Nov. 20, 1951 W. S. IVANS, JR 2,575,961

VARIABLE WIDTH PULSE GENERATING SYSTEM

Filed Oct. 31, 1947 2 SHEETS—SHEET 1

FIG. 1

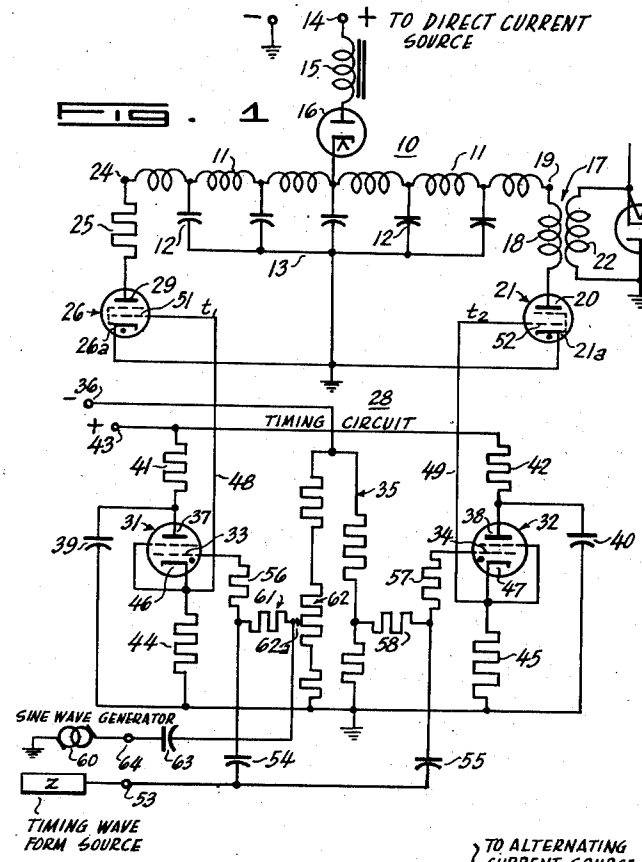


FIG. 2

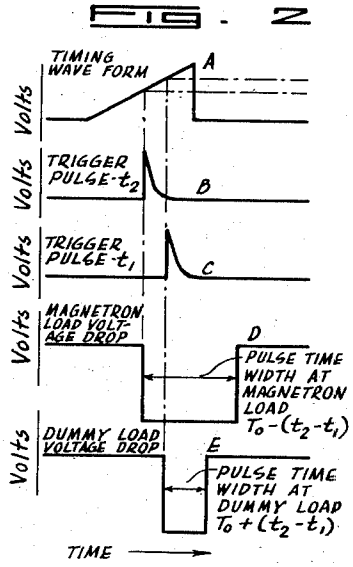


FIG. 3

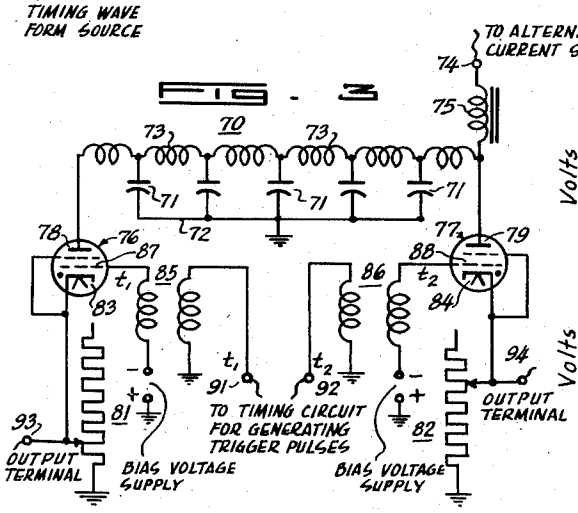
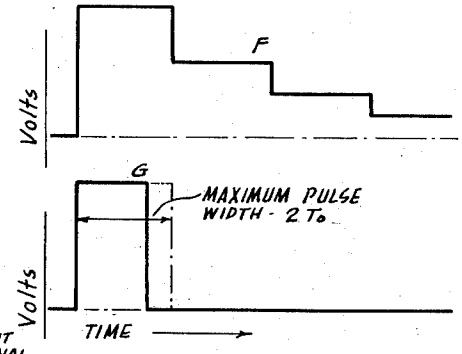


FIG. 4



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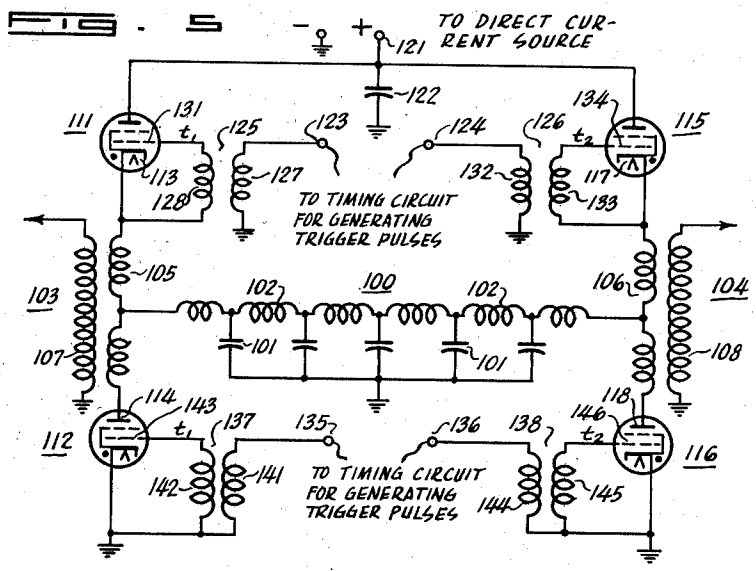
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FIG. 5



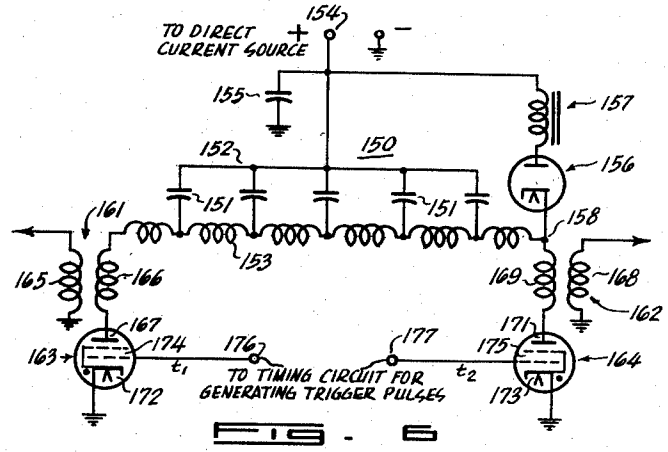


FIG. 6

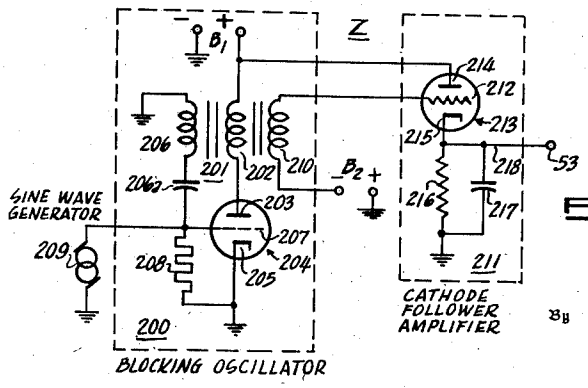


FIG. 7

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UNITED STATES PATENT OFFICE

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VARIABLE WIDTH PULSE GENERATING SYSTEM

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Application October 31, 1947, Serial No. 783,390

21 Claims. (Cl. 250—27)

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The present invention relates to electrical pulse generating systems and more particularly to improved pulse generating systems which produce substantially rectangular pulses of electrical energy.

