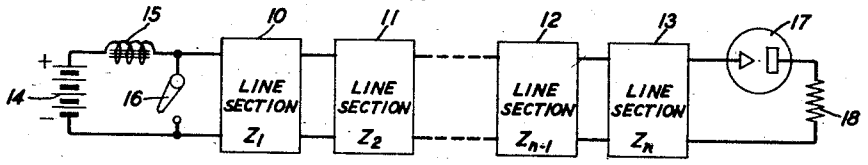
May 13, 1947. W. M. GOODALL 2,420,309

IMPULSE GENERATOR

Filed Jan. 10, 1944

FIG. 1



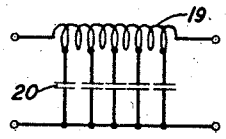


FIG. 2

FIG. 3

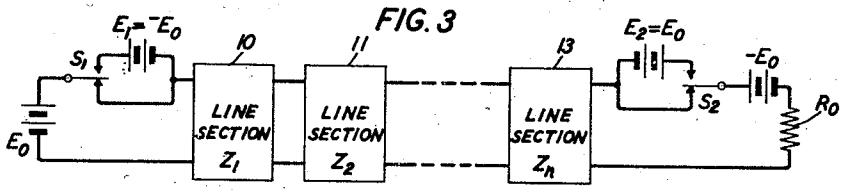


FIG. 4

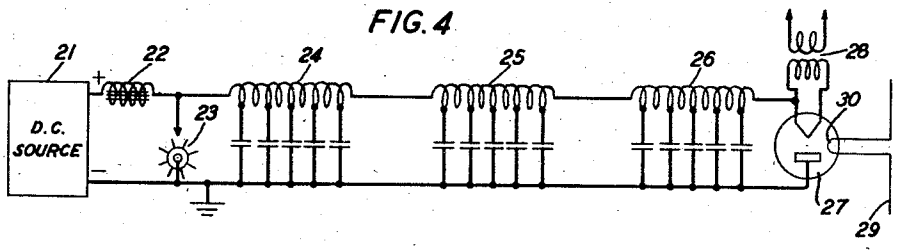
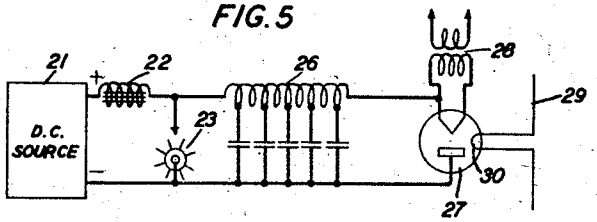


FIG. 5



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IMPULSE GENERATOR

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Application January 10, 1944, Serial No. 517,681

6 Claims. (Cl. 178—44)

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This invention relates to impulse generators and more particularly to circuits for generating impulses of very short duration and high intensity. Its general objects are the production of short impulses of substantially rectangular wave form and the transformation of such impulses to increase their voltage relatively to that of the power source. Other objects are to provide an efficient impulse generator for use with a load device having unidirectional conductivity; to provide for stepping up the voltage of an impulse without the use of electromagnetic transformers; and to diminish the effects of parasitic capacities in impulse generating systems.

In impulse transmission systems, for example, radio echo systems, employing periodically recurrent high frequency pulses of great intensity and extremely short duration, it has been found desirable that the individual trains of high frequency oscillations should have a substantially rectangular envelope wave form. This wave form is conveniently obtained by exciting the anode circuit of a high frequency vacuum tube oscillator by direct current impulses of corresponding rectangular wave form and intensity, the high frequency energy being derived from that contained in the direct current impulse.

Heretofore, the generation of extremely short impulses of suitable shape and intensity for use in echo devices has presented a problem of considerable magnitude for the reasons that direct currents at the required voltage are not readily obtained and that electromagnetic transformers capable of providing the necessary voltage transformation without impairing the wave form are costly and difficult to construct. One solution of the problem has made use of the successive wave reflections at the junctions in a chain of line sections having different characteristic impedances to effect the desired voltage transformation of an impulse propagated along the chain. A system of this type is disclosed in the copending application of S. Darlington, Serial No. 499,193, filed August 19, 1943. In that system, the last line section is terminated in an open circuit and is connected in series with the load as a capacitive two-terminal impedance. Since it is usually necessary to have one terminal of the load device grounded, the arrangement requires both sides of the last line section to be at potentials above ground, thereby causing the parasitic ground capacities of the line to be introduced into the circuit. Unless compensated in some way, these parasitic capacities may bring

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about a substantial deterioration of the pulse wave form.

