Jan. 6, 1948. | B. M. OLIVER | 2,433,863

PULSE GENERATION CIRCUIT

Filed May 13, 1943 | 2 Sheets-Sheet 1

FIG. 1

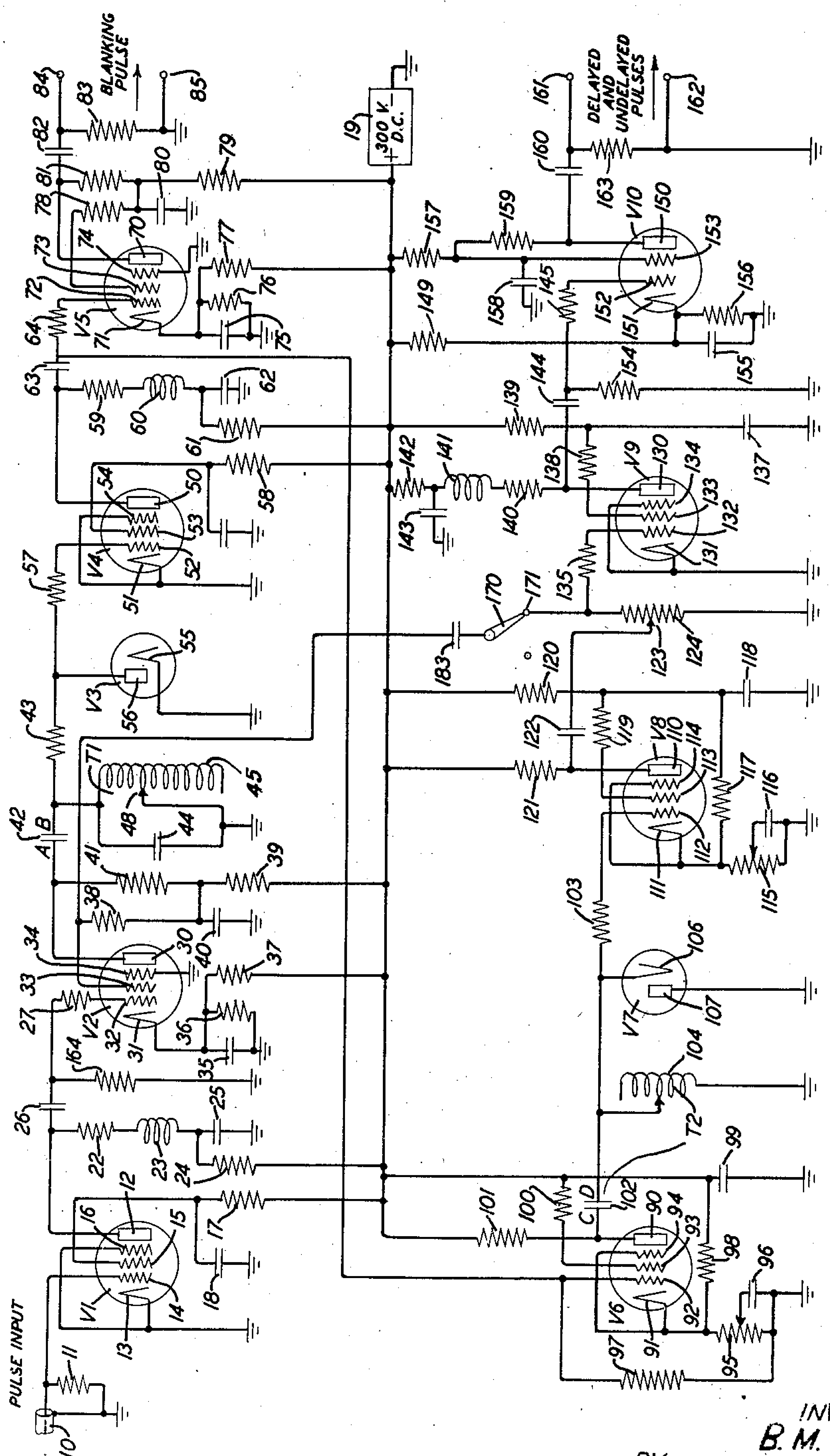

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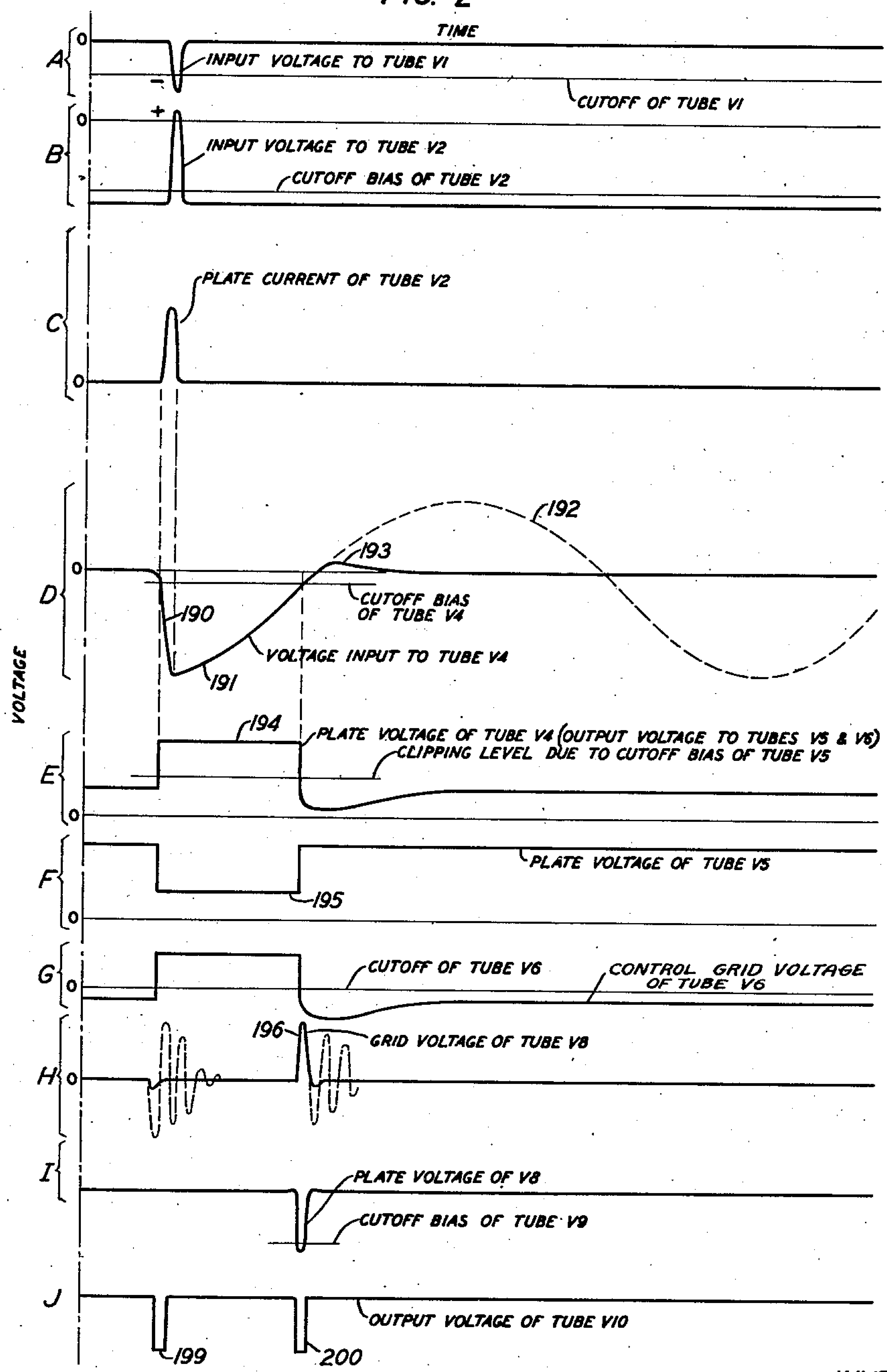
FIG. 2



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PULSE GENERATION CIRCUIT

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12 Claims. (Cl. 250—27)

This invention relates to electric circuits and more specifically to pulse generation circuits.

It is an object of the present invention to provide a novel pulse generator. A more specific object is to provide apparatus for generating a sharp pulse occurring at a controllable period of time after an initiating pulse. Still another object is to provide novel apparatus for generating a flat-topped pulse of controllable time duration. Other objects and features of the invention will be apparent from the following description.

In accordance with a specific embodiment of the present invention, chosen by way of example for illustrative purposes, a tuned circuit of parallel-connected inductance and capacity members is shock-excited by a sharp pulse and the resultant wave is damped after a fraction (one-fourth) of an oscillation cycle. The resultant pulse obtained across this antiresonant circuit is utilized to produce a rectangular or square-topped pulse whose time duration is substantially equal to one-quarter period of the natural oscillation of said circuit, plus one-half the duration of the exciting pulse. The rectangular pulse can be used, for example, for blanking purposes in television cathode ray tubes, or it can be used as a blanking or a notch pulse in oscilloscope circuits or in radio object-locator (radar) systems. As the duration of the rectangular wave is a linear function of the period of the tuned circuit, variation of the tuning of this circuit, such as by varying the inductance or the capacitance thereof, will vary the length of this period. The pulse obtained across the antiresonant circuit has a much greater slope at its zero intercept than is the case in a wave produced by a resistance-capacity circuit. The duration of the pulse is therefore more accurately controllable in the circuit arrangement of the present invention.

