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Weiss

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[54] **BI-PHASIC CURRENT STIMULATION SYSTEM**

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[51] **Int. Cl.²** **A61N 1/36**

[58] **Field of Search** ..... 128/420, 421, 422, 423, 128/419 B, 419 C, 419 E, 419 G, 419 PG, 419 R

[56] **References Cited**

UNITED STATES PATENTS

3,523,539	8/1970	Lavezzo	128/422
3,563,247	2/1971	Bowers	128/419 PG
3,589,370	6/1971	McDonald	128/422
3,727,616	4/1973	Lenzkes	128/419 E
3,835,865	9/1974	Bowers	128/419 PG

FOREIGN PATENTS OR APPLICATIONS

707,011	3/1965	Canada	128/419 R

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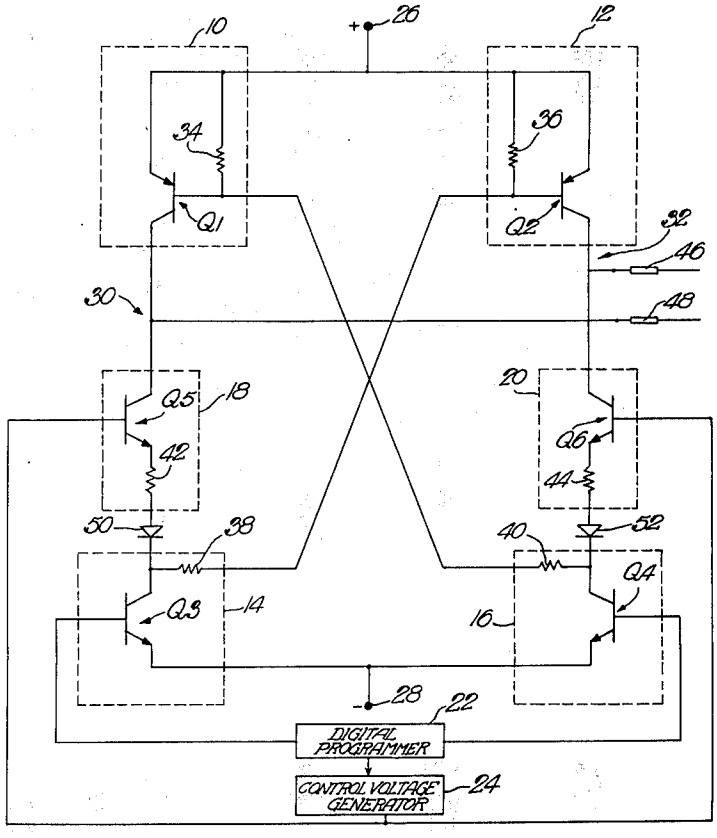
[57] **ABSTRACT**

A circuit for producing current-controlled bi-phasic pulses to stimulate living tissue includes two conducting paths connected in parallel between high and low voltage terminals, with each of the conducting paths having first and second switches connected in series therein. The intersections of the respective first and second switches in each of the paths define output terminals across which bi-phasic pulses are produced. These output terminals include electrode members for electrically attaching them to living tissues. Interconnecting circuits connect the first switch of each of the conducting paths with the second switch of the other conducting path to respectively open and close the second switches in response to the first switches of opposite paths being opened and closed. A digital programmer alternately drives one of the first switches open and the other closed. Current controlling valves are connected in the paths between the low voltage terminal and the output terminals to selectively control current flow through the electrodes.

