US 20130231655A1

(19) **United States**

(12) **Patent Application Publication**

Budzelaar et al.

(10) **Pub. No.: US 2013/0231655 A1**

(43) **Pub. Date: Sep. 5, 2013**

(54) **INTERFERENCE REDUCTION AND SIGNAL TO NOISE RATIO IMPROVEMENT FOR ULTRASOUND CARDIAC ABLATION MONITORING**

(75) Inventors: **Franciscus Paulus Maria Budzelaar**, Eindhoven (NL); **Nenad Mihajlovic**, Eindhoven (NL); **Steven Antonie Willem Fokkenrood**, 'S-Hertogenbosch (NL)

(73) Assignee: **KONINKLIJKE PHILIPS ELECTRONICS N.V.**, EINDHOVEN (NL)

(21) Appl. No.: **13/884,696**

(22) PCT Filed: **Nov. 15, 2011**

(86) PCT No.: **PCT/IB2011/055084**

§ 371 (c)(1),
(2), (4) Date: **May 10, 2013**

(30) **Foreign Application Priority Data**

Nov. 18, 2010	(EP)	10191687.2
Mar. 18, 2011	(EP)	11158848.9

Publication Classification

(51) **Int. Cl.**

A61B 18/18	(2006.01)
A61B 8/08	(2006.01)

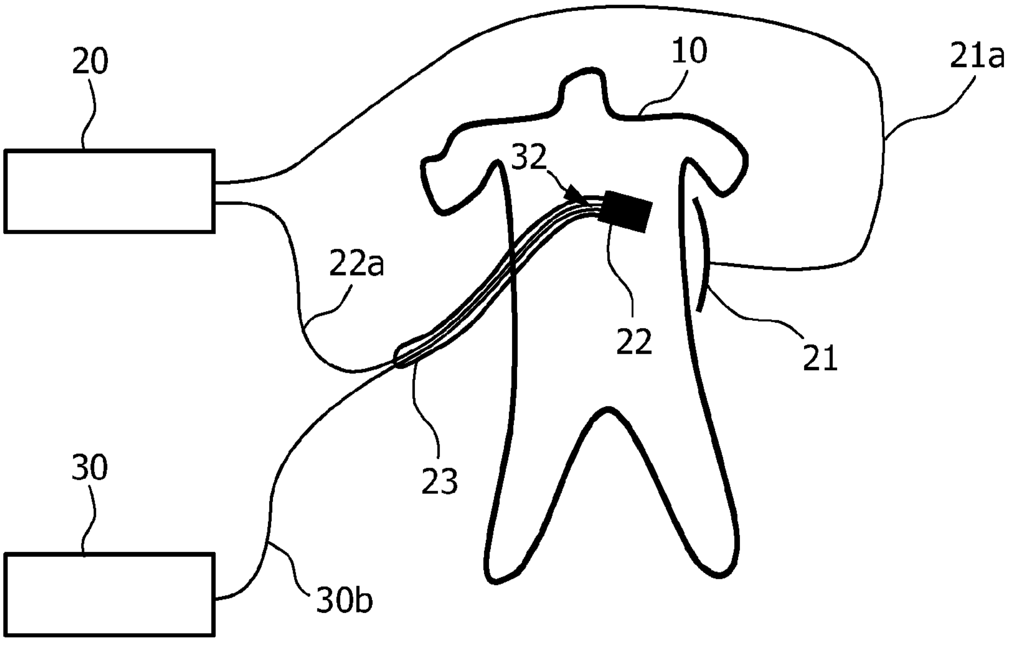
(52) **U.S. Cl.**

CPC .. ***A61B 18/18*** (2013.01); ***A61B 8/52*** (2013.01)

USPC **606/33**

(57) **ABSTRACT**

In cardiac ablation for treatment of atrial fibrillation where lesions have to be made to the heart wall, an ultrasound monitoring mechanism is adapted to assess the progress of the lesion, so that a surgeon can provide lesions with adequate depth, wherein interference caused by an ablation device is reduced and signal to noise ratio of echo signals is improved.