The square-topped pulse is also utilized in accordance with a further aspect of this invention to generate a second sharp pulse at its trailing edge which second pulse is preferably produced by shock-exciting with a voltage step function a second tuned circuit of series-connected inductance and capacity members and damping the resultant wave within a fraction of an oscillation cycle. The length of the output pulse can be varied by tuning the second tuned circuit. If desired, the original pulse used to shock-excite the first tuned circuit (or an amplified version thereof) can be applied to an output circuit along with the second sharp pulse.

The invention in its different aspects will be more readily understood by referring to the following description taken in connection with the accompanying drawings forming a part thereof in which:

Fig. 1 is a circuit diagram of a pulse generating arrangement in accordance with the invention; and

Fig. 2 comprises various diagrammatic and graphical representations to aid in understanding and explaining the invention.

Referring more specifically to the drawings, Fig. 1 shows, by way of example to make clear the principles of operation of the present invention, a circuit arrangement for forming an "echo" pulse having an accurately controllable delay with respect to an initiating pulse, and also for generating a blanking pulse (preferably of rectangular form) of controllable duration. The circuit shown in Fig. 1 comprises ten vacuum tubes designated V1 to V10, inclusive. Briefly stated, V1 is an amplifier and phase inverting tube; V2, V3 and V4 form an arrangement for generating a flat-topped pulse (ordinarily called a square-topped pulse) starting substantially at the commencement of the initiating pulse and ending a controllable period of time later; V5 is an amplifier, phase inverter, and clipper for the square-topped wave; V6, V7 and V8 form an arrangement for utilizing the square-topped wave to generate a sharp pulse commencing substantially at the ending of said square-topped wave, the duration of the sharp or "echo" pulse being controllable; and V9 and V10 are amplifiers, phase inverters and clippers for the pulse outputs of tubes V2 and V8. (A pulse simultaneous with the initiating pulse is developed in the screen circuit of V2.)

The initiating pulse, which can be generated by a multivibrator, or by any other means for producing sharp pulses, is applied to the tube V1 from an input coaxial cable 10 terminated by a resistance 11. The tube V1 includes an anode 12, a cathode 13, a control grid 14, a screen grid 15, and a suppressor grid 16. The resistance 11 is connected between the control grid 14 and the cathode 13, the cathode being connected to ground. The suppressor grid 16 is connected to the cathode 13, while the screen grid 15 is connected through the voltage-dropping resistor 17 to the positive pole of a direct current source 19 of, for example, 300 volts, the negative pole of which is connected to ground. A by-pass condenser 18 is connected between the screen grid 15 and ground. The anode 12 is connected through the resistor 22, inductance 23, and the resistor 24 to the positive pole of the source 19, the common terminal of the inductance member 23 and the resistance member 24 being by-passed to ground through the capacity element 25. The inductance member 23 serves to provide high frequency equalization, while the condenser 25 and resistor 22 provide low frequency equalization. The members 24 and 25 also help to filter the high voltage supply circuit. The anode 12 is also connected through the coupling condenser 26 and the "anti-sing" resistor 27 (to prevent parasitic oscillations) to the control grid 32 of the tube V2 which also comprises an anode 30, a cathode 31, a screen grid 33 and a suppressor grid 34. Bias for the grid 32 is provided by means of a capacity member 35 and a resistance member 36 shunted thereacross, these two members being connected between the cathode and ground. The "bleeder" resistor 37 is also connected between the cathode 31 and the positive pole of the source 19 to place the cathode 31 at a positive potential even when no current is flowing through the tube. The suppressor grid 34 is connected to ground while the screen grid 33 is connected through an "anti-sing" resistor member 38 and a resistor 39 to the positive pole of the source 19, the common terminal of the resistors 38 and 39 being connected through a capacity member 40 to ground. The members 39 and 40 serve as a filter and also provide low frequency equalization. The anode 30 is connected through resistor 41 and the resistor 39 to the positive pole of the source 19. Resistor 164 serves as a grid leak.

