing circuit 25, 27 and the sensing of a subsequent event with the second ventricular sensing circuit 45 during the same time cycle. The control circuit 14 is arranged such that no pacing pulse is delivered by the second ventricular pacing circuit 47 during this time cycle. This procedure also involves determining the variation in AR2 and the determination of an appropriate value for Δ_{AR2} and to store the determined value for Δ_{AR2} in the memory 15.

Analogously, the control circuit 14 is arranged to carry out a search procedure for determining PR1, and to store the determined value of PR1 in the memory 15. This procedure includes the sensing with the first atrial sensing and/or pacing circuit 25, 27 and the sensing of a subsequent event with the first ventricular sensing circuit 35 during the same time cycle. No pacing pulse is delivered by the first ventricular pacing circuit 37 during this time cycle. The procedure for determining PR1 also involves determining the variation in PR1 and the determination of an appropriate value for Δ_{PR1} and to store the determined value for Δ_{PR1} in the memory 15.

The control circuit 14 is also arranged to carry out a search procedure for determining PR2, and to store the determined value of PR2 in the memory 15. This procedure includes the sensing with the first atrial sensing and/or pacing circuit 25, 27 and the sensing of a subsequent event with the second ventricular sensing circuit 45 during the same time cycle. The control circuit 14 is arranged such that no pacing pulse is delivered by the second ventricular pacing circuit 47 during this time cycle. This procedure also involves determining the variation in PR2 and the determination of an appropriate value for Δ_{PR2} and to store the determined value for Δ_{PR2} in the memory 15.

AR1, AR2, PR1 and PR2 can be determined as a mean or average value similarly to the determination of V1R2 described above. Also the procedures for determining Δ_{AR1}, Δ_{AR2}, Δ_{PR1} and Δ_{PR2} can be performed in a similar manner to that described above in connection with the determination of Δ_{V1R2}.

It can be noted that it is above stated that no pacing pulse is delivered by certain pacing circuits during the time cycles when the different intrinsic conduction times are determined. It is of course also possible to deliver a pacing pulse during the same time cycle if such a pacing pulse is delivered during a part of the time cycle when it will not interfere with the detection of the intrinsic conduction. This can for example be achieved if certain pacing intervals, such as AV or PV, are increased during such determination of intrinsic conduction times.

Furthermore, the control circuit 14 is arranged to determine a time gap VV_{cts}, that is to be used instead of VV during said capture threshold search. VV_{cts} is hereby selected as the smallest of the following values:
VV and

V1R2 - ER2 - Δ_{V1R2},
but if V1R2 - ER2 - Δ_{V1R2} is less than 0, then VV_{cts} is selected to be 0.

Furthermore, the control circuit 14 is arranged to determine a time AV_{cts}, that is to be used instead of AV during said capture threshold search. AV_{cts} is hereby selected as the smallest of the following values:
AV,
AR1 - ER1 - Δ_{AR1}, and
AR2 - VV_{cts} - ER2 - Δ_{AR2},
but with the additional condition that AV_{cts} shall not be less than a predetermined minimum value for AV_{cts}, wherein said minimum value is ≥ 0, even if AR1 - ER1 - Δ_{AR1} or AR2 - VV_{cts} - ER2 - Δ_{AR2} is less than said minimum value. The minimum value for AV_{cts} can for example be 50ms.

Moreover, the control circuit 14 is arranged to determine a time PV_{cts}, that is to be used instead of PV during said capture threshold search. PV_{cts} is hereby selected as the smallest of the following values:
PV,
PR1 - ER1 - Δ_{PR1}, and
PR2 - VV_{cts} - ER2 - Δ_{PR2},
but with the additional condition that PV_{cts} shall not be less than a predetermined minimum value for PV_{cts}, wherein said minimum value is ≥ 0, even if PR1 - ER1 - Δ_{PR1} or PR2 - VV_{cts} - ER2 - Δ_{PR2} is less than said minimum value. The minimum value for PV_{cts} can for example be 25ms.

Finally, the control circuit 14 is arranged to be able to use the determined values for VV_{cts}, AV_{cts} and PV_{cts} instead of VV, AV and PV when actually performing a capture threshold search.

The invention also provides a method of, in a human or animal being, performing a capture threshold search with the help of a heart stimulating device.

Fig. 4 discloses very schematically a flow chart for such a method. At the same time, this figure illustrates schematically how a device 10 according to the invention can operate.

The device normally operates with times VV, AV and/or PV, ER1 and ER2 as explained above.

A capture threshold search can be performed at regular intervals, for example once a day, or when a certain number of loss of capture has been detected.

If a capture threshold search is to be carried out, then first the values for V1R2, AR1, AR2, PR1, PR2, Δ_{V1R2}, Δ_{AR1}, Δ_{AR2}, Δ_{PR1} and Δ_{PR2} are determined. These values can for example be determined as explained above or in any other suitable manner. For example, if any of these values is known before with sufficient accuracy, then it may not be necessary to perform a special search for finding out this value. Moreover, these values can either be determined just before the capture threshold search is performed, or these values can have been determined earlier.

Thereafter a the times VV_{cts}, AV_{cts} and PV_{cts}, that that are to be used instead of VV, AV and PV, respectively, during said capture threshold search are determined. These times can be determined as follows.

VV_{cts} is selected as the smallest of the following values:
VV and
V1R2 - ER2 - Δ_{V1R2},
but if V1R2 - ER2 - Δ_{V1R2} is less than 0, then VV_{cts} is selected to be 0.

