Feb. 18, 1947. D. E. MAXWELL 2,416,111

PULSE GENERATING CIRCUIT

Filed June 19, 1944

Fig. 1.

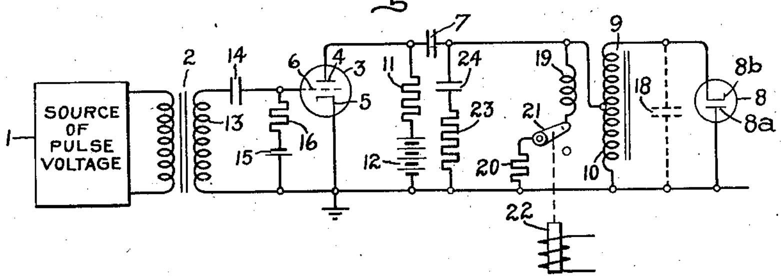


Fig. 2.

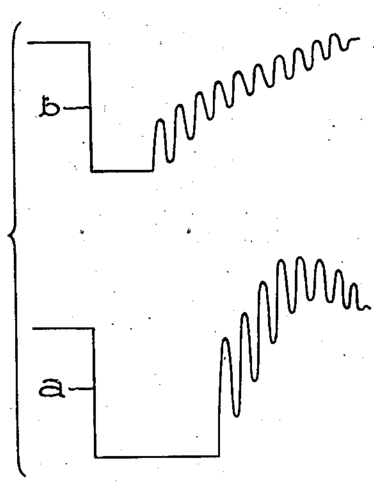
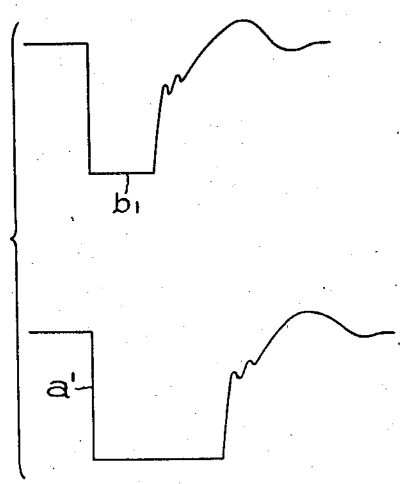


Fig. 3.



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2,416,111

PULSE GENERATING CIRCUIT

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9 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 pulse to provide a more nearly rectangular pulse wave form.

Many radio communication and detection circuits in current use employ pulse modulated rather than continuous carrier waves for transmission. The modulating pulses are of very short duration, for example of the order of 1 microsecond, and preferably are of substantially rectangular wave shape. The pulsed carrier wave may be utilized in various ways, such as by transmission and reflection of a series of pulses for object detection, or by signal modulation of the pulse width, amplitude, or frequency to convey intelligence.

The pulse modulated carrier waves are commonly produced by generating voltage pulses of the desired characteristics and utilizing the pulses to modulate the output of a high frequency oscillator, such as a magnetron oscillator or the like. In such modulating circuits a pulse transformer is frequently interposed between the pulse generator and the magnetron oscillator, both to increase the voltage applied to the magnetron tube and to provide a charging path for the capacitive pulse-forming element.

In certain applications it is found desirable that a single apparatus be capable of supplying pulses of selectable duration or width, a typical variation in width being over a range of the order of 5:1. For example, a single pulse generator may be required to supply either a 0.5 mircosecond pulse or a 2.5 microsecond pulse. Heretofore, considerable difficulty has been encountered in providing such a versatile pulse generating apparatus, especially where the pulse load circuit is inductive, as it is when a pulse transformer is used. Such transformer may be designed to produce desirably shaped pulses of only one width. If the transformer is designed to produce a well-shaped wide pulse, an appreciably narrower pulse will exhibit a very slow decay of voltage at the trailing edge; while, if the transformer is designed to produce a well-shaped narrow pulse, the magnetizing current will be excessive on the wide pulse, resulting in poor pulse efficiency and voltage reversal at the trailing edge of each pulse. In either case, the trailing edge of each pulse is characterized also by severe oscillations of very high frequency resulting from the leakage reactance and distributed capacitance within the pulse transformer itself. On the other hand, a pulse transformer designed for pulses of intermediate width leaves much to be desired, because both wide and narrow pulses will then have unsatisfactory wave shapes.