This invention contemplates the formation or generation of pulses by the utilization of a transmission line type pulse-forming network in conjunction with electronic space discharge devices and power supply and discharge timing devices. Pulse forming networks, or artificial transmission lines, as they are sometimes designated, have energy-storage and transmission delay characteristics which adapt them to the formation of accurate rectangular pulses. In the generation of pulses having high energy levels it is particularly desirable that the pulse-forming network be discharged through a load by means of gas-filled electronic space discharge devices such as thyratron tubes since such tubes are capable of passing high currents with little power loss. An additional characteristic of the thyratron tube which renders it satisfactory for high level applications is the necessity of using but very little controlling energy to initiate the transition of the tube from a non-conducting state to the highly conducting state which is required by the pulse-forming operation.

Prior art methods of pulse formation have utilized pulse-forming networks in association with electronic space discharge devices and power supply and discharge synchronizing devices but such prior art methods have been restricted to those applications which require a relatively constant time width pulse output. This has been necessitated by reason of an operating characteristic of gas-filled electronic space discharge devices, such as thyratron tubes, and to the inflexibility of the transmission delay time characteristic of pulse-forming networks. The operating characteristic of a gas-filled electronic space discharge device which has this restrictive effect is the faculty that once such devices have been triggered from a non-conducting state to a conducting state, conduction will normally be maintained until the anode-cathode potential decreases to a very low value or is reversed in polarity, regardless of the character or duration of the triggering or discharge initiating waveform. In the formation of pulses the thyratron tube or equivalent device is connected in series with a load device and with the pulse-forming network during the time interval of pulse generation. The time interval between the initiation of conduction through the thyratron tube

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and the cessation of conduction therein is ordinarily equivalent to the time required for the charging or discharging of the pulse-forming network. In conventional applications this time interval is determined by the transmission delay time of the pulse-forming network in use, and represents the time required for the voltage and current wave, initiated at the instant the space discharge device is rendered conductive, to traverse the pulse-forming network, be reflected by the effective open-circuit discontinuity at the end opposite to the load device, and to return to the starting point, thereby terminating the period of conduction of the space discharge device, provided that the proper impedance relationship has been maintained between the load device and the pulse-forming network. Since the transmission delay time of pulse-forming networks is not readily susceptible to variation, particularly if a constant network impedance is to be maintained, the time width of the output pulse is essentially fixed. In the past, efforts to obtain variations in output pulse time width in pulse generating systems have been confined generally to mechanical switching between various sections of the pulse-forming network, or to short-circuiting of the load device a predetermined time after conduction has begun in the space discharge device. These expedients to effect variations are not particularly satisfactory. Mechanical switching devices ordinarily produce only discrete changes in output pulse width, are apt to be cumbersome, and are not adapted to the very rapid and continuous changes in pulse width demanded by pulse width modulation communication systems, this defect being due primarily to the mechanical inertia of the switch elements. The use of short-circuiting devices across the output load is likewise unreliable for such devices render the system susceptible to malfunctioning because of the production of transient disturbances during the short-circuiting operation.

It is therefore an object of the present invention to provide an improved form of pulse-generating system for producing substantially rectangular pulses of electrical energy and wherein variations in pulse time width is effectively and readily obtained.

Another object of the invention resides in the provision of an improved pulse-forming system which affords continuous electronic control of output pulse time width between zero time width up to the maximum time width available from a given pulse-forming network (which latter time

width is ordinarily twice the transmission delay time of the network).

Another object of the invention lies in providing an improved pulse-generating system employing two load devices, connected to the opposite ends of the pulse-forming network, and wherein the total pulse time width characteristic of a given pulse-forming network can be divided in any desired ratio between the two load devices during the pulse-forming operation.

A further object of the invention is the provision of an improved pulse-forming system having continuous electronic control of the output pulse time width and adapted for use in applications which require variations in load impedance, and which system permits desired variations without the appearance of objectionable reflected waveforms in the load output.

Other objects and features of the invention will be readily apparent to those skilled in the art from the following specification and appended drawings illustrating certain preferred embodiments of the invention in which:

Figure 1 is a schematic circuit diagram of a pulse-generating system embodying the principles of the invention; in this embodiment the invention utilizes a single output load and a resistive dummy load;

Figure 2 is a series of graphs which illustrate various time relationships involved in the pulse-generating system of Figure 1;

Figure 3 illustrates another embodiment of the invention;

Figure 4 illustrates pulse waveforms;

Figure 5 illustrates another embodiment of the invention;

Figure 6 illustrates still another embodiment of the invention;

Figure 7 is an illustration of a timing or synchronizing waveform source utilized by the invention.

Having reference now more particularly to the drawings, Figure 1 is illustrative of one embodiment of the invention. The pulse-generating system shown in Figure 1 comprises a usual pulse-forming network, indicated generally at 10, the discharge from which approximates a rectangular waveform and which is composed of a plurality of series inductances 11 and shunt capacitors 12. One side of each of the capacitors 12 is connected to a common lead 13, with the opposite sides thereof being connected one to the other, by the inductances 11. The number of inductances 11 and capacitors 12 utilized is dependent upon the degree of rectangularity desired in the output pulse. In general, the greater the number of such components employed, the more nearly rectangular will be the output pulse waveform for a given pulse time width. The pulse-forming network 10 is the equivalent of a section of transmission line having a characteristic impedance $\sqrt{l/c}$, wherein l is the effective inductance of one of the series inductances 11 and c is the capacitance of one of the shunt capacitors 12, and which line has a one-way transmission delay time of $\sqrt{LC}$, where L represents the total effective inductance and C the total effective capacitance of the transmission line 10.

The pulse-forming network 10 is charged from a positive direct-current source, which may be a battery, with the energy being provided at a terminal 14 and passing therefrom through a series charging inductance 15 and a series diode 16. During the period that this energy is stored by the pulse-forming network 10 the network is largely capacitive in effect, with the combination of the charging inductance 15 and the aggregate of shunt capacitors 12 functioning as a series resonant circuit which charges the capacitors to a voltage considerably higher than the supply voltage, a value of 1.7 times the supply voltage having been found to be readily obtainable. This capacitor charging takes place in a half-cycle of the series resonant frequency because the unidirectional current flow characteristic of the series diode 16 prevents the continuation of the charging oscillation, leaving the capacitors 12 charged to the highest attained positive voltage. The charge on the network capacitors 12 represents a store of electrical energy which may be released to provide short rectangular pulses of high peak power level. The value of the charging inductance 15 is required to be such that the charging half-cycle is completed between successive discharges of the line at the highest discharge repetition rate to be employed. During the brief pulse-generating operation, the relatively high inductance of this element 15 effectively isolates the power source from the pulse-forming network 10.

Connected to the pulse-forming network 10 is a pulse transformer 17 having a primary 18, one side of which is connected, in series, to a high potential terminal 19 of the network and the other side to the anode 20 of a thyratron tube 21, the cathode 21*a* of which tube is connected to ground. The secondary 22 of transformer 17 is connected to a suitable load, which in the present instance, for illustrative purposes only, is a magnetron oscillator 23. The high-potential terminal 24 at the opposite end of pulse-forming network 10 is connected through a dummy resistance load 25 to the anode 29 of a thyratron tube 26, the cathode 26*a* of which tube is connected to ground. In this illustrative application both the magnetron load and the dummy load are made to have effective impedance equal to the characteristic impedance of the pulse-forming network 10. The thyratron tubes 21 and 26 are characteristically normally non-conducting, and will remain so until triggered into a conducting state, independently of one another, by the application of positive pulses applied to their respective control grids.