AV_{cts} is selected as the smallest of the following values:
AV,
AR1 - ER1 - Δ_{AR1}, and
AR2 - VV_{cts} - ER2 - Δ_{AR2},
but with the additional condition that AV_{cts} shall not be less than a predetermined minimum value for AV_{cts}, for example 50ms, even if AR1 - ER1 - Δ_{AR1} or AR2 - VV_{cts} - ER2 - Δ_{AR2} is less than 50ms.

PV_{cts} is selected as the smallest of the following values:
PV,
PR1 - ER1 - Δ_{PR1}, and
PR2 - VV_{cts} - ER2 - Δ_{PR2},

but with the additional condition that PV_{cts} shall not be less than a predetermined minimum value for PV_{cts}, for example 25ms, even if PR1 - ER1 - Δ_{PR1} or PR2 - VV_{cts} - ER2 - Δ_{PR2} is less than 25ms.

The method then also includes the step of actually performing a capture threshold search by using VV_{cts}, AV_{cts} and PV_{cts} instead of VV, AV and PV. Based on the capture threshold search, a suitable stimulation amplitude can be selected. The stimulation amplitude is set such that a certain safety margin is achieved. How to select a certain safety margin is known from prior devices that operate with an evoked response detection.

The method can be performed on a human or animal being suffering from congestive heart failure, for example on a on a human or animal being suffering from a bundle branch block.

It should be noted that it is of course only necessary to determine and use those values which are essential for the operation in the particular case. For example, if sensing in the atrium is not used, then it is of course not necessary to determine PV_{cts} or the values needed for determining PV_{cts}.

The invention is not limited to the described embodiments but may be varied and modified within the scope of the following claims.

Claims

1. An implantable heart stimulating device (10) including a control circuit (14) comprising:

at least one memory (15);

a first atrial sensing and/or pacing circuit (25, 27), adapted to communicate with a first atrial sensing and/or pacing electrode (21, 22) suited to be positioned in an atrium (1A) of a heart, wherein said first atrial sensing and/or pacing circuit (25, 27) is adapted to enable sensing and/or pacing of such an atrium (1A);

a first ventricular sensing circuit (35), adapted to communicate with a first ventricular sensing electrode (31, 32) suited to be positioned in or at a first ventricle (1V) of a heart, wherein said first ventricular sensing circuit (35) is adapted to enable sensing of such a ventricle (1V);

a first ventricular pacing circuit (37), adapted to communicate with a first ventricular pacing electrode (31, 32) suited to be positioned in or at a first ventricle (1V) of a heart, wherein said first ventricular pacing circuit (37) is adapted to enable pacing of such a ventricle (1V);

a second ventricular sensing circuit (45), adapted to communicate with a second ventricular sensing electrode (41, 42) suited to be positioned in or at a second ventricle (2V) of a heart, wherein said second ventricular sensing circuit (45) is adapted to enable sensing of such a ventricle (2V);

a second ventricular pacing circuit (47), adapted to communicate with a second ventricular pacing electrode (41, 42) suited to be positioned in or at a second ventricle (2V) of a heart, wherein said second ventricular pacing circuit (47) is adapted to enable pacing of such a ventricle (2V);

said control circuit (14) being arranged to be able to detect an evoked response to a pacing pulse delivered by said first ventricular pacing circuit (37) by sensing, with said first ventricular sensing circuit (35), within a first time window (ER1) that follows after a pacing pulse delivered by said first ventricular pacing circuit (37);

said control circuit (14) being arranged to be able to detect an evoked response to a pacing pulse delivered by said second ventricular pacing circuit (47) by sensing, with said second ventricular sensing circuit (45), within a second time window (ER2) that follows after a pacing pulse delivered by said second ventricular pacing circuit (47);

said control circuit (14) being arranged to be able to operate with time cycles corresponding to normal heart cycles;

said control circuit (14) being arranged to be able to operate, during the normal operation of the device (10), with a value PV and/or AV, where PV is the time between the sensing with said first atrial sensing and/or pacing circuit (25, 27) and a subsequent pacing pulse, which may also be inhibited, of said first ventricular pacing circuit (37) and AV is the time between the pacing with said first atrial sensing and/or pacing circuit (25, 27) and a subsequent pacing pulse, which may also be inhibited, of said first ventricular pacing circuit (37);

said control circuit (14) being arranged to, within a time cycle, be able to deliver pacing pules with both said first ventricular pacing circuit (37) and said second ventricular pacing circuit (47) with a time gap VV, during the normal operation of the device (10), between a pacing pulse delivered, or inhibited, by said first ventricular pacing circuit (37) and a pacing pulse delivered, or inhibited, by said second ventricular pacing circuit (47), wherein said time gap VV is ≥ 0;

said control circuit (14) being arranged to be able to carry out a capture threshold search, by, during a plurality of time cycles, vary the energy of the pacing pulses delivered by said first ventricular pacing circuit (37) and said second ventricular pacing circuit (47) and to detect, with said first ventricular sensing circuit (35) and said second ventricular sensing circuit (45), respectively, possible evoked responses during said first time window (ER1) and said second time window (ER2), respectively, such that a suitable pulse energy for the pacing pulses delivered by said first ventricular pacing circuit (37) and said second ventricular pacing circuit (47), respectively, is determined;

wherein said control circuit (14) is arranged to determine a time gap VV_{cts}, that is to be used instead of VV during said capture threshold search, wherein the determination of said time gap VV_{cts} involves the calculation of a value

$V1R2 - ER2 - \Delta_{V1R2}$,

where V1R2 is a value which is stored in said memory (15) and which represents the time between a pacing pulse delivered by said first ventricular pacing circuit (37) and a subsequent event sensed by said second ventricular sensing circuit (45) during a time cycle when no pacing pulse is delivered by said second ventricular pacing circuit (47), ER2 is said second time window and Δ_{V1R2} is a predetermined value that takes expected variations in V1R2 into account,

and wherein VV_{cts} is determined such that

$VV_{cts} \leq V1R2 - ER2 - \Delta_{V1R2}$ but with the additional condition that VV_{cts} shall not be less than 0 even if $V1R2 - ER2 - \Delta_{V1R2}$ is less than 0.

