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(54) **SYSTEM FOR NEURAL STIMULATION WITH RESPIRATORY FEEDBACK**

SYSTEM ZUR NERVENSTIMULATION MIT ATEM-FEEDBACK

SYSTÈME DE STIMULATION NEURALE AVEC RETOUR RESPIRATOIRE

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EP 2 076 314 B1

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Description

TECHNICAL FIELD

[0001] This document relates generally to neural stimulation and particularly to a system for controlling neural stimulation using a respiratory signal.

BACKGROUND

[0002] Electrical stimulation of the autonomic nervous system has been applied to modulate various physiologic functions. One example is the modulation of cardiac functions and hemodynamic performance using neural stimulation. The myocardium is innervated with sympathetic and parasympathetic nerves. Activities in these nerves, including artificially applied electrical stimuli, modulate the heart rate and contractility (strength of the myocardial contractions). Electrical stimulation applied to the parasympathetic nerves, such as the cardiac branch of the vagus nerve, is known to decrease the heart rate and the contractility, lengthen the systolic phase of a cardiac cycle, and shorten the diastolic phase of the cardiac cycle. Electrical stimulation applied to the sympathetic nerves is known to have essentially the opposite effects. The ability of the electrical stimulation of the autonomic nerves in modulating the heart rate and contractility is utilized to treat abnormal cardiac conditions, such as to improve hemodynamic performance for heart failure patients and to control myocardial remodeling and prevent arrhythmias following myocardial infarction. However, the autonomic nervous system regulates functions of many organs of the body. Neural stimulation pulses delivered to the autonomic nervous system to treat a cardiac disorder may unintentionally modulate various other physiologic functions. Therefore, there is a need to prevent or control unintended, potentially adverse effects when neural stimulation is applied to the autonomic nervous system.

[0003] US 2004/0210261 shows a neural stimulation system delivering vagal nerve stimulation and cardiac pacing stimulation. The stimulation is modified in response to detection of apneas.

[0004] US 6 021 352 shows a neural stimulation system configured to provide inspiration synchronous treatment of respiratory disorders, such as sleep apnea.

[0005] US 2003/0153953 also shows a neural stimulation system for treatment of respiratory disorders, such as sleep apnea.

SUMMARY

[0006] The above object, according to the invention, is solved by a neural stimulation system comprising the features of claim 1. preferred embodiments of this system are defined in the dependent claims.

[0007] Embodiments, aspects, examples and implementations of the present disclosure which do not fall

under the appended claims are not part of the present invention.

[0008] A neural stimulation system controls the delivery of neural stimulation using a respiratory signal as a therapy feedback input. The respiratory signal is used to increase the effectiveness of the vagal nerve stimulation, while decreasing potentially adverse side effects in respiratory functions.

[0009] In one embodiment, a neural stimulation system includes a stimulation output circuit, a respiratory signal input, and a synchronization module. The stimulation output circuit delivers neural stimulation pulses. The respiratory signal input receives a respiratory signal indicative of respiratory cycles and respiratory parameters. The synchronization module includes a peak detector and a delay timer. The peak detector detects peaks of the respiratory signal. The delay timer times a delay interval starting with each of the detected peaks of the respiratory signal. The stimulation delivery controller causes the stimulation output circuit to deliver a burst of the neural stimulation pulses when the delay interval expires.

[0010] This Summary is an overview of some of the teachings of the present application and not intended to be an exclusive or exhaustive treatment of the present subject matter. Further details about the present subject matter are found in the detailed description and appended claims. The scope of the present invention is defined by the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The drawings illustrate generally, by way of example, various embodiments discussed in the present document. The drawings are for illustrative purposes only and may not be to scale.

FIG. 1 is an illustration of a neural stimulation system and portions of an environment in which the neural stimulation system is used.

FIG. 2 is an illustration of a respiratory signal indicative of respiratory cycles and respiratory parameters.

FIG. 3 is an illustration of a delivery of neural stimulation pulses synchronized to respiratory cycles.

FIG. 4 is a block diagram illustrating a respiratory cycle-synchronized neural stimulation system.

FIG. 5 is a block diagram illustrating a specific respiratory cycle-synchronized neural stimulation system of FIG. 4.

FIG. 6 is a flow chart illustrating a method for synchronizing neural stimulation to respiratory cycles.

FIG. 7 is a block diagram illustrating a respiratory disorder-responsive neural stimulation system.

FIG. 8 is a block diagram illustrating a specific respiratory disorder-responsive neural stimulation system of FIG. 7.

FIG. 9 is a flow chart illustrating a method for adjusting neural stimulation in response to a respiratory

disorder.

FIG. 10 is a flow chart illustrating a method for adjusting neural stimulation in response to a respiratory disorder.

FIG. 11 is a block diagram illustrating a respiratory cycle-synchronized respiratory disorder-responsive neural stimulation system.

FIG. 12 is a block diagram illustrating another respiratory disorder-responsive neural stimulation system.

FIG. 13 is a block diagram illustrating a specific respiratory disorder-responsive neural stimulation system of FIG. 12.

FIG. 14 is a flow chart illustrating a method for responding to a respiratory disorder during neural stimulation.

FIG. 15 is a flow chart illustrating a method for controlling a neural stimulation treating a non-respiratory disorder.

DETAILED DESCRIPTION

[0012] In the following detailed description, reference is made to the accompanying drawings which form a part hereof, and it is to be understood that the following detailed description provides examples, and the scope of the present invention is defined by the appended claims.

[0013] The relationship between a respiratory rate and a respiratory cycle length (also known as breathing interval), as used in this document, is the relationship between a frequency and its corresponding period. If a respiratory rate is given in breaths per minute, its corresponding respiratory cycle length in seconds is calculated by dividing 60 by the respiratory rate (where 60 is the number of seconds in a minute). Any process, such as a comparison, using a respiratory rate is to be modified accordingly when a respiratory cycle length is used instead. For example, if a low respiratory rate is detected when the respiratory rate falls below a threshold rate, an equivalent process is to detect the low respiratory rate when the respiratory cycle length exceeds a corresponding threshold interval. The appended claims should be construed to cover such variations.

[0014] This document discusses a neural stimulation system that synchronizes delivery of neural stimulation to respiratory cycles and/or adjusts delivery of neural stimulation in response to detection of a respiratory disorder (disordered breathing) such as apnea, hypopnea, or dyspnea. In one embodiment, the neural stimulation system delivers neural stimulation to autonomic nerves such as the vagus nerve of the parasympathetic nervous system. The stimulation of the vagus nerve is referred to as vagal nerve stimulation or vagal nerve modulation. Vagal nerve stimulation may be applied to treat heart diseases, hypertension, inflammatory disease, epilepsy, diabetes, depression, and other ailments. However, vagal nerve stimulation may also cause undesirable effects in respiration such as reduced respiratory rate and re-

duced tidal volume, and worsen the condition of a patient who already suffers from a respiratory disorder. Therefore, respiratory disorders such as apnea, hypopnea, and dyspnea have been contraindication for vagal nerve stimulation. In one embodiment, the neural stimulation system senses a respiratory signal indicative of respiratory cycles and synchronizes the delivery of neural stimulation to the respiratory cycles. This provides an inherent negative feedback that reduces the intensity of neural stimulation when the respiratory rate decreases. In another embodiment, the neural stimulation system detects respiratory disorders such as apnea, hypopnea, and dyspnea. If such a respiratory disorder is detected, the delivery of neural stimulation is adjusted to reduce the intensity of stimulation, suspend the stimulation, or apply a respiratory therapy using neural stimulation or other means to treat the detected respiratory disorder. In other embodiments, the neural stimulation system also delivers neural stimulation to the sympathetic system.

[0015] FIG. 1 is an illustration of a neural stimulation system 100 and portions of an environment in which system 100 is used. System 100 includes implantable medical device 110 that delivers neural stimulation pulses through leads 106 and 108, an external system 120, and a telemetry link 125 providing for communication between implantable medical device 110 and external system 120. For illustrative purposes only, FIG. 1 shows that lead 106 includes an electrode 107 coupled to a nerve 102 of the sympathetic nervous system, and lead 108 includes an electrode 109 coupled a nerve 104 of the parasympathetic nervous system. Nerves 102 and 104 innervate a heart 101. In various embodiments, implantable medical device 110 provides neural stimulation to any one or more nerves through one or more leads for modulating one or more functions of the circulatory system including heart 101. Such leads include implantable neural leads each including at least one electrode for sensing neural activities and/or delivering neural stimulation pulses. One example of such an electrode includes a cuff electrode for placement around the vagus nerve.

[0016] Implantable medical device 110 delivers the neural stimulation pulses and includes a respiration-controlled neural stimulation circuit 130. Respiration-controlled neural stimulation circuit 130 controls the delivery of neural stimulation pulses using indications of respiratory cycles and functions extracted from a respiratory signal. In one embodiment, respiration-controlled neural stimulation circuit 130 detects a predetermined type respiratory fiducial point from each respiratory cycle and synchronizes the delivery of neural stimulation pulses to that respiratory fiducial point. In another embodiment, respiration-controlled neural stimulation circuit 130 detects predetermined type respiratory disorders and suspends or adjusts the delivery of neural stimulation pulses upon detection of a respiratory disorder. In one embodiment, implantable medical device 110 is capable of monitoring physiologic signals and/or delivering therapies in addition to the neural stimulation. Examples of such additional

therapies include cardiac pacing therapy, cardioversion/defibrillation therapy, cardiac resynchronization therapy, cardiac remodeling control therapy, drug therapy, cell therapy, and gene therapy. In various embodiments, implantable medical device 110 delivers the neural stimulation in coordination with one or more such additional therapies.

[0017] External system 120 provides for control of and communication with implantable medical device 110 by a physician or other caregiver. In one embodiment, external system 120 includes a programmer. In another embodiment, external system 120 is a patient management system including an external device communicating with implantable medical device 110 via telemetry link 125, a remote device in a remote location, and a telecommunication network linking the external device and the remote device. The patient management system allows access to implantable medical device 110 from the remote location, for purposes such as monitoring patient status and adjusting therapies. In one embodiment, telemetry link 125 is an inductive telemetry link. In an alternative embodiment, telemetry link 125 is a far-field radio-frequency (RF) telemetry link. Telemetry link 125 provides for data transmission from implantable medical device 110 to external system 120. This includes, for example, transmitting real-time physiologic data acquired by implantable medical device 110, extracting physiologic data acquired by and stored in implantable medical device 110, extracting patient history data such as occurrences of arrhythmias and therapy deliveries recorded in implantable medical device 110, and/or extracting data indicating an operational status of implantable medical device 110 (e.g., battery status and lead impedance). Telemetry link 125 also provides for data transmission from external system 120 to implantable medical device 110. This includes, for example, programming implantable medical device 110 to acquire physiologic data, programming implantable medical device 110 to perform at least one self-diagnostic test (such as for a device operational status), programming implantable medical device 110 to deliver one or more therapies and/or to adjust the delivery of one or more therapies, and/or transmitting externally acquired physiologic and/or other patient data for used by implantable medical device 110 to control the one or more therapies.

[0018] FIG. 2 is an illustration of a respiratory signal indicative of respiratory cycles and respiratory parameters including respiratory cycle length, inspiration period, expiration period, non-breathing period, and tidal volume. The inspiration period starts at the onset of the inspiration phase of a respiratory cycle, when the amplitude of the respiratory signal rises above an inspiration threshold, and ends at the onset of the expiration phase of the respiratory cycle, when the amplitude of the respiratory cycle peaks. The expiration period starts at the onset of the expiration phase and ends when the amplitude of the respiratory signal falls below an expiration threshold. The non-breathing period is the time interval between the end

of the expiration phase and the beginning of the next inspiration phase. The tidal volume is the peak-to-peak amplitude of the respiratory signal.

[0019] The respiratory signal is a physiologic signal indicative of respiratory activities. In various embodiments, the respiratory signal includes any physiology signal that is modulated by respiration. In one embodiment, the respiratory signal is a transthoracic impedance signal sensed by an implantable impedance sensor. In another embodiment, the respiratory signal is extracted from a blood pressure signal that is sensed by an implantable pressure sensor and includes a respiratory component. In another embodiment, the respiratory signal is sensed by an external sensor that senses a signal indicative of chest movement or lung volume.

[0020] FIG. 3 is an illustration of a delivery of neural stimulation pulses synchronized to respiratory cycles. In the illustrated embodiment, peaks 320 of a respiratory signal 300 are detected as the respiratory fiducial points. A delay interval 330 starts upon the detection of each of peaks 320. A burst of neural stimulation pulses 310 is delivered to a nerve such as the vagus nerve when delay interval 330 expires. In various other embodiments, onset points of the inspiration phases, ending points of the expiration phases, or other threshold-crossing points are detected as the respiratory fiducial points.

[0021] FIG. 4 is a block diagram illustrating a respiratory cycle-synchronized neural stimulation system 440. System 440 includes a respiratory sensor 426, a sensor processing circuit 428, and respiration-controlled neural stimulation circuit 430.

[0022] Respiratory sensor 426 senses a physiologic signal indicative of the respiratory cycles and the respiratory parameters. In one embodiment, respiratory sensor 426 includes an implantable sensor incorporated into implantable medical device 110. In a specific embodiment, respiratory sensor 426 is an impedance sensor that senses a transthoracic impedance signal indicative of respiration. In another embodiment, respiratory sensor 426 includes an implantable sensor or a portion thereof. The implantable sensor is communicatively coupled to the implantable medical device via one or more leads or via telemetry. In a specific embodiment, respiratory sensor 426 is an implantable pulmonary artery pressure (PAP) sensor or a portion thereof. The implantable PAP sensor communicates with implantable medical device 100 via RF or ultrasonic telemetry. An example of the implantable PAP sensor is discussed in U.S. Patent Application Serial No. 11/249,624, entitled "METHOD AND APPARATUS FOR PULMONARY ARTERY PRESSURE SIGNAL ISOLATION", filed on October 13, 2005, assigned to Cardiac Pacemakers, Inc., published as US 2007/088221 A1. In another embodiment, respiratory sensor 426 includes an external sensor that senses the expansion and contraction of the chest or a portion thereof. The external sensor communicates with implantable medical device 100 via RF or ultrasonic telemetry.