The present invention employs reflecting line sections for the shaping and the voltage transformation of the impulses as in the system disclosed in the above-mentioned Darlington application. Parasitic capacity effects are minimized by the use of grounded line sections throughout in combination with a load device having unidirectional conductivity. The line sections are all connected in tandem and the load device is connected directly to the output terminals of the chain, the arrangement being made possible as the result of a new method of graduating the line impedances described hereinafter.

In its simplest form the invention may employ a single line section which in that case functions primarily to develop the rectangular wave form of the impulse. In its other embodiments the invention may comprise a chain of two or more line sections appropriately graduated in their impedances to provide both wave shaping and voltage transformation.

The nature of the invention will be more fully understood from the following detailed description and by reference to the accompanying drawing in which:

Fig. 1 is a schematic showing of a general form of the invention;

Fig. 2 illustrates the circuit arrangement of a line element used in the invention;

Fig. 3 is a circuit schematic used for explaining the operation of the circuit;

Fig. 4 is a schematic showing of a practical form of the invention; and,

Fig. 5 shows a simple form of the invention employing only a single line section.

Referring to Fig. 1, the system comprises a tandem chain of line sections **10**, **11**, **12**, **13**, a source of direct current **14** connected to the input end of the chain through a choke coil **15** of large inductance, and an output circuit including a diode **17** and a load resistor **18** connected in series. A switch **16** bridged across the input terminals of the chain of lines provides means for discharging the lines to generate the impulses. The diode **17** is poled to block the flow of current from the source **14**. In the figure the diode and the load resistor are shown as separate elements, but in practical circuits they may be combined in a single device having unidirectional conductivity as, for example, when the load is constituted by the plate circuit of a vacuum tube oscillator arranged to be excited by the generated impulses. The line sections should have

negligibly small energy dissipation and should have linear phase shift characteristics. They may be portions of actual transmission lines, for example, coaxial conductor lines, but to save space it is generally desirable to construct them as artificial lines. A suitable artificial line construction is shown in Fig. 2 in which one side of the line comprises a single helical coil 19, the other side being grounded, and in which a plurality of equal capacities such as 20 are bridged between the two sides at uniformly spaced points along the coil. Artificial lines of this type can readily be made to simulate the characteristics of an ideal dissipationless line at all frequencies up to several million cycles per second.

To enable the system to generate rectangular impulses of desired intensity and duration, the line sections have equal electrical lengths and delay times and, in addition, have different characteristic impedances which increase from section to section towards the output end of the chain. The values of the impedances follow a particular law which not only provides for the desired degree of voltage transformation but also ensures that only a single pulse of definite duration will be produced. This law of gradation may be expressed as follows: In a system comprising n networks operating into a load of resistance R_0, the characteristic impedance Z_r of the rth network counting from the input end is

$$Z_r=\frac{R_0 r(r+1)}{n(n+1)} \tag{1}$$

The impedances thus increase in accordance with the series of products 1.2; 2.3; 3.4; etc., the last section having an impedance equal to that of the load. As will be shown later, the voltage of the impulse delivered to the load is

$$\frac{n}{2}$$

times the voltage to which the line capacities are charged.

Examples of the impedance values obtaining in systems having different numbers of line sections are given below:

$n=2$

$$Z_1=\frac{2}{6}R_0;\ Z_2=R_0$$

$n=3$

$$Z_1=\frac{2}{12}R_0;\ Z_2=\frac{6}{12}R_0;\ Z_3=R_0 \tag{2}$$

$n=4$

$$Z_1=\frac{2}{20}R_0;\ Z_2=\frac{6}{20}R_0;\ Z_3=\frac{12}{20}R_0;\ Z^4=R_0$$

In the operation of the system to produce repeated impulses, the switch 16 is closed momentarily at regular intervals, an impulse being produced in the output circuit at each closure. The repeated operation of the switch may be effected in any suitable manner or, as described later, a rotary spark gap may be employed in place of a switch to produce repeated momentary short circuits. During the period that the switch is open, current flows from source 14 into the lines and charges the line capacities. If the switch remains open long enough, the lines would be charged to a voltage equal to that of the source, but when the charging is repeated at regular short intervals, the action of the choke coil, as is well known, is to increase the voltage to which the lines are charged to substantially twice that of the source. A resistor might be used instead of the choke coil, but in that case the voltage doubling effect would be absent and a certain amount of energy would be dissipated in the resistance. During the charging period, diode 17 blocks the flow of current in the output circuit and prevents the charge on the lines from leaking off. At the end of the charging period, switch 16 is closed momentarily permitting the lines to discharge through its contacts and thereby generating an impulse in the output circuit.

