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D. E. MAXWELL

2,415,302

PULSE GENERATING CIRCUIT

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Fig. 1.

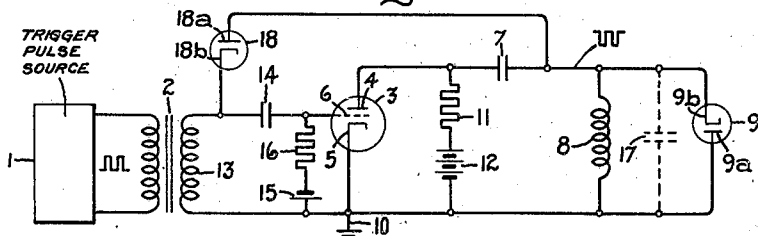


Fig. 2.

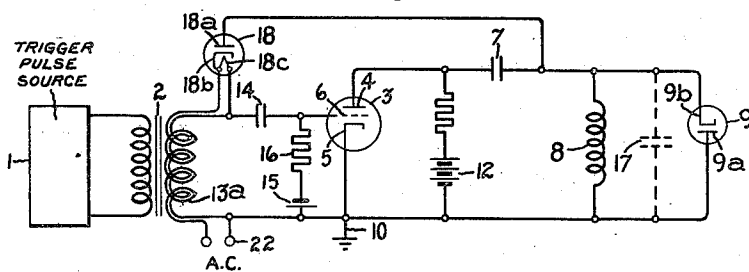


Fig. 3.

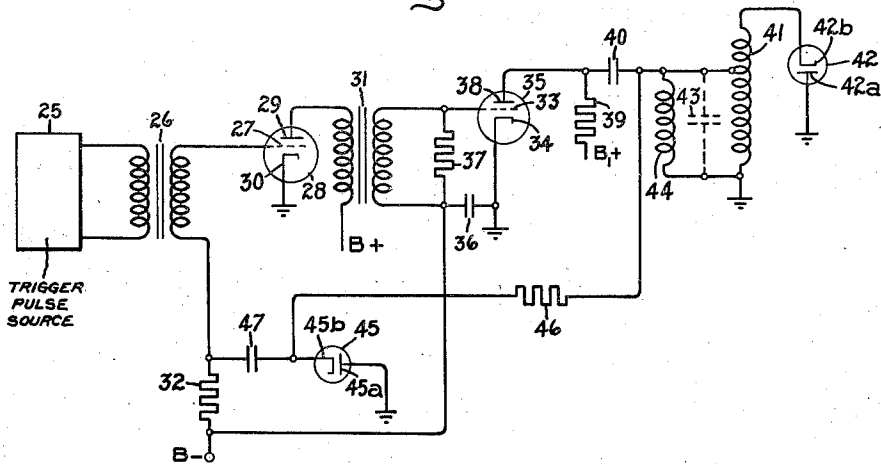
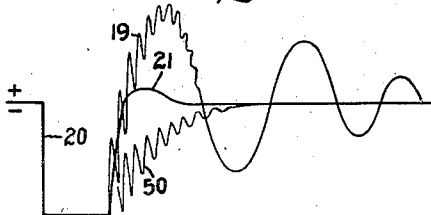


Fig. 4.



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UNITED STATES PATENT OFFICE

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PULSE GENERATING CIRCUIT

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11 Claims. (Cl. 250-27)

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My invention relates to electric pulse generating circuits, and more particularly to means for shaping the trailing edge of a voltage pulse to provide a more nearly rectangular pulse wave form.

