

Oct. 7, 1947.

R. G. CLAPP

2,428,616

ELECTRICAL PROTECTIVE DEVICE

Filed Nov. 2, 1943

2 Sheets-Sheet 1

FIG. 1.

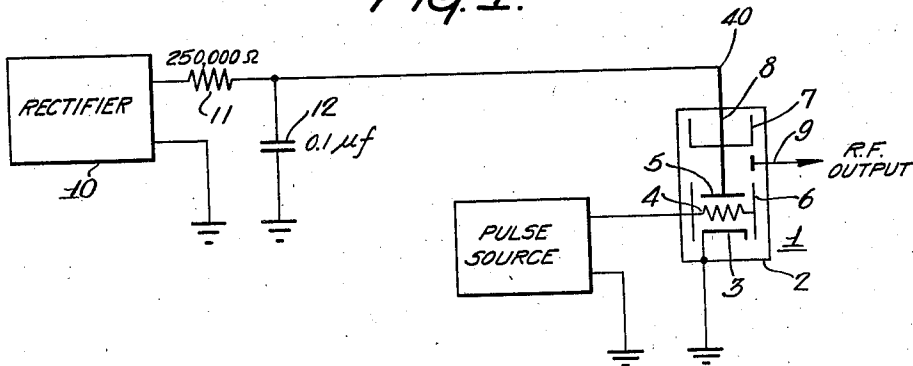


FIG. 2.

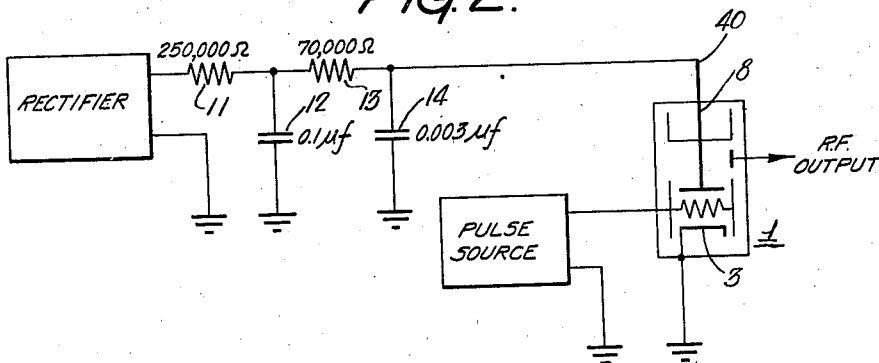
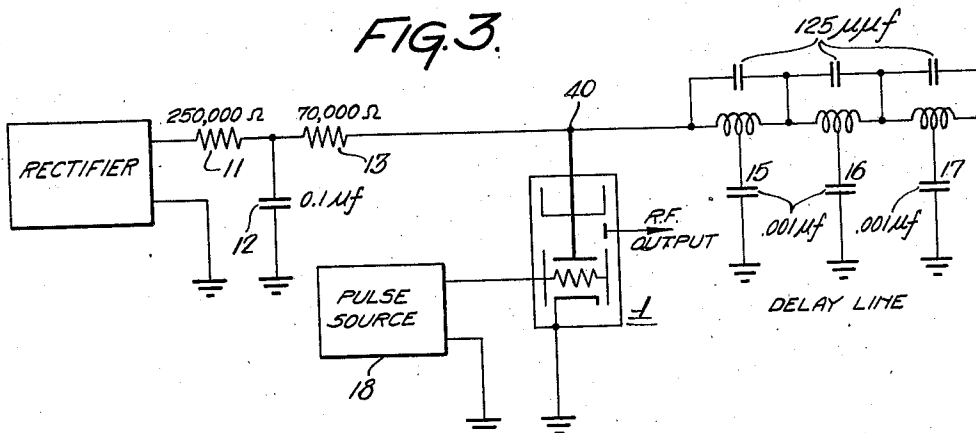


FIG. 3.



Inventor:
Richard G. Clapp
by his Attorneys
Houson + Houson

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FIG. 4.