7 Claims, 2 Drawing Figures



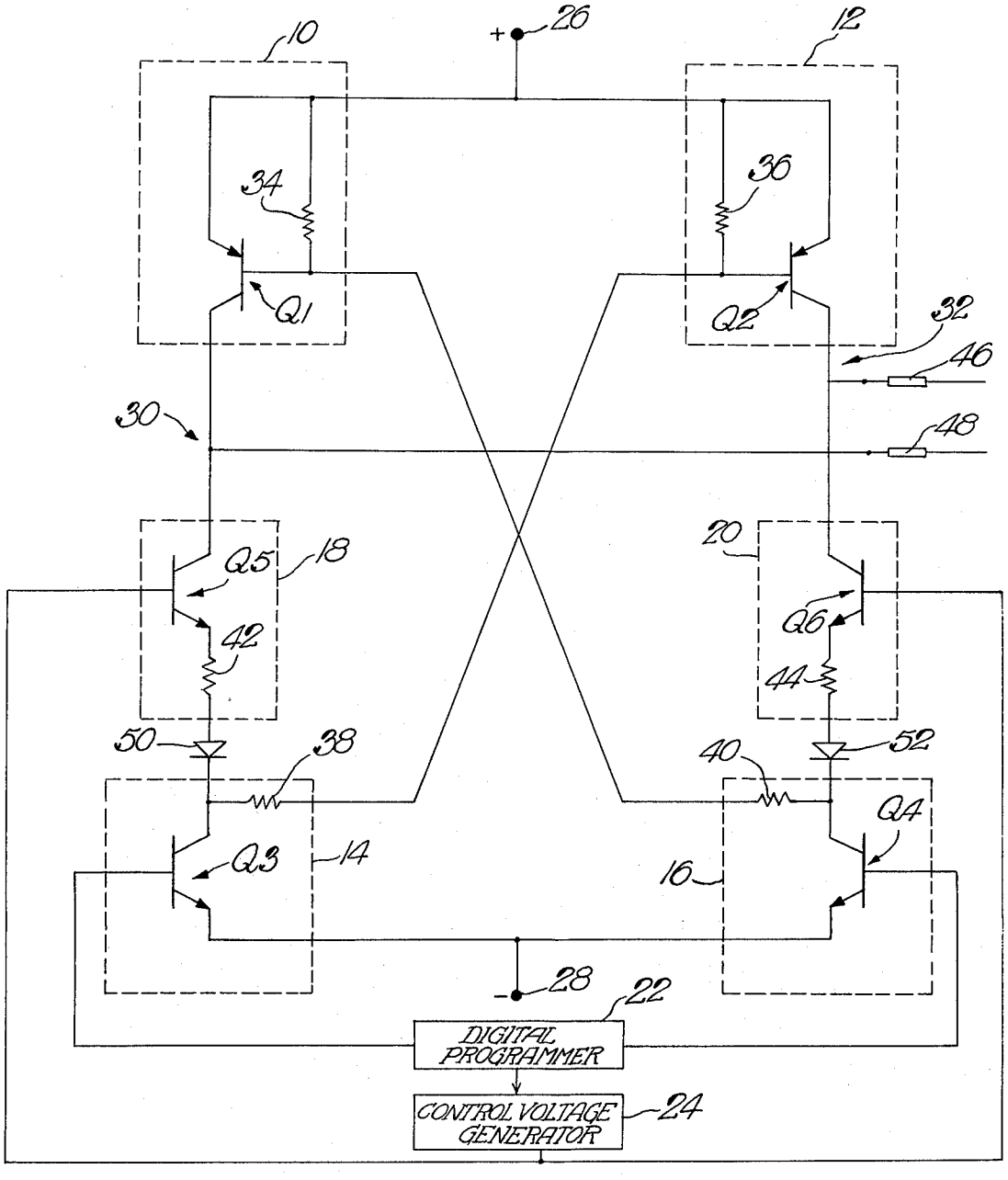

10
26
12
34
36
Q1
Q2
32
46
30
48
Q5
18
20
Q6
42
44
50
38
40
52
Q3
14
16
Q4
28
22
DIGITAL PROGRAMMER
CONTROL VOLTAGE GENERATOR
24

Fig. 1

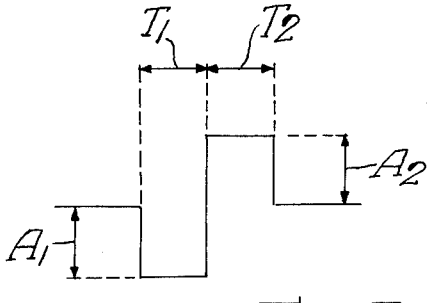

T1
T2
A2
A1

Fig. 2

BI-PHASIC CURRENT STIMULATION SYSTEM

BACKGROUND OF THE INVENTION

This invention relates broadly to the art of electronic stimulators and more particularly to devices for generating current controlled, bi-phasic pulses to stimulate areas of the brain, nerves, or other organs.

In behavioral research, stimulation of certain areas of the brain is often used to find ways to suppress intractable pain, aggressive behavior, or to explore brain structures and their influence on the behavior of animals or humans. Brain stimulation is also applied in efforts to fight other disorders associated with the brain.

In addition to brain research, electrical stimulation is also widely used to restore proper functioning of various organs such as hearts, lungs, or bladders in cases where the control of these organs is disturbed because of disease, injury, or other causes.

The effects elicited by electrical stimulations are, to a large extent, determined by the amounts of current flow rather than by the magnitudes of applied voltages. Since the impedance between points of stimulation varies widely and may even change during stimulation, the current will also change even if the voltage is maintained at a constant level. This makes it difficult to control the amount of current flow. Thus, it is an object of this invention to provide an electrical stimulation circuit which provides an adjustable, controllable, stimulating current.

Further, if pulses of one polarity only are used for stimulation, electro/chemical effects tend to create unfavorable interactions between electrodes and tissues. Many researchers, therefore, prefer stimulation pulses in both polarities, such as with a negative pulse, followed immediately by a positive pulse, preferably each being of equal magnitude and duration. Thus, it is an object of this invention to provide an electrical circuit for providing such pulses.