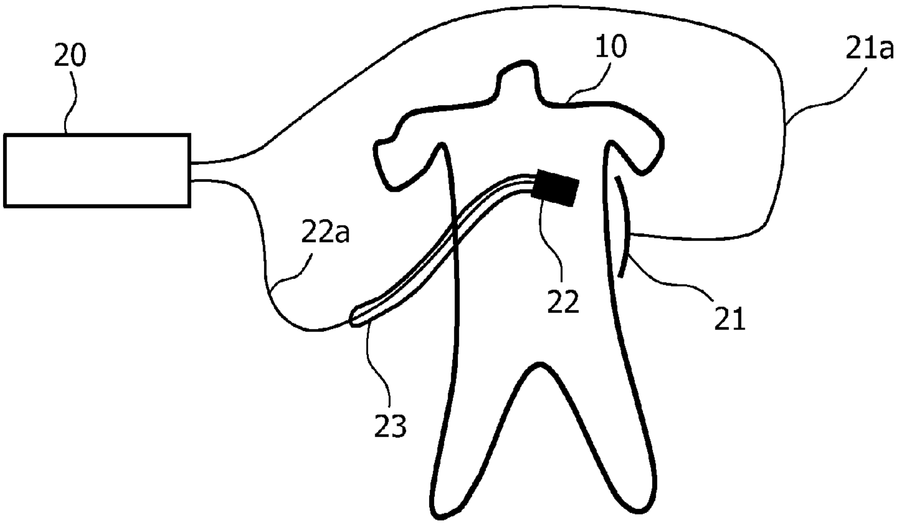


FIG. 1

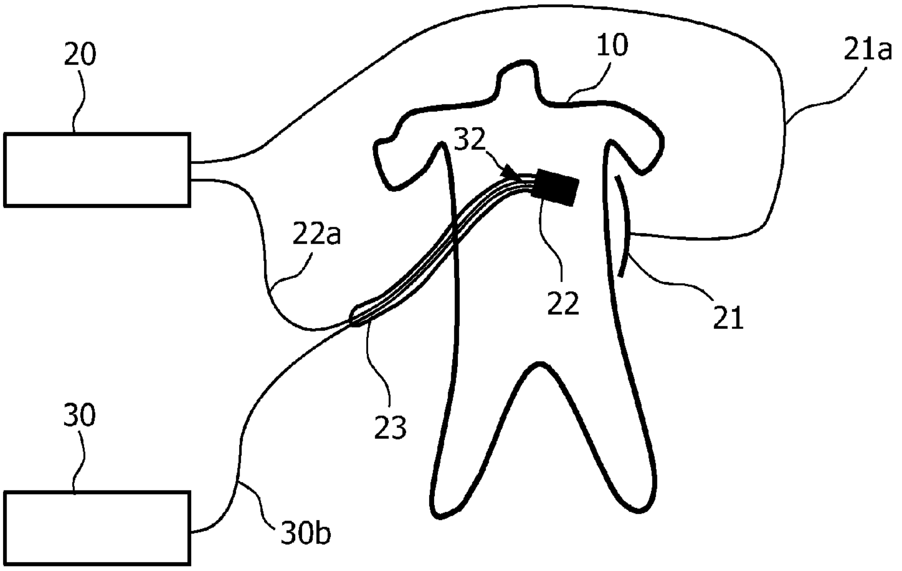


FIG. 2

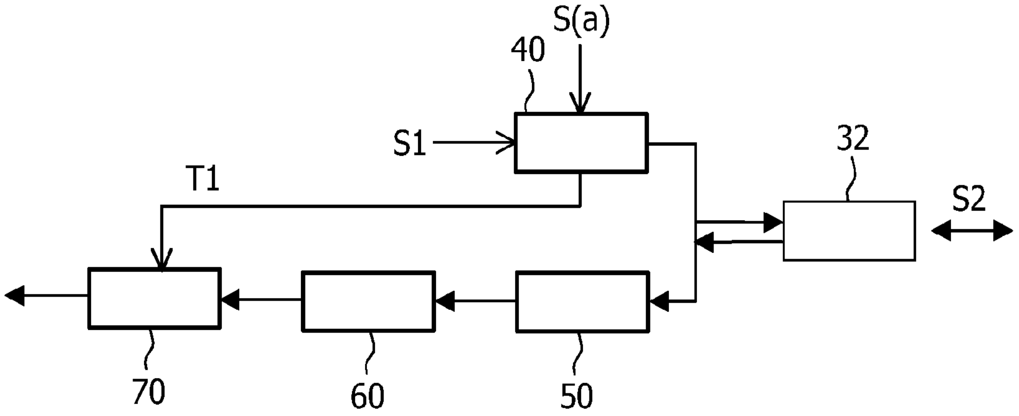


FIG. 3

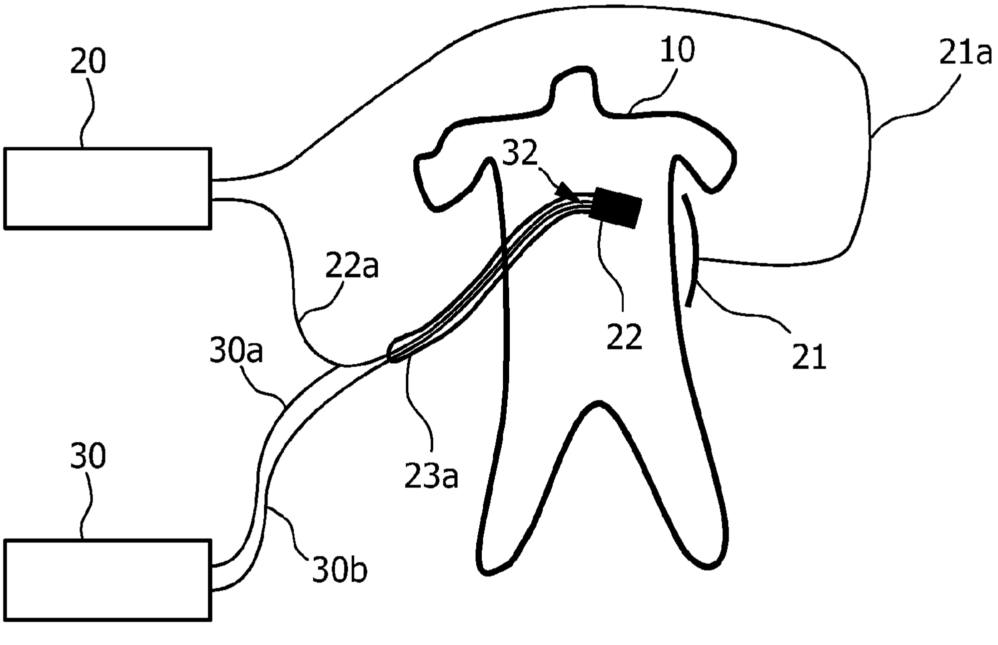


FIG. 4

FIG. 5

FIG. 6

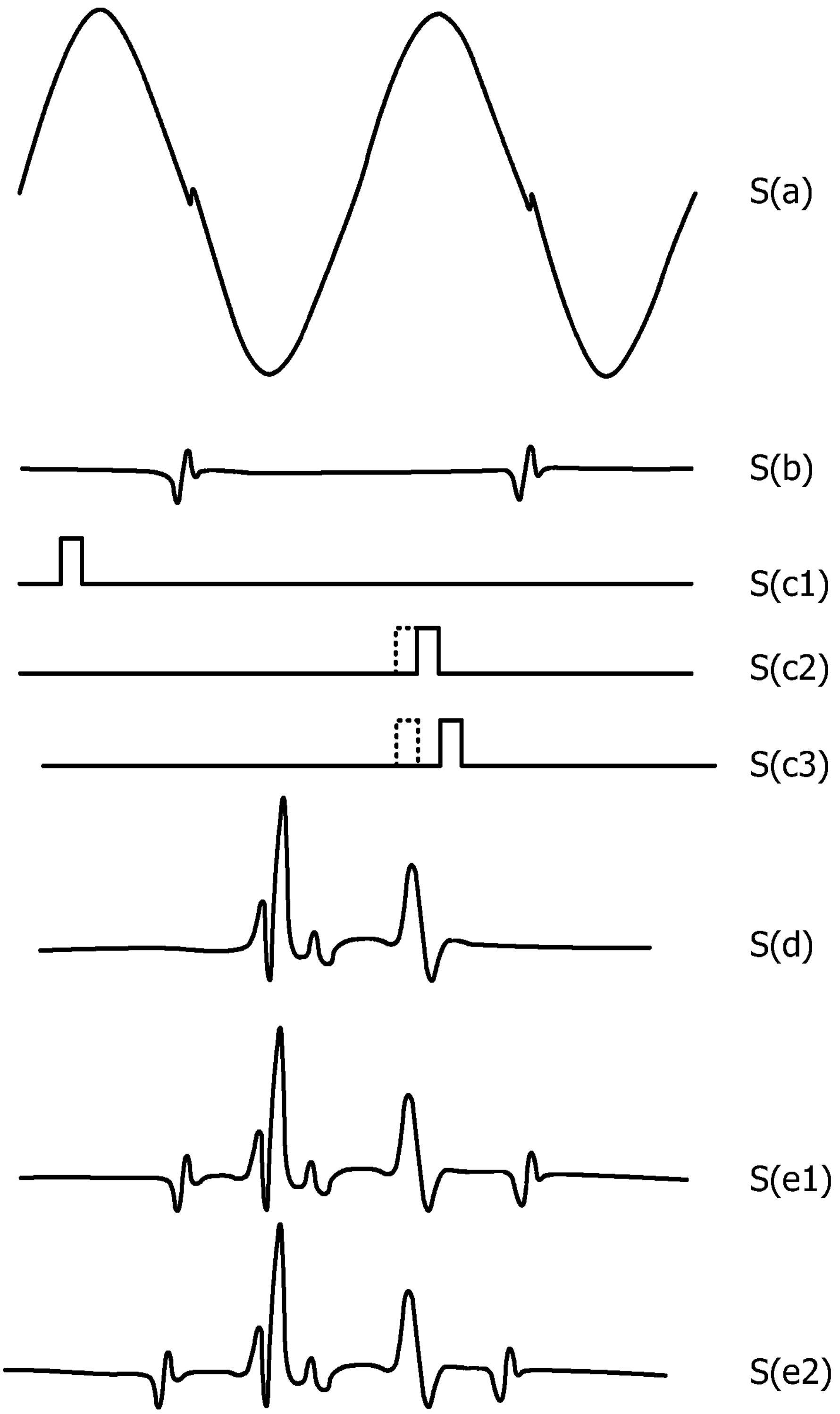


FIG. 7

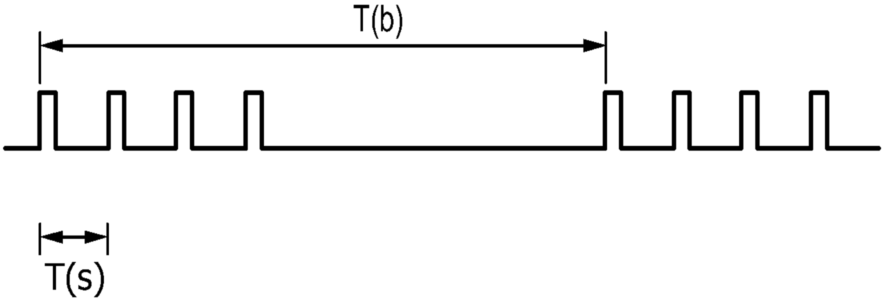


FIG. 8

INTERFERENCE REDUCTION AND SIGNAL TO NOISE RATIO IMPROVEMENT FOR ULTRASOUND CARDIAC ABLATION MONITORING

FIELD OF THE INVENTION

[0001] The present invention relates to a system, apparatus, method and computer program product for interference reduction in ultrasound cardiac ablation applications, especially for interference reduction during RF ablation using RF catheters having ultrasound transducers for monitoring the progress of lesions made to cardiac tissue.

BACKGROUND OF THE INVENTION

[0002] Cardiac ablation technology as a common procedure for treating atrial fibrillation usually is based on an ablation device with an ablation electrode provided within a radiofrequency (RF) catheter for navigating within a patient's body. The ablation electrode is provided at the distal end of the catheter so that tissue located between the ablation electrode and an indifferent electrode positioned next to the patient's body can be treated. Combined with an imaging system, usually based on ultrasound (US), such an ablation device is aimed to provide lesions of a specific depth to the atrial wall of a patient's heart. The lesions formed by an ablation conduct much less than healthy tissue, and thus effectively break any electrical paths over which the signals that cause the fibrillation are conducted. Generally, the lesions that are made should penetrate the complete atrial wall resp. heart wall for this procedure to be an effective treatment for atrial fibrillation, wherein e.g. in humans, the atrial wall can be up to 8 mm thick. However, a lesion that is made too deep can be lethal; e.g. the oesophagus is a critical organ that should not be affected. Therefore, an ultrasound (US) transducer coupled with the ablation device is provided, especially built into the ablation catheter, and, where applicable, integrated adjacent to the ablation electrode, in order to generate information related to the progress of the ablation treatment. That is to say, US monitoring can give the surgeon a feedback mechanism on the progress of a lesion, which may increase the success rate of the procedure. Nonetheless, RF ablation causes interferences with US signals, so that in many cases, US monitoring is not reliable or trustworthy enough, and tissue ablation resp. treatment of atrial fibrillation cannot be done effectively.