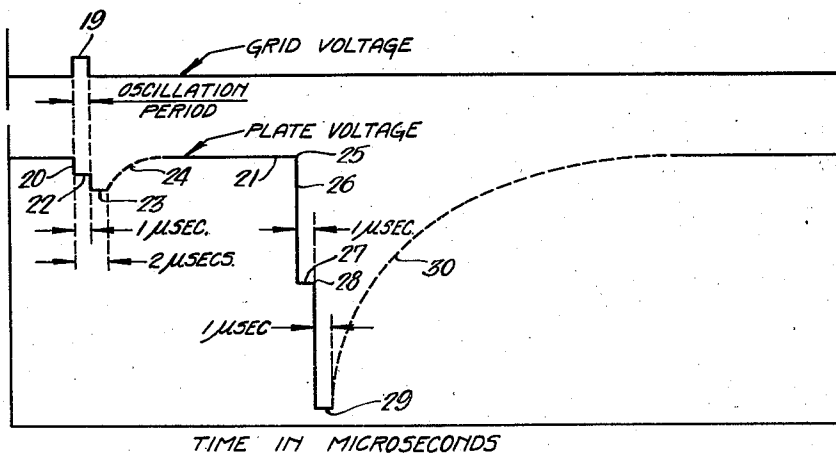
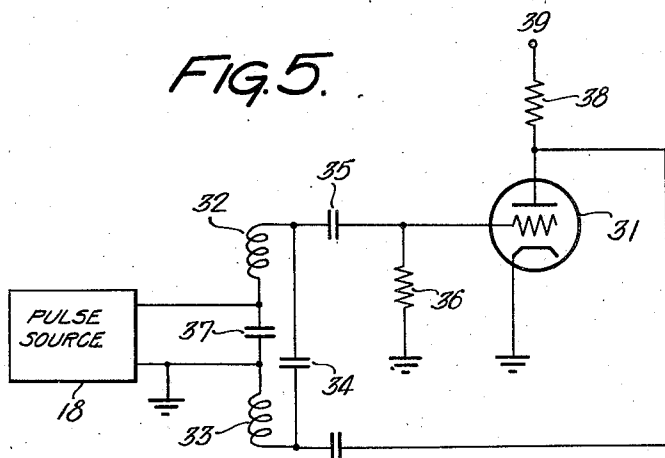


FIG. 5.



Inventor:
Richard G. Clapp
by his Attorneys
Howson + Howson

UNITED STATES PATENT OFFICE

2,428,616

ELECTRICAL PROTECTIVE DEVICE

Richard G. Clapp, Haverford, Pa., assignor, by
mesne assignments, to Philco Corporation,
Philadelphia, Pa., a corporation of Pennsyl-
vania

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4 Claims. (Cl. 250—27)

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This invention relates to a method and means for protecting electrical devices and circuits from the deleterious effects of arcing or spark-over. More particularly, the invention relates to a circuit arrangement for utilizing a delay line as a means for swiftly clearing high voltage electrical systems of undesired or fortuitous electric arcs. The present invention has been found particularly useful as a means for protecting space discharge devices, and particularly high voltage vacuum tubes, from damage resulting from inter-electrode spark-over.

In the construction of light-weight, portable, radio detecting and ranging equipment (Radar), it has been found expedient to utilize, as the source of high frequency pulse signals (interrupted continuous waves), a small oscillator triode having its electrodes very closely spaced so as to decrease electron transit time as much as possible, and thus permit use of the device at very high frequencies. In order to derive substantial amounts of power from such tubes, it is customary to operate them at very high plate voltages, so high in fact, that arcing within the tube frequently occurs, ultimately destroying the tube, or at least unduly shortening its life.

In consequence of this difficulty it has been customary to operate these tubes in accordance with the known plate pulsing method, wherein the high voltage plate potential is applied to the tube only during the brief pulse intervals during which carrier energy is actually generated. In conventional Radar equipment the pulse duration may be of the order of one microsecond, and the pulses may occur at the rate of 1000 per second, there being an interval of about 1000 microseconds between pulses. Thus it will be seen that during, say 99.9% of the time no spark-over can occur since the tube is not then subjected to operating plate potentials. Moreover, in the event that spark-over should occur during one of the short pulse periods, the ensuing arc will be quickly extinguished by the normal termination of the said period. Consequently, when plate pulsing is employed, spark-over has not proved to be a serious problem.

In the grid-pulsed mode of operation, however, spark-over and arcing have given substantial trouble, since in this system the cathode-anode circuit of the tube is permanently connected to the high voltage source, the tube being turned on and off at the desired rate by the application of a suitable pulse- or switching-signal to the control grid. Since the arc within the tube, e. g. between plate and cathode, cannot be terminated

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by the signal applied to the control grid, the arc may persist until the tube is destroyed, or at least until its emission is seriously reduced. In practice, such spark-over usually occurs intermittently, gradually gaining in frequency until the tube is either physically destroyed or otherwise rendered useless, usually by destruction of the cathode.

