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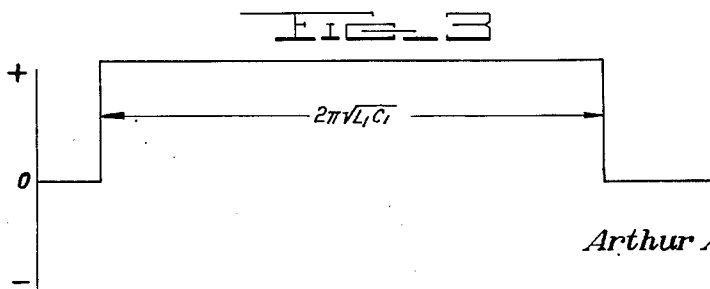
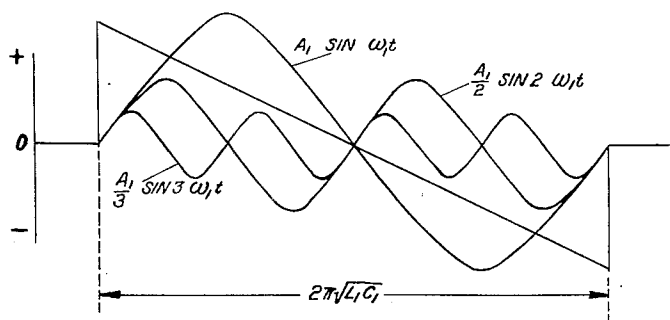
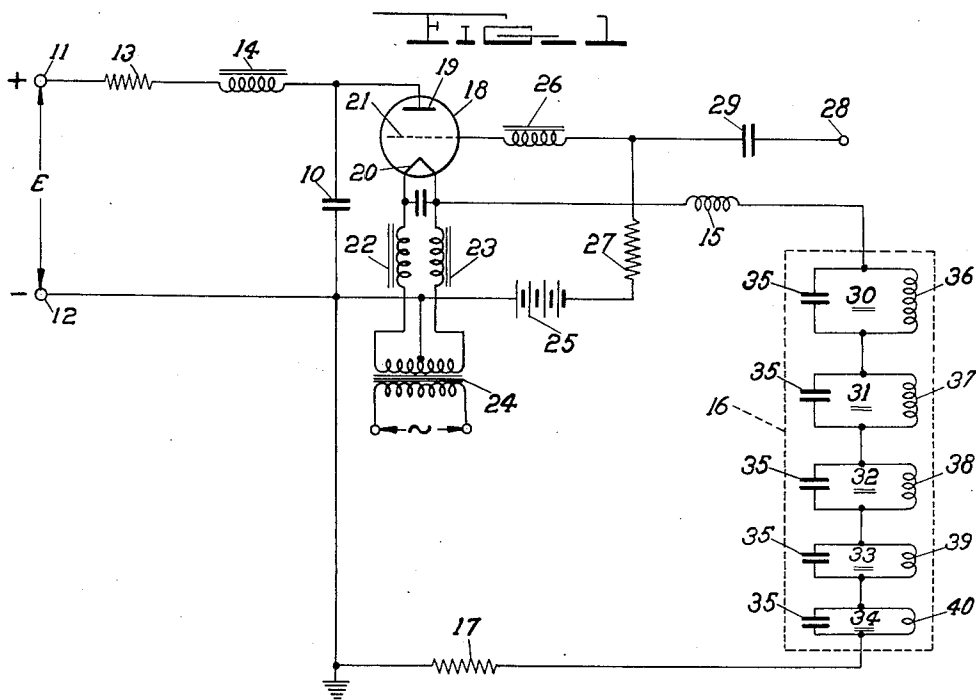
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RECTANGULAR AND SAW-TOOTH IMPULSE GENERATOR

Filed June 19, 1942

3 Sheets-Sheet 1



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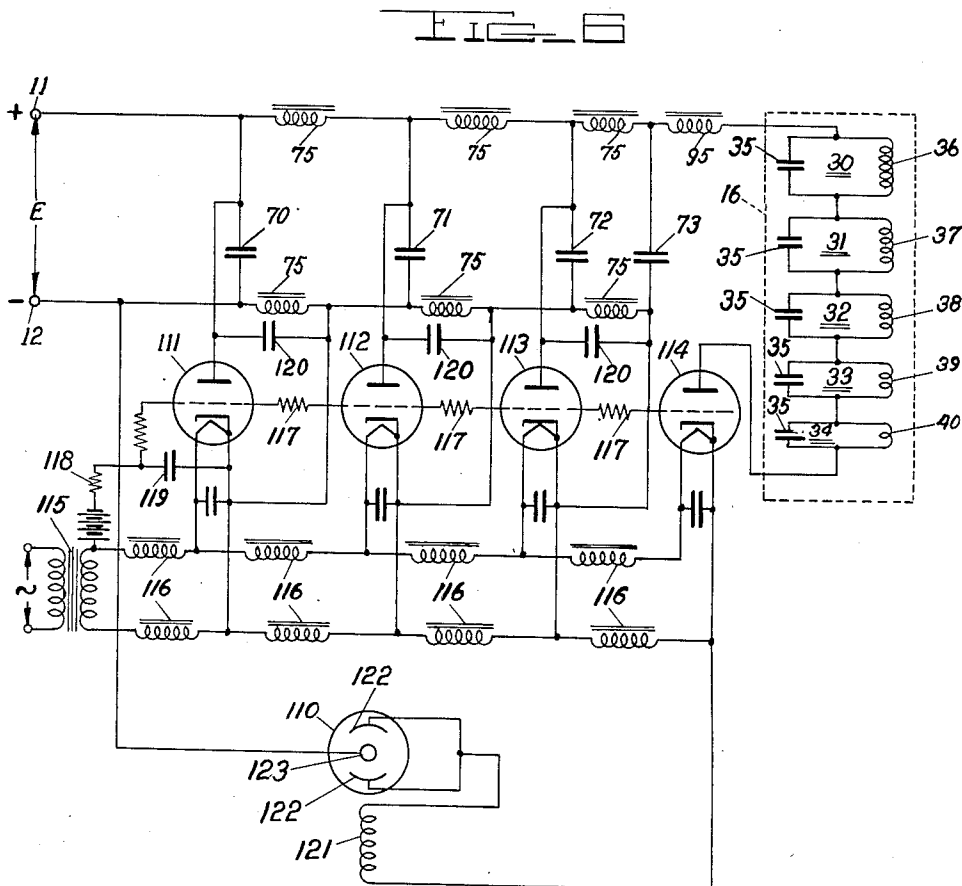
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RECTANGULAR AND SAW-TOOTH IMPULSE
GENERATOR

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30 Claims. (Cl. 250—36)

(Granted under the act of March 3, 1883, as
amended April 30, 1928; 370 O. G. 757)

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This invention relates to electrical impulse generators and more particularly to circuits capable of generating electrical impulses having rectangular and saw-tooth wave forms.