2. An implantable heart stimulating device (10) according to claim 1, wherein the control circuit (14) is arranged such that VV_{cts} is selected as the smallest of the following values:
VV and
$V1R2 - ER2 - \Delta_{V1R2}$,
but if $V1R2 - ER2 - \Delta_{V1R2}$ is less than 0, then VV_{cts} is selected to be 0.

3. An implantable heart stimulating device (10) according to claim 1 or 2, wherein the control circuit (14) is arranged to determine a time AV_{cts}, that is to be used instead of AV during said capture threshold search, wherein the determination of said time AV_{cts} involves the calculation of a value
$AR1 - ER1 - \Delta_{AR1}$,
where AR1 is a value which is stored in said memory and which represents the time between a pacing pulse delivered by said first atrial sensing and/or pacing circuit (25, 27) and a subsequent event sensed by said first ventricular sensing circuit (35) during a time cycle when no pacing pulse is delivered by said first ventricular pacing circuit (37), ER1 is said first time window and Δ_{AR1} is a predetermined value that takes expected variations in AR1 into account,
and wherein AV_{cts} is determined such that
$AV_{cts} \leq AR1 - ER1 - \Delta_{AR1}$ but with the additional condition that AV_{cts} shall not be less than a predetermined minimum value for AV_{cts}, wherein said minimum value is ≥ 0, even if $AR1 - ER1 - \Delta_{AR1}$ is less than said minimum value.

4. An implantable heart stimulating device (10) according to claim 3, wherein the determination of said time AV_{cts} also involves the calculation of a value
$AR2 - VV_{cts} - ER2 - \Delta_{AR2}$,
where AR2 is a value which is stored in said memory and which represents the time between a pacing pulse delivered by said first atrial sensing and/or pacing circuit (25, 27) and a subsequent event sensed by said second ventricular sensing circuit (45) during a time cycle when no pacing pulse is delivered by said second ventricular pacing circuit (47), VV_{cts} is as previously defined, ER2 is said second time window and Δ_{AR2} is a predetermined value that takes expected variations in AR2 into account, and wherein AV_{cts} is determined such that
$AV_{cts} \leq AR2 - VV_{cts} - ER2 - \Delta_{AR2}$ but with the additional condition that AV_{cts} shall not be less than a predetermined minimum value for AV_{cts}, wherein said minimum value is ≥ 0, even if $AR2 - VV_{cts} - ER2 - \Delta_{AR2}$ is less than said minimum value.

5. An implantable heart stimulating device (10) according to claim 4, wherein the control circuit (14) is arranged such that AV_{cts} is selected as the smallest of the following values:

AV,

AR1 - ER1 - Δ_{AR1}, and

AR2 - VV_{cts} - ER2 - Δ_{AR2},

but with the additional condition that AV_{cts} shall not be less than a predetermined minimum value for AV_{cts}, wherein said minimum value is ≥ 0, even if AR1 - ER1 - Δ_{AR1} or AR2 - VV_{cts} - ER2 - Δ_{AR2} is less than said minimum value.

6. An implantable heart stimulating device (10) according to any one of claims 3-5, wherein the minimum value for AV_{cts} is larger than 0 but less than 90ms.

7. An implantable heart stimulating device (10) according to claim 6, wherein the minimum value for AV_{cts} is larger than 30ms but less than 70ms.

8. An implantable heart stimulating device (10) according to any one of the preceding claims, wherein the control circuit (14) is arranged to determine a time PV_{cts}, that is to be used instead of PV during said capture threshold search, wherein the determination of said time PV_{cts} involves the calculation of a value

PR1 - ER1 - Δ_{PR1},

where PR1 is a value which is stored in said memory (15) and which represents the time between an event sensed by said first atrial sensing and/or pacing circuit (25, 27) and a subsequent event sensed by said first ventricular sensing circuit (35) during a time cycle when no pacing pulse is delivered by said first ventricular pacing circuit (37), ER1 is said first time window and Δ_{PR1} is a predetermined value that takes expected variations in PR1 into account,

and wherein PV_{cts} is determined such that

$PV_{cts} \leq$ PR1 - ER1 - Δ_{PR1} but with the additional condition that PV_{cts} shall not be less than a predetermined minimum value for PV_{cts}, wherein said minimum value is ≥ 0, even if PR1 - ER1 - Δ_{PR1} is less than said minimum value.

9. An implantable heart stimulating device (10) according to claim 8, wherein the determination of said time PV_{cts} also involves the calculation of a value

PR2 - VV_{cts} - ER2 - Δ_{PR2},

where PR2 is a value which is stored in said memory (15) and which represents the time between an event sensed by said first atrial sensing and/or pacing circuit (25, 27) and a subsequent event sensed by said second ventricular sensing circuit (45) during a time cycle when no pacing pulse is delivered by said second ventricular pacing circuit (47), VV_{cts} is as previously defined, ER2 is said second time window and Δ_{PR2} is a predetermined value that takes expected variations in PR2 into account,
and wherein PV_{cts} is determined such that
$PV_{cts} \leq PR2 - VV_{cts} - ER2 - \Delta_{PR2}$ but with the additional condition that PV_{cts} shall not be less than a predetermined minimum value for PV_{cts}, wherein said minimum value is ≥ 0, even if $PR2 - VV_{cts} - ER2 - \Delta_{PR2}$ is less than said minimum value.