In accordance with the present invention, means are provided for extinguishing inter-electrode arcs within such a short time of their institution that no appreciable damage results therefrom. Through the practice of this invention the use of grid-pulsed high voltage space discharge devices is made feasible, and the advantages of grid pulsed operation made available for practicable utilization.

It is a principal object of the present invention to provide an electric circuit means which, in response to the occurrence of an undesired electric arc, or spark-over, shall act automatically to quench or extinguish the arc.

It is a further object of the invention to provide an arc quenching means whose presence shall have no substantial effect upon the normal operation of the system in which it is employed.

It is another object of the invention to provide an arc quenching device in which means are provided for delaying the operation of the device so that it shall exert no substantial effect upon pulse signals of predetermined duration to which the quenching device is normally subjected.

It is still another object of the invention to provide an arc quenching circuit having novel means for reducing the arc-producing voltage to such a low level that the arc is no longer sustained.

Other objects and features of the invention will become apparent hereinafter. The invention itself will best be understood by reference to the following drawings, in which

Figure 1 is a schematic diagram of a grid-pulsed RF oscillator circuit constructed in accordance with the prior art;

Figure 2 is a schematic diagram of an improved grid-pulsed RF oscillator having certain of the features of the present invention;

Fig. 3 is a schematic diagram of a preferred embodiment of the invention;

Fig. 4 is a diagram used in explaining the operation of the circuit of Fig. 3; and

Fig. 5 is an alternative form of oscillator which may be substituted for the oscillator of Figs. 1, 2, or 3.

It is believed that the present invention will

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best be understood if reference is first made to Fig. 1, which illustrates a grid-pulsed ultra high frequency oscillator circuit of a type preceding the present invention. The source 1 of ultra high frequency (UHF) or radio frequency (RF) oscillations is here shown to consist of a triode oscillator mounted in a suitable oscillator cavity 2. The triode comprises a cathode element 3, a grid 4, and a plate 5. The triode may be of a type known as a "lighthouse tube" (e. g. type 464-A) in which the cathode, grid, and plate electrodes are arranged in closely adjacent parallel planes, and are generally circular or disk-like in form. Inside the cavity 2 there may be provided a suitable grid cylinder 6 which is physically supported by the peripheral portion of the grid 4, and electrically connected thereto. A plate choke 7 is usually associated with the central conductor or "plate pillar" 8 which runs down the cavity 2 to the plate 5. The cathode 3 is electrically connected to the base of the cavity as shown. The oscillator 1 provides a UHF oscillation, the frequency of which depends upon the design and dimensions of the cavity. An output signal may be derived by inserting a suitable probe 9, capacitive, inductive, or conductive, into the cavity in a manner well understood in the art.

Plate voltage may be supplied to the cavity oscillator from any suitable high voltage source, such for example as the high voltage rectifier 10. The necessary filtering may be provided, for example, by a suitable filter section comprising the series resistor 11 and the shunt condenser 12.

The cavity oscillator 1 may be switched periodically from an inactive or non-oscillating condition to an operative or oscillating condition by the application to the control grid 4 of a suitable switching signal, so as to provide, in the output of the oscillator, an interrupted carrier wave signal. The switching signal may be derived from a suitable pulse source, so designated in the drawing. In a typical form of the system the oscillator may be switched on-and-off at the rate of 1000 times per second, each operative period being of the order of one microsecond.

In systems of the character described it is usual to employ plate voltages of an unusually high order considering the size and spacing of the elements and tube electrodes involved. It is not uncommon to employ plate voltages of the order of 3000 volts, even though the electrode spacing in the triode is very materially less than that which is customary in tubes ordinarily operated at no more than 250 volts. In consequence, as already indicated, internal spark-over or arcing is frequently encountered, the arc occurring between the plate and grid, or between the plate, grid, and cathode. In the event of an arc, and in the absence of means for extinguishing the arc, all of the electrical energy stored in the filter condenser 12 is discharged through the tube. If the filter section employs circuit components adequate properly to filter the output of the rectifier 10, e. g. a shunt output filter condenser of 0.1 microfarad, there will ordinarily be sufficient electrical energy in the output condenser to damage the tube rather seriously. Continued repetition of such arcing may either destroy the tube, or render it otherwise useless.