There has long been a need in the art for means, of simple design and construction, capable of generating high voltage electrical impulses of rectangular or saw-tooth wave forms with a high degree of stability and efficiency, with such means so characterized that the impulses are of constant duration and are generated at an extremely high rate of speed so that the same may be utilized for controlling operation of various electrical machines, especially devices operating on ultra high frequencies.

The principal object of the present invention is to provide the foregoing means.

Another object is to provide a novel circuit arrangement for discharging a potential storing device at a constant rate for a predetermined period of time.

Another object is to provide novel means for periodically discharging a condenser through a discharge circuit at a constant rate in accordance with a preselected synchronizing source whereby flow of constant current is maintained in the discharge circuit for a predetermined period of time in a periodic manner determined by the synchronizing source.

Another object is to provide an impulse generator for producing electrical impulses of rectangular and saw-tooth wave forms including a condenser which is periodically discharged through a discharge circuit including an impedance having a definite relation with the capacity of said condenser and so characterized that a substantially linearly varying voltage is generated across the impedance for a predetermined period of time following the instant the condenser discharge commences and so that constant current flows through the discharge circuit for such predetermined period of time.

Another object is to provide an impulse generator having the foregoing characteristics wherein the impedance means comprises a filter network having a plurality of capacitance and inductance combinations, with each combination tuned to a different frequency and serially connected in harmonic relationship, and with the value of capacitances having a definite relationship to the value of the condenser.

Another object is to provide an electrical impulse generator having a plurality of condensers that are charged in parallel relation with a source of potential including novel means for

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serially discharging the condensers through a discharge circuit having certain characteristics so that constant flow of current is maintained through the discharge circuit for a predetermined period of time following the instant the condensers are serially discharged therethrough, and so that the voltage output of the generator is of a value substantially greater than the potential charge on the condensers.

Still another object of the present invention is to provide novel means for applying a transient linear sweep on the cathode ray oscillograph.

Still another object is to provide novel means for anode keying of ultra high frequency oscillator circuits.

Still another object is to provide a novel electrical arrangement for periodically supplying electrical energy of constant values, of a predetermined duration, to the electrical and magnetic fields of a magnetron employed in ultra high frequency oscillator circuits whereby impulse operation of such circuits is obtained.

Other objects and features of the invention will appear more fully from the following detailed description when considered together with the accompanying drawings which disclose several embodiments of the invention. It is to be expressly understood, however, that the drawings are designed for purposes of illustration only and not as a definition of the limits of the invention, reference for the latter purpose being had to the appended claims.

In the drawings, wherein similar reference characters denote similar parts throughout the several views:

Fig. 1 is a diagrammatic showing of an electrical impulse generator embodying the principles of the present invention;

Fig. 2 is a schematic illustration of a saw-tooth voltage wave form produced by the generator disclosed in Fig. 1;

Fig. 3 is a schematic illustration of a rectangular voltage wave form produced by the generator disclosed in Fig. 1;

Fig. 4 is a showing of a further application of the impulse generator disclosed in Fig. 1;

Fig. 5 is a diagrammatic illustration of a further embodiment of the present invention, and

Fig. 6 is a diagrammatic showing of a still further embodiment of the invention.

With reference more particularly to Fig. 1 of the drawings, and electrical impulse generator embodying the principles of the present invention is disclosed therein including a potential storing device, such as a capacitance 10. A

source of potential from terminals 11 and 12 is applied to the high and low potential terminals of capacitance 10, respectively, with impedance 13 and choke coil 14 included in the high potential connection, to charge the capacitance. The generator further includes a discharge circuit comprising inductance 15, filter network 16 and a resistance 17, connected in series between the high and low potential terminals of capacitance 10. In order to control discharge of the capacitance through such discharge circuit a gaseous electron discharge device 18 is connected between the high potential terminal of the capacitance and inductance 15. More particularly, device 18 comprises a conventional triode gas tube having a plate 19, a filament 20 and a control electrode 21. Plate 19 is connected to the high potential terminal of capacitance 10, while filament 20 is connected to inductance 15, and to the low potential terminal of the capacitance, or ground potential, through choke coils 22 and 23 and the secondary winding of transformer 24. The heater voltage for filament 20 is applied thereto in a conventional manner through transformer 24. Control electrode 21 is connected to the low potential terminal of bias supply 25, through choke coil 26 and impedance 27, to normally maintain the control electrode negatively biased and device 18 in a de-ionized condition. Control electrode 21 is also connected to a synchronizing source at point 28, through capacitance 29. When the bias on control electrode 21 is increased above the cut-off potential of device 18, upon application of a positive potential at point 28, device 18 is ionized to form an electrical connection between the high potential terminal of capacitance 10 and inductance 15 whereby the capacitance discharges serially through inductance 15, filter-network 16 and resistance 17 to ground potential. The time constants of choke coils 22 and 23 are of such duration to prevent discharge of capacitance 10 there-through, for a predetermined period of time following the instant device is ionized, as will appear more fully hereinafter. The synchronizing source applied to point 28 for controlling the discharge of capacitance 10 may comprise equally spaced positive impulses, or any form of alternating current capable of periodically ionizing device 18 at a desired rate.

Filter network 16 includes a plurality of serially connected filter sections 30, 31, 32, 33 and 34. Each of the filter sections include a capacitance 35, of equal capacity, and an inductance, of different values, connected in parallel with the capacitance so that each filter section 30, 31, 32, 33 and 34 resonates at a different frequency. Filter section 30 includes inductance 36 of a predetermined value to tune the filter section at a certain frequency which may be considered the fundamental frequency since the duration of the rectangular and saw-tooth impulses produced by the generator is determined thereby, while inductances 37, 38, 39 and 40 respectively included in filter sections 31, 32, 33 and 34, are of predetermined values to tune each of the filter sections to frequencies equal to a certain harmonic of the frequency of filter section 30, or of the fundamental frequency. Filter section 31 is tuned to a frequency equal to the first harmonic of the fundamental frequency, while filter sections 32, 33 and 34 are respectively tuned to frequencies equal to the second, third and n th harmonic of the fundamental

frequency. In order to obtain a series harmonic filter having the foregoing characteristics the values of inductances 37, 38, 39 and 40 are inversely proportional to the square of the harmonic number of the filter sections in which each inductance is included. The characteristic impedance value of each filter section is therefore inversely proportional to the harmonic of the fundamental frequency to which each filter is tuned. The transient impedance value of filter network 16, that is, the impedance value of the network for a predetermined period of time following the instant a source of current flows therethrough, thus varies as a linear function of time for a predetermined period of time determined by the fundamental frequency of the filter network, which in the present instance, is the resonant frequency of filter section 30.