Also connected to the anode 30 of the tube V2 is the terminal A of the condenser 42, the terminal B of which is connected through the resistors 43 and 57 to the control grid 52 of the tube V4 which also includes an anode 50, a cathode 51, a screen grid 53, and a suppressor grid 54. Connected between the terminal B of the condenser 42 and ground is a tuned circuit comprising a condenser 44 and a variable inductance member 45 connected in parallel. A movable inner terminal 48 of the inductance member 45 is connected to ground. The diode tube V3 and the resistance member 43 are also connected in circuit between the point B and ground. Preferably, the tube V3 comprises a cathode 55 connected to ground and an anode 56 connected to the resistor 43. The resistance of the member 43 plus the resistance of the tube V3 preferably equals the critical damping resistance of the inductance-capacity tuned circuit (which is equal to $\frac{1}{2}\sqrt{L/C}$, where L is the inductance between terminal B and terminal 48, and c is the capacity of the member 44). The condenser 44 and the variable inductance 45 comprise a tuned circuit T1 which is shock-excited by output pulses from the tube V2, while the tube V3 and the resistor 43 help damp out the oscillations caused by the shock excitation of this tuned circuit. Grid current in the tube V4 may also serve to damp out these oscillations, as will be pointed out hereinafter in detail.

The cathode 51 and the suppressor grid 54 of the tube V4 are preferably connected to ground. The resistor 57 is connected to the control grid 52, while the screen grid 53 is connected through a resistor 58 to the positive terminal of the source 19. The anode 50 is connected through a resistor 59 and inductance member 60 and resistance 61 to the positive terminal of the source 19, the condenser 62 being provided between the common terminal of the members 60, and 61 and ground. Members 59, 60, 61, and 62 are respectively similar in function to members 22, 23, 24, and 25 in the anode circuit of tube V1. The anode 50 is also connected through a coupling condenser 63 and an "anti-sing" resistor 64 to the control grid 72 of the tube V5 which also includes an anode 70, a cathode 71, a screen grid 73 and a suppressor grid 74. Bias for the tube V5 is provided by means of the condenser 75 and the resistor 76 shunted thereacross, these two elements being connected between the cathode and ground. The cathode 71 is also connected through a "bleeder" resistor 77 to the positive pole of the source 19. Resistor 97 serves as a grid leak. The suppressor grid 74 is connected to ground, while the screen grid 73 is connected through the resistors 78 and 79 to the positive pole of the source 19, the common terminal of resistors 78 and 79 being connected through condenser 80 to ground. The functions of members 79 and 80 are respectively similar to those of members 39 and 40 in the anode circuit of tube V2. The anode 70 is connected through the resistors 81 and 79 to the positive pole of the source 19. The anode 70 can be coupled to any suitable output circuit for utilizing a blanking pulse by means of, for example, a coupling condenser 82 and a resistor 83. This blanking pulse is a rectangular wave in the negative direction extending from the commencement of the initiating pulse from the input circuit 10 to the time the oscillation from the circuit T1 again exceeds the cut-off bias of V4. It can be used, by way of example, in a radio object-locator system to blank out all "echoes" and noise in a composite signal wave between each transmitted pulse and a desired "echo" signal so the blanked-out portion will not be visible on the screen of a cathode ray oscilloscope. It can be combined with the signal wave or it can be applied to the control electrode of the oscilloscope to cut off the beam therein periodically.

The rectangular wave in the positive direction produced at the plate of the tube V4 is applied to the control grid 92 of the tube V6 which also includes an anode 90, a cathode 91, a screen grid 93, and a suppressor grid 94. The cathode 91 and the suppressor grid 94 are connected to ground through a resistor 95 having a condenser 96 shunted across a portion thereof. The resistor 97 is connected between the control grid 92 and ground and serves as a grid leak. The cathode 91 is also connected through a "bleeder" resistor 98 to the positive pole of the source 19, the terminal of the resistor 98 remote from the cathode 91 being connected through the by-pass condenser 99 to ground. The screen grid 93 is connected through a resistor 100 to the positive pole of the source 19, while the anode 90 is connected through a resistor 101 to the same point. The anode 90 is connected to the terminal C of the condenser 102, the terminal D of which is connected through a resistor 103 to the control grid 112 of the tube V8, which also includes an anode 110, a cathode 111, a screen grid 113, and a suppressor grid 114. Connected between the terminal D and ground is an inductance member 104 which forms with the condenser 102 a series tuned circuit T2. In parallel with the inductance member 104 is the anode-cathode path of the tube V7 which preferably comprises a cathode 106 connected to the terminal D of the condenser 102 and an anode 107 connected to ground. The diode V7 serves to damp out, within a fraction of an oscillation, the wave set up in the inductance 104 in a manner which will be described more fully below.