The pairs of triggering pulses t_1 and t_2 required to effect conduction of these tubes independently of one another are produced by a control circuit or timing system indicated generally at 28. The control circuit 28 comprises a pair of thyratron tubes 31 and 32, both of which are held in a normally non-conducting state by the impressing of negative voltages upon their control grids 33 and 34, with the negative voltages being provided by a resistive network 35, which is connected between ground and a negative voltage supply terminal 36. Connected between the anodes 37 and 38 of the tubes 31 and 32, respectively, and ground are capacitors 39 and 40 upon which positive charges are stored, which charges are impressed through resistors 41 and 42 from a positive voltage source (not shown) which connects to terminal 43. A pair of resistors 44 and 45 connect the cathodes 46 and 47 of tubes 31 and 32, respectively, to ground, and a pair of lead lines 48 and 49 connect the same cathodes 46 and 47 to the control grids 51 and 52 of main thyratron tubes 26 and 21.

Raising the potential in a manner to be described, on the grids of control circuit thyratron

tubes 31 and 32 momentarily to a level which will establish conduction in these tubes will cause condensers 39 and 40 to discharge rapidly through their respective associated tubes and through the series cathode resistors 44 and 45. During this discharge, positive exponentially decaying pulse waveforms are produced at the cathode resistors 44 and 45, which are of an amplitude and duration sufficient to trigger the main thyratron tubes 26 and 21 into a conducting state. After discharge of the capacitors 39 and 40 current will cease to flow through the trigger-generating thyratron tubes 31 and 32 owing to the lack of a sufficient potential across the capacitors 39 and 40 to maintain a discharge, and these latter tubes revert to their normally non-conducting character. The capacitors 39 and 40 are slowly charged again through resistors 41 and 42 by the positive electrical energy provided at terminal 43 and then discharged during the succeeding pulse-forming operation in the manner described.

Triggering of the thyratron tubes 31 and 32 to permit discharge of capacitors 39 and 40 is effected by the superimposing of a positive-going timing or synchronizing waveform, having a sawtooth voltage-time characteristic, upon the negative bias voltages existing at the control grids 33 and 34 of these tubes 31 and 32. The timing waveform is supplied from a usual source Z which connects at terminal 53, and passes simultaneously through blocking capacitors 54 and 55 and their associated isolating resistors 56 and 57 to the control grids 33 and 34 of thyratron tubes 31 and 32. The instant of conduction of each thyratron tube 31 and 32, and thus the instant of generation of each trigger pulse t_1 and t_2, is determined by the steepness of the timing waveform and by the amount of negative bias voltage applied to control grids 33 and 34 by the resistive network 35. The elements comprising the source Z for the sawtooth timing waveform are shown in Figure 7. It is understood that the source Z herein described is but one form of sawtooth wave generating circuit that may be utilized with the present invention. The exact construction of this circuit forms no part of the invention. As shown in Figure 7 this circuit comprises a blocking oscillator 200 composed of a transformer 201 having a central winding 202, to one end of which power is provided for the transformer from a positive direct current source B_1. The other end of winding 202 is connected to the anode 203 of a triode vacuum tube 204, the cathode 205 of which tube is connected to ground. A second winding 206 of the transformer 201 has one end connected to ground and the opposite end connected through a capacitor 206a to the control grid 207 of the tube 204; a resistance 208 is also connected to this control grid 207 and to ground. A sine wave generator 209 provides a source of modulating current and is connected to the control grid 207. Any device or source providing a modulating waveform may be employed. The blocking oscillator 200 is connected to a cathode follower amplifier 211, the connection thereto being made by joining one end of a third winding 210 of transformer 201 to the control grid 212 of a triode vacuum tube 213 included in amplifier 211. The opposite end of winding 210 is connected to a direct current voltage source B_2 which provides the negative bias voltage for the control grid 212 of tube 213. The anode 214 of tube 213 is connected to the positive direct current source B_1. The cathode 215 of tube 213 is connected to ground through a resistance 216. A capacitor 217 connects to cathode 215 and to ground. A lead 218 interconnects the cathode 215 and the terminal 53 at which the timing waveform for control circuit 28 is introduced.

The time phasing of the trigger pulses can be controlled by variation of the relative bias voltages applied to the thyratron tubes 31 and 32. In the present embodiment, for sake of illustration a fixed bias voltage has been provided at the control grid 34 of thyratron tube 32 and a variable bias voltage has been provided at the control grid 33 of thyratron tube 31. Resistor 58 interconnects resistive network 35 and isolating resistor 57 associated with control grid 34 of thyratron tube 32 whereby a fixed bias voltage is applied to this control grid. To effect variation of the bias voltage at control grid 33 there is provided a potentiometer 62 interconnected between the negative voltage supply terminal 36 and ground, with the potentiometer 62 having a variable arm 62a. Resistor 61 interconnects variable arm 62a and isolating resistor 56 associated with control grid 33 of thyratron tube 31 whereby a variable bias voltage is applied to this control grid. Adjustment of the variable arm 62a to desired positions results in a fixed pulse width output at the magnetron oscillator 23 for each setting of the variable arm.

As shown, the variable arm 62a of potentiometer 62 is connected through a blocking capacitor 63 to a terminal 64, at which terminal a modulating waveform may be applied. As here shown a usual sine wave generator 60 provides the modulating waveform; any usual modulating wave source may be utilized. Through this means the bias voltage at the control grid 33 of thyratron tube 31 may be varied, with the pulse width output at the magnetron oscillator 23, in this case, varying in accordance with the variations in the modulating waveforms that may be supplied. Thus two methods of varying the pulse width output of the embodiment of Figure 1 are provided, one by movement of the adjustable arm 62a of the potentiometer 62, and the other by supplying a varying modulating waveform to the arm 62a.

Pulse formation in the embodiment of Figure 1 occurs when the pulse-forming network 10 discharges, with the pulse-forming network 10 discharging when the main thyratron tubes 21 and 26 controlling it are triggered into a conductive state by pulses provided by the tubes 31 and 32.

Triggering of thyrotron tube 26 into conduction connects dummy resistance load 25 into the pulse-forming network 10 and a voltage and current wave is formed which transverses network 10, traveling toward thyratron tube 21 connected to the opposite end thereof. Upon arrival of this wave at tube 21 the conductive state of the latter is terminated, because of a reduction to zero of the anode-cathode potential, to terminate the output pulse appearing at the magnetron oscillator 23. Similarly, arrival of the voltage and current wave initiated by the conduction of thyratron tube 21 terminates conduction of thyratron tube 26, leaving the pulse forming network completely discharged.

The pulse-forming network will again be charged from current supplied by the direct-current source at terminal 14 and passing therefrom through the charging inductance 15 and

the series diode 16, and will be discharged once more when a pair of trigger impulses are provided to activate the thyratron tubes 21 and 26 to initiate another pulse generating operation.

A circuit 28 for effecting phased pairs of triggering pulses from single sawtooth-form timing pulses has been described. The circuit 28, as has been stated, is understood to be illustrative of but one form of timing circuit adapted to be manually adjusted to provide any desired fixed output pulse width from zero up to the maximum time width which the network 10 is capable of producing, or which may be made to produce any desired variation in the width of successive output pulses within these limits, as in accordance with the characteristics of a modulating waveform.

Practical application of the invention has been had and a construction in accordance with Figure 1 has been assembled and tested. A ten section pulse-forming network 10 was devised having a one-way transmission delay time of 1 microsecond and a characteristic impedance of 50 ohms, which network was charged from a positive 4000 volt direct-current source, through a charging inductance 15, having a value of 2.75 henrys, and a type 3B24 series diode 16. A 50 ohm resistance, substantially non-inductive, was utilized as the dummy load 25. A pulse transformer 17 having a 4.5 to 1 turns ratio was employed with connection being made to a type 725A magnetron oscillator 23. The main space discharge tubes 21 and 26 were hydrogen thyratrons of the 4C35 type, and the trigger generating tubes 31 and 32 were miniature thyratrons of the 2D21 type. With this combination of elements, continuously controllable division of the network pulse output between the magnetron oscillator 23 load and the dummy load 25 was obtained. The precision of triggering obtained was such that the variation or jitter in output pulse width and time position was negligible, estimated at being less than 0.02 microsecond.

