

July 12, 1955

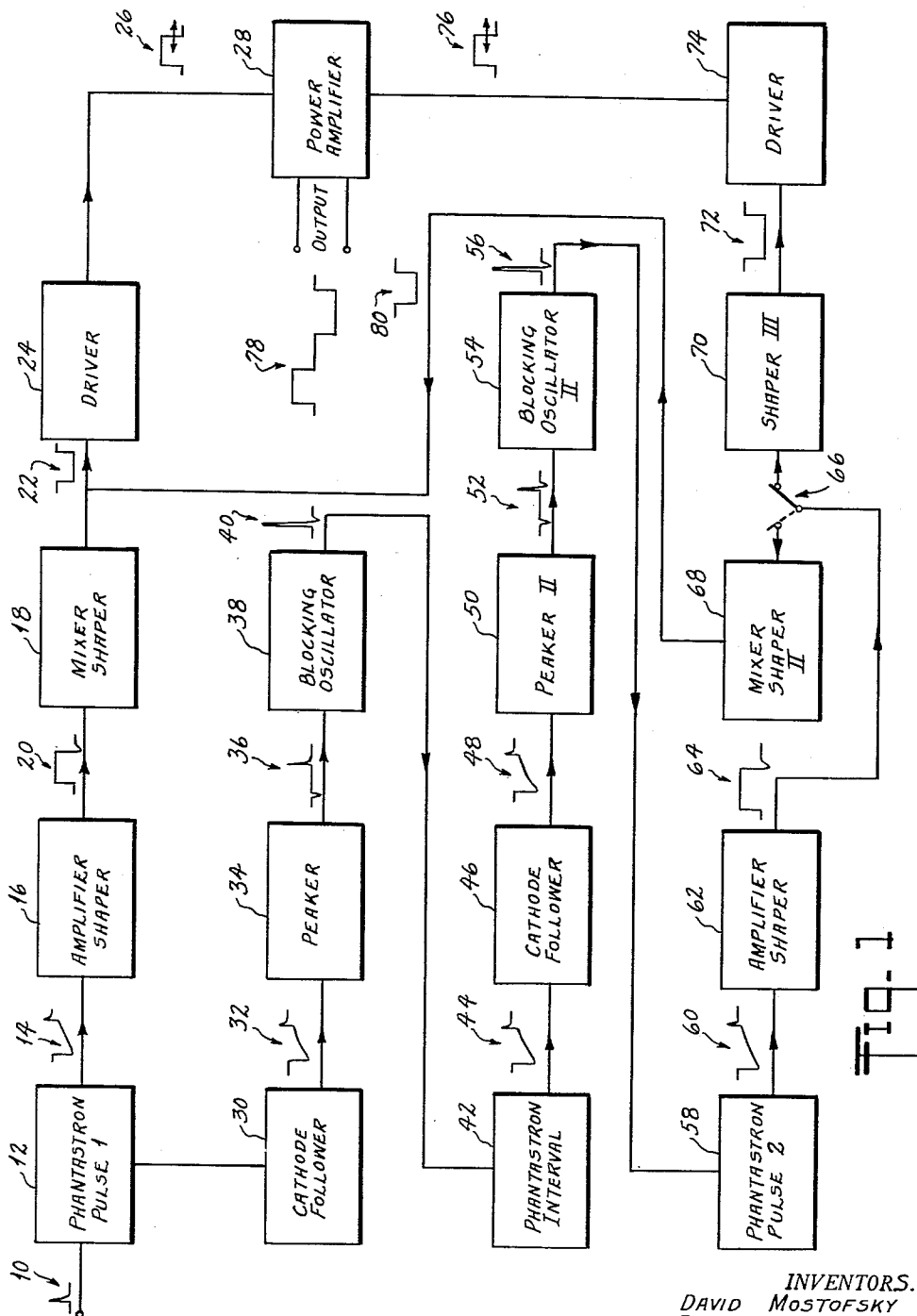
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2,713,120

