

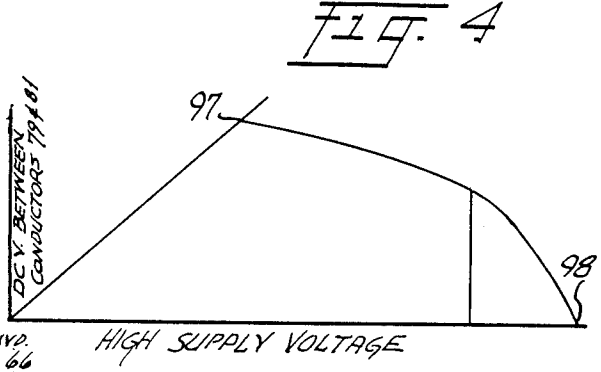
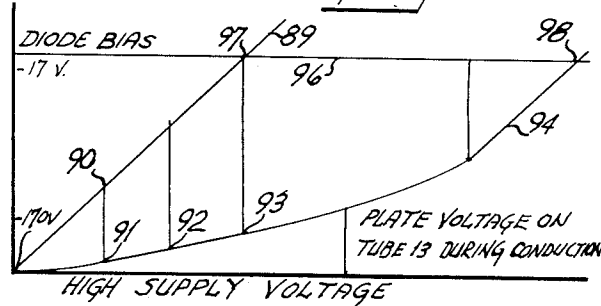
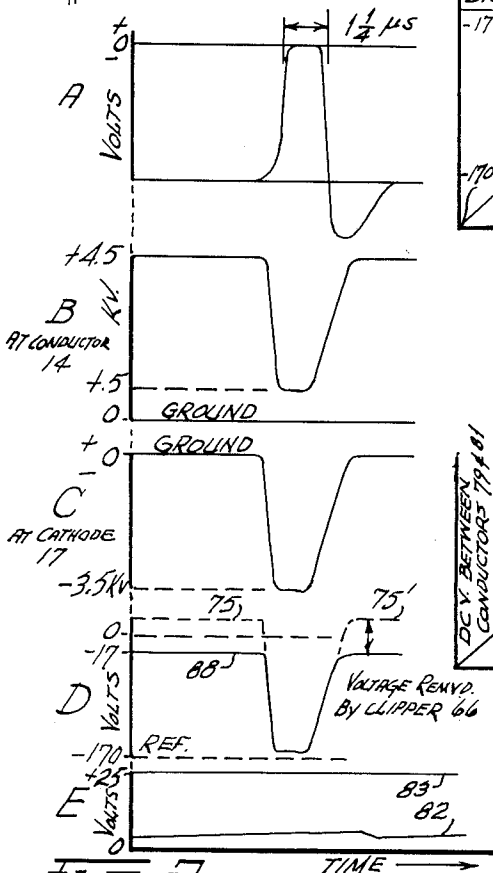
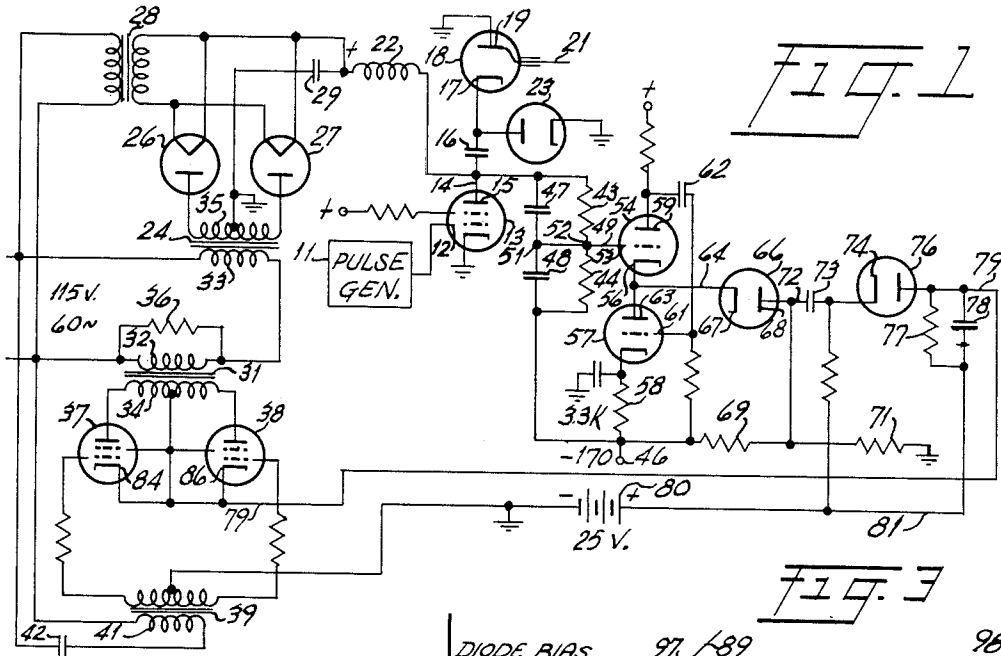
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PULSED MICROWAVE GENERATOR WITH AUTOMATIC CURRENT CONTROL