[0003] In other words, currently, in spite of any imaging system, these ablation procedures are performed without a proper mechanism to assess the exact progress of the lesion, as there is e.g. capacitive coupling of RF signals into US signals, i.e. RF signals interfere with US signals. This causes the surgeon to be very cautious, e.g. due to the danger of injury from overheating. Further, in case of underheating, the treatment is ineffective. Therefore, even if US monitoring is integrated in the ablation system, there remain a significant number of treatments which are not effective. In all these cases, the lesions could not have been made such that the electrical paths over which the signals that cause the fibrillation are conducted are effectively disrupted.

[0004] Therefore, a requirement for radio frequency (RF) catheters is more adequate control of the lesion development in the tissue, especially in real-time during RF ablation. A system that can provide a real-time feedback of the lesion development as well as real-time information about the depth of the lesion, especially with respect to the thickness of the tissue at the treatment site, would prevent injury and death, e.g. also from overheating in RF catheter ablation procedures. As mentioned above, high-frequency ultrasound (US) can be used to monitor the progression of the lesion boundary in motion-mode (M-mode) imaging, but the referred disadvantages are not overcome yet. The RF signal interferes with the US signal such that tissue reflections cannot be seen easily.

SUMMARY OF THE INVENTION

[0005] It is an object of the present invention to provide an apparatus, a system and a method for treating tissue based on RF ablation and for monitoring treatment progress and tissue characteristics based on ultrasound which enables a surgeon to provide lesions of adequate depth to the tissue. It is a further object of the present invention to reduce the danger of injury from overheating. It is another object of the present invention to reduce the effect of capacitive coupling of RF signals into US signals, especially in order to enhance ultrasound based monitoring of ablation depth. Also, it is an object of the present invention to provide an ultrasound cardiac ablation monitor which is less susceptible resp. prone to any interference between RF and US signals, and to facilitate US monitoring of tissue characteristics in general, also in context with treatment of any other tissue than atrial walls. In other words, it is an aim of the present invention to improve US monitoring when US signals interfere with any other signals, e.g. RF ablation signals.