[0023] Sensor processing circuit 428 produces the res-

piratory signal using the physiologic signal. The respiratory signal is indicative of respiratory cycles and respiratory parameters including one or more of respiratory cycle length, inspiration period, expiration period, non-breathing period, tidal volume, and minute ventilation. In one embodiment, sensor processing circuit 428 removes unwanted components of the physiologic signal to isolate the respiratory components of the physiologic signal. One example includes isolating the respiratory components of a PAP signal, which is discussed in U.S. Patent Application Serial No. 11/249,624, published as US 2207/088221 A1. In one embodiment, sensor processing circuit 428 extracts one or more of the respiratory parameters. In one embodiment, sensor processing circuit 428 and respiration-controlled neural stimulation circuit 430 are both housed in implantable medical device 110. In another embodiment, sensor processing circuit 428 is part of an implantable or external sensor that includes respiratory sensor 426.

[0024] Respiration-controlled neural stimulation circuit 430 is a specific embodiment of respiration-controlled neural stimulation circuit 130 and includes a stimulation output circuit 432 and a controller 434. Stimulation output circuit 432 delivers neural stimulation pulses via electrodes such as electrodes 107 and 109. Controller 434 includes a respiratory signal input 436, a synchronization module 438, and a stimulation delivery controller 446. Respiratory signal input 436 receives the respiratory signal indicative of respiratory cycles and respiratory parameters. Synchronization module 438 synchronizes the delivery of the neural stimulation pulses to the respiratory cycles and includes a respiratory fiducial point detector 442 and a delay timer 444. Respiratory fiducial point detector 442 detects predetermined-type respiratory fiducial points in the respiratory signal. Delay timer 444 times a delay interval starting with each of the detected respiratory fiducial points. Stimulation delivery controller 446 causes stimulation output circuit 432 to deliver a burst of the neural stimulation pulses when the delay interval expires.

[0025] FIG. 5 is a block diagram illustrating a respiratory cycle-synchronized neural stimulation system 540, which is a specific embodiment of respiratory cycle-synchronized neural stimulation system 440. System 540 includes respiratory sensor 426, sensor processing circuit 428, and a respiration-controlled neural stimulation circuit 530.

[0026] Respiration-controlled neural stimulation circuit 530 is a specific embodiment of respiration-controlled neural stimulation circuit 430 and includes stimulation output circuit 432, a sensing circuit 550, and a controller 534. Sensing circuit 550 senses one or more neural signals using electrodes such as electrodes 107 and 109. Controller 534 includes respiratory signal input 436, a synchronization module 538, and a stimulation delivery controller 546. Synchronization module 538 synchronizes the delivery of the neural stimulation pulses to the respiratory cycles. Such synchronization between respi-

ratory cycles and neural stimulation provides a negative feedback to mitigate undesirable effects such as abnormally long respiratory cycle lengths caused by the neural stimulation. In one embodiment, the synchronization between respiratory cycles and neural stimulation allows the neural stimulation to mimic the natural heart rate modulation by the respiration where the heart rate increases during the inspiration phase and decreases during the expiration phase. In a further embodiment, in addition to synchronizing neural stimulation to respiratory cycles, synchronization module 538 also synchronizes the neural stimulation to cardiac cycles and/or circadian cycles. Synchronization module 538 includes a peak detector 542, a delay timer 544, and a delay generator 548. Peak detector 542 is a specific embodiment of respiratory fiducial point detector 442 and detects high or low peaks of the respiratory signal. In one embodiment, peak detector 542 detects high peaks illustrated in FIG. 3 as peaks 320. Delay timer 544 times the delay interval that starts with the detected peaks. In one embodiment, the delay interval is programmable between approximately 0 and 5 seconds. In another embodiment, delay generator 548 adjusts the delay interval using the respiratory signal. In a specific embodiment, delay generator 548 calculates the delay interval as a function of the respiratory cycle length. Stimulation delivery controller 546 is a specific embodiment of stimulation delivery controller 446 and controls the delivery of the neural stimulation pulses by executing a stimulation algorithm including a set of stimulation parameters. In various embodiments, the stimulation parameters include pulse amplitude, pulse width, stimulation frequency or inter-pulse interval, number of pulses per burst, and stimulation sites. Stimulation delivery controller 546 causes stimulation output circuit 432 to deliver a burst of the neural stimulation pulses when the delay interval expires.

[0027] FIG. 6 is a flow chart illustrating a method 600 for synchronizing neural stimulation to respiratory cycles. In one embodiment, method 600 is performed by respiration-controlled neural stimulation circuit 430 or 530.

[0028] A respiratory signal is received at 610. The respiratory signal is indicative of respiratory cycles and respiratory parameters. Examples of the respiratory parameters include the respiratory cycle length, the inspiration period, the expiration period, the non-breathing interval, the tidal volume, and the minute ventilation. In various embodiments, the respiratory signal is, or is derived from, a physiologic signal indicative of the respiratory cycles and the respiratory parameters. Examples of the physiologic signal include a transthoracic impedance signal and blood pressure signals such as a PAP signal.

[0029] A respiratory fiducial point is detected from the respiratory signal at 620. Examples of the respiratory fiducial point include high or low peaks of the respiratory signal and threshold-crossing points in the respiratory signal.

[0030] A delay interval is started at 630, when the respiratory fiducial point is detected. In one embodiment,

the delay interval is programmable between approximately 0 and 5 seconds. In another embodiment, the delay interval is adjusted using the respiratory signal. In a specific embodiment, the delay interval is calculated as a function of the respiratory cycle length and/or one or more other respiratory parameters extracted from the respiratory signal.

[0031] A burst of neural stimulation pulses is delivered when the delay interval expires at 640. In various embodiments, the delivery of the neural stimulation pulses is controlled by executing a stimulation algorithm including a set of stimulation parameters such as one or more of pulse amplitude, pulse width, stimulation frequency or inter-pulse interval, number of pulses per burst, and stimulation sites.

[0032] FIG. 7 is a block diagram illustrating a respiratory disorder-responsive neural stimulation system 740. System 740 includes respiratory sensor 426, sensor processing circuit 428, and a respiration-controlled neural stimulation circuit 730.

[0033] - Respiration-controlled neural stimulation circuit 730 is a specific embodiment of respiration-controlled neural stimulation circuit 130 and includes stimulation output circuit 432 and a controller 760. Controller 760 includes respiratory signal input 436, a respiratory disorder detector 752, a stimulation adjustment module 754, and a stimulation delivery controller 756. Respiratory disorder detector 752 detects predetermined-type respiratory disorders using the respiratory signal received by respiratory signal input 436. Stimulation adjustment module 754 adjusts the delivery of the neural stimulation pulses in response to the detection of each of the respiratory disorders. In one embodiment, stimulation adjustment module 754 stops the execution of a stimulation algorithm in response to the detection of a respiratory disorder. Stimulation delivery controller 756 controls the delivery of the neural stimulation pulses by executing one or more stimulation algorithms.

[0034] FIG. 8 is a block diagram illustrating a respiratory disorder-responsive neural stimulation system 840, which is a specific embodiment of respiratory disorder-responsive neural stimulation system 740. System 840 includes respiratory sensor 426, sensor processing circuit 428, a physiologic sensor 870, another sensor processing circuit 872, and a respiration-controlled neural stimulation circuit 830.

[0035] Physiologic sensor 870 senses one or more physiologic signals in addition to the physiologic signal sensed by respiratory sensor 426 and the one or more neural signals sensed by sensing circuit 550. In various embodiments, physiologic sensor 870 senses one or more of cardiac signals, signals indicative of heart sounds, cardiac and/or transthoracic impedance signals, and signals indicative of blood oxygen level. Sensor processing circuit 872 processes the one or more physiologic signals sensed by physiologic sensor 870 for use by respiration-controlled neural stimulation circuit 830 in controlling the neural stimulation. In various em-

bodiments, physiologic sensor 870 or portions of physiologic sensor 870 are included in implantable medical device 110 or communicatively coupled to implantable medical device 110 via one or more leads or telemetry.

5 In various embodiments, sensor processing circuit 872 or portions sensor processing circuit 872 are included in implantable medical device 110 or communicatively coupled to implantable medical device 110 via one or more leads or telemetry.

10 **[0036]** Respiration-controlled neural stimulation circuit 830 is a specific embodiment of respiration-controlled neural stimulation circuit 130 and includes stimulation output circuit 432, sensing circuit 550, and a controller 860. Controller 860 is a specific embodiment of controller 760 and includes respiratory signal input 436, a respiratory disorder detector 852, a physiologic signal input 876, a physiologic event detector 874, a stimulation adjustment module 854, and a stimulation delivery controller 856.

15 **[0037]** Respiratory disorder detector 852 detects one or more respiratory disorders using the respiratory signal. In the illustrated embodiment, respiratory disorder detector 852 includes an apnea detector 862, a hypopnea detector 864, and a dyspnea detector 866. In various other 20 embodiments, respiratory disorder detector 852 includes any one or more of apnea detector 862, hypopnea detector 864, and dyspnea detector 866. In various embodiments, respiratory disorder detector 852 also detects abnormal values of one or more respiratory parameters, 25 such as a low respiratory rate when the respiratory rate is below a threshold rate, a low tidal volume when the tidal volume is below a detection threshold volume, and a low minute ventilation when the minute ventilation is below a detection threshold value.

30 **[0038]** Apnea is characterized by abnormally long non-breathing periods. Apnea detector 862 detects apnea by comparing the non-breathing period to a detection threshold period. Apnea is detected when the non-breathing period exceeds the detection threshold period. 35 Hypopnea is characterized by abnormally shallow breathing, i.e., low tidal volume. Hypopnea detector 864 detects hypopnea by comparing the tidal volume to a detection threshold volume. Hypopnea is detected when the tidal volume is below the detection threshold volume.

40 In one embodiment, the tidal volume is an average tidal volume over a predetermined time interval or a predetermined number of respiratory cycles. Dyspnea is characterized by rapid shallow breathing, i.e., high respiratory rate-to-tidal volume ratio. Dyspnea detector 866 detects 45 dyspnea by comparing the ratio of the respiratory rate to the tidal volume to a detection threshold ratio. Dyspnea is detected when the ratio exceeds the threshold ratio. In various embodiments, the threshold period, the detection threshold volume, and/or the threshold ratio are empirically established. An example of apnea and hypopnea 50 detection using a respiratory signal such as a transthoracic impedance signal is discussed in U.S. Patent Application Serial No. 10/309,770, entitled "DETECTION

OF DISORDERED BREATHING," filed on December 4, 2002, assigned to Cardiac Pacemakers, Inc., published as US 2004/111040 A1. An example of dyspnea detection using a respiratory signal such as a transthoracic impedance signal is discussed in U.S. Patent Application Serial No. 11/229,316, entitled "RAPID SHALLOW BREATHING DETECTION FOR USE IN CONGESTIVE HEART FAILURE STATUS DETERMINATION," filed on September 16, 2005, assigned to Cardiac Pacemakers, Inc., published as US 2007/073168 A1.

[0039] Physiologic signal input 876 receives the one or more physiologic signals sensed by physiologic sensor 870 and processed by sensor processing circuit 872. Physiologic event detector 874 detects one or more physiologic events from the one or more physiologic signals. In various embodiments, physiologic event detector 874 detects one or more of changes in cardiac signal morphology, changes in heart sound waveform morphology, changes in impedance signal morphology, and changes in blood oxygen saturation.

[0040] Stimulation adjustment module 854 adjusts the delivery of the neural stimulation pulses in response to at least the detection of a respiratory disorder by respiratory disorder detector 852. In one embodiment, stimulation adjustment module 854 adjusts the delivery of the neural stimulation pulses in response to the detection of a respiratory disorder by respiratory disorder detector 852 and the detection of a physiologic event by physiologic event detector 874. Stimulation delivery controller 856 controls the delivery of the neural stimulation pulses by executing one or more stimulation algorithms. Stimulation adjustment module 854 includes a stimulation switch 868. Stimulation switch 868 stops executing a first stimulation algorithm in response to the detection of a respiratory disorder such as apnea, hypopnea, or dyspnea. For example, the first stimulation algorithm is executed to treat a cardiac condition by vagal nerve stimulation. If apnea, hypopnea, or dyspnea is detected, the vagal nerve stimulation is to be stopped to avoid the worsening of the condition due to the vagal nerve stimulation designed for treating the cardiac condition. In one embodiment, stimulation switch 868 resumes the execution of the first stimulation algorithm after a predetermined suspension period. In another embodiment, stimulation switch 868 resumes the execution of the first stimulation algorithm when the respiratory disorder is no longer detected. In another embodiment, stimulation switch 868 resumes the execution of the first stimulation algorithm after a predetermined suspension period. In another embodiment, stimulation switch 868 resumes the execution of the first stimulation algorithm in response to a stimulation command issued by a user such as a physician using external system 120. In one embodiment, in addition to stopping the execution of the first stimulation algorithm, stimulation switch 868 starts executing a second stimulation algorithm in response to the detection of the respiratory disorder. In a specific embodiment, the second stimulation algorithm provides lower stimulation in-

tensity when compared to the first stimulation algorithm. Switching from the first stimulation algorithm to the second stimulation algorithm lowers the stimulation pulse amplitude, shortens stimulation pulse width, lowers the stimulation frequency, reduces the number of pulses per burst, and/or changes stimulation sites. In another specific embodiment, the first stimulation algorithm is used to treat a non-respiratory disorder such as a cardiac disorder, and the second stimulation algorithm is used to treat the detected respiratory disorder, such as apnea, hypopnea, and dyspnea. Switching from the first stimulation algorithm to the second stimulation algorithm switches the treatment for the non-respiratory disorder to the treatment for the respiratory disorder. In another specific embodiment, the first stimulation algorithm is used to treat the non-respiratory disorder, and the second stimulation algorithm is used to treat the detected respiratory disorder in addition to treating the non-respiratory disorder. Switching from the first stimulation algorithm to the second stimulation algorithm switches the treatment for the non-respiratory disorder to the treatment for both the respiratory disorder and the non-respiratory disorder.

[0041] In one embodiment, the "respiratory disorder" discussed in this document refers to a respiratory disorder associated with sleep (i.e., sleep disordered breathing, such as sleep apnea, sleep hypopnea, or sleep dyspnea). The one or more physiologic signals indicate whether a patient is sleeping. For example, physiologic sensor 870 includes an activity sensor, a posture sensor, and/or one or more other sensors that senses a signal being a factor indicating sleeping. Physiologic event detector 874 detects sleeping based on the one or more physiologic signals and produces a sleeping signal indicating whether the patient is sleeping. In one embodiment, physiologic event detector 874 detects sleeping based on the one or more physiologic signals and the time of the day. Respiratory disorder detector 852 detects such one or more respiratory disorders when the sleeping signal is present. Stimulation adjustment module 854 adjusts the delivery of the neural stimulation pulses in response to at least one respiratory disorder detected during sleep. In other embodiments, the "respiratory disorder" discussed in this document includes a respiratory disorder that occurs while the patient is awake or sleep.

