

July 29, 1952

H. J. WHITE

2,605,310

ROTARY SPARK GAP MODULATOR

Filed Oct. 30, 1945

4 Sheets-Sheet 1

FIG.1

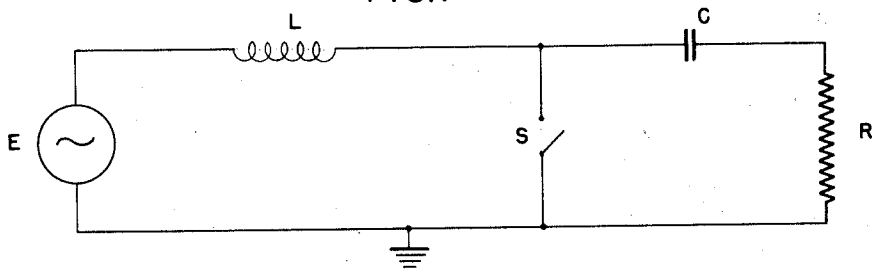
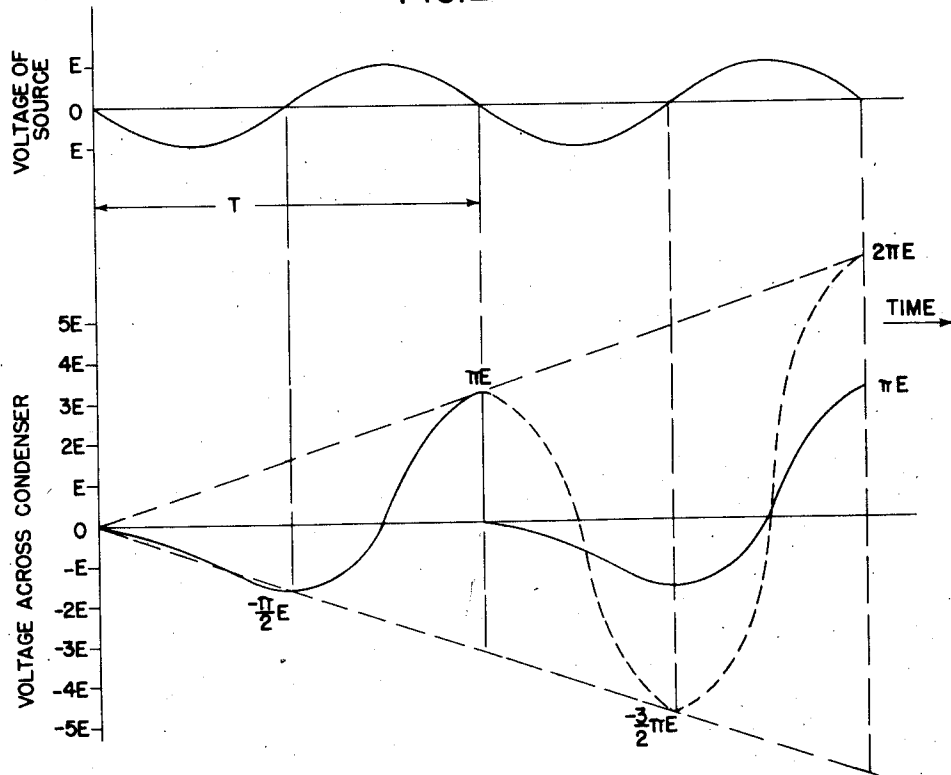