10. An implantable heart stimulating device (10) according to claim 9, wherein the control circuit (14) is arranged such that PV_{cts} is selected as the smallest of the following values:
PV,
$PR1 - ER1 - \Delta_{PR1}$, and
$PR2 - VV_{cts} - ER2 - \Delta_{PR2}$,
but with the additional condition that PV_{cts} shall not be less than a predetermined minimum value for PV_{cts}, wherein said minimum value is ≥ 0, even if $PR1 - ER1 - \Delta_{PR1}$ or $PR2 - VV_{cts} - ER2 - \Delta_{PR2}$ is less than said minimum value.

11. An implantable heart stimulating device (10) according to any one of claims 8-10, wherein the minimum value for PV_{cts} is larger than 0 but less than 60ms.

12. An implantable heart stimulating device (10) according to claim 11, wherein the minimum value for PV_{cts} is larger than 10ms but less than 40ms.

13. An implantable heart stimulating device (10) according to any one of the preceding claims, wherein the control circuit (14) is arranged to be able to carry out a search procedure for determining V1R2, and to store the determined value of V1R2 in said memory (15), such that this stored value can be used when determining VV_{cts} in accordance with claim 1 or 2.

14. An implantable heart stimulating device (10) according to claim 13, wherein the control circuit (14) is arranged such that the procedure for determining V1R2 also involves determining the variation in V1R2 and the determination of an

appropriate value for Δ_{V1R2} and to store the determined value for Δ_{V1R2} in said memory (15), such that this stored value can be used when determining VV_{cts} in accordance with claim 1 or 2.

15. An implantable heart stimulating device (10) according to claim 13 or 14, wherein the control circuit (14) is arranged such that the procedure for determining V1R2 includes the delivery of a pacing pulse by said first ventricular pacing circuit (37) and the sensing of a subsequent event by said second ventricular sensing circuit (45) during the same time cycle, wherein the control circuit (14) is arranged to carry out this procedure during a part of the time cycle when no atrial events are likely to be sensed by said second ventricular sensing circuit (45).

16. An implantable heart stimulating device (10) according to any one of the preceding claims, wherein the control circuit (14) is arranged to be able to carry out a search procedure for determining AR1, and to store the determined value of AR1 in said memory (15), such that this stored value can be used when determining AV_{cts} in accordance with any one of claims 3-7.

17. An implantable heart stimulating device (10) according to claim 16, wherein the control circuit (14) is arranged such that the procedure for determining AR1 also involves determining the variation in AR1 and the determination of an appropriate value for Δ_{AR1} and to store the determined value for Δ_{AR1} in said memory (15), such that this stored value can be used when determining AV_{cts} in accordance with any one of claims 3-7.

18. An implantable heart stimulating device (10) according to claim 16 or 17, wherein the control circuit (14) is arranged such that the procedure for determining AR1 includes the delivery of a pacing pulse by said a first atrial sensing and/or pacing circuit (25, 27) and the sensing of a subsequent event by said first ventricular sensing circuit (35) during the same time cycle, wherein the control circuit (14) is arranged such that no pacing pulse is delivered by said first ventricular pacing circuit (37) during this time cycle.

19. An implantable heart stimulating device (10) according to any one of the preceding claims, wherein the control circuit (14) is arranged to be able to carry out

a search procedure for determining AR2, and to store the determined value of AR2 in said memory (15), such that this stored value can be used when determining AV_{cts} in accordance with any one of claims 4-7.

20. An implantable heart stimulating device (10) according to claim 19, wherein the control circuit (14) is arranged such that the procedure for determining AR2 also involves determining the variation in AR2 and the determination of an appropriate value for Δ_{AR2} and to store the determined value for Δ_{AR2} in said memory (15), such that this stored value can be used when determining AV_{cts} in accordance with any one of claims 4-7.

21. An implantable heart stimulating device (10) according to claim 19 or 20, wherein the control circuit (14) is arranged such that the procedure for determining AR2 includes the delivery of a pacing pulse by said a first atrial sensing and/or pacing circuit (25, 27) and the sensing of a subsequent event by said second ventricular sensing circuit (45) during the same time cycle, wherein the control circuit (14) is arranged such that no pacing pulse is delivered by said second ventricular pacing circuit (47) during this time cycle.

22. An implantable heart stimulating device (10) according to any one of the preceding claims, wherein the control circuit (14) is arranged to be able to carry out a search procedure for determining PR1, and to store the determined value of PR1 in said memory (15), such that this stored value can be used when determining PV_{cts} in accordance with any one of claims 8-12.

23. An implantable heart stimulating device (10) according to claim 22, wherein the control circuit (14) is arranged such that the procedure for determining PR1 also involves determining the variation in PR1 and the determination of an appropriate value for Δ_{PR1} and to store the determined value for Δ_{PR1} in said memory (15), such that this stored value can be used when determining PV_{cts} in accordance with any one of claims 8-12.

24. An implantable heart stimulating device (10) according to claim 22 or 23, wherein the control circuit (14) is arranged such that the procedure for determining PR1 includes the sensing with said first atrial sensing and/or pacing circuit (25, 27) and the sensing of a subsequent event by said first ventricular sensing circuit (35)

during the same time cycle, wherein the control circuit (14) is arranged such that no pacing pulse is delivered by said first ventricular pacing circuit (37) during this time cycle.