Another object of this invention is to provide a circuit for generating bi-phasic, current-controlled pulses with current amplitudes of both negative and positive portions thereof being proportional to an applied control voltage.

Still another object of this invention is to provide a current controlled, bi-phasic or mono-phasic pulse generator whose output impedance is high enough to allow the use of its stimulation electrodes for measuring the response to stimulation, e.g. brain stimulation, EEG recordings and the like.

Still another object of this invention is to provide a circuit for generating bi-phasic or mono-phasic current controlled pulses, the characteristics of which are controlled by a programmer.

SUMMARY OF THE INVENTION

According to principles of this invention, two parallel paths connected between two voltage terminals each have first and second series-connected switches therein with the switch intersections thereof defining output terminals across which pulse-generator output bi-phasic, current controlled, pulses are produced. The first switch of the first path is interconnected to the second switch of the second path, and vice versa, to assure that the first and second switches of opposite paths are opened and closed together. A driving device alternately drives the first switch of the first path "on" or "closed," and the first switch of the second path "off," or "open," and vice versa. The driving mechanism measures the time period that the switches are in open and closed positions. Electronic valves are located in each of the first and second paths between the first voltage terminal and the output terminals to selectively control current flow to the electrodes.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description of a preferred embodiment of the invention, as illustrated in the accompanying drawings in which reference characters refer to the same parts throughout the different views. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating principles of the invention in a clear manner.

FIG. **1** is a schematic diagram of a current controlled, bi-phasis pulse generator employing principles of this invention; and

FIG. **2** is a diagrammatic representation of an output pulse of the bi-phasic pulse generator of FIG. **1.**

DESCRIPTION OF THE PREFERRED EMBODIMENT

The preferred embodiment of the pulse generator of this invention, illustrated in FIG. **1,** comprises two first transistor switches **10** and **12,** two second transistor switches **14** and **16,** a pair of current control valve devices **18** and **20,** a digital programmer **22** and a control voltage generator **24.** The pulse generator is energized by a +20 volts, positive voltage terminal **26** and a −20 volts, negative voltage terminal **28** and forms two parallel connected, main conducting paths **30** and **32** between these voltage terminals. In practice, a single 40 volt source could be used.

The first transistor switches **10** and **12** comprise PNP transistors Q1 and Q2 and **22K** control resistors **34** and **36.** The second transistor switches **14** and **16** comprise NPN transistors Q3 and Q4 and **100K** control resistors **38** and **40.** In this regard, the interconnection between the positive voltage terminal **26** and the base of the transistor Q1 via the resistor **34** holds transistor Q1 in an off state when transistor Q4 is off and no current can flow through resistor **40.** When transistor Q4 is on, a current path is established from the positive voltage terminal **26** through both the Q1 base-to-emitter junction, and the resistor **34,** the resistor **40,** and the transistor Q4 to the negative voltage terminal **28,** thereby placing transistor Q1 in an on state. There is a similar interaction between the resistors **36** and **38** and the transistors Q2 and Q3.

The first and second current control valve devices **18** and **20** respectively comprise NPN transistors Q5 and Q6 and series resistors **42** and **44.**

In the preferred embodiment, the switching transistors Q1, Q2, Q3, and Q4 are chosen to operate, for practical purposes, in an on-off fashion while the current control transistors Q5 and Q6 are chosen to operate in a gradual manner for regulating current flow.

Electrodes **46** and **48,** which are adapted to be electrically attached to living tissue, are respectively electrically connected to the main conducting paths **30** and **32** between the transistor switch **10** and the first current control valve device **18** and between the transistor switch **12** and the second current control valve device **20.**

The digital programmer 22 is connected to the bases of the switching transistors Q3 and Q4 and selectively provides gating signals to these transistors. The digital programmer 22 also drives the control voltage generator 24 which, in turn, selectively produces steady-state control voltages at the bases of the first and second current control transistors Q5 and Q6.

Diodes 50 and 52 prevent excess reverse voltages from occurring between the bases and emitters of the current control transistors Q5 and Q6.

In operation, the electrodes 46 and 48 are connected to living tissue, such as nerves or other organs, either directly or indirectly. When it is desired to transmit bi-phasic pulses to the living tissue, the digital programmer 22 gates the switching transistor Q3 on and the switching transistor Q4 off for a time period of T1 and then gates the switching transistor Q4 on and switching transistor Q3 off for an identical time period T2.