FIG.2



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FIG. 3

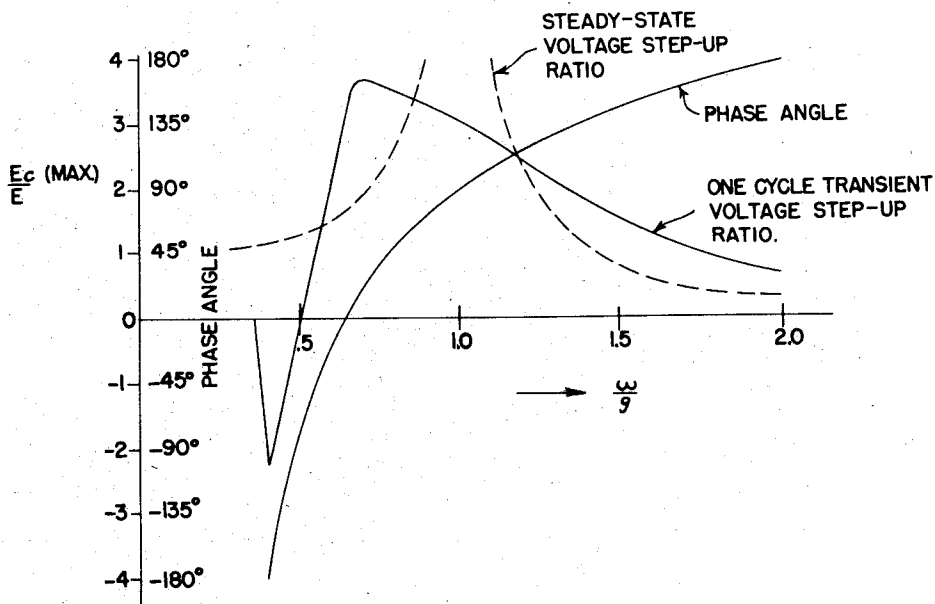
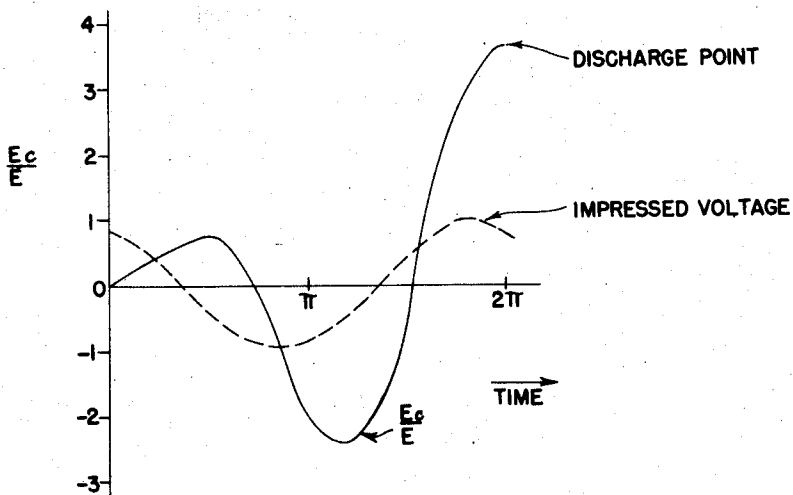


FIG. 4



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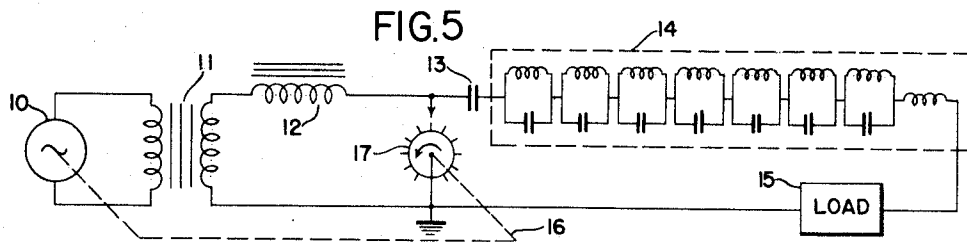
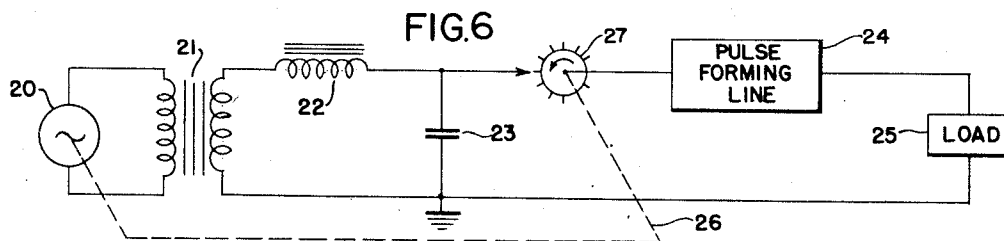
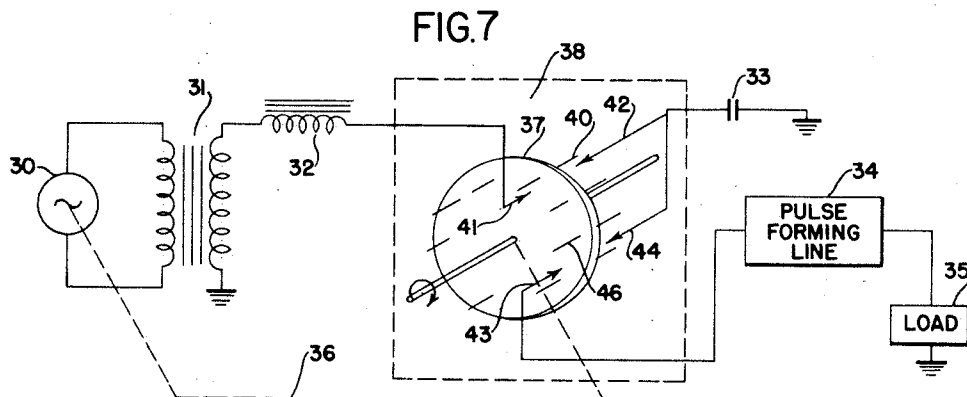
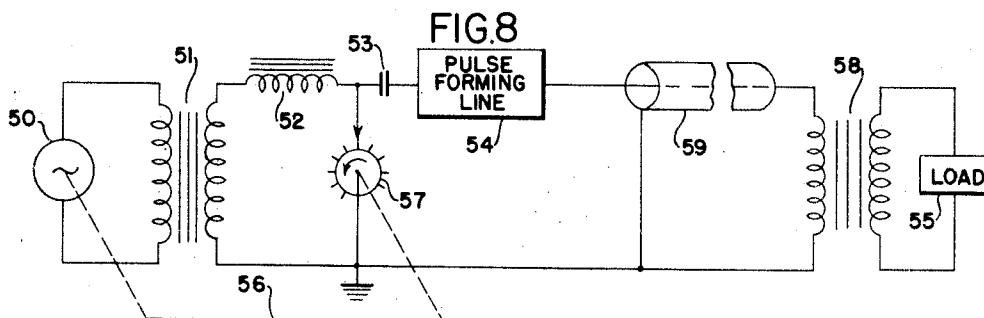
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4 Sheets-Sheet 3