ELECTRONIC STIMULATOR

Filed Oct. 22, 1952

3 Sheets-Sheet 1



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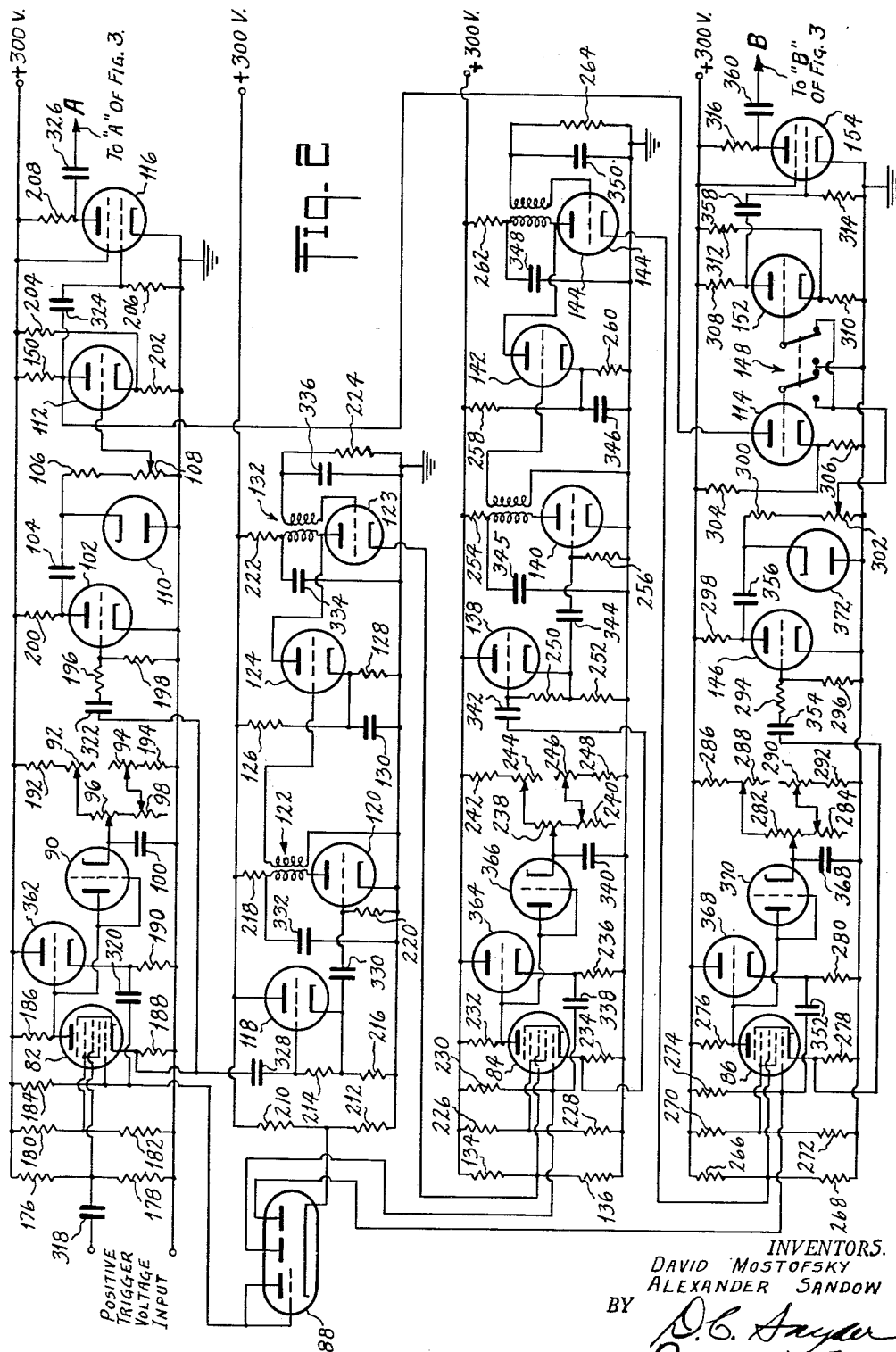
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3 Sheets-Sheet 2