[0006] At least one of these objects is achieved by an apparatus as claimed in claim **1**, a device as claimed in claim **4**, a system for interference reduction as claimed in claim **14**, and a method for interference reduction as claimed in claim **6**.

[0007] Thereby, the present invention is applicable, inter alia, for therapy concepts where ultrasound is used for monitoring e.g. tissue characteristics, in particular when there is a highly repetitive interference signal, so for instance an interference signal of a RF ablation device. In particular, in context with RF ablation, the problem solved by the present invention relies, inter alia, in the following. Usually, the RF signal interferes with the US signal such that tissue reflections cannot be seen easily, since the RF signal is of much larger amplitude compared to US tissue reflections. More specifically, the frequency of the RF ablation signal is about 450 kHz, and US lesion monitoring is performed with frequencies higher than 10 MHz. However, the RF signals contain high frequency harmonics which significantly affect the US signals in the bandwidth of the US transducer. Until now, it has not been possible to filter out the RF ablation signal coupled into the US signal with an analogue filter.

[0008] The invention is based, inter alia, on the following recognitions. The ablation signal and therefore the interference picked up by the ultrasound transducer are of a repetitive nature. Although the exact shape of the interference signal cannot be estimated on forehand, this shape changes only slowly in time. The main cause for changes of this interference signal is the change of impedance of the tissue due to lesion formation, and the changes in the tissue occur only slowly. In one illustrative example, considering an ultrasound system operating at 20 MHz in water offering a resolution of roughly 30 μm, the fastest motion in the tissue is caused by blood flowing through capillaries, which is less than 4.5 mm/s. This means that in case two echo scans are taken less than 3 ms apart, the loss of details caused by motion is negligible, as the extend of motion is in the order of 0.0135 mm, i.e. below the resolution of 30 μm. At frequencies of 10 MHz and higher, the typical penetration depths in tissue is limited to less than 1 cm. With a speed of sound of approximately 1500 m/s in tissue, this results in a typical measurement time of less than 13 μs. Therefore, in this illustrative example, the maximum number of echo scans that can be taken during a period of 3 ms and that will be almost identical is 230, resulting from the period of maximum 3 ms and the measurement time of less than 13 μs. Thus, several ultrasound scans can be performed, each delivering an at least approximately equal signal sequence, and these signals can be compared to any interference signals in order to obtain an averaged US echo signal and/or to synchronize US scans to RF ablation signals, as further elucidated in context with embodiments of the invention. Thereby, a major advantage is that the apparatus, system and device for interference reduction can be used with existing commonly used ablation systems, especially without modifications, even if these systems generate substantial RF interference. That is to say, it is not necessary to alter existing systems.

[0009] Thereby, the present invention proposes a mechanism in which several ultrasound (US) scans can be performed, especially in a rapid succession within such a time period that loss of detail due to tissue or fluid motion is lesser than the resolution provided by the ultrasound system. This can be done in a burst like mode, especially by considering the polarity of subsequent pulses. I.e., the US scans of each burst can be timed, and the bursts themselves can be timed as well. Thereby, interference reduction can be simply achieved by providing the pulses in a rapid succession, so that motion of tissue or patient movement does not have a significant negative effect on the quality of US echo signals.

[0010] According to a first aspect, combining detected interference signals with a respective ultrasound echo signal for providing a combined echo signal and averaging at least two of the combined echo signals in order to obtain an averaged echo signal with high signal to noise ratio can lead to better US based monitoring, especially of the ablation depth. In other words, a combined echo signal corresponds to a signal received from the transducer comprising the signal wanted for imaging and the interference signal. Thereby, it came into notice that it can be sufficient to average the echo signals of a limited number of US scans.

[0011] Averaging the scans resp. signals can result in a better signal to noise ratio (SNR) of an echo signal since the US component is at least approximately the same in the subsequent scans while the interference signal and noise may be different. Averaging can provide reduced interference and thus reconstructed US echo signals. That is to say, in the practical circumstances of an ablation intervention, having short measurement times per scan and a low speed of objects to be tracked, according to the invention, in one example of an application, up to 230 scans can be taken that are almost mutually identical. However, much fewer scans may be required. Based on averaging, interference reduction can be simply achieved by increasing the signal to noise ratio, so that ultrasound echo signals can be obtained with a higher quality.

[0012] According to a second aspect which can be combined with the above first aspect, the ultrasound device can be connected to the ablation device in order to enable synchronization of excitation pulses to RF ablation signals so that a respective interference signal of interference between echo signals and ablation signals has a predetermined phase. Thus, by synchronizing a respective ultrasound excitation pulse to the ablation signals, the interference will have a predetermined phase, especially with respect to the recorded echo signals, which enables e.g. the phase of US signals to be shifted on purpose in relation to the phase of ablation signals. Based on synchronization, interference reduction can be simply achieved by taking into account the phase of interference signals, so that on purpose, the phase of echo signals can be adjusted in relation to the phase of the ablation signals.

[0013] Thus, the present invention reduces the unavoidable interference caused by the harmonics of the strong RF ablation signals on the ablation electrode which are coupled with ultrasound signals received from an ultrasound transducer, wherein the US transducer can reside within this ablation electrode. Therefore, the present invention also provides the advantages of fewer restrictions in US transducer arrangement as well as less requirements to shielding. At the same time, it increases the signal to noise ratio (SNR) of the measured US echo signals and therefore penetration depth of US signals into the cardiac tissue.

[0014] According to a third aspect which can be combined with any one of the above first and second aspects, a pulse generating device for interference reduction in radiofrequency (RF) ablation applications using ultrasound based monitoring can be provided, wherein the pulse generating device is arranged for receiving an RF ablation signal, receiving a start burst signal for starting a first burst of at least two ultrasound scans including ultrasound signals, generating excitation pulses, synchronizing the excitation pulses to said

[0015] RF ablation signals so that an interference signal of interference between echo signals and ablation signals has a predetermined phase, and the pulse generating device can further be arranged for providing timing information to a signal processing unit in order to time said excitation pulses and the start of a subsequent scan and/or the start of a second burst of scans in relation to ablation signals. In other words, US signals can be provided in a burst like mode with subsequent pulses having different polarity. In the received scans resp. signals, the US component can be reversed for each subsequent scan while the interference signal will be the same. By subtracting signals in subsequent scans from each other, the US component can be doubled, while the interference signal is cancelled out. A resulting signal can be obtained which is based on an averaging of combined signals. The combined signals can be obtained from combining interference signals to US echo signals, wherein in the resulting signal, the ultrasound echo is amplified, especially doubled, and the interference is reduced, especially cancelled out.