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FIG. 9

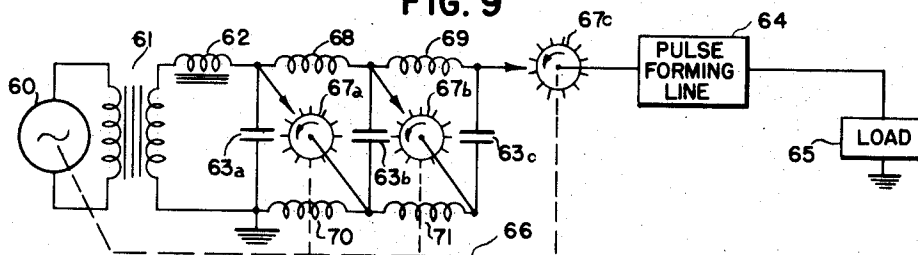


FIG. 10

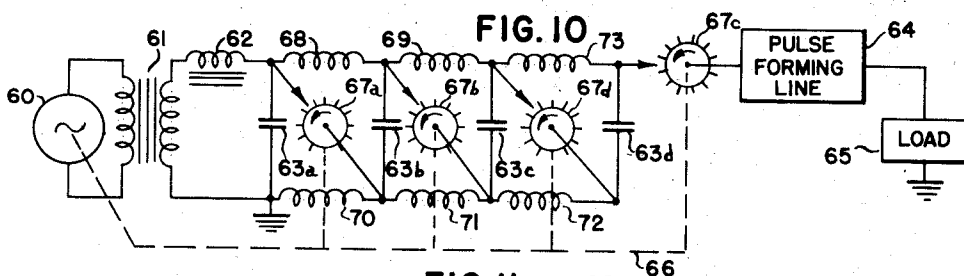


FIG. 11

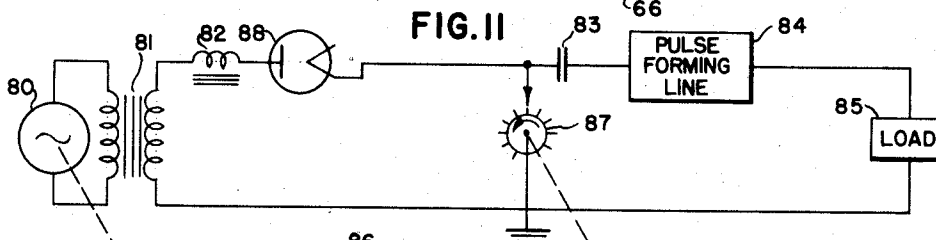
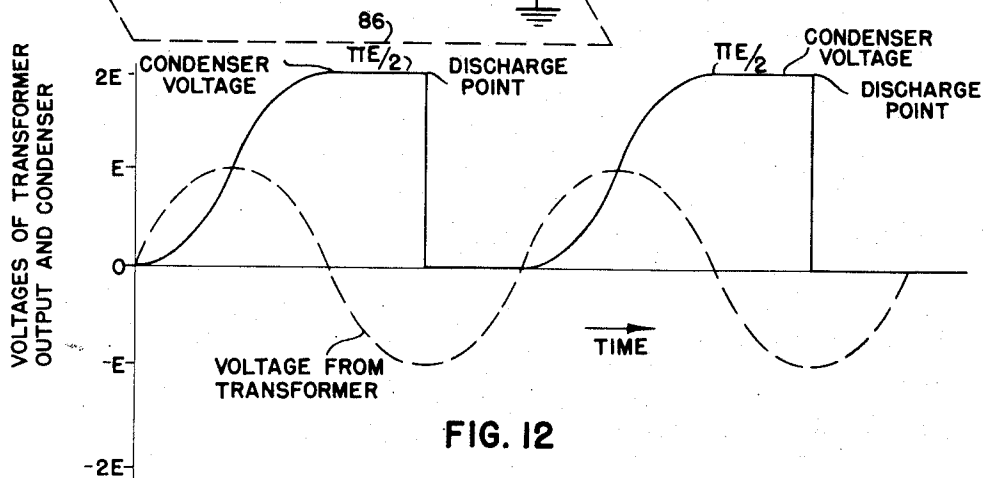


