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STABILIZED PULSE FORMING CIRCUIT INCLUDING A GAS TUBE

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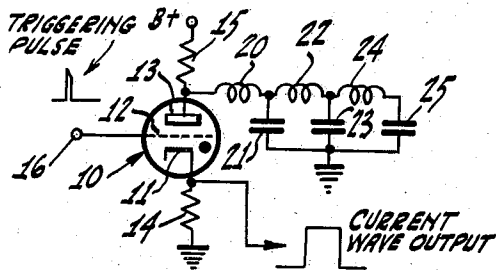


Fig. 1.

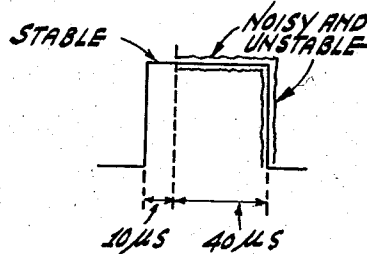


Fig. 2.

PRIOR ART

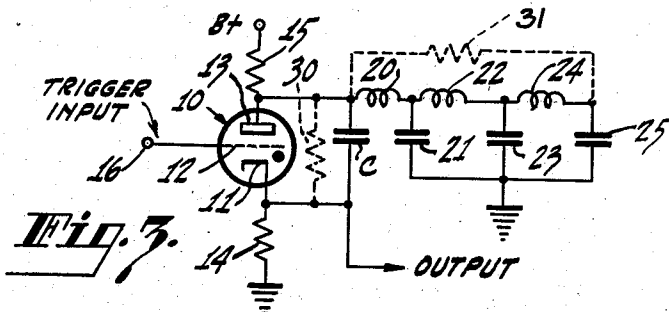


Fig. 3.

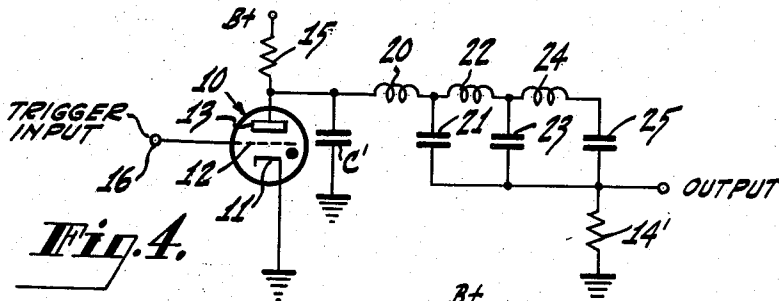


Fig. 4.

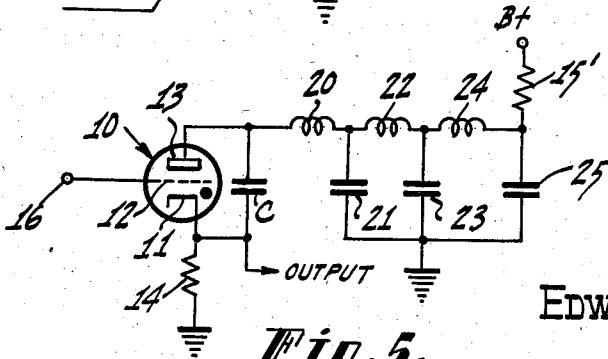


Fig. 5.

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STABILIZED PULSE FORMING CIRCUIT INCLUDING A GAS TUBE

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11 Claims. (Cl. 315-237)

This invention relates to a pulse forming circuit, and particularly, to a pulse forming circuit including a hot cathode gas tube and a delay line which determines the width of the output pulse. An output pulse is generated in response to a trigger pulse applied to the control electrode of the gas tube.

Hot cathode gas tubes are advantageously used in pulse forming circuits because they have large current carrying capacity with a very small voltage drop across the tube during conduction. It has been found however that the output pulse generated from such a circuit is not perfectly square but includes disturbances in the amplitude of the pulse and variations in the trailing edge of the pulse. These disturbances cause noisy and unstable operation which is very objectionable in various applications of pulse forming circuits.

It is an object of this invention to provide a pulse forming circuit including a gas tube and a delay line, the circuit being characterized in providing an output pulse which is free of disturbances caused by the inherent characteristics of the gas tube. It is another object of this invention to provide an improved pulse forming circuit which generates a pulse having a stable trailing edge.