25. An implantable heart stimulating device (10) according to any one of the preceding claims, wherein the control circuit (14) is arranged to be able to carry out a search procedure for determining PR2, and to store the determined value of PR2 in said memory (15), such that this stored value can be used when determining PV_{cts} in accordance with any one of claims 9-12.

26. An implantable heart stimulating device (10) according to claim 25, wherein the control circuit (14) is arranged such that the procedure for determining PR2 also involves determining the variation in PR2 and the determination of an appropriate value for Δ_{PR2} and to store the determined value for Δ_{PR2} in said memory (15), such that this stored value can be used when determining PV_{cts} in accordance with any one of claims 9-12.

27. An implantable heart stimulating device (10) according to claim 25 or 26, wherein the control circuit (14) is arranged such that the procedure for determining PR2 includes the sensing with said first atrial sensing and/or pacing circuit (25, 27) and the sensing of a subsequent event by said second ventricular sensing circuit (45) during the same time cycle, wherein the control circuit (14) is arranged such that no pacing pulse is delivered by said second ventricular pacing circuit (47) during this time cycle.

28. An implantable heart stimulating system comprising:
an implantable heart stimulating device (10) according to any one of the preceding claims, and
said first atrial sensing and/or pacing electrode (21, 22),
said first ventricular sensing electrode (31, 32),
said first ventricular pacing electrode (31, 32),
said second ventricular sensing electrode (41, 42), and
said second ventricular pacing electrode (41, 42),
wherein said electrodes are operationally connected to said device (10).

29. An implantable heart stimulating system according to claim 28 further comprising a plurality of leads (20, 30, 40), on which said electrodes (21, 22; 31, 32; 41, 42) are positioned, which leads (10, 20, 30) are connected to said device (10).

30. An implantable heart stimulating system according to claims 28 or 29, wherein said first ventricular sensing electrode (31, 32) is the same as said first ventricular pacing electrode (31, 32) and said second ventricular sensing electrode (41, 42) is the same as said second ventricular pacing electrode (41, 42).

31. A method of, in a human or animal being, performing a capture threshold search with the help of a heart stimulating device that, during the normal operation of the device, is set up to operate with times VV, AV and/or PV, ER1 and ER2, where VV is the time between a pacing pulse delivered, or inhibited, to a first ventricle and a pacing pulse delivered, or inhibited, during the same heart cycle, to a second ventricle, wherein said time gap VV is ≥ 0, where AV is the time between a pacing pulse to a first atrium and a subsequent pacing pulse, which may also be inhibited, to said first ventricle, where PV is the time between a sensed event in said first atrium and a subsequent pacing pulse, which may also be inhibited, to said first ventricle, where ER1 is the evoked response detection window for the first ventricle and where ER2 is the evoked response detection window for the second ventricle,
which method includes the following steps:
determine a value V1R2, where V1R2 represents the time between a pacing pulse to the first ventricule and a subsequent event in the second ventricle, during a heart cycle when no pacing pulse is delivered to the second ventricle;
determine Δ_{V1R2}, where Δ_{V1R2} is a value that takes expected variations in V1R2 into account;
determine a time gap VV_{cts}, that is to be used instead of VV during said capture threshold search, such that
$VV_{cts} \leq V1R2 - ER2 - \Delta_{V1R2}$ but with the additional condition that VV_{cts} shall not be less than 0 even if $V1R2 - ER2 - \Delta_{V1R2}$ is less than 0; and
perform a capture threshold search by using VV_{cts} instead of VV.

32. A method according to claim 31, wherein VV_{cts} is selected as the smallest of the following values:
VV and
$V1R2 - ER2 - \Delta_{V1R2}$,

but if V1R2 - ER2 - Δ_{V1R2} is less than 0, then VV_{cts} is selected to be 0.

33. A method according to claim 31 or 32, also including the following steps:
determine a value AR1, where AR1 represents the time between a pacing pulse to the first atrium and a subsequent event in the first ventricle, during a heart cycle when no pacing pulse is delivered to the first ventricle;
determine Δ_{AR1}, where Δ_{AR1} is a value that takes expected variations in AR1 into account;
determine a time AV_{cts}, that is to be used instead of AV during said capture threshold search, such that
$AV_{cts} \leq AR1 - ER1 - \Delta_{AR1}$ but with the additional condition that AV_{cts} shall not be less than a predetermined minimum value for AV_{cts}, wherein said minimum value is ≥ 0, even if $AR1 - ER1 - \Delta_{AR1}$ is less than said minimum value; and
perform a capture threshold search by using AV_{cts} instead of AV.

34. A method according to claim 33, including the following steps:
determine a value AR2, where AR2 is a value which represents the time between a pacing pulse to the first atrium and a subsequent event in the second ventricle, during a heart cycle when no pacing pulse is delivered to the second ventricle;
determine Δ_{AR2}, where Δ_{AR2} is a value that takes expected variations in AR2 into account;
determine AV_{cts} such that
$AV_{cts} \leq AR2 - VV_{cts} - ER2 - \Delta_{AR2}$ but with the additional condition that AV_{cts} shall not be less than a predetermined minimum value for AV_{cts}, wherein said minimum value is ≥ 0, even if $AR2 - VV_{cts} - ER2 - \Delta_{AR2}$ is less than said minimum value; and
perform a capture threshold search by using AV_{cts} instead of AV.

35. A method according to claim 34, wherein AV_{cts} is selected as the smallest of the following values:
AV,
$AR1 - ER1 - \Delta_{AR1}$, and
$AR2 - VV_{cts} - ER2 - \Delta_{AR2}$,
but with the additional condition that AV_{cts} shall not be less than a predetermined minimum value for AV_{cts}, wherein said minimum value is ≥ 0, even if $AR1 - ER1 - \Delta_{AR1}$ or $AR2 - VV_{cts} - ER2 - \Delta_{AR2}$ is less than said minimum value.