[0016] According to a fourth aspect which can be combined with any one of the above first, second and third aspects, alternatively or additionally, US signals can be provided, especially in a burst mode, with subsequent pulses having the same polarity as the ultrasound echo signals but being slightly shifted in phase with respect to the signals of the ablation device. In the received scans, through synchronizing the ultrasound excitation pulses resp. the ultrasound signals, the US component remains at the same time (position) while the interference signal can be shifted. Again, by averaging the signals of a number of scans, the signal to noise ratio (SNR) of echo signals is improved.

[0017] According to a fifth aspect which can be combined with any one of the above first, second, third and fourth aspects, responsive to the polarity of excitation pulses, combined echo signals may have alternating positive and negative polarity, in order to add signals for which the positive excitation is used and to subtract the ones with negative excitation, and/or combined echo signals have same polarity as the ultrasound echo signals according to excitation pulses each with same polarity. Thereby, interference reduction can be simply achieved by increasing the response signal and cancelling out interference. Additionally, the pulse generating device can be arranged to carry out synchronization of the excitation pulses to the RF ablation signals so that a respective interference signal of interference between echo signals and ablation signals has a predetermined phase, and the system can further be arranged to provide a start burst signal to said pulse generating device in order to trigger the pulse generating device to generate a sequence of synchronized ultrasound excitation pulses. Further, the phase of the combined echo signals can be shifted with respect to the ablation signal. Thereby, interference reduction can be simply achieved by conserving useful signals while decreasing noise level and level of interfered signals. The repetition rate can be chosen such that no echoes are recorded from previous excitation pulses.

[0018] Of course other interference reduction options can be used. For example, bursts can be carried out and repeated in specific time periods with specific scanning time, so that an appropriate synchronization method can be found for any application in which interference occurs.

[0019] The apparatus described above may be implemented as an apparatus including an ablation device, an US device, and several devices for averaging and/or synchronizing. As an alternative, any devices for averaging and/or synchronizing may be integrated in the ablations device and/or in the US device.

[0020] It shall be understood that the apparatus of claim **1**, the device of claim **4**, the system of claim **14**, the method of claim **6**, and the computer program of claim **15** have similar and/or identical preferred embodiments, in particular, as defined in the dependent claims.

[0021] It shall be understood that a preferred embodiment of the invention can also be any combination of the dependent claims with the respective independent claim.

[0022] These and other aspects of the invention will be apparent from and elucidated with reference to the embodiments described hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] In the following drawings:

[0024] FIG. **1** shows a schematic drawing of a conventional arrangement for cardiac ablation within a human body;

[0025] FIG. **2** shows a schematic drawing of the ablation system of FIG. **1** in conjunction with ultrasound monitoring;

[0026] FIG. **3** shows a schematic block diagram of a basic system setup for interference reduction according to the present invention;

[0027] FIG. **4** shows a schematic drawing of an arrangement for cardiac ablation according to the present invention;

[0028] FIG. **5** schematically shows examples of signals of a first embodiment of interference reduction technique;

[0029] FIG. **6** schematically shows a typical scan sequence of the first embodiment of interference reduction technique;

[0030] FIG. **7** schematically shows examples of signals of a second embodiment of interference reduction technique; and

[0031] FIG. **8** schematically shows a typical scan sequence of the second embodiment of interference reduction technique;

DETAILED DESCRIPTION OF EMBODIMENTS

[0032] In the following embodiments, an enhanced interference reduction system is proposed, especially for tissue ablation applications where US imaging is influenced by RF signals so that a surgeon's treatment possibilities are restricted.

[0033] According to the embodiments, an averaging of combined signals is carried out and additionally, synchronization of ultrasound excitation pulses to ablation signals can be carried out. Hence, the interference reduction system is adapted to increase signal to noise ratio of US signals.

[0034] In the following, two embodiments using averaging as well as synchronizing are described, starting from a brief description of state of the art.

[0035] FIG. **1** shows a schematic drawing of a conventional arrangement for cardiac ablation within a human body **10**, wherein an ablation electrode **22** is provided within a catheter **23** to be navigated within the human body **10** in order to treat tissue located between the ablation electrode **22** and an indifferent electrode **21**. Ablation electrode **22** and indifferent electrode **21** are connected to an ablation device **20** via ablation wire **22*a*** and connection **21** a respectively.

[0036] FIG. **2** shows a schematic drawing of the ablation system of FIG. **1**, but in conjunction with an ultrasound device **30**. A small high frequency ultrasound transducer **32** is built into the ablation catheter **23** of an ablation device **20** in such a way that the use of that catheter **23** is not changed. Using this transducer **32**, tissue, especially the heart wall, can be visualized during the ablation procedure. The ultrasound device **30** is physically connected to the ablation system **20** in such a way that the ultrasound transducer **32** is provided in direct proximity to an ablation electrode **22**. Using an ultrasound device **30** in such close proximity of an ablation electrode **22** introduces a practical problem, as ablation is typically performed using a sinusoidal signal with a frequency between 440 and 480 KHz, and with a power of 20 to 50 watt. The tissue forms a load in the order of 100 to 300 ohm. The voltage required for ablation is therefore easily several tens of volts. But the harmonics of the base frequency are very difficult to suppress, and strong harmonics can be measured up to several megahertz. High frequency ultrasound in the range of 10 to 50 MHz is needed to visualize the heart wall with sufficiently resolution. Though the base frequency of the ablation is far outside the band of interest, the harmonics of it are within this band. In a practical system, it is thus extremely difficult, i.e. practically not feasible to sufficiently shield the US transducer **32** to reduce the interference of the ablation device **20** to a sufficiently low level. Consequently, there is a need for special mechanisms to reduce interference.

[0037] A second problem with such an ultrasound system is that the signal to noise ratio (SNR) limits the depths to which the ultrasound system can see resp. scan/analyze the tissue. Tissue attenuation increases with frequency, so a trade-off must be made between resolution, which means frequency, and penetration depth. Thus, with this technology of state of the art, due to interference and limited US visibility, a surgeon must be very cautions not to damage tissue or provide lesions that are too deep.