[0042] In one embodiment, the "respiratory disorder" discussed in this document refers to a respiratory disorder induced by neural stimulation. A patient may have one or more respiratory disorders that are unrelated to the vagal nerve stimulation. The respiratory disorder induced by neural stimulation includes a respiratory disorder that is caused or worsened by the vagal nerve stimulation. In one embodiment, the one or more physiologic signals sensed by physiologic sensor 870 indicate whether a respiratory disorder is induced by the vagal nerve stimulation. For example, because speech may interfere with the detection of the one or more respiratory disorders, physiologic sensor 870 includes an accelerometer or microphone to detect a signal indicative of speech.

Physiologic event detector 874 detects speech using the signal and produces a speech signal indicating whether the patient is talking. Respiratory disorder detector 852 detects one or more respiratory disorders when the speech signal is not present. In another example, respiratory disorder detector 852 detects the one or more respiratory disorders using the respiratory signal sensed during the vagal nerve stimulation and stored baseline respiratory parameters. The baseline respiratory parameters are produced from the respiratory signal sensed while the vagal nerve stimulation is not delivered. Respiratory disorder detector 852 uses the baseline respiratory parameters to isolate the effect of the vagal nerve stimulation in the respiratory signal for the detection of the one or more respiratory disorders. In various embodiments, respiratory disorder detector 852 detects one or more respiratory disorders induced by vagal nerve stimulation using the respiratory signal and other signals such as a signal indicative of whether the vagal nerve stimulation is being delivered, a signal indicative of time of the day, and one or more physiologic signals allowing for determination of whether a respiratory disorder is caused or worsened by the vagal nerve stimulation. Stimulation adjustment module 854 adjusts the delivery of the neural stimulation pulses in response to at least one respiratory disorder induced by the delivery of the neural stimulation pulses.

[0043] FIG. 9 is a flow chart illustrating a method 900 for adjusting neural stimulation in response to a respiratory disorder. In one embodiment, method 900 is performed by respiration-controlled neural stimulation circuit 730 or 830.

[0044] The neural stimulation is controlled by using a plurality of stimulation parameters at 910. The neural stimulation is delivered to treat a non-respiratory disorder. In one embodiment, neural stimulation is delivered to treat a cardiac condition, such as to treat heart failure or to control cardiac remodeling.

[0045] A respiratory signal is received at 920. The respiratory signal is indicative of respiratory cycles and respiratory parameters. Examples of the respiratory parameters include the respiratory cycle length, the inspiration period, the expiration period, the non-breathing period, the tidal volume, and the minute ventilation. In various embodiments, the respiratory signal is, or is derived from, a physiologic signal indicative of the respiratory cycles and the respiratory parameters. Examples of the physiologic signal include a transthoracic impedance signal and blood pressure signals such as a PAP signal.

[0046] A respiratory disorder is being detected at 930. Examples of the respiratory disorder include abnormal respiratory parameter values such as low respiratory rate, low tidal volume, and low minute ventilation, apnea, hypopnea, and dyspnea. Apnea is detected when the non-breathing period exceeds a detection threshold period. Hypopnea is detected when the tidal volume is below a detection threshold volume. Dyspnea is detected when the ratio of the respiratory rate to the tidal volume

exceeds a detection threshold ratio.

[0047] If the respiratory disorder is detected at 935, the neural stimulation is adjusted by adjusting one or more of the stimulation parameters at 940. The neural stimulation is adjusted to terminate or mitigate the detected respiratory disorder. In one embodiment, the neural stimulation is adjusted to decrease the intensity of the stimulation. In another embodiment, the neural stimulation is suspended for a predetermined period of time or until the respiratory disorder is no longer detected. In another embodiment, the neural stimulation is adjusted to treat the detected respiratory disorder.

[0048] FIG. 10 is a flow chart illustrating a method 1000 for adjusting neural stimulation in response to the detection of a respiratory disorder. Method 1000 is a specific embodiment of method 900. In one embodiment, method 1000 is performed by respiration-controlled neural stimulation circuit 730 or 830.

[0049] The neural stimulation is controlled by executing a first stimulation algorithm at 1010. In one embodiment, the first stimulation algorithm is designed to treat a cardiac condition, such as heart failure.

[0050] A respiratory signal is received at 1020. The respiratory signal is indicative of respiratory cycles and respiratory parameters. Examples of the respiratory parameters include the respiratory cycle length, the inspiration period, the expiration period, the non-breathing period, the tidal volume, and the minute ventilation. In various embodiments, the respiratory signal is, or is derived from, a physiologic signal indicative of the respiratory cycles and the respiratory parameters. Examples of the physiologic signal include a transthoracic impedance signal and blood pressure signals such as a PAP signal.

[0051] A respiratory disorder is being detected at 1030. Examples of the respiratory disorder include abnormal respiratory parameter values such as low respiratory rate, low tidal volume, and low minute ventilation, apnea, hypopnea, and dyspnea. Apnea is detected when the non-breathing period exceeds a detection threshold period. Hypopnea is detected when the tidal volume is below a detection threshold volume. Dyspnea is detected when the ratio of the respiratory rate to the tidal volume exceeds a detection threshold ratio.

[0052] If the respiratory disorder is detected at 1035, the execution of the first stimulation algorithm is stopped at 1040. Whether to execute a second stimulation algorithm is determined at 1050. If the second stimulation algorithm is determined to be executed at 1055, the neural stimulation is controlled by executing the second stimulation algorithm at 1070. In one embodiment, the second stimulation algorithm is selected to lower the stimulation intensity provided by the first stimulation algorithm. In another embodiment, the second stimulation algorithm is selected to treat the detected respiratory disorder, such as apnea, hypopnea, or dyspnea.

[0053] If the second stimulation algorithm is determined not to be executed at 1055, whether to resume the execution of the first stimulation algorithm is deter-

mined at 1060. During or after the execution of the second stimulation algorithm, whether to resume the execution of the first stimulation algorithm is also determined at 1060. If the execution of the first stimulation algorithm is resumed at 1065, the neural stimulation is again controlled by executing a first stimulation algorithm at 1010. In one embodiment, the execution the first stimulation algorithm is to be resumed after a predetermined suspension period. In another embodiment, the execution the first stimulation algorithm is to be resumed when the respiratory disorder is no longer detected. In another embodiment, the execution the first stimulation algorithm is to be resumed in response to a stimulation command issued by a user such as a physician.

[0054] In one embodiment, in addition to the response to the detection of the respiratory disorder, the delivery of the neural stimulation pulses is adjusted in response to the detection of a physiologic event. Examples of such a physiologic event include changes in cardiac signal morphology, changes in heart sound waveform morphology, changes in impedance signal morphology, and changes in blood oxygen saturation.

[0055] FIG. 11 is a block diagram illustrating a respiratory cycle-synchronized respiratory disorder-responsive neural stimulation system 1140. System 1140 represents a combination of systems 440 or 540 and systems 740 or 840. In the illustrated embodiment, system 1140 includes respiratory sensor 426, sensor processing circuit 428, and a respiration-controlled neural stimulation circuit 1130. In various specific embodiments, system 1140 may include any combination of components of systems 440, 540, 740, and 840 as discussed above.

[0056] Respiration-controlled neural stimulation circuit 1130 is a specific embodiment of respiration-controlled neural stimulation circuit 130 and includes stimulation output circuit 432 and a controller 1180. Controller 1180 includes respiratory signal input 436, respiratory disorder detector 752, stimulation adjustment module 754, synchronization module 438, and stimulation delivery controller 1182. Stimulation delivery controller 1182 controls the delivery of the neural stimulation pulses from stimulation output circuit 432 by synchronizing the delivery to the respiratory cycles, as controlled by synchronization module 438, and by responding to the detection of each respiratory disorder, as controlled by stimulation adjustment module 754.

[0057] FIG. 12 is a block diagram illustrating a respiratory disorder-responsive neural stimulation system 1240. System 1240 includes respiratory sensor 426, sensor processing circuit 428, and a respiration-controlled neural stimulation circuit 1230.

[0058] Respiration-controlled neural stimulation circuit 1230 is another specific embodiment of respiration-controlled neural stimulation circuit 130 and includes a therapy output device 1284 and a controller 1286. Therapy output device 1284 delivers one or more therapies including a neural stimulation therapy treating a non-respiratory disorder. Controller 1286 includes respiratory

signal input 436, respiratory disorder detector 752, a therapy adjustment module 1288, and a therapy delivery controller 1290. Therapy adjustment module 1288 adjusts delivery of the one or more therapies in response to the detection of a respiratory disorder by respiratory disorder detector 752. Therapy delivery controller 1290 controls the delivery of the one or more therapies using parameters set and adjusted by therapy adjustment module 1288.

[0059] In one embodiment, system 1240 provides for one or more neural stimulation therapies that include at least one neural stimulation therapy treating a non-respiratory disorder. When the respiratory disorder is detected, system 1240 starts a neural stimulation therapy treating the detected respiratory disorder and/or adjusts the neural stimulation therapy treating the non-respiratory disorder. When a respiratory disorder such as apnea is detected, the neural stimulation therapy is suspended or adjusted for a lower intensity, or a separate neural stimulation therapy is delivered to treat the detected respiratory disorder. In another embodiment, system 1240 provides the neural stimulation therapy treating the non-respiratory disorder and another therapy treating the detected respiratory disorder. When the respiratory disorder is detected, system 1240 starts the other therapy treating the detected respiratory disorder and/or adjusts the neural stimulation therapy treating the non-respiratory disorder.

[0060] FIG. 13 is a block diagram illustrating a respiratory disorder-responsive neural stimulation system 1340, which is a specific embodiment of respiratory disorder-responsive neural stimulation system 1240. System 1340 includes respiratory sensor 426, sensor processing circuit 428, and a respiration-controlled neural stimulation circuit 1330.

[0061] Respiration-controlled neural stimulation circuit 1330 is a specific embodiment of respiration-controlled neural stimulation circuit 1230 and includes a therapy output device 1384 and a controller 1386. Therapy output device 1384 includes a non-respiratory stimulation output circuit 1332 and a respiratory therapy output device 1396. Non-respiratory stimulation output circuit 1332 delivers the neural stimulation therapy through electrodes or transducer(s) to treat a non-respiratory disorder, such as a cardiac disorder. Respiratory therapy output device 1396 delivers a respiratory therapy that treats the detected respiratory disorder. In one embodiment, respiratory therapy output device 1396 delivers another neural stimulation therapy through electrodes or transducer(s) to treat the respiratory disorder, such as by stimulating different nerves or nerve branches. Examples of treating respiratory disorders using neural stimulation are discussed in U.S. Patent Application Serial No. 11/151,122, entitled "SYSTEM FOR NEURAL CONTROL OF RESPIRATION," filed on June 13, 2005, published as US 2006/282131 A1, and U.S. Patent Application Serial No. 11/320,500, entitled "NEURAL STIMULATOR TO TREAT SLEEP DISORDERED BREATHING," filed on

December 28, 2005, published as US 2007/150006 A1. In another embodiment, respiratory therapy output device 1396 delivers a therapy treating the respiratory disorder that is other than a neural stimulation therapy. Examples of such therapies treating the respiratory disorder include cardiac pacing therapies and an external pressure therapy. An example of treating respiratory disorders using cardiac pacing is discussed in U.S. Patent Application Serial No. 10/798,794, entitled "RATE REGULARIZATION OF CARDIAC PACING FOR DISORDERED BREATHING THERAPY," filed on March 11, 2004, assigned to Cardiac Pacemakers, Inc., published as US 2005/065566 A1. An example of treating respiratory disorders using an external pressure therapy, delivered by a continuous positive airway pressure (CPAP) device controlled by an implantable medical device, is discussed in U.S. Patent Application Serial No. 10/930,979, entitled "coordinated use of respiratory and cardiac therapies for sleep disordered breathing," filed on August 31, 2004, assigned to Cardiac Pacemakers, Inc., published as US 2005/061320 A1. Controller 1386 includes respiratory signal input 436, respiratory disorder detector 752, a therapy adjustment module 1388, and a therapy delivery controller 1390. Therapy adjustment module 1388 includes a non-respiratory stimulation adjustment module 1354 and a respiratory therapy adjustment module 1392 to provide for a coordinated response to each detection of the respiratory disorder by respiratory disorder detector 752. In one embodiment, in response to the detection of the respiratory disorder, respiratory therapy adjustment module 1392 starts the delivery of the respiratory therapy that treats the detected respiratory disorder. If the respiratory disorder is terminated or mitigated to a tolerable degree in response to the delivery of the respiratory therapy, non-respiratory stimulation adjustment module 1354 does not adjust the neural stimulation therapy treating the non-respiratory disorder. If the respiratory disorder is not terminated or mitigated to the tolerable degree in response to the delivery of the respiratory therapy, non-respiratory stimulation adjustment module 1354 stops the delivery, or reduces the intensity, of the stimulation therapy treating the non-respiratory disorder. In another embodiment, in response to the detection of the respiratory disorder, respiratory therapy adjustment module 1392 starts the delivery of the respiratory therapy that treats the detected respiratory disorder, and non-respiratory stimulation adjustment module 1354 stops the delivery, or reduces the intensity, of the stimulation therapy treating the non-respiratory disorder. Non-respiratory stimulation adjustment module 1354 resumes the normal delivery of the stimulation therapy treating the non-respiratory disorder after a predetermined time interval or when the respiratory disorder is no longer detected by respiratory disorder detector 752, such as by restoring stimulation parameters to those used prior to the detection of the respiratory disorder. Therapy delivery controller 1390 includes a non-respiratory stimulation delivery controller 1356 and a res-

piratory therapy delivery controller 1394. Non-respiratory stimulation delivery controller 1356 controls the delivery of the stimulation therapy treating the non-respiratory disorder using stimulation parameters set and adjusted by non-respiratory stimulation adjustment module 1354. Respiratory therapy delivery controller 1394 controls the delivery of the respiratory therapy treating the detected respiratory disorder using therapy (neural or cardiac stimulation, or other types of therapy) parameters set and adjusted by respiratory therapy adjustment module 1392.