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3 Sheets-Sheet 3

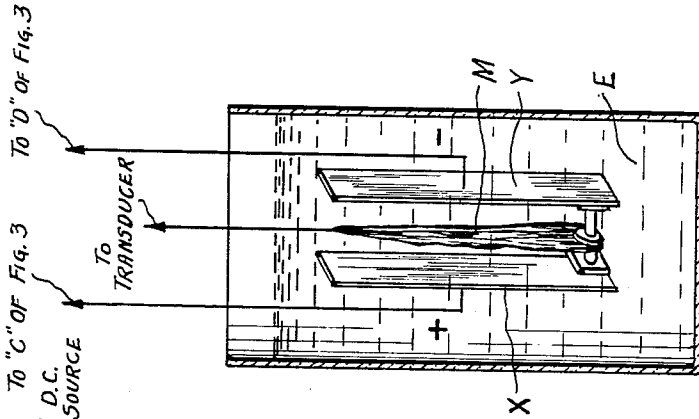


FIG. 4

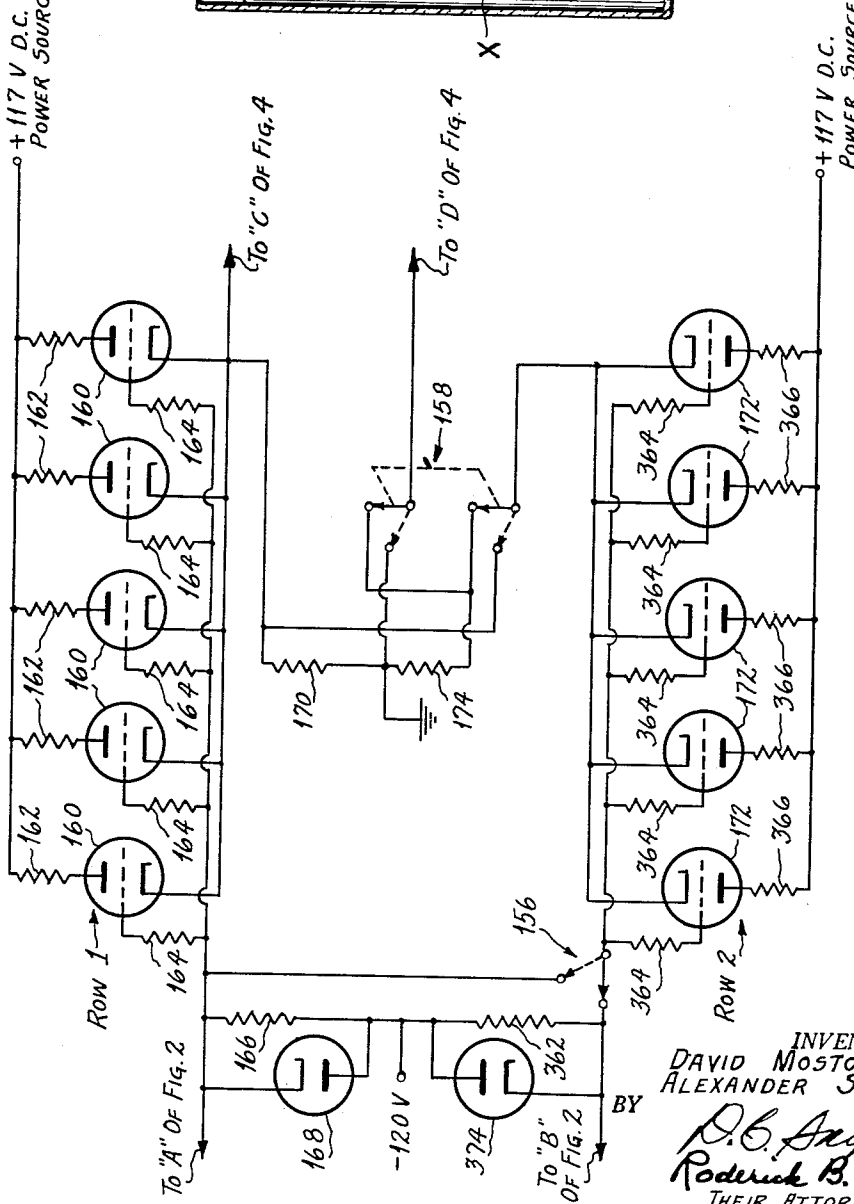


FIG. 3

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2,713,120

ELECTRONIC STIMULATOR

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Application October 22, 1952, Serial No. 316,292

10 Claims. (Cl. 250—27)

This invention relates to electronic stimulators and is directed particularly to a high current output, dual pulse, electronic stimulator for physiologic purposes.

Physiologic stimulators heretofore used were generally electronic devices which produced variously shaped voltage pulses for application directly through wires to living structures such as nerve or muscle. A voltage output was suitable in such cases, for the living tissue involved opposed the flow of current with a high impedance (of the order of 1000 ohms or more), and the electric power required, therefore, was insignificantly small.

A new stimulation technique has recently been developed in which a physiologic structure, a muscle, for example, is immersed in an electrolytic bath containing two large so called "massive" silver-silver chloride electrodes symmetrically flanking the muscle. An electric stimulating pulse must pass from electrode to electrode through the intervening electrolytic solution and on its way stimulate the muscle supported in the electrolyte. The actual impedance of such a massive electrode system is in the order of 9 ohms. To cover the varied needs of the physiologic experiments, currents ranging from a fraction of an ampere to as high as 5 amperes are required to activate the contractile response of the muscle. It is manifest that under such conditions of stimulation, high impedance output voltage generators heretofore employed in direct connection with the muscle have inappropriate characteristics.