[0038] FIG. **3** shows a basic system setup according to the invention in order to reduce both problems mentioned above with the same approach. A start burst signal **51** triggers a pulser **40** to generate a sequence of pulses to excite the ultrasound transducer **32**. The pulser **40** also receives an ablation signal S(a) so that it can synchronize the pulses to the ablation signal S(a). In other words, the ultrasound device is connected to or provided with a pulse generating device **40** which is arranged for receiving the RF ablation signals generated by an ablation device. The ultrasound transducer **32** is arranged for receiving an ultrasound echo signal generated in response to ultrasound excitation pulses, especially in response to each ultrasound excitation pulse. These acoustic signals provided by the transducer **32** can be forwarded to amplifier **50** in order to be processed as echo signals of which the signal to noise ratio is to be increased by averaging, wherein an interference signal of interferences between RF ablation signals and US signals is detected. Especially, the ultrasound transducer can be designed for detecting interference signals. Detection can be carried out with respect to each excitation pulse, or alternatively, with respect to specific excitation pulse, e.g. every other excitation pulse or every third excitation pulse. Detection can further be carried out with respect to a respective US echo signal. The ultrasound echo signals can be processed by the amplifier **50**. The detected interference signals can be combined to respective ultrasound echo signals in order to obtain combined echo signals. In other words, a combined echo signal corresponds to a signal received from the transducer comprising the signal wanted for imaging and the interference signal. The combined echo signals can be amplified in the amplifier **50** and converted to digital signals in an A/D converter **60** in order to be provided to a signal processing unit **70**. The signal processing unit **70** can be arranged for averaging at least two of said combined echo signals. That is to say, signal processing in signal processing unit **70** can take care of the required averaging and can also receive timing information **T1** from the pulser **40** in order to time the start of the next scan resp. a subsequent burst. Thereby, the signal processing part can be performed in hardware or software. The implementation in hardware is preferred, as it can seriously reduce the data that needs to be transferred to the system using the ultrasound signal. All other modules are hardware modules.

[0039] With this technology, averaging as well as synchronization can be carried out. This means that the signal to noise ratio of US echo signals can be increased, and despite interference, an US transducer can be embedded in direct proximity of an ablation electrode.

[0040] FIG. **4** shows a regular ablation device **20** with a modified ablation catheter **23***a*, the modified ablation catheter **23***a* being arranged for providing both ablation electrode **22** and US transducer **32** in such a way that interference does not noticeably affect US imaging quality. The ablation electrode **22** and an US transducer **32** are provided at the distal end of the catheter **23***a* for navigating within a body in order to treat atrial fibrillation by providing lesions to cardiac tissue. The US transducer **32** can be embedded in the ablation electrode **22**, and it is well shielded to minimize the interference that it picks up from the ablation signal. In other words, advantageously, the US transducer **32** can be used with existing commonly used ablation systems (as shown in FIG. **2**), especially without the requirement of any modifications to the ablation electrode or catheter, even if these systems generate substantial RF interference. Thus, it is not necessary to substantially alter existing systems, so that the proposed apparatus, device and system for interference reduction basically can be implemented in all these commonly used ablations systems. The ultrasound device **30** resp. a pulser generates or causes generation of at least two scans resp. excitation pulses in a rapid succession, especially within such a time period that loss of detail due to tissue or fluid motion is lesser than the resolution provided by the ultrasound device. Thereby, the ultrasound device **30** can also be connected to a pulser arranged for generation of excitation pulses. These pulses can be synchronized to the ablation signal, wherein a connection **30***a* between the ultrasound device **30** and the ablation device **20** is provided, especially in the form of an additional cable from ablation wire **22***a* to the ultrasound device **30**. Also, a pulser can be arranged for receiving the RF ablation signals.

[0041] Due to averaging, the signal to noise ratio (SNR) of echo signals can be increased. Noise is a truly random process, and adding n identical but noisy signals will increase the signal power by a factor of n^2, but noise only with $\sqrt{n}$, therefore the signal to noise ratio can be increased with $\sqrt{n}$. So, by using e.g. two scans, SNR can be increased with 3 dB.

[0042] FIG. **5** schematically shows the sequence in which the signals according to a first embodiment of interference reduction technique can be provided. Several ultrasound scans are performed in a rapid succession (signal burst) with alternating polarity, wherein the scans can be performed by an ultrasound transducer communicating with a pulse generating device for generating excitation pulses, each scan being carried out in response to a respective excitation pulse. That is to say, responsive to positive and negative excitation pulses with alternating polarity, a combined echo signal S(e), S(f) can be provided with alternating positive and negative polarity, wherein a respective combined echo signal S(e), S(f) is composed of an ultrasound signal S(d) and an interference signal S(b). In the following, the principle of interference reduction technique according to the first embodiment is shortly explicated. A positive ultrasound excitation pulse S(c) is locked (i.e., synchronized) to the ablation signal S(a) so that the interference will have a fixed phase, especially with respect to the recorded US echo signals. Finally, the resulting echo signals S(e) for which the positive excitation is used are added, and the ones with negative excitation are subtracted.

[0043] Therein, FIG. **5** shows a very simplified example of the signals involved. Ablation signal S(a) with harmonics is typically several tens of volts. As example, cross-over distortion is shown at the negative edge of the sinusoidal signal, generating high level harmonics. Signal S(b) is the resulting interference signal picked up by the US transducer. This signal will typically be in the range of microvolts to millivolts. Signal S(c) shows a positive US excitation pulse for the transducer, especially locked to the ablation signal S(a). The US echo signal S(d) shows an example response when no interference would be present.

[0044] Combined US echo signal S(e) shows the same signal, but with interference, so is the sum of signals S(d) and S(b), using a positive excitation pulse. Analogously, combined US echo signal S(f) is the result of a negative excitation signal. The resulting response is the same as signal S(e), but with opposite polarity, using a negative excitation pulse. The added interference however has the original polarity. Subtracting S(f) from S(e) results in a signal in which theoretically the response signal is doubled and the interference is cancelled out.

[0045] In practice, it might occur that some interference remains as the interference is not completely stationary and as there will be some jitter between the ultrasound excitation pulse and the ablation signal. Also, the response to a negative excitation pulse is not necessarily exactly the opposite to that invoked by a positive excitation pulse, e.g. because of nonlinearities of tissue and/or transducer, or because of any imperfections in the electronic system.