[0062] In one embodiment, system 1340 allows for a neural stimulation therapy to be applied to a patient who is otherwise contraindicated for that neural stimulation therapy. For example, vagal nerve stimulation is known to improve hemodynamic performance and/or controlling ventricular remodeling in heart failure patients. However, a substantial percentage of heart failure patients also suffer from apnea, and the vagal nerve stimulation may worsen that abnormal respiratory condition. System 1340 potentially allows application of vagal nerve stimulation to these heart failure patients while monitoring or treating the apnea, thereby removing apnea as a contraindication for vagal nerve stimulation. In this embodiment, respiratory disorder detector 752 includes at least apnea detector 862. In a specific embodiment, in addition to responding to the detection of apnea, non-respiratory stimulation adjustment module 1354 provides feedback control of the vagal nerve stimulation improving hemodynamics and/or controlling ventricular remodeling using a non-respiratory physiological parameter as an input. The feedback control functions to maintain the non-respiratory physiological parameter within a target range. For example, non-respiratory stimulation adjustment module 1354 receives cardiac parameters such as the patient's heart rate or heart rate variability and adjusts the intensity of the vagal nerve stimulation to maintain the heart rate or heart rate variability within a target range.

[0063] FIG. 14 is a flow chart illustrating a method 1400 for adjusting neural stimulation in response to the detection of a respiratory disorder. The neural stimulation is a therapy for treating a non-respiratory disorder, such as heart failure. In one embodiment, method 1400 is performed by respiration-controlled neural stimulation circuit 1230 or 1330.

[0064] The neural stimulation is controlled by using stimulation parameters at 1410. In one embodiment, the stimulation parameters are selected for treating a cardiac condition, such as to improve hemodynamic performance or control ventricular remodeling in a heart failure patient. A specific embodiment of step 1410 is discussed below, with reference to FIG. 15.

[0065] A respiratory signal is received at 1420. The respiratory signal is indicative of respiratory cycles and respiratory parameters. Examples of the respiratory parameters include the respiratory cycle length, the inspiration period, the expiration period, the non-breathing period, the tidal volume, and the minute ventilation. In various embodiments, the respiratory signal is, or is derived

from, a physiologic signal indicative of the respiratory cycles and the respiratory parameters. Examples of the physiologic signal include a transthoracic impedance signal and blood pressure signals such as a PAP signal.

[0066] A respiratory disorder is being detected at 1430. Examples of the respiratory disorder include abnormal respiratory parameter values such as low respiratory rate, low tidal volume, and low minute ventilation, apnea, hypopnea, and dyspnea. In one embodiment, apnea is detected while the neural stimulation is applied to the heart failure patient.

[0067] If the respiratory disorder is detected at 1435, a respiratory therapy is delivered at 1440, to treat the detected respiratory disorder. In one embodiment, the respiratory therapy includes another neural stimulation therapy which uses stimulation parameters selected to treat the detected respiratory disorder. In another embodiment, the respiratory therapy includes one or more therapies other than neural stimulation.

[0068] Whether the detected respiratory disorder is mitigated is determined at 1450 by comparing a respiratory parameter to a mitigation threshold. The detected respiratory disorder is considered "mitigated" when its degree is reduced to a tolerable degree at which the detected respiratory disorder is considered not to be harmful to the patient. In various embodiments, the respiratory disorder is detected by comparing the respiratory parameter to a detection threshold, and whether the detected respiratory disorder is mitigated is determined by comparing the respiratory parameter to the mitigation threshold. In one embodiment, the detection threshold and the mitigation threshold are equal. In another embodiment, the detection threshold and the mitigation threshold are substantially different. For example, apnea is detected when the non-breathing period exceeds a detection threshold period, and is determined to be mitigated when the non-breathing period falls below a mitigation threshold period. Hypopnea is detected when the tidal volume is below a detection threshold volume, and is determined to be mitigated when the tidal volume rises above a mitigation threshold volume. Dyspnea is detected when the ratio of the respiratory rate to the tidal volume exceeds a detection threshold ratio, and is determined to be mitigated when that ratio falls below a mitigation threshold ratio.

[0069] If it is determined that the detected respiratory disorder has been mitigated at 1455, the neural stimulation is continued to be controlled at 1410 without adjusting the stimulation parameters selected to treat the non-respiratory disorder. If it is determined that the detected respiratory disorder has not been mitigated at 1455, the stimulation parameters are adjusted at 1460 for lowering the intensity, or stopping the delivery, of the neural stimulation for treating the non-respiratory disorder.

[0070] FIG. 15 is a flow chart illustrating a method 1500 for controlling the neural stimulation treating the non-respiratory disorder. Method 1500 represents a specific embodiment of step 1410 of method 1400. In one embodi-

ment, method 1500 is performed by non-respiratory stimulation adjustment module 1354.

[0071] Method 1500 provides for feedback control of the neural stimulation treating the non-respiratory disorder. The neural stimulation is delivered at 1510, using the stimulation parameters selected to treat the non-respiratory disorder. A non-respiratory response to the neural stimulation is monitored at 1520. If the non-respiratory response is within a target range at 1525, the neural stimulation is continued to be delivered at 1510, without adjusting the stimulation parameters. If the non-respiratory response is not within a target range at 1525, the stimulation parameters are adjusted at 1530, and the neural stimulation is continued to be delivered at 1510 using the adjusted stimulation parameters. In one embodiment, the non-respiratory response is measured by a non-respiratory physiological parameter. For example, for a neural stimulation therapy treating a cardiac disorder, method 1500 is applied to maintain one or more of cardiac parameters such as heart rate, heart rate variability, and blood pressure each within its target range.

[0072] With step 1410 performed using method 1500, method 1400 allows the neural stimulation to be adjusted for both treatment of the non-respiratory disorder while limiting potential harm associated with an adverse side effect of the neural stimulation. For example, for a heart failure patient, method 1400 allows the neural stimulation to be adjusted for maintaining a parameter such as heart rate, heart rate variability, or blood pressure within its predetermined target range without causing or worsening a sustained apnea.

[0073] It is to be understood that the above detailed description is intended to be illustrative, and not restrictive. Other embodiments will be apparent to those of skill in the art upon reading and understanding the above description. The scope of the invention should, therefore, be determined with reference to the appended claims.

Claims

1. A neural stimulating system, comprising:

- a stimulation output circuit (432) adapted to deliver a neural stimulation therapy;
- a stimulation delivery controller (1182) coupled to the stimulation output circuit, the stimulation delivery controller adapted to control the delivery of the neural stimulation therapy by executing a first stimulation algorithm adapted to treat a non-respiratory disorder using vagal nerve stimulation;
- a respiratory signal input (436) adapted to receive a respiratory signal indicative of respiratory cycles;
- a respiratory disorder detector (752) coupled to the respiratory signal input, the respiratory disorder detector adapted to detect a respiratory

- disorder induced by the vagal nerve stimulation using the respiratory signal;
 a stimulation switch (868) coupled to the respiratory disorder detector and the stimulation delivery controller, the stimulation switch adapted to stop executing the first stimulation algorithm in response to the detection of the respiratory disorder induced by the vagal nerve stimulation; and
 a synchronization module (438) coupled to the stimulation delivery controller and the respiratory signal input, the synchronization module adapted to synchronize the delivery of the neural stimulation therapy to the respiratory cycles.
2. The system according to claim 1, wherein the respiratory signal is indicative of a non-breathing period, and the respiratory disorder detector comprises an apnea detector adapted to detect apnea by comparing the non-breathing period to a detection threshold period.
 3. The system according to claim 1, wherein the respiratory signal is indicative of a tidal volume, and the respiratory disorder detector comprises a hypopnea detector adapted to detect hypopnea by comparing the tidal volume to a detection threshold volume.
 4. The system according to claim 1, wherein the respiratory signal is indicative of a respiratory rate and a tidal volume, and the respiratory disorder detector comprises a dyspnea detector adapted to detect dyspnea by comparing a ratio of the respiratory rate to the tidal volume to a detection threshold ratio.
 5. The system according to any of the preceding claims, wherein the stimulation switch is adapted to resume executing the first stimulation algorithm after a predetermined suspension period.
 6. The system according to any of claims 1 to 4, wherein the stimulation switch is adapted to resume executing the first stimulation algorithm when the respiratory disorder is no longer detected.
 7. The system according to any of the preceding claims, wherein the stimulation switch is adapted to stop executing the first stimulation algorithm and start executing a second stimulation algorithm in response to the detection of the respiratory disorder.
 8. The system according to any of the preceding claims, wherein the stimulation output circuit is adapted to deliver neural stimulation pulses.
 9. The system according to claim 8, wherein the synchronization module comprises:
 - a respiratory fiducial point detector to detect respiratory fiducial points from the respiratory signal; and
 - a delay timer adapted to time a delay interval starting with each of the detected respiratory fiducial points, and wherein the stimulation delivery controller is adapted to cause the stimulation output circuit to deliver a burst of neural stimulation pulses when the delay interval expires.
 10. The system according to claim 9, wherein the respiratory fiducial point detector comprises a peak detector adapted to detect peaks of the respiratory signal, and the delay timer is adapted to time a delay interval starting with each of the detected peaks of the respiratory signal.
 11. The system according to any of claims 9 and 10, wherein the synchronization module comprises a delay generator adapted to adjust the delay interval using the respiratory signal.
 12. The system according to claim 11, wherein the delay generator is adapted to calculate the delay interval as a function of one or more of the respiratory parameters.
 13. The system according to any of the preceding claims, further comprising:
 - an implantable medical device including at least the stimulation output circuit, the stimulation delivery controller, the respiratory signal input, the respiratory disorder detector, and the stimulation switch;
 - an implantable respiratory sensor adapted to sense a physiologic signal; and
 - a sensor processing circuit adapted to produce the respiratory signal using the physiologic signal.
 14. The system according to claim 13, wherein the implantable respiratory sensor comprises an implantable impedance sensor adapted to sense a transthoracic impedance.
 15. The system according to claim 13, wherein the implantable respiratory sensor comprises an implantable pulmonary artery pressure (PAP) sensor.

Patentansprüche

1. Nervenstimulationssystem, welches aufweist:
 - eine Stimulationsausgabeschaltung (432), die ausgestaltet ist zum Zuführen einer Nervensti-

- mulationstherapie;
eine Stimulationszuführungs-Steuervorrichtung (1182), die mit der Stimulationsausgabeschaltung gekoppelt ist, welche Stimulationszuführungs-Steuervorrichtung ausgestaltet ist zum Steuern der Zuführung der Nervenstimulationstherapie durch Ausführen eines ersten Stimulationsalgorithmus, der ausgestaltet ist zum Behandeln einer Nicht-Atmungsstörung unter Verwendung einer Stimulation des Nervus vagus; einen Atmungssignaleingang (436), der ausgestaltet ist zum Empfangen eines Atmungssignals, das Atmungszyklen anzeigt; einen Atmungsstörungsdetektor (752), der mit dem Atmungssignaleingang gekoppelt ist, wobei der Atmungsstörungsdetektor ausgestaltet ist zum Erfassen einer Atmungsstörung, die durch die Stimulation des Nervus vagus induziert wird, unter Verwendung des Atmungssignals; einen Stimulationsschalter (868), der mit dem Atmungsstörungsdetektor und der Stimulationszuführungs-Steuervorrichtung gekoppelt ist, wobei der Stimulationsschalter ausgestaltet ist zum Anhalten der Ausführung des ersten Stimulationsalgorithmus als Antwort auf die Erfassung der durch die Stimulation des Nervus vagus induzierten Atmungsstörung; und ein Synchronisationsmodul (438), das mit der Stimulationszuführungs-Steuervorrichtung und dem Atmungssignaleingang gekoppelt ist, wobei das Synchronisationsmodul ausgestaltet ist zum Synchronisieren der Zuführung der Nervenstimulationstherapie mit den Atmungszyklen.
2. System nach Anspruch 1, bei dem das Atmungssignal eine Nicht-Atmungsperiode anzeigt und der Atmungsstörungsdetektor einen Apnoe-Detektor aufweist, der ausgestaltet ist zum Erfassen einer Apnoe durch Vergleichen der Nicht-Atmungsperiode mit einer Erfassungsschwellenwertperiode.
 3. System nach Anspruch 1, bei dem das Atmungssignal ein Tidalvolumen anzeigt und der Atmungsstörungsdetektor einen Hypopnoe-Detektor aufweist, der ausgestaltet ist zum Erfassen einer Hypopnoe durch Vergleichen des Tidalvolumens mit einem Erfassungsschwellenwertvolumen.
 4. System nach Anspruch 1, bei dem das Atmungssignal eine Atmungsrate und ein Tidalvolumen anzeigt, und der Atmungsstörungsdetektor einen Dyspnoe-Detektor aufweist, der ausgestaltet ist zum Erfassen einer Dyspnoe durch Vergleichen eines Verhältnisses der Atmungsrate zu dem Tidalvolumen mit einem Erfassungsschwellenwertverhältnis.
 5. System nach einem der vorhergehenden Ansprüche, bei dem der Stimulationsschalter ausgestaltet ist zur Wiederaufnahme der Ausführung des ersten Stimulationsalgorithmus nach einer vorbestimmten Aussetzungsperiode.
 6. System nach einem der Ansprüche 1 bis 4, bei dem der Stimulationsschalter ausgestaltet ist zum Wiederaufnehmen der Ausführung des ersten Stimulationsalgorithmus, wenn eine Atmungsstörung nicht länger erfasst wird.
 7. System nach einem der vorhergehenden Ansprüche, bei dem der Stimulationsschalter ausgestaltet ist zum Anhalten der Ausführung des ersten Stimulationsalgorithmus und zum Starten der Ausführung eines zweiten Stimulationsalgorithmus als Antwort auf die Erfassung der Atmungsstörung.
 8. System nach einem der vorhergehenden Ansprüche, bei dem die Stimulationsausgabeschaltung ausgestaltet ist zum Liefern von Nervenstimulationsimpulsen.
 9. System nach Anspruch 8, bei dem das Synchronisationsmodul aufweist:
 - einen Atmungsfiduzialpunkt-Detektor zum Erfassen von Atmungsfiduzialpunkten aus dem Atmungssignal; und
 - einen Verzögerungszeitgeber, der ausgestaltet ist zur Zeitbestimmung des Startens eines Verzögerungsintervalls mit jedem der erfassten Atmungsfiduzialpunkte,
 - und wobei die Stimulationszuführungs-Steuervorrichtung ausgestaltet ist zum Bewirken, dass die Stimulationsausgabeschaltung ein Bündel von Nervenstimulationsimpulsen zuführt, wenn das Verzögerungsintervall abläuft.
 10. System nach Anspruch 9, bei dem der Atmungsfiduzialpunkt-Detektor einen Spitzendetektor aufweist, der ausgestaltet ist zum Erfassen von Spitzen des Atmungssignals, und der Verzögerungszeitgeber ausgestaltet ist zum Bestimmen des Startens eines Verzögerungsintervalls mit jeder der erfassten Spitzen des Atmungssignals.
 11. System nach einem der Ansprüche 9 und 10, bei dem das Synchronisationsmodul einen Verzögerungsgenerator aufweist, der ausgestaltet ist zum Einstellen des Verzögerungsintervalls unter Verwendung des Atmungssignals.
 12. System nach Anspruch 11, bei dem der Verzögerungsgenerator ausgestaltet ist zum Berechnen des Verzögerungsintervalls als eine Funktion von einem oder mehreren der Atmungsparameter.