Accordingly, it is one object of this invention to provide an electric stimulator that can produce high-current pulses across an uncommonly low impedance.

It is another object to provide a stimulator of the character described that can produce a unit-cycle consisting of two rectangular pulses each of which is independently variable, in duration from 30 to 25,000 microseconds, and in amplitude.

It is another object to provide a stimulator of the above nature wherein the individual pulses comprising the unit-cycle can be set, selectively, to be of either the same or opposite relative polarity.

It is another object to provide a stimulator of the character described wherein the interval separating the individual pulses of the unit-cycle is independently variable in duration from zero to 25,000 microseconds.

It is a further object of the invention to provide such a stimulator wherein the timing variables are smoothly and continuously adjustable.

It is a further object of the invention to provide such a stimulator wherein the unit-cycle can be obtained on demand either once, or repetitively at rates from one every ten seconds to 600 per second for an indefinite or limited time interval.

Other objects and many of the attendant advantages of this invention will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the following drawings wherein:

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Fig. 1 is a block diagram of the improved stimulator illustrating pulse wave shapes from circuit to circuit.

Fig. 2 is an electrical schematic diagram of the pulse generator and synchronizer circuits of the improved stimulator.

Fig. 3 is an electrical schematic diagram of the power amplifier circuit of the improved stimulator; and

Fig. 4 illustrates the massive electrode arrangement for stimulation of a muscle experimented upon in accordance with the invention.

The overall operation of the stimulator as illustrated in Fig. 1 will first be given. The first pulse of a unit-cycle is initiated by a positive trigger pulse 10 of about 30 volts supplied by a separate trigger generator, (not shown). The trigger generator can be, for example, a variable frequency thyatron-controlled relaxation oscillator. Such pulse generators are well-known in the art and therefore not further described herein. The input pulse 10 triggers the first phantastron 12, the time interval of which determines the time of the first pulse.

The output wave-form of the phantastron circuit 12 is trapezoidal, as indicated by the numeral 14. Therefore two shaping circuits 16 and 18 follow, the first providing an output wave-shape as indicated by the numeral 20, and the second the required substantially rectangular wave-shape 22. The second shaper 18 also functions as a mixer when it is desired that the two unit-pulses be of the same polarity, (as hereinbelow more fully described); the second pulse being introduced in its output circuit. The shaper-mixer stage 18 is followed by a driver stage 24, which produces a large rectangular pulse 26 of about 230 volts for input to a power amplifier stage 28.

The output of the first phantastron 12 is also fed through a cathode follower 30, the output wave-form of which is indicated by the numeral 32, to a differentiating circuit or peaker 34. The output wave-form of the peaker, indicated by the numeral 36, comprises a positive spike corresponding to the trailing edge of the first phantastron pulse 14, and is used to trigger a blocking oscillator circuit 38 to provide a narrow pulse 40 of the order of 1 microsecond in duration. This pulse, in turn, is fed into an interval phantastron 42, which determines the interval between the individual pulses of the unit-cycle.

The output 44 of the interval phantastron 42 is fed through a cathode follower 46, the output 48 of which is fed into a second differentiating circuit peaker 50. The output 52 of the peaker 50 comprises a sharp positive voltage pulse that is used to trigger a second blocking oscillator 54. A sharp trigger voltage 56 is obtained from the second blocking oscillator. This marks the trailing edge of the output wave-form 44 of the interval phantastron and initiates the action of a third phantastron 58, thereby determining the beginning of the second output pulse of the unit-cycle. Therefore, the interval between the trailing edge of the first pulse and the beginning of the second pulse is determined by the time of the interval phantastron 42.

The output 60 of the third or "pulse 2" phantastron 58 is trapezoidal, like that of the first or "pulse 1" phantastron 12, and is followed by an amplifier-shaper 62 to obtain a rectangular pulse 64, which is fed selectively through a single-pole double-throw switch 66 either to a mixer-shaper 68 or a shaper 70, depending upon whether it is desired to have the individual pulses of the unit-cycle of the same or opposite polarity. Thus, if the switch 66 is thrown to the right, as shown in the drawing, the pulse 64 from the amplifier-shaper 62 is fed through the shaper 70, the output of which is a negative rectangular pulse 72, into a driver stage 74, the output 76 of which is a positive rectangular pulse 46, thence directly into the power amplifier 28, whereby an output unit-cycle 78 having individual pulses of oppo-

site relative polarity is produced, as hereinbelow more fully described. If the switch 66 is thrown to the left, as indicated by the dotted-line position, the pulse 64 is fed through the mixer-shaper 68, the output of which is a negative rectangular pulse 80, into the driver 24 together with the pulse 22 and in timed relation with respect thereto, thence into the power amplifier 28 to produce a unit-cycle the individual pulses of which are of the same polarity.