In accordance with one embodiment of the invention, and as illustrated in Fig. 2, a current-limiting resistor 13 is connected between the output of the filter (i. e. the juncture of resistor 11 and condenser 12) and the plate pillar 8. In addition a relatively small condenser 14 is connected

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between the plate-end of the resistor 13 and the cathode 3 of the oscillator triode, in this case ground. The condenser 14 is charged to rated output voltage (e. g. 3000 volts) during the relatively long period between pulses, and it should be of just sufficient capacity to enable it to deliver substantially rated plate voltage to the oscillator triode throughout the oscillating period (e. g. 1 microsecond). Where a type 464-A tube is used, with 3000 volts on the plate, the condenser may have to supply about 0.7 ampere at substantially rated voltage for about one microsecond. It is inevitable, of course, that, during the period of oscillation, i. e. during the load period, the voltage across the condenser will vary (i. e., fall) as energy is taken from the condenser by the triode. However, so long as the voltage is not permitted to drop more than, say 5%, no undesired results will be experienced. If the voltage varies too greatly during the oscillating period undesired frequency modulation of the generated carrier is apt to occur. Between pulses the condenser is recharged to rated voltage through the current limiting resistor 13.

In the device of Fig. 2 a series resistor 13 of 70,000 ohms may be utilized, together with a shunt condenser 14 of 0.003 microfarad.

In the event that a spark or arc should occur, the energy in the condenser 14 will discharge through the triode, and this discharge will be accompanied by a rapid fall in condenser voltage. When this voltage has fallen sufficiently, the arc is no longer sustained. Once the arc is extinguished normal conditions are rapidly restored, the voltage on the condenser returning to normal after an interval determined by the time constant of the resistor-condenser combination 13-14. It will be noted that the arc in the triode cannot be sustained directly by the voltage across filter condenser 12 because the series current-limiting resistor 13 limits the instantaneous current which can be derived from that source to a very low value.

With regard to the circuits of Figs. 1 and 2, and with particular reference to the circuit constants there indicated, it is to be noted that by resorting to the present invention it has been possible to reduce the size of the condenser immediately in shunt with the oscillator by a factor of $\frac{1}{3}$. It therefore follows that the electrical energy available in the system of Fig. 2, in the event of an arc, is only about $3\frac{1}{3}\%$ of that present in the circuit of Fig. 1.

While the embodiment of Fig. 2 represents a substantial advance over the system of Fig. 1, it leaves much to be desired in systems where it is important or essential that the plate voltage be maintained invariable throughout the oscillation period. In the preferred embodiment, illustrated in Fig. 3, a construction is provided which combines the protective features of Fig. 2, together with the advantage of a plate current source whose voltage remains at a predetermined, substantially fixed level throughout the oscillation period. In this embodiment the current limiting resistor 13 of Fig. 2 is retained, but in place of the condenser 14 there is provided a suitable delay line, so designated in the drawing, whose remote end is preferably open circuited as illustrated, or terminated in an impedance which is high compared to the characteristic impedance of the line. Preferably the line is one comprising series inductance and shunt capacitance elements, and the simplest lines of this character are suitable. In the design of the

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artificial line, resort may be had to conventional line theory, the principal requirements being that the line's characteristic impedance be preferably as purely resistive as design considerations permit. Preferably also the characteristic impedance is kept reasonably low for a reason which will appear hereinafter. In one physical embodiment of the invention a characteristic impedance of 150 ohms was found satisfactory. In this particular embodiment the line consisted of three identical bridged-T sections, each section comprising a series inductance of 17 microhenries bridged by a condenser of 125 micromicrofarads, with a 0.001 microfarad shunt condenser connected between the midpoint of the inductance and the other side of the line, in this instance ground. This particular line was chosen because it provided a practically constant delay over most of the frequency band occupied by the pulse signals applied to the input circuit of the oscillator.

While the circuit of Fig. 3 has an important attribute not possessed by that of Fig. 2, to be explained hereinafter, the circuit of Fig. 3 protects the oscillator triode from damage due to spark-over in much the same way as that of Fig. 2 in that in the event of spark-over the only energy available to pass through the tube in any appreciable quantity is that available on the three shunt condensers 15, 16, and 17. These condensers should be only of such magnitude that they are enabled to supply the normal requirements of the oscillator during the oscillation period, their initial charge being restored during the relatively long inactive period between pulses. It may be noted that in Fig. 3 the sum of the capacities of the three shunt condensers 15, 16, and 17 is equal to the capacity of the single shunt condenser 14 of Fig. 2.

