PULSE FORMING APPARATUS

Filed Nov. 25, 1960 2 Sheets-Sheet 1

Fig. 1.

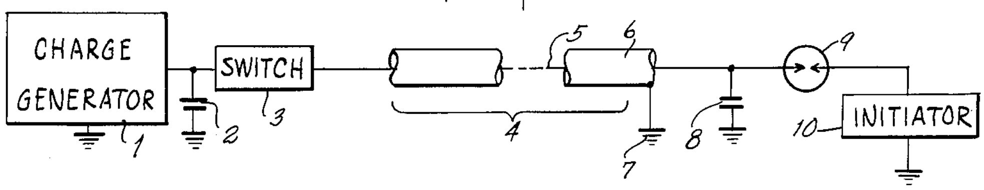


Fig. 2.

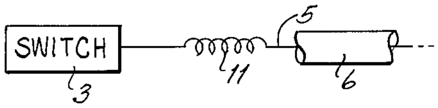


Fig. 3.

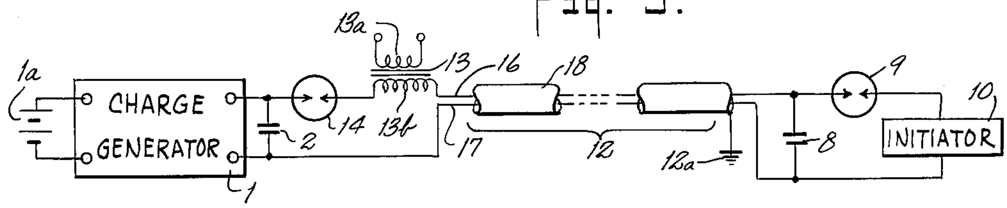


Fig. 4.

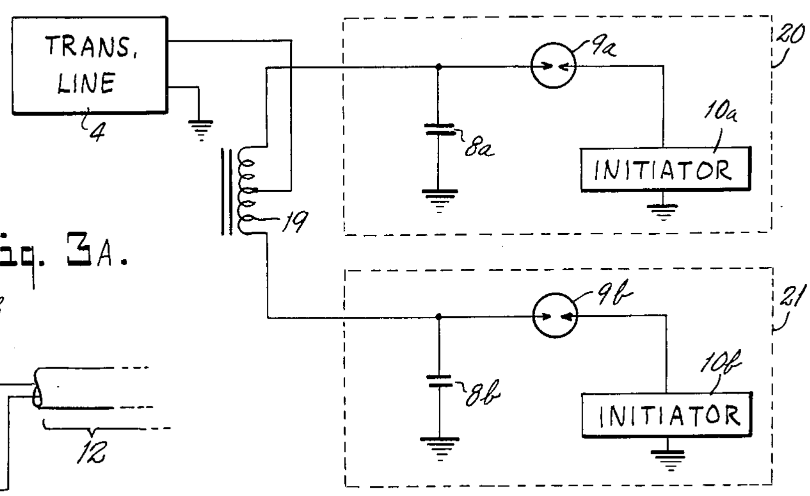


Fig. 3A.

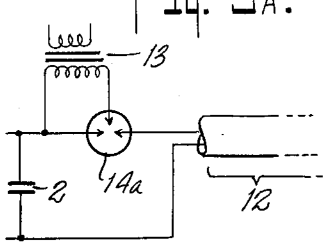

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Fig. 5.

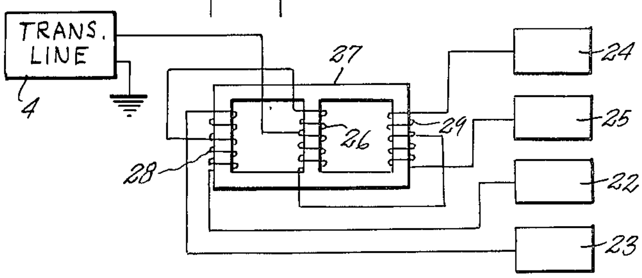



Fig. 5A.

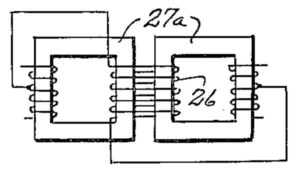



Fig. 6.