13. System nach einem der vorhergehenden Ansprüche, welches weiterhin aufweist:

eine implantierbare medizinische Vorrichtung enthaltend zumindest die Stimulationsausgabeschaltung, die Stimulationszuführungs-Steuer-
5 vorrichtung, den Atmungssignaleingang, den Atmungsstörungsdetektor und den Stimulations-
schalter;
einen implantierbaren Atmungssensor, der aus-
10 gestaltet ist zum Erfassen eines physiologische
Signals; und
eine Sensorverarbeitungsschaltung, die aus-
gestaltet ist zum Erzeugen des Atmungssignals
15 unter Verwendung des physiologischen Sig-
nals.

14. System nach Anspruch 13, bei dem der implantierbare Atmungssensor einen implantierbaren Impedanz-Sensor, der zum Erfassen einer Transthoraximpedanz ausgestaltet ist, aufweist.
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15. System nach Anspruch 13, bei dem der implantierbare Atmungssensor einen implantierbaren Lungenarteriendruck (PAP)-Sensor aufweist.
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Revendications

1. Système de stimulation neurale, comprenant :

un circuit de sortie de stimulation (432) adapté pour délivrer une thérapie de stimulation neurale ;
un contrôleur de délivrance de stimulation (1182) couplé au circuit de sortie de stimulation, le contrôleur de délivrance de stimulation étant adapté pour contrôler la délivrance de la thérapie de stimulation neurale en exécutant un premier algorithme de stimulation adapté pour traiter un trouble non respiratoire en utilisant une stimulation du nerf vagal ;
une entrée de signal respiratoire (436) adaptée pour recevoir un signal respiratoire indicatif de cycles respiratoires ;
un détecteur de trouble respiratoire (752), couplé à l'entrée de signal respiratoire, le détecteur de trouble respiratoire étant adapté pour détecter un trouble respiratoire induit par la stimulation du nerf vagal en utilisant le signal respiratoire ;
un commutateur de stimulation (868) couplé au détecteur de trouble respiratoire et au contrôleur de délivrance de stimulation, le commutateur de stimulation étant adapté pour arrêter l'exécution du premier algorithme de stimulation en réponse à la détection du trouble respiratoire induit par la stimulation du nerf vagal ; et

un module de synchronisation (438) couplé au contrôleur de délivrance de stimulation et à l'entrée de signal respiratoire, le module de synchronisation étant adapté pour synchroniser la délivrance de la thérapie de stimulation neural par rapport aux cycles respiratoires.

2. Système selon la revendication 1, dans lequel le signal respiratoire est indicatif d'une période de non respiration, et le détecteur de trouble respiratoire comprend un détecteur d'apnée adapté pour détecter une apnée en comparant la période de non respiration à une période de seuil de détection.

3. Système selon la revendication 1, dans lequel le signal respiratoire est indicatif d'un volume tidal, et le détecteur de trouble respiratoire comprend un détecteur d'hypo-apnée adapté pour détecter une hypo-apnée en comparant le volume tidal à un volume de seuil de détection.

4. Système selon la revendication 1, dans lequel le signal respiratoire est indicatif d'un rythme respiratoire et d'un volume tidal, et le détecteur de trouble respiratoire comprend un détecteur de dyspnée adapté pour détecter une dyspnée en comparant un rapport du rythme respiratoire sur le volume tidal à un rapport de seuil de détection.

5. Système selon l'une quelconque des revendications précédentes, dans lequel le commutateur de stimulation est adapté pour reprendre l'exécution du premier algorithme de stimulation après une période de suspension prédéterminée.

6. Système selon l'une quelconque des revendications 1 à 4, dans lequel le commutateur de stimulation est adapté pour reprendre l'exécution du premier algorithme de stimulation lorsque le trouble respiratoire n'est plus détecté.

7. Système selon l'une quelconque des revendications précédentes, dans lequel le commutateur de stimulation est adapté pour arrêter l'exécution du premier algorithme de stimulation et pour démarrer l'exécution d'un second algorithme de stimulation en réponse à la détection du trouble respiratoire.

8. Système selon l'une quelconque des revendications précédentes, dans lequel le circuit de sortie de stimulation est adapté pour délivrer des impulsions de stimulation neurale.

9. Système selon la revendication 8, dans lequel le module de synchronisation comprend :

un détecteur de point de référence respiratoire pour détecter des points de référence respira-

- toires à partir du signal respiratoire ; et
 une minuterie de retard adaptée pour cadencer
 un intervalle de retard qui démarre à chacun des
 points de référence respiratoires détectés, et
 dans lequel : 5
- le contrôleur de délivrance de stimulation
 est adapté pour faire en sorte que le circuit
 de sortie de stimulation délivre une salve
 d'impulsions de stimulation neurale lorsque 10
 l'intervalle de retard a expiré.
- 10.** Système selon la revendication 9, dans lequel le dé-
 tecteur de point de référence respiratoire comprend
 un détecteur de crête adapté pour détecter des crê- 15
 tes du signal respiratoire, et la minuterie de retard
 est adaptée pour cadencer un intervalle de retard
 qui démarre à chacune des crêtes détectées du si-
 gnal respiratoire. 20
- 11.** Système selon l'une quelconque des revendications
 9 et 10, dans lequel le module de synchronisation
 comprend un générateur de retard adapté pour ré-
 gler l'intervalle de retard en utilisant le signal respi- 25
 ratoire.
- 12.** Système selon la revendication 11, dans lequel le
 générateur de retard est adapté pour calculer l'inter-
 valle de retard en fonction d'un ou de plusieurs pa- 30
 ramètre(s) respiratoire(s).
- 13.** Système selon l'une quelconque des revendications
 précédentes, comprenant en outre :
 un dispositif médical implantable incluant au 35
 moins le circuit de sortie de stimulation, le contr-
 ôleur de délivrance de stimulation, l'entrée de
 signal respiratoire, le détecteur de trouble respi-
 ratoire et le commutateur de stimulation ;
 un capteur respiratoire implantable adapté pour 40
 détecter un signal physiologique ; et
 un circuit de traitement de capteur adapté pour
 produire le signal respiratoire en utilisant le si-
 gnal physiologique. 45
- 14.** Système selon la revendication 13, dans lequel le
 capteur respiratoire implantable comprend un cap-
 teur d'impédance implantable adapté pour détecter
 une impédance thoracique. 50
- 15.** Système selon la revendication 13, dans lequel le
 capteur respiratoire implantable comprend un cap-
 teur de pression d'artère pulmonaire (PAP) implan-
 table. 55