In one aspect, the invention comprises a hot cathode gas tube such as a thyratron having an anode connected through a resistor to a positive terminal of a source of uni-directional current and having a cathode connected through a resistor to ground (the negative terminal of the source of uni-directional potential). An artificial delay line is connected from the anode of the gas tube to ground. A trigger pulse is applied to the control electrode of the gas tube to initiate the generation of an output pulse across the cathode resistor, the output pulse having a width determined by the artificial delay line. A capacitor is connected directly across the gas tube from the anode electrode to the cathode electrode. The purpose of the capacitor is to prevent a rapid fall in the anode potential after the tube starts conducting and to thereby prolong the period of time when an excess of ions is created within the tube. It has been found that when an excess of ions is present within the tube the disturbances inherent in the normal operation of the tube are eliminated.

Other objects and aspects of the invention will be apparent to those skilled in the art from the following detailed description taken in conjunction with the appended drawing, wherein:

Fig. 1 is a circuit diagram of a pulse forming circuit according to the prior art;

Fig. 2 is a representation of an output wave form of a pulse forming circuit such as that shown in Fig. 1;

Fig. 3 is a circuit diagram of a pulse forming circuit constructed according to the teachings of this invention and including a capacitor connected from the anode to the cathode of the gas tube;

Fig. 4 is another embodiment of the invention wherein an output of different polarity is obtained from an

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output resistor connected between the delay line and ground; and

Fig. 5 is another circuit variation which involves series feed of the B+ potential, rather than shunt feed.

Referring now to Figs. 1 and 2 for a description of a known pulse forming circuit, a hot cathode gas tube 10, which may be a thyratron, has a filament (not shown), a cathode 11, a control electrode 12, and an anode 13. The cathode 11 is connected through a cathode resistor 14 to ground. The anode 13 is connected through a load resistor 15 to the B+ terminal of a source of uni-directional potential (not shown). The negative terminal of the source is connected to ground. The control electrode 12 is connected to an input terminal 16 to which a triggering pulse is applied. The anode 13 is also connected to a three-section artificial delay line, the first section of which is made up of inductor 20 and capacitor 21, the second section of which is made up of inductor 22 and capacitor 23 and the third section of which is made up of inductor 24 and capacitor 25. The other end of the artificial delay line is connected to ground. An output pulse as shown in Fig. 2 is obtained with respect to ground from the cathode 11 of gas tube 10. The width of the output pulse is determined by the design of the delay line according to a formula which is well known in the art. Delay line pulse generators are shown and described following page 238 of volume 19 entitled "Waveforms" of the Radiation Laboratory Series, first edition, published by McGraw-Hill Book Co., Inc., 1949. The theory of delay lines is set forth in Chapter 22 of the same book. The design and construction of electrical delay lines is set forth in volume 17, chapter 6, of the same series. Delay line pulse generators are shown and described in Patent No. 2,608,654, issued on August 26, 1952, to J. C. Street, and entitled "Pulse-Forming Circuit."

The output pulse may be as shown in Fig. 2 and for purposes of discussion may be assumed to be in the order of 50 microseconds wide. It will be noted from Fig. 2 that the first few microseconds of the pulse is stable in amplitude and is free of noise, that is, free of disturbances in the amplitude of the pulse. Following the stable portion of the pulse there is a portion which is noisy and unstable. This portion of the pulse is characterized in having fluctuations in the amplitude of the pulse and fluctuations which result in variation in the time at which the trailing edge of the pulse occurs. These variations alter the width of the pulse and may be very objectionable in many applications. It is believed that during the first few microseconds of the pulse, the pulse is stable by reason of the effect of the interelectrode capacitance of the gas tube 10. It is believed that this interelectrode capacitance tends to delay the time at which the anode potential drops after the tube becomes conductive. The capacitance, in delaying the drop in anode potential, causes an excess of ions to be formed within the tube, and this excess of ions exists for a short period of time during which the output pulse is free of disturbances.