FIG. 12

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ROTARY SPARK GAP MODULATOR

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Application October 30, 1945, Serial No. 625,664

20 Claims. (Cl. 171-97)

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This invention relates to modulators, particularly those in which a circuit is provided through which a pulse forming network is charged from a source of alternating voltage and then discharged to pulse a transmitter. A spark gap is used to effectively connect the line for charging from this source and when the line is charged or later to effectively connect it for discharging through any suitable load.

It is an object of this invention to provide a circuit for charging a capacity in a pulse forming network.

It is a further object of this invention to provide a circuit for charging a capacity in a pulse forming network and controlled by a spark gap.

It is a further object of this invention to provide a circuit either resonant or non-resonant to the frequency of the voltage source, which will substantially increase the voltage which would otherwise be applied to charge a capacity in a pulse forming network.

Other and further objects will appear during the course of the following description.

In very high frequency circuits where the electromagnetic output is pulsed, a magnetron is usually employed as a source of high frequency energy. To trigger or pulse this magnetron a relatively high voltage in the neighborhood of ten or twenty kilovolts, depending on the characteristics of the particular magnetron, is necessary. This voltage is applied to the magnetron during the entire period of oscillation. It is characteristic of magnetrons that if this voltage falls appreciably from rated during the oscillation period, modes of oscillation other than the one desired may result. This causes serious loss of power, lowered magnetron efficiency, and difficulties in tuning, since unwanted frequencies are present in the output. Therefore, the triggering voltage must arise rapidly, remain constant during the oscillating period, and decrease rapidly to zero at the end. In other words, an energizing voltage of rectangular wave form is desirable.

This energizing voltage or pulse may be obtained from the discharge of a pulse forming network. Such a network consists of electrical elements so proportioned and arranged as to stimulate the characteristics of an open circuited uniform line of electrical length equal to one half the pulse duration. It ordinarily comprises a capacity which stores energy from the source and a so-called pulse forming line which shapes the pulse when the energy stored in the capacity passes through the line. This network is alternately charged and discharged by suitable

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switching. In the instant disclosure a spark gap is used. To obtain a discharge pulse of high voltage from this network, it is necessary that the line be charged to a high voltage, ordinarily, twice the voltage necessary to pulse the magnetron. This requires a high voltage source of energy with the inherent disadvantages of such a voltage. The present invention incorporates a circuit between the network and the source which substantially reduces the voltage required by the source and yet charges the network to full voltage necessary to pulse the magnetron. This circuit operates in cooperation with the spark gap. It will now be described in more detail in conjunction with the accompanying drawings where:

Fig. 1 is a circuit diagram useful in explaining the theory of this invention;

Figs. 2, 3 and 4 are charts of certain waveforms obtainable from Fig. 1;

Figs. 5, 6, 7, 8, 9, 10 and 11 are each a diagram of an embodiment of the invention; and

Fig. 12 is a chart of certain waveforms obtainable from Fig. 11.

In the diagram in Fig. 1 an inductance L and a capacity C are connected in series with an alternating source of voltage of peak value E . The period T of the alternating voltage and the inductance and capacity are all of such magnitude as to provide a series resonant circuit. The relationship between these three values may be expressed by the equation

$$T = 2\pi\sqrt{LC}$$

When the alternating voltage E of waveform as shown in the upper portion of Fig. 2 is applied to the inductance and capacity the transient by means of which the voltage across condenser C changes from the initial condition to the steady state is shown in the lower portion of Fig. 2 by the full line followed by the broken line. In the case where there is no dissipation the condenser voltage continues to alternate with an ever-increasing amplitude. With the damping as provided by load R the peaks do not linearly increase as shown in the Fig. 2 but increase exponentially toward a limiting value which is the steady state peak alternating voltage across the condenser. If the load R represents a magnetron, the energy stored in condenser C may be used to pulse this magnetron by closing switch S when this transient has been allowed to proceed for one-half, one, or two cycles, or more, and then opening switch S when condenser C has substantially discharged. The variation of the voltage in condenser C for one-cycle charging

is shown by the full line in the lower portion of Fig. 2. The storage voltage has the following peak values for various firing times:

Time	Peak Values	
	Theoretical	Actual
One-half cycle.....	$-\frac{\pi}{2}E$	-1.47E
One cycle.....	πE	2.8E
Two cycle.....	$2\pi E$	5E

It may be noted that the actual values depend on the resistance of load R, and the values shown are merely representative of loads likely to be encountered in practice.