Figure 2 depicts curves which are illustrative of the time values involved in the operation of the embodiment of Figure 1; the time relationships between the timing waveform which initiates trigger formation at thyratron tubes 31 and 32, the trigger pulses t_2 and t_1, the pulses generated at the magnetron oscillator 23 output load and at the dummy load 25 for a particular setting of the control grid 33 bias level at thyratron tube 31, are represented, respectively, by curves A, B, C, D and E. The setting of the bias level of control grid 33 of tube 31 is for purpose of illustration made more negative than the level at the control grid 34 of tube 32, so that trigger formation at the latter tube occurs before trigger formation at tube 31. The output pulse time width at the magnetron oscillator 23 is equal to $T_0-(t_2-t_1)$, where T_0 represents the one-way transmission delay time of the pulse-forming network and t_2 and t_1 are the time instants of effecting conduction of thyratron tubes 21 and 26 respectively. The interval (t_2-t_1) can be varied between the limits of plus T_0 and minus T_0 to produce full variation in the pulse width appearing at the magnetron load 23, from zero width to twice T_0, which is the maximum width obtainable.

It is noted that the relative voltage amplitudes illustrated in Figure 2 have been exaggerated for a more ready understanding of the invention. In practice, the output waveforms appearing at the magnetron oscillator 23 and the dummy resistance load 25 may have many times the amplitude of the timing waveform and trigger pulses, and the actual magnetron oscillator terminal voltage drop is greater than the dummy load voltage drop, owing to the effect of transformer 17. All waveforms shown are idealized, inasmuch as perfectly sharp leading and trailing edges are not obtainable in practice.

The circuit illustrated in Figure 1 is satisfactory for use particularly in those applications in which the pulse power dissipated by the dummy load 25 is of no consequence. During each pulse-forming discharge of the network 10 the energy stored in the network capacitors 12 is almost completely dissipated, this being a consequence of providing a magnetron load 23 and a dummy load 25 which have effective impedances equal to the characteristic impedance of the network 10. During discharge the voltage of each traveling wave has an amplitude approximately one-half that of the network storage potential and the traversing of the network by these waves almost completely exhaust the stored energy. In some applications this is an advantage in that the recharging cycle produces the same network storage energy after each discharge regardless of the manner of division of pulse width output. There are, however, applications in which it is expedient to reduce the impedance of the dummy load to a condition approaching short-circuit, in order to reduce the dissipated power. Figure 3, which will be described in detail hereinafter, is illustrative of a circuit embodying this variation.

The present invention contemplates the use of either a pair of useful load devices, or of one useful load device and a dummy load device, as has just been described in connection with Figure 1, with one device connected at each end of a pulse-forming network, and with the connection between the load devices and the energy-storing network being controlled by electronic space discharge devices, such as thyratron tubes. As is well known, thyratron tubes are normally non-conducting and are triggered into a conducting state by the application thereto of relatively low energy triggering pulses. The triggering pulses required for use in the present invention are provided in spaced pairs. The particular mechanism and devices for producing the triggering pulses form no part of this invention; any usual means for so doing may be employed, and it is understood that the method hereinbefore described is to be taken as merely illustrative. The period between pairs of triggering pulses represents the period between pulse generation by the pulse-forming system. The time phasing relationship which exists between the individual triggering pulses which constitute a pair determines the manner of division of the total time width characteristic of the pulse-forming network between the two load devices. In the instance where a single useful load device and a dummy load are utilized, the time phasing of the trigger pulses determines the time width of the output pulse appearing at the single useful load. The dummy load here may be of either a dissipative or non-dissipative character, or it may be a device for returning energy to the primary supply source, or further, under some circumstances, it may be a short circuit. However, in each case the principle of pulse time width variation is the same. For in the present invention as a dummy load device is connected to its appropriate end of the pulse-forming net-

work, through the triggering of its associated space discharge device into conduction, a voltage and current wave is formed which traverses the pulse-forming network traveling toward the opposite load device and space discharge device. The arrival of this wave at the opposite end of the pulse-forming network terminates the conductive state of the electronic space discharge device there present by its either reducing the anode-cathode potential of this space discharge device to a value too low to sustain conduction or by reversing the polarity of the anode-cathode potential, and thereby terminates the output pulse appearing at the load.

If two useful load devices are contemplated in association with a pulse-forming network, with these load devices having an impedance equal to the characteristic impedance of the network, a complete charge or discharge of the pulse-forming network will take place in a period varying from an amount equal to the one-way transmission delay time of the network to an amount twice such network delay time, dependent upon the manner of division of the total pulse output width between the two load devices. The time width of the pulse appearing at the output loads may be indicated by the expressions $T_0+(t_2-t_1)$ for one load, and $T_0-(t_2-t_1)$ at the other, where T_0 represents the one-way transmission delay time of the pulse-forming network, t_1 represents the time of triggering of the space discharge device which connects a load device at one end of the pulse-forming network, and t_2 is the time of triggering of the space discharge device which connects a dummy load or a load device at the opposite end of the network. The time interval (t_2-t_1) is controlled by the generating system which provides the pair of triggering impulses for operation of the two space discharge devices connected to the ends of the pulse-forming network. Variation of the time interval (t_2-t_1) between the limits of plus and minus T_0 represents the complete variation of pulse output division between the two loads. With a condition of $t_2=t_1$ both trigger pulses are applied simultaneously, and the output pulse at each load will have a time width T_0.

Where but a single useful load device is to be utilized, having an impedance which may be varied over a wide range, it is expedient to use a dummy load having an impedance either equal to or lower than the characteristic impedance of the pulse-forming network in order that the output load waveform will be free of the undesirable reflected waveforms which ordinarily follow the principal pulse waveform in applications where the effective output load impedance is higher than the impedance of the pulse-forming network. The use of a dummy load of the character above specified provides for the formation of a voltage and current wave of such magnitude that the cessation of conduction of the space discharge device associated with the output load device is assured despite wide variations in impedance.

A dummy load having an impedance lower than the network impedance provides a current and voltage wave which on arrival at the opposite end will cause a reversal of polarity of the voltage appearing across the output load space discharge device located there. This will effectively terminate conduction in such space discharge device, since inherently electronic space discharge devices such as thyratron tubes, which are ordinarily utilized and are best suited for this type of pulse-forming system, are capable, normally, of conduction in only one direction. The output pulse time width at the single useful load is therefore to be indicated by the expression $T_0+(t_2-t_1)$, with t_2 and t_1 representing respectively the time of triggering of the dummy load and the output load device.

The above discussed electrical charge of opposite polarity appearing at the output load space discharge device terminates conduction therein, as has been stated, but tends to persist after the pulse-forming operation has been accomplished. This charge represents a storage of energy in the pulse-forming network. This energy may be removed through the use of a clipping diode, or it can be effectively reversed in polarity through the use of a diode and series inductance to provide a part of the energy required for the formation of the succeeding pulse or pulses, as will be hereinafter more fully described and explained.

The various embodiments of the present invention will all make use of traveling voltage and current waves which originate from opposite ends of a section of electrical transmission line or equivalent pulse-forming network. These traveling waves are initiated by rendering conductive the pair of normally non-conducting electronic space discharge devices provided at each end of the pulse-forming network. It is here again noted that the time relationship between the beginning of conduction of each of these space discharge devices determines the time width of the output pulses which will be produced at the two independent load devices. The arrival of a traveling wave originating at one end at the opposite end of a pulse-forming network results in a cessation of conduction of the space discharge device connected to the load at such opposite end and a consequent cessation of the pulse output appearing at such load, provided that the proper impedance relationships have been maintained.