The closing of switch 16 is equivalent in its effect to the sudden application to the line terminals of a reverse voltage equal to the charge voltage. Such a voltage produces a charging current, the wave front of which travels along the lines neutralizing the original charges as it goes. The effect is not felt immediately at the output circuit, but only after a time long enough to permit the discharging wave to traverse the whole chain. At each junction point the wave front is stepped up in voltage, since it meets an increased impedance, and as the cumulative result of the transformations at the successive junction, it arrives at the output circuit greatly magnified. Being of reverse polarity from the charging voltage, the discharging pulse can drive current through the diode and the load resistor.

In any chain of lines with different characteristic impedances, the passage of an impulse is accompanied by the generation of echo pulses due to reflections at the junction points. These echo pulses arrive at the output end at later times and ordinarily would tend to sustain the current produced by the original pulse or else produce a sequence of separate pulses. By virtue of the particular manner in which the line impedances are graduated in the systems of the invention, the delayed pulses combine in such a way as to quench the initial pulse sharply so that all of the energy stored in the line passes to the load in a single flat-topped impulse of predetermined duration.

A direct development of the rule for proportioning the line impedances is a lengthy and somewhat difficult procedure, but it is comparatively simple to show that the gradation defined by Equation 1 produces the desired results in the most general case where the number of line sections is not restricted.

For this purpose it is convenient to analyze the operation of the system in terms of an equivalent circuit in which the successive physical happenings can be simulated by the introduction of step voltages of appropriate magnitudes. Such a circuit is shown in Fig. 3, wherein 10, 11 and 13, are line sections corresponding to those in Fig. 1. Voltage E_0 in the input circuit represents the voltage to which the lines have been charged just prior to the closing of the short-circuiting switch. Resistance R_0 in the output circuit is that of the load. To simulate the effect of the diode in blocking current from the charging source, a voltage $-E_0$ is included in the output circuit. The closing of discharge switch 16 in Fig. 1 is simulated by the introduction into the input circuit by means of switch S_1 of a voltage E_1 equal to E_0 but of reverse sign. In the output circuit a second switch S_2 permits the introduction of a voltage E_2 equal to E_0. This switch is operated at the instant the discharge pulse reaches the output circuit, thereby neutralizing the original blocking voltage at that point. It will be clear that the successive states of the circuit in Fig. 3 correspond to the following conditions in the circuit of Fig. 1; first, before the closing of switch 16, the lines are charged to the voltage E_0 and

this voltage appears across the diode in the output circuit. Second, after the closing of switch 16, the voltage in the input circuit is reduced to zero but the voltage across the diode in the output circuit is maintained until the discharge wave front reaches the output circuit. Third, after the discharge wave front reaches the output circuit, the voltage across the diode disappears and the voltage in the circuit is reduced to zero. These correspondences are sufficient to establish the equivalence of the two systems with respect to their transients which can now be determined as the response of the system in Fig. 3 to the two successively applied voltages.

The reflection coefficient at the input of the rth, section for a wave propagated towards the output is, by definition,

$$\sigma_r=\frac{Z_r-Z_{r-1}}{Z_r+Z_{r-1}} \tag{3}$$

where the Z's denote characteristic impedances and σ is the reflection coefficient. Upon the insertion of the appropriate values for the impedances by means of Equation 1, Equation 3 becomes

$$\sigma_r=\frac{1}{r} \tag{4}$$

The voltage transformation factor at the input of the rth section is

$$1+\sigma_r=\frac{r+1}{r} \tag{5}$$

which means that the voltage developed at this point is equal to $(1+\sigma_r)$ times the voltage applied to the preceding line section.

It is easy to see, then, that as the result of the cumulative effect of the succesive reflections, a step voltage $-E_0$ be applied to the input of the system, will develop a voltage at the input terminals of the rth section equal to

$$-\frac{E_0}{2}(r+1) \tag{6}$$

and, at the input of the last section, a voltage equal to

$$-\frac{E_0}{2}(n+1) \tag{7}$$

This pulse will pass through the last section and on arriving at the output circuit will be impressed on the load resistor without further change, since at that instant the voltage across the diode disappears and since the load resistance matched the line impedance.