For the case of non-resonance, that is where the damped natural or characteristic angular frequency of the charging circuit is not equal to the frequency of the applied alternating voltage, there is still a voltage gain across the condenser over the applied alternating voltage, if the transient is limited to one or two cycles duration. This gain may even exceed that for the resonant case. The voltage gain for the non-resonant case, especially when the timing is rather far off resonance, may be thought of as being due to the phenomenon of beats, the beats occurring between the steady-state voltage of angular frequency ω and the transient voltage of angular frequency g . The voltage rises to high peak values for a few cycles and then subsides to the steady-state value as the transient dies out. In the resonant case, on the other hand, the voltage rises to higher and higher peak values, the steady-state value being limited in magnitude only by damping.

It is clear that, in general, damping cannot be important in the non-resonant case. An exception must be made for the case of near resonance, that is when $g \approx \omega$. However, in dealing with transients of one or two cycles duration damping may usually be neglected.

In Fig. 3 the ratio of the maximum voltage appearing across the condenser to the peak of the alternating applied voltage is plotted as full line against

$$\frac{\omega}{g}, \frac{\omega}{g}$$

being a measure of the deviation of the frequency of the applied voltage from the characteristic resonance frequency of the charging circuit. This is for the case where the condenser is allowed to charge for one cycle of the applied voltage. It is seen that maximum step-up ratio for this case is about 3.7 and occurs when

$$\frac{\omega}{g}$$

is .70 as compared with a value of about 3.1 when

$$\frac{\omega}{g}$$

is unity. It is to be emphasized that this result is only for one cycle of charge. The steady state value of the step-up ratio is shown by the dotted line, and with no dissipation has a value of infinity when

$$\frac{\omega}{g}$$

is unity. The phase angle is represented by the dot and dash line, and in order to have the volt-

age across the condenser rise to this maximum value in one charging cycle it is necessary to have the applied voltage in the proper phase relationship at the time of opening switch S. For maximum value of the step-up ratio the phase angle will be about 21 degrees.

In Fig. 4 is disclosed as a full line the condenser voltage transient for maximum step-up ratio over one charging cycle, which is of a time duration equal to the period of the applied wave. This is only for the case where

$$\frac{\omega}{g}$$

is .70. The impressed alternating voltage is shown by a dotted line.

In the embodiment in Fig. 5 a source of alternating voltage 10, usually 400 cycles, is impressed on a transformer 11. The output of transformer 11 is connected in series with an inductance 12 and a capacity 13. A spark gap 17 is provided having a fixed electrode and a rotatable wheel having a plurality of electrodes evenly and circumferentially spaced thereon. Each rotating electrode passes sufficiently close to the fixed electrode to permit the separating air to break under the influence of the voltage existing thereacross at the time of passing, and thus form a low resistance path for discharge of any energy which may be stored in condenser 13. After the rotating electrode passes the fixed electrode the arc is broken, to be reformed upon the arrival of the succeeding rotating electrode. It is thus seen that the spark gap 17 operates as a switch. Pulse forming line 14 is in series with condenser 13. This line may be a Guillemin line as shown. Load 15 completes the series circuit.

The wheel of spark gap 17 is preferably mechanically linked with the rotating member of alternating voltage source 10 as shown by dotted line 16. This provides for the shorting of the spark gap at any desired rate with respect to the frequency of the impressed voltage and further for this shorting to occur in any desired phase relationship with respect to the applied voltage wave.

The values of inductance 12 and capacity 13 are chosen to permit either resonant or non-resonant charging therethrough as desired from an applied voltage of known frequency. Spark gap 17 is so mechanically linked as to be driven from the rotating member of source 10 at a rate and phase such that condenser 13 will charge for the desired time depending on whether condenser 13 is to be resonantly or non-resonantly charged and then discharged through the then shorted spark gap to energize load 15 during part or all of the shorted period.

While pulse forming line 14 is in series with inductance 12 and condenser 13 during charge, it does not have any appreciable effect on the charging. The frequency of the impressed voltage is low in comparison with any resonant frequencies of this line. The inductances of this line offer a very low impedance at the frequency of the voltage impressed. Furthermore, the condensers of this line do not acquire any appreciable charge, except when the line is discharging.