It is well known by those skilled in the art that pulse modulation has wide application to radio communication and detection circuits. Preferably, the generated modulating pulses are of substantially rectangular wave shape. However, pulse load circuits, such as modulating circuits and the like, frequently are of an inductive nature, so that the wave shape of applied pulses is affected by the energy stored in the inductive circuit at the end of each pulse. This problem is commonly encountered when the output of a pulse generating circuit is utilized to modulate the high frequency oscillations of a magnetron oscillator. In such a circuit a pulse transformer or simply a charging reactor is commonly interposed between the pulse generator and the magnetron oscillator tube. When a transformer is used it serves both to increase the voltage applied to the magnetron and to provide a charging path for the capacitive pulse-forming energy storing element. Since the reactor or transformer and the load circuit ordinarily include a certain amount of stray and distributed capacitance, it is found that at the termination of each pulse the energy stored in the conductive circuit elements has a tendency to initiate transient high frequency oscillations in the resonant circuit comprising the transformer or reactor and the stray and distributed capacities. Such high frequency oscillation at the trailing edge of a rectangular voltage pulse is objectionable for a number of reasons. In the first place, the inverse voltage peaks produced by the oscillation add to the charging voltage of the pulse-forming element thereby tending to produce arc-over of the pulse triggering tube. Another objectionable feature of the trailing edge oscillation is that the voltage peaks of polarity similar to that of the desired pulse tend to start oscillation of the magnetron tube in undesired spurious modes.

Commonly, trailing edge oscillations of the character described are damped by diode clipper tubes connected across the pulse load circuit in such a manner that they are non-conductive for the desired pulse voltages, but conduct inverse oscillation voltages, thereby to dissipate the stored energy. Such clipper tubes, however, are large and expensive, because they must withstand the full pulse voltage in the non-conductive direction, must be capable of conducting high peak cur-

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rents, and because they require appreciable heat dissipating capacity to dissipate the considerable stored energy in the pulse transformer or charging reactor.

Accordingly, it is an object of my invention to provide new and improved means for shaping the trailing edge of voltage pulses to provide more nearly rectangular pulse wave shapes.

It is a further object of my invention to provide new and improved means for suppressing undesired high frequency oscillations at the trailing edges of electric pulses.

It is a still further and more specific object of my invention to provide non-linear inverse feedback means for suppressing trailing edge oscillations at the termination of voltage pulses.

It is a particular object of my invention to provide low current, diode damping circuit for suppressing trailing edge oscillations in high voltage pulse generating circuits.

Briefly, in accordance with my invention, unilateral conducting means, such as a diode or other electron discharge device, is connected for response to voltage oscillations across a pulse load circuit in such manner that the oscillations are fed back in inverse phase relation to the input of the pulse triggering tube, thereby to suppress the oscillations.

My invention itself will be more fully understood and its objects and advantages further appreciated by referring now to the following detailed specification taken in conjunction with the accompanying drawing, in which Figs. 1 and 2 are schematic circuit diagrams of pulse generating circuits embodying my invention in one form; Fig. 3 is a schematic circuit diagram of a pulse generating circuit embodying my invention in another form; and Fig. 4 is a graphical representation of various pulse wave shapes illustrating the operation and effect of my invention.

Referring now to the drawing, and particularly to Fig. 1, I have shown a pulse generating circuit comprising a source 1 of substantially rectangular recurrent voltage pulses. The recurrent, and preferably periodic, pulses originating at the source 1 are supplied through a transformer 2 to the input circuit of an electron discharge device 3. The discharge device 3 comprises an anode 4, a cathode 5, and a control electrode 6 and is connected as a trigger switch in the output circuit of a pulse-forming capacitive energy-storing element, shown by way of example as a condenser 7. The electron discharge device or pulse triggering tube 3 is periodically rendered conductive by positive voltage pulses from the source 1, there-

by to connect the condenser 7 for pulse discharge through an output circuit including a charging reactor 8 and a magnetron oscillator tube 9 connected in parallel circuit relation. The magnetron oscillator 9 includes a grounded anode 9a and a cathode 9b.

The charging reactor 8 serves as a direct current path for recharging the condenser 7 at the termination of each pulse. The condenser charging circuit also includes a high resistance 11 and a source of unidirectional electric potential, such as a battery 12, connected in series circuit relation between the anode and cathode of the electron discharge device 3. The cathode 5 of the discharge device 3 and the negative terminal of the battery 12 are grounded through the ground lead 10.

