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2,905,820

INTERMITTENT DISCHARGE PULSE GENERATORS

Filed July 20, 1954

2 Sheets-Sheet 1

FIG. 1

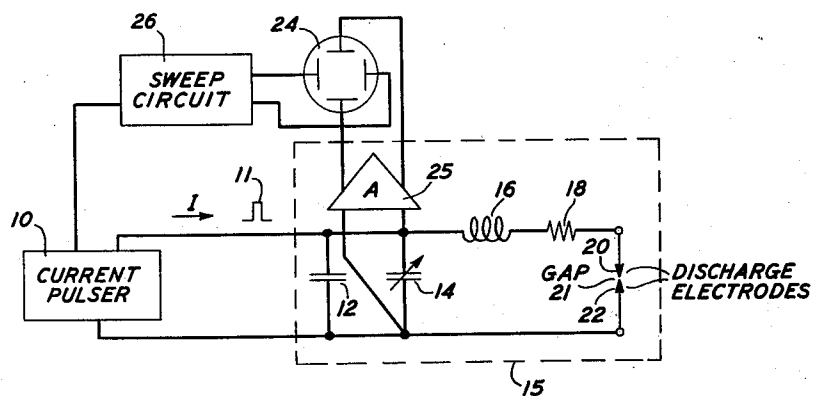


FIG. 2

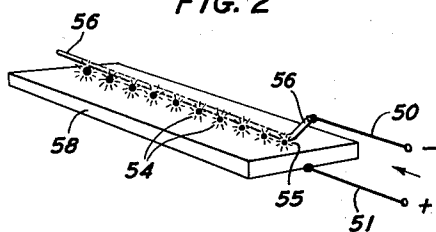


FIG. 3

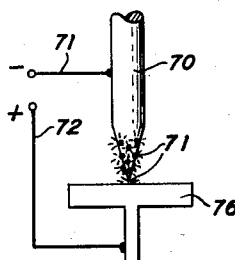


FIG. 4

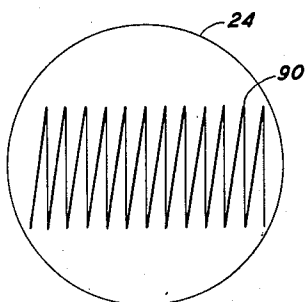
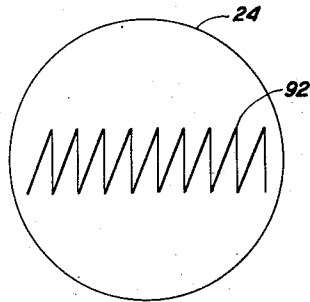