[0046] Preferably, the repetition rate is chosen such that no echoes are recorded from previous excitation pulses. However, the total sequence of pulses should be as short as possible so that blood cell motion, which is assumed to be one of the fastest motions occurring in the visibility field of an US transducer, does not cause deterioration of the ultrasound image, or as the case may be, the US based monitoring.

[0047] FIG. **6** shows an example of a typical scan sequence according to the first embodiment of interference reduction technique. In this example, each burst contains four scans, two positive scans and two negative scans. The burst repetition period T(b) can be in the order of e.g. 10 to 100 ms. More specifically, the burst repetition period T(b) can also be in the order of e.g. 1 ms or less, if high scan rates are advantageous in order to reduce interference, which might depend on the interference signal. The scan repetition period T(s), i.e. the time between two consecutive scans, can be in the order of e.g. 10 μs to 100 μs.

[0048] FIG. **7** schematically shows the sequence in which the signals according to a second embodiment of interference reduction technique can be provided. Several ultrasound scans are performed in a rapid succession (signal burst) with the same polarity as the ultrasound echo signals S(d). That is to say, responsive to excitation pulses each having same polarity, combined echo signals S(e**1**), S(e**2**) are provided with same polarity. In the following, the principle of interference reduction technique according to this second embodiment is shortly explicated. Likewise to the first embodiment, a respective ultrasound excitation pulse S(c**1**), S(c**2**), S(c**3**) is synchronized to the ablation signal, but for each pulse, the phase with respect to the ablation system is shifted on purpose. Therefore, the RF interference will also have a slightly shifted phase with respect to the recorded echo signals S(d). Finally, the resulting echo signals S(e**1**), S(e**2**) for which the positive excitation is used are averaged, and the interfered signal decreases if more averaging is done.

[0049] Therein, FIG. **7** shows a very simplified example of the signals involved. Signal S(a) is the ablation signal with harmonics. As example, cross-over distortion is shown at the negative edge of the sinusoidal signal, generating high level harmonics. Signal S(b) is the resulting interference signal picked up by the transducer. Signals S(c**1**), S(c**2**) and S(c**3**) show first, second and third excitation pulse respectively for the transducer. Signal S(d) shows an example for an US response (echo signal) when no interference would be present. Signal S(e**1**) shows the same signal, but with interference, obtained when first excitation pulse, especially according to signal S(c**1**), is applied. Signal S(e**2**) shows a signal with interference when second excitation pulse, especially according to signal S(c**2**), is applied. It can be seen that interfered signal S(e**2**) is a bit shifted with respect to interfered signal S(e**1**). The resulting response represents an average value of signals S(e**1**) and S(e**2**) and of other similarly generated signals. In such a way, a useful signal will remain, while noise level and level of an interfered signal will decrease as the number of averaging increases.

[0050] As mentioned in context with FIG. **5**, the repetition rate can be chosen such that no echoes are recorded from previous excitation pulses. However, the total sequence of pulses should be as short as possible so that blood cell motion, which is assumed to be one of the fastest motions occurring in the visibility field of an US transducer, does not cause deterioration of the ultrasound image, or as the case may be, the US based monitoring.

[0051] FIG. **8** shows an example of a typical scan sequence according to the first embodiment of interference reduction technique. In this example, each burst contains four positive scans, but the number of scans can be varied also. As in context with the first embodiment, the burst repetition period T(b) can be in the order of e.g. 10 to 100 ms. The scan repetition period T(s), i.e. the time between two consecutive scans, can be in the order of e.g. 10 μs to 100 μs.

[0052] It shall be understood that there is a sequence in which signals according to a third embodiment of interference reduction technique can be provided, the third embodiment being a combination of the first and second embodiments, i.e. positive and negative scans as well as shifting. In each pair of subsequent pulses, a positive and a negative excitation pulse is used, and the resulting echoes are subtracted. This suppresses the interference while increasing the SNR. However, some residual interference might be unavoidable. For the next pair, the phase with respect to the ablation system is slightly shifted, and the same procedure is repeated. The residual interference has the same strength but a different phase compared to the previous pair. Therefore, by averaging these pairs of pulses, the residual interference can be suppressed further than in the first embodiment.

[0053] In summary, in cardiac ablation for treatment of atrial fibrillation where lesions have to be made to the heart wall, an ultrasound monitoring mechanism is adapted to assess the progress of the lesion, so that a surgeon can provide lesions with adequate depth, wherein interference caused by an ablation device is reduced and signal to noise ratio of echo signals is improved. In other words, in RF applications where US imaging is used, an interference reduction system is adapted to at least substantially cancel out interference effects, so that US based monitoring is enhanced, especially monitoring of ablation depth. Other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims.

[0054] In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality.

[0055] A single processor, sensing unit or other unit may fulfill the functions of several items recited in the claims. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage.

[0056] It is noted that the proposed solution according to the above embodiments can be implemented at least partially in software modules at the relevant functional blocks of FIG. **3**. The resulting computer program product may comprise code means for causing a computer to carry out the steps of the above procedures of functions of FIG. **3**. Hence, the procedural steps are produced by the computer program product when run on the computer.

[0057] A computer program may be stored/distributed on a suitable medium, such as an optical storage medium or a solid-state medium supplied together with or as part of other hardware, but may also be distributed in other forms, such as via the Internet or other wired or wireless telecommunication systems.

[0058] Any reference signs in the claims should not be construed as limiting the scope thereof.

[0059] In cardiac ablation for treatment of atrial fibrillation where lesions have to be made to the heart wall, an ultrasound monitoring mechanism is adapted to assess the progress of the lesion, so that a surgeon can provide lesions with adequate depth, wherein interference caused by an ablation device is reduced and signal to noise ratio of echo signals is improved.

1. An apparatus for interference reduction in radiofrequency (RF) ablation applications using real-time ultrasound based monitoring, said apparatus comprising:

an ablation device (**20**) arranged for generating RF ablation signals (S(a)) supplied to an ablation electrode (**22**),

an ultrasound device (**30**);

an ultrasound transducer (**32**) connected to said ultrasound device (**30**);

wherein said apparatus is arranged for generating at least two ultrasound excitation pulses (S(c); S(c**1**), S(c**2**), S(c**3**)) in order to excite said ultrasound transducer (**32**), said ultrasound transducer (**32**) being arranged for performing an ultrasound scan for each ultrasound excitation pulse, each ultrasound scan including ultrasound signals (S**2**), and for receiving at least two combined ultrasound signals (S(e), S(e**1**), S(e**2**), S(f);

wherein the received combined ultrasound signals each include an interference signal (S(b)) of interference between said RF ablation signals (S(a)) and an ultrasound echo signal (S(d)) in response to an ultrasound excitation pulse,

wherein at least one received combined ultrasound signal is processed with at least another one received combined ultrasound signal in order to reduce the negative effect on ultrasound based monitoring that would be caused by said interference signal (S(b)).