The input circuit of the pulse triggering tube 3 comprises a secondary winding 13 of the input transformer 2 connected between the cathode 5 and control electrode 6 of the discharge device 3 through a suitable coupling capacitor 14. The discharge device 3 is negatively biased to cutoff by any suitable means, such as for example a battery 15 and a grid resistor 16 connected between the cathode 5 and the control electrode 6.

It is found in practice that the charging reactor 8 and the magnetron oscillator tube 9 have a certain amount of stray and distributed capacitance to ground. This capacitance is indicated by dotted lines 17 in Fig. 1 as capacitance between the anode and cathode of the magnetron tube 9. The stray and distributed capacities represented by the capacitor 17 form with the charging reactor 8 a resonant circuit having a high natural frequency of oscillation with respect to the repetition rate of the pulses from the source 1. For the charging reactor circuit shown this natural frequency of oscillation is ordinarily of the order of 100 kilocycles per second. The pulse repetition rate, on the other hand, is ordinarily of the order of 500 to 5000 pulses per second in radio detection apparatus or pulse communication apparatus.

For the purpose of suppressing oscillations in the tuned circuit 8, 17 at the termination of each pulse, I provide a non-linear inverse feedback circuit comprising a diode rectifier 18 connected between the output and input circuits of the pulse triggering tube 3. More specifically, the anode 18a of the diode 18 is connected to the cathode 9b of the magnetron 9 and the cathode 18b of the diode 18 is connected to the control electrode 6 of the discharge device 3 through the coupling capacitor 14.

In operation, the pulse generating circuit of Fig. 1 functions in the following manner. As previously mentioned, the discharge device 3 is biased to cutoff by the battery 15. During non-conducting periods of the tube 3 the condenser 7 is charged to substantially the full voltage of the battery 12 through the charging circuit comprising the resistor 11, the condenser 7, and the charging inductor 8. The voltage pulses applied from the source 1 through the transformer 2 recurrently and periodically impress positive potentials upon the control electrode 6 for predetermined pulse intervals, thereby to render the discharge device 3 conductive for such intervals. When the discharge device 3 becomes conductive, the condenser 7 discharges through the discharge device 3 and the load circuit comprising the magnetron oscillator tube 9 and the charging reactor 8. The voltage drop through the discharge device 3 is relatively small, so that substantially

the full voltage of the condenser 7 is impressed across the reactor 8 and the magnetron 9.

The inductance of the charging reactor 9 is made sufficiently great that comparatively little current flows through the reactor during the pulse period. During the pulse, however, a small amount of current is gradually built up in the reactor 9, so that at the termination of the pulse a certain amount of energy is stored in the reactor. At the termination of the pulse discharge this stored energy tends to initiate an oscillatory charge and discharge of the distributed and stray capacitance represented by the condenser 17. In the absence of the feedback circuit through the diode rectifier 18, this oscillation would cause a fluctuation of voltage across the reactor 8 and magnetron 9 in the manner illustrated by the curve 19 of Fig. 4. It is the purpose of the feedback circuit through the rectifier 18 to suppress such oscillation and to shape the trailing edge of the pulse 20 of Fig. 4 in the manner of the line 21 of Fig. 4.