When current flows through a filter network having the foregoing characteristics a voltage is generated across the network that varies as a substantially linear function for a predetermined period of time, since the transient impedance of the filter network offers an opposition to current flow therethrough that varies substantially as a linear function of time for such predetermined period of time following the instant current initially flows therethrough. As mentioned heretofore, the fundamental frequency of the filter network determines the period of time following the initial flow of current therethrough during which a substantially linear voltage is generated across the filter. Such period of time is equal to $2\pi\sqrt{L_1C_1}$, wherein L_1 and C_1 correspond respectively to the values of inductance 36 and capacitance 35 of filter section 30. The foregoing may be more readily understood with reference to Fig. 2 of the drawings wherein the voltage generated across filter network 16 as well as the voltages generated in the filter sections during the time interval $2\pi\sqrt{L_1C_1}$ are shown. At the instant current initially flows through the filter network generation of sinusoidal voltages is initiated in sections 30, 31, 32, 33 and 34. Such sinusoidal voltages are of predetermined frequencies determined by the capacitance and inductance of each filter section. More particularly, the sinusoidal voltage generated across filter section 30 is at a frequency corresponding to the fundamental frequency of the filter network and a complete sinusoidal cycle is generated during the time interval $2\pi\sqrt{L_1C_1}$. Also, the sinusoidal voltages appearing across filter sections 31, 32, 33 and 34 are at frequencies corresponding to certain harmonics of the fundamental frequency, for reasons mentioned heretofore, and such sinusoidal oscillations continue in each of the latter filter sections for a period of time equal to $2\pi\sqrt{L_1C_1}$. Since the characteristic impedance value of each filter section is inversely proportional to the harmonic number to which each is tuned, the amplitudes of the sinusoidal voltages generated across each section are inversely proportional to the harmonic numbers thereof. As shown in Fig. 2, the sinusoidal voltage generated across filter section 30 is expressed by the function $A_1 \sin \omega_1 t$, wherein A_1 represents the voltage across the section, and $\omega_1 t$ the frequency at which the section is tuned. Since filter section 30 is tuned to a frequency corresponding to the first harmonic of the fundamental frequency, and furthermore since the characteristic impedance of the filter sections is inversely proportional to the harmonic number of the fundamental frequency to which the sec-

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tions are tuned, the voltage generated across filter section 31 is expressed as

$$\frac{A_1}{2} \sin 2\omega_1 t$$

Moreover, since the voltage generated across filter section 32 is expressed as

$$\frac{A_1}{3} \sin 3\omega_1 t$$

the total voltage generated across a series harmonic filter, such as filter network 16, having n number of filter sections, is expressed as

$$E_{\text{total}} = A_1 \sin \omega_1 t + \frac{A_1}{2} \sin 2\omega_1 t + \frac{A_1}{3} \sin 3\omega_1 t + \dots + \frac{A_1}{n} \sin n\omega_1 t$$

The foregoing expression is a Fourier series for a saw-tooth wave form. With an infinite number of serially connected filter sections having the proper harmonic relationship therebetween, the total voltage generated across such a filter produces a perfect saw-tooth wave form, as shown in Fig. 2. Since a large number of filter sections is required in order to obtain a perfect saw tooth-wave form, inductance 15 is connected in series with filter network 16 so that a substantially linear voltage is generated across the filter network without necessitating employment of an impracticable number of filter sections.

As mentioned heretofore, one of the objects of the present invention is to provide an electrical apparatus including a condenser so characterized that the condenser is discharged at a constant rate, for a predetermined period of time following the instant the condenser is initially discharged, whereby a constant flow of current is maintained for such predetermined period of time. It has been found that in order to discharge capacitance 10 through inductance 15, filter network 16 and resistance 17, at a constant rate, the value of capacitance 10 must have a definite relationship with the value of capacitances 35 of filter network 16. Since the charge on capacitance 10 is equal to the capacity of the capacitance times the voltage impressed thereon, the rate of change of the charge, or the discharge current, is equal to

$$\frac{dq}{dt}$$

If the capacitance 10 is discharged at a constant rate, namely, by constant current, then

$$\frac{dq}{dt}$$

must necessarily equal a constant value. Since $q=CV$,

$$C \frac{dv}{dt}$$

also equals such a constant value and, C therefore equals

$$i / \frac{dv}{dt}$$

where C equals the capacity of capacitance 10. This latter expression is the rate of change of voltage of capacitance 10, when the latter discharges at a constant rate, in terms of the capacity C of the capacitance. Since capacitance 10 discharges through filter network 16, the value of the capacitance may also be expressed as a function of the rate of change of voltage

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across the filter network. The rate of change of the voltage across filter 16 is equal to

$$\frac{V}{2+R} \times \frac{(2+R)T}{2ZV}$$

wherein V is the voltage applied to capacitance 10, R the resistance of the discharge circuit, Z the characteristic impedance of filter network 16 and T the time constant of the filter network. Therefore,

$$C = \frac{V}{2+R} \times \frac{(2+R)T}{2ZV}$$

Since T equals $2\pi\sqrt{L_1 C_1}$, the value of C may be expressed as

$$2\pi \frac{\sqrt{L_1 C_1}}{2Z}$$

and furthermore, since

$$Z = \frac{\pi}{2} \sqrt{\frac{L_1}{C_1}}$$

when $t=0$,

$$C = \frac{2\pi\sqrt{L_1 C_1}}{\frac{\pi}{2}\sqrt{L_1/C_1}} = 2C_1$$

It is to be expressly understood therefore, that capacitances 35 have capacity values equal to one-half the capacity of capacitance 10. With the foregoing arrangement, capacitance 10 discharges at a constant rate for the period of time $2\pi\sqrt{L_1 C_1}$ following the instant the capacitance initially discharges, and therefore, a constant current is maintained in the discharge circuit comprising conductance 15, filter network 16 and resistance 17 for the period $2\pi\sqrt{L_1 C_1}$ following the instant capacitance 10 is discharged upon operation of device 18.

Since a substantially constant current is maintained in the discharge circuit for a predetermined period of time following each instant that capacitance 10 is discharged there-through, a substantially constant voltage is maintained across resistance 17 for a period of time equal to $2\pi\sqrt{L_1 C_1}$. Such rectangular voltage form is shown in Fig. 3. It is to be expressly understood, that the saw-tooth voltage form generated across filter 16 and the rectangular voltage form maintained across impedance 17, are generated simultaneously and are of equal duration. The foregoing may be more readily understood with simultaneous reference to Figs. 2 and 3. As will appear more fully hereinafter, resistance 17 may comprise any electrical device to which periodic application of constant current is desired, such as a high frequency oscillator circuit for example.