The pairs of triggering pulses which render the space discharge devices conductive can be generated by any of the usual methods well known to the art, and the relative time phase relationship between the trigger pulses which constitute a pair can be rapidly and continuously varied, producing a correspondingly rapid and continuous change in the time width of successive pulses produced at the load device or devices. Pulse formation in accordance with this invention can be accomplished through either charging or discharging of a pulse-forming network, or by alternate charging and discharging of the network, as will be hereinafter described. Any one of a variety of load devices may be expeditiously employed in the present invention, for example: resistance loads, magnetron oscillators, laboratory pulse generators and other similar apparatus useful in applications wherein there is desired to employ accurate, rapidly repeated signals of short duration. The arrangement of components can be varied to accord with the requirements of particular operational situations without departing from the spirit and scope of this invention. Electronic space discharge devices of the gas filled thyratron type, being efficient and easily controlled, are particularly well suited to this method of pulse formation, as has been discussed; however, other types of space discharge devices can be used, such as high-vacuum discharge devices or spark discharge devices. The electrical power source utilized to charge the pulse-forming network for the production of pulses may be either alternating or direct current.

The embodiment of Figure 3 is an illustration of a circuit wherein the impedance of the dummy load is reduced to a condition approaching short circuit in order to reduce dissipated power. This embodiment comprises a pulse-forming network, indicated generally at 70, which provides a discharge of approximately rectangular waveform, and which is composed of a plurality of shunt capacitors 71, each of which has one side connected to a common lead 72, and the opposite sides connected one to the other by inductances 73. As with the pulse-network 10, the number of condensers 71 and inductances 73 utilized by pulse-network 70 is dependent on the degree of rectangularity desired in the output pulse. Network 70 is provided with electrical energy at terminal 74, from an alternating current high voltage source, not shown, with the charge passing from terminal 74 through a charging inductance 75. The storage of a charge on pulse-forming network 70 is accomplished in fundamentally the same manner as in the case of the pulse-forming network 10 of the embodiment of Figure 1. However, a restriction on the operation of network 70 arises due to the omission of a series charging diode similar to diode 16 of Figure 1. This restriction is placed upon the repetition rate and time phase position of the pulse-forming action, for this action must occur in network 70 during a positive portion of the line potential storage waveform, which follows the alternations in voltage of the alternating current power source which charges network 70. However in many applications, such as in some radar systems, this restriction is not a serious one, as the output pulse repetition rate may profitably be synchronous with the power supply frequency.

The point of connection of the charging inductance 75 to the pulse-forming network 70 is not critical for the charging efficiency will be substantially the same whatever the point of connection, and during the pulse-forming operations the relatively high inductance of device 75 effectively isolates the power source from network 70.

A pair of thyratron tubes 76 and 77 are connected to opposite ends of the pulse-forming network 70, with the connection being made to the anodes 78 and 79 of these tubes. Variable load resistances 81 and 82 are provided, one associated with each tube 76 and 77, which variable load resistances are connected between cathodes 83 and 84 of tubes 76 and 77, respectively, and ground. A pair of pulse transformers 85 and 86 are connected, respectively, to control grid 87 of tube 76 and control grid 88 of tube 77, and provide negative bias voltages on such grids whereby the thyratron tubes 76 and 77 are held in normally non-conducting state. Pairs of trigger pulses t_1 and t_2 are generated by external timing circuits, not shown to avoid repetition, but which may be of the type utilized by the embodiment of Figure 1 and indicated generally at 28, and which is associated with the source Z which provides a sawtooth wave. Any other similar circuit may of course be utilized. These trigger pulses t_1 and t_2 are applied to the control grids 87 and 88 of tubes 76 and 77 through terminals 91 and 92 of the pulse transformers 85 and 86. Again as in the case of the embodiment of Figure 1 the time phasing of the trigger pulse pairs determines the time division of the pulse forming network output, which in the present embodiment is to be divided between the load resistances 81 and 82. Terminals 93 and 94 are provided, respectively, at load resistances 81 and 82 at which the output of network 70 will appear to be carried to the point of utilization.

To illustrate a useful characteristic of the pulse-forming system of Figure 3, it will be assumed that the load resistance 82 has an impedance several times the magnitude of the characteristic impedance $\sqrt{l/c}$ of the pulse forming network 70. In the conventional method of forming pulses, a pulse output characteristic similar to curve F shown in Figure 4 would be obtained at output terminal 94. This condition could be obtained in the system of Figure 3 by deliberately omitting trigger pulses t_1, so that tube 76 and its associated load resistance 81 would be effectively isolated from the network 70. An output waveform of this character is undesirable in applications which require rectangular pulse output; therefore, in the conventional pulse-forming systems, the load impedance must be restricted to magnitudes equal to or lower than the magnitude of the characteristic impedance of the pulse-forming network. In the system of Figure 3, to obtain a rectangular pulse at output terminal 94 the load impedance is not subject to this restriction, because of the utilization of the load resistance 81 and its associated tube 76. Load resistance 81 is set to an impedance value equal to or less than the characteristic impedance of the network 70 and by triggering the two thyratron tubes 76 and 77 by means of paired trigger pulses the rectangular characteristic of the pulse output at output terminal 94 can be maintained despite a wide range of impedance mismatch, and the load output 82 may have either a higher or lower impedance than the characteristic impedance of the network 70. The traveling voltage and current wave provided when load resistance 78 is utilized in the system, which wave traverses the pulse-forming network to act upon the thyratron tube 77 at the opposite end, is the effective factor in securing the desired rectangular characteristic. A pulse waveform of the type that will appear at output terminal 94 in the present embodiment of the invention is illustrated by curve G of Figure 4. It is here noted that the pulse waveform is free of undesirable reflections, and that the pulse width is variable between zero and $2T_0$.

A negative charge may be left on the capacitors 71 of pulse-forming network 70 in the operation thereof. This negative charge will ordinarily be reversed during the succeeding network charging cycle, after the thyratron tubes 76 and 77 have recovered to their normal non-conducting state wherein they are again adapted to be used to provide energy for succeeding pulse formations. In particular applications, the load resistance 81 may be replaced by a direct connection to ground, in which case the thyratron tube 76 is used only for the control of the output pulse width and for the provision of a greater impedance flexibility at output terminal 94.

The load impedance flexibility obtainable by the use of the present invention is particularly useful in such applications as pulse modulation of magnetrons, where the magnetron impedance ordinarily rises as the applied pulse voltage is lowered below the optimum value; or in use with laboratory pulse generators, where a wide range of output impedance values is desirable.

Figure 5 illustrates another embodiment of the invention wherein variable-width pulse formation is accomplished during both the charge and the discharge of a pulse-forming network.

As shown this embodiment comprises a pulse-forming network 100, similar in operation and construction to pulse-forming networks 10 and 70 hereinbefore described. Network 100 is composed of a plurality of interconnected shunt capacitors 101 and series inductances 102. A pair of pulse-transformers 103 and 104 is connected to the network 100 at opposite ends thereof through windings 105 and 106 of such transformers. Connections to load devices, not shown and which may be magnetron oscillators, resistances, other radio apparatus or the like, are made through winding 107 of pulse-transformer 103 and through winding 108 of pulse-transformer 104. It is preferred that the values of the load impedances and the pulse transformer ratios be so chosen that each load device presents an impedance in series with the pulse-forming network 100 equal to the characteristic impedance of the network during charging and discharging operations. A thyratron tube 111 is connected to one end of the winding 105 of transformer 103 and a second thyratron tube 112 is connected to the opposite side thereof, the connections being made through the cathode 113 of tube 111 and anode 114 of tube 112. Two thyratron tubes 115 and 116 are similarly connected to opposite ends of winding 106 of transformer 104, through cathode 117 of tube 115 and anode 118 of tube 116. The windings 105 and 107 of pulse-transformer 103 and windings 106 and 108 of pulse-transformer 104 are so arranged that current flow into the pulse-forming network 100 during the charging operation and current flow out of the network during the discharging operation produces pulses of the same polarity at the load devices to be associated with this system. Thyratron tubes 111 and 115 are effective in producing pulse formations during the charging of the pulse-forming network 100 and the oppositely disposed thyratron tubes 112 and 116 are effective in producing pulse formation during the discharging of the network 100.