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PULSED MICROWAVE GENERATOR WITH AUTOMATIC CURRENT CONTROL

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This invention relates to electrical pulse generators in which the pulse current is maintained constant despite varying loads being imposed on the generator.

Although the applications of this invention are many and varied it is particularly useful under the severe conditions of high voltage magnetron operation for the particular purpose of maintaining constant magnetron current in spite of the wide variation in internal impedance found in individual magnetron tubes. In this service the pulse rate may be as high as 60 kilocycles per second and the power applied to the magnetron may be at thousands of volts, with a constant direction of pulse current, so that the usual automatic current control devices are inapplicable.

A further advantage in employing the device of this invention in magnetron pulsing circuits is to protect the pulsing tube against injury due to internal sparking in the magnetron, and in general to protect the pulsing tube against injury due to the short-circuiting of whatever load may be applied to it.

In general, operation of the invention depends upon the sensing of the voltage drop through the pulsing tube, detecting its peak magnitude, and through a control circuit changing the high voltage applied to both the load and the pulsing tube in such direction as effectively to maintain the voltage drop of the pulsing tube constant, thus maintaining the load peak pulse current at a predetermined constant value.

The principal purpose of this invention is thus to provide a device for automatically maintaining a constant peak pulse current in a pulsed load circuit.

Another purpose of this invention is to provide a device for automatically maintaining constant peak pulse current in a pulsed magnetron microwave generator, the plate resistance of which may vary over wide range of values.

Still another purpose of this invention is to provide a protective circuit for a pulser which insures against unreasonably high current flow therethrough or excessive internal dissipation of power.

A further understanding of this invention may be secured from the detailed description and drawings, in which:

Figure 1 is a schematic diagram illustrative of an embodiment of the invention.

Figure 2 illustrates the waveforms which exist at several points in the circuit.

Figure 3 depicts the manner in which the voltages vary at several points in the circuit.

Figure 4 is the characteristic curve of the direct-current control voltage.

Referring now to Fig. 1, a pulse generator 11 of conventional design generates pulses of a selected frequency and form. For example, the pulses may have a frequency of 50 kilocycles per second, a duration of 1¼ microseconds and have a form that is essentially a rectangular positive-going half-cycle, with its maximum potential that of ground. Such a pulse is illustrated by the

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waveform A of Fig. 2. A pulse train of this type is applied to the control grid 12 of a tetrode amplifier 13 which may be considered as the final amplifier of the pulse generator 11. This tube comprises what is known as a hard tube pulser. The plate 15 of the tetrode 13 is connected through conductor 14 and a condenser 16 to the cathode 17 of a magnetron microwave-generating tube 18, the anode structure 19 of which is grounded with microwave energy being abstracted at the coupling 21. The tetrode 13 inverts the pulses and produces at its plate 15 a potential having the wave form B of Fig. 2. The condenser 16 isolates the plate supply, removing the direct-current component from the output but its function may be regarded as being to take a positive charge from the high voltage supply circuit during the intervals between pulses, and to discharge through the tetrode 13 to ground when the tetrode 13 becomes conductive during the occurrence of a pulse. Since the voltage across a condenser can not change instantaneously, the condenser terminal connected to the magnetron cathode becomes highly negative and draws current from ground through the magnetron. During the pulse time this circuit, consisting in effect of the magnetron 18, condenser 16, and pulser 13 in series, is effectively isolated from the high voltage supply by an inductance 22 connected in the supply conductor.