The peculiar operation of the delay line system, which distinguishes it from the operation of Fig. 2, may best be explained by referring to the diagram of Fig. 4. In the upper portion of the drawing there is shown a graph of the grid signal voltage. This voltage, which is in the form of a switching-signal, is derived from the pulse source 18, and applied to the control grid of the oscillator triode to control the oscillation thereof. During the inactive period, which may comprise 99.9% of a complete operating cycle, the source 18 (Fig. 3) supplies an output voltage which is sufficiently negative to bias the oscillator below plate current cutoff. During the oscillation period the source 18 supplies a square pulse 19 (Fig. 4) which drives the oscillator grid sufficiently positive to permit oscillation during what is referred to as the oscillation period. In Fig. 4, for purposes of illustration, this period is of 1 microsecond duration.

Although the artificial delay line is physically very short, the oscillation period of one microsecond expires before the reflected plate current pulse returns to the input end, or simultaneously therewith, and consequently, although the far end of the line is open-circuited, the impedance seen looking into the line, during the short oscillation period, is the characteristic, or surge, impedance of the line. Since the line is now effectively the source of plate current (due to the charge residing in the condensers 15, 16, and 17) the plate current source appears to have an internal impedance equal to the characteristic impedance of the line. In the physical embodiment hereinbefore discussed, this impedance amounted

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to 150 ohms, and since, during the oscillation period the triode draws 0.7 ampere, the plate voltage is diminished by about 150×0.7 volts, i. e. by approximately 100 volts, during this period. This drop is indicated in Fig. 4 by the portion 20 of the plate voltage graph 21. Since the characteristic impedance of the delay line is substantially pure resistance the voltage drops almost instantaneously, and then remains constant at the level 22 during the oscillation period. Because of this the oscillator triode is enabled to operate at constant plate voltage, and consequently undesired frequency modulation effects are largely avoided.

From the foregoing it will be evident that, by choosing a delay line having not too high a characteristic impedance, no substantial drop in plate voltage is effected by operation of the oscillator. In the example under consideration the drop of 100 volts, from an initial value of 3000 volts, is not regarded as substantial. This is particularly true since the operating plate voltage level of 2900 remains fixed throughout the oscillation period.

Preferably the delay line is of such length that at the conclusion of the oscillation period, or shortly thereafter, the pulse of plate voltage, which occurred across the input terminals of the line at the start of the oscillation period, returns—after reflection from the open-circuited end of the line—to the input terminal of the line. Since the return pulse is in the same polarity as the initiating pulse it also produces an effective lowering of the plate voltage. If the oscillation period terminates at precisely the instant that the reflected pulse returns (as shown in Fig. 4), and if the losses in the delay line are small, as is preferred, the returning pulse will approach, in magnitude, twice the magnitude of the initiating pulse. In the case under consideration the initiating pulse (i. e. the plate voltage drop) had an amplitude of approximately 100 volts, represented by the voltage drop 20, and consequently the voltage drop produced by the reflected pulse is represented by the difference between the normal voltage level and that represented at 23. This new voltage level persists without substantial change for the duration of the original pulse, i. e. 1 microsecond, after which the voltage returns to normal along a path 24 which approximates the discharge curve of a condenser, but which may vary therefrom depending upon the characteristics of the particular line employed.

When it is desired that the front of the reflected pulse shall return at precisely the instant that the oscillation period terminates, as illustrated in Fig. 4, the delay line should be of such length that its delay time (the time required for an impulse to travel from one end of the line to the other) is substantially equal to one-half the oscillation period.

Let us now assume that, at the instant designated 25, an arc occurs between the anode and cathode of the oscillator tube of Fig. 3. The sudden imposition of a heavy load (which may approach a short circuit in magnitude) upon the effective source of plate current, i. e. the delay line, causes a sudden and very considerable drop in plate voltage, as indicated by the falling portion 26 of the plate voltage graph. A new voltage level 27 is then maintained until the instant 28 at which time the reflected pulse returns from the end of the line and drives the plate voltage still farther down, reaching the new level designated 29. This level may be of the order of zero

volts, or it may be above or even below zero, the precise magnitude of the reflected pulse depending upon a number of factors such as the plate impedance of the tube during the arc, the design and losses of the delay line, and possibly other factors. In any event the plate voltage in a properly constructed system will fall so low that the arc can no longer be maintained, with the result that the tube is speedily cleared of the undesired condition. Shortly after the voltage level 29 is reached, the voltage again returns to normal along a path 30 which approximates the discharge curve of a condenser, but which may vary therefrom depending upon the particular circuit constants employed.