Accordingly, it is one object of my invention to provide a new and improved pulse generating

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circuit arranged to provide substantially rectangular pulses of selectable duration over an appreciable range of pulse widths.

It is a further object of my invention to provide, in a pulse generating circuit including a pulse transformer, means for suppressing trailing edge voltage oscillations of both high and low frequencies.

It is a still further object of my invention to provide a multiple width electric pulse generating circuit having means for effecting a rapid voltage decay at the trailing edge of each pulse and means for suppressing trailing edge oscillations.

In accordance with my invention, I provide a pulse transformer designed particularly to provide an optimum wave shape for the widest contemplated pulse. Such design demands, among other things, a transformer having a primary inductance sufficiently great that the magnetizing current and trailing edge oscillations will not be objectionably large for the wide pulse. Such a transformer, however, does not store sufficient energy during the shortest contemplated pulse interval to effect rapid decay of pulse voltage at the trailing edge of the pulse. Therefore, in order to provide sufficient energy storage to avoid slow voltage decay at the trailing edge of a short pulse, I connect across the pulse transformer an inductive network arranged to increase the effective magnetizing current and energy storage for short pulses to a value sufficient to cause rapid decay of the pulse voltage at the trailing edge of a short pulse. Switching means are provided for disabling the auxiliary inductive circuit when wide pulses are desired. Preferably, energy dissipating means is also provided across the pulse transformer for preventing violent voltage oscillations at the trailing edge of the pulse, while permitting rapid voltage decay.

My invention 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 Fig. 1 is a schematic circuit diagram of a pulse generating circuit embodying my invention and Figs. 2 and 3 are graphical representations of 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 voltage pulses of selectable width or duration. The succession of pulses originating in the source **1** is supplied through a transformer **2** to the input circuit of an electron discharge device **3**. The electron 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 storage 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, thereby to connect the condenser 7 for pulse discharge through an output circuit including an autotransformer 9 and a magnetron oscillator tube 8 having an anode 8a and a cathode 8b.

As shown in the drawing, the magnetron oscillator tube 8 is connected across the secondary winding of the autotransformer 9, the primary winding 10 of which is connected in parallel circuit relation with the pulse discharge path through the magnetron oscillator 8. The primary winding 10 of the autotransformer 9 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 current supply, such as the 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 anode 8a of the magnetron oscillator 8, as well as the negative terminal of the battery 12 and one terminal of the autotransformer 9, are connected together and grounded, as shown at Fig. 1.

The input circuit for 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 cut-off by any suitable means, such as, for example, a battery 15 and a grid resistor 16 connected between the cathode 5 and control electrode 6.

It is found in practice that the autotransformer 9 and the magnetron oscillator tube 8 have a certain amount of stray and distributed capacitance to ground. This capacitance is indicated at 18 by dotted lines in Fig. 1 as capacitance between the anode and cathode of the magnetron 8. The stray and distributed capacities represented by the capacitor 18 form with the autotransformer 9 a resonant circuit having a natural frequency of oscillation relatively high with respect to the repetition rate of the pulses from the source 1. This natural oscillation frequency 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. The autotransformer 9 has also a certain amount of internal leakage inductance and distributed capacitance. In pulse transformers of the type commonly employed in the generation of pulses of the character described, these internal circuit constants tend to initiate a very high frequency trailing edge oscillation superposed upon the 100 kilocycle oscillation described above. These superposed high frequency oscillations are ordinarily of the order of 7 to 10 megacycles per second.

The autotransformer 9 is designed to provide an optimum pulse wave shape for the pulses of longest duration contemplated, for example 2.5 microseconds. Since the autotransformer is connected in parallel circuit relation with the unidirectionally conducting magnetron oscillator tube 8, such design demands that the transformer be provided with sufficient inductance so that the energy stored in the transformer during the relatively long pulse will not be so great as to produce undesirably violent high frequency oscillations in the resonant circuit 9, 18 at the termination of a pulse. On the other hand, the transformer inductance must permit sufficient magnetizing current and energy storage to effect a rapid decay of pulse voltage at the pulse termination. A transformer designed to meet these requirements in the optimum manner will have such a high inductance that appreciably shorter pulses, for example of the order of 0.5 microsecond, will not store sufficient energy in the transformer to effect a rapid decay of pulse voltage at the termination of the pulse. Accordingly, for such short pulses, the trailing edge of the pulse will demonstrate a gradual decay of voltage, rather than a sharp decay as desired.