FIG. 5



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FIG. 6

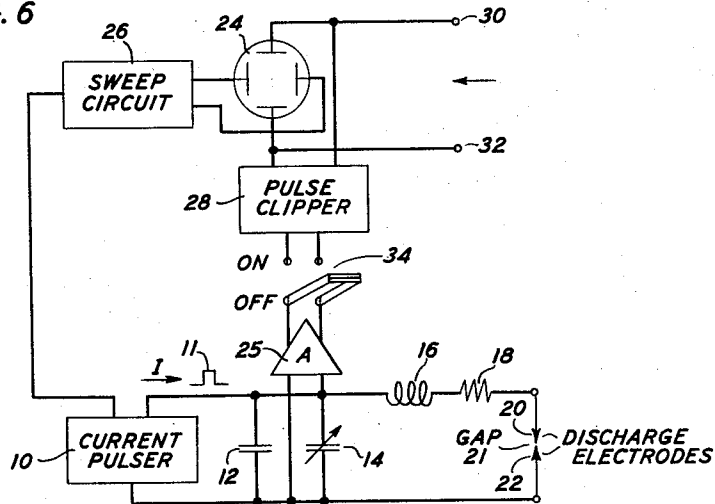


FIG. 7

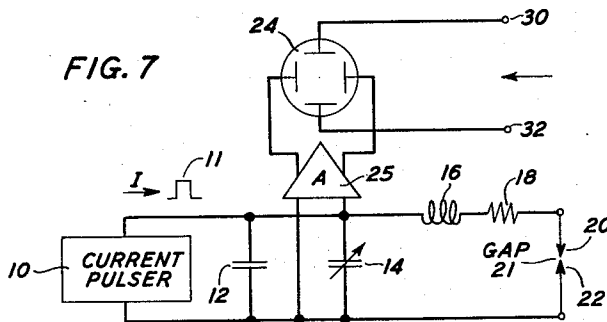
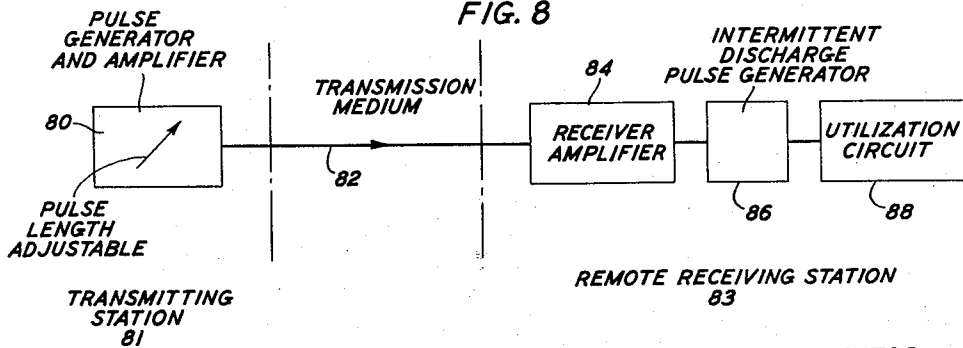


FIG. 8



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INTERMITTENT DISCHARGE PULSE GENERATORS

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6 Claims. (Cl. 331-165)

This invention relates to wave and pulse generators providing a succession of extremely short energy pulses, successive pulses being accurately and equally spaced in time, the time interval of successive pulses being extremely short. The invention further relates to arrangements and systems for utilizing said generators. More particularly this invention relates to the utilization of the phenomena of a self-propagating intermittent discharge to generate extremely short energy pulses, accurately and equally spaced in time, the time interval of successive pulses being extremely short but adjustable throughout a substantial range. Pulse lengths and/or pulse spacings in the order of a tenth of a microsecond, for example, are readily obtained with arrangements embodying the principles of the present invention. The number of pulses in a particular group of successive pulses is also readily controlled and varied.

If a single, short duration, limited, constant-current pulse is impressed across a pair of suitably arranged, closely spaced, electrodes associated with a local circuit, including appropriate inductive and capacitive reactances, a number of discrete spark discharges occurring at regular closely spaced time intervals and in an ordered spacial array on the cathode or negative electrode, can be obtained. The intermittent nature of the discharge is believed to result from the associated local circuit behaving in the manner of a relaxation oscillator. Each spark discharge is in the nature of an explosion and gives rise to a "blast" acoustic wave. The next successive discharge will therefore occur at that point in the "blast" acoustic wave from the previous discharge which best satisfies the conditions for electrical breakdown, the time interval between successive discharges being largely determined by the constants of the associated local circuit.

The relaxation type of "oscillation" with which the present invention is solely concerned should not be confused with the sinusoidal oscillations resulting from the more familiar phenomena of ordinary electrical resonance. The latter comprises a surging of power to and fro between the capacitive and inductive elements of an electrical circuit and gives rise to sinusoidal oscillation of the circuit at its resonant frequency, i.e. at the frequency for which the inductive reactance and the capacitive reactance of the circuit are equal. Such a circuit can be shock excited by a single instantaneous spurt of energy and will continue to oscillate at its natural resonant frequency until the energy of the single spurt has been dissipated by the resistive components of the circuit. The oscillations will continue for many times the duration of the instantaneous exciting energy pulse, unless the circuit includes large resistive, i.e. dissipative or damping, components. The phenomena is, of course, analogous to the vibration of a taut, undamped piano wire in response to a single instantaneous blow.

