

United States Patent

Hagfors

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[54] MEDICAL-ELECTRONIC STIMULATOR, PARTICULARLY A CAROTID SINUS NERVE STIMULATOR WITH CONTROLLED TURN-ON AMPLITUDE RATE

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[52] U.S. Cl. 128/421, 128/419 C, 307/141.4,
307/293, 328/77

[51] Int. Cl. A61n 1/36

[58] Field of Search 128/419-422;
328/8, 9, 76, 77, 85, 90; 307/293, 141, 141.4

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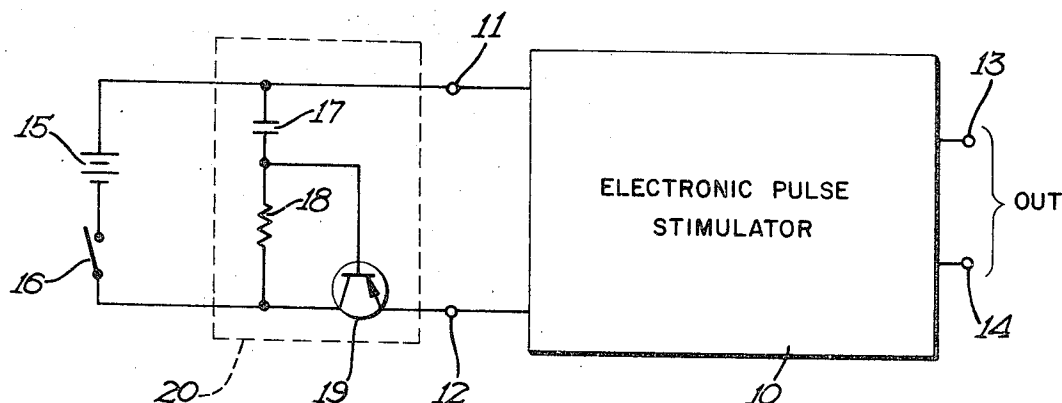
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[57]

ABSTRACT

Electronic circuitry for providing electrical stimulation signals to a selected portion of the body including circuitry for automatically gradually increasing the amplitude of only the initial output stimulating signals to a predetermined level which is maintained until turnoff.