Pulse generator and synchronizer circuit description

The basic timing and pulse-forming action of the stimulator is performed by the identical phantastron circuits comprising the pentodes 82, 84 and 86 for the "pulse 1" phantastron, the interval phantastron, and the "pulse 2" phantastron, respectively (see Fig. 2). Since the action of phantastron circuits has been fully described in the literature (see, for example, the article: Design of Phantastron Time Delay Circuits, published in the April 1948 issue of "Electronics," page 100) it is deemed sufficient to say here that the output of such a circuit is a negative trapezoidal pulse, smoothly variable over a wide range and with a fall and rise time that is quite rapid. Individual diodes comprising the vacuum tube 88 are included in the grid circuits of each of the phantastron circuits to permit operation at rates up to 600 or more unit-cycles per second with the relatively wider pulses and intervals. These diodes permit a more rapid recovery of the grid voltage after the pulse.

The timing of the phantastron pulses is determined by the voltage applied to the pentode plates, and, except for extremely narrow time intervals, there is a linear relationship between this voltage and the pulse width. Thus, in the "pulse 1" phantastron circuit, the control voltage is applied to the plate of the pentode 82 through a diode 90 which isolates the plate from the control voltage during the phantastron cycle when the plate voltage is lowered. The two 5000 ohm potentiometers 92, 94 in the phantastron circuit are adjustments that determine the maximum and minimum voltage obtained from the 20,000 ohm potentiometer 96, which is the phantastron pulse width control. The 500 ohm potentiometer 98 is a fine control. The condenser 100, connected from the cathode of the diode 90 to ground, makes the adjustment of the potentiometers "smooth," and permits the location of the potentiometers to be remote from the phantastron circuit.

The output of the "pulse 1" phantastron is taken from the cathode of the pentode 82. This trapezoidal voltage pulse (see pulse 14 of Fig. 1), goes to the grid of a triode 102 where grid clipping action flattens the pulse. On the plate of this tube the pulse is a positive rectangular voltage with a negative overshoot (see pulse 20 of Fig. 1). This pulse is coupled to the next stage through a large time constant network comprising the condenser 104, the resistor 106 and potentiometer 108. The diode 110 connecting the grid side of the condenser 104 to ground is a "clumper" or "D. C. restorer" which keeps the D. C. level on the grid of the succeeding stage fixed, despite wide changes in pulse rate, pulse width, and setting of the potentiometer 108 connected to the grid of the triode 112 comprising the following stage. The potentiometer 108 determines the amplitude of the output pulses. The triode 112 is biased to cut-off so that only the positive part of the pulse is amplified. The negative overshoot portion, therefore, is not obtained in the plate circuit of this tube. It will be noted that the plate of the triode 112 is connected to the plate of the triode 114, but since these tubes are each biased to "cut-off" they do not load each other. It can be seen, however, that a pulse introduced on the grid of the triode 114 will appear at the plate of the triode 112.

From the plate of the triode 112, the rectangular

pulse, which is now negative (see pulse 22, Fig. 1) is applied to the grid of a vacuum tube 116, which is the driver stage for the power amplifier, to be described hereinbelow. It should be noted that the grid of the driver tube 116 supplies its own restorer action, since its cathode is directly connected to ground and the pulses are negative at the grid.

The pulse interval is the time from the trailing edge of the first pulse to the beginning of the second pulse. This interval is determined by the duration of the interval phantastron circuit comprising the pentode 84. This phantastron is triggered by a spike that corresponds to the trailing edge of the first phantastron output pulse (see pulse 40 of Fig. 1).