36. A method according to any one of claims 33-35, wherein the minimum value for AV_{cts} is larger than 0 but less than 90ms.

37. A method according to claim 36, wherein the minimum value for AV_{cts} is larger than 30ms but less than 70ms.

38. A method according to any one of claims 31-37, also including the following steps:
determine a value PR1, where PR1 represents the time between a sensed event in the first atrium and a subsequent event in the first ventricle, during a heart cycle when no pacing pulse is delivered to the first ventricle;
determine Δ_{PR1}, where Δ_{PR1} is a value that takes expected variations in PR1 into account;
determine a time PV_{cts}, that is to be used instead of PV during said capture threshold search, such that
$PV_{cts} \leq PR1 - ER1 - \Delta_{PR1}$ but with the additional condition that PV_{cts} shall not be less than a predetermined minimum value for PV_{cts}, wherein said minimum value is ≥ 0, even if $PR1 - ER1 - \Delta_{PR1}$ is less than said minimum value; and
perform a capture threshold search by using PV_{cts} instead of PV.

39. A method according to claim 38, including the following steps:
determine a value PR2, where PR2 is a value which represents the time between a sensed event in the first atrium and a subsequent event in the second ventricle, during a heart cycle when no pacing pulse is delivered to the second ventricle;
determine Δ_{PR2}, where Δ_{PR2} is a value that takes expected variations in PR2 into account;
determine PV_{cts} such that
$PV_{cts} \leq PR2 - VV_{cts} - ER2 - \Delta_{PR2}$ but with the additional condition that PV_{cts} shall not be less than a predetermined minimum value for PV_{cts}, wherein said minimum value is ≥ 0, even if $PR2 - VV_{cts} - ER2 - \Delta_{PR2}$ is less than said minimum value; and
perform a capture threshold search by using PV_{cts} instead of PV.

40. A method according to claim 39, wherein PV_{cts} is selected as the smallest of the following values:
PV,
$PR1 - ER1 - \Delta_{PR1}$, and

PR2 - VV_{cts} - ER2 - Δ_{PR2},
but with the additional condition that PV_{cts} shall not be less than a predetermined minimum value for PV_{cts}, wherein said minimum value is ≥ 0, even if PR1 - ER1 - Δ_{PR1} or PR2 - VV_{cts} - ER2 - Δ_{PR2} is less than said minimum value.

41. A method according to any one of the claims 38-40, wherein the minimum value for PV_{cts} is larger than 0 but less than 60ms.

42. A method according to claim 41, wherein the minimum value for PV_{cts} is larger than 10ms but less than 40ms.

43. A method according to any one of claims claim 31-42, wherein the method is performed on a human or animal being suffering from congestive heart failure.

44. A method according to any one of claims claim 31-43, wherein the method is performed on a on a human or animal being suffering from a bundle branch block.