11 Claims, 4 Drawing Figures



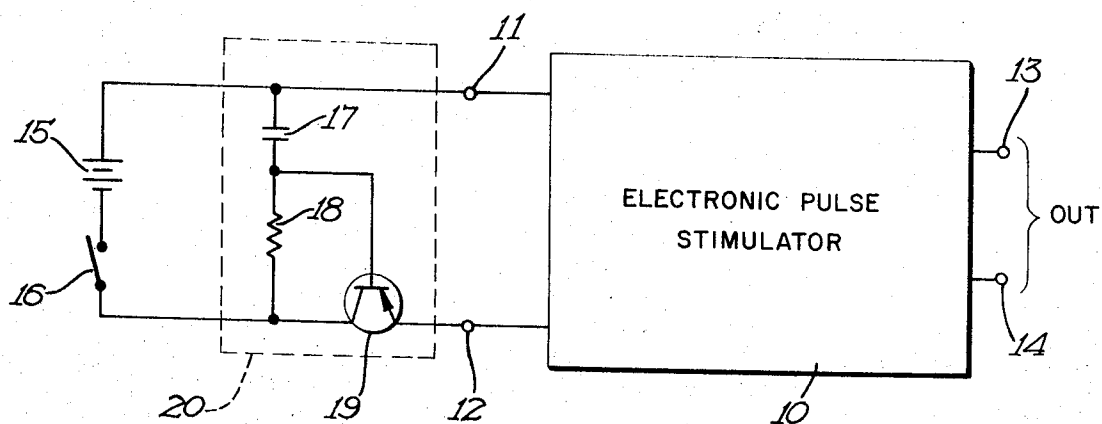


FIG 1

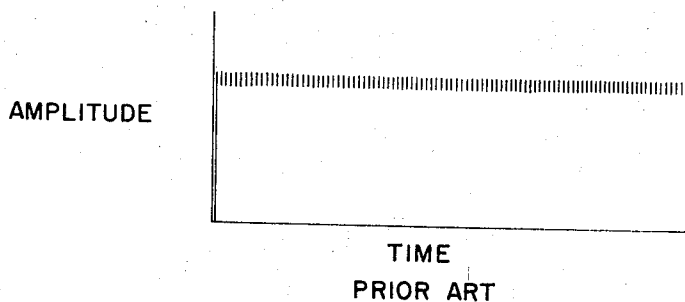


FIG 3

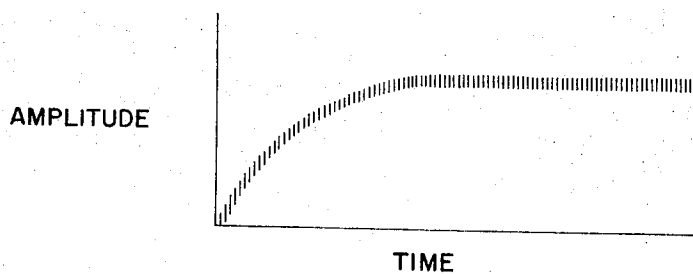


FIG 4

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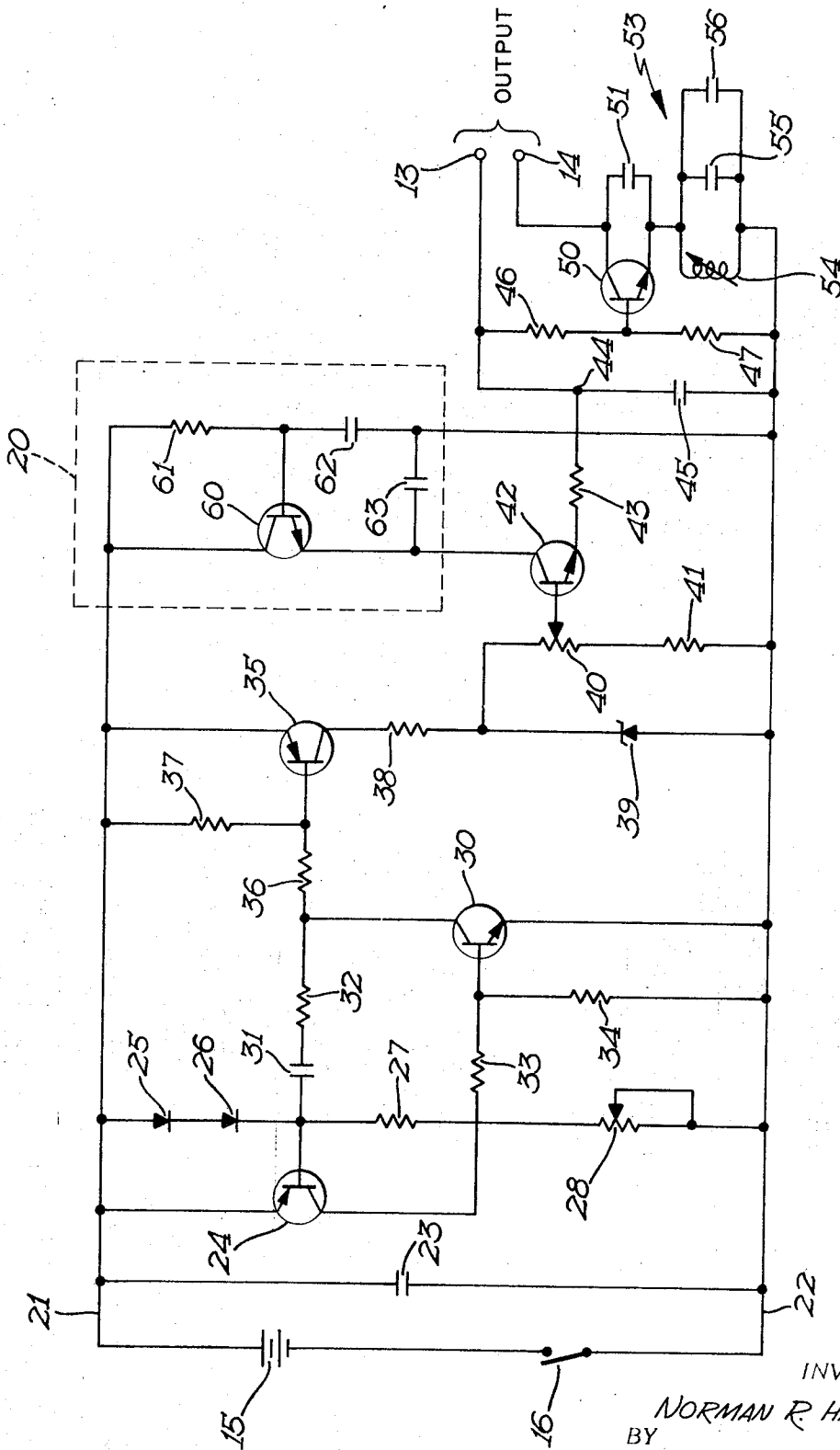