As contrasted with this, the relaxation type of oscillation of interest in connection with arrangements of the present invention requires a circuit the constants of which are such that the circuit is not shock excited into a

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sinusoidally resonant condition by application of the energy pulse. A mathematical relation between the circuit parameters which insures such a nonresonant condition will be given hereinbelow. In the arrangements of the present invention when a sustained, constant-current, energy pulse is applied, the capacitive elements of the circuit must first be charged to a voltage sufficient to cause a spark discharge across a very small gap. It is desirable for the purposes of the present invention that this discharge be as nearly instantaneous as possible. Therefore it is the teaching of the present application that only the inherent, or distributed, inductance and resistance of the circuit leads should be included between the capacity being charged and the gap across which the spark discharge occurs. It is further required that the current from the constant current source be insufficient to sustain the spark discharge. Accordingly, after instantaneous discharge of the capacitive components of the circuit, the constant current pulse again starts charging them until a second instantaneous spark discharge occurs and the cycle repeats, i.e. the overall circuit is performing a phenomena which is aptly designated as a relaxation type of oscillation. It is significant in connection with applicant's arrangements that no spark discharge can take place following the termination of the applied constant current pulse. With the very low resistive and inductive circuit components employed, the relaxation oscillation will not be sinusoidal but will, obviously, closely approximate a sawtooth type of wave.

The distance between successive discharges along the cathode surface is, in accordance with the above theory, determined by the velocity of the blast acoustic wave, so that, with various arrangements of the invention, to be described hereinunder in detail, a series of spark discharges, evenly spaced in both time and distance can be readily obtained.

The time between the successive spark discharges of the relaxation circuit must be sufficiently short that the blast or shock wave shall not have become too attenuated to induce a spark discharge at its front otherwise the successive spark discharges will not be displaced by equal increments of distance but will each take place at the point of minimum separation between the electrodes, any traveling of the sparks being erratic and resulting only from pitting and mounding of the electrodes. As will be described in detail hereinunder a sawtooth shaped wave having identical successive "teeth," each tooth being of very steep slope and very short duration is readily derived by arrangements of the invention. Also, by clipping the sawtooth wave a series of very short pulses occurring regularly at very short, equal and accurately determinable intervals of time can be readily obtained.

Accordingly, a principal object of the invention is to produce by relatively simple and reliable electrical means a sawtooth wave, successive teeth of which are identical, extremely short, and accurately shaped.

A further principal object of the invention is to afford by relatively simple and readily adjustable electrical means a series of substantially identical, accurately timed, electrical pulses occurring at uniform intervals, said intervals each being a small fraction of a microsecond.

Another object is to provide a system in which a series of pulses of definite predetermined number and spacing can be generated at a remote point by transmitting a single longer square wave pulse to said remote point.

Other objects will become apparent during the course of the following detailed description of illustrative embodiments of the principles of the invention and from the appended claims.

The principles of the invention will be more readily perceived from the detailed description hereinunder of

structures embodying said principles, taken in conjunction with the accompanying drawings, in which:

Fig. 1 is an electrical schematic diagram of a circuit employed in illustrating the principles of the invention;

Fig. 2 shows one form of discharge electrodes suitable for use in particular circuits of the invention;

Fig. 3 illustrates another form the discharge electrodes may take;

Figs. 4 and 5 show sawtooth wave forms which can be generated in circuits of the invention;

Fig. 6 shows a circuit of the invention arranged to provide accurately and closely spaced marker pulses on a cathode ray oscilloscope trace;

Fig. 7 shows a circuit of the invention employed to provide a very rapid repetitive horizontal sweep sawtooth wave for a cathode ray oscilloscope; and

Fig. 8 illustrates a system whereby a series of pulses of predetermined number and spacing can be generated at a remote point by transmitting a single longer square wave pulse to said remote point.