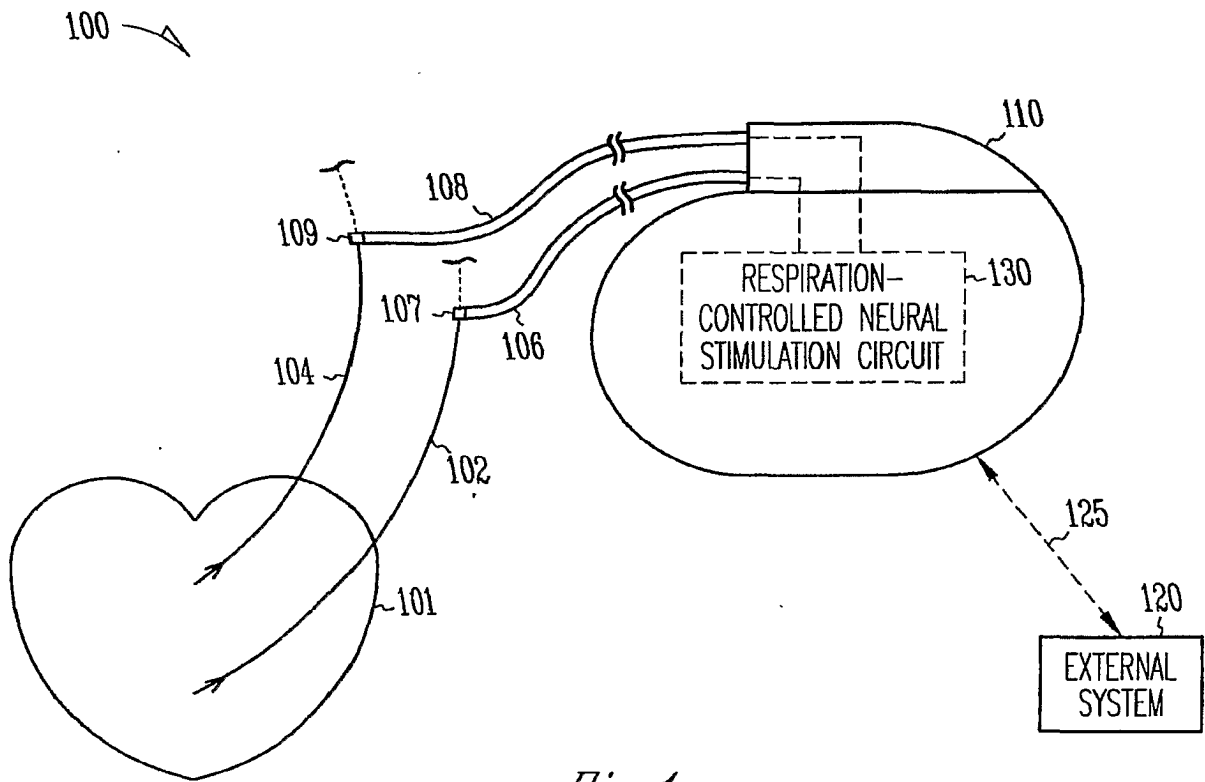


Fig. 1

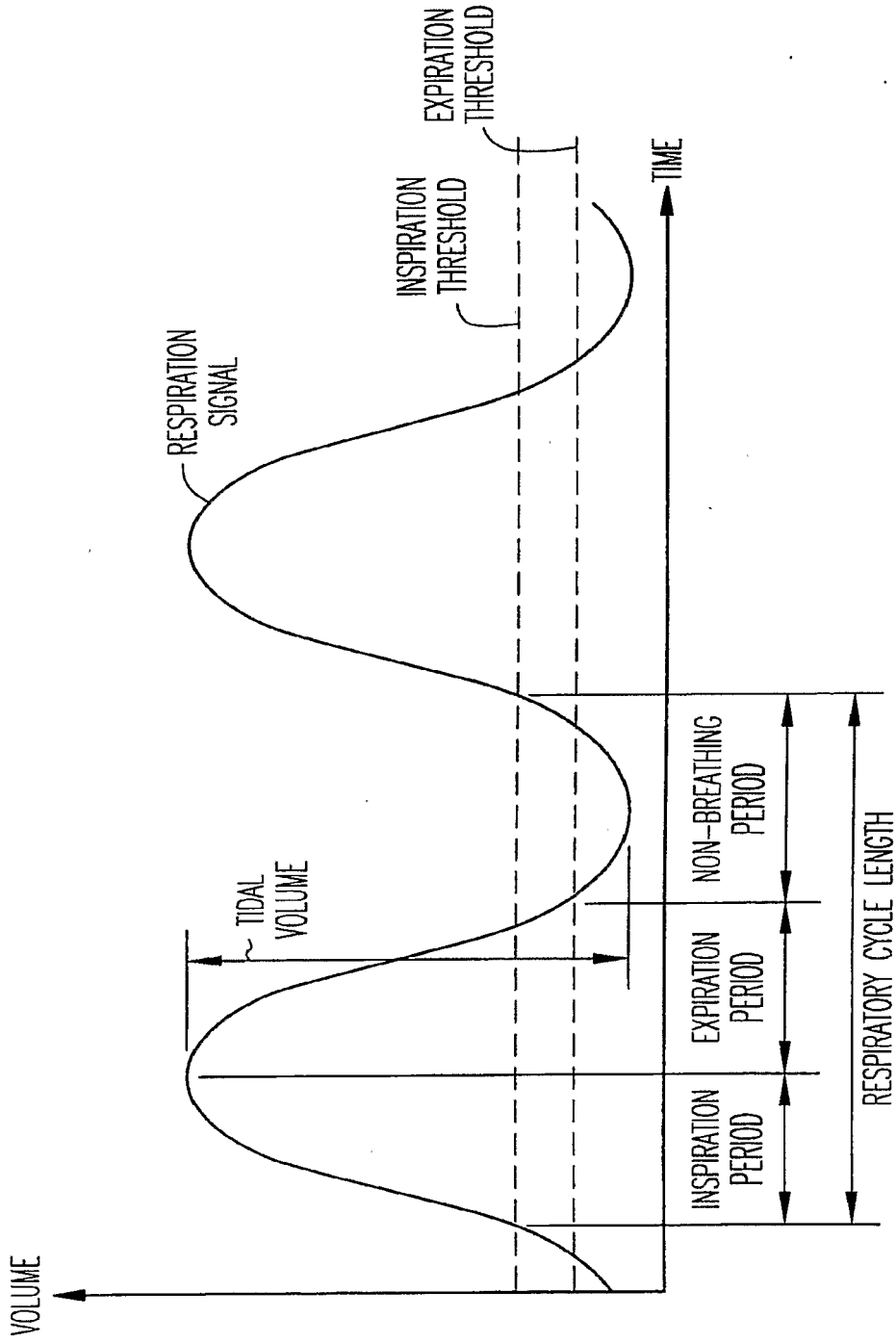


Fig. 2

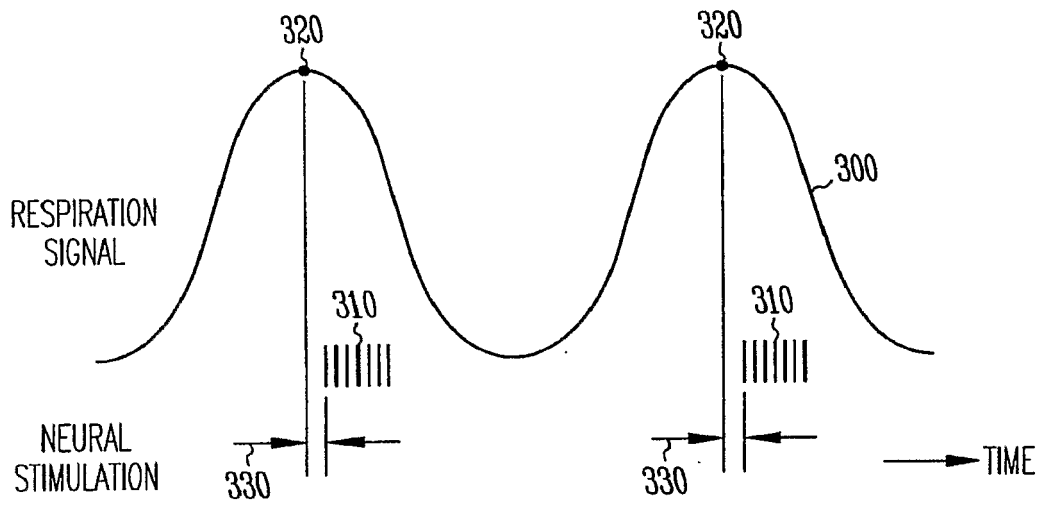


Fig. 3

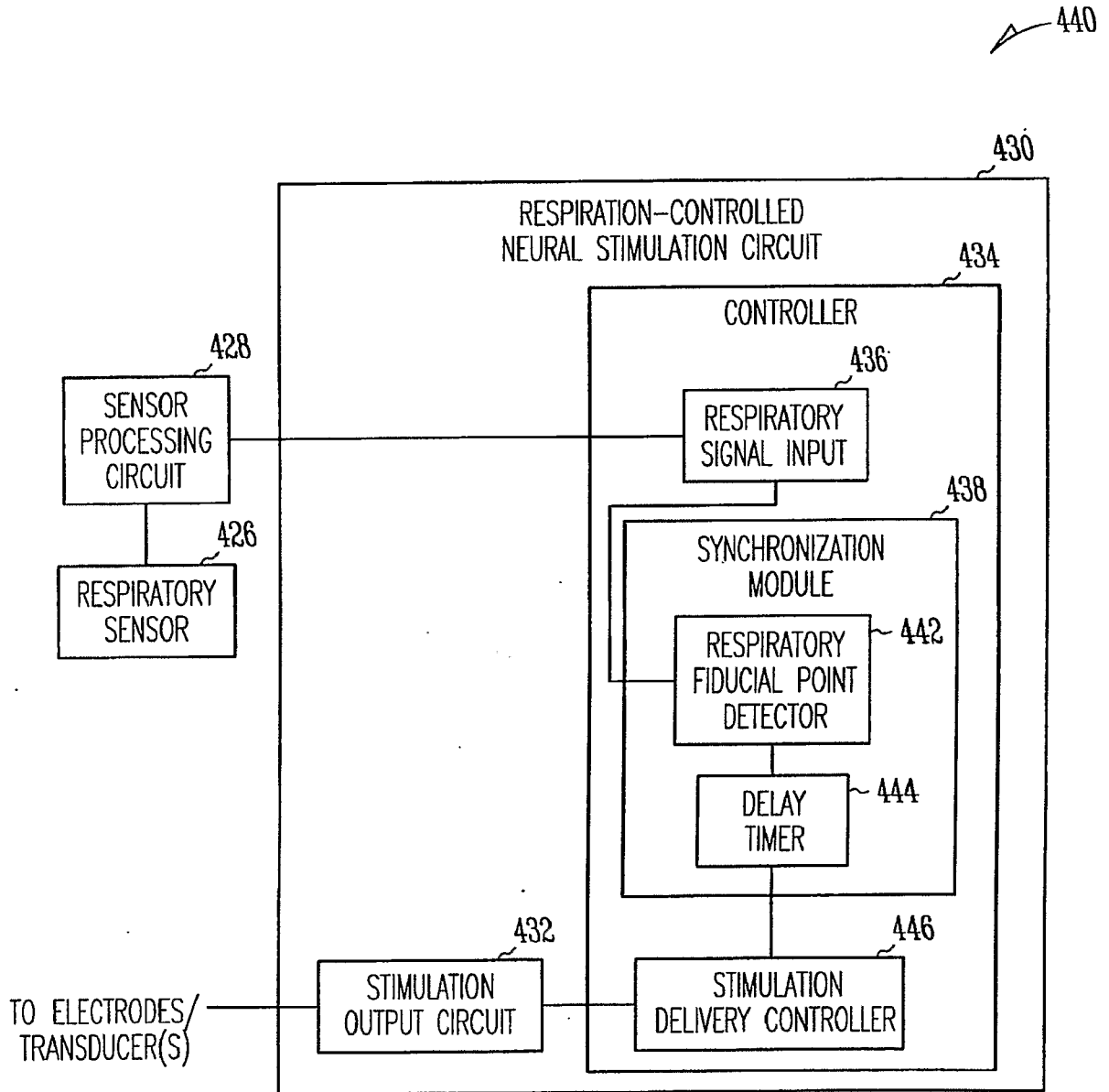


Fig. 4

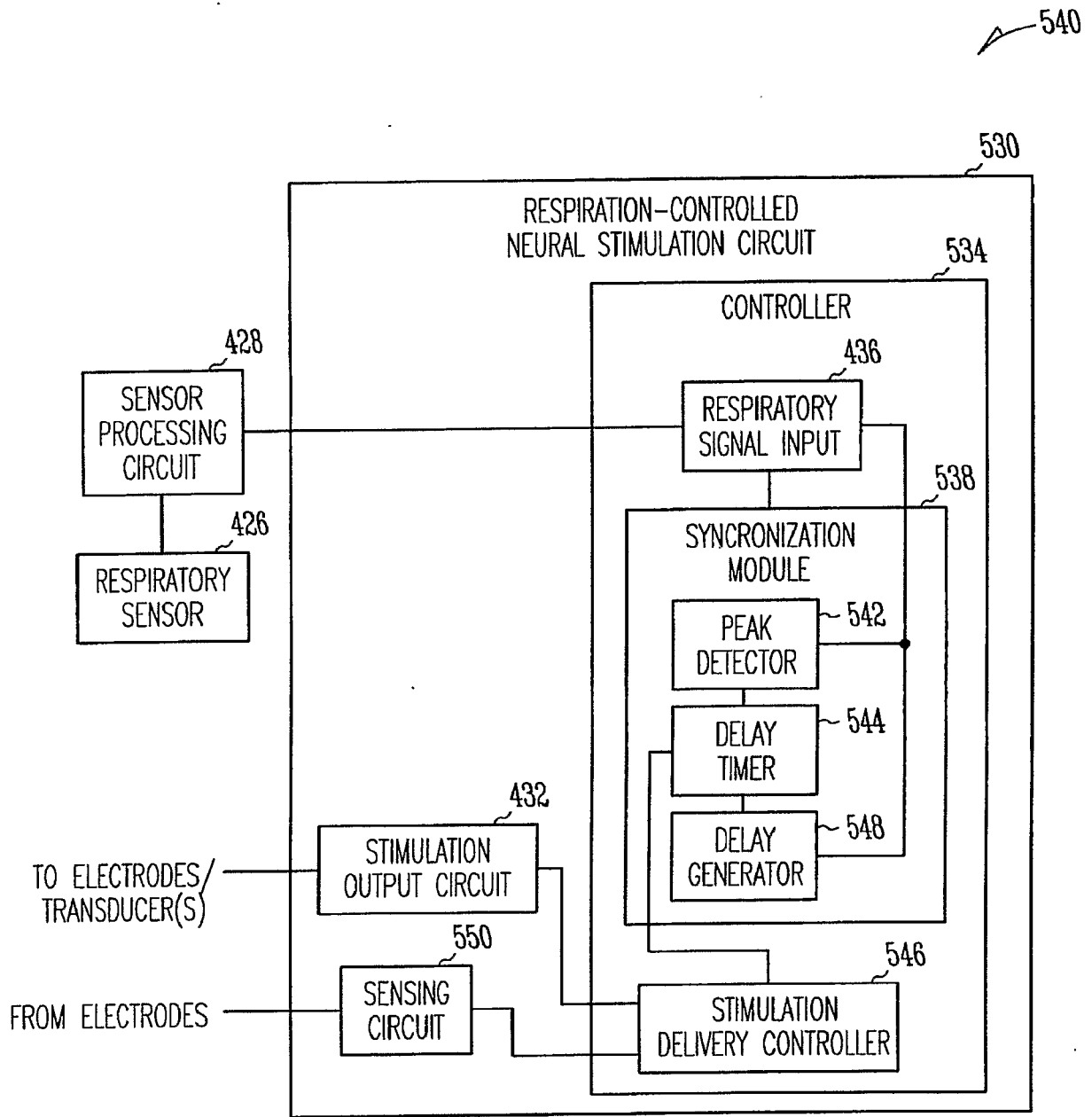


Fig. 5

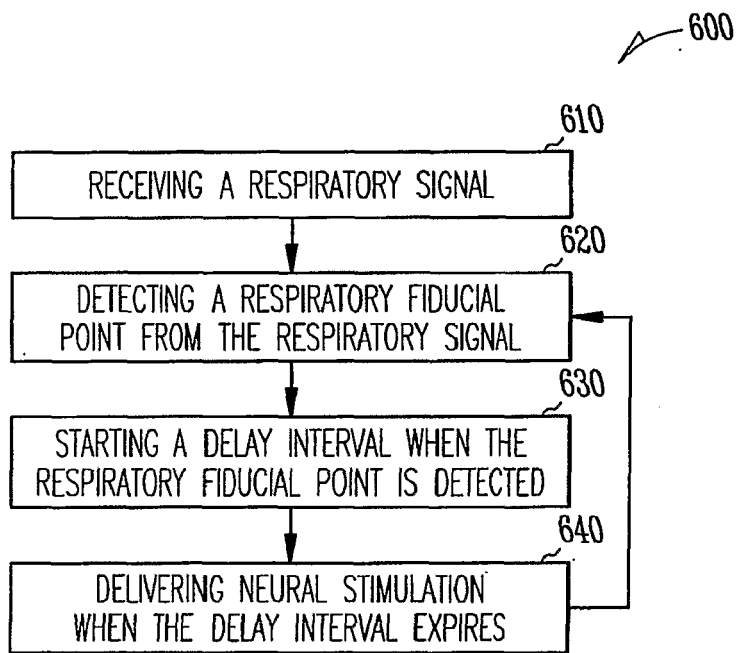


Fig. 6

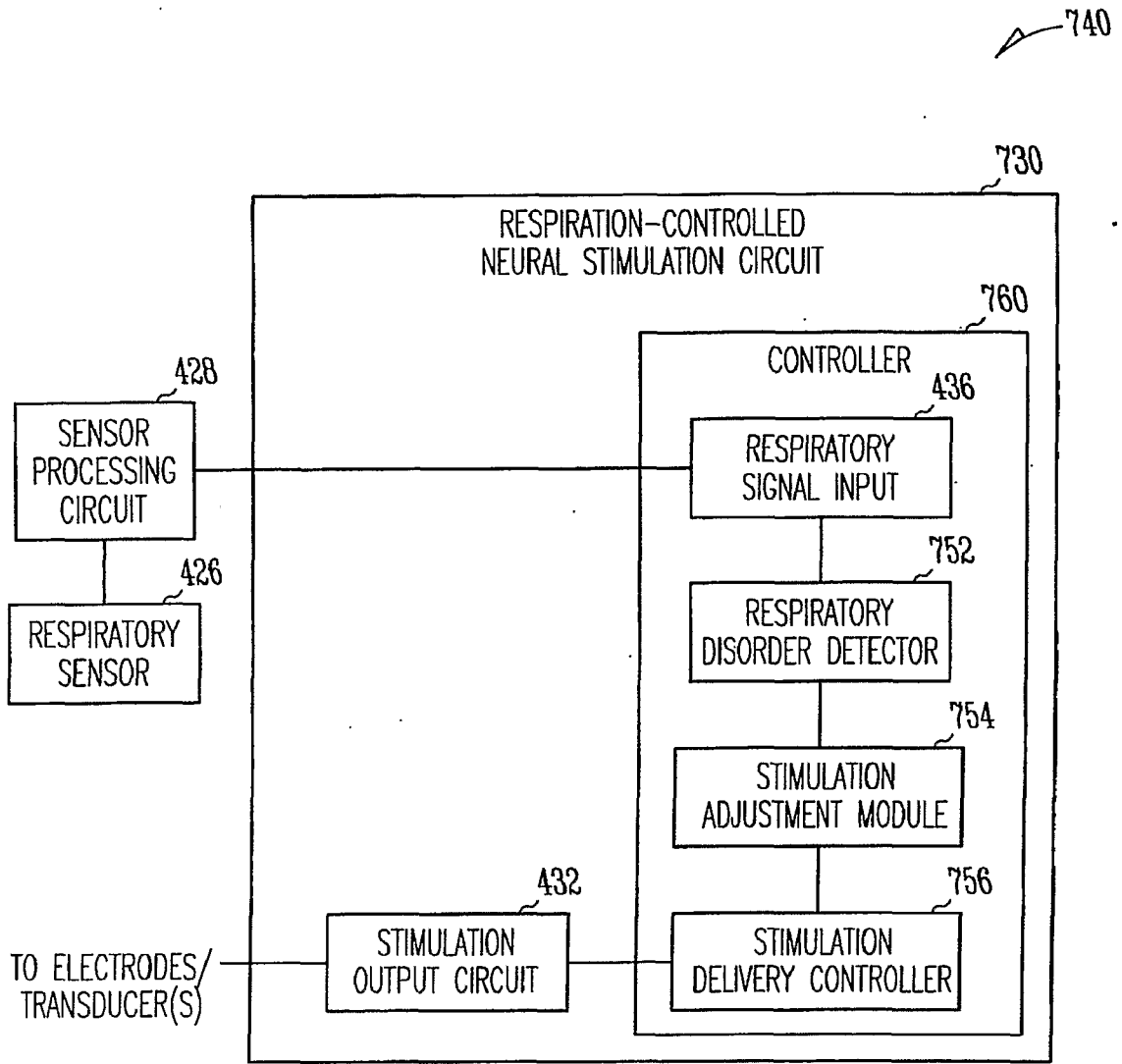


Fig. 7

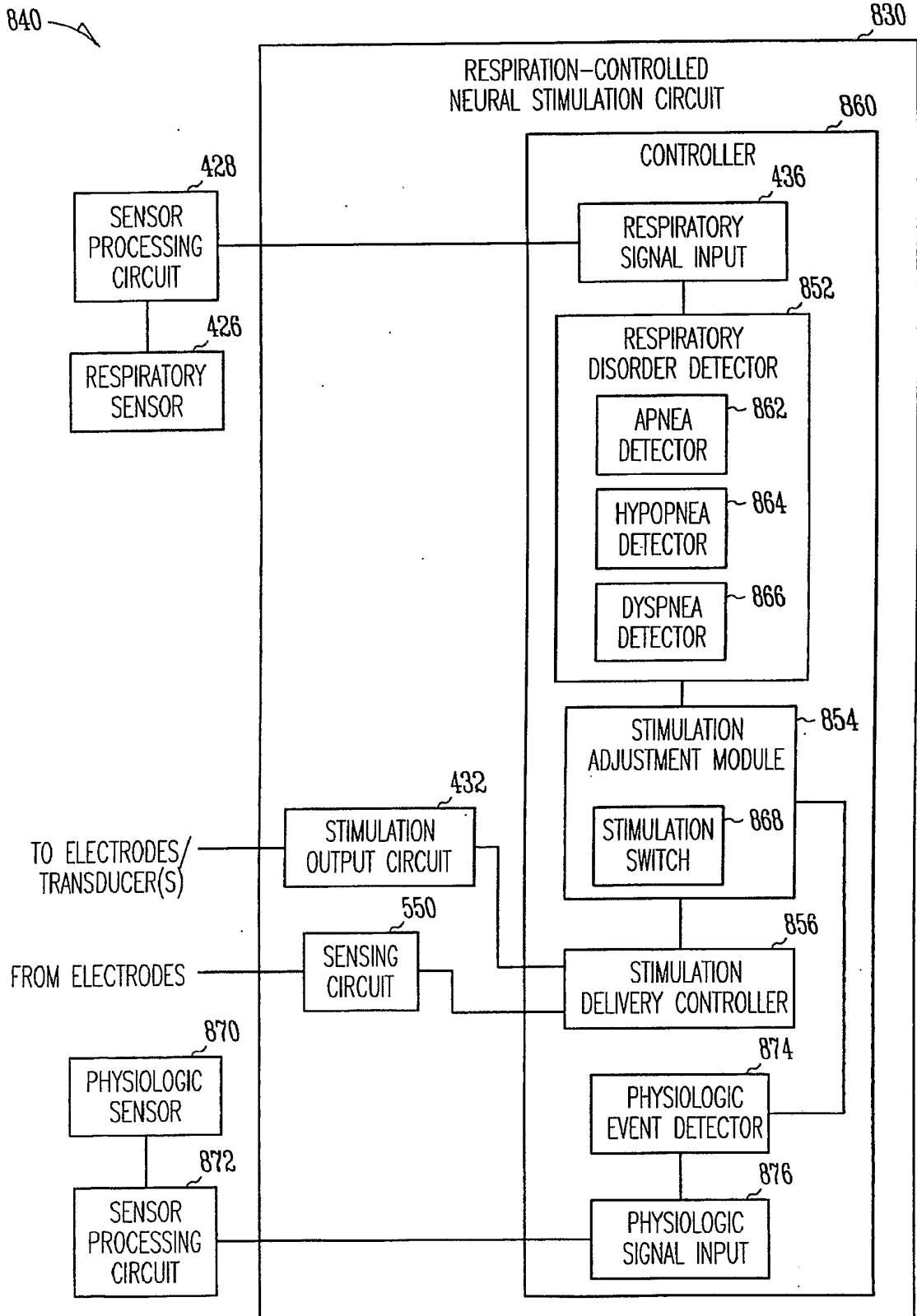


Fig. 8

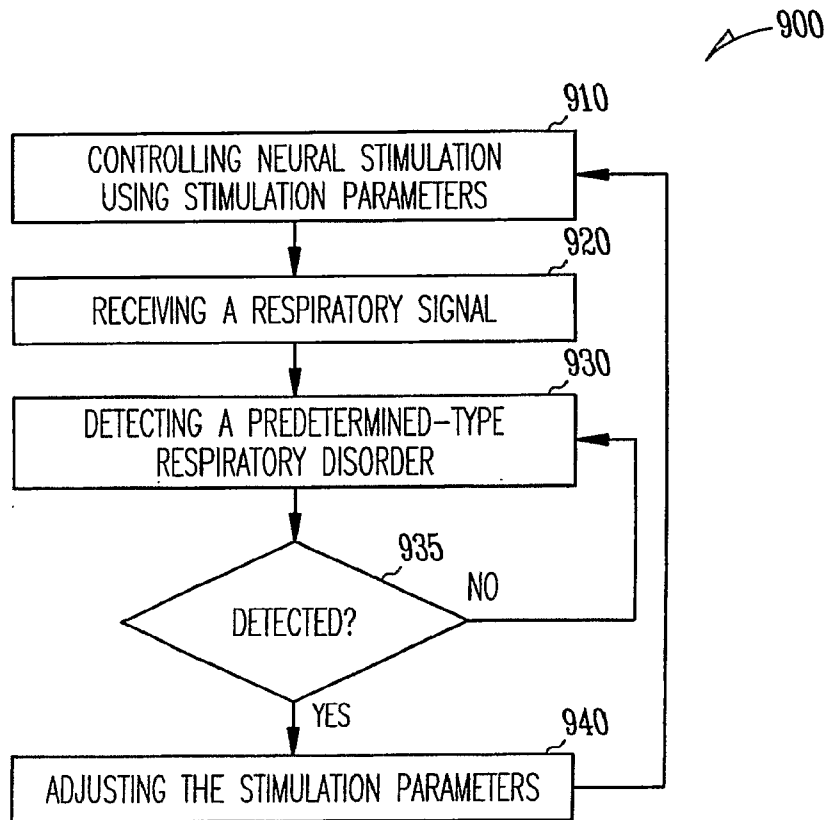


Fig. 9

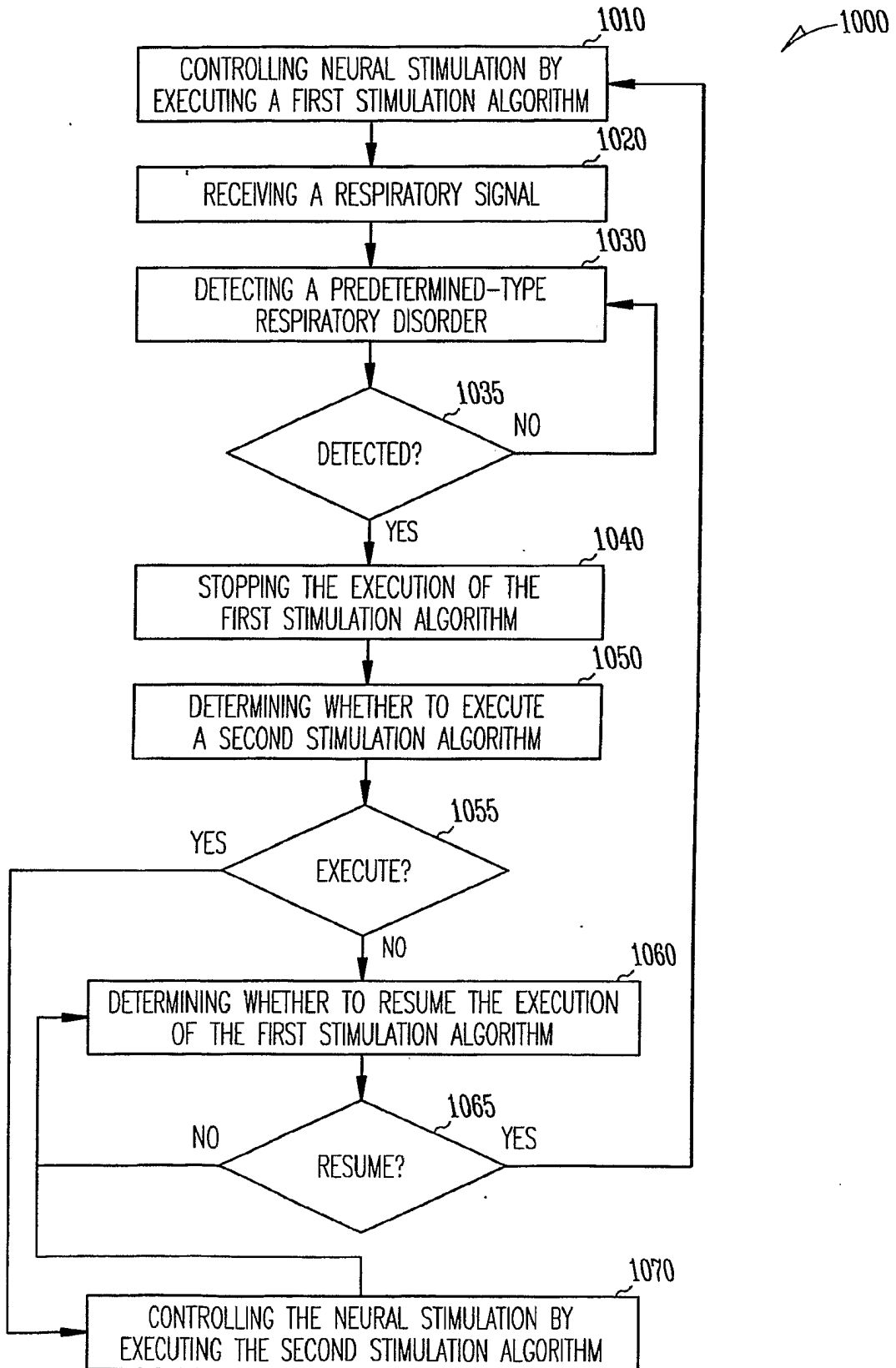


Fig. 10

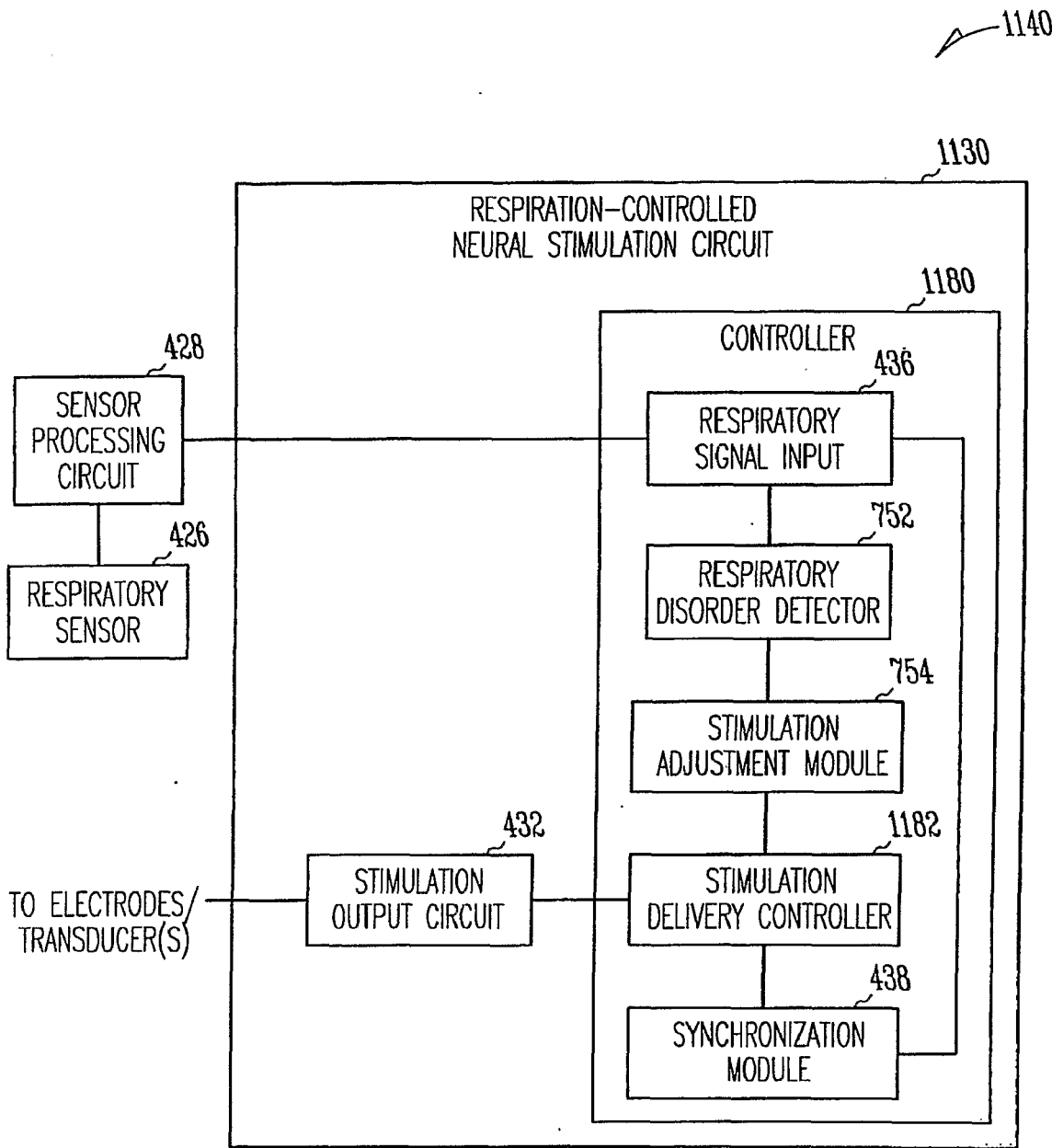


Fig. 11

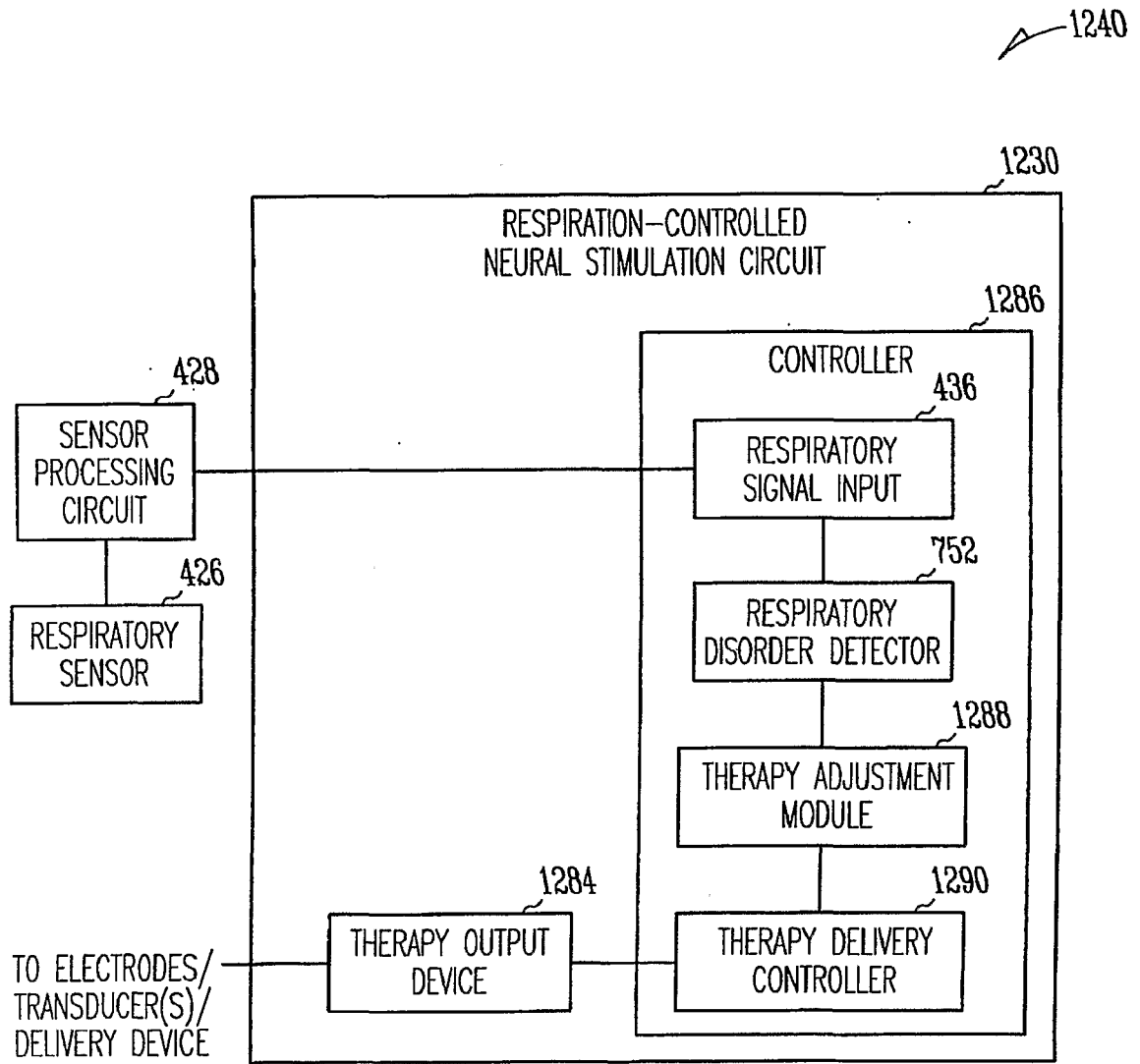


Fig. 12

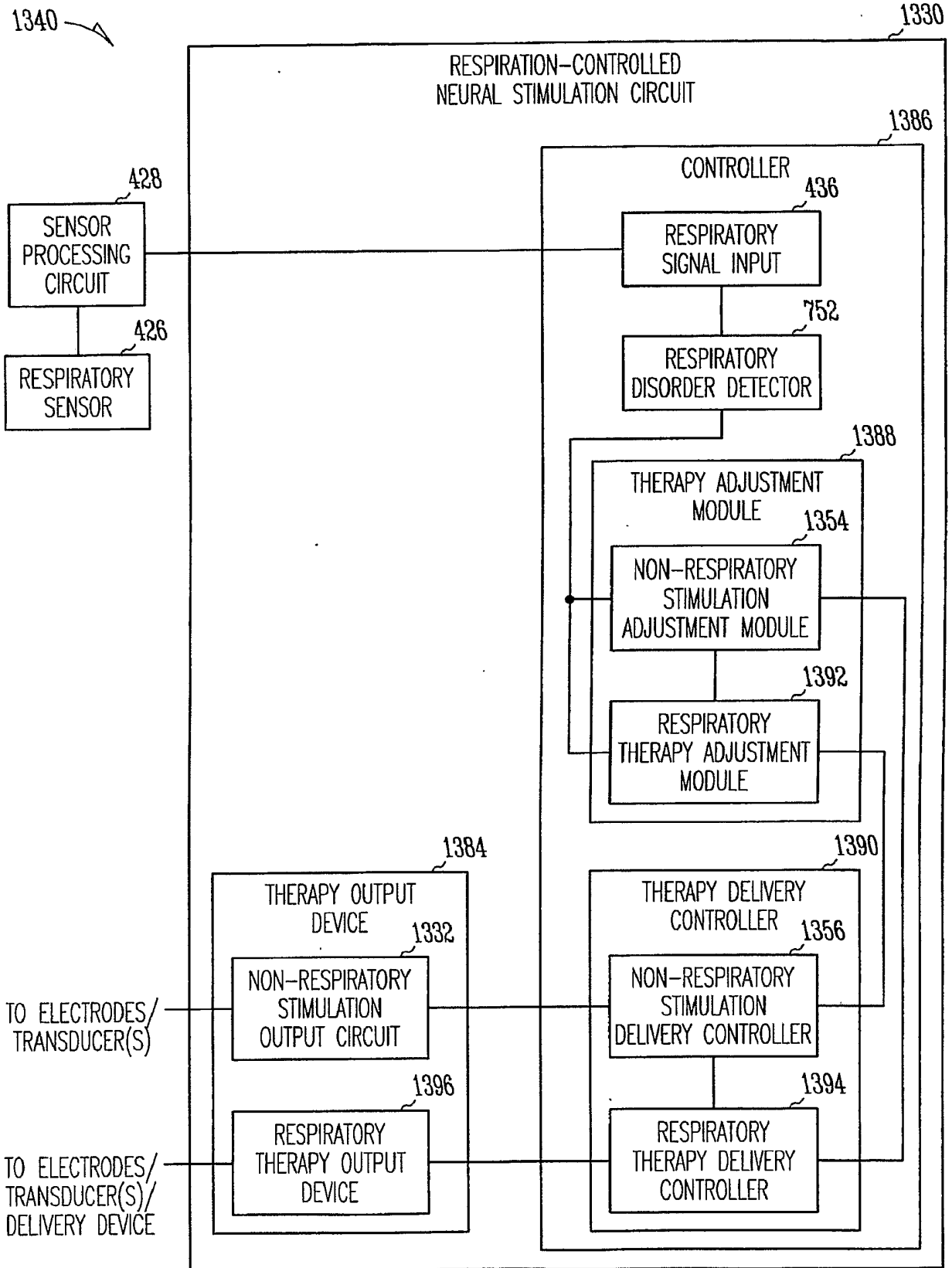


Fig. 13

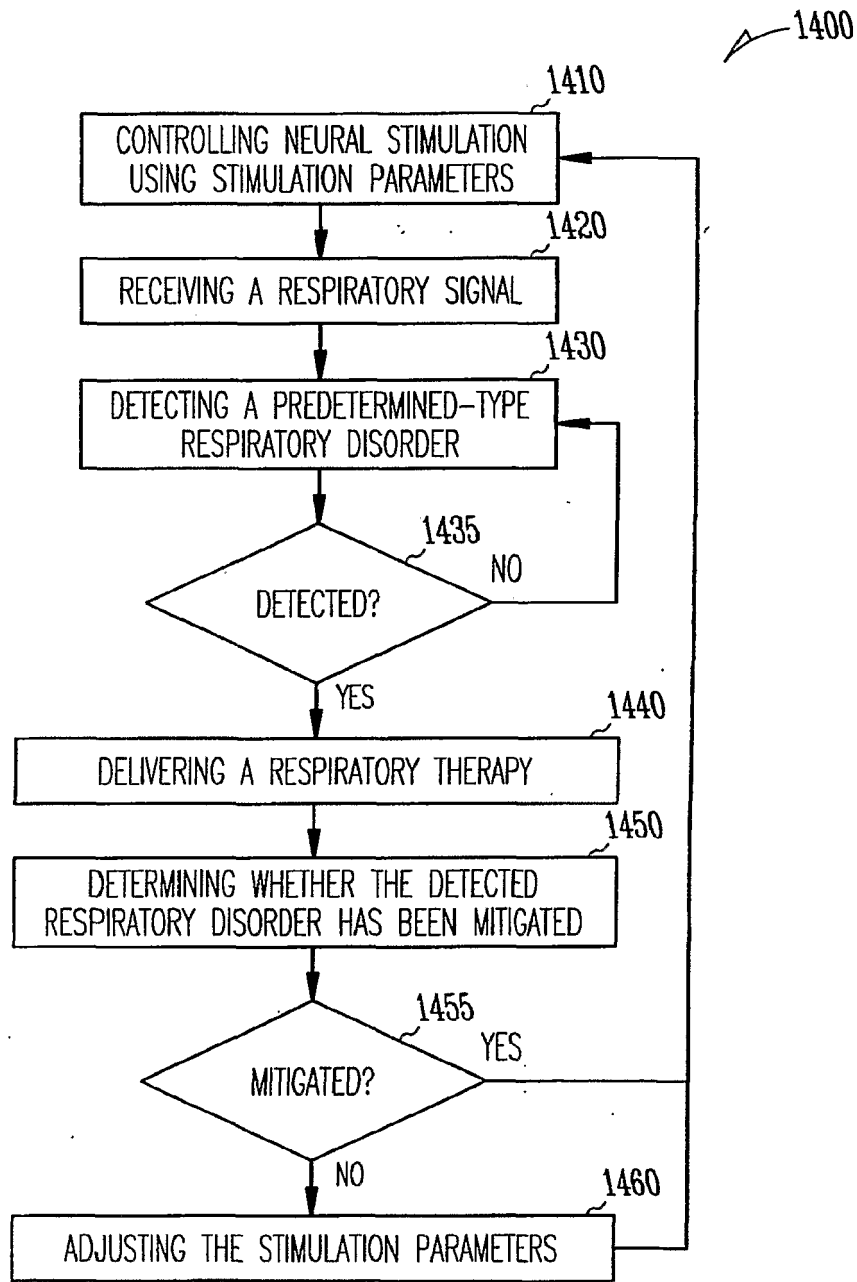


Fig. 14

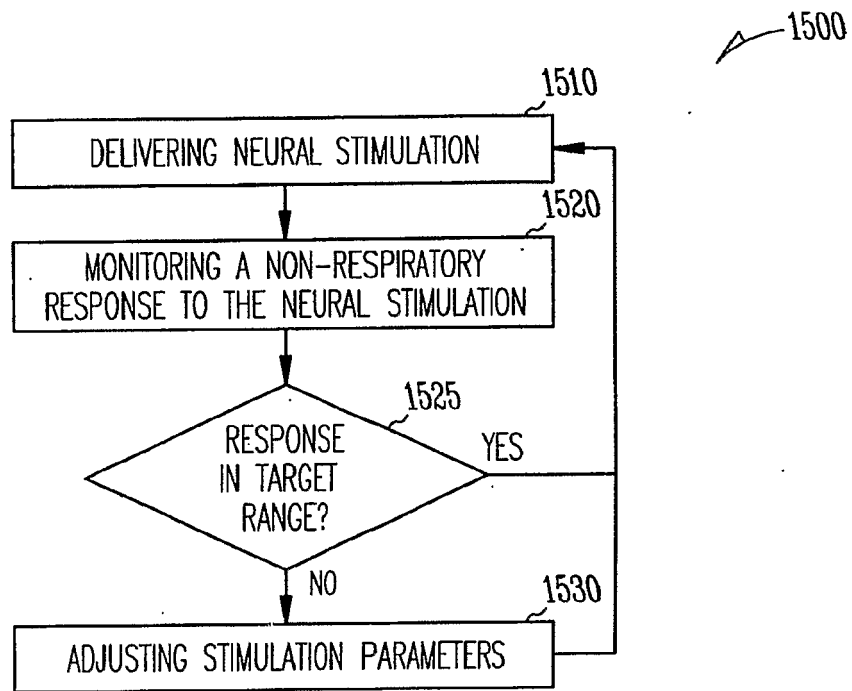