FIG 2

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MEDICAL-ELECTRONIC STIMULATOR, PARTICULARLY A CAROTID SINUS NERVE STIMULATOR WITH CONTROLLED TURN-ON AMPLITUDE RATE

BACKGROUND OF THE INVENTION

This invention is concerned with medical-electronic pulse stimulators, and more particularly with an improvement to automatically provide for the gradual increase of the amplitude of the initial output signals from the pulse stimulating circuitry. Electrical stimulation of nerves, muscles, or other tissue, for medical purposes, is well known in the art. Some examples of well-known circuitry are heart pacers and carotid sinus nerve stimulators. The electrical stimulation of nerves, muscles or other tissue is often accompanied by undesirable side effects caused by stimulation of adjacent nerve fibers, for example. It has been discovered that in many cases these side effects are transitory in nature and persist for only a short period of time after stimulus by means of electrical signals is first applied. It is theorized that the stimulating signals, when turned on at full stimulating amplitude, cause the afferent nerve fibers to fire giving a sensation of electrical shock. It appears that these afferent fibers then accommodate to the stimulus signal, and will no longer fire.

The apparatus of this invention overcomes the above-mentioned undesirable side effects by providing circuitry for gradually increasing the amplitude of the initial stimulating signals to a predetermined stimulus level. It has been found that if the stimulus is turned on gradually, the afferent nerve fibers accommodate to the stimulus signal without depolarizing and provide little or no sensation of electrical shock, and that the stimulating signals may thereafter be maintained at the predetermined level without adverse reaction. Therefore, the apparatus of this invention has been designed for implantable, transcutaneous, and external stimulators to provide pulse or other stimulus turn-on characteristics which will be accommodated by the afferent nerve fibers to prevent a transitory response.

SUMMARY OF THE INVENTION

Briefly described, the apparatus of this invention comprises amplifier means connected between a selected portion or all of the circuitry for providing stimulating signals and the source of energy which provides the electrical power to the circuitry. The amplifier means is controlled by electrical time constant circuitry which is connected by switch means across the source of electrical energy. In the preferred embodiment of the drawings, the time constant means is shown as a serial RC circuit, that is, a resistor and a capacitor connected in series. When the switch is closed, the time constant causes a gradual buildup of charge in the capacitor. The charge on the capacitor is used to control the initial output of the amplifier which in turn controls the current reaching the circuitry for providing stimulating signals, in this circuit a train of pulses. By gradually increasing the initial output of the amplifier, the initial amplitude of the train of output pulses will also be gradually increased to its maximum or predetermined level. As described above, this gradual increase of the initial amplitude of the signals which provide stimulus will reduce or remove the transitory response that causes an uncomfortable feeling in the patient receiving the stimulation.

IN THE DRAWINGS

FIG. 1 is a combination schematic and block diagram showing an embodiment using the apparatus of this invention;

FIG. 2 is a schematic diagram of electronic pulse stimulating circuitry using another embodiment of the apparatus of this invention;

FIG. 3 is a graph indicating a typical envelope for a train of prior art stimulating pulses; and

FIG. 4 is a graph indicating the envelope of a train of stimulating pulses provided by the apparatus of this invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In FIG. 1 there is shown in block diagram an electronic stimulator 10. Stimulator 10 has a pair of input terminals 11 and 12 adapted to be connected to a source of electrical energy, and a pair of output terminals 13 and 14 across which the stimulator provides a train of output pulses. A source of electrical energy, here shown as batteries 15, is connected between input terminal 11 and one side of a switch 16. The apparatus of this invention for gradually increasing the initial output amplitude of the stimulating signals is shown enclosed within dotted lines and indicated generally as 20. Apparatus 20 comprises a capacitor 17 and resistor 18 serially connected across source 15 and switch 16. Apparatus 20 also includes a transistor 19, having an emitter connected to input terminal 12, a collector connected to the other side of switch 16, and a base connected to a junction between capacitor 17 and resistor 18.

