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(54) "IMPROVEMENTS IN IMPLANTABLE ELECTROMEDICAL DEVICES FOR BODY TISSUE STIMULATION"

(71) We, MEDTRONIC INC, a corporation organised and existing under the laws of the State of Minnesota United States of America of 3055 Old Highway Eight, P.O. Box 1453 Minneapolis Minnesota 55440 United States of America do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:

This invention relates to a body implantable electromedical device for detecting externally applied signals and for applying pulses in response thereto through a lead to selected body tissue.

In the prior art, as exemplified by United Kingdom Patent No. 1,495,391, a transmitter and receiver system is provided in which pulse bursts are applied from a transmitter external to the body through electrodes affixed to the skin and detected by an implanted receiver, which filters the pulse bursts and applies pulses to a lead coupled between the receiver and selected body tissue. As used herein, the term "pulse burst" is defined as a series of radio frequency signal cycles occurring continuously for a desired time.

The implanted receiver circuit as shown in Figure 6 of United Kingdom Patent No. 1,495,391, is a dual channel receiver designed to detect and filter pulse burst signals having two different carrier frequencies. Each channel of the receiver circuit includes a rectifier for providing one polarity of the received alternating current signal to a filter, which consists of a parallel resistor-capacitor combination, having component values selected to eliminate the radio frequency carrier wave for that channel. After filtering, there remains a pulse signal having a duration equivalent to the duration of the radio frequency pulse burst. Between the filter and the lead is an output capacitor through which the pulse signal is applied, thereby causing a signal to be provided to the lead and, hence the tissue. The signal applied to the lead has a substantially instantaneous leading edge rise and an exponentially decaying trailing edge. The time constant of the exponentially decaying trailing edge is determined by the value of the output capacitor and the resistor value within the filter.

One problem with the above-described circuit is that as the repetition frequency of the pulses applied to the output capacitor increases beyond a certain value, the output capacitor cannot completely discharge through the resistor of the filter. Thus, at the time a new pulse is provided, a substantial amount of DC bias remains in the capacitor, and in order to overcome this bias and provide a proper magnitude pulse to the tissue, it is necessary that the pulse provided to the capacitor be increased in magnitude. This, in turn, requires that the pulse provided external to the implanted receiver and detected thereby be increased in magnitude.

The external transmitting device is a battery-powered transmitter which is described in the above-mentioned patent. To increase the magnitude of the pulse generated by the external device, an extra drain on the battery powering the device is required. This, in turn, results in a shorter life for the battery and the additional expense and inconvenience to the patient in changing batteries.

The present invention provides a body implantable electromedical device for connection to a lead for connecting the device to bodily tissue for electrical stimulation thereof, said device including means for detecting a signal generated externally of the body, the signal comprising a series of bursts of r.f. alternating current, means responsive to the detected signal for providing a respective pulse lasting for substantially the duration of each external pulse burst, energy storage means coupled to receive each said pulse for providing a respective output signal to said lead in response to each said pulse, and switch means coupled to said energy storage means and arranged to be switched to provide a path for discharge of said energy storage means during each interim period between the application of successive pulses to said energy storage means, such that, in use, said energy storage means is discharged through said bodily tissue.

A preferred embodiment of the subject invention is hereafter described with reference being made to the following Figures, in which:

Figure 1 is a circuit diagram of the receiver portion of an implanted dual channel stimulating device; and

Figure 2 is a series of waveforms useful in understanding the operation of the embodiment of Figure 1.

Referring now to Figure 1, a dual channel stimulating device 10 is shown which includes a transmitter portion 12 and a receiver portion 14. Receiver portion 14 is implanted beneath the skin 16 of a human or other animal and receives radio frequency energy from transmitter portion 12 which includes a transmitter circuit 18 coupled to an antenna 20.

Receiver portion 14 is implanted beneath the skin such that receiver antenna 22 is in close proximity with the inner surface of the skin 16. In this manner, transmitter antenna 20 may be placed on the opposite side of skin 16 in alignment with receiver antenna 22, whereby the radio frequency signals transmitted from antenna 20 are received by antenna 22.