During time period T1, when the switching transistor Q3 is on, a current flow is established through the control resistors 36 and 38 to lower the potential appearing at the base of the switching transistor Q2. This places the switching transistor Q2 in an on mode of operation. Thus, a circuit is established between the positive voltage terminal 26 and the first electrode 46 through the switching transistor Q2. A circuit is also completed between the second electrode 48 and the negative voltage terminal 28 via the current control transistor Q5, the resistor 42, and diode 50, and the switching transistor Q3. Thus, a circuit is completed from the positive voltage terminal 26 to the negative voltage terminal 28 via living tissue connected to the electrodes 46 and 48. It should be noted that during time period T, both of the switching transistors Q4 and Q1 are locked in off modes.

During the time period T2 the switching transistor Q3 is turned off so that the voltage appearing at the base of the switching transistor Q2 rises to the voltage of the positive voltage terminal 26, which, in turn, turns off the switching transistor Q2. Thus, the electrode 46 is no longer connected to the high voltage terminal 26. However, the switching transistor Q4 is turned on by the digital programmer 22 so that the voltage at the base of the switching transistor Q1 rises to turn on this transistor. Thus, the electrode 48 is now in communication with the positive voltage terminal 26. Also, the other electrode 46 is now in communication with the negative voltage terminal 28 via the second current control device 20, the diode 52 and the switching transistor Q4. Thus, the polarities, and current flow, of the electrodes 46 and 48 have been reversed.

Before and after the time periods T1 and T2, the digital programmer does not place either the third or fourth switching transistors Q3 and Q4 in on modes of operation so that neither of the electrodes 46 and 48 are connected to the positive and negative voltage terminals 26 and 28. The output signal appearing at electrodes 46 and 48 before, after, and during the time periods T1 and T2 can be graphically represented as shown in FIG. 2.

In the preferred embodiment, the control voltage generator 24 provides steady-state control voltages ranging from 1.4 to 5 volts. It should be understood that the magnitude of a selected control voltage determines the magnitudes of current signals applied by the electrodes 46 and 48 to living tissue.

It should be further appreciated that the duration of the pulses can be accurately controlled by the digital programmer 22.

In addition, during periods of no pulses, since all four transistor switches are open, the electrodes 46 and 48 can be used for recording purposes.

While the invention has been particularly shown and described with reference to a preferred embodiment, it will be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the invention. For example, various voltage magnitudes at voltage terminals 26 and 28 could be employed and it is not necessary that one of the supply voltages be either negative or positive. With regard to voltage magnitude, the high voltage source limit is determined by the perimeters of the transistors chosen and/or by the maximum current which has to be driven through the highest expected load impedance. Further, the transistors could be replaced by other types of electrical valves.

The embodiment of the invention in which an exclusive property or privilege are claimed are defined as follows:

1. A bi-phasic pulse generator for producing pulses to stimulate living tissue comprising:
   - first and second voltage terminals having voltages of different magnitudes;
   - first and second conducting paths connected in parallel between said first and second voltage terminals, each of said first and second conducting paths including first and second switches connected in series, with said first switch being connected electrically closer to said first voltage terminal than said second switch and the intersections of said first and second switches in each of said paths defining output electrodes across which pulse-generator output bi-phasic pulses are produced;
   - interconnecting means for connecting said first switch of said first conducting path with said second switch of said second conducting path and said first switch of said second conducting path with said second switch of said first conducting path to respectively close and open said second switches in response to said first switches of opposite paths being opened and closed; and,
   - a driving means for alternately driving one of said first switches open and the other closed for a first predetermined time period, and vice versa for a second predetermined time period.

2. A bi-phasic pulse generator as in claim 1 wherein is further included current-control, valve means connected in each of said paths between said first voltage terminal and said output electrodes to thereby control the flow of current through said electrodes.

3. A bi-phasic pulse generator as in claim 2, wherein said switches and control means comprise transistors.

4. A bi-phasic pulse generator as claimed in claim 1, wherein said driving means comprises a programming circuit means for alternately driving said first switches in a programmed sequence.

5. A bi-phasic pulse generator as claimed in claim 1, wherein said output electrodes include means for electrically attaching said electrodes to living tissue.

6. A bi-phasic pulse generator for producing pulses to stimulate living tissue comprising:
   - first and second voltage terminals having different voltage potentials thereon;

first and second output electrodes adapted to be attached to living tissue;

a control circuit means connected between each of said first and second voltage terminals and to each of said output electrodes for alternately connecting said first voltage terminal to said first electrode and said second voltage terminal to said second electrode and said first voltage terminal to said second electrode and said second voltage terminal to said first electrode, said control circuit means connected between said first voltage terminal and each

of said electrodes including electronic valve means for selectively controlling the magnitude of current flow between said first voltage terminal and both of said first and second electrodes; and

a control means attached to said electronic valve means for selectively adjusting the flow of current through said valve means.

7. A bi-phasic pulse generator as claimed in claim **6** wherein said electronic valve means comprise transistors.

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