In more detail in Fig. 1, a pair of closely spaced discharge electrodes 20, 22 forming a spark gap 21 of, for example, approximately 0.5 mil long, is shunted by a circuit comprising a resistive impedance 18, an inductive impedance 16 and a pair of capacitive impedance elements 12 and 14, the element 14 preferably being adjustable. Normally elements 12, 16 and 18 can be the distributed constants of the circuit and 14 is a small discrete adjustable capacitor added and adjusted to provide, with the distributed constants of the circuit, a period of relaxation oscillation, for the combination, of the required length for the individual pulses of each particular wave train it is desired to generate.

Current pulser 10 is a constant current generator, of any of the several types well known to the art, which will supply substantially flat-topped pulses 11 of from one-half to several microseconds in duration. As shown, it is connected across the paralleled capacitive elements 12 and 14. The voltage applied by pulser 10 should be sufficient to cause a spark discharge across gap 21. A steady metal arc will not be established so long as the quantity

$$\sqrt{\frac{V_B^2 C}{I^2} + 1} e^{-\frac{r}{2} \pi \sqrt{\frac{C}{L}}} \quad (1)$$

is less than unity, where

V_B is the breakdown voltage developed across the gap;
 I is the current passing through the gap;

C is the effective capacity of the local circuit shunting the gap, i.e., capacities 12 and 14;

L is the inductance of the local circuit, i.e., inductance 16;

r is the resistance of the local circuit, i.e., resistance 18;

e is the base of naperian logarithms; and

π is substantially 3.1416, the number of radians in a half cycle.

A peculiarity noted in connection with the phenomenon of a self-propagating intermittent discharge of the type with which this application is concerned is that while the initial breakdown voltage required to produce the first spark discharge is relatively high, subsequent spark discharges in the resulting train all take place at a considerably lower and substantially constant voltage. By way of example, with an electrode separation of 50,000 A., using gold electrodes in air, a voltage of between 600 to 900 volts was found necessary to produce the first spark discharge but the succeeding discharges in the train all occurred at 340 volts, which is substantially the minimum breakdown voltage in air. The regular spacing of the successive discharges along the cathode of a pair of parallel electrodes would therefore appear to indicate that a particular portion of the acoustic blast wave produces the most favorable condition for the next successive spark discharge at a distance determined by the velocity of the

acoustic shock wave and the time constant of the associated oscillatory circuit.

Considering each spark discharge as an explosion, the approximate formula, given by G. I. Taylor in an article published in the Proceedings of the Royal Society for 1950, page 158, may be used to determine the position of the shock front of the acoustic wave generated, the approximate formula being

$$t = 0.926 R^{5/2} p^{1/2} E^{-1/2} \quad (2)$$

where

t = time since the last explosion

R = radial coordinate of shock wave front

p = density of gas surrounding explosion

E = total energy released.

For small electrode separations the breakdown point in the shock wave will be quite near the front of the shock wave. The breakdown will be affected also by the ions carried along by the large fraction of the gas which follows closely behind the shock front. These ions will be effective in reducing the statistical time lag and will also tend to reduce the effective separation between the electrodes and thus act in the same sense as the decreasing density distribution. As is well known to those skilled in the art, the velocity of a blast or shock wave is greater than that of an ordinary acoustic wave and, where sufficient energy is present in the blast, it can be as much as twice that of an ordinary acoustic wave in the same medium.

In Fig. 2 a form of the electrodes with which the plausibility of the shock wave theory of propagation of the intermittent discharge is made evident, is shown. In Fig. 2 the cathode 56 (negative electrode) is, for example, a copper wire of 2.5 mils diameter, the right end of the wire being turned up, as shown, the remainder of the wire being straight. The anode electrode 58 is a flat copper plate arranged closely adjacent to electrode 56 but not quite parallel therewith so at the closest point 55, the separation between the electrodes is 0.5 mil while at the left end of the electrodes the spacing has increased to 1.0 mil, by way of example.