To best understand the operation of the apparatus of FIG. 1, assume first that switch 16 is open. Therefore, there will be no charge on capacitor 17 and no output signals from stimulator 10. When output signals are desired, switch 16 is closed. This will connect the electrical time constant apparatus, comprising the serial RC circuit of capacitor 17 and resistor 18, across source 15. As capacitor 17 cannot charge instantaneously, there will be no current flow through the amplifier comprising transistor 19, and therefore no power to stimulator 10, instantaneously.

As the electrical time constant apparatus remains connected across source 15, a charge will buildup in capacitor 17 and the resulting voltage change at the junction between capacitor 17 and resistor 18 will be felt on the base of the amplifier comprising transistor 19 to turn it on and provide a current flow through terminals 11 and 12 to stimulator 10. This current flow will allow operation of the electronic stimulator 10 which will in turn provide the desired train of output signals. As the charge across capacitor 17 continues to gradually increase, the current flow through transistor emitter-follower connected 19 will also gradually increase until the maximum current flow from source 15 is reached. During this time the resulting gradual increase of current flow to stimulator 10 will cause a corresponding gradual increase in the output amplitude of the initial signals. This gradual increase of the amplitude of only the initial output signals to a maximum or predetermined amplitude is the desired result to alleviate the undesirable feelings caused in the patient receiving the train of pulses, which undesirable feeling is present when the initial turn-on of the train of pulses is at full amplitude and is apparently caused by stimulation of adjacent nerve fibers.

Referring now to FIG. 2 there is shown another embodiment of the apparatus of this invention. In FIG. 2 the disclosed schematic is that of a radiofrequency pulse transmitter of a type presently in use in the art, for transmitting a train of stimulating pulses via RF to an implanted receiver which is connected to the tissue that is to be stimulated.

In FIG. 2, output terminals 13 and 14, source 15 and switch 16 bear the same numbers as for FIG. 1. Also, the improvement comprising the apparatus of this invention is again enclosed in dotted lines and denoted as 20. Source 15 has one terminal connected to a positive bus 21, and another terminal connected through switch 16 to a negative bus 22. A capacitor 23, for voltage stabilization purposes, is connected between buses 21 and 22. A transistor 24 has its emitter connected to bus 21. The base of transistor 24 is connected through a pair of diodes 25 and 26 to bus 21, and through a resistor 27 and a variable resistor 28 to bus 22. A transistor 30 has its emitter connected to bus 22. The base of transistor 30 is connected through a resistor 33 to the collector of transistor 24, and through a resistor 34 to bus 22. The collector of transistor 30 is connected through a resistor 32 and a capacitor 31 to the base of transistor 24. A transistor 35 has its emitter connected

to bus 21. The base of transistor 35 is connected through a resistor 36 to the collector of transistor 30, and through a resistor 37 to bus 21. The collector of transistor 35 is connected through a serial combination of a resistor 38 and a Zener diode 39 to bus 22. A junction between resistor 38 and diode 39 is connected to bus 22 through a serial combination of a potentiometer 40 and a resistor 41. A transistor 42 has its base connected to the wiper arm of potentiometer 40, and its emitter connected through a resistor 43 to a junction 44. Junction 44 is connected through a capacitor 45 to bus 22, and directly to output terminal 13. A pair of serially connected resistors 46 and 47 are connected between junction 44 and bus 22. A transistor 50 has its base connected to a junction between resistors 46 and 47, and its collector connected directly to output terminal 14. A capacitor 51 is connected between the collector and emitter of transistor 50. The emitter of transistor 50 is connected through an RF tank circuit 53 to bus 22. Tank circuit 53 comprises a parallel combination of a variable inductance 54, a capacitor 55 and a capacitor 56.

The apparatus of this invention 20 is connected as follows: a transistor 60 has its emitter connected to the collector of transistor 42. The collector of transistor 60 is connected to bus 21. The base of transistor 60 is connected through a resistor 61 to bus 21, and through a capacitor 62 to bus 22. A capacitor 63 is connected between the emitter of transistor 60 and bus 22 to provide lower circuit impedance in a manner well known in the art.