The trailing edge of the negative pulse tends to cause the voltage of the magnetron cathode 17 to rise and when its potential has risen very slightly above ground, a diode 23 connected between the cathode 17 and ground commences to conduct. This action prevents the potential of the cathode 17 from rising much above ground, cutting off the positive half cycle of the pulse and resulting in the waveform C, of Fig. 2, being effective at the magnetron.

The high voltage supply has a range of +3500 volts to +4500 volts, and is maintained at such voltage value as to keep the magnetron peak pulse current constant. In the series circuit comprising pulser 13, condenser 16, and magnetron 18, during a pulse the voltage V_L across the magnetron is equal to the voltage V_c to which the condenser has been charged minus the voltage drop V_T through the pulser, or

$$V_L = V_c - V_T$$

This is approximately true throughout the pulse duration because the discharge time constant of the condenser and the circuit resistance is made much greater than the pulse length. Since the magnetron load current, I_L , equals the voltage divided by the impedance, or

$$I_L = \frac{V_L}{Z_L}$$

then

$$I_L = \frac{V_c - V_T}{Z_L}$$

This makes it evident that any change in the magnetron load current I_L caused by a change in the magnetron impedance can be redressed by a change of the voltage V_c to which the condenser is charged between pulses. The circuit constants are such that the effective charging voltage is approximately equal to the high voltage supply output voltage; thus the control of magnetron current is exercised by control of the high voltage supply.

The high voltage supply circuit includes a high voltage transformer 24 and a pair of diodes 26 and 27 connected for full-wave rectification, together with the usual filament transformer 28 and filter condenser 29. Automatic control of the high voltage output level is exercised through the medium of a control transformer 31 which has its primary winding 32 connected in series

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with the primary winding 33 of the high voltage transformer 24. The primary winding 32 may be considered as a variable impedance controlling the voltage applied to the power transformer primary winding 33, the variability being secured by the loading of the secondary winding 34. The ends of the secondary winding 34 are connected to the plates of two thyatron tubes 37 and 38, the cathodes and shield grids of which are returned to the midpoint of the winding 34, and the primary winding 32 is shunted by a resistor 36 of such value as to secure proper operation of tubes 37 and 38. The control grids of the thyatrons are connected to the secondary winding terminals of a grid transformer 39 whose primary winding 41 is connected to the power supply through a series condenser 42. The thyatron grid voltage is therefore retarded in phase by approximately 90° relative to the thyatron plate voltage. The two halves of secondary winding 34 draw current through the primary winding 32 on alternate half cycles during only portions of the respective half cycles because of the grid phase displacement. The power drawn through the primary winding 32 by reason of its secondary loading results in a reduction of the primary impedance and consequently produces an increase of potential applied to the high voltage primary winding 33 of the high voltage transformer 24 with a resulting increase in the voltage output of its secondary winding 35. Thus the magnitude of this secondary voltage is dependent on the grid bias conditions of the thyatron tubes 37 and 38.

In order to control the bias conditions in the control grid circuits of thyatron tubes 37 and 38, a control signal is derived from the voltage existing at the plate conductor 14 of the pulser tube 13. This signal voltage is derived by means of a suitable voltage divider so that the fraction of the high voltage derived has a magnitude which is independent of frequency. This is accomplished by the use of a pulse voltage divider consisting of two resistors 43 and 44 in series between the plate conductor 14 and negative potential terminal 46, which for pulse signals acts as if it were at ground potential since the supply source is shunted by a large condenser having negligible impedance to pulse signals. Each resistor is shunted by a condenser 47 and 48, with the output conductor 49 connected to the common terminals 51 and 52 of the resistors and condensers. The ratio of resistances may be of any amount; for the present purpose the input voltage is conveniently reduced by a factor of about 20, so that the ratio of the resistance of resistor 43 to that of resistor 44 is about 20:1. In order to preserve the linear relation to frequency, the ratio of the reactances of the condensers must equal the resistor ratio.