Fig. 15

REFERENCES CITED IN THE DESCRIPTION

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专利名称(译)	具有呼吸反馈的神经刺激系统		
公开(公告)号	EP2076314B1	公开(公告)日	2017-04-12
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[标]申请(专利权)人(译)	心脏起搏器股份公司		
申请(专利权)人(译)	心脏起搏器, INC.		
当前申请(专利权)人(译)	心脏起搏器, INC.		
[标]发明人	HAEFNER PAUL A JAMES KRISTOFER J LEE KENT LIBBUS IMAD CAPARSO ANTHONY V KWOK JONATHAN PU YACHUAN		
发明人	HAEFNER, PAUL, A. JAMES, KRISTOFER, J. LEE, KENT LIBBUS, IMAD CAPARSO, ANTHONY, V. KWOK, JONATHAN PU, YACHUAN		
IPC分类号	A61N1/36 A61B5/08 A61B5/00		
CPC分类号	A61B5/08 A61B5/4035 A61B5/4818 A61N1/3601 A61N1/36114 A61N1/36053		
优先权	11/468595 2006-08-30 US		
其他公开文献	EP2076314A2		
外部链接	Espacenet		

摘要(译)

神经刺激系统使用呼吸信号作为治疗反馈输入来控制神经刺激的递送。呼吸信号用于增加神经刺激的有效性,例如迷走神经刺激,同时减少呼吸功能中的潜在不良副作用。在一个实施例中,神经刺激系统使用呼吸信号中的呼吸基准点和延迟间隔使神经刺激脉冲的输送与呼吸循环同步。在另一个实施例中,神经刺激系统检测呼吸病症,并且作为响应,调节神经刺激脉冲的递送和/或递送治疗检测到的呼吸病症的呼吸疗法。

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A61B 5/08 (2006.01) A61B 5/08 (2006.01)

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(87) International publication number: WO 2008/027339 (06.03.2008 Gazette 2008/10)

(54) **SYSTEM FOR NEURAL STIMULATION WITH RESPIRATORY FEEDBACK**
SYSTEM ZUR NERVENSTIMULATION MIT ATEM-FEEDBACK
SYSTEME DE STIMULATION NEURALE AVEC RETOUR RESPIRATOIRE

(84) Designated Contracting States:
• LIBBUS, Imad, St. Paul, Minnesota 55105 (US)
• CAPARSO, Anthony, V., San Jose, California 95134 (US)
• KWOK, Jonathan Dennis, New Jersey 07834 (US)
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