Power for effecting operation of this pulse-generating system is provided by a high voltage direct current source with a positive polarity connection being made at terminal 121. A capacitor 122 is connected between terminal 121 and ground, which capacitor acts to reduce the effective impedance of the power supply during the network charging operation.

Pairs of trigger pulses t_1 and t_2 for operating thyratron tubes 111 and 115 are supplied at terminals 123 and 124 from a trigger generating circuit, or source, not shown and which again may be of the type utilized by the embodiment of Figure 1; which pulses pass through isolating pulse transformers 125 and 126 associated with these tubes 111 and 115. The pulse transformer 125 associated with tube 111 has a winding 127 connected to ground and a winding 128 connected between the control grid 131 of the tube and the winding 105 of pulse transformer 103. The pulse transformer 126 associated with tube 115 has one winding 132 which is connected to ground and a second winding 133 interconnecting the control grid 134 of tube 115 and winding 106 of pulse transformer 104.

A similar arrangement for effecting operation of the thyratron tubes 112 and 116 is provided. The pairs of trigger pulses t_1 and t_2 for effecting operation of these tubes 112 and 116 are supplied by a trigger generating circuit, not shown, which is connected to terminals 135 and 136. An isolating pulse transformer 137 is connected between terminal 135 and thyratron tube 112 and a second isolating pulse transformer 138 is provided between terminal 136 and thyratron tube 116. The pulse transformer 137 has a first winding 141 connected between terminal 135 and ground and a second winding 142 connected between the control grid 143 of tube 112 and ground. The pulse transformer 138 is provided with a winding 144 connected between terminal 136 and ground, and a winding 145 connected between the control grid 146 of tube 116 and ground.

The rate at which the external generating circuits, which is understood to be of the type utilized by the embodiment of Figure 1, employed by the present embodiment provides the pairs of trigger pulses for operating the various thyratron tubes of the present embodiment determines the repetition rate at which charge and discharge of the pulse-forming network 100 occurs. The phasing of the trigger pulses which constitute a pair determines the manner of division of the pulse output of network 100 to the load devices connected to pulse-transformer 103 and pulse-transformer 104. It is understood that the phasing may be accomplished in any well-known manner, the method described in connection with the embodiment of Figure 1, it is contemplated, may here be employed.

The circuit of Figure 5 operates in the same fashion during both the charging and discharging stages to produce variable width pulses. In each instance the space discharge devices provided at each end of the network 100 are triggered into conduction to effect a flow of current and to initiate current and voltage waves which travel from one end toward the opposite end of the network and upon arrival there effect a cessation in conduction of the space discharge device there located and consequently cause cessation of the pulse output in the load connected thereto. A high pulse repetition rate is obtainable with this embodiment of the invention since charging and discharging of the network is accomplished very rapidly.

As has been stated the thyratron tubes 111 and 115 produce pulse formations during charging of network 100 and the thyratron tubes 112 and 116 are operative during discharge of network 100.

Assuming that zero potential exists on pulse-forming network 100, triggering of tubes 111 and 115 into conduction by a pair of trigger pulses results in the initiation of pulse output at both of the load devices at pulse-transformers 103 and 104. Traveling voltage and current waves are formed in network 100 having voltage amplitudes approximately equal to one-half the supply voltage amplitude. The arrival of the respective traveling waves at the opposite ends of network 100 halts conduction of the tubes 111 and 115 and terminates the pulse output appearing at each load device and leaves the network 100 charged to approximately the full supply voltage. The next operation involves the discharge of network 100 when thyratron tubes 112 and 116 are triggered into conduction by a pair of trigger pulses supplied at terminals 135 and 136 and through isolating pulse transformers 137 and 138. Again the pulse output at each load device associated with pulse-transformers 103 and 104 is initiated at the moment of conduction of the associated thyratron tube and is terminated by the arrival of the voltage and current traveling wave initiated at the moment of conduction of the thyratron tube connected at the

opposite end of the network. As during the charging operation, the phasing of the trigger pulses which constitute a pair determines the manner of division of pulse-forming network output between the two load devices. The time width of the pulse output appearing at the load device at pulse-transformer 103 is given by the expression $T_0+(t_2-t_1)$ and the time width of the pulse output at the load device at pulse-transformer 104 is given by the expression $T_0-(t_2-t_1)$, with T_0 representing the one-way transmission delay time of the pulse-forming network 100 and t_1 and t_2 representing the time of triggering into conduction of thyratron tubes 111 and 115, or alternatively, tubes 112 and 116.

Figure 6 illustrates an embodiment of the invention which provides for the formation of pulses during the rapid charging of a pulse-forming network from a source of electrical energy, with the charge formed on the network capacitance being either dissipated or reversed in polarity during the time period between pulse formation.

As in the other embodiments a pulse-forming network equivalent to a section of electrical transmission line is employed, herein indicated generally at 150. This network 150 is also comprised of a plurality of shunt capacitors 151, joined by a common lead line 152, at one of their sides, and interconnected at their other sides by a plurality of series inductances 153. High voltage from a direct current source is provided for the pulse-forming network 150 at a terminal 154. A capacitor 155 is connected between the high voltage terminal 154 and ground, and is provided to effectively decrease the impedance of the high voltage source during the pulse-generating operation, which will ordinarily require a very high momentary current flow from the current source, most of this momentary current being supplied from the charge accumulated on capacitor 155.

A series diode 156 and series inductance 157 are connected between the terminal 158 of network 150 and the high voltage terminal 154.

A pair of output pulse transformers 161 and 162 is connected to the network 150, one at each end thereof. Also connected to the opposite ends of the network 150, by the transformers 161 and 162, are thyratron tubes 163 and 164. Pulse transformer 161 is provided with a winding 165 which is connected to ground and a winding 166 which interconnects anode 167 of tube 163 and the network 150; and pulse transformer 162 has a winding 168 which connects to ground and a second winding 169 which connects anode 171 of tube 164 to network 150.

The load devices to be employed with this embodiment of the invention are connected thereto by the windings 165 of pulse-transformer 161 and 168 of pulse-transformer 162.

The thyratron tubes 163 and 164 utilized are of the usual normally non-conducting type, and have their cathodes 172 and 173 connected to ground. The tubes 163 and 164 are rendered conductive by the application of positive triggering waveforms t_1 and t_2 provided at their respective control grids 174 and 175. The connection of tubes 163 and 164 to a source of triggering waveforms, not shown, is made at the terminals 174 and 175. The triggering waveform source, it is understood, may be of any usual construction, and one which may be utilized, it is contemplated, is the type employed by the embodiment of Figure 1.

The present embodiment of the invention will operate as follows, assuming first an absence of charge on the capacitors 151 of pulse-forming network 150: on triggering of the thyratron tubes 163 and 164 into conduction there results a flow of current through pulse transformers 161 and 162 and there will be initiated a pulse output at the load devices associated with the pulse transformers 161 and 162. Traveling voltage and current waves are initiated by the flow of current at the two ends of the network 150, which waves traverse the network in a time equal to the transmission delay time of the pulse-forming network. Conduction of each thyratron tube 163 and 164 and pulse output at the load devices controlled by these tubes is terminated by the arrival of the traveling wave from the opposite end of the network 150, thus with the cessation of conduction of both thyratrons the pulse-generating operation is completed. The pulse-forming network 150 is left in a charged condition immediately following the pulse-generating operation. The magnitude and polarity of this charge is such as to prevent conduction in either thyratron. This charge is reversed in polarity before the next pulse-generating operation; reversal is accomplished through the use of the series diode 156 and the series inductance 157 connected to the network 150. The combination of the inductance 157 and the aggregate of the line capacitors 151 results in a half-cycle of oscillatory discharge through the series diode 156, which permits current flow in one direction only. This action effectively reverses the polarity of the charge on the network capacitors 151. The net effect is to provide an increased supply voltage for the formation of the succeeding pulses. The value of the series inductance 157 is so chosen that the reversal half-cycle takes place within the time period between the generation of successive pulses. A restriction upon the minimum time of reversal is imposed by the deionization time of the thyratron tubes. The relatively high reactance of the series inductance 157 effectively isolates it from the pulse-forming network during the brief interval of pulse-generation. The duration of the conduction interval of each thyratron tube, and the consequent time duration of the rectangular pulse output in the associated load devices, is determined by the transmission delay time of the pulse-forming network 150 and upon the relative time phasing of the triggering into conduction of the thyratron tubes. It is understood that, as in the other embodiments of the invention, the time phase of the triggering pulses can be adjusted either manually or in accordance with a modulating waveform to provide for continuously variable division of the pulse width characteristic of the pulse-forming network between the two load devices employed.