In order to improve the characteristics of my pulse generating circuit for short pulses, I provide in parallel circuit relation with the primary winding 10 of the autotransformer 9 an inductive circuit including an inductive impedance 19 connected in series circuit relation with a resistor 20 through a contact 21 of an electromagnetic relay 22. The relay 22 is controlled in any desired manner to connect the network 19, 20 in parallel circuit relation with the transformer primary winding 10 when short pulses are being generated and to disable the network 19, 20 when long pulses are generated. When the network 19, 20 is connected in circuit with the transformer, the effect of the network is to store additional energy in the inductive impedance 19 during the pulse intervals thereby to increase the effective magnetizing current and to increase the stored energy available for release at the termination of each pulse. The sum of the energy now stored in the transformer 9 and the inductor 19 is sufficient to produce a rapid decay of pulse voltage at the trailing edge of each pulse. The additional stored energy of course adds to the tendency to produce oscillations in the 100 kilocycle range at termination of each pulse. In order to maintain such oscillations within practical limits, the resistor 20 is provided and is of such value that the trailing edge oscillations in the 100 kilocycle range are rapidly damped out.

From the foregoing explanation, it is to be noted that it is necessary to design the autotransformer 9 itself so that, for long duration pulses with the network 19, 20 disabled, the energy stored in the transformer 9 itself is sufficient to produce a rapid decay of pulse voltage at the trailing edge while the network 19, 20 is so designed that the sum of the energy stored in the inductor 19 and the transformer 9, when the network 19, 20 is connected in circuit for short duration pulses, is sufficient to produce a similar rapid decay of pulse voltage at the termination of the short pulses. In either case, the energy necessary to produce a rapid voltage decay is also sufficient to initiate more or less violent trailing edge voltage oscillations at two characteristic frequencies. While the resistor 20 is sufficient to damp the lower frequency oscillation at about 100 kilocycles, additional means is necessary for suppressing the high frequency oscillations at about 7 to 10 megacycles arising from the internal circuit constants of the pulse transformer 9 itself. For this purpose, an additional damping resistor 23 may be connected in series circuit relation with a blocking capacitor 24 across the primary winding 10 of the autotransformer 9. The resistor 23 is preferably non-inductive and the capacitor 24 is of very small capacitance. This damping network 23, 24 is more fully described and claimed in my copending application, Serial No. 539,221, filed June 7, 1944.

In view of the foregoing detailed description of the function and arrangement of the various elements of the pulse generating circuit shown at Fig. 1, the mode of operation of the circuit as a whole will be understood from the following brief description. As previously mentioned, the electron discharge device 3 is normally biased to cut-off by the battery 15. When the discharge device 3 is not conducting, the condenser 7 is maintained charged to substantially the full voltage of the battery 12 through a charging circuit comprising the resistor 11, the condenser 7, and the primary winding 10 of the autotransformer 9. The voltage pulses applied from the source 1 through the transformer 2 are arranged periodically to impress positive potentials upon the control electrode 6 for predetermined pulse periods thereby to render the discharge device 3 conductive. When the discharge device 3 becomes conductive, the condenser 7 discharges through a load circuit comprising the discharge device 3, the magnetron oscillator tube 8, and the upper portion of the autotransformer 9. 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 magnetron oscillator tube 8 and the upper portion of the autotransformer 9.

It will be noted that there is connected also across this load circuit the primary winding 10 of the autotransformer 9. However, since the autotransformer primary winding 10 is highly inductive, very little magnetizing current flows through the primary winding during the pulse period. During the period of the pulse, however, a small amount of magnetizing current is gradually built up in the transformer winding 10 so that at the termination of the pulse a certain amount of energy is stored in the winding 10. This stored energy produces a rapid decay of voltage at the termination of the pulse discharge and initiates both a relatively low frequency oscillatory charge and discharge of the distributed and stray capacitance represented by the condenser 18 and the high frequency oscillations characteristic of the internal transformer circuit constants.