The cathode 111 and the suppressor grid 114 of the tube V8 are connected to ground through a resistor 115 across a portion of which is connected a condenser 116. The resistor 115 and the condenser 116 are used to provide bias for the tube V8. The cathode is also connected to the positive pole of the source 19 through a "bleeder" resistor 117 and the resistor 120. The by-pass condenser 118 is connected between ground and the terminal of the resistor 117 remote from the cathode. The screen grid 113 is connected to the positive pole of the source 19 through a resistor 119 and the resistor 120, the common terminal of the resistors 119 and 120 being connected through the by-pass condenser 118 to ground. The plate 110 is connected through the resistor 121 to the positive pole of the source 19 and through a coupling condenser 122 to an intermediate terminal 123 of an input resistor 124 for the tube V9, the resistor being connected between ground and a contact member 171 of a switch 170 for a purpose which will be described hereinafter.

The tube V9 includes an anode 130, a cathode 131, a control grid 132, a screen grid 133, and a suppressor grid 134. The upper terminal of the resistor 124 is connected through an "anti-sing" resistor 135 to the control grid 132. The cathode 131 and the suppressor grid 134 are connected to ground and the screen grid is connected through the resistor 138 and the resistor 139 to the positive pole of the source 19, the common terminals of the resistors 138 and 139 being connected through a condenser 137 to ground. The plate 130 is connected through the resistor 140, inductance member 141 and resistor 142 to the positive pole of the source 19, the common terminal of the members 141 and 142 being connected through the condenser 143 to ground. The members 140, 141, 142, and 143 have functions respectively similar to members 22, 23, 24, and 25 in the anode circuit of tube V1. The purpose of the tube V9 is to amplify a pulse produced in the output of the circuit of the tube V8 and also, as will be pointed out below, to amplify the negative pulses produced in the screen grid output circuit of the tube V2 and to clip the tops of these pulses.

The anode 130 of the tube V9 is connected through a coupling condenser 144 and an "anti-sing" resistor 145 to the control grid 152 of the tube V10 which also includes an anode 150, a cathode 151, and a screen grid 153. A grid-leak resistor 154 is connected between the common terminal of the members 144 and 145 and ground. The cathode 151 is connected to ground through the parallel-connected capacity member 155 and resistance member 156 which forms with the resistor 149 a potentiometer to provide bias for the grid 152 of such value that the tube V10 acts to clip the bottoms of the positive pulses from V9. The screen grid 153 is connected through the resistor 157 to the positive pole of the source 19 and through the by-pass condenser 158 to ground. The anode 150 is connected through the resistors 159 and 157 to the positive pole of the source 19 and through a coupling condenser 160 to one terminal 161 of an output circuit, the other terminal 162 of which is connected to ground. A resistance member 163 can be connected between the terminals 161 and 162, if desired.

If it is desired to have the original pulse, or rather an amplified and clipped version thereof, appear in the output circuit connected to the terminals 161, 162, the switch 170 is connected to the contact 171, thus connecting the screen grid of the tube V2 through the blocking condenser 183 to the control grid 132 of the tube V9.