2. The apparatus according to claim **1**, wherein said apparatus is arranged for processing at least two of said combined ultrasound signals by averaging in order to obtain an averaged echo signal with high signal to noise ratio.

3. The apparatus according to claim **1**, wherein said ultrasound device (**30**) is connected to said ablation device (**20**) in order to enable synchronization of said excitation pulses to said RF ablation signals so that a respective interference signal (S(b)) of interference between echo signals (S(d)) and ablation signals (S(a)) has a predetermined phase.

4. (canceled)

5. (canceled)

6. A method of reducing interference in radiofrequency (RF) ablation applications using real-time ultrasound based monitoring, said method comprising:

a. generating RF ablation signals S(a) and detecting said RF ablation signals S(a);

b. generating at least two ultrasound excitation pulses (S(c); S(c**1**), S(c**2**), S(c**3**)), and providing said ultrasound excitation pulses to an ultrasound transducer (**32**) for performing ultrasound scans in response to said ultrasound excitation pulses;

c. receiving an at least two combined ultrasound signal (S(de), S(e**1**), S(e**2**), S(f)), wherein the received combined ultrasound signals each include an interference signal (S(b)) of interference between said RF ablation signals (S(a)) and an ultrasound echo signal (S(d)) in response to an ultrasound excitation pulse;

d. processing at least one received combined ultrasound signal with at least another one received combined ultrasound signal in order to reduce a negative effect on ultrasound based monitoring that would be caused by said interference signal (S(b)).

7. The method of claim **6**,

wherein the processing includes averaging at least two of said combined ultrasound signals to obtain an averaged echo signal with high signal to noise ratio.

8. The method according to claim **7**, wherein one of the at least two combined ultrasound signals is responsive to a positive excitation pulse and another one of the at least two combined ultrasound signals is responsive to a negative excitation pulse, the positive excitation pulse and the negative excitation pulse having alternating polarity.

9. The method according to claim **7**, wherein said averaging is carried out in such a way that said combined ultrasound signals for which said positive excitation is used are added, and the ones with negative excitation are subtracted, obtaining a resulting signal in which the ultrasound echo is amplified, and in which the interference is reduced.

10. The method according to claim **7**, further comprising:

synchronizing said ultrasound excitation pulses to said ablation signal so that interference signal (S(b)) has a predetermined phase.

11. The method according to claim **7**, wherein responsive to excitation pulses each having same polarity, combined ultrasound signals (S(e), S(f); S(e**1**), S(e**2**)) are provided with same polarity as said ultrasound echo signals (S(d)), and

wherein said averaging is carried out in such a way that said combined ultrasound signals for which the positive excitation is used are averaged, obtaining a resulting signal.

12. The method according to claim **7**, the method further comprising:

synchronizing said ultrasound excitation pulses to said ablation signal, wherein the phase of said ultrasound echo signals (S(d)) is shifted with respect to said ablation signals so that said interference signal (S(b)) will have a shifted phase with respect to said ultrasound echo signals (S(d)).

13. The method according to claim **7**, the method further comprising:

before said step of averaging, amplifying said combined ultrasound signal;

before said step of averaging, converting said combined ultrasound signal to a digital ultrasound signal;

after said step of averaging, providing timing information (T**1**) from said pulse generating device (**40**) to said signal processing unit (**70**), and synchronizing said ultrasound excitation pulses to said ablation signal,

wherein generating at least two ultrasound excitation pulses (S(c); S(c**1**), S(c**2**), S(c**3**)) in a rapid succession is done in a burst like mode, each burst containing at least four scans, each scan being preferably less than 0.1 ms apart to a subsequent scan, and each burst being preferably more than 1 ms apart to a subsequent burst, said pulse generating device (**40**) receiving a start burst signal (S**1**) in order to generate a sequence of excitation pulses, said timing information (T**1**) being used for timing the start of a subsequent burst.

14. (canceled)

15. A computer program product comprising code means for producing the steps of claim **7** when run on a computing device.

* * * * *

专利名称(译)	超声心脏消融监测的干扰降低和信噪比改善		
公开(公告)号	US20130231655A1	公开(公告)日	2013-09-05
申请号	US13/884696	申请日	2011-11-15
[标]申请(专利权)人(译)	BUDZELAAR弗朗西斯PAULUS MARIA 米哈伊洛维奇内纳德 FOKKENROOD史蒂芬ANTONIE WILLEM		
申请(专利权)人(译)	BUDZELAAR，弗朗西斯PAULUS MARIA 米哈伊洛维奇，内纳德 FOKKENROOD，史蒂芬ANTONIE WILLEM		
当前申请(专利权)人(译)	皇家飞利浦电子N.V.		
[标]发明人	BUDZELAAR FRANCISCUS PAULUS MARIA MIHAJLOVIC NENAD FOKKENROOD STEVEN ANTONIE WILLEM		
发明人	BUDZELAAR, FRANCISCUS PAULUS MARIA MIHAJLOVIC, NENAD FOKKENROOD, STEVEN ANTONIE WILLEM		
IPC分类号	A61B18/18 A61B8/08		
CPC分类号	A61B8/0883 A61B18/18 A61B8/5207 A61B18/14 A61B18/1492 A61B19/5244 A61B2018/00577 A61B2018/00738 A61B2018/00839 A61B2018/0088 A61B2019/5251 A61B2019/5263 A61B2019/5278 A61B2019/5289 B06B1/0629 G01S7/52077 G01S15/899 A61B8/52 A61B8/12 A61B34/20 A61B2034/2051 A61B2034/2063 A61B2090/364 A61B2090/3782		
优先权	2010191687 2010-11-18 EP 2011158848 2011-03-18 EP		
外部链接	Espacenet USPTO		

摘要(译)

在用于治疗心房颤动的心脏消融中，必须对心脏壁进行损伤，超声监测机制适于评估病变的进展，以便外科医生可以提供具有足够深度的病变，其中由消融引起的干扰降低了器件，改善了回波信号的信噪比。