The pulse on the cathode of the first phantastron pentode 82 not only is connected to the shaping circuits, as hereinabove described, but also goes to a trigger-forming circuit by way of a cathode follower circuit comprising the triode 118, which isolates the first phantastron circuit from the circuits that follow. The action of the triode 120 following the cathode follower stage is to differentiate the trapezoidal pulse. Thus, on the secondary of the pulse transformer 122 in the plate circuit of the triode 120 a narrow positive spike is obtained (see pulse 36 of Fig. 1), corresponding to the trailing edge of the output pulse of the first phantastron. This spike voltage triggers a blocking oscillator comprising a triode 123 after going through an isolation stage comprising the triode 124. The triode 124 is normally cut off by virtue of the bias network in its cathode consisting of the resistors 126, 128 and the condenser 130, and therefore conducts only during the positive spike that is derived from the trailing edge of the output pulse of the first phantastron. The flow of current through the triode 124 passes through a blocking oscillator transformer 132 whence, by transformer action, this current is applied regeneratively to the grid of the triode 123 to initiate the blocking oscillator action. The blocking oscillator triode 123 is biased to cut-off by the network comprising voltage divider resistors 134 and 136 which supplies voltage to the second grid of the interval phantastron pentode 84. The sharp positive pulse (see pulse 40 of Fig. 1), from the cathode of the blocking oscillator triode 123 is directly coupled to the interval phantastron pentode 84, which it triggers. The time from the beginning to the end of the interval phantastron pulse (see pulse 44 of Fig. 1), determines the time interval between the two output pulses of the stimulator.

The output of the interval phantastron comprising the pentode 84 is differentiated and a blocking oscillator pulse corresponding to the trailing edge is obtained in the same manner as described above. Thus, the circuits associated with the tubes 138, 140, 142, and 144 are the same as those of tubes 118, 120, 124 and 123, respectively. The output voltage spike of the blocking oscillator comprising the triode 144 triggers the "pulse 2" phantastron pentode 86, the output pulse of which after shaping, determines the second rectangular output pulse.

The output of the "pulse 2" phantastron is "shaped" in the amplifier-shaper comprising the triode 146 and then is utilized in one of two ways, selectively. If a unit-cycle of two rectangular output pulses of the same polarity is required, the pulse from the triode 146 is switched, by means of the double-pole double-throw switch 148, to the grid of the triode 114 from which, by way of the plate register 150 common to the triode 112, it is applied to the driver comprising the triode 116. When pulses in the unit-cycle of opposite polarity are desired, the pulse from the triode 146 is switched to a shaper circuit comprising the triode 152, from the plate of which it goes to the grid of a second driver comprising the tube 154. The reason for this switching will be apparent in the following description of the power amplifier stage. Thus, either two pulses are obtained at the driver tube 116, or one each at tubes 116 and 154.

Power amplifier circuit description

Fig. 3 is a schematic drawing of the power amplifier circuit. The amplifier derives its plate power directly from a 117 volt D. C. service line. It comprises a plurality of triodes connected in parallel and, either in single-ended or push-pull arrangement, depending upon whether output pulses of the same or opposite polarity are desired. The single-pole double-throw switch 156 and the double-pole double-throw switch 158 control the operation of the amplifier. Thus, when the switches are at their solid-line position as shown in Fig. 3, the operation of the amplifier is such as to provide a unit-cycle having individual pulses of opposite polarity.

The circuit comprises a row (row 1), of triodes 160 having individual plate resistors 162 and grid isolating resistors 164. The triodes 160 are heavily biased beyond cut-off by connection of the isolating resistors 164 to a source of negative voltage supply of about 120 volts through a common bias resistor 166. A diode 168 across the bias resistor 166 clamps the bias at this fixed value. Thus, no current flows through the tubes except when a pulse is received from the pulse generator and synchronizer circuit (Fig. 2). The circuit is arranged as a cathode follower, the output load being connected across the common cathode resistor 170 connected between the cathodes of the triode 162 and ground. The parallel triodes 160 of row 1 serve to amplify the positive output pulse of the unit-cycle. A similar circuit comprising a plurality of triodes 172 (row 2) is connected to receive the second pulse from the pulse generator and synchronizer circuit and deliver across a common cathode resistor 174 the second or negative output pulse of the unit-cycle. The cathode resistors 170 and 174 are of about 200 ohms each so that there is no appreciable loading of the massive electrode device.

Though the rows 1 and 2 as illustrated comprise five triodes each, it is to be understood that more could be added to each row to increase the output power of the amplifier.

When the switches 156 and 158 are at the dotted-line position as shown in Fig. 3, the operation of the amplifier is such as to provide a unit-cycle having individual pulses of positive polarity. In this case it will readily be seen that the triodes 172 of row 2 are switched to operate in parallel with the triodes 160 through the common cathode load resistor 170; the low impedance output terminal being connected to ground.