When the inductive reactor 19 is not connected in the circuit, the lower frequency oscillations are not of objectionable amplitude, and the high frequency oscillations are damped by the network 23, 24. When short pulses are received from the trigger voltage source 1, the inductive network 19, 20 is connected in circuit in order to store sufficient energy to effect rapid trailing edge pulse voltage decay. The reactor 19 increases the tendency of the circuit to develop oscillations in the range of 100 kilocycles, but the resistor 20 effects satisfactory damping of such oscillations. The network 23, 24 functions as before to damp the high frequency oscillations at 7 to 10 megacycles, but is relatively ineffective for the lower frequency oscillations.

To illustrate the effect of the networks 19, 20 and 23, 24 connected in parallel circuit relation with the primary winding 10 of the autotransformer 9, I have shown at Fig. 2 a diagram *a* illustrating a typical pulse wave shape for a 2.5 microsecond pulse obtained from the secondary winding of the pulse transformer 9 when the transformer 9 is designed to provide 2.5 microsecond pulses and the networks 19, 20 and 23, 24 are not connected in circuit with the transformer. At diagram *b* of Fig. 2, I have illustrated a typical wave shape for a 0.5 microsecond pulse as obtained from the same transformer under similar conditions. Referring now to Fig. 3, I have shown similar diagrams *a'* and *b'* illustrating the wave shapes of 2.5 and 0.5 microsecond pulses, respectively, which are obtained from the same transformer 9 when the networks 19, 20 and 23, 24 are connected in parallel circuit relation with the primary winding 10.

While I have described only one preferred embodiment of my invention by way of illustration, 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, a capacitive pulse-forming energy storage element, a load circuit including an inductive energy storage element, means for establishing a succession of pulse discharges of said capacitive storage element through said load circuit, said means comprising switching means and means for rendering said switching means conductive for recurrent pulse intervals of selectable duration, said inductive element storing sufficient energy during pulse intervals of maximum duration to effect a rapid voltage decay at the termination of each such pulse interval, and an additional inductive energy storage element arranged to be connected in parallel circuit relation with said first inductive element to facilitate the formation of pulses of shorter duration than said maximum.

2. In combination, a capacitive pulse-forming storage element, a load circuit including an inductive energy storage element, means for establishing a succession of pulse discharges of said capacitive storage element through said load circuit, said means comprising switching means and means for rendering said switching means conductive for recurrent pulse intervals of selectable duration, said inductive element storing sufficient energy during pulse intervals of maximum duration to effect a rapid decay of voltage at the termination of each pulse interval, means including a source of electric current supply for charging said capacitive storage element between said pulse intervals, an additional inductive energy storage element arranged to be connected in parallel circuit relation with said first inductive element to facilitate the formation of pulses of shorter duration than said maximum, and means for damping electric oscillations initiated by said stored energy at the termination of each of said pulse discharges comprising a resistor connected in series circuit relation with said additional inductive energy storage element.

3. An electric pulse generating circuit comprising a capacitive pulse-forming storage element, a load circuit including an inductive energy storage element, means for establishing a succession of pulse discharges of said capacitive storage element through said load circuit, said means comprising switching means and means for rendering said switching means conductive for recurrent pulse intervals of selectable duration, said inductive element storing sufficient energy during pulse intervals of maximum duration to effect a rapid

decay of voltage at the termination of each pulse interval, means including a source of electric current supply for charging said capacitive storage element between said pulse intervals, and means for facilitating the formation of pulses of shorter duration than said maximum comprising an additional inductive energy storage element and a resistor arranged selectably to be connected in circuit with said first inductive energy storage element.

4. An electric pulse generating circuit comprising a capacitive pulse-forming energy storage element, a load circuit including a unidirectional conducting device, means for establishing a succession of pulse discharges of said capacitive storage element through said load circuit including switching means and means for recurrently rendering said switching means conductive for pulse intervals of selectable duration, means including an inductive energy storage element connected across said unidirectional conducting device, said inductive element storing sufficient energy during pulse intervals of maximum duration to effect a rapid voltage decay at the termination of each pulse interval, and an additional inductive energy storage element arranged selectably to be connected in series circuit relation with a resistor across said first inductive energy storage element during the formation of pulses of shorter duration than said maximum.