The reduced voltage at conductor 49 therefore has the same form as the voltage on the plate of tetrode 13, as illustrated at B, Fig. 2, and also has as a direct-current magnitude a selected fraction thereof, i. e. in the present instance 1/20. This potential is applied to the control grid 53 of a cathode follower tube 54, in order to isolate succeeding parts of the circuit. The cathode follower is made to follow negative direction pulses by connecting its cathode 56 through a resistance tube 57 and through a relatively low resistor 58 having, for example, a resistance of 3300 ohms, to the source of negative potential at 46. The plate 59 of the cathode follower 54 is connected to the control grid 61 of resistance tube 57 through a condenser 62. Although ordinarily the output of a cathode follower follows negative signals with less fidelity than it follows positive signals, the addition of the resistance tube 57 increases the fidelity of response to negative pulses, such as those applied through conductor 49.

Faithful response is secured because, upon application of a negative pulse to the grid 53, the plate current of tube 54 is reduced and the potential of plate 59 therefore rises. This rise in plate potential applies a positive pulse

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to the grid 61 of tube 57, thereby decreasing the resistance of that tube and thus lowering the voltage of its plate 63. The potential of the output conductor 64 connected to plate 63 and cathode 56 therefore follows with fidelity the negative pulse applied to the input conductor 49.

The upper part of the waveform B, Fig. 2, applied at reduced voltage through the divider network 43, 44 and cathode follower 54, is cut off by a diode clipper 66 having its cathode 67 connected to conductor 64 and its plate 68 returned to negative potential secured from a voltage divider consisting of resistors 69 and 71 connected between negative terminal 46 and ground. The output form at conductor 72 is therefore similar to C, Fig. 2, except for the direct-current voltage level and for pulse magnitude, and is shown at 88 in graph D, with representative voltage levels. The voltage before clipping by diode clipper 66 is shown dotted at 75 and 75'.

The conductor 72 is coupled by condenser 73 to the cathode 74 of a diode 76 followed by a biasing resistor 77 and a shunt condenser 78. This combination of diode, resistor and condenser serves as a peak rectifier, and produces as an output between conductors 79 and 81 a direct-current voltage plus a small amount of alternating current due to imperfect filtering, having a magnitude representative of the peak magnitude of the applied pulses. The magnitude of the voltage of conductor 79 relative to ground is therefore the algebraic sum of the voltage between conductors 79 and 81, and the 25-volt potential of battery 80 connected between conductor 81 and ground. The sum is on the order of +5 volts. This algebraic sum voltage is shown in E, Fig. 2, at 82, the distance between the lines 82 and 83 representing the potential difference of conductors 79 and 81.

The 5-volt difference between conductor 79 and ground is applied between the cathodes and control grids of the thyatrons 37 and 38, thus superimposing a direct-current bias upon the previously-described alternating current bias. The effect of this superimposition is to control the time during the cycle at which current begins to flow in the thyatrons. Therefore, the durations of the conductive periods of the tubes and hence their averaged currents are in part controlled by the magnitude of this direct-current bias, and these averaged currents in turn control the voltage output level of the high voltage power supply at its output conductor 14.

This control has an inverse characteristic, that is when the current through tube 13 increases, increasing the voltage drop thereacross, the herein described control circuit increases the positive potential applied through conductor 79 to the cathodes 84 and 86 with respect to their grids, since the pulse output of tube 66 decreases, reducing the direct current output of tube 74, and making conductor 79 less negative with respect to conductor 81. This reduces the current drawn by the thyatron tubes 37 and 38 and increases the impedance of the primary winding 32. This in turn reduces the high-voltage supply output voltage so as to keep the current output constant.

The pulse waveform existing at conductor 72 is the same as the lower portion of the pulse applied to the plate 15 of the pulser tube 13, and is illustrated at D, Fig. 2 in solid lines. The upper level 88 represents a voltage less than the open-circuit voltage applied by the high voltage supply to the plate 15 in the intervals between pulses, and its voltage level is held fixed by the voltage divider consisting of resistors 69 and 71. As was stated, the high voltage power supply is of the automatically adjustable type. Since conductor 49 is directly coupled to the output of the high voltage rectifier through resistor 43 and choke coil 22, the potential of conductor 49 with respect to -170 v. is one twentieth of the high voltage rectifier output potential. That is, the relationship is linear, and can be graphically depicted by a straight line as at 89, Fig. 3. However, at any selected adjustment of the high voltage supply the volt-