As already stated, the sudden introduction of the neutralizing voltage E_2 in Fig. 3 simulates the sudden disappearance of the voltage across the diode. This voltage divides equally between the load resistance and the line impedance and combines with the arriving pulse to produce a resultant voltage V_R across the load of value

$$V_r=-n\frac{E_0}{2} \tag{8}$$

The voltage amplification of the line system is therefore equal to half the number of line sections in the system and when the voltage doubling action of the charging choke coil is taken into account the amplification is twice this value.

Since the output pulse can be attributed to the application of simple step voltages to the system, its amplitude will remain substantially constant until some other voltage arises to modify it. Such a voltage is developed by echo pulses produced at the several line junctions. The first echo pulses

to arrive at the output circuit will comprise the reflection from the input terminals of the last line section of the wave produced by the sudden introduction of the voltage E_2 together with those pulses which after starting from the input end of the system have been delayed by an equal time because of reflections at the internal junctions of the system. The minimum time before the appearance of any echo voltages is thus equal to 2T or twice the delay time of each section.

It is possible to develop an expression for the sum of all of these echo voltages and to show that it is of just the right value and sign to neutralize the original pulse. It is easier, however, to show that at the end of the time 2T the original pulse will have dissipated all of the energy originally stored in the system so that no further pulses can occur.

By reference to the standard formulae for the delay time and the characteristic impedance of a given length of uniform dissipationless line, the electrostatic capacities of the several line sections may be shown to have values according to the equation

$$C_r=\frac{T}{Z_r}=\frac{T}{R_0}\frac{n(n+1)}{r(r+1)} \tag{9}$$

where C_r denotes the capacity of the rth line section and T denotes the delay time. For a system comprising n line sections graduated in impedance in accordance with Equation 1, the total capacity C has the value

$$C=\frac{T}{R_0}(n+1)n\Sigma_1^n\frac{1}{r(r+1)}$$

$$=\frac{n^2T}{R_0} \tag{10}$$

The energy W stored in the system before discharging is therefore given by

$$W=\frac{n^2T}{2R_0}E_0^2 \tag{11}$$

which is exactly equal to the energy dissipated in the load by the voltage pulse V_R as defined by Equation 8 in the time of its duration 2T. It is thus demonstrated that, with the impedance gradation described, a single output pulse of rectangular wave form is produced each time the discharging switch is applied, the duration of the pulse being determined by the length of the line section and the amplitude by the number of sections. In the case where only a single section is used, the impulse has a voltage equal to half the voltage to which the line is charged, the line section serving primarily as a wave shaping means.

The foregoing discussion of the principles of the invention has been based on the assumption that the line sections are all portions of uniform dissipationless lines. It has been found, however, that the performance of the circuits is not materially altered by the presence of a small amount of energy dissipation in the lines and also that the ideal performance may be closely approximated when artificial lines such as shown in Fig. 2 or of other appropriate configuration are used. When artificial lines comprising lumped inductances and capacities are used, it is desirable that their phase shift characteristics should be substantially linear throughout a range extending up to a frequency several times that represented by the reciprocal of the pulse duration time. Stated otherwise, the range in which the phase shift is linear should be broad enough to include at least several harmonics of the frequency defined by the reciprocal of the duration time.

Fig. 4 shows the circuit arrangement of a practical embodiment of the invention employing three line sections and providing a voltage transformation ratio of three. The circuit is commonly referred to as a voltage tripler since the output voltage is three times that produced in a single section device where the line section functions principally to produce the rectangular wave form of the impulse. When the action of the charging choke coil is taken into account, this is substantially three times the voltage of the charging source. The circuit is supplied with energy from a direct current source 21 which may, for example, be a rectifier taking current from a power line or other primary source of alternating current. 22 is a charging choke coil corresponding to 15 in Fig. 1. The discharging switch is a rotary spark gap 23 driven by a motor, not shown. The number of points on the rotary portion of the gap and the speed of the driving motor may be chosen to provide various impulse rates up to about 2,000 per second. The three line sections 24, 25, 26 are of the type shown in Fig. 2 and may be designed to produce impulses of lengths from about one half to one microsecond. The unidirectional load device 27 is a diode magnetron oscillator, for example, of the type disclosed in United States Patent 2,063,342, issued December 8, 1936, to A. L. Samuel, the construction of this device being such that it is operated preferably with its anode grounded. The filamentary cathode of the oscillator tube is heated by low frequency alternating current supplied to it through an insulating transformer 28 from a low voltage source, not shown. The high frequency pulses are supplied to a radiator 29, shown as a conventional dipole, through a small coupling loop 30 which penetrates into one of the resonant cavities of the magetron.