Receiver antenna 22 consists of two coils 24 and 26 which may be wound in parallel with respect to each other in a common winding but electrically isolated except at the common reference junction 28. Each of the coils 24 and 26 are coupled serially with respective second coils 30 and 32. A capacitor 34 is connected in parallel with the series coils 24 and 30 and a capacitor 36 is coupled in parallel with the serially coupled coils 26 and 32. The inductance value of coils 24 and 30 and the capacitance of capacitor 34 are selected such that a tuned circuit is formed which will respond only to the carrier frequency selected for channel one. Similarly, the conductance value of coils 26 and 32 and the capacitance of capacitor 36 are selected so that a second tuned circuit is formed which will respond only to the carrier frequency for channel two.

The connection between capacitors 34 and 36 is connected to junction 28 and this point serves as a point of reference potential, or ground, for dual channel receiver 14. The remaining portion of receiver 14 is divided into two equal channels, designated as CH1 (channel one) and CH2 (channel two). For the sake of brevity, only channel one will be described in detail hereafter with primed like reference numbers being shown for like components in channel two.

The junction between capacitor 34 and coil 30 is connected to the anode of a rectifier such as diode 38 and also to the cathode of a rectifier, such as diode 40. The cathode of diode 38 is connected to one end of a parallel combination of capacitor 42 and resistor 44 which form a low-pass filter. The other ends of capacitor 42 and resistor 44 are connected to the point of reference potential. The anode of diode 40 is connected to one end of the parallel combination of capacitor 46 and resistor 48 which also form a low-pass filter and the other ends of capacitor 46 and resistor 48 are connected to the point of reference potential. In addition, the cathode of diode 38 is connected to one end of output capacitor 50, the other end of which is coupled through the lead (not shown) to the tissue to which the pulse is to be applied.

A transistor 52 is connected with its main electrodes between the junction of diode 38 and capacitor 50 and the point of reference potential. Specifically, the collector is connected to the junction of diode 38 and capacitor 50 and the emitter is connected to the point of reference potential. The base of transistor 52 is connected through a resistor 54 to the junction between capacitor 50 and diode 38 and also through a resistor 56 to the anode of diode 40.

In operation, a series of pulse burst signals are applied from transmitter 18 to antenna 20. These pulse bursts are controlled as to duration and amplitude of the carrier and, in the dual channel stimulator shown in Figure 1, may comprise two carrier frequencies each with independent width and amplitude controls.

Referring to Figure 2, waveform A represents one of the two series of pulse bursts which are applied from transmitter 18. It should be noted that these bursts are of radio frequency, alternating current signals, and can be controlled by circuitry within transmitter 18 to last for variable periods of time and to be of variable amplitudes. The radiated pulse bursts from antenna 20 are inductively coupled to antenna 22 and applied through the appropriate tuned circuit, consisting of coils 24 and 30, and capacitor 34. From the tuned circuit, the alternating current waveform is rectified by diodes 38 and 40 such that waveform B is provided at the cathode of diode 38 and waveform C is provided at the anode of diode 40. After rectification, waveforms B and C are passed through low-pass filters consisting of capacitor 42 and resistor 44 for waveform B and capacitor 46 and resistor 48 for waveform C, and, thereafter appear respectively as waveforms D and E shown in Figure 2. It should be noted that waveforms D and E are one-half of one radio frequency cycle out of phase with one another due to the operation of diodes 38 and 40. However, due to the high frequency of the radio frequency signals, this is negligible with respect to the pulse width.

At the time the pulse of waveform D is applied to output capacitor 50 and causes a jump on the lead side of capacitor 50, waveform E is at a negative value and maintains transistor 52 in a non-conductive state. After the leading edge of waveform D is applied to capacitor 50, the voltage across capacitor 50 builds up to the magnitude of the pulse of signal D.

After the conclusion of the positive pulse of signal D and the negative pulse of signal E, the voltage stored in capacitor 50 is applied through resistor 54 to render transistor 52 to the conductive state. With transistor 52 conductive, the voltage across capacitor 50 discharges through the low resistance path of conductive transistor 52 and the body tissue. This discharge can readily be accomplished between the pulses of signals D and E.

