DUAL CHANNEL STIMULATOR

Inventor: Terrell M. Williams, Minneapolis, Minn.

Assignee: Medtronic, Inc., Minneapolis, Minn.

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ABSTRACT

A body implantable stimulator having two output channels. Pulses from an external pulse generator are transmitted alternately on different carrier frequencies. An implantable receiver, including a frequency detector, separates the frequencies and applies each to a different output channel. The frequency detector is comprised totally of passive elements, and, in a preferred embodiment, the amplitude of the pulses applied to one channel may be externally regulated independently of the amplitude of the pulses applied to the other channel. Alternately, an amplitude range may be independently established for each channel and the amplitude of the pulses regulated proportionately within their range. Pulse width and repetition rate can also be independently controlled.

10 Claims, 3 Drawing Figures
DUAL CHANNEL STIMULATOR

BACKGROUND OF THE INVENTION

The application of electrical pulses to various portions of the body for such purposes as muscle or nerve stimulation is well known. For example, pain alleviation through nerve stimulation or motor control through nerve or muscle stimulation have been successfully demonstrated. The stimulating pulses have been applied transcutaneously by external stimulators as well as internally with implantable devices. One form which the implantable devices have taken are RF-Powered implantable stimulators, an example of which is a well-known bilateral dorsal column stimulator used for pain alleviation through nerve stimulation.

The earlier prior art pain alleviation devices were found unsuitable when the pain to be supressed was diffuse and bilateral. For example, a stimulation of the cord dorsum with a single electrode placed off mid-line several millimeters was inadequate to abolish bilateral pain in the ipsilateral side. To overcome this problem, a second electrode was added to provide stimuli at the same time and amplitude as the first electrode. The resulting bilateral stimulator requires two leads and tend to cause an undesirable cross stimulus of nerve depolarization which may occur when the biological volume conductors are excited at two different sites simultaneously. Also, since the amplitude difference between causing pain and relieving pain may be very small, an output amplitude determined by the highest threshold of the two electrode sites was found to have potential to cause pain or discomfort in the lower threshold electrode site.

Similarly, in many applications of motor control through dual muscle stimulation two simultaneous outputs of equal amplitude may be inappropriate. For example, hip stabilization may require abdution of the leg and hip extension. Each of the muscles involved in such a program will have a different threshold (the lowest stimulation providing muscle contraction) as well as a different stimulation requirement to provide super maximal contraction. It is necessary to stimulate each muscle within the range defined by the threshold level and the level at which super maximal contraction is obtained. Thus, each output must be capable of being independently regulated at least to the point of setting the stimulus range. Of course, the stimulation must also be "simultaneous" which, in this context, means that the muscle contractions must be concurrent although they may be produced by alternating or non-simultaneous stimulating pulses.

SUMMARY OF THE PRESENT INVENTION

The present invention provides an RF-powered receiver including a frequency detector capable of providing a dual channel output. The frequency detector is formed totally of passive elements and the power level of the pulses applied to each channel is regulated externally in an associated transmitter. The transmitter produces and transmits alternating pulses on different carrier frequencies and the power level of the pulses at each frequency may be regulated totally independently of each other. In a preferred embodiment, the pulse power level is regulated by controlling the pulse amplitude. In an alternative amplitude control embodiment, an amplitude range may be independently established for each frequency and the amplitude of the pulses regulated proportionately within their range. The pulse power level may also be controlled by independently regulating the pulse width and, of course, where necessary the pulse repetition rate may be independently controlled by appropriate modifications to the transmitter.

The dual channel stimulator provided by the present invention may be applied to any dual muscle or nerve application and is uniquely suited to the hip stabilization environment described above. The invention consists essentially of an antenna and first and second passive circuit means each resonating with the antenna at different frequencies, two output electrodes including channel isolation means for isolating the first and second passive circuit elements and an external transmitter which produces and transmits, at different carrier frequencies, alternating pulses whose power level is capable of being regulated at least partially independently.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a preferred embodiment of a transmitter forming a portion of the present invention.

FIG. 2 illustrates a modification of the preferred embodiment of FIG. 1.

FIG. 3 illustrates a preferred embodiment of a receiver forming a portion of the present invention.

DETAILED DESCRIPTION OF THE DRAWINGS

FIG. 1, which is a preferred embodiment of a transmitter which may be used to practice the present invention, shows a pulse generator 10 which generates pulses at twice the desired stimulation rate for reasons to be more fully explained below. The pulse generator may be of any known type which is capable of operating within the required restraints, all of which are well known in the prior art.