The source 21 may be capable of supplying direct current at a voltage of about 12,000 volts. With inductance charging this would result in about a 20,000 volt charge on the line condensers, in which case an impulse of about 30,000 volts would be delivered to the oscillator terminals. This compares with an impulse voltage of about 10,000 volts that would be obtained with a single line section arranged primarily to develop a rectangular pulse shape. The spark gap 23 breaks down each time one of the rotating points comes into juxtaposition with the fixed point and provides a discharge path of very low resistance. Since the pulse duration, including the delay time introduced by the line sections is generally short in comparison with the interval between successive impulses, the system can be fully discharged during the passage of the spark and can be fully charged again before the next spark occurs.

Fig. 5 illustrates a simple form of impulse generator in accordance with the invention in which only a single line section is used. The circuit is the same as that of Fig. 4 except that the first two line sections are omitted. Like numbers refer to corresponding parts in the two figures. The line section has a characteristic impedance equal to the resistance of the load device. The impulse voltage generated is of rectangular wave form and has a duration equal to twice the delay time of the line section. The line section here functions primarily as an impulse shaping means to provide the desired rectangular wave shape and does not introduce any voltage amplification, the impulse voltage being equal to half the voltage to which the line is charged.

In the circuits illustrated in the drawings, the charging source is shown connected at the input end of the chain of lines, this position being advantageous in the respect that the charging circuit elements are not subject to the high voltage of the amplified impulses developed in multiple section systems. It is not necessary, however, that the charging circuit be connected at this point and it may, if circumstances so dictate, be bridged across the lines at any other accessible point, the only requirement being that the impedance of the charging choke coil be sufficiently high so that its presence does not disturb the impedance relationships of the lines.

What is claimed is:

1. A generator of impulses having substantially rectangular wave form and preassigned duration comprising a wave transmission line having a delay time equal to one half the preassigned duration of the impulses, a load device, connected to one end of said line, said device having unidirectional conductivity and having an impedance in its conductive direction substantially equal to the characteristic impedance of the line, a source of direct current included in a circuit bridged across said line, said load device being poled to oppose the flow of current from said source, and circuit closing means included in a circuit connected to the other end of said line for periodically discharging the line through the load in its conductive direction.

2. A pulse generator in accordance with claim 1 in which the wave tranmission line is a four-terminal network comprising lumped reactance elements and having a substantially linear phase shift characteristic throughout a frequency band which is broad relatively to the frequency value defined by the reciprocal of the preassigned impulse duration.

3. A generator of impulses having substantially rectangular wave form comprising a plurality of wave transmission lines of different charactistic impedances and of equal electrical lengths connected in sequence to form a composite line in which the impedances of the successive portions increase progressively from one end to the other, a load device having unidirectional conductivity connected to the high impedance end of the composite line, a source of direct current included in a circuit bridged across said composite line, said load device being poled to oppose the voltage of said source, and circuit closing means connected to the low impedance end of said composite line for periodically discharging said line through the load device in its conductive direction.

4. An impulse generator comprising a plurality of wave transmission networks having equal delay characteristics coupled sequentially to form a composite line, a unidirectionally conductive load device connected to one end of said composite line, a source of direct current included in a circuit bridged across said line, said load device being poled to oppose the voltage of said source, and circuit closing means connected at the other end of said line for periodically discharging said line through the load device in its conductive direction, said transmission networks having transmission characteristics simulating those of non-dissipative uniform lines in a wide frequency range and having different characteristic impedances which increase progressively from one network to the next in the direction towards the load in such manner that each discharge of the composite line takes the form of a

single impulse of substantially rectangular wave form.

5. An impulse generator in accordance with claim 4 in which the characteristic impedances of the several wave transmission networks increase from one to the next according to the series of products.

1.2; 2.3; 3.4; 4.5 . . .

the last network adjacent the load device having an impedance equal to the impedance of the load in its conductive direction.

6. An impulse generator comprising a plurality of wave transmission lines having different characteristic impedances and equal delay times connected in tandem to form a composite line, a unidirectionally conductive load device connected to the output end of said composite line, a source

of direct current included in a circuit bridged across said composite line, said load device being poled to oppose the voltage of said source, and short-circuiting means connected to the input end of said composite line for discharging said line through said load device in its conductive direction, said wave transmission lines having characteristic impedances of values according to the equation

$$Z_r=\frac{Rr(r+1)}{n(n+1)}$$

wherein Z_r denotes the characteristic impedance of the r^n line from the input end of the system, R is the resistance of the load in its conductive direction, and n is the total number of wave transmission lines.

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