An advantage common to the various embodiments of the invention, which is realized when both of the load devices have equal impedance, is the fact that for a given pulse repetition rate, the load offered by the pulse-forming network to the primary power supply is constant, regardless of the manner in which the pulse output is divided. This permits pulse-width adjustment or modulation without an attendant change in pulse amplitude, since the voltage regulation of the power supply does not become a factor in determining output pulse amplitude unless the repetition rate is changed.

While certain preferred embodiments of the

invention have been specifically disclosed, it is understood that the invention is not limited thereto as many variations will be readily apparent to those skilled in the art and the invention is to be given its broadest possible interpretation within the terms of the following claims.

I claim:

1. In a pulse generating circuit, a pulse-forming network wherein electrical energy is adapted to be stored, said network having a connection to a source of electric current supply load devices connected to said network and at each end thereof, means for intermittently electrically interconnecting said load devices with said network comprising a normally non-conducting electronic space discharge device operatively associated with each of said load devices and having a series connection therewith and a connection to ground and means operatively connected to said electronic space discharge devices for rendering said space discharge devices conductive to thereby initiate pulse generation.

2. In a pulse generating circuit, a pulse-forming network wherein electrical energy is adapted to be stored, said network having a connection to a source of electric current supply load devices, each having an impedance equal to the characteristic impedance of the network, connected to said network and at each end thereof, a normally non-conducting electronic space discharge device operatively associated with each of said load devices and having a series connection therewith and a connection to ground, and means operatively connected to said electronic space discharge devices rendering said space discharge device conductive, and independently of one another, to thereby initiate pulse generation.

3. In a pulse generating circuit, a pulse-forming network wherein electrical energy is adapted to be stored, said network having a connection to a source of electric current supply load devices connected to said network and at each end thereof, a normally non-conducting electronic space discharge device operatively associated with each of said load devices and having a series connection therewith and a connection to ground, and means operatively connected to said electronic space discharge devices for rendering said space discharge devices conductive, and independently of one another, to thereby initiate pulse generation, said means for rendering said space discharge devices conductive comprising means operative to effect division of the maximum pulse time width characteristic of the pulse-forming network in a predetermined ratio between said load devices.

4. In a pulse generating circuit, a pulse-forming network wherein electrical energy is adapted to be stored, said network having a connection to a source of electric current supply load devices connected to said network and at each end thereof, a normally non-conducting electronic space discharge device operatively associated with each of said load devices and having a series connection therewith and a connection to ground, and means operatively connected to said electronic space discharge devices for rendering said space discharge devices conductive, and independently of one another, to thereby initiate pulse generation, said means for rendering said space discharge devices conductive comprising means to establish the length of the time interval between successive pulse-generating operations.

5. In a pulse generating circuit, a pulse-forming network wherein electrical energy is adapted to be stored, said network having a connection to a source of electric current supply load devices connected to said network and at each end thereof, a normally non-conducting electronic space discharge device operatively associated with each of said load devices and having a series connection therewith and a connection to ground, and means operatively connected to said electronic space discharge devices for rendering said space discharge devices conductive, and independently of one another, to thereby initiate pulse generation, said means for rendering said space discharge devices conductive comprising means operative to effect division of the maximum pulse time width characteristic of the pulse-forming network in a predetermined ratio between said load devices, and means to establish the length of the time interval between successive pulse-generating operations.

6. In a pulse generating circuit, an electrical transmission line section, wherein electrical energy is adapted to be stored, said transmission line section having a connection to a source of electric current supply, load devices connected to said transmission line and at each end thereof, a normally non-conducting electronic space discharge device associated with each of said load devices and having a series connection therewith and a connection to ground, means operatively connected to said electronic space discharge devices for rendering said space discharge devices conductive to discharge rapidly the energy stored in said transmission line section and thereby initiate pulse generation and means for isolating said transmission line section from its source of electrical energy during the pulse generation period.

7. In a pulse generating circuit, an electrical transmission line section, wherein electrical energy is adapted to be stored, said transmission line section having a connection to a source of electric current supply, load devices, each having an impedance equal to the characteristic impedance of the transmission line section, connected, in series, to said transmission line and at each end thereof, a normally non-conducting electronic space discharge device associated with each of said load devices and having a series connection therewith and a connection to ground, means operatively connected to said electronic space discharge devices for rendering said space discharge devices conductive, and independently of one another, to discharge rapidly the energy stored in said transmission line section and thereby initiate pulse generation and means for isolating said transmission line section from its source of electrical energy during the pulse generation period.

8. In a pulse generating circuit, an electrical transmission line section, wherein electrical energy is adapted to be stored, said transmission line section having a connection to a source of electric current supply, load devices connected to said transmission line and at each end thereof, a normally non-conducting electronic space discharge device associated with each of said load devices and having a series connection therewith and a connection to ground, means operatively connected to said electronic space discharge devices for rendering said space discharge devices conductive, and independently of one another, to discharge rapidly the energy stored in said transmission line section and thereby initiate pulse generation and means for isolating said transmission line section from its source of electrical energy during the pulse generation peri-

od, said means for rendering said space discharge devices conductive comprising means operative to effect division of the maximum pulse time width characteristic of the transmission line section in a predetermned ratio between said load devices.

9. In a pulse generating circuit, an electrical transmission line section, wherein electrical energy is adapted to be stored, said transmission line section having a connection to a source of electric current supply, load devices connected to said transmission line and at each end thereof, a normally non-conducting electronic space discharge device associated with each of said load devices and having a series connection therewith and a connection to ground, means operatively connected to said electronic space discharge devices for rendering said space discharge devices conductive, and independently of one another, to discharge rapidly the energy stored in said transmission line section and thereby initiate pulse generation and means for isolating said transmission line section from its source of electrical energy during the pulse generation period, said means for rendering said space discharge devices conductive comprising means to establish the length of the time interval between successive pulse-generating operations.

10. In a pulse generating circuit, an electrical transmission line section, wherein electrical energy is adapted to be stored, said transmission line section having a connection to a source of electric current supply, load devices, each having an impedance equal to the characteristic impedance of the transmission line section, connected, in series, to said transmission line and at each end thereof, a normally non-conducting electronic space discharge device associated with each of said load devices and having a series connection therewith and a connection to ground, means operatively connected to said electronic space discharge devices for rendering said space discharge devices conductive, and independently one of another, to discharge rapidly the energy stored in said transmission line section and thereby initiate pulse generation and means for isolating said transmission line section from its source of electrical energy during the pulse generation period, said means for rendering said space discharge devices conductive comprising means operative to effect division of the maximum pulse time width characteristic of the transmission line section in a predetermined ratio between said load devices, and comprising means to establish the length of the time interval between successive pulse generating operations, the amplitude of the output pulse appearing at the load devices and the electrical energy drain of the transmission line section remaining substantially constant for all divisions of the output pulse time width.

11. In a pulse generating circuit, an electrical transmission line section, wherein electrical energy is adapted to be stored, said transmission line section having a connection to a source of electric current supply, load devices, each having an impedance equal to the characteristic impedance of the transmission line section, connected in series to said transmission line and at each end thereof, a normally non-conducting electronic space discharge device associated with each of said load devices and having a series connection therewith and a connection to ground, means operatively connected to said electronic space discharge devices for rendering said space discharge devices conductive, and independently of one another, to discharge rapidly the energy stored in said transmission line section and thereby initiate pulse generation and means for isolating said transmission line section from its source of electrical energy during the pulse generation period, said means for rendering said space discharge devices conductive including means operable to vary the time relationship between the instants of conduction of said electronic space discharge devices to vary the amount of energy that will be provided at each load as the transmission line section is discharged in response to the activation of said electronic space discharge devices.