In operation of the electrical impulse generator disclosed in Fig. 1, a source of direct current potential is applied across capacitance 10 from terminals 11 and 12 through impedance 13 and choke coil 14 to charge the capacitance. A synchronizing source, such as a series of equally spaced positive impulses, is applied to control electrode 21, of device 18, for periodically ionizing the latter, to periodically discharge capacitance 10 through serially connected inductance 15, filter network 16 and resistance 17. Impedance 13 and choke coil 14 are so selected that application of constant potential from terminals 11 and 12 to capacitance 10 is delayed for a period of time equal to $2\pi\sqrt{L_1 C_1}$ following each instant the capacitances discharged. Capacitances 35 of filter network

16 have a value equal to one-half the value of capacitance 10 in order to maintain the discharge of capacitance 10 at constant rate, as pointed out heretofore. Since capacitance 10 discharges at a constant rate for a period of time $2\pi\sqrt{L_1C_1}$ following each instant device 13 is ionized, constant current flows through inductance 15 and filter network 16 for the period $2\pi\sqrt{L_1C_1}$. As mentioned heretofore, filter network 16 is so characterized to maintain an opposition to the flow of current therethrough that varies as a substantially linear function of time, for a period of time equal to $2\pi\sqrt{L_1C_1}$, following the instant current initially flows therethrough. Therefore, a voltage is generated across filter 16 that varies as a substantially linear function of time for the period $2\pi\sqrt{L_1C_1}$, following the instant capacitance 10 is discharged, as shown in Fig. 2. Also, since constant current flows through resistance 17 for the period of time $2\pi\sqrt{L_1C_1}$, a substantially constant potential is maintained across the resistance during such period of time, as shown in Fig. 3. After lapse of the time interval $2\pi\sqrt{L_1C_1}$, the voltage across filter network 16, and across resistance 17, abruptly diminishes to zero and device 13 is thus abruptly deionized to terminate the discharge of capacitance 10. In this regard, the time constants of choke coils 22 and 23 are much greater than the time interval $2\pi\sqrt{L_1C_1}$ so that discharge of capacitance 10 therethrough is prevented during the time when device 13 is in an ionized state. Inductance 15, as mentioned above, functions to maintain the discharge current substantially constant without utilizing an impracticable number of harmonic filter sections in filter network 16. The electrical impulses generated by the apparatus disclosed in Fig. 1 are of a substantially sawtooth and rectangular wave form and may be employed separately or simultaneously for controlling operation of various electrical devices as will appear more fully hereinafter.

In Fig. 4 of the drawings the impulse generator described heretofore is shown interconnected with an electrical device whereby indications of irregular transient voltages are obtained. The indicating device is shown as a cathode ray oscillograph 50 including cathode 51 and anode 52 for generating an electron beam, a control electrode 53 for controlling the intensity of the electron stream, and a pair of deflection plates 54 and 55 for controlling the deflection of the electron beam. The saw-tooth and rectangular voltage wave forms produced by the impulse generator described heretofore are fed to certain elements of the oscillograph to produce a transient linear sweep of the electron beam as well as to modulate the intensity of the electron beam during the period of the linear sweep.

The impulse generator disclosed in Fig. 4 is similar to the generator described heretofore with the exception that certain elements therein are of different character and certain other elements have been added thereto in order to render the generator applicable for operation in connection with the oscillograph 50, as well as to illustrate changes that may be made therein when a different operating frequency is desired. With regard to the latter, inductances 36, 37 and 38 are shown as choke coils, while inductance 56 is serially connected in the discharge circuit at the low potential side of the filter network. Resistance 57 is connected between the high poten-

tial terminal of capacitance 10 and plate 19, of device 13, and is bypassed by condenser 58 in order to accelerate operation of the generator. In this connection, resistance 57 has a value approximately equal to the characteristic impedance of filter network 16. Cathode 51, of oscillograph 50, is supplied with high voltage from source 59 through resistor 60, while anode 52 and deflection plate 55 are also supplied with high voltage from point 59 by way of resistors 60 and 61. The voltage for deflecting the electron beam of the oscillograph is applied to deflection plate 54 from the high potential side of filter network 16 through electrical conductor 62. The low potential side of filter network 16 is connected to control electrode 53, through blocking condenser 63, while the control electrode is also connected to point 59 through resistor 64. A resistor 65, of sufficient value to provide the voltage required for the extent of intensity modulation desired, is connected in the discharge circuit of capacitance 10 between condenser 63 and ground potential.

In operation of the electrical arrangement disclosed in Fig. 4, device 13 is periodically rendered in an ionized state to periodically discharge capacitance 10 through the discharge circuit comprising inductance 15, filter network 16 and resistor 65 in a manner similar to operation of the impulse generator disclosed in Fig. 1. At each instant device 13 becomes ionized, a certain potential immediately appears across filter network 16 and resistor 65. The voltage across the filter network varies as a substantially linear function of time for the period $2\pi\sqrt{L_1C_1}$ and then abruptly decreases to zero potential, while the voltage across resistor 65 remains substantially constant during such period of time and then abruptly diminishes to zero potential. When the voltages across the filter network and the resistor diminish, device 13 is abruptly deionized and discharge of capacitance 10 is terminated. Since the high voltage terminal of filter network 16 is connected to a deflection plate 54, the electron beam of oscillograph 50 is linearly deflected whenever device 13 is ionized. The substantially constant voltage generated across resistor 65 is applied to control grid 53 to modulate the intensity of the electron beam during deflection thereof. A substantially linear sweep is thus produced on the viewing screen of oscillograph 50 which propagates at a high rate with great stability. This apparatus provides extremely efficient means for indicating irregular transient voltages since the linear sweep produced on the oscillograph is extremely uniform, and furthermore, since the electron beam is simultaneously modulated with a substantially constant potential.