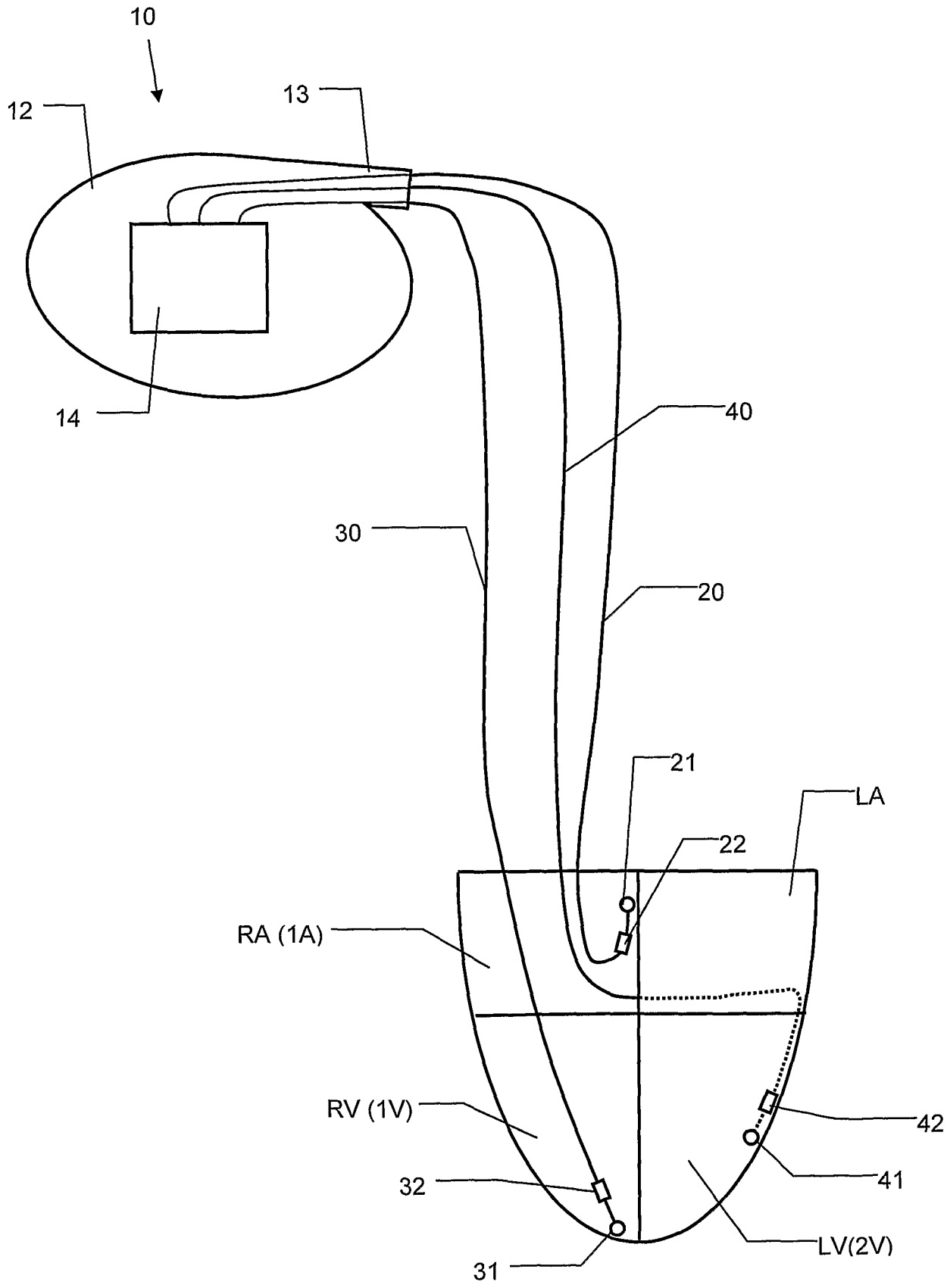

FIG 1

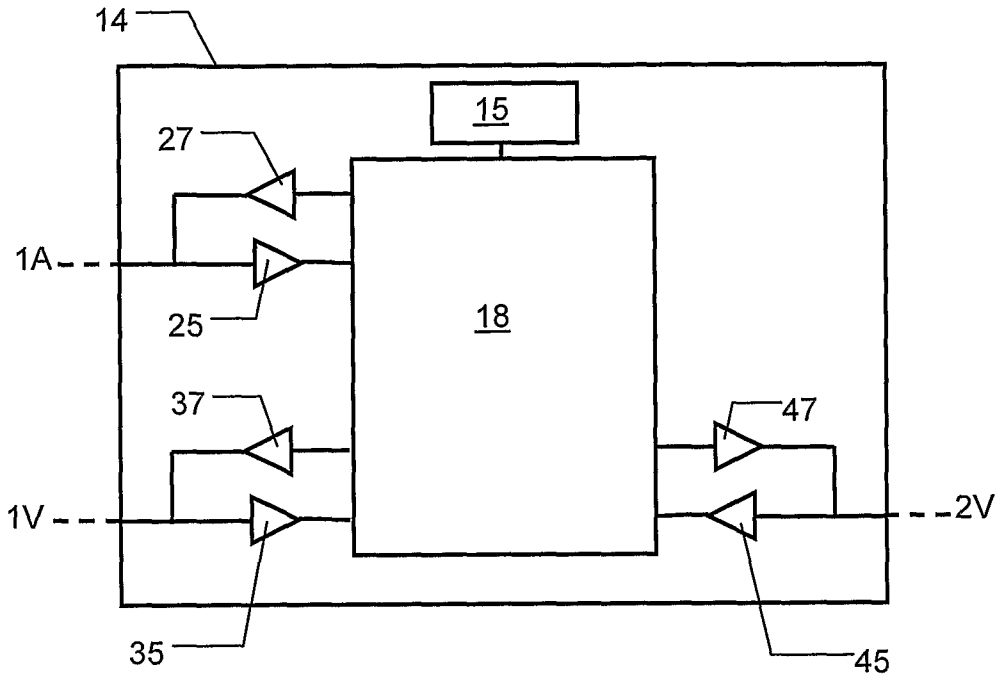

FIG 2

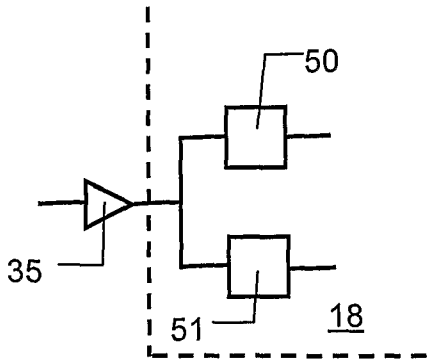

FIG 3

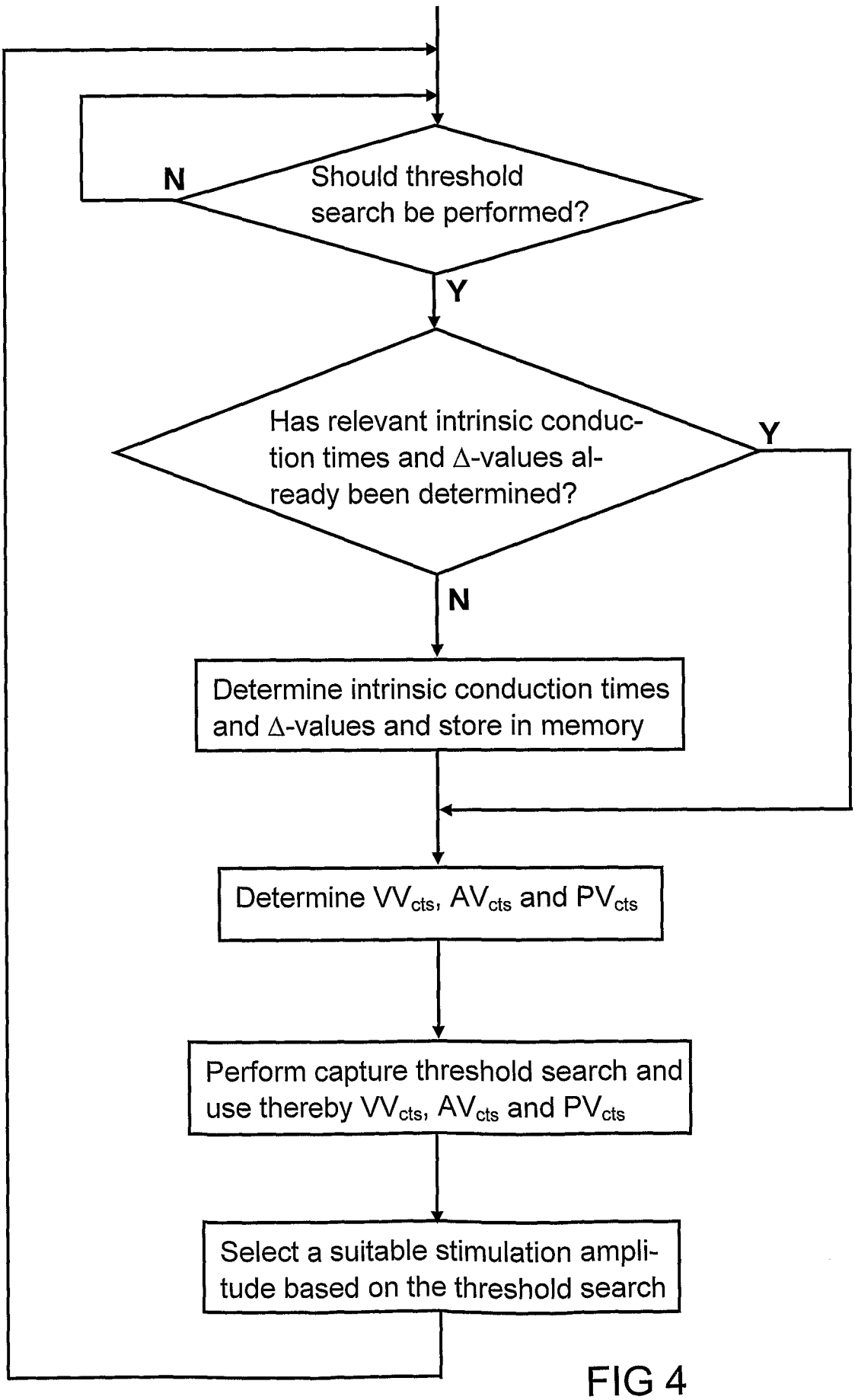
Should threshold search be performed?
N
Y
Has relevant intrinsic conduction times and Δ-values already been determined?
Y
N
Determine intrinsic conduction times and Δ-values and store in memory
Determine VVcts, AVcts and PVcts
Perform capture threshold search and use thereby VVcts, AVcts and PVcts
Select a suitable stimulation amplitude based on the threshold search

FIG 4

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE2005/001629

A. CLASSIFICATION OF SUBJECT MATTER

IPC: see extra sheet
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: A61N

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

SE,DK,FI,NO classes as above

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

EPO-INTERNAL, WPI DATA, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6832112 B1 (BORNZIN, G A), 14 December 2004 (14.12.2004), abstract ---	1-44
A	WO 2005028030 A1 (ST JUDE MEDICAL AB), 31 March 2005 (31.03.2005), abstract ---	1-44
A	US US6904321 B1 (BORNZIN, G A ET AL), 7 June 2005 (07.06.2005), abstract ---	1-44
A	EP 1430928 A1 (ST JUDE MEDICAL AB), 23 June 2004 (23.06.2004), abstract ---	1-44

[X] Further documents are listed in the continuation of Box C. [X] 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
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 May 2006	19 -05- 2006
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Gordana Ninkovic /LR Telephone No. +46 8 782 25 00

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6456881 B1 (BORNZIN, G A ET AL), 24 Sept 2002 (24.09.2002), abstract ---	1-44
A	US 20030195579 A1 (BRADLEY, K ET AL), 16 October 2003 (16.10.2003), abstract ---	1-44