Fig. 3 shows a pulse forming circuit constructed in accordance with the teachings of this invention wherein the circuit of Fig. 1 is modified by the addition of a capacitor C connected directly through low impedance conductors from the anode 13 to the cathode 11 of the gas tube 10. Capacitor C has a value of capacitance which is much smaller than the capacitance of capacitors 21, 23 and 25 of the delay line. The three sections of the delay line are made of inductors and capacitors which are identical one with another and therefore capacitors 21, 23 and 25 are equal in value. The capacitor C is selected to have a value of less than 1/5 the value of one of the identical capacitors 21, 23 and 25. In the design of a pulse circuit as shown in Fig. 3, a capacitor C will

be selected having as small a value of capacitance as will provide an output pulse which is stable and free of disturbances throughout its entire duration. If the value of the capacitor is too small, the stabilizing effect will not continue throughout the duration of the output pulse. If the value of capacitor C is too large, it will exert a disturbing influence on the output signal immediately following the trailing edge of the output pulse. This disturbance takes the form of a ringing. That is, damped oscillations are generated at a frequency determined by the values of the various components in the circuit. Therefore, the proper value for capacitor C is one which provides an amount of capacitance just large enough to stabilize the output wave form throughout the duration of the output pulse.

In applications of the pulse forming circuit where ringing immediately following the output pulse, even though of small amplitude, must be prevented, a damping resistor 30 may be shunted across the capacitor C. The shunting resistor is shown in Fig. 3 by dotted lines. The ringing results from the interaction of the several capacitive and inductive elements in the circuit. The ringing may be damped by shunting a resistor across one or more of the capacitive and inductive elements. For example, a resistor 31 shunted across the three inductors 20, 22, and 24 may take the place of and be a substitute for damping resistor 30.

The value of the cathode resistor 14 is selected to provide a proper impedance match for the artificial delay line and therefore the value of resistance is equal to the square root of the inductance of one of inductors 20, 22 or 24 divided by the square root of the capacitance of one of capacitors 21, 23, or 25. As is known, the duration of the output pulse is given by the formula

$$2N\sqrt{LC}$$

wherein N is the number of sections of the delay line, L is the inductance of each of the inductors and C is the capacitance of each of the capacitors in the delay line. The value of the anode resistor 15 is selected to provide a charging circuit including capacitors 21, 23, and 25 which has a time constant sufficiently short to insure that the capacitors will be fully charged up in the period of trigger pulses. The design formula customarily used requires that the time period between trigger pulses shall equal 3 to 10 times the product of resistor 15 and the total capacitance of capacitors 21, 23 and 25.

As stated above, the value of capacitor C can be so chosen that it stabilizes the output pulse during its entire duration. To satisfy this requirement, the circuit should be constructed with circuit elements which satisfy the following formula:

$$t \approx T \ln KCER$$

where t is the required stable period of time which normally is also the time duration of the output pulse, in microseconds, T is the tube diffusion time constant in microseconds, K is a complicated constant depending upon the tube characteristics, C is the capacitance of capacitor C in micro-microfarads, E is the B+ voltage, and R is the line terminating resistance or the resistance of resistor 14. T, the tube diffusion time constant, depends upon the geometry of the tube 10, upon the molecular weight of the gas in the tube and upon the gas pressure. By way of example, an RCA type 2D21 thyratron tube has a value of T of about 100, and a value of K equal to about 1.42×10^{-7} . A circuit having a pulse duration of 50 microseconds and therefore a quiet time or stable period for 50 microseconds and including the above mentioned thyratron tube, might employ a capacitor C having a value of 470 micro-microfarads, a B+ source of 250 volts and a terminating resistor 14 of 100 ohms.

It will be understood that if the output pulse duration is very long, the value of capacitor C required to sta-

bilize the output pulse throughout its duration may be so large as to cause disturbing oscillations immediately following the trailing edge of the pulse. If this is the case, a choice must be made as to whether to stabilize the entire duration of the pulse and tolerate the ringing immediately following the trailing edge of the pulse, or to stabilize only an initial portion of the pulse so that the ringing is of very slight amplitude. If ringing is to be avoided, the value of capacitor C should not exceed $\frac{1}{5}$ the value of the individual capacitors 21, 23 and 25.

Fig. 4 shows an alternative arrangement of the pulse forming circuit wherein the output resistor 14' is connected from the delay line to ground rather than from ground to the cathode 11 of tube 10 as shown in Figs. 1 and 3. The output resistor 14' is determined in value in the same manner as has been described in connection with resistor 14 and the only difference between the circuits of Figs. 4 and 3 is that the polarity of the output pulse is reversed with respect to ground. It will be noted that the capacitor C' is directly connected from the anode of the tube to the cathode, the cathode being grounded.

Fig. 5 shows a timing circuit exactly the same as those previously described except that it is series fed with B+ potential through resistor 15' which is otherwise the same as resistor 15 in the previous figures. Figs. 1, 3 and 4 show a shunt fed system for the delay line.