With electrode leads 50, 51 connected into the circuit of Fig. 1 as shown for electrodes 20, 22, thereof, when a constant current pulse 11 is supplied by pulser 10, as described above, a spark discharge 54 will first take place at point 55 after which successive spark discharges 54 will occur at evenly spaced time intervals and distances to the left of point 55 as indicated in Fig. 2, the discharges ceasing with the termination of the control pulse 11 from pulser 10. By way of example, in an experimental circuit of the type illustrated by Figs. 1 and 2, successive discharges occurred at time intervals of $\frac{1}{10}$ microsecond and space intervals of 4 mils. For this timing the time interval between the first and last of the discharges 54 of Fig. 2 would be $\frac{1}{10}$ microsecond which would correspond to a control pulse 11 from pulser 10 of approximately one microsecond duration.

If instead of the electrodes illustrated in Fig. 2, those shown in Fig. 3 are employed, i.e., a conically pointed cathode 70 the tip of which is closely spaced from a flat plate anode 76, a series of spark discharges 74 will again be obtained, the first discharge taking place at the tip of the cathode 70 but subsequent discharges appearing around the conical end of cathode 70 at points above the tip thereof.

Assuming the same circuit constants as for the illustrative example given immediately above for electrodes 56 and 58 above, again 10 successive spark discharges, occurring at time intervals of $\frac{1}{10}$ microsecond and spaced from each other by space intervals of approximately 4 mils are obtained.

Returning to Fig. 1, a cathode ray oscilloscope 24 having horizontal and vertical deflecting plates, as shown, is provided. Its horizontal deflecting plates are supplied

with a sweep wave from sweep circuit 26. Sweep circuit 26 is synchronized by energy from pulser 10 and provides a substantially linear sweep wave of substantially the duration of the longest pulse provided by pulser 10. The vertical deflecting plates of oscilloscope 24 are connected to amplifier 25 which is connected across capacitor 14. With this arrangement typical indications of the sawtooth wave occurring across capacitor 14 are as shown in Figs. 4 and 5 horizontal distance representing time and vertical distance representing amplitude.

For convenient reference later in this specification, the portion of the circuit of Fig. 1 enclosed by the dash line 15 will be referred to as an "intermittent discharge sawtooth wave generator." With the addition of a pulse clipper 28 of Fig. 6, at its output terminals, the combination becomes an "intermittent discharge pulse generator."

In Fig. 4 curve 90 represents a sawtooth wave obtained with a particular setting or value of the capacity of condenser 14 which provides 12 identical linear sweeps each having a duration of 0.20 microsecond.

In Fig. 5 curve 92 represents a sawtooth wave obtained with a greater setting or value of the capacity of condenser 14 which provides 9 identical linear sweeps each having a duration of 0.33 microsecond.

In Fig. 6 is shown a modification of the circuit of Fig. 1 in which a pulse clipper circuit 28 and switch 34 have been added, so that the amplified sawtooth wave derived from across capacitors 12, 14 can be clipped and the resulting pulses applied to the vertical deflecting plates of oscilloscope 24 to provide a series of accurately-timed, short, vertical marker pulses along the trace of the ray of the oscilloscope 24 for comparison with or calibration of an external signal wave applied to terminals 30 and 32. Alternatively the short, accurately-timed, pulses from clipper 28 can be applied to the intensity control electrode of the cathode ray oscilloscope 24 to provide a series of bright spots along the trace of the oscilloscope 24, in accordance with arrangements well known to those skilled in the art. The remaining components of Fig. 6 are the same as the correspondingly numbered components of Fig. 1, as described in detail above.

A further circuit of the invention is shown in Fig. 7, in which the amplified sawtooth wave from amplifier 25 is applied to the horizontal deflecting plates of the oscilloscope 24 to provide an extremely fast, accurately-timed, horizontal sweep for observing the character of very short duration input signals applied to terminals 30, 32 leading to the vertical deflecting plates of the oscilloscope 24. Again, the remaining components of Fig. 7 are the same as the correspondingly numbered components of Figs. 1 and 6, described in detail above.