In reviewing the operation of the apparatus of FIG. 2, it will be apparent to one of normal skill in the art that transistors 24 and 30 and their associated electrical components comprise a pulse generator that will act to provide output pulses as long as switch 16 is closed. When switch 16 is closed the voltage from source 15 will be felt between buses 21 and 22. There will be a current flow through diodes 25 and 26, resistor 27 and variable resistor 28. Capacitor 31 will not be charged, and the drop across diodes 25 and 26 will forward bias the emitter-base junction of transistor 24 to turn it on. The turn-on of transistor 24 will cause a current flow through resistors 33 and 34 thus causing a forward bias at the emitter-base junction of transistor 30 to turn it on. When transistor 30 turns on a charging path will be provided for capacitor 31, and when the charge on capacitor 31 has reached a sufficient level it will bias off transistor 24, which will in turn bias off transistor 30. The charge on capacitor 31 will then discharge through the path comprising resistor 37, resistor 36, resistor 32, capacitor 31, resistor 27 and resistor 28. When a sufficient lowering of the charge on capacitor 31 has been accomplished transistor 24 will again turn on and the cycle will repeat. Thus there is an output train of pulses generated as long as switch 16 is closed.

It will also be apparent to one of normal skill in the art that transistor 35 and Zener diode 39, along with their associated electrical components, comprise a voltage regulator. Operating in a manner apparent to one of normal skill in the art, the output pulse from the pulse generator causes a current flow through resistors 36 and 37 to forward bias the emitter-base junction of transistor 35 thus causing a current flow through resistor 38, potentiometer 40 and resistor 41. Diode 39 acts to regulate the voltage of this portion of the circuit.

Transistor 42 in combination with potentiometer 40 operate as an output amplitude adjustment, with the capability of varying the amplitude of the output according to the positioning of the wiper arm of potentiometer 40. Assuming first that the apparatus 20 is not present, and that, as in the prior art, the collector of transistor 42 is connected directly to bus 21, then the current flow through transistor 40 will cause the forward biasing of the emitter-base junction of transistor 42, causing a current flow through resistor 43 to junction 44. This will charge transistor 45 and be felt across the serial combination of resistors 46 and 47. Transistor 50 will then be turned on to provide energy to the tank circuit 53 and the RF oscillator interconnection of these components will cause a train of RF output pulses at terminals 13 and 14, the amplitude of which is controlled by the setting of potentiometer 40.

Returning now to the apparatus of FIG. 2, in which the apparatus 20 is present, it can be seen that the output of transistor 42 will not be provided to the RF oscillator until the amplifier comprising transistor 60 has been turned on. It can also be seen that the time constant apparatus, comprising the serial combination of resistor 61 and capacitor 62 across the power supply, controls the turn-on of transistor emitter-follower connected 60. That is, when switch 16 is closed there will have been no charge on capacitor 62 and there will therefore not be an instantaneous forward biasing of the emitter-base junction of transistor 60. As capacitor 62 gradually charges through resistor 61, the forward bias of the emitter-base junction of transistor 60 will gradually increase, and the current flow therethrough to the collector of transistor 42 will correspondingly gradually increase. When capacitor 62 is fully charged then the maximum current flow will be available through transistor 60 and transistor 42.

It thus becomes apparent that the amplitude of the initial pulses available through transistor 42 to the RF oscillator is gradually increased, and that only the initial pulses of the resulting train of RF pulses will be correspondingly gradually increased. Thus the RF receiver which is connected to the tissue of the patient will receive a train of pulses of which the initial pulses gradually increase in amplitude to a predetermined value, and the possibility of an unpleasant feeling due to the transitory side effects caused by the immediate full amplitude turn-on of the train of pulses will be alleviated.

In testing the apparatus of FIGS. 1 and 2, it has been determined, for the RF pulse transmitter of FIG. 2, that the connection of apparatus 20 at the position in the circuitry as shown in FIG. 2 is preferable to that of FIG. 1 for purposes of conservation of energy. The connection possibility suggested in the embodiment of FIG. 1, that is, where the apparatus 20 is placed between the source of energy 15 and all of circuitry 10, is believed to be the preferred embodiment for purposes of stability. Other embodiments than those shown in the drawings have been used, for example the placement of apparatus 20 so as to provide gradual increase of power supply voltage to both the voltage regulator and output amplitude adjustment apparatus of FIG. 2, and it will be apparent that the placement of apparatus 20 to select gradual control of any selected portion of the pulse stimulator circuitry is in any case within the scope of this invention.