It is apparent from the foregoing that according to the teachings of this invention, disturbances in the output wave of a circuit including a gas tube are prevented by the connection of a capacitor directly from the anode of the gas tube to the cathode of the gas tube. The capacitor is effective in preventing noise and instability by reason of its prolonging the period of time during which the anode voltage of the tube remains at a high value immediately following the start of conduction through the tube. The value of the capacitor is made sufficiently large to stabilize the output of the tube for the desired time period following the initiation of conduction through the tube. Normally the capacitor may have a value such that the output pulse of the pulse forming circuit is stable throughout its entire duration.

What is claimed is:

1. A pulse forming circuit comprising a gas tube including a cathode and an anode, an artificial delay line including capacitors and inductors and having terminals coupled respectively to said cathode and said anode, and a capacitor connected from said anode to said cathode, said last-mentioned capacitor having a value equal to less than $\frac{1}{5}$ the value of any of the capacitors in each section of said artificial delay line.
2. A pulse forming circuit comprising a gas tube having a cathode, a control electrode and an anode, an output resistor connected to said cathode, an artificial delay line including a plurality of sections of inductors and capacitors coupled to said anode and to said output resistor, and a capacitor connected directly from said anode to said cathode, said capacitor having a value less than one fifth the value of each of said capacitors in said delay line, and means to supply a triggering pulse to said control electrode.
3. A pulse forming circuit as defined in claim 2 and in addition a damping resistor connected across said capacitor.
4. A square wave forming circuit as defined in claim 2 and in addition a damping resistor connected across one or more of the inductor elements of said artificial delay line.
5. A square wave forming circuit as defined in claim 2 and in addition a damping resistor connected across one or more of the capacitor elements of said artificial delay line.
6. A square wave generator comprising, a gas tube having a cathode, control electrode and an anode, said cathode being connected to a point of reference potential, an

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artificial delay line including a plurality of sections of inductors and capacitors, a resistor, said artificial delay line being connected directly to said anode and to said cathode thru said resistor, an output terminal connected to said resistor, and a capacitor connected directly from said anode to said cathode, said capacitor having a value less than one-fifth the value of each of said capacitors in the delay line.

7. A square wave generator comprising, a gas tube having a cathode, control electrode and an anode, a cathode resistor coupling said cathode to a point of reference potential, an artificial delay line including a plurality of sections of capacitors and inductors, said artificial delay line being connected between said anode and said point of reference potential, means to apply a unidirectional potential to said anode and to said delay line at the end closest to said anode, and a capacitor connected directly from said anode to said cathode, said capacitor having a value less than one-fifth the value of each of said capacitors in the delay line.

8. A square wave generator comprising, a gas tube having a cathode, control electrode and an anode, said cathode being connected to a point of reference potential, an artificial delay line including a plurality of sections of inductors and capacitors, an output terminal, said artificial delay line being connected between said anode and said output terminal, an output resistor coupled between said output terminal and said point of reference potential, and a capacitor connected directly from said anode to said point of reference potential, said capacitor having a value less than one-fifth the value of each of said capacitors in the delay line.

9. A square wave generator comprising, a gas tube having a cathode, control electrode and an anode, a cathode resistor coupling said cathode to a point of reference

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potential, an artificial delay line including a plurality of sections of capacitors and inductors, said artificial delay line being connected between said anode and said point of reference potential, means to apply a unidirectional potential to said anode thru said delay line, and a capacitor connected directly from said anode to said cathode, said capacitor having a value less than one-fifth the value of each of said capacitors in the delay line.

10. A pulse forming circuit comprising a gas tube including a cathode and an anode, an artificial delay line having terminals coupled respectively to said cathode and said anode and including a plurality of sections each having an inductor and a capacitor, all of said capacitors in said sections being equal in value, said sections being connected in cascade, and a capacitor connected between said anode and said cathode and having a value not exceeding one-fifth the value of each of said capacitors in said sections of said delay line.

11. A square wave generator comprising a gas tube having a cathode, control electrode and an anode, an artificial delay line including a plurality of sections of inductors and capacitors, a resistor, said artificial delay line being connected directly to said anode and to said cathode through said resistor, an output terminal connected to said resistor, and a capacitor connected directly from said anode to said cathode, said capacitor having a value less than one-fifth the value of each of said capacitors in the delay line.

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