Another embodiment of the invention is shown in Fig. 5 of the drawings. This embodiment discloses an electrical impulse generator, embodying the novel principles included in the generators described heretofore, in combination with other means whereby extremely high voltage electrical impulses are produced. The impulse generator is so characterized that the voltage of the impulses is a number of times greater than the voltage applied to the generator, and that the generator is capable of producing such impulses at an extremely rapid rate. Such an impulse generator has numerous applications, especially for applying high voltage impulses for controlling operation of ultra high frequency circuits, such as anode keying of ultra high frequency oscil-

lators. More particularly, the impulse generator comprises a plurality of potential storing devices which are charged with constant potential in parallel relation, with means for discharging the devices in series whereby an output voltage is obtained that is substantially greater than the input voltage by a factor equal to one-half the number of potential storing devices employed. The potential storing devices are periodically serially discharged through a discharge circuit having characteristics similar to the discharge circuits of the generators disclosed in Figs. 1 and 2 in order to maintain the discharge current substantially constant for a predetermined period of time following each instant the potential storing devices are discharged.

As shown, the impulse generator comprises a plurality of capacitances 70, 71, 72, 73 and 74 which are charged in parallel relation through choke coils 75 with a constant potential applied to input terminals 11 and 12. In order to serially discharge the capacitances, the high voltage terminal of capacitance 70 is adapted to be connected to the low voltage terminal capacitance 71, while the high voltage terminals of capacitances 71, 72 and 73 are respectively adapted to be connected to the low voltage terminals of capacitances 72, 73 and 74. A discharge apparatus 76 is provided for periodically forming the foregoing connections in synchronism whereby capacitances 70, 71, 72, 73 and 74 are periodically serially discharged. Apparatus 76 comprises a plurality of spark gap discharge devices 77, 78, 79 and 80 each of which respectively include an electrode 81, 82, 83 and 84 mounted on shaft 85 which is rotated at a predetermined constant speed by motor 86. Each of the spark gap discharge devices further include a pair of electrodes which cooperate with the rotary electrodes in such a manner that an electrical connection is formed therebetween upon rotation of shaft 85. Stationary electrode 87 of device 77 is connected to the high voltage terminal of capacitance 70 while the other stationary electrode 88 of the device is connected to the low voltage terminal of capacitance 71, while stationary electrodes 89, 91 and 93 of devices 78, 79 and 80 are respectively connected to the high voltage terminals of capacitance 71, 72 and 73 and stationary electrodes 90, 92 and 94 of the latter devices are respectively connected to the low voltage terminals of capacitances 72, 73 and 74. Upon rotation of motor 86, therefore, devices 77, 78, 79 and 80 are synchronously discharged to serially connect capacitances 70, 71, 72 and 73 and to thus apply the combined charges on the latter capacitances to capacitance 74. The high voltage terminal of capacitance 74 is connected through inductance 95 to stationary electrode 96 of spark gap discharge device 97. Device 97 includes electrode 98 mounted on shaft 85 for synchronous rotation with rotary electrodes 81, 82, 83 and 84. The other stationary electrode 99 of device 97 is connected to the electrical apparatus to which the output of the generator is applied. In the instant arrangement, an ultra-high frequency oscillator circuit 100, including vacuum tubes 101 and 102 is disclosed with the anodes of the tubes connected to electrode 99. The low potential terminal of the oscillator is connected to low voltage input terminal 12. Rotary electrodes 81, 82, 83, 84 and 98 are connected to ground potential through condensers 103 in order to accelerate discharge of the spark gap devices whereby extremely rapid operation of the generator is obtained.

In order to maintain the high voltage output of

spark gap device 97, that is, the voltage applied to oscillator 100, substantially constant for a predetermined period of time following the instant capacitances 70, 71, 72, 73 and 74 are serially discharged, means are included in the serial connections between capacitances 70, 71, 72, 73 and 74 for maintaining the discharge of the capacitances at a substantially constant rate during such predetermined period of time. Such means comprises the harmonic filter network 16 included in the generator shown in Figs. 1 and 2. In the instant arrangement, however, individual sections of the filter network are connected between the high voltage terminal of one capacitance and the low voltage terminal of the next capacitance of the series. Section 30 of filter network 16 is serially connected between capacitances 70 and 71, filter sections 30 and 31 are serially connected between capacitances 71 and 72 and between capacitances 72 and 73, while filter sections 33 and 34 are serially connected between capacitances 73 and 74. Filter sections 33 and 34 are serially connected in a single discharge circuit between a pair of capacitances in order to illustrate the use of more than one section in such circuits. In any event, the filter sections must necessarily be connected in series in accordance with the harmonic of the fundamental frequency, the resonant frequency of section 30, to which each of the sections is tuned. Filter sections 30, 31, 32, 33 and 34 function in a manner similar to operation of filter network 16 described heretofore to maintain an opposition to current flow therethrough that varies as a substantially linear function of time for a period of time equal to $2\pi\sqrt{L_1C_1}$, following the instant current initially flows therethrough. Also, the value of capacitances 35 are equal to one-half the series value of capacitances 70, 71, 72, 73 and 74 so that the discharge current through spark gap device 97 is maintained substantially constant for the period $2\pi\sqrt{L_1C_1}$, for reasons discussed heretofore.

Operation of the impulse generator as shown in Fig. 5 is similar to the operation of the generators described heretofore. At the instant spark gap discharge devices 77, 78, 79, 80 and 97 form an electrical connection between the stationary electrodes thereof, capacitances 70, 71, 72, 73 and 74 are serially discharged at a constant rate and a substantially constant potential, greater than the potential applied to terminals 11 and 12, is applied across the input and output terminals of oscillator 100 for a period of time equal to $2\pi\sqrt{L_1C_1}$. Choke coils 75 and inductance 95 have time constants equal to $2\pi\sqrt{L_1C_1}$ to prevent recharging of capacitances 70, 71, 72, 73 and 74 until the application of constant current terminates. Motor 86 is rotated at a speed determined by the rate of electrical impulses that are desired to be applied to oscillator 100.

A still further embodiment of the invention is shown in Fig. 6. This embodiment discloses an electrical arrangement for impulse operation of a magnetron oscillator circuit wherein the electrical as well as the magnetic fields of the magnetron are supplied with suitable voltages from a single source. The impulse generator disclosed in Fig. 6 incorporates the novel features of the generators previously described and includes capacitances 70, 71, 72 and 73 which are charged in parallel relation through choke coils 75 with a source of constant potential applied to input terminals 11 and 12. The capacitances are periodically serially discharged through filter net-

work 16 and a magnetron oscillator 110. Filter network 16 includes the novel characteristics mentioned heretofore, and capacitances 35 thereof are of values equal to one-half the series value of capacitances 70, 71, 72 and 73 so that the discharge current through the filter network, and hence through magnetron oscillator 110, remain substantially constant for the period $2\pi\sqrt{L_1C_1}$ following the instant capacitances are serially discharged.