The embodiment in Fig. 6 is similar to that in Fig. 5 except that the spark gap and charging condenser are reversed in position. The operation is similar to the preceding embodiment. When the gap is opened condenser 23 charges in accordance with its capacity and the inductance

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of inductor 22. The condenser discharges when the gap is short circuited to energize load 25, the time of discharge is the cycle depending on the rate of rotation and the phasing of the wheel of gap 27. In this embodiment the voltage source is not effectively disconnected during the discharging of the condenser as in the preceding embodiment.

In the embodiment shown in Fig. 7 a spark gap generally indicated by numeral 38 is employed having a rotary disc 37 through which extends a plurality of peg type electrodes such as 40 and 46. Disc 37 rotates in a definite relationship with the rotating element of source 30 to provide for charging and discharging at the proper time in the cycle of the alternating voltage. Condenser 33 is charged through the circuit formed when one of the peg electrodes, say 40, is disposed in alignment with fixed electrodes 41 and 42. At a later time after this charging circuit is broken another of the peg electrodes, say 46, is aligned with electrodes 43 and 44 to form a circuit for discharge of condenser 33 through line 34 and load 35. It is to be noted that the charging time of condenser 33 is more limited than in preceding cases due to the short time that peg electrode 40 is aligned with the electrodes 41 and 42 to form a circuit. Hence the time constant of the charging circuit formed by inductance 32 and condenser 33 must be relatively small. This is obtained by making inductance 32 small. This embodiment has the advantage of slightly higher efficiency, since the source of power is never connected when the load is being pulsed by the network.

The embodiment in Fig. 8 is somewhat similar to that disclosed in Fig. 5. The Fig. 8 embodiment is particularly useful where the load which may be a magnetron has its output connected to an antenna, and the antenna is separated by a considerable distance from the power units which include source 50 and transformer 51 in the drawing. Long radio frequency lines tend to make a magnetron unstable and should be avoided if possible. Likewise transmission of high voltages over extended distances where equipment of this nature is likely to be used is undesirable. These difficulties are overcome here by forming the pulse as in previous embodiments, but at relatively low voltage, and transmitting this pulse over a coaxial line 59. Load 55 as usually encountered in practice will have a resistance much higher than the characteristic impedance of the coaxial line. To match the line to the load and also to step the relatively low voltage pulse up to a useful value, a pulse transformer 58 is inserted between the output of the coaxial line and the load.

In the embodiment of Fig. 9 three condensers 63a, 63b, and 63c are charged in parallel and discharged in series by the switching action of three rotary spark gaps 67a, 67b, and 67c mechanically linked together and to voltage source 60 as shown by dotted line 66. These three spark gaps open and close their respective circuits in synchronism. When the circuits across the gaps are open, condensers 63a, 63b, and 63c are either resonantly or nonresonantly charged as desired from source 60. When the spark gaps close their respective circuits these condensers discharge in series, the charge voltage across each being additively applied through line 64 to load 65. This is possible since inductors 68, 69, 70 and 71 are substantially short circuits to the charging current and substantially open circuits to

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the discharging current. This is due to the frequency components of the discharging current being much higher than the frequency components of the charging current. Obviously, this circuit is not restricted in use to three groups of storage condensers and spark gaps. Any number of groups of condensers and spark gaps may be used with the inductors properly arranged. The embodiment in Fig. 10 shows an additional condenser and spark gap group added to the preceding embodiment.

In the embodiment in Fig. 11 a diode 88 is inserted in series with the output of transformer 81. Since the resistance of diode 88 is negligible during the positive voltage wave, condenser 83 will charge to a theoretical value of

$$\frac{\pi E}{2}$$

during the positive cycle of the voltage from transformer 81. This rise of the charge of condenser 83 is shown in Fig. 12 which is similar in this respect to Fig. 2. On the negative cycle of the transformer voltage condenser 83 is unable to discharge due to the rectifying action of diode 88, and the voltage across the condenser retains its

$$\frac{\pi E}{2}$$

value. When rotary spark 87 forms a short circuit on the peak of the half cycle opposite to that on which the condenser charged, the condenser will discharge through line 84 to produce an energizing pulse on load 85 as in previous modifications.

Although in all embodiments the inductance (12 in Fig. 5) has been shown separate from the transformer, it is to be understood that this inductance in all embodiments may be incorporated in the transformer as leakage inductance to eliminate any external inductance, and the term "inductance" as used in the claims includes this leakage inductance.

Numerous additional applications of the above disclosed principles of the invention will occur to those skilled in the art and no attempt has been made here to exhaust such possibilities. The scope of the invention is defined in the following claims.

I claim:

1. A pulse generator, comprising means for storing electrical energy, means for forming a pulse, and a switch alternately connecting said energy storing means to a source of alternating voltage to permit energy to be stored therein and connecting said energy storing means through said pulse forming means to a load to permit said stored energy to be discharged through said pulse forming means and to be impressed as a pulse on said load, the action of said switch being synchronized with the frequency of said alternating voltage.