In suppressing the trailing edge oscillations, the diode rectifier 18 functions in the following manner. During the pulse interval, the cathode 9b of the magnetron 9 is negative with respect to the grounded anode 9a, so that the anode 18a of the diode 18 is negative with respect to ground. At the same time, the triggering pulse on the secondary winding 13 of the transformer 2 raises the cathode 18b of the rectifier 18 to a potential positive with respect to ground. Accordingly, during the pulse interval, the rectifier 18 remains non-conductive. At the termination of the pulse, and as soon as the energy stored in the reactor 8 effects a reversal of voltage across the magnetron 9, the anode 18a of the rectifier 18 is driven positive with respect to ground. At this time, the triggering pulse on the transformer winding 13 has disappeared, so that the cathode 18b of the rectifier 18 is at ground potential. Accordingly, as soon as a reverse voltage appears across the magnetron tube 9, the rectifier 18 conducts, thereby to impress a positive impulse upon the control electrode 6 of the triggering discharge device 3. The grid potential of the discharge device 3 is thus raised from below cutoff to some value at which conduction again takes place, or tends to take place. Conduction through the tube 3 impresses across the charging reactor 8 and magnetron 9 a voltage opposed to the positive oscillation voltage initiating discharge through the rectifier 18. As a result of this action, there occurs a very effective damping of the positive voltage peaks across the magnetron 9.

It is believed that, in operation, the positive voltage fed back through the diode rectifier 18 to the grid of the discharge device 3 will never reach a value sufficient to overcome the negative bias upon the control electrode 6 before complete damping of the positive voltage swing across the charging reactor 8 is effected. Therefore, substantially no power is supplied to the control electrode 6 of the discharge device 3 and the current through the diode rectifier 18 will be very low. Accordingly, the diode rectifier 18 may be a tube of small peak current rating, in contrast to the high peak emissivity and large heat dissipating capacity required for a diode damper tube connected across the electrodes of the magnetron 9.

It will be noted from Fig. 1 that the cathode 18b of the diode rectifier 18 is not at ground potential. Accordingly when the cathode 18b is provided with a heater, the heater will not be at

ground potential and it will be necessary to provide a very low capacity filament winding in order to avoid shunting the trigger pulse source 1.

At Fig. 2 I have shown an alternative arrangement for energizing a cathode heater of the diode rectifier 18. In the circuit shown at Fig. 2, the cathode heater 18c is supplied from a suitable source of alternating current supply 22 through a double secondary winding 13a on the transformer 2. In all other respects the circuit of Fig. 2 is similar to that of Fig. 1.

At Fig. 3, I have shown a further embodiment of my invention wherein the non-linear inverse feedback circuit is so arranged that the diode rectifier therein need not withstand the full pulse voltage in its non-conductive direction. In accordance with the modification of Fig. 3, the feedback diode may be a small receiver-type tube having both low peak-current and low peak-voltage rating.

Referring now more particularly to Fig. 3 of the drawing, I have shown a source 25 of triggering pulses arranged to supply, through a transformer 26, positive potentials to the control electrode 27 of an electron discharge device 28 having an anode 29 and a grounded cathode 30. The anode 29 of the discharge device 28 is connected through the primary winding of a coupling transformer 31 to a suitable source of positive potential indicated upon the drawing as B+. By way of specific example, the positive potential source B+ may be of the order of 2500 volts. The control electrode 27 of the discharge device 28 is biased negatively from a suitable source of negative potential B- which is connected through a resistor 32 to one terminal of the secondary winding of the coupling transformer 26. With the assumed positive potential of 2500 volts upon the anode 29 of the discharge device 28, the negative biasing potential from the source B- may suitably be of the order of 200 volts.

The secondary winding of the coupling transformer 31 is connected between the control electrode 33 and the grounded cathode 34 of a second electron discharge device 35 through a coupling capacitor 36. The control electrode 33 of the discharge device 35 is biased negatively from the potential source B- through the secondary winding of the coupling transformer 31. A resistor 37 is connected across the secondary winding of the coupling transformer 31 to provide a fixed load on the transformer during the non-conducting period of the device 28.

The discharge device 35 corresponds to the pulse triggering discharge devices 3 of Figs. 1 and 2 and includes an anode 38 connected through a charging resistor 39 to a suitable source of positive unidirectional electric current supply B1+. In conformity with the voltage values hereinbefore specified by way of example, the potential source B1+ may supply approximately 5000 volts.