A	US 6122545 A (STRUBLE, C L ET AL), 19 Sept 2000 (19.09.2000), abstract ---	1-44
A	US 5716383 A (KIEVAL, R S ET AL), 10 February 1998 (10.02.1998), abstract --- --------	1-44

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE2005/001629

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☒ Claims Nos.: 31-44
because they relate to subject matter not required to be searched by this Authority, namely:

Claims 31-44 relate to a method of treatment of the human or animal body by surgery or by therapy, as well as diagnostic methods /Rule 39.1(iv). Nevertheless, a search has been executed for these claims. The search has been based on the alleged effects of the device.

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

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

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

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

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

International patent classification (IPC)
A61N 1/37 (2006.01)
A61N 1/368 (2006.01)

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Use the application number as username.
The password is **CYEXHAEKEZ**.

Paper copies can be ordered at a cost of 50 SEK per copy from PRV InterPat (telephone number 08-782 28 85).

Cited literature, if any, will be enclosed in paper form.

US	6832112	B1	14/12/2004	NONE			
WO	2005028030	A1	31/03/2005	AU	2003263723	A	00/00/0000
				SE	0301494	D	00/00/0000
US	US6904321	B1	07/06/2005	NONE			
EP	1430928	A1	23/06/2004	SE	0203728	D	00/00/0000
				US	6961613	B	01/11/2005
				US	20040116971	A	17/06/2004
US	6456881	B1	24/09/2002	US	6904321	B	07/06/2005
US	20030195579	A1	16/10/2003	US	6915164	B	05/07/2005
US	6122545	A	19/09/2000	EP	1075308	A	14/02/2001
				US	6070101	A	30/05/2000
				US	6081748	A	27/06/2000
				WO	9955415	A	04/11/1999
US	5716383	A	10/02/1998	NONE			