age level at conductor 49 just before the beginning of a pulse is specific and constant, as at point 90 in Fig. 3. When a pulse occurs, the voltage at the plate 15 drops to a point dependent upon the relative impedances of tube 13 and magnetron 18, and is represented in Fig. 3 by the point 91. The distance between the line 89 and the point 91 therefore represents one twentieth of the pulse magnitude existing across magnetron 18 at this abscissa, and the ordinate of point 91 represents one twentieth of the voltage drop in the tube 13. Similarly, at other supply voltages as at 92 and 93 the tube internal voltage drops are represented by the ordinates of these points. The curve 94 connecting these points 91, 92 and 93 is representative of the voltage drop of the tube 13. It must be kept in mind that the curve 89 represents conditions obtaining between pulses, during which the condenser 16 is charged to a voltage V_c represented by a point on the line 89, and that the curve 94 represents pulse peak conditions, when the pulser circuit is effectively isolated from the high voltage supply by the choke 22.

It is obvious that since the plate 68 of the diode 66 is at a fixed potential of -17 volts, applied voltages which are more positive than this level will not be detected in diode 76. This condition is schematically represented in Fig. 3 by the horizontal line 96, independent of the high voltage magnitude, which sets a limit to the effect of the output of diode 66 on diode 76. This effect is proportional to the lengths of the vertical lines extending between the lower of lines 89 and 96, and line 94, which lengths represent pulse voltage magnitudes. These lines and the area within which they exist are replotted in Fig. 4. This figure constitutes the operating characteristic of diode 76 and exhibits by its trailing slope between the limits 97 and 98 the desired inverse characteristic which is taken as the operating range of the system. Thus any tendency towards increase in current flow through the magnetron and pulser tube results in a compensating reduction of the high voltage supply potential.

While the invention has been described in connection with a particular and important application, namely, as used in controlling the current flow through a magnetron nevertheless the principle thereof may be utilized in many other relations. One skilled in the art will, for example, readily appreciate that the invention is equally applicable in controlling current flow through such loads as linear resistors or non-linear resistors such as germanium and other crystals as well as arc discharges.

What is claimed is:

1. An automatic pulse current control for a variable impedance load comprising, means for applying voltage pulses to said load to produce corresponding current pulses therethrough, means for securing a reduced peak pulse voltage magnitude representative of the peak magnitude of said current pulses, means for securing a continuous voltage representative of said reduced peak pulse voltage magnitude, and control means for controlling said first-named means in accordance with the magnitude of said continuous voltage whereby said current pulse peak magnitude is held constant despite variations of said impedance load.

2. A pulse current regulator for a variable resistance load comprising, a pulser tube, a condenser and said load connected to form a series circuit, means for applying a direct-current potential to said pulser tube and said condenser, and means for varying the voltage level to which said condenser is charged in response to the potential drop existing in said pulser tube during the occurrence of pulses through said series circuit.

3. An automatic pulse current control for a variable resistance load comprising, a pulser tube and a condenser connected in series with said load, a direct voltage supply source connected to the junction of said

pulser tube and said condenser, means for deriving a potential from said pulser tube having a magnitude proportional to the peak current amplitude of the pulses therethrough, and means operative by said derived potential for varying the voltage of said supply source as an inverse function of said derived potential.

4. An automatic control for a magnetron having at least two electrodes, the interelectrode impedance of which tends to vary comprising, a pulser tube and a condenser connected in series with said magnetron, means for applying a direct current potential to said pulser tube and said condenser, and means for varying the voltage level to which said condenser is charged between pulses in proportion to the potential drop existing in said pulser tube during the occurrence of pulses therein.

5. An automatic control for a magnetron having at least two electrodes, the interelectrode impedance of which tends to vary comprising, a pulser tube and a condenser connected in series with said magnetron, a direct voltage supply source connected to the junction of said pulser tube and said condenser, means for deriving a potential from said pulser tube the magnitude of which is proportional to the peak amplitude of the pulses therethrough, and means operative by said derived potential for varying the voltage of said supply source as an inverse function of said derived potential.