The output of the pulse generator 10 passes over a first line 11 to a variable resistance 12. Variable resistance 12 regulates the ultimate limit in all the resulting stimuli in a manner which will become apparent. The output of the variable resistance 12 is transmitted over a line 14 to a second variable resistance 15 and over a line 16 to a third variable resistance 17. The variable resistances 15 and 17, along with the variable resistance 12, are well known in the art and are capable, independently of each other, of regulating the power level of pulses leaving them by regulating the voltage amplitude of those pulses through variations in their resistances. Other known devices may be substituted for the resistances 15 and 17 so as to alter any characteristic or parameter of the pulses, pulse width or shape, for example. The output of variable resistance 15 is transmitted to gate 20 through a line 21 and the output from variable resistance 17 is transmitted to a second gate 22 through a line 23.

The output from the pulse generator 10 is also transmitted through a line 25 to the c input terminal of a D flip-flop 26. The flip-flop 26 has its q output terminal connected to the gate 20 by a line 28, while a second line 29 connects the flip-flop q output terminal to the gate 22. A feedback line 30 connects the q output terminal and the d input terminal of the flip-flop 26.

In the embodiment shown in FIG. 1, gates 20 and 22 may be analog switches which will "pass" the signals appearing on line 21 and 23 respectively when a control signal is present on the associated line 28 and 29.
Each of the gates 20 and 22 as well as flip-flop 26 receive every pulse generated by the pulse generator 10. Flip-flop 26 alternates high and low on its output terminals $q$ and $\bar{q}$ on every other pulse which causes the gates 20 and 22 to alternate their outputs and thus produce a pair of pulse trains in which the pulses of one alternate in time with the pulses of the other. Each pulse of the pulse train passed by the gates 20 and 22 have a pulse width identical to the output of pulses from the pulse generator 10. Also, the pulse repetition rate in the train of pulses originating at the gates 20 and 22 will be one-half that of the pulse generator 10. However, because of the independent regulation of the variable resistances 15 and 17 the amplitude of the pulses originating from one of the gates 20 and 22 may be controlled independently of the amplitude of the pulses originating at the other gates.

The train of pulses originating at gate 20 are applied over a line 31 to a 460 KHz, oscillator 32, over a line 33 to a tuned amplifier 34 and finally to an antenna 35. Similarly, the pulse train originating at gate 22 is transmitted by a line 36 to a 200 KHz, oscillator 37, over a line 38 to a tuned amplifier 39 and finally to antenna 35. The means by which the pulse trains originating at gates 20 and 22 are transmitted by antenna 35 over different carrier frequencies are well known to the art and need no further particularization.

Referring now to FIG. 2, there is shown a modification of the preferred embodiment of FIG. 1. With the modification of FIG. 2, the variable resistances 12, 15 and 17 may be eliminated and the pulses from the pulse generator 10 may be applied directly from line 11 to lines 21 and 23. Also, the gates 20 and 22 may be analog switches as described with reference to FIG. 1 or, alternatively, the gates 20 and 22 may be logic gates, an AND gate, for example. The modification of FIG. 2 is intended to be inserted principally between the oscillators 32 and 37 and the tuned amplifiers 34 and 39 by breaking the lines 33 and 38. Into line 33, a minimum/maximum regulator 40 is inserted. Regulator 40 consists of a first variable resistance 70, connected between line 33 and ground, and a second variable resistance 71 connected between the output of the variable resistance 70 and ground. Similarly a second minimum/maximum regulator 43 is inserted in line 38. Regulator 43 consists of a first variable resistance 72, connected between line 38 and ground, and a second variable resistance 73 connected between the output of the first variable resistance 72 and ground. Variable resistances 70 and 72 are minimum regulators and their outputs are transmitted to an analog switch 42 via lines 74 and 75, respectively. Variable resistances 71 and 73 are minimum regulators and their outputs are transmitted to an analog switch 44 via lines 76 and 77, respectively. The outputs of analog switches 42 and 44 are applied across a variable resistance 46 whose output is transmitted to a third analog switch 47. The output of analog switch 47 is applied to the lines 33 and 38. The signal appearing on line 29 is transmitted to analog switches 42 and 44 via lines 48 and 49 and to analog switch 47 by a line 45.

The minimum/maximum regulators 40 and 43 are of the type which may be operated upon to establish a minimum output on the lines 76 and 77 equal to the threshold of the nerve or muscle which is desired to be stimulated and a maximum on lines 74 and 75 equal to some predetermined maximum value of stimulation.

For motor control applications, the maximum value of the minimum/maximum regulators 40 and 43 could be the stimulation level capable of producing a super maximal muscle contraction. There are many minimum/maximum regulators known to the art, any one of which may be employed as an alternative to the embodiment of FIG. 2.