A capacitive pulse-forming energy storing element shown as a condenser 40 is connected through the discharge device 35 to a load circuit comprising an autotransformer 41 and a magnetron oscillator 42 having an anode 42a and a cathode 42b. The condenser 40 is connected across the primary winding of the transformer 41 through the discharge device 35, and the magnetron oscillator 42 is connected across the secondary winding of the transformer 41, the anode 42a of the magnetron being grounded. In conformity with the voltage values heretofore mentioned by way of example, the pulse voltage across the secondary winding of the transformer

41 may be of the order of 12,000 volts. As in the embodiment of my invention illustrated at Figs. 1 and 2, the stray and distributed capacitance of the load circuit is illustrated by dotted lines at 43 as a capacitance connected across the primary winding of the autotransformer 41 of Fig. 3.

At Fig. 3, I have shown an inductive reactor 44 connected in parallel circuit relation with the primary winding of the autotransformer 41. While the reactor 44 forms no part of my present invention, it is useful in adapting the pulse generating circuit for the formation of very short pulses of lesser duration than those for which the transformer 41 is in itself designed. In operation, the reactor 44 augments the energy storing capacity of the pulse transformer 41, thereby to increase the tendency of the stored inductive energy in the load circuit to initiate high frequency oscillations at the termination of each pulse. The transformer 41 establishes very high frequency oscillations which are interposed upon the oscillations set up by the reactor 44. The stored energy of these elements is useful to a certain degree in effecting a rapid decay of voltage at the termination of a desired pulse, but continuing oscillations after the voltage across the primary winding of the autotransformer initially decays to zero are undesirable.

For the purpose of suppressing such continuing oscillations, I provide a non-linear inverse feedback circuit comprising a diode rectifier 45 or other suitable electron discharge device having its anode 45a grounded and its cathode 45b connected to the ungrounded end of the primary winding of the autotransformer 41 through a current limiting resistor 46. The cathode 45b of the diode rectifier 45 is also connected to the control electrode 27 of the discharge device 28 through a coupling capacitor 47 and the secondary winding of the coupling transformer 26.

In operation of the pulse generating circuit shown at Fig. 3, positive voltage pulses generated at the source 25 are applied to the control electrode 27 and render the discharge device 28 conductive for predetermined pulse intervals. The pulses are amplified in voltage in the discharge device 28 and applied with positive polarity through the transformer 31 to the control electrode 33 of the pulse triggering discharge device 35. The positive triggering pulses from the transformer 31 render the discharge device 35 conductive during the predetermined pulse intervals, thereby to permit pulse discharge of the capacitor 40 through the magnetron tube 42, the pulse transformer 41, and the inductor 44. Between pulse intervals, the capacitor 40 is recharged from the potential source B1+ through the charging resistor 39, the inductor 44, and the primary winding of the pulse transformer 41.

If it is assumed, by way of example, that the reactor 44 is omitted and that the generated pulses are of shorter duration than those for which the transformer 41 is itself designed, the voltage decay at the termination of each pulse would be gradual, as indicated by the curve 50 of Fig. 4. With the addition of the inductor 44, however, to increase the energy stored in the resonant circuit during each pulse, the voltage decay at the termination of each pulse is more rapid, but also becomes of an oscillatory nature, as indicated by the curve 19 of Fig. 4. The non-linear inverse feedback circuit through the diode rectifier 45 suppresses positive or inverse voltage peaks of the oscillatory discharge, thereby to shape the trailing edge of the pulse 20 of Fig. 4.

in the manner of the full line curve 21. The action of the non-linear feedback circuit of Fig. 3 will be evident from the following explanation.

During the pulse, the negative voltage across the primary winding of the autotransformer 41 applies a negative potential to the cathode 45b of the diode 45, so that the diode conducts. The diode current is limited to a suitable value by the resistor 46. It will be observed that during the pulse interval, with the diode 45 conducting, the relatively small voltage drop across the diode 45 introduces a small amount of negative feedback to the control electrode 27 of the discharge device 28 through the coupling capacitor 47. This negative feedback, however, is unobjectionable because the amplitude of the positive pulses from the source 25 is sufficient to render the discharge device 28 conductive despite the negative feedback.