FIGS. 3 and 4 are graphs of the pulse train amplitude versus time for representing the difference between the prior art output pulse trains and the pulse trains from apparatus utilizing this invention. FIG. 3 is a prior art output pulse train where it can be seen that almost instantaneously the train of pulses reaches its full amplitude. It is this sudden rise to full amplitude which is believed to cause the side effects and unpleasant feelings in the patient, probably due to stimulation of adjacent tissue to the tissue it is desired to stimulate. FIG. 4, a graph on the same scale as FIG. 3, depicts the gradual rise to full amplitude of the initial pulses of the output pulse train of stimulators including the invention disclosed herein. It is believed that with this gradual turn-on of only the initial portion of the stimulating signals, the adjacent fibers will accommodate to the stimulus signals without depolarizing and will provide little or no sensation to the patient.

What is claimed is:

1. In electronic circuitry for providing output electronic stimulating signals to a selected portion of the body the signals providing a plurality of pulses, the circuitry adapted to be connected to a source of electrical energy, the improvement comprising: means for gradually increasing the amplitude of the initial pulses of the output stimulating signals to a predetermined value; energy terminal means adapted to be connected to the source of electrical energy; and further means for connecting said means for gradually increasing the amplitude between said energy terminal means and a selected portion of the electronic circuitry.

2. The improvement of claim 1 in which said means for gradually increasing the amplitude includes: input and output

terminals for connection, respectively, to said energy terminal means and the selected portion of the electronic circuitry; amplifier means connected between said input and output terminals and having a control terminal; electrical time constant means; and means connecting said time constant means to said control terminal and across said energy terminal means.

3. The improvement of claim 2 in which said electrical time constant means comprises: resistance means and capacitance means; means for connecting said resistance means between said control terminal and one polarity of said energy terminal means; and means for connecting said capacitance means between said control terminal and another polarity of said energy terminal means.

4. The improvement of claim 3 in which said amplifier means comprises: a transistor having input and output electrodes connected to said input and output terminals, and having a control electrode connected to said control terminal.

5. The improvement of claim 4 in which said transistor is connected in emitter-follower configuration.

6. In electronic pulse stimulator apparatus for providing an output train of pulses, the stimulator adapted to be connected to a source of electrical energy and including pulse generator means and output amplitude control means, the improvement comprising: energy terminal means adapted to be connected to the source of electrical energy; means for automatically gradually increasing the amplitude of the initial pulses of the output train of pulses to a predetermined value; and means for connecting said means for gradually increasing the amplitude between said energy terminal means and the output amplitude control means.

7. The improvement of claim 6 in which said means for gradually increasing the amplitude includes: amplifier means connected between said energy terminal means and the output

amplitude control means; electrical time constant means; means for connecting said time constant means across said energy terminal means; and means connecting said time constant means to said amplifier means for the control thereof.

8. The improvement of claim 7 in which said electrical time constant means comprises: resistance means and capacitance means connected in series across said energy terminal means; and said capacitance means connected to said amplifier means for controlling the output thereof dependent on the electrical charge in said capacitance means.

9. The improvement of claim 8 in which said amplifier means comprises: a transistor having input, output and control electrodes; said input and output electrodes connected to, respectively, said energy terminal means and said output amplitude control means; and said control electrode connected to said capacitance means.

10. The improvement of claim 9 in which said transistor is connected in emitter-follower configuration.

11. In a carotid sinus nerve stimulator for providing stimulating signals to a selected nerve fiber between being turned on and turned off, the improvement comprising: means automatically responsive to the stimulator being turned on for gradually increasing the amplitude of the initial stimulating signals to a predetermined level maintained until the stimulator is turned off; said means comprising time constant means connected to control the initial current flow through at least a position of the nerve stimulator; and including energy terminal means adapted to be connected to a source of energy; and said time constant means comprising an RC circuit connected between at least a position of the nerve stimulator and said terminal means.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,645,267 Dated February 29, 1972

Inventor(s) Norman R. Hagfors

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Abstract, "turnoff" should be --turn-off--.
Column 1, line 14, "well-known" should be --well known--.
Column 2, line 39, "transistor emitter-follower connected" should be --emitter-follower connected transistor--.
Column 2, line 55, "radiofrequency" should be --radio frequency--.
Column 4, line 7, "transistor emitter-follower connected" should be --emitter-follower connected transistor--.
Column 6, line 28, "position" should be --portion--.
Column 6, line 31, "position" should be --portion--.

Signed and sealed this 27th day of June 1972.

(SEAL)

Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

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