The operation of the circuit shown in Fig. 1 is as follows, reference also being made to Fig. 2 which comprises various diagrammatic and graphical representations to aid in understanding and explaining the invention. The input pulse which, as shown in Fig. 2A, is a sharp negative pulse having, for example, a duration of about one microsecond is repeated four hundred times per second. It can be generated by any suitable means, such as by the well-known multivibrator arrangement or by any other well-known vacuum tube pulse generator, or by any suitable mechanical means. It can be, for example, a pulse sent from the transmitter of a radio object-locator or a pulse bearing a definite time relation, either before or after, to the transmitted pulse. This pulse is applied to the input circuit of tube V1 which acts as an amplifier and phase inverter and produces a pulse, like that shown in Fig. 2B, which is applied to the input circuit of the tube V2. If the input pulse to the tube V1 is of positive polarity (instead of negative) and of sufficient voltage, V1 may be dispensed with. The tube V2 is normally cut off but it becomes conducting when the positive pulse shown in Fig. 2B is applied to its grid and passes a current of approximately 150 milliamperes when the pulse drives the grid to zero bias. All but the direct component of the plate current of the tube V2 passes through the coupling condenser 42 to the tuned circuit comprising, for example, a 1,000 micromicrofarad condenser 44 which is shunted by a portion of the coil 45. The condenser 44 is charged by the plate current of V2 so that point B (and hence the control grid of tube V4) becomes negative with respect to ground. The plate current of the tube V2 is shown in Fig. 2C. The shape of the negative pulse produced by the charging of the condenser 44 is indicated by the portion 190 of the voltage wave in Fig. 2D representing the voltage applied to the grid of the tube V4 in Fig. 2. Point B is at substantially zero potential before the tube V2 becomes conducting and the terminal A of the condenser 42 is at approximately 300 volts. When the tube V2 becomes conducting, the terminal A quickly drops to about 100 volts potential and the terminal B is driven very quickly to a negative potential of about 200 volts. The condenser 44 starts to discharge through the inductance member 45 forming the portion 191 of the voltage wave shown in Fig. 2D. In the absence of damping means this wave would tend to pass the zero axis and assume successively the values indicated by the dotted line portion 192. However, these oscillations are damped within approximately one-quarter of an oscillation cycle by means of the resistance 43 and the diode V3 which becomes conducting as soon as the point B becomes slightly positive. As all of the energy producing the oscillations is absorbed in the circuit including the resistance 43 and the diode V3 (and the parallel connected circuit including resistance 57 and the control grid-cathode circuit of the tube V4), the oscillations are completely damped as shown by the full line portion 193 of the waves shown in Fig. 2D. If desired, the tube V3 and the resistance 43 can be omitted, the resistance 57 being made fairly low. In this latter situation, when the tube V4 starts to draw grid current because of the control grid 52 becoming positive, the oscillations are damped. It should be noted that the portion 191 of the wave shown in Fig. 2D intersects the cut-off bias of the tube V4, shown in Fig. 2D, at a fairly steep angle (much steeper than would be the case if a resistance-capacity circuit were used instead of the inductance-capacity circuit of this invention). This causes the operation of the circuit to be more stable. The tube V4 is cut off by the negative pulse represented by the portions 190 and 191 of the wave shown in Fig. 2D for a period of time which is approximately equal to about one-quarter period of an oscillation cycle plus one-half the duration of the pulse from tube V2. This is true because with a symmetrical driving pulse, the resulting oscillation is of the form

$$-e_0 \cos \omega\left(t-\frac{\Delta t}{2}\right)$$

where Δt is the width of the driving pulse, and $t=0$ at the start of the driving pulse. The first intercept of the oscillation occurs when

$$\omega\left(t-\frac{\Delta t}{2}\right)=\frac{\pi}{2}$$

Solving,

$$t=\frac{\pi}{2\omega}+\frac{\Delta t}{2}=\frac{T}{4}+\frac{\Delta t}{2}$$

where

$$T=\frac{2\pi}{\omega}=\text{the period of the oscillation}$$

The positive pulse 194 thus produced on the plate of the tube V4, shown in Fig. 2E, is applied to the tube V5 and causes this tube to conduct for a period of time corresponding to the duration of the top of the pulse 194 and to generate a useful negative blanking pulse across the terminals 84 and 85. This pulse is shown as pulse 195 in Fig. 2F. For example, this blanking pulse may be used to cut off the beam of a cathode ray oscillograph for a period of time corresponding to the length of the pulse 195 or it may be added to the received video signal in radio object locator systems to blank out all signals between each transmitted pulse and a predetermined point in each train of received signals. The length of the blanking pulse 195 can be varied by tuning the circuit T1 as by varying the position of the inner coil connection 48. The length of the delay interval represented by the pulse 195 is a linear function of the period of the tuned circuit T1. This period in turn is proportional to the square root of the inductance of the member 45 forming part of this tuned circuit. This inductance is proportional to the square of the number of turns comprising the coil 45. Accordingly, the length of the delay interval is a linear function of the number of turns included in this coil. Obviously, other ways of varying the tuning of the circuit T1 can be utilized such as making the condenser 44 variable, for example.