At the trailing edge of each pulse, nothing of consequence occurs until the voltage across the primary winding of the autotransformer 41 reverses and becomes positive. As soon as such voltage reversal takes place, the diode 45 becomes non-conducting. When the diode 45 ceases conduction, the total positive voltage across the primary winding of the autotransformer 41 appears across the resistor 46 and the resistor 32 in series, since the capacitor 47 offers substantially no impedance for oscillation voltage of the frequencies here involved. Since the voltage of oscillations across the primary winding of the autotransformer 41 are of great intensity compared to the bias voltage from the source B-, the proportionate part of the oscillation voltage appearing across the resistor 32 is sufficient in intensity and of proper polarity to render or tend to render the discharge device 28 momentarily conductive when the voltage across the primary winding of the autotransformer 41 swings positive. As soon as the discharge device 28 becomes conductive, a positive potential is placed upon the control electrode 33 of the discharge device 35 thereby to render the device 35 conductive and permit discharge of the condenser 40 through the autotransformer primary winding. The discharge voltage opposes the positive oscillation voltage, thereby to prevent build-up of the oscillations. By so suppressing positive voltage peaks, the shape of the trailing edge of the pulse 20 of Fig. 4 is constrained to follow the curve 21. It will be noted, of course, that since the net voltage across the primary winding of the autotransformer 41 does not actually become negative as a result of feedback through the coupling capacitor 47, the magnetron oscillator 42 remains non-conductive after it is shut off by the initial voltage decay.

From the numerical example of voltage values given throughout the above description of Fig. 3, it will be noted that the voltage applied to the rectifying diode 45 at no time even approaches in intensity the voltage appearing across the secondary winding of the autotransformer 41. When the output voltage of the autotransformer 41 is of the order of 12,000 volts, as mentioned hereinbefore by way of example, the diode 45 may have peak inverse voltage rating of the order of 1000 volts.

While I have described, by way of example, only certain preferred embodiments of my invention, many modifications will occur to those skilled in the art, and I therefore wish to have it understood that I intend in the appended claims to cover all such modifications as fall within the true spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. In combination, an electron discharge device including an anode, a cathode, and a control electrode, means including said control electrode for recurrently rendering said discharge device conductive for predetermined pulse intervals, a capacitive pulse-forming energy storing element, a load circuit connected to said capacitive element through said discharge device, said load circuit including an inductive energy storing element having a tendency to initiate voltage oscillations across said load circuit at the termination of each of said pulse intervals, and means for suppressing said oscillations including unilateral conducting means connected between said load circuit and said control electrode to render said discharge device conductive in response to a reversal of voltage across said load circuit.

2. In combination, an electron discharge device including an anode, a cathode, and a control electrode, means including said control electrode for recurrently rendering said discharge device conductive for predetermined pulse intervals, a capacitive pulse-forming energy storing element, a load circuit connected to said capacitive element through said discharge device, said load circuit having impressed thereon recurrent voltage pulses of one polarity and including an inductive energy storing element having a tendency to initiate voltage oscillations across said load circuit at the termination of each of said pulses, and means for suppressing said oscillations including unilateral conducting means connected between said load circuit and said control electrode to render said discharge device conductive in response to voltages of opposite polarity across said load circuit.

3. In combination, an electron discharge device including an anode, a cathode, and a control electrode, means including said control electrode for recurrently rendering said discharge device conductive for predetermined pulse intervals, a capacitive pulse-forming energy storing element, a load circuit connected to said capacitive element through said discharge device, said load circuit including an inductive energy storing element, and unilateral conducting means connected between said load circuit and said control electrode to render said discharge device conductive in response to voltage oscillations in said load circuit initiated by said inductive element at the termination of each pulse interval.