2. A pulse generator comprising, a source of alternating voltage, a capacity for storing electrical energy, an inductance, a pulse forming line, a load and a rotary spark gap, said rotary spark gap alternately connecting said capacity and inductance in series with said source to permit said capacity to charge from said source and connecting said capacity in series with said pulse forming line and said load to permit said capacity to discharge through said pulse forming line and said load, the magnitudes of said capacity and inductance being so related

that said capacity charges to a maximum value during the time of connection to said source, and the motion of said rotary spark gap being synchronized with the frequency of said alternating voltage.

3. A pulse generator, comprising an inductance and a capacity, the magnitudes of said inductance and capacity being such as to form a resonant circuit when connected in series across a source of alternating voltage, a pulse forming line, a rotary spark gap having a rotating disc and a plurality of peg electrodes extending therethrough, said peg electrodes when rotated with said disc alternately connecting said capacity and said inductance to said source of alternating voltage to permit said capacitance to resonantly charge to a maximum value and connecting said capacity to said pulse forming line to permit said capacity to discharge through said line whereby a pulse may be impressed on a load connected to said line.

4. A pulse generator, comprising an inductance and a rotary spark gap in series and adapted to be connected to a source of alternating voltage, a capacity and pulse forming line connected in series to the junction of said inductance and said spark gap, said spark gap acting alternately to permit said capacity to charge from said source and to permit said capacity to discharge through said line when said capacity is charged to a desired value to present a pulse at its output, a coaxial cable connected to the output of said line, a pulse transformer having its primary connected to the output of said coaxial cable and its secondary adapted to be connected to a load whereby the load may be matched to the cable and the voltage of the pulse at the secondary of the transformer may be increased.

5. A pulse generator comprising, an inductance, a diode and a rotary spark gap in series and adapted to be connected across a source of alternating voltage, a capacity and pulse forming line connected in series through a load across said gap, said spark gap acting alternately to permit said capacity to charge from said source and to permit said capacity to discharge through said line when said capacity is charged to a maximum value to impress a pulse on said load, said diode being so poled as to permit said capacity to charge from said source but to prevent said capacity from discharging through said source, and the motion of said rotary spark gap being synchronized with the frequency of said alternating voltage.

6. A pulse generator, comprising a first capacity and a first inductance in series and adapted to be connected across a source of alternating voltage, a second inductance, a second capacity and a third inductance connected in series across said first capacity, a spark gap connected from the junction of said first inductance and said first capacity to the junction of said second capacity and said third inductance, a second spark gap and pulse forming line in series and effectively connected to the junction of said second inductance and said second capacity, said spark gaps being operable in synchronism to alternately present high impedances to permit said capacities to charge in parallel from said source and when said capacities are charged to a desired value to present low impedances to permit said capacities to discharge in series through said line to impress a pulse on a load connected thereto, the magnitudes of said second

and third inductances being such as to be substantially a short circuit to the charging current and substantially an open circuit to the discharging current.

7. A pulse generator comprising, a capacitor, an inductor, a source of alternating voltage serially connected to said inductor, the magnitudes of the inductance and capacitance of said inductor and capacitor being such that said inductor and capacitor are adapted to form a resonant circuit at the frequency of said alternating voltage when said capacitor is connected across said inductor and said source of alternating voltage, a pulse forming line, a load serially connected to said pulse forming line, and a rotary spark gap for alternately completing first and second circuits, said first circuit being isolated from said second circuit, said first circuit comprising said capacitor connected across said inductor and said source of alternating voltage, said second circuit comprising said capacitor connected across said line and said load.

8. A pulse generator comprising a capacitor, an inductor, a source of alternating voltage serially connected to said inductor, the magnitudes of the inductance and capacitance of said inductor and capacitor being such that said inductor and said capacitor are adapted to form a resonant circuit at the frequency of said alternating voltage source when said capacitor is connected across said serially connected inductor and source of alternating voltage, a pulse forming line, a load serially connected to said pulse forming line, and a rotary spark gap having a rotating disk and a plurality of peg electrodes extending through said disk, said peg electrodes when rotated with said disk alternately connecting said capacitor across said serially connected inductor and source of alternating voltage to permit said capacitor to charge resonantly to a maximum value and connecting said capacitor across said serially connected pulse forming line and load to permit said capacitor to discharge through said line whereby a pulse is impressed on said load.

9. Apparatus as defined in claim 8 wherein each of said peg electrodes is parallel to the axis of rotation of said disk and wherein the rotary motion of said rotary spark gap is synchronized with the frequency of said alternating voltage.