The output pulse from the tube V4 (shown in Fig. 2E) is applied to the input circuit of the tube V6 in the output circuit of which is the series-connected tuned circuit T2 comprising the condenser 102 and the inductance member 104. The tube V6 conducts a pulse of plate current similar to that in the tube V5. The control grid voltage of the tube V6 is shown in Fig. 2G. As soon as the plate current of the tube V6 starts to flow, the tube V7 conducts and damps at once any oscillations of the series tuned circuit; when

the plate current of V6 ceases, a positive transient is produced. During the time the plate current flows, the condenser 102 is discharged. (It previously had a potential of 300 volts across it as the tube V6 was cut off, thus placing the terminal C of the condenser 102 at a potential of about 300 volts, the terminal D being at substantially ground potential.) When the grid of the tube V6 is again driven negative, the plate of the tube V6 is driven positive through the plate resistor 101, causing a sinusoidal oscillation of the tuned circuit which lasts for one-half of a cycle (see Fig. 2H), the remainder being damped by the tube V7. The substantially undamped oscillations which would exist in the absence of tube V7 are shown in dotted lines in Fig. 2H and the actual wave which is applied to the grid of the tube V8 is shown as a full line. The first positive peak 196 of the sinusoidal oscillations causes a short negative pulse of plate voltage in the tube V8 as shown in Fig. 2I, developing a negative pulse on the grid of tube V9, the magnitude of which depends on the setting of the potentiometer resistor 124 in the input circuit of the tube V9. At the same time the input pulse after some amplification by the tubes V1 and V2 also appears on the grid of the tube V9 if it is desired to have both pulses present in the output circuit connected between the terminals 161 and 162. Both pulses are amplified and clipped at both ends by the tubes V9 and V10 to produce the output pulses 199 and 200 shown in Fig. 2J provided the echo gain control 123 is set at the full gain position. If a reduced setting is used the top of the echo will not be clipped and the output amplitude of the echo may be reduced to any desired value, including zero. The tuned circuit T2 in the output circuit of tube V6 determines the output pulse length, that is, the length of the pulse 200 in Fig. 2J. Thus, it will be appreciated that the circuit of this invention produces an output pulse 200, which can be either an approximate replica of the input pulse shown in Fig. 2A or, as shown in Fig. 2J, a shaped pulse which is spaced a controllable period of time away from the initiating pulse. In other words, in accordance with this invention the distance between the two pulses 199 and 200 in Fig. 2J (either or both of which may be present in the output) can be varied as can also the duration of the pulse 200. Obviously, the amplitude of either or both of the pulses can be controlled as desired to make one larger than another or both the same size. The pulse 200 can be used, for example, to initiate a sweep circuit whose starting time for each cycle occurs at a desired period of time after the transmission of a pulse to a radio object locator system. As another example, the circuit of this invention can be used in testing radar receivers by causing the pulse 200 to simulate an echo pulse, the pulse 199 representing a transmitted pulse. The pulse 200 can be moved continuously with reference to the pulse 199 by varying the tuning of the tuned circuit T1.

Obviously the invention, in any one of its several aspects, may be embodied in circuit arrangements which differ from those described above by way of example.

What is claimed is:

1. In combination, a condenser, an inductance element having terminals respectively connected to those of said condenser, means for applying to said condenser to charge it a series of potential

pulses of short duration compared with the natural period of oscillation of the circuit comprising said condenser and said inductance element, unilaterally conducting means in effective shunt to said condenser so poled that said charges cannot flow therethrough and that reverse charging of said condenser, from energy stored in said inductance element by the discharge of said condenser therethrough, is prevented, and means for utilizing the potential set up across said inductance element to produce a rectangular potential wave composed of pulses of substantially equal amplitude.

2. In combination, a condenser, a variable inductance element having terminals respectively connected to those of said condenser, means for applying to said condenser to charge it a series of potential pulses of short duration compared with the natural period of oscillation of the circuit comprising said condenser and said variable inductance element, unilaterally conducting means in effective shunt to said condenser so poled that said charges cannot flow therethrough and that reverse charging of said condenser, from energy stored in said inductance element by the discharge of said condenser therethrough, is prevented, and means for utilizing the potential set up across said inductance element to produce a rectangular wave the duration of each pulse of which is equal to that of the other pulses thereof and which is dependent upon the inductance of said variable inductance element.

3. In combination, means for producing a rectangular voltage pulse, a series-connected tuned circuit of inductance and capacity, said circuit having a natural period of oscillation which is long compared with the duration of said pulse, and means for applying said rectangular pulse to said tuned circuit to produce a sharp pulse of shorter duration than that of said rectangular pulse, said sharp pulse commencing substantially at the termination of said rectangular voltage pulse.

4. The combination of elements as in claim 3 in which means are provided for varying the tuning of said circuit.

5. In combination, a condenser, an inductance element having terminals respectively connected to those of said condenser, means for shock-exciting the circuit formed by said condenser and inductance element to produce an oscillation, means for damping said oscillation as soon as it first reverses its direction, and means for utilizing the wave produced by said shock excitation and damping to form a second pulse substantially similar in shape to the pulse used to shock-excite the circuit but delayed with respect thereto.