In the schematic diagrams of Figs. 1 to 3 the vacuum tube oscillator illustrated is one known as a cavity type oscillator. The invention is perfectly general in its application, however, and it may be associated with any conventional oscillator circuit, whether low frequency or ultra high frequency, and whether the control grid of the oscillator tube is supplied with a modulation frequency or not. A conventional oscillator circuit of the Hartley type is illustrated in Fig. 5. As shown, the oscillator comprises a triode 31, a split tank coil 32-33, a tank tuning condenser 34, and a grid condenser-grid leak combination 35-36. A source 18 of pulse signals may be connected in the grid circuit of the oscillator as shown, an RF bypass condenser 37 being connected in shunt with the pulse source to provide an RF signal path thereacross. An impedance 38, which may be a resistor or an RF choke, is connected between the triode plate and the high voltage terminal 39. If it is desired to substitute the oscillator of Fig. 5 for any of the oscillators of Figs. 1, 2, and 3, the latter may be disconnected, and the terminal 39 of Fig. 5 connected to the high voltage terminal 40 of the said figures.

The present invention is not limited to the specific circuits and electrical constants disclosed in the accompanying drawings, and it will be evident to those skilled in the art that the broad underlying principles disclosed herein admit of considerable latitude in the construction of the protective networks contemplated by the invention.

I claim:

1. In a pulse-operated vacuum tube circuit embodying a vacuum tube and a high voltage plate supply source therefor, said vacuum tube having cathode and anode electrodes and a control electrode, a protective circuit for said vacuum tube comprising a resistor connected between one terminal of said source and one of the electrodes of said vacuum tube, a connection between the other terminal of said source and the other electrode of said vacuum tube, means for applying control pulses to said control electrode to render said vacuum tube operative during each pulse period, and a delay line having its input terminals connected in shunt with said vacuum tube, and its output terminals open-circuited, the shunt capacitance of said delay line being of such magnitude as to enable it to store electrostatically only that electrical energy required to maintain said vacuum tube in an operating condition throughout the pulse period, said resistor being of sufficient magnitude to limit to a very low value the instantaneous current which can be derived

directly from said source, whereby to prevent damage to said tube in the event of spark-over therein.

2. A protective circuit as claimed in claim 1, wherein the delay time of the line is substantially equal to one-half the said pulse period.

3. In a pulse-operated oscillator circuit embodying a resonant circuit, a vacuum tube having an anode, a cathode and a control electrode, and a high voltage plate supply source therefor having positive and negative terminals, said vacuum tube being subject to fortuitous internal arcing, an arc extinguishing circuit comprising a resistor connected between the positive terminal of said source and the anode of said vacuum tube, a connection between the negative terminal of said source and the cathode of said vacuum tube, means for applying control pulses to said control electrode to render said vacuum tube operative during each pulse period, and a delay line comprising series inductance and shunt capacitance having its input terminals connected in shunt with the anode-cathode circuit of said vacuum tube and whose output terminals are substantially open-circuited, the shunt capacity of said delay line being of substantially no greater magnitude than that required to enable the line to store electrostatically only that electrical energy required to maintain the oscillator in serviceable operating condition throughout the pulse period, said resistor being of sufficient magnitude to limit the instantaneous current which can be derived directly from said source to a value less than that required to sustain an arc between the electrodes of said vacuum tube.

4. In a pulse-operated electron tube circuit, an electron tube having cathode, anode and control electrodes, a high voltage anode supply source, connections between said source and said cathode and anode, means for effecting intermittent pulse excitation of said control electrode, a resistor serially included in one of said power supply connections and having a magnitude sufficient to limit to a low value the current flow from said source to said tube in the event of a spark-over within the tube, and a delay line, including capacitance and inductance, having its input terminals effectively connected to said anode and cathode, and, through said resistor, to said source, the shunt capacitance of said delay line being of such magnitude as to enable it to store electrostatically only that electrical energy required to maintain said vacuum tube in an operating condition throughout the pulse period.

RICHARD G. CLAPP.

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