Operation

Fig. 4 illustrates the method of stimulating a muscle in accordance with the invention. The muscle M immersed in an electrolyte E is clamped in position at its lower end, and its upper end is mechanically connected to a recording transducer (not shown), which can be a piezoelectric device, for example. Actuation of the transducer by the contractile response of the muscle to stimulation produces a proportional output voltage that is recorded by suitable electrical recording apparatus. The massive plates or electrodes X and Y are connected to the output of the electric stimulator.

If pulses in the unit-cycle of opposite polarity are desired, the switches in Figs. 2 and 3 are set to their full-line positions. If pulses of the same polarity are desired, the switches will be set at their dotted-line positions. Pulse and interval widths are controlled by adjustment of the respective potentiometers in the "pulse 1" phantastron circuit comprising the pentode 82, the interval phantastron comprising the pentode 84, and the "pulse 2" phantastron comprising the phantastron 86. The amplitudes of the first and second pulses are independently controlled by adjustment of the potentiometers 108 and 302 in the plate circuits of triodes 102 and 146, respectively.

In order that the invention can be practiced with the least amount of routine circuit design, the following list

of circuit element values found to be satisfactory in a practical embodiment of the invention is given:

POTENTIOMETERS

		Ohms
5	92	5,000
	94	5,000
	96	20,000
	98	500
	108	50,000
10	238	20,000
	240	500
	244	5,000
	246	5,000
	282	20,000
15	284	500
	288	5,000
	292	5,000
	302	50,000

RESISTORS

20	106	500,000
	134	50,000
	136	5,000
	150	50,000
25	162	50
	164	10,000
	166	1,000
	170	200
	174	200
30	176	50,000
	178	5,000
	180	15,000
	182	5,600
	184	1,000
35	186	5,000
	188	10,000
	190	25,000
	192	12,000
	194	3,000
40	196	33,000
	198	500,000
	200	40,000
	202	2,700
	204	150,000
45	206	1,200
	208	15,000
	210	47,000
	212	8,200
	214	500,000
	216	60,000
50	218	50,000
	220	500,000
	222	27,000
	224	27,000
	226	15,000
55	228	5,600
	230	1,100
	232	5,000
	234	10,000
	236	25,000
60	242	12,000
	248	3,000
	250	500,000
	252	60,000
	254	50,000
65	256	500,000
	258	270,000
	260	10,000
	262	27,000
70	264	270,000
	266	50,000
	268	5,000
	270	15,000
	272	5,600
75	274	1,100

	Ohms
276	5,000
278	10,000
280	25,000
286	12,000
292	3,000
294	33,000
296	500,000
298	40,000
300	500,000
304	150,000
306	2,700
308	50,000
310	2,700
312	150,000
314	1,200
316	15,000

CONDENSERS

	microfarads
100	16
104	4
130	50
318	200
320	0.09
322	1
324	4
326	2
328	0.2
330	0.5
332	16
334	0.05
336	500
338	0.09
340	16
342	0.2
344	0.5
345	16
346	50
348	0.05
350	500
352	0.09
354	1
356	4
358	4
360	2
368	16

VACUUM TUBES

82	6SA7
84	6SA7
86	6SA7
88	6AT6
90	6SN7(1/2)
102	6SL7(1/2)
110	6H6(1/2)
112	6S77(1/2)
114	6SL7(1/2)
116	6V6
118	6SN7(1/2)
120	6SN7(1/2)
123	6SN7(1/2)
124	6SN7(1/2)
138	6SN7(1/2)
140	6SN7(1/2)
142	6SN7(1/2)
144	6SN7(1/2)
146	6SL7(1/2)
152	6SL7(1/2)
154	6V6
160	6AS7
168	6H6(1/2)
172	6AS7
362	6SN7(1/2)
364	6SN7(1/2)
366	6SN7(1/2)
368	6SN7(1/2)

	Ohms
370	6SN7(1/2)
372	6H6(1/2)
374	6H6(1/2)

Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention can be practiced otherwise than as specifically described.

What is claimed is:

1. A generator for producing pulses in a unit-cycle consisting of first and second pulses separated by a time interval comprising a source of trigger voltage impulses, means, actuated by an impulse from said source of trigger voltage impulses, for producing a first output pulse, means for deriving a second trigger voltage impulse coincident with an edge of said first output pulse, means actuated by said trigger voltage impulse for producing a second output pulse, means for deriving a third trigger voltage impulse coincident with an edge of said second output pulse, means, actuated by said third trigger voltage impulse, for producing a third output pulse, a power amplifier, and means for combining said first and third output pulses in said power amplifier to produce an output unit-cycle voltage wherein the first pulse, an interval determined by the width of the second pulse, and the third pulse appear in sequence.