5. In combination, an electron discharge device including an anode, a cathode, and a control electrode, means for supplying to said control electrode a succession of voltage pulses of selectable duration arranged recurrently to render said discharge device conductive for predetermined selectable pulse intervals, a capacitive pulse-forming energy storage element, a load circuit connected to said capacitive storage element through said discharge device, said load circuit including an inductive energy storage element having a magnetizing current sufficient to provide a rapid voltage decay at the termination of pulses of maximum selectable duration, a second inductive energy storage element, and switching means for connecting said inductive storage elements in parallel circuit relation to increase the effective magnetizing current in said load circuit thereby to facilitate the formation of pulses of shorter duration than said maximum.

6. In combination, an electron discharge device including an anode, a cathode, and a control electrode, means for supplying to said control electrode a succession of voltage pulses of selectable duration arranged recurrently to render said discharge device conductive for predetermined selectable pulse intervals, a capacitive pulse-forming energy storage element, a load circuit connected to said capacitive storage element through said discharge device, said load circuit including an autotransformer and a unidirectionally conducting device connected across the transformer secondary winding, the magnetizing current of said transformer storing sufficient energy in said transformer during pulses of maximum selectable duration to provide a rapid voltage decay at the termination of each such pulse, and means for increasing the effective magnetizing current of said transformer for pulses of shorter duration than said maximum comprising an inductive energy storage element and an energy dissipating resistor arranged for selectable connection in parallel circuit relation with the primary winding of said transformer.

7. In combination, a capacitive pulse-forming

energy storage element, a load circuit including an inductive energy storage element, means for establishing a succession of pulse discharges of said capacitive storage element through said load circuit, said means comprising switching means and means for rendering said switching means conductive for recurrent pulse intervals of selectable duration, said inductive element storing sufficient energy during pulse intervals of maximum selectable duration to effect a rapid voltage decay at the termination of each such pulse interval, a second inductive energy storage element, switching means for connecting said second inductive energy storage element in parallel circuit relation with said first inductive energy storage element thereby to increase the effective magnetizing current of said load circuit for pulses of shorter duration than said maximum, and means for damping electric oscillations initiated by said stored energy at the termination of each pulse discharge comprising a resistor connected in parallel circuit relation with said first energy storage element.

8. In combination, an electron discharge device including an anode, a cathode, and a control electrode, means for supplying to said control electrode a succession of voltage pulses of selectable duration arranged recurrently to render said discharge device conductive for predetermined selectable pulse intervals, a capacitive pulse-forming energy storage element, a load circuit including an autotransformer having a primary winding connected across said capacitive pulse-forming element through said discharge device, said load circuit including also a unilateral conducting device connected across the secondary winding of said transformer, the magnetizing current of said transformer being sufficient for pulses of maximum duration to effect rapid voltage decay of said pulses at the termination thereof, means for increasing the effective magnetizing current of said transformer comprising an inductive energy storage element, switching means for connecting said inductive energy storage element in parallel circuit relation with the primary winding of said autotransformer during the occurrence of pulses of shorter duration than said maximum, and means for suppressing high frequency electric oscillations across said transformer at the termination of each pulse discharge comprising a resistor and a blocking capacitor connected in series circuit relation across the terminals of said transformer primary winding.

9. A generating circuit for voltage pulses of selectable duration comprising a pulse-forming energy storage element, a load circuit including an inductive energy storage element, switching means for connecting said load circuit to said pulse-forming element for pulse intervals of selectable duration, said inductive element storing sufficient energy during pulses of maximum duration to effect a rapid voltage decay at the termination of each such pulse, and means for selectably increasing the inductive energy storage capacity of said load circuit thereby to facilitate the formation of pulses of shorter duration than said maximum.

DONALD E. MAXWELL.

REFERENCES CITED

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

FOREIGN PATENTS

Number	Country	Date
497,147	British	Dec. 9, 1938