As shown in this embodiment, capacitances 70, 71, 72 and 73 are serially discharged through gaseous tubes 111, 112 and 113, while the charge on capacitance 73 through filter network 16 and magnetron oscillator 110 is controlled by the gaseous tube 114. The anodes of gaseous tubes 111, 112 and 113 are connected to the high voltage terminals of capacitance 70, 71 and 72 respectively, while the cathodes of the tubes are respectively connected to the low voltage terminals of capacitances 71, 72 and 73. The cathodes of tubes 111, 112 and 113 are supplied with a source of synchronizing voltage from transformer 115, through choke coils 116, while the control grids of the tubes are connected together through resistances 117 and are supplied with the output of transformer 115 through resistance 118 and through condenser 119. With the foregoing arrangement, tubes 111, 112 and 113 are ionized in accordance with the output of transformer 115, resistance 118 and condenser 119 properly phasing the voltage supplied to the control grids of the tubes in such a manner that the tubes are ionized when the output voltage of transformer 115 is passing a null point. Furthermore, with this arrangement, a single source is employed for supplying the cathode voltage as well as for synchronous keying the tubes. Since the control grids of the tubes are inter-connected by way of resistances 117, whenever one of the tubes is ionized the grids of the other tubes are driven positive to render the latter tubes in an ionized state and thus obtain substantially synchronous discharge of the tubes. Condensers 120 are connected across the input and output of each of tubes 111, 112 and 113 in order to accelerate ionization of the tubes and to thus further maintain synchronous discharge thereof. Filter network 16 is serially connected between the high potential terminal of capacitance 73 and the anode of tube 114, while magnetron oscillator 110 is serially connected between cathode of tube 114 and low potential input terminal 12. The control grid of tube 114 is connected to the grids of the other discharge tubes through a resistance 117, and the cathode thereof is supplied with voltage from transformer 115 through choke coils 116, so that tube 114 is ionized in synchronism with ionization of tubes 111, 112 and 113. The magnetron oscillator 110 comprises a magnetron yoke 121 for producing the magnetic field, anodes 122 for producing electrical field and cathode 123. Magnetic yoke 121 and anodes 122 are serially connected to the output of tube 114, while cathode 123 is connected to low potential input terminal 12.

In operation of the impulse generator disclosed in Fig. 6, capacitances 70, 71, 72 and 73 are charged in parallel relation from a constant potential applied to terminals 11 and 12, and are serially discharged through filter network 16 and magnetron oscillator 110 in a periodic manner controlled by synchronizing source applied to transformer 115. Whenever gaseous tubes 111, 112, 113 and 114 are synchronously ionized, in

accordance with the output of transformer 115, capacitances 70, 71 and 72 are serially discharged and the combined charge on the latter capacitances are applied to capacitances 73. The increased charge on capacitance 73 is supplied through filter 16 to magnetron oscillator 110 by way of gaseous tube 114. Due to the characteristics of filter network 16 and the relationship between capacitances 35 thereof and the values of capacitances 70, 71, 72 and 73, the latter capacitances are discharged at a constant rate for a period of time equal to $2\pi\sqrt{L_1C_1}$ following the instant tubes 111, 112, 113 and 114 synchronously discharge. During such period of time, therefore, substantially constant current flows through magnetic yoke 121, anodes 122 and cathode 123 thus applying substantially constant potential thereto for producing equal magnetic and electrical fields in the magnetron oscillator. Choke coils 75 and 116 have time constants substantially equal to or greater than, the time interval $2\pi\sqrt{L_1C_1}$ to prevent charging of capacitances 70, 71, 72 and 73 during the period of constant current application, and so that tubes 111, 112, 113 and 114 are abruptly de-ionized after lapse of such period.

There is thus provided by the present invention novel electrical impulse generators for producing high voltage electrical impulses of rectangular and saw-tooth wave forms. The impulse generators are so characterized that the same are capable of operating in such a manner to produce electrical impulses at an extremely high rate whereby the same may be employed for controlling operation of ultra-high frequency electrical equipment. Moreover, the present invention provides apparatuses for effectively indicating irregular transient voltages, as well as a novel electrical arrangement for periodically applying high voltage rectangular impulses to a magnetron oscillator in such a manner that the magnetic as well as the electrical fields thereof are simultaneously produced thus allowing such oscillator to operate at high efficiency and stability.

Although several embodiments of the invention have been described and disclosed herein, it is to be expressly understood that various changes and substitutions may be made therein without departing from the spirit of the invention as well understood by those skilled in the art. Reference therefore will be had to the appended claims as a definition of the limits of the invention.

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

What is claimed is:

1. In an electrical impulse generator, a condenser, means charging said condenser with a source of potential, a discharge circuit including bilateral impedance means having an opposition to current flow therethrough that varies as a substantially linear function of time for a predetermined period of time following the instant current initially flows therethrough, and means discharging said condenser through said circuit, the capacity of said condenser and the value of said impedance means having a predetermined relationship to maintain substantially constant flow of current from said condenser through said circuit for said predetermined period of time following the instant said condenser is discharged

through said circuit, whereby said condenser discharges at a constant rate during such predetermined period of time.

2. In an electrical impulse generator, a condenser, means applying a source of constant potential to said condenser, a discharge circuit including a load impedance and capacitance means in series therewith, said discharge circuit so characterized as to offer an opposition to flow of current therethrough that varies as a substantially linear function of time for a predetermined period of time following the instant current initially flows therethrough, and means discharging said condenser through said circuit, the capacity of said condenser and the value of said capacitance means being so related that the flow of current from said condenser through said circuit remains substantially constant for said predetermined period of time following the instant said condenser is discharged through said circuit whereby said condenser discharges at a constant rate for such predetermined period of time.

3. In an electrical impulse generator, a condenser, means applying a source of constant potential to said condenser, a discharge circuit including a load impedance and capacitance means in series therewith, said discharge circuit so characterized as to offer an opposition to flow of current therethrough that varies as a substantially linear function of time for a predetermined period of time following the instant current initially flows therethrough, and means discharging said condenser through said circuit, said condenser having a capacity twice the value of said capacitance means for maintaining the current flow from said condenser through said circuit substantially constant for said predetermined period of time following the instant said condenser is discharged through said circuit whereby said condenser discharges at a constant rate for such predetermined period of time.

4. In an electrical impulse generator, a condenser, means applying a source of constant potential to said condenser, a discharge circuit including a load impedance and capacitance means in series therewith, said discharge circuit so characterized as to offer an opposition to flow of current therethrough that varies as a substantially linear function of time for a predetermined period of time following the instant current initially flows therethrough, and means to periodically discharge said condenser through said circuit, the capacity of said condenser and the value of said capacitance means being so related that the flow of current from said condenser through said circuit remains substantially constant for said predetermined period of time following the instant said condenser is discharged through said circuit whereby said condenser discharges at a constant rate for such predetermined period of time in a periodic manner.