If it were not for the provision of transistor 52, diode 40, resistors 54 and 56, and the filter consisting of capacitor 46 and resistor 48 and the various connections therebetween, capacitor 50 would be forced to discharge through resistor 44 which is a part of the low-pass filter. However, since resistor 44 must be in the order of a minimum of 5,000 ohms in order to be approximately ten times the size of the tissue resistance, which is in the order of 500 ohms, to avoid loading the circuit, the time constant between capacitor 50 and resistor 44 is large, and, thus, capacitor 50 cannot substantially discharge for rates above a certain level. However, with conductive transistor 52, the time constant is very small and capacitor 50 can substantially discharge during the time between the pulses.

WHAT WE CLAIM IS:

1. A body implantable electromedical device for connection to a lead for connecting the device to bodily tissue for electrical stimulation thereof, said device including means for detecting a signal generated externally of the body, the signal comprising a series of bursts of r.f. alternating current, means responsive to the detected signal for providing a respective pulse lasting for substantially the duration of each external pulse burst, energy storage means coupled to receive each said pulse for providing a respective output signal to said lead in response to each said pulse, and switch means coupled to said energy storage means and arranged to be switched to provide a path for discharge of said energy storage means during each interim period between the application of successive pulses to said energy storage means, such that, in use, said energy storage means is discharged through said bodily tissue.

2. A device as claimed in claim 1 wherein said pulse providing means includes rectifier means and filter means, said rectifier means being responsive to said detected signal for providing a burst of pulses of a single polarity to said filter means which in response thereto provides said pulse.

3. A device as claimed in claim 2 wherein said filter means comprises a parallel coupled resistor and capacitor.

4. A device as claimed in any preceding claim including control means for controlling said switch means, said control means being responsive to said detected signal for providing a respective pulse to a control electrode of said switch, opposite in polarity to said first mentioned respective pulse for maintaining the switch open during the presence of said first mentioned respective pulse.

5. A device as claimed in claim 4 wherein said control means includes second rectifier means and second filter means, said second rectifier means being responsive to said detected signal for providing a burst of pulses of a single polarity to said second filter means which in response thereto provides a respective said second mentioned pulse for each burst.

6. A device as claimed in claim 5 wherein said second filter means comprises a parallel coupled resistor and capacitor.

7. A device as claimed in any preceding claim wherein said switch means comprises a semiconductor switching device.

8. A device as claimed in claim 7 wherein said device comprises a transistor.

9. A device as claimed in any preceding claim wherein said energy storage means comprises a capacitor.

10. A body implantable electromedical device substantially as described with reference to the accompanying drawings.

FRANK B. DAHN & CO.,
Imperial House,
15–19 Kingsway,
London WC2B 6UZ.
For the Applicants.

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2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

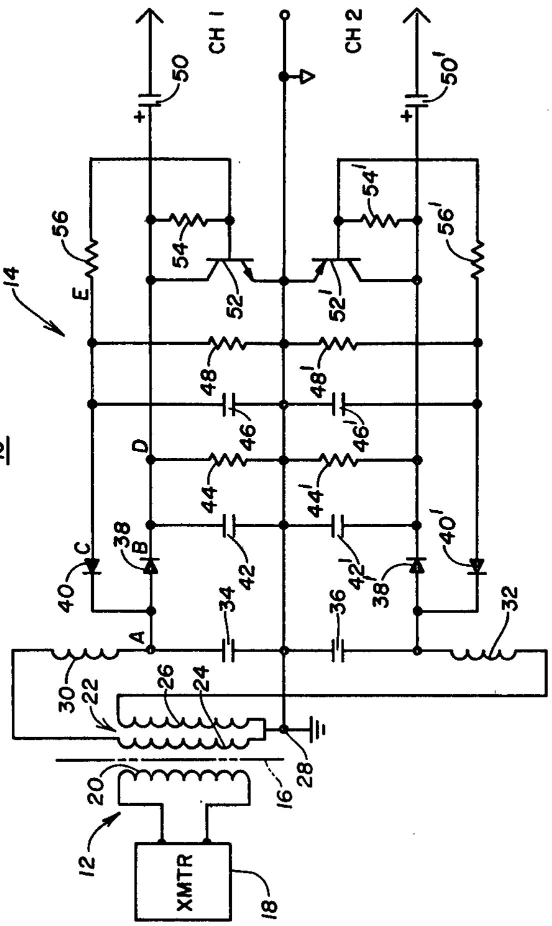

Fig.1

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1577575 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 2

Fig. 2