In Fig. 8, a system of the invention for providing, at a remote point, trains of pulses having predetermined numbers of pulses in each of the various trains, is shown. The particular advantage of the system is that between the transmitting station 81 and the remote receiving station 83, relatively long flat-topped, constant current, pulses can be transmitted, the length of the pulse transmitted determining at the remote receiving station the number of pulses generated in the train of resulting pulses. The frequency bandwidth required for the transmission medium 82 can therefore be very much less than would be required for transmitting the much shorter pulses of the resulting pulse train.

In more detail, at the transmitting station 81, a pulse generator and amplifier 80 is provided the length of pulse generated thereby being adjustable to lengths corresponding, respectively, to the number of pulses desired in successive pulse trains to be generated at the remote receiving station 83.

Pulses from generator 80 are transmitted over the transmission path 82, which may be a wave guide, a coaxial line, or a radio link, by way of example, to the remote receiving station 83. At station 83 the pulses from generator 80 are received and amplified in receiver

amplifier 84 and applied to an intermittent discharge pulse generator 86, which can comprise, as described hereinabove, the intermittent discharge sawtooth wave generator 15 of Fig. 1 and a pulse clipper 28 of Fig. 6, the output of the generator 86 being connected to a utilization circuit 88 which can be a computing, accounting, or similar type of device. For example, utilization circuit 88 can respond to various combinations of pulse trains, depending upon the number of pulses in each of several successive trains, in a variety of ways to provide intelligence at station 83 of particular operations being performed at the transmitting station 81.

Numerous and varied applications and modifications of the above-described illustrative arrangements, within the spirit and scope of the invention, will readily occur to those skilled in the art. No attempt to exhaustively illustrate all such applications and modifications has here been made.

What is claimed is:

1. A pulse generator comprising in combination a source of substantially constant current pulses, a relaxation circuit including a pair of closely spaced stationary spark discharge electrodes and inductive, resistive, and capacitive impedances connected in a series loop and proportioned according to the relation;

$$\left[\sqrt{\frac{V_B^2 C}{I^2 l} + 1} \right] e^{-\frac{r}{2\pi} \sqrt{\frac{C}{l}}} < 1$$

- where V_B is the breakdown voltage developed across the electrodes, I is the current passing between the electrodes, C and l are respectively the effective capacitance and inductance in the series loop, r is the resistance of the series loop, e is the base of naperian logarithms, and π is the number of radians per half cycle, means for applying the output of said current pulse source across the capacitive impedance in said series loop to produce in said relaxation circuit relaxation discharge oscillations having a period which is a fraction of that of the applied pulse, and a utilization circuit connected across said capacitive impedance, whereby a constant current pulse applied to said capacitive impedance is converted by the relaxation action of said series loop into a series of identical high frequency closely spaced sawtooth waves appearing across said utilization circuit.

2. The arrangement defined in claim 1 and means in said utilization circuit for clipping the sawtooth wave to obtain a plurality of discrete pulses closely and accurately spaced in time.

3. A pulse generator comprising in combination a source of substantially constant current pulses having a period of at least one-half microsecond, a relaxation circuit including a pair of closely spaced stationary spark discharge electrodes and inductive, resistive, and capacitive impedances connected in a series loop and proportioned according to the relation;

$$\left[\sqrt{\frac{V_B^2 C}{I^2 l} + 1} \right] e^{-\frac{r}{2\pi} \sqrt{\frac{C}{l}}} < 1$$

- where V_B is the breakdown voltage developed across the electrodes, I is the current passing between the electrodes, C and l respectively are the effective capacitance and inductance in the series loop, r is the resistance of the series loop, e is the base of naperian logarithms, and π is the number of radians per half cycle, means for applying the output of said current pulse source across the capacitive impedance in said series loop to produce in said relaxation circuit relaxation discharge oscillations having a period which is a fraction of a microsecond, and a utilization circuit connected across said capacitive impedance, whereby a constant current pulse applied to said capacitive impedance is converted by the relaxation action of said series loop into a series of identical high frequency closely spaced sawtooth waves appearing across said utilization circuit.