12. In a pulse generating circuit, an electrical transmission line section, wherein electrical energy is adapted to be stored, said transmission line section having a connection to a source of electric current supply, a load device provided at each end of said transmission line section and connected in series thereto, each of said load devices having an impedance equal to the characteristic impedance of the transmission line section, a normally non-conducting electronic space discharge device associated with each of said load devices and having a series connection therewith and a connection to ground, means operatively connected to said electronic space discharge devices to provide pairs of triggering electrical pulses for rendering said space discharge devices conductive, and independently of one another, to discharge rapidly the energy stored in said transmission line section and thereby initiate pulse generation and means for isolating said transmission line section from its source of electrical energy during the pulse generation period, said means for rendering said electronic space discharge devices conductive comprising a plurality of a normally non-conducting electronic space discharge device, one connected to each of said first mentioned discharge devices and adapted when they become conductive to trigger said first mentioned discharge devices into conduction, and means to provide bias voltage upon the control grids of said second mentioned discharge devices, said bias providing means including means to vary the bias provided upon at least one of said control grids of said second mentioned discharge devices.

13. In a pulse generating circuit, an electrical transmission line section, wherein electrical energy is adapted to be stored, said transmission line section having a connection to a source of electric current supply, a load device provided at each end of said transmission line section and connected in series thereto, each of said load devices having an impedance equal to the characteristic impedance of the transmission line section, a normally non-conducting electronic space discharge device associated with each of said load devices and having a series connection therewith and a connection to ground, means operatively connected to said electronic space discharge devices to provide pairs of triggering electrical pulses for rendering said space discharge devices conductive, and independently of one another, to discharge rapidly the energy stored in said transmission line section and thereby initiate pulse generation and means for isolating said transmission line section from its source of electrical energy during the pulse generation period, said means for rendering said electronic space discharge devices conductive comprising a plurality of a normally non-conducting electronic space discharge device, one connected to each of said first mentioned discharge devices and adapted when they become

conductive to trigger said first mentioned discharge devices into conduction, and means to provide bias voltage upon the control grids of said second mentioned discharge devices, said bias providing means including means to vary the bias provided upon the control grid of one of said second mentioned discharge devices and to provide a fixed bias voltage to the control grid of the other of said discharge devices, and means connected to said control grids to initiate periodically the flow of current therethrough.

14. In a pulse generating circuit, an electrical transmission line section, wherein electrical energy is adapted to be stored, said transmission line section having a connection to a source of electric current supply, a pair of load devices connected in series to said transmission line, one at each end thereof, one of said load devices having an impedance equal to the characteristic impedance of the transmission line section, and the other of said load devices being subject to a variation of impedance with relation to the characteristic impedance of said transmission line section, a normally non-conducting electronic space discharge device associated with each of said load devices and having a series connection therewith and a connection to ground, means operatively connected to said electronic space discharge devices for rendering said space discharge devices conductive, and independently of one another, to thereby initiate pulse generation and means for isolating said transmission line section from its source of electrical energy during the pulse generation period.

15. In a pulse generating circuit, an electrical transmission line section, wherein electrical energy is adapted to be stored, said transmission line section having a connection to a source of electric current supply, a pair of load devices connected in series to said transmission line, one at each end thereof, one of said load devices having an impedance lower than the characteristic impedance of the transmission line section, and the other of said load devices being subject to a variation of impedance with relation to the characteristic impedance of said transmission line section, a normally non-conducting electronic space discharge device associated with each of said load devices and having a series connection therewith, and a connection to ground, means operatively connected to said electronic space discharge devices for independently rendering said space discharge devices conductive, and independently of one another, to discharge rapidly the energy stored in said transmission line section and thereby initiate pulse generation and means for isolating said transmission line section from its source of electrical energy during the pulse generation period.

16. In a pulse generating circuit, an electrical transmission line section, wherein electrical energy is adapted to be stored, said transmission line section having a connection to a source of electric current supply, load devices connected to said transmission line and at each end thereof and means for intermittently electrically interconnecting said load devices with said transmission line section comprising, two normally nonconducting electronic space discharge devices associated with each of said load devices and having a series connection therewith and a connection to ground, and means operatively connected to said electronic space discharge devices for rendering, in pairs, said space discharge devices conductive alternately to store rapidly and to discharge rapidly the said energy stored in said transmission line section and thereby effect pulse generation.

17. In a pulse generating circuit, an electrical transmission line section, wherein electrical energy is adapted to be stored, said transmission line section having a connection to a source of electric current supply, load devices connected to said transmission line and at each end thereof and means for intermittently electrically interconnecting said load devices with said transmission line section comprising, two normally nonconducting electronic space discharge devices associated with each of said load devices and having a series connection therewith and a connection to ground, and means operatively connected to said electronic space discharge devices for rendering said space discharge devices conductive and in pairs, which pairs comprise one space discharge device at each end of said transmission line, alternately to store rapidly and to discharge rapidly the said energy stored in said transmission line section and thereby effect pulse generation, said means for rendering said electronic space discharge devices conductive comprising means operative on said pairs of space discharge devices to render each member of a pair conductive independently of one another during a pulse generating operation.

18. In a pulse generating circuit, an electrical transmission line section, wherein electrical energy is adapted to be stored, said transmission line section having a connection to a source of electric current supply, load devices connected to said transmission line and at each end thereof and means for intermittently electrically interconnecting said load devices with said transmission line section comprising, two normally nonconducting electronic space discharge devices associated with each of said load devices and having a series connection therewith and a connection to ground, means operatively connected to said electronic space discharge devices for rendering said space discharge devices conductive and in pairs comprised of one space discharge device at each end of said transmission line, one pair of which operates to rapidly charge the transmission line with electrical energy and the other pair operates to rapidly discharge said stored energy, with pulse formation occurring during both the charging and the discharging of said transmission line.

19. In a pulse generating circuit, an electrical transmission line section, wherein electrical energy is adapted to be stored, said transmission line section having a connection to a source of electric current supply, load devices connected to said transmission line and at each end thereof and means for intermittently electrically interconnecting said load devices with said transmission line section comprising, two normally nonconducting electronic space discharge devices associated with each of said load devices and having a series connection therewith and a connection to ground, means operatively connected to said electronic space discharge devices for rendering said space discharge devices conductive and in pairs comprised of one space discharge device at each end of said transmission line, one pair of which operates to rapidly charge the transmission line with electrical energy while simultaneously forming pulses at said load devices, and the other pair operates to discharge said stored energy to form pulses.

20. In a pulse generating circuit, an electrical transmission line section, wherein electrical energy is adapted to be stored, said transmission

line section having a connection to a source of electric current supply, load devices connected to said transmission line and at each end thereof and means for intermittently electrically interconnecting said load devices with said transmission line section comprising, a normally non-conducting electronic space discharge device associated with each of said load devices and having a series connection therewith and a connection to ground, and means operatively connected to said electronic space discharge devices for independently rendering said space discharge devices conductive to rapidly store energy in said transmission line section while simultaneously forming pulses at said load devices.

21. In a pulse generating circuit, an electrical transmission line section, wherein electrical energy is adapted to be stored, said transmission line section having a connection to a source of electric current supply, load devices connected to said transmission line and at each end thereof, a normally non-conducting electronic space discharge device associated with each of said load devices and having a series connection therewith and a connection to ground, means operatively

connected to said electronic space discharge devices for independently rendering said space discharge devices conductive to rapidly store energy in said transmission line section while simultaneously forming pulses at said load devices, and means for reversing said stored energy to provide part of the energy required for succeeding pulses.

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