5. In an electrical impulse generator, a condenser, means applying a source of constant potential to said condenser, a discharge circuit including a load impedance and capacitance means in series therewith, said discharge circuit so characterized as to offer an opposition to flow of current therethrough that varies as a substantially linear function of time for a predetermined period of time following the instant current initially flows therethrough, and means responsive to an external synchronizing source for periodically discharging said condenser, said condenser having a capacity twice the value of said capacitance means for maintaining the current flow

from said condenser through said circuit substantially constant for a predetermined period of time following the instant said condenser is discharged through said circuit whereby said condenser discharges at a constant rate for a predetermined period of time in a periodic manner determined by said synchronizing source.

6. In an electrical impulse generator, a condenser, means charging said condenser with a source of potential, a discharge circuit including a load impedance and capacitance means in series therewith connected to said condenser, said discharge circuit being so characterized as to offer an opposition to flow of constant current therethrough that varies substantially as a linear function of time for a predetermined period of time following the instant constant current initially flows therethrough, an electron discharge device included in said circuit for controlling the discharge of said condenser, and means periodically rendering said device conducting for periodically discharging said condenser through said circuit, the capacity of said condenser and the value of said capacitance means being so related that the flow of current from said condenser through said circuit remains substantially constant for said predetermined period of time following each instant said condenser is discharged through said circuit whereby said condenser discharges at a constant rate for such predetermined period of time in a periodic manner.

7. In an electrical impulse generator, a condenser, a charging circuit for applying a constant potential to said condenser, a discharge circuit including capacitance means connected to said condenser, said discharge circuit being so characterized as to offer an opposition to flow of constant current therethrough that varies as a substantially linear function of time for a predetermined period of time following the instant current initially flows therethrough, an electron discharge device included in said circuit for controlling the discharge of said condenser, means periodically rendering said device conducting for periodically discharging said condenser through said circuit, the capacity of said condenser and the value of said capacitance means being so related that the flow of current from said condenser through said circuit remains substantially constant for said predetermined period of time following the instant said condenser is discharged through said circuit, means rendering said device non-conducting after lapse of said predetermined period of time, and time delay means included in said charging circuit for preventing application of constant potential to said condenser during said predetermined period of time.

8. In an electrical impulse generator, a condenser, means applying a source of constant potential to said condenser, a discharge circuit connected to said condenser, said discharge circuit including a series of capacitance and inductance combinations so characterized as to offer an opposition to flow of current therethrough that varies as a substantially linear function of time for a predetermined period of time following the instant current initially flows therethrough, and means discharging said condenser through said circuit, the capacity of said condenser and the value of said capacitance means being so related that the flow of current from said condenser through said circuit remains substantially constant for said predetermined period of time following the instant said condenser is discharged through said circuit whereby said condenser dis-

charges at a constant rate for such predetermined period of time.

9. In an electrical impulse generator, a condenser, means applying a source of constant potential to said condenser, a discharge circuit connected to said condenser, said discharge circuit including a plurality of capacitance and inductance combinations tuned to different frequencies and connected in harmonic relation to offer an opposition to current flow therethrough that varies as a substantially linear function of time for a predetermined period of time following the instant current initially flows therethrough, and means discharging said condenser through said circuit, the capacity of said condenser and the value of said capacitance means having a predetermined relationship to establish a substantially constant flow of current from said condenser through said circuit for said predetermined period of time following the instant said condenser is discharged through said circuit whereby said condenser discharges at a constant rate for such predetermined period of time.

10. In an electrical impulse generator, a condenser, means charging said condenser with a source of constant potential, a discharge circuit connected to said condenser, said discharge circuit including a filter network having capacitance means and being so characterized to maintain an opposition to the flow of current therethrough that varies as a substantially linear function of time for a predetermined period of time following the instant current initially flows therethrough, means discharging said condenser through said circuit, and said condenser having a capacity twice the value of said capacitance means for maintaining the current flow from said condenser through said circuit substantially constant for said predetermined period of time following the instant said condenser is discharged through said circuit whereby the voltage generated across said filter varies as a substantially linear function of time during such predetermined period of time.

11. In an electrical impulse generator, a condenser, means charging said condenser with a source of constant potential, a discharge circuit connected to said condenser, said discharge circuit including a filter network having a plurality of parallel connected capacitances and inductances tuned to different frequencies and serially connected in harmonic relation to maintain an opposition to the flow of current therethrough that varies as a substantially linear function of time for a predetermined period of time following the instant current initially flows therethrough, means discharging said condenser through said circuit, and said condenser having a capacity twice the value of said capacitance means for maintaining the current flow from said condenser through said circuit substantially constant for said predetermined period of time following the instant said condenser is discharged through said circuit whereby the voltage generated across said filter varies as a substantially linear function of time during such predetermined period of time.

12. In an electrical impulse generator, a condenser, means applying a source of potential to said condenser, a discharge circuit including a filter network and an impedance, said filter network including capacitance means and so characterized as to offer an opposition to the flow of current therethrough that varies as a substantially linear function of time for a predetermined period of time following the instant cur-

rent initially flows therethrough, means periodically discharging said condenser through said circuit, the capacity of said condenser and the value of said capacitance means being so related that the flow of current from said condenser through said circuit remains substantially constant for said predetermined period of time following the instant said condenser is discharged through said circuit whereby a substantially linearly varying voltage is generated across said filter and a substantially constant potential is generated across said impedance during said predetermined period of time.

13. In an electrical impulse generator, a condenser, means charging said condenser with a source of constant potential, a discharge circuit connected to said condenser, means discharging said condenser through said circuit, and bilateral impedance means included in said circuit for maintaining an opposition to current flow therethrough that varies as a substantially linear function of time for a predetermined period of time following the instant current initially flows therethrough, the last-named means having a predetermined relationship with the capacity of said condenser to maintain substantially constant current flow from said condenser through said circuit for said predetermined period of time.

14. In an electrical impulse generator, a plurality of condensers, means charging said condensers in parallel relation with a source of constant potential, a discharge circuit including a load impedance and impedance means in series therewith to maintain an opposition to current flow therethrough that varies as a substantially linear function of time for a predetermined period of time following the instant current initially flows therethrough, and means serially discharging said condensers through said discharge circuit, the capacities of said condensers and the value of said impedance means having a predetermined relationship to maintain substantially constant flow of current from said condensers through said circuit for said predetermined period of time.