10. A pulse generator comprising, an inductor, a source of alternating voltage, a rotary spark gap, said inductor and said rotary spark gap being serially connected across said voltage source, a capacitor and a load, said capacitor and said load being serially connected across said rotary spark gap, said rotary spark gap being synchronized with the frequency of said alternating voltage source for alternately charging said capacitor and discharging said capacitor through said load when said capacitor is charged to a desired value.

11. A pulse generator comprising, a source of alternating voltage, an inductor, a rotary spark gap, said inductor and said rotary spark gap being serially connected across said voltage source, a capacitor, a pulse forming line, and a load, said capacitor, said pulse forming line and said load being serially connected across said rotary spark gap, said rotary spark gap acting alternately to permit said capacitor to discharge through said pulse forming line when said capacitor is charged to a desired value whereby a pulse is produced across said load.

12. Apparatus as defined in claim 11 wherein the motion of said rotary spark gap is synchronized with the frequency of said alternating voltage.

13. A pulse generator comprising, a first capacitor, a first inductor, a second inductor, a source of alternating voltage, said first capacitor, said first inductor and said second inductor being serially connected across said source of alternating voltage, said first capacitor being connected between said first and second inductors, a third inductor, a second capacitor, a fourth inductor, said third inductor, said second capacitor and said fourth inductor being serially connected across said first capacitor, said third inductor being connected directly to said first inductor, said fourth inductor being connected directly to said second inductor, discharge means connected between the junction of said first inductor and said first capacitor and the junction of said second capacitor and said fourth inductor, second discharge means, a load serially connected to said second discharge means, said load and said second discharge means being connected between the junction of said third inductor and said second capacitor and one side of said voltage source.

14. Apparatus as in claim 13 wherein said first and second discharge means are first and second spark gaps.

15. Apparatus as in claim 13 wherein said first and second discharge means are first and second rotary spark gaps synchronized with the frequency of said alternating voltage source.

16. A pulse generator comprising, a network, said network having n capacitors and $n-1$ first rotary spark gaps, n being any integer greater than one, said first rotary spark gaps and said capacitors being serially connected so that each first rotary spark gap is connected between two of said capacitors, there being $2n$ successive capacitor terminals in said series arrangement, $n-1$ first inductors, one of said first inductors being connected between each pair of successive even-numbered capacitor terminals, considering said capacitor terminals as being numbered from 1 at one end of said capacitor-rotary spark gap series arrangement to $2n$ at the other end, $n-1$ second inductors, one of said second inductors being connected between each pair of successive odd-numbered capacitor terminals, a source of alternating voltage, a third inductor, said source and said third inductor being serially connected across the capacitor between the first and second of said capacitor terminals, a second rotary spark gap, a pulse forming line, and a load, said second rotary spark gap, said pulse forming line and said load being serially connected across said capacitor-rotary spark gap series arrangement, said first and second rotary spark gaps being synchronized with the frequency of said alternating voltage source.

17. A pulse generator comprising, a plurality of capacitors and a like plurality of rotary spark gaps serially connected in alternating fashion beginning with one of said capacitors and ending with one of said spark gaps, a pulse forming line

and a load serially connected in the order named to said one spark gap, a different plurality of inductors, connected one each between corresponding plates of adjacent ones of said capacitors, a source of alternating voltage and a charging impedance serially connected across said one capacitor, said rotary spark gaps being synchronized in rotation with the frequency of said alternating voltage source.

18. A pulse generator comprising, a pulse forming line and a load serially connected, a plurality of capacitors and a plurality of inductors, a source of alternating voltage connected in series with a charging impedance, a plurality of rotary spark gaps synchronized in rotation with the frequency of said alternating voltage source arranged to permit said capacitors to be resonantly charged in parallel through said charging impedance from said source and to be discharged in series through said pulse forming line when each of said capacitors is charged to a desired value whereby a pulse is produced across said load.

19. A pulse generator comprising, a capacitor, an inductor, a source of alternating voltage, a pulse forming line, and a rotary spark gap synchronized in motion with the frequency of said alternating source, said rotary spark gap alternately permitting said capacitor to charge through said inductor from said source and to discharge through said pulse forming line when said capacitor is charged to a desired value whereby a pulse may be formed at the output of said line.

20. A pulse generator comprising, a capacitor for storing electrical energy, an inductor, a source of alternating voltage, the magnitude of the inductance of said inductor being such as to form a circuit resonant at the frequency of said source when connected in series with said capacitor, a pulse forming line, and a rotary spark gap synchronized in rotation with the frequency of said alternating source, said rotary spark gap alternately permitting said capacitor to resonantly charge through said inductor from said source and to discharge through said pulse forming line when said capacitor is charged to a desired value whereby a pulse may be formed at the output of said line.

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