6. An automatic current control for a magnetron having at least two electrodes between which the impedance may vary comprising, means for applying pulses of high potential between the electrodes of said magnetron to produce corresponding current pulses therethrough, means for securing a reduced peak pulse voltage magnitude representative of the peak magnitude of said current pulse, means for securing a continuous voltage representative of said reduced peak pulse voltage magnitude, and control means for controlling said first-named means in accordance with the magnitude of said continuous voltage whereby said current pulse peak magnitude is held constant despite variations of the internal impedance of said magnetron.

7. An automatic current control for a magnetron having at least two electrodes between which the impedance may vary comprising, a pulser tube connected to said magnetron for applying direct-current voltage pulses thereto to produce current pulses therethrough, a high voltage source driving said pulser tube, means for securing reduced voltage pulses representative in waveform of the voltage drop through said pulser tube, diode peak rectifier circuit means actuated by said last-named means for producing a direct voltage proportional to the voltage drop through said pulser tube, a variable inductive reactor in series with said high voltage source, and means responsive to the direct voltage output of said diode peak rectifier circuit for changing the reactance of said variable inductive reactor.

8. An automatic current control for a pulsed magnetron microwave generator having at least two electrodes between which the impedance may vary comprising, a pulser tube connected to said magnetron for applying direct-current voltage pulses thereto whereby current pulses are produced therein that may vary in accordance with internal impedance variation, a high voltage source driving said pulser tube, a voltage divider connected across said pulser tube having a reduced output voltage representative in form of the pulser voltage, a diode detector connected to said voltage divider for actuation by said reduced output voltage, a diode peak rectifier connected to said diode detector for actuation therefrom, said diode peak rectifier generating a continuous direct-current output voltage, a transformer having a primary winding for driving said high voltage source, a variable inductor in series with said primary winding, and circuit means for varying said inductor in accordance with the magnitude of said direct-current output voltage.

9. An automatic current control for a pulsed mag-

netron microwave generator having at least two electrodes between which the impedance may vary comprising, a high voltage direct-current source, a condenser charged by said high voltage source, pulser tube means connected to said condenser and said magnetron for periodic discharge of the condenser through said magnetron to cause a current therethrough having a magnitude depending upon the impedance thereof, voltage divider means connected across said pulser tube means to produce a reduced output voltage representative in form of the pulser means internal voltage drop, a diode detector connected to said voltage divider means for actuation by said reduced output voltage, a diode peak rectifier connected to said diode detector for actuation therefrom to produce a continuous direct-current output voltage, a high voltage transformer having a primary winding, said transformer driving said high voltage direct-current source, a variable inductor in series with said primary winding, and circuit means for varying the inductance of said inductor in accordance with the magnitude of said direct-current output voltage.

10. An automatic current control for a pulsed magnetron microwave generator having at least two electrodes between which the impedance may vary comprising, a high voltage direct-current source, a condenser charged by said high voltage source, pulser tube means connected to said condenser and said magnetron for periodic discharge of the condenser through said magnetron to cause a current therethrough having a magnitude depending upon the impedance thereof, voltage divider means connected across said pulser tube means to produce a reduced output voltage representative in form of the pulser means internal voltage drop, a diode detector connected to said voltage divider means for actuation by said reduced output voltage, a diode peak rectifier connected to said diode detector for actuation therefrom to produce

a continuous direct-current output voltage, a high voltage transformer having a primary winding, said transformer driving said high voltage direct-current source, a second transformer having its primary winding connected in series with said high-voltage transformer primary winding, as least one thyatron connected to the secondary winding of said second transformer, an alternating power source connected to said high voltage transformer, means for energizing the control grid of said thyatron from said alternating power source synchronously with the energization of the high voltage transformer but out of phase therewith, and means for applying said continuous direct-current output voltage to the control grid of said thyatron, thereby controlling its firing phase and the degree of loading that it applies to said second transformer and by means thereof controlling the primary voltage applied to said high-voltage transformer.

11. A pulse current regulator for a variable resistance load comprising, a pulser tube and a condenser connected in series with said load, means for applying a direct-current potential to said pulser tube and said condenser, and means responsive to the potential drop existing in said pulser tube during the occurrence of pulses therein for varying the voltage level to which said condenser is charged.

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