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4. A pulse generator comprising in combination a source of substantially constant current pulses, a relaxation circuit including a pair of closely spaced stationary spark discharge electrodes and inductive, resistive, and capacitive impedances connected in a series loop and proportioned according to the relation;

$$\left[\sqrt{\frac{V_B^2 C}{I^2 l} + 1} \right] e^{-\frac{r}{2\pi} \sqrt{\frac{C}{l}}} < 1$$

where V_B is the breakdown voltage developed across the electrodes, I is the current passing between the electrodes, C and l are respectively the effective capacitance and inductance in the series loop, r is the resistance of the series loop, e is the base of naperian logarithms, and π is the number of radians per half cycle, means for applying the output of said current pulse source across the capacitive impedance in said series loop to produce in said relaxation circuit relaxation discharge oscillations having a period which is a fraction of that of the applied pulse, a utilization circuit connected across said capacitive impedance, and means for varying the value of said capacitive impedance thereby controlling the period of the output wave, whereby a constant current pulse applied to said capacitive impedance is converted by the relaxation action of said series loop into a series of identical high frequency closely spaced sawtooth waves appearing across said utilization circuit.

5. A pulse generator comprising in combination a source of substantially constant current pulses, a pair of closely spaced stationary spark discharge electrodes consisting of a flat plate electrode and a conical electrode arranged with its pointed end closely spaced from said flat plate electrode, a relaxation circuit including said discharge electrodes and inductive, resistive, and capacitive impedances connected in a series loop and proportioned according to the relation;

$$\left[\sqrt{\frac{V_B^2 C}{I^2 l} + 1} \right] e^{-\frac{r}{2\pi} \sqrt{\frac{C}{l}}} < 1$$

where V_B is the breakdown voltage developed across the electrodes, I is the current passing through the electrodes, C and l are respectively the effective capacitance and inductance in the series loop, r is the resistance of the series loop, e is the base of naperian logarithms, and π is the number of radians per half cycle, means for applying the output of said current pulse source across the capacitive impedance in said series loop to produce in said relaxation circuit relaxation discharge oscillations having a period which is a fraction of that of the applied pulse, and a utilization circuit connected across said capacitive impedance, whereby a constant current pulse applied to said capacitive impedance is converted by the relaxation action of said series loop into a series of identical high frequency closely spaced sawtooth waves appearing across said utilization circuit.

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tions having a period which is a fraction of that of the applied pulse, and a utilization circuit connected across said capacitive impedance, whereby a constant current pulse applied to said capacitive impedance is converted by the relaxation action of said series loop into a series of identical high frequency closely spaced sawtooth waves appearing across said capacitive impedance.

6. A pulse generator comprising in combination a source of substantially constant current pulses, a pair of closely spaced stationary spark discharge electrodes having nearly parallel contiguous surfaces extending linearly from an end point of minimum separation to an opposite end point of maximum but still small separation, a relaxation circuit including said discharge electrodes and inductive, resistive, and capacitive impedances connected in a series loop and proportioned to the relation;

$$\left[\sqrt{\frac{V_B^2 C}{I^2 l} + 1} \right] e^{-\frac{r}{2\pi} \sqrt{\frac{C}{l}}} < 1$$

where V_B is the breakdown voltage developed across the electrodes, I is the current passing between the electrodes, C and l are respectively the effective capacitance and inductance in the series loop, r is the resistance of the series loop, e is the base of naperian logarithms, and π is the number of radians per half cycle, means for applying the output of said current pulse source across the capacitive impedance in said series loop to produce in said relaxation circuit relaxation discharge oscillations having a period which is a fraction of that of the applied pulse, and a utilization circuit connected across said capacitive impedance, whereby a constant current pulse applied to said capacitive impedance is converted by the relaxation action of said series loop into a series of identical high frequency closely spaced sawtooth waves appearing across said utilization circuit.

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