6. In combination, a condenser, an inductance element having terminals respectively connected to those of said condenser, means for shock-exciting the tuned circuit formed by said condenser and inductance element to produce an oscillation, means for damping said oscillation as soon as it first reverses its direction, and means for utilizing the wave produced by said excitation and damping to form a second pulse substantially similar in shape to the pulse used to shock-excite the circuit but delayed with respect thereto, the amount of the time delay being dependent upon the constants of said tuned circuit.

7. In combination, a first tuned circuit of inductance and capacity, means for shock-exciting said circuit, means for damping and shaping the oscillation initiated by said shock excitation after a fraction of an oscillation cycle to produce a square-topped pulse for each shock excitation, a second tuned circuit of inductance and capacity, means for utilizing each pulse produced by the shock excitation of said first tuned circuit to shock excite the second tuned circuit, means for damping substantially completely oscillations tending to be formed at the leading edge of said square-topped pulse and for damping all of the oscillations started at the trailing edge of said square-topped pulse except for a one-half cycle voltage pulse, and means for utilizing said last-mentioned pulse.

8. The combination of elements as in claim 7 and being further characterized in that said second tuned circuit has a natural period of oscillation which is shorter than that of said first tuned circuit.

9. In combination, a space current device having an anode, a cathode and a control element, means for biasing said control element with respect to said cathode so that said device is normally cut off, a capacity element, an inductance element, means for connecting said capacity element and said inductance element in a series circuit including the anode-cathode path of said space current device, unilaterally conducting means connected across said inductance element and being so poled that it conducts when the potential of the terminal of the inductance element connected to the capacity element is lower than the potential of the other terminal of the inductance element, means for applying a substantially rectangular positive pulse to the cathode-control element circuit of said device to make said device conducting for the duration of said pulse, and means for utilizing the resultant single voltage pulse appearing across said inductance element starting substantially simultaneously with the trailing edge of said rectangular positive pulse.

10. The combination of elements as in claim 9 in which said last-mentioned means includes means for producing a square-topped voltage pulse.

11. In combination, means for producing a first series of pulses, and means for forming a second series of pulses under control of the pulses in said first series each delayed by a definite amount from the corresponding pulse in the first series, said last-mentioned means comprising a first tuned circuit of inductance and capacity members, means for shock exciting said circuit under control of each of the pulses of said first series to quickly charge said capacity member and thereby set up an oscillation in said tuned circuit, means for damping said oscillation in approximately one fourth of an oscillation cycle and thereby forming in response to each pulse in said first series a negative voltage pulse across said condenser, means for clipping the lower portion of each of said negative pulses and for inverting the phase thereof to form a series of positive square-topped pulses each starting substantially with the leading edge of a pulse in said first series and terminating after a period of time equal to said definite amount, said period being determined by the width of said pulse in the first series and the time constant of said tuned circuit, a second tuned circuit comprising inductance and capacity members, means under control of each of said positive square-topped pulses for starting oscillations at the time of occurrence of the leading and trailing edges thereof, means for damping substantially all of the oscillations at said leading edges and all of the oscillations at said

trailing edges except for the first positive half cycle of each of them, and means for clipping each of said positive half cycles to produce a square-topped pulse forming one of the pulses of said second series.

12. Means under control of a first short voltage pulse for generating a second pulse at the termination of a desired delay period beginning with the application of said first pulse to said means, comprising means for utilizing said control pulse to produce a relatively long rectangular pulse and means for utilizing the trailing edge of said long pulse to generate a third pulse comprising a tuned circuit including in series relation a capacity element, an inductance element and a source of direct potential, said circuit having a natural period which is small compared with the duration of said long pulse, and control means for discharging said condenser under control of the leading edge of said long pulse comprising a unilaterally conducting device connected across the terminals of said inductance element poled in the direction to conduct current from said condenser during said discharge, said control means causing said condenser to charge again when said trailing edge of said long pulse is applied to said control means to set up a potential pulse across said inductance element.

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REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
2,063,025	Blumlein	Dec. 8, 1936
2,139,432	Andrieu	Dec. 6, 1938
2,181,309	Andrieu	Nov. 28, 1939
2,226,706	Cawein	Dec. 31, 1940
2,256,336	Beatty	Sept. 16, 1941
2,113,214	Luck	Apr. 5, 1938
2,153,202	Nichols	Apr. 4, 1939
2,085,402	Vance	June 29, 1937
2,188,653	Faudell et al.	Jan. 30, 1940
2,244,003	Eaglesfield et al.	June 3, 1941
2,408,061	Grieg	Sept. 24, 1946