15. In an electrical impulse generator, a plurality of condensers, means charging said condensers in parallel relation with a source of constant potential, a load impedance, and a discharge circuit for serially discharging said condensers through said load impedance, said discharge circuit including impedance means in series with the load impedance to maintain an opposition to current flow through said circuit that varies as a substantially linear function of time for a predetermined period of time following the instant current initially flows therethrough, the capacities of said condensers and the value of said impedance means having a predetermined relationship to maintain substantially constant flow of current from said condensers through said circuit for said predetermined period of time following the instant said condensers are serially discharged through said circuit whereby a substantially constant potential, greater than said constant potential, is maintained across said load impedance for said predetermined period of time.

16. In an electrical impulse generator, a plurality of condensers, means charging said condensers in parallel relation with a source of constant potential, an impedance, a discharge circuit including impedance means for serially discharging said condensers through said imped-

ance, said impedance means including a plurality of capacitance and inductance combinations to maintain an opposition to current flow through said circuit that varies as a substantially linear function of time for a predetermined period of time following the instant current initially flows therethrough, the capacities of said condensers and the value of said impedance means having a predetermined relationship to maintain substantially constant flow of current from said condensers through said circuit for said predetermined period of time following the instant said condensers are serially discharged through said circuit whereby a substantially constant potential, greater than said constant potential, is maintained across said impedance for said predetermined period of time.

17. In an electrical impulse generator, a plurality of condensers, means charging said condensers in parallel relation with a source of constant potential, an impedance, a discharge circuit including impedance means for serially discharging said condensers through said impedance, said impedance means including a plurality of capacitance and inductance combinations tuned to different frequencies and serially connected in harmonic relationship to maintain an opposition to current flow through said circuit that varies as a substantially linear function of time for a predetermined period of time following the instant current initially flows therethrough, the capacities of said condensers and the value of said impedance means being so related that the flow of current from said condensers through said circuit remain substantially constant for said predetermined period of time following the instant said condensers are serially discharged through said circuit whereby a substantially constant potential, greater than said constant potential, is maintained across said impedance for said predetermined period of time.

18. In an impulse generator, a plurality of condensers, means charging said condensers in parallel relation from a source of constant potential, and means discharging said condensers through an impedance to maintain a substantially constant potential across said impedance for a predetermined period of time, the last-named means including means for synchronously forming electrical connections between said condensers to synchronously discharge said condensers in series, impedance means included in series in each of said connections, each of said impedance means having a predetermined relationship with the impedance means included in the other connections to maintain an opposition to current flow through said serially connected condensers that varies as a substantially linear function of time for a predetermined period of time following the instant said condensers are serially discharged, and the value of said impedance means having a predetermined relationship with the capacities of said condensers to maintain the discharge of said condensers at a constant rate for such predetermined period of time.

19. In an impulse generator, a plurality of condensers, means charging said condensers in parallel relation with a source of constant potential, and means discharging said condensers through an impedance in such a manner as to maintain a substantially constant potential across said impedance for a predetermined period of time, the last-named means including means for synchronously forming electrical connections be-

tween said condensers in such a manner as to synchronously discharge said condensers in series, impedance means included in each of said connections, each of said impedance means comprising inductance and capacitance combinations tuned to different frequencies and so related to the other impedance means to maintain an opposition to current flow through said serially connected condensers that varies as a substantially linear function of time for a predetermined period of time following the instant said condensers are serially discharged, and the value of said impedance means being so related to the capacities of said condensers to maintain the discharge of said condensers at a constant rate for such predetermined period of time.

20. In combination with an oscillator circuit, a plurality of condensers, means charging said condensers in parallel relation with a source of constant potential, and means discharging said condensers through said oscillator circuit to maintain a substantially constant potential across said circuit for a predetermined period of time, the last-named means including means for synchronously forming electrical connections between said condensers to synchronously discharge said condensers in series, impedance means included in series in each of said connections, each of said impedance means having a predetermined relationship to the impedance means included in the other connections to maintain an opposition to current flow through said serially connected condensers that varies as a substantially linear function of time for a predetermined period of time following the instant said condensers are serially discharged, and the value of said impedance means having a predetermined relationship to the capacities of said condensers to maintain the discharge of said condensers at a constant rate for such predetermined period of time.

21. An impulse generator comprising charge storage means, a load impedance and, means for discharging the charge storage means through the load impedance including in series a circuit having a resonant period twice the discharge time.

22. An impulse generator comprising charge storage means, a load impedance, and means for discharging the charge storage means through the load impedance, including in series a plurality of inductance-capacity networks resonant at different frequencies.

23. An impulse generator comprising charge storage means, a load impedance, and means for discharging the charge storage means through the load impedance including in series a plurality of inductance-capacity networks resonant at frequencies substantially harmonically related.

24. An impulse generator comprising charge storage means, a load impedance and means for discharging the stored charge through the load impedance comprising resonant circuit means transiently operative under shock excitation to control the discharge current during the discharge period.

25. An intermittent high frequency wave group generating system having a vacuum tube oscillator and a power supply circuit therefor comprising a charge storing circuit, means charging the charge storing circuit with a constant potential, and means periodically connecting the storage circuit to the vacuum tube oscillator comprising a rotary spark gap.

26. An electrical impulse generator comprising a circuit having a plurality of condensers connected in parallel, means including a plurality of spark gaps each disposed in series connection with respect to said condensers, means to supply energy to said condensers, means to control breakdown of said gaps to effect discharge of the energy stored in said condensers in series additive relation through said gaps to produce a large discharge impulse, an output load resistance, an inductance coil in series between said spark gaps and said output load resistance to control the rise-to-decay time ratio of the produced impulse.

27. The generator defined in claim 26 wherein the gap breakdown control means comprises means to control the spacing of the gaps.

28. A system for generating regularly repetitive high voltage electrical pulses comprising a plurality of condensers and discharge devices connected alternately in series, means for charging the condensers to a voltage below the breakdown voltage of said discharge devices including a source of charging energy connected to said condensers in parallel, a source of low voltage electrical triggering pulses, a vacuum tube comprising a cathode, a control grid and an anode, means for connecting said source of low voltage electrical pulses to said grid, and means for connecting said cathode and anode to the respective terminals of one of said condensers.

29. A system for generating electrical pulses as set forth in claim 28, in which said charging source is connected to supply said anode of said vacuum tube with a high potential.

30. An electrical impulse generator comprising a circuit having a plurality of energy storage

means connected in parallel, means including a plurality of voltage discharge means each disposed in series connection with respect to said energy storage means, means to supply energy to said energy storage means, means to control breakdown of said voltage discharge means to effect discharge of the energy stored in said voltage storage means in series additive relation through said voltage discharge means to produce a large discharge impulse, a load impedance, and inductance means in series between said voltage discharge means and said load impedance to control the rise-to-decay time ratio of the produced impulse.

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