The analog switches 42 and 44 are of the type which will normally pass the signals appearing on lines 74 and 76. A signal appearing on lines 48 and 49 will cause analog switches 42 and 44 to block the signal on lines 74 and 76 and pass the signal appearing on lines 75 and 77. Thus, when the $q$ terminal of flip-flop 26 is high, the signal appearing across the variable resistance 46 will be that originating at the oscillator 32 as modified by the minimum/maximum regulator 40 while, when the $\bar{q}$ terminal of flip-flop 26 is high the signal being applied across variable resistance 46 will be the signal originating from the oscillator 37 as modified by the minimum/maximum regulator 43.

The signals applied across the variable resistance 46 are the maximum and minimum values determined by the regulators 40 and 43. For example, the maximum signal from variable resistance 70 will be applied to one side of the variable resistance 46 at the same time that the minimum signal from variable resistance 71 is applied to the other. In this way, a range is established and any value within the range may be selected by manually manipulating the variable resistance 46. Of course, the range established by the regulators 40 and 43 are independent of each other. The signal operated upon by variable resistance 46 is applied to the analog switch 47 which will apply its input to the line 33 in the absence of a signal on line 45. Thus, a signal originating at line 33 will be reapplied to the line 33 and to the tuned amplifier 34. Similarly, a signal from the oscillator 37 appearing on line 38 will be reapplied to the line 38 and the tuned amplifier 39 through the action of the concurrent signal appearing on line 45 from the $\bar{q}$ terminal of flip-flop 26 which causes the analog switch 47 to apply its input to the line 38.

From the above, it can be seen that the preferred embodiment of FIG. 1 will provide two transmitted pulse train signals on differing carrier frequencies with the amplitude of the pulses of each pulse train being capable of regulation independently of the other. With the modification of FIG. 2, a minimum and maximum level for the amplitude of pulses in each pulse train is established independently of each other while the amplitude level is then proportionately controlled for each pulse train. That is, through the action of the variable resistance 46 the amplitude level of the pulses of each pulse train will be substantially equal percentage of their amplitude range as established by the minimum/maximum regulators 40 and 43. In either case, some independence of amplitude control is obtained as may be necessary for the intended application. Of course, some other pulse parameter may be operated upon, pulse width or shape, for example, to obtain the desired independent control of pulse power level. Pulse width may be controlled by employing the signals which appear on lines 31 and 36 to trigger separate one-shots each having a variable pulse duration. Such one-shots are known to the art. Pulse shape may be controlled through appropriate filtering techniques.

Referring to FIG. 3, there is shown a preferred embodiment of the receiver portion of the present inven-
tion, including a frequency detector. An antenna 50 is shown serially connected with a capacitor 51 and an inductor 52. These passive circuit elements comprise a reactive voltage divider and they are selected to resonate with the antenna 50 at one of the carrier frequencies, 460 KH, for example. A second inductance 54 and capacitance 55 are similarly serially connected with the antenna 50 for resonating with the Antenna 50 at a second carrier frequency, 200 KH, for example. The inductance 54 and capacitance 55 form a reactive voltage divider in a manner similar to that of the capacitance 51 and inductance 52. For the stated carrier frequencies, it has been found that operative values of the components which form the frequency detector are as follows: 50, 20 μh; 51, 1,800 pf; 52, 47 μh; 54, 47 μh; 55, 8,200 pf.

A first output channel is formed by an active output electrode 56 connected to the point 80 between the inductance 54 and capacitance 55 by an output capacitor 57 and diodes 58 and 59. A second output channel is formed by an active output electrode 56 connected to the point 69 between the capacitance 51 and inductance 52 by an output capacitor 61 and diodes 62 and 63. A capacitor 64 is connected to a point between the diodes 58 and 59 and ground and a resistance 65 is connected to a point between the output capacitor 57 and the diode 58 and ground. Similarly, a capacitor 66 is connected to a point between a diode 62 and 63 and ground and a resistance 67 is connected to a point between the output capacitor 61 and the diode 62 and ground. An inactive or common electrode 68 is provided in a known manner.

In operation, and assuming component values as stated above and that the transmitter is transmitting a pulse on the 460 KH, carrier frequency, the capacitance 51 and inductance 52 will resonate with the antenna 50 and produce a voltage at a point 69. This voltage will be sufficient to breakdown the diodes 62 and 63 and will thereby produce an output pulse at the active electrode 60. The capacitor 66 acts as a filter for the signal applied to the active electrode 60 and the output capacitor 61 and resistance 67 insures biphasic stimulation. The action of the capacitor 61 and 66, the resistance 67 and rectification function of diode 63 are all known to the art. Also, the operation of the output capacitance 57, resistance 65, diode 59 and capacitance 64 in the first output channel are identical to the corresponding elements 61, 63 and 66 described above with reference to the second output channel.

With reference to the inductance 54 and capacitance 55, and still assuming the same component values and a transmission at 460 KH, there will be a voltage generated at point 80. However, by proper selection of the components 54 and 55 and taking into account their operation as a reactive voltage divider, the voltage at point 70 with a transmission of 460 KH, will be insufficient to breakdown the diodes 58 and 59 and, no output signal will appear at output electrode 56. Similarly, with the capacitor 55 and inductance 54 resonating with the antenna 50 at 200 KH, the voltage generated at point 69 will be lower than that necessary to breakdown the diodes 62 and 63 and no output signal will appear at output electrode 60. It should be noted that by reversing the position of the inductance 52 and capacitor 51 a much larger voltage will appear at point 69 with a 200 KH, transmission, which voltage may be sufficient to breakdown the diodes 62 and 63. Therefore, the selection of the components 51, 52, 54 and 55 is important not only for the purpose of resonating with the antenna 50 at the appropriate frequency, but also, their operation in their respective branches as reactive voltage dividers plays a significant part in the operation of the receiver of FIG. 3. Further, from the above description it can be seen that the diodes 58, 59, 62 and 63 function as channel isolators while the diodes 58 and 62 have the additional function of preventing a current flow through the filter of the other channel.

The receiver shown in FIG. 3 is capable of receiving and separating simultaneous transmissions at the two carrier frequencies. Thus, each of the output electrodes 56 and 60 may have a simultaneous output. This characteristic makes it possible to employ a transmitter in which the repetition rate of the pulses transmitted on each channel may be independently established even though that may result in simultaneous transmissions. An obvious modification to the transmitter of FIG. 1 by which independent pulse repetition rates may be established is through the use of separate pulse generators for each channel. They may allow for variable repetition rates, as desired, by techniques known to the art. Of course, even in a two pulse generator form, a single antenna 35 may be employed.

From the above, it is apparent that applicant has provided a stimulator for electrically stimulating portions of the body, including a transmitter and receiver, the receiver including a frequency detector composed entirely of passive elements. Obviously, many modifications and variations of the present invention other than those specifically set forth with reference to FIG. 2 are possible in light of the above teaching. It is therefore to be understood that, within the scope of the appended claims, the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. A body implantable receiver which comprises: antenna means; first and second passive frequency detector means connected in parallel with each other and said antenna means for resonating with said antenna means at a first and a second frequency, respectively; dual channel output means including active output electrode means in each channel, and means interconnecting said passive frequency detector means and said dual channel output means for isolating each output means channel from signals produced by resonance at a different one of said first and second frequencies.

2. The body implantable receiver of claim 1 wherein said first and second passive frequency detector means each comprise reactive voltage divider means.

3. The body implantable receiver of claim 2 wherein said channel isolating means comprises: first diode means interconnecting said first frequency detector means voltage divider means and one of said output channels; and second diode means interconnecting said second frequency detector means voltage divider means and the other of said output channels.

4. A stimulator for electrically stimulating portions of the body which comprises: means for transmitting signals at a first and a second frequency; antenna means for receiving said transmitted signals;
first and second passive frequency detector means connected in parallel with each other and said antenna means for resonating with said antenna means at said first and second frequency, respectively;
dual channel output means including active output electrode means in each channel; and means interconnecting said passive frequency detector means and said dual channel output means for isolating each output means channel from signals produced by resonance at a different one of said first and second frequencies.
5. The stimulator of claim 4 wherein said first and second passive frequency detector means each comprise reactive voltage divider means.
6. The stimulator of claim 5 wherein said channel isolating means comprises:
   first diode means interconnecting said first frequency detector means voltage divider means and one of said output channels; and second diode means interconnecting said second frequency detector means voltage divider means and the other of said output channels.
7. The stimulator of claim 6 wherein said transmitting means comprises means for regulating the parameters of the signals at said first and second frequency.
8. The stimulator of claim 7 wherein said signals are pulses and the regulated parameter is pulse amplitude.
9. The stimulator of claim 8 wherein said regulating means comprises means for independently setting an amplitude range for the pulses at each frequency and means for controlling the amplitude of said pulses within said ranges.
10. The stimulator of claim 8 wherein said regulating means comprises means for independently controlling the amplitude of the pulses at each frequency.

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