2. A generator for producing rectangular pulses in a unit-cycle consisting of first and second pulses separated by a time interval comprising a source of trigger voltage impulses, means, actuated by an impulse from said source of trigger voltage impulses, for producing a first rectangular output pulse, means for deriving a second trigger voltage impulse coincident with the trailing edge of said first rectangular output pulse, means, actuated by said second trigger voltage impulse for producing a second rectangular output pulse, means for deriving a third trigger voltage impulse coincident with the trailing edge of said second rectangular output pulse, means, actuated by said third trigger voltage impulse, for producing a third rectangular output pulse, a power amplifier, and means for combining said first and third rectangular output pulses in said power amplifier to produce an output unit-cycle voltage wherein the first rectangular pulse, an interval determined by the width of the second rectangular pulse, and the third rectangular pulse appear in sequence.

3. The invention as defined in claim 2 wherein means is provided for independently varying the duration of each of said first, second and third rectangular pulses.

4. The invention as defined in claim 2 including switch means in said power amplifier for changing the relative polarity of said first and third pulses so as to be of the same or opposite relative polarity, selectively.

5. A generator for producing rectangular pulses in a unit-cycle consisting of first and second pulses separated by a time interval comprising a source of trigger voltage impulses, each of which is adapted to initiate a unit-pulse cycle, a first phantastron circuit triggered by an impulse from said source whereby an output pulse of trapezoidal configuration is obtained, means for shaping the trapezoidal pulse output of said first phantastron into a first rectangular pulse, an "interval" phantastron circuit, means controlled by the voltage change comprising the trailing edge of the output pulse of said first phantastron for initiating a second trapezoidal output pulse from said "interval" phantastron, a third phantastron, means controlled by the voltage change comprising the trailing edge of the output pulse of said "interval" phantastron for initiating a third trapezoidal output pulse from said third phantastron, means for shaping the trapezoidal pulse output of said third phantastron into a second rectangular pulse, a power amplifier and means for combining said first and second pulses in said power amplifier to produce an output unit-cycle voltage wherein the first rectangular

pulse, the interval and the second rectangular pulse appear in sequence.

6. The invention as defined in claim 5 including means for independently varying the duration of each of said first "interval" and second output pulses.

7. The invention as defined in claim 5 including switch means in said power amplifier for changing the relative polarity of said first and second pulses so as to be of the same or opposite polarity, selectively.

8. A generator for producing rectangular pulses in a unit cycle consisting of two pulses each of which is independently variable in duration and amplitude, the time interval between the two pulses of each unit being also variable, said generator comprising a source of synchronizing impulses each of which is adapted to initiate a unit pulse cycle, a first phantastron triggered by a synchronizing impulse from said source and designed to yield an output pulse of trapezoidal configuration, means for shaping the trapezoidal pulse output of said first phantastron into a first rectangular pulse, a first driver circuit, a power amplifier to which the said rectangular pulse is applied through said first driver circuit, means for differentiating the trapezoidal pulse output of said first phantastron, a first blocking oscillator, means for employing the differentiated first phantastron pulse to trigger said first blocking oscillator and thereby yield a further trigger impulse, a second phantastron, means for employing the trigger impulse from said first blocking oscillator to initiate con-

duction of said second phantastron at a time corresponding to the instant of occurrence of the trailing edge of said first rectangular unit pulse, a second blocking oscillator, means for employing the pulse output of said second phantastron to trigger said second blocking oscillator and produce a still further pulse which marks the leading edge of the second rectangular unit pulse, so that the operation of said second phantastron determines the time interval between the said two unit pulses, a third phantastron triggered by the said second blocking oscillator pulse and yielding an output pulse of trapezoidal configuration and means for shaping the trapezoidal pulse output of said third phantastron into a rectangular pulse.

9. A pulse generator according to claim 8, further comprising means for applying the rectangular pulse output from said third phantastron to said power amplifier through said first driver circuit, whereby an output is obtained from said amplifier in which the first and second pulses of each unit cycle are of the same polarity.

10. A pulse generator according to claim 8, further comprising a second driver circuit, and means for applying the rectangular pulse output from said third phantastron to said power amplifier through said second driver circuit, whereby an output is obtained from said amplifier in which the first and second pulses of each unit cycle are of opposite polarity.

No references cited.