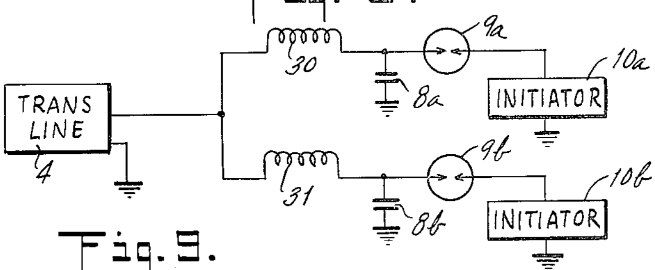



Fig. 8.

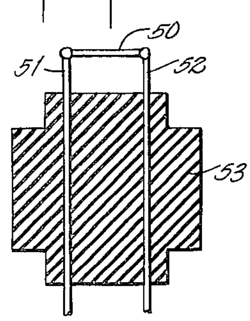
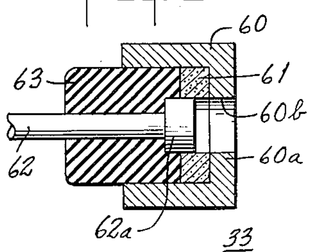



Fig. 9.



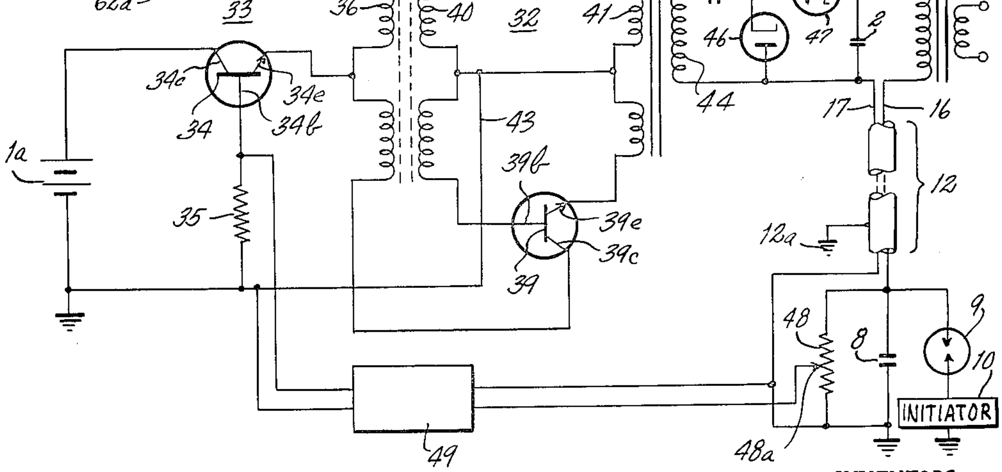




Fig. 7.

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3,255,366

# PULSE FORMING APPARATUS

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Filed Nov. 25, 1960, Ser. No. 71,807
7 Claims. (Cl. 307—106)

This invention relates to apparatus for initiating an explosion or igniting combustible material, by the use of heat and/or shock waves, and particularly to electrical apparatus for producing heat and/or shock waves at a location remote from the source of electrical energy.

Electrically-operated devices for producing heat and/or shock waves are generically termed initiators and have been in use for many years for initiating combustion or for detonation of explosives. One common form of initiator is termed an exploding bridge wire, and consists of an unsupported section of wire bridging a gap. The bridge wire has physical characteristics such that when it is energized by an impulse of given intensity (i.e., relatively steep wave front, relatively high current), it is immediately vaporized, thereby releasing heat and causing a shock wave in its immediate vicinity. Such bridge wires, when so energized, are used to initiate combustion or detonation of explosives which are relatively insensitive to shock and heat. Similar bridge wires are sometimes energized with impulses of lower intensity (i.e., smaller currents of longer duration) to ignite combustible materials and to ignite relatively sensitive explosives.

A transmission line between a source of electrical energy and a bridge wire tends to distort and attenuate a steep wave front impulse produced at the source. As the distance between the source and the bridge wire increases, the distortion and attenuation in the transmission line increases. This distortion and attenuation is of no importance in connection with bridge wires which are energized by low intensity impulses. On the other hand, such distortion and attenuation has in the past limited the practical distance between the source and the bridge wire, where high intensity energization is used. One particular factor in the distortion which is troublesome is the decrease in the steepness of the wave front. Another troublesome factor is the decrease in amplitude which is characteristic of attenuation.

One of the many uses for initiators of the type described is for starting rocket engines. As rocket engines increase in size, the point of initiation is moved farther and farther from the source of electrical energy. In many current rockets, the distance in question is of the order of 50 feet. In other types of installations, the distance may be even greater. A transmission line of that length may severely distort and attenuate a steep front energy pulse so that when the pulse reaches the initiator, its wave front may be reduced in slope. Consequently, the shock wave produced by the initiator may be reduced in intensity so as to result in a failure to fire.

The electrical transmission system between the source of electrical energy and the initiator is subject to accidental pickup of electrical energy from external sources. Such external sources may be either static electricity, or electromagnetic fields, particularly from communication and radar systems, or power circuits, which may be either alternating or direct current. When electrical energy is accidentally picked up by the transmission system, there are two possible types of failure at the initiator.

The most serious type of failure which may occur at the initiator is an accidental explosion or initiation of combustion at a time when it is not desired. The other type of failure is serious although not usually dangerous. It is commonly termed "dud-out" and consists of a destruction of the initiator structure, for example, the exploding bridge wire. Such destruction may take place by electrical energization with a current insufficient in magnitude to produce the heat and/or shock waves necessary to start an explosion. If an exploding bridge wire is destroyed in this manner by stray energization, then when it is desired thereafter to produce an explosion, the explosion will not be initiated because of the absence of the bridge wire.

An object of this invention is to provide an improved system for transmitting a steep front electrical pulse, with minimum distortion and attenuation, to an electrical device responsive to such a steep front pulse and located remotely from the source of electrical energy.

Another object is to provide an improved transmission system of the type described including means to inhibit the delivery to the load device of accidentally picked up electrical energy.

Another object is to provide an improved transmission system of the type described, in which the load device is an initiator.

The foregoing and other objects of the invention are attained in the apparatus described herein. This apparatus includes a transmission system having at the receiving end of the transmission line a receiving unit including a capacitor connected between the conductors of the transmission line, and, in parallel with the capacitor, an enclosed spark gap connected in series with a steep front pulse responsive initiator. When an electrical pulse is sent over the transmission line, it must first charge the capacitor, before any energy can be delivered to the initiator. When the capacitor charges to a potential equal to the breakdown potential of the enclosed gap, the energy stored on the capacitor is discharged through the initiator in the form of a pulse having a steep front. Thus even though the original pulse may be attenuated in the transmission line, the pulse which is actually delivered to the initiator does have a steep wave front.

In one modification of the transmission system, after taking into account the distributed inductance and capacitance of the transmission line, an inductance coil is coordinated with the line resistance and the capacitance of the capacitor at the receiving end of the line in order to provide a potential increasing effect.

In another modification of the transmission system, the source of energy feeding the transmission line is controlled by a potential which is fed back from the capacitor in order to maintain the charge of the capacitor at a predetermined potential approaching the breakdown potential of the enclosed gap.

Other modificaitons of the transmission system are shown, including arrangements for supplying a plurality of initiators over one transmission line.

Several of the transmission systems disclosed include further improvements with respect to prevention of accidental energization of the initiator by stray fields, etc.

Other objects and advantages of the invention will become apparent from a consideration of the following specification and claims, taken together with the accompanying drawing.

In the drawing:

FIG. 1 is an electrical wiring diagram of a transmission system which is a feature of the present invention;

FIG. 2 is an electrical wiring diagram of a modification of the circuit of FIG. 1;

FIGS. 3, 3A and 4, 5, 5A, 6 and 7 are electrical wiring diagrams of further modifications of the circuit of FIG. 1;

FIG. 8 is a somewhat diagrammatic illustration of a prior art type of initiator; and

FIG. 9 is a cross-sectional view of another form of initiator of the semiconductor gap type, which may be used in the systems of the present invention.

## FIG. 1

This figure illustrates an electrical circuit including a charge generator shown diagrammatically at **1**, a storage capacitor **2**, a switch **3**, a shielded transmission line **4** including a central conductor **5** and a shield **6** connected to ground at **7**, and a receiving unit including a capacitor **8** connected between the wire **5** and ground and an enclosed spark gap **9** connected in series with an initiator **10**. The series group including the gap **9** and the initiator **10** is connected in parallel with capacitor **8** between the receiving end of the conductor **5** and ground.

The charge generator **1** may be of any suitable type. For a simple illustration, it may include a battery and a conversion device for changing the energy available at the battery to more appropriate potential levels, and charging the capacitor **2** with the converted energy. A suitable charge generator is illustrated in FIG. 7 and described in detail below.

The switch **3** may be any device suitable for opening and closing the circuit through the transmission line **5**. For instance, switch **3** may be a mechanical switch or any other device capable of shifting between a low impedance condition (e.g., closed circuit) in which the capacitor **2** sends a relatively large current through the wire **5** and a high impedance condition (e.g., open circuit) in which substantially no current is sent through the wire **5**. For example, switch **3** might be an electronic switch or a trigger and gap arrangement as shown in FIG. 3 and described below.

The initiator **10** may be one of the devices illustrated in FIGS. 8 and 9.

## OPERATION (FIG. 1)

When the switch **3** is closed, a current impulse starts flowing through the conductor **5** to the capacitor **8**. This impulse may appear as having a steep wave front at the switch **3**, but it is attenuated by the transmission line **4**, so that at the capacitor **8** it appears with a wave front having a more gradual slope. As the capacitor **8** charges, the potential across it eventually reaches the breakdown potential of the gap **9**, at which time the capacitor **8** discharges and transmits an impulse with a steep wave front to the initiator **10**. Capacitor **8**, gap **9**, and initiator **10** should be in as close proximity to each other as is conveniently possible, to ensure maximum steepness of the wave front at the initiator **10**.

It may be seen that the transmission system of FIG. 1 delivers a steep front electrical impulse to the initiator **10** regardless of the fact that the steep front impulse which appeared at the output side of the switch **3** may have had its wave front substantially distorted before it reached the receiving end of the line **3**. The system may be regarded as a pulse forming system for delivering a pulse of desired shape to the initiator **10**.

## FIG. 2

This figure illustrates a modification of the circuit of FIG. 1 in which an inductor **11** is inserted in series with the transmission line conductor **5**. The inductor **11** is coordinated with the line resistance and the capacitance of capacitor **8** so as to produce a potential increasing or "voltage doubling" effect, thereby enabling the use of a charge generator **1** having an output potential lower than the potential of the enclosed gap **9**.

The inductor **11** reduces the amplitude of the current flowing through the transmission line. Since the losses in the transmission line vary as the square of that current, this indicative loading is effective to reduce the power losses in the line and thereby to insure the delivery of a greater potential to the receiving units.

## FIG. 3

The circuit of FIG. 3 differs from the circuit of FIG. 1 by the substitution of a different transmission line generally indicated at **12** for the transmission line **4** of FIG. 1 and by the replacement of the generalized switch **3** of FIG. 1 with a trigger input transformer **13** and an enclosed gap **14**.



The transmission line **12** comprises two conductors **16** and **17** enclosed within a shield **18**, which is grounded at **12***a*. The shielded transmission line **12** provides a balanced line with both conductors **16** and **17** at the same potential with respect to ground. By virtue of the shield **18**, stray ground currents do not pass through the conductors **16** and **17** and hence do not supply any energy to the initiator **10**. The shielding is also effective to keep out stray electromagnetic fields and to prevent accidental contact between conductors **16** and **17** and power circuits.

By using the gap **14** and the trigger transformer **13**, the load of the transmission line is kept off the storage capacitor **2** until the breakdown potential of gap **14** is reached. That breakdown potential is selected so that it is not exceeded by the charge generator **1**, but is only exceeded by a breakdown signal supplied through the trigger transformer **13**. Accidental supply of energy from the charge generator **1** to the initiator **10** is thereby prevented.

The transformer **13** is effective to load the line **12** inductively in the same manner that inductor **11** of FIG. 2 loads the line **4**.

## FIG. 3A

This figure illustrates a modification of the circuit of FIG. 3, which utilizes a three-point gap **14***a* in place of the two-point gap **14** of FIG. 3. A three-point gap may be desirable in some installations because it can be fired with less energy than in the case of the two-point gap. However, the two-point gap has a higher breakdown potential and hence an increased safety factor. For that reason, the two-point gap is preferred for most installations.

## FIG. 4

This circuit illustrates an arrangement for energizing two initiators **10***a* and **10***b* from a single source through a single transmission line. The transmission line is indicated diagrammatically at **4** and may be the same as the transmission line **4** of FIG. 1. Alternatively, a balanced and shielded transmission line such as that shown in FIG. 3 may be used. The receiving end of the transmission line is connected to the mid-point of a balancing transformer **19**. The opposite end terminals of the transformer **19** are connected respectively to receiving units **20** and **21**. The receiving unit **20** comprises a capacitor **8***a*, a gap **9***a* and an initiator **10***a*, while the receiving unit **21** comprises a capacitor **8***b*, a gap **9***b*, and an initiator **10***b*. The capacitors, gaps and initiators of the respective receiving units correspond to the capacitor **8**, gap **9** and initiator **10** of FIG. 1.

The transformer **19** of FIG. 4 acts as a splitting transformer and maintains equal currents to the load capacitors **8***a* and **8***b*. This insures that the two capacitors charge at nearly the same rate, so that the time differential between the breakdown of the initiator spark gaps will be very small, i.e., of the order of a few microseconds. Furthermore, if one gap fires before the other, the current in that one half of the balancing transformer is effective to induce additional potential in the other half of the transformer winding so as to increase the current into the receiving unit which has not yet fired.

## FIG. 5

In this figure, there is shown an arrangement for supplying four receiving units numbered respectively **22**, **23**, **24** and **25** over a single transmission line **4**. The transmission line **4** is connected to the mid-point of the primary winding **26** of a transformer **27** having secondary windings **28** and **29** mounted on separate legs of the transformer core. The respective end terminals of the primary winding **26** are connected to the mid-points of the secondary windings **28** and **29**. The receiving units **22** and **23** are connected to the end terminals of winding **28**, and the receiving units **24** and **25** are connected to the respective end terminals of the winding **29**.

The transformer **27** acts in the same manner as the balancing transformer **19** to balance the load currents between the two groups of receiving units **22** and **23** on the one hand and **24** and **25** on the other hand. Furthermore, it acts to balance the load currents between receiving unit **22** and receiving unit **23** and also between receiving unit **24** and receiving unit **25**.

Flux induced in the transformer core by primary winding **26** has two parallel paths, one through winding **28** and one through winding **29**. If either secondary winding **28** or secondary winding **29** is heavily loaded, as when the initiators fire, the other parallel path remains effective to energize the unloaded secondary winding.

The transformers **19** and **27** of FIGS. 4 and 5 act as inductive loads on the transmission line in the same manner as the winding **11** of FIG. 2.

There is shown in FIG. 5A, a transformer **27*a*** corresponding to the transformer **27** but having a somewhat different core structure. The center leg of the core on which the winding **26** is wound actually consists of two separate cores spaced apart by an air gap. The winding **28** is wound on one of the two cores and the winding **29** on the other.

A plurality of loads may be connected to a single source in multiples of two, as shown in FIGS. 4 and 5. In the case of an odd number of loads, one half of one of the transformer windings such as **28** or **29**, may be left open without affecting the operation of the system.

Although the circuits of FIGS. 4 and 5 are shown with the grounded transmission line of FIG. 1, they may be used with equal facility with the balanced and shielded transmission line of FIG. 3.

## FIG. 6

Another possible method of connecting two receiving units to the same transmission line is illustrated in this figure. One of the receiving units is connected to the transmission line **4** through an inductor **30** and the other receiving unit is connected to the transmission line **4** through an inductor **31**.

While this arrangement will effectively divide the load between the two receiving units, it does not have the effect of providing additional triggering voltage to a receiving unit which may be lagging.

## FIG. 7

This figure shows a circuit similar to that of FIG. 3. This circuit differs from FIG. 3 in that the details of the circuits in the charge generator **1** are shown. The charge generator **1** includes an oscillator generally indicated at **32** supplied from battery **1*a*** through a voltage regulator **33**. The voltage regulator is controlled by a feed-back from the potential across the capacitor **8**. In this modification, capacitor **8**, instead of being normally discharged, is maintained nearly at the breakdown potential of the gap **9**. Thus the trigger pulse from transformer **13** required to break down the gap and initiate the explosion is reduced in magnitude as compared to the trigger pulse required in FIG. 3 and the other modifications. Consequently, the time required between the application of the trigger pulse to the transformer **13** and the initiation of the explosion may be substantially reduced in this figure below the time required in the other figures.

The voltage regulator **33** comprises a transistor **34** having a collector **34*c***, an emitter **34*e*** and a base **34*b***. Collector **34*c*** is connected to the positive terminal of battery **1*a***. Base **34*b*** is connected through