4. In combination, an electron discharge device including an anode, a cathode, and a control electrode, means including said control electrode for recurrently rendering said discharge device conductive for predetermined pulse intervals, a capacitive pulse-forming energy storing element, a load circuit connected to said capacitive element through said discharge device, said load circuit including an inductive energy storing element having a tendency to initiate voltage oscillations across said load circuit at the termination of each of said pulse intervals, and means including a unilaterally conducting device for supplying said oscillations to said control electrode thereby to render said discharge device conductive to suppress said oscillations.

5. In an electric pulse generating circuit including a resonant load circuit and an electron discharge device having a control electrode, means including said control electrode for rendering said discharge device conductive for predetermined pulse intervals, and means for suppressing natural frequency oscillations in said

load circuit at the termination of said pulse intervals comprising unilateral conducting means connected between said resonant circuit and said control electrode to render said electron discharge device conductive in response to said oscillations.

6. In an electric pulse generating circuit including an energy storing load circuit having a tendency to initiate natural frequency oscillations and an electron discharge device having a control electrode, means including said control electrode for rendering said discharge device conductive for predetermined pulse intervals to provide in said load circuit voltage pulses of one polarity, and means for suppressing said natural frequency oscillations at the termination of said pulse intervals comprising unilateral conducting means connected between said load circuit and said control electrode to render said electron discharge device conductive in response to voltages of opposite polarity in said load circuit.

7. In combination, an electron discharge device including an anode, a cathode, and a control electrode, means including said control electrode for recurrently rendering said discharge device conductive for predetermined pulse intervals, a capacitive pulse-forming energy storing element, a load circuit connected to said capacitive element through said discharge device, said load circuit including an inductive energy storing element having a tendency to initiate voltage oscillations across said load circuit at the termination of each of said pulse intervals, and means for suppressing said oscillations comprising unilateral conducting means connected to supply said oscillations to said control electrode.

8. In an electric pulse generating circuit including an energy storing load circuit having a tendency to initiate natural frequency oscillations and an electron discharge device having a control electrode, means including said control electrode for rendering said discharge device conductive for predetermined pulse intervals, and means for suppressing said natural frequency oscillations at the termination of said pulse intervals comprising unilateral conducting coupling means between said load circuit and said control electrode, said coupling means being connected to remain substantially ineffective during said pulse intervals.

9. In an electric pulse generating circuit, an electron discharge device having a control electrode, a load circuit including an inductive element, means for rendering said discharge device recurrently conductive for predetermined desired pulse intervals, said inductive element having a tendency to initiate electric oscillations in said

load circuit at the termination of each pulse, and coupling means including a unilateral conducting device connected between said load circuit and said control electrode, said unilateral conducting device being disposed to render said coupling means substantially non-responsive to desired pulses in said load circuit.

10. In an electric pulse generating circuit, an electron discharge device having a control electrode, a load circuit including an inductive element, means for rendering said discharge device recurrently conductive for predetermined pulse intervals to establish in said load circuit a succession of voltage pulses of one predetermined polarity, said inductive element having a tendency to initiate electric oscillations in said load circuit at the termination of each pulse, and coupling means including a unilateral conducting device connected between said load circuit and said control electrode, said unilateral conducting device being disposed to render said coupling means substantially non-responsive to load circuit voltages of said one polarity.

11. In combination, an electron discharge device including an anode, a cathode, and a control electrode, means including said control electrode for recurrently rendering said discharge device conductive for predetermined pulse intervals, a capacitive pulse-forming energy storing element, a load circuit connected to said capacitive element through said discharge device, said load circuit including an inductive energy storing element having a tendency to initiate voltage oscillations across said load circuit at the termination of each of said pulse intervals, and unilateral conducting coupling means for supplying said oscillations to said control electrode thereby to render said discharge device conductive to suppress said oscillations, said coupling means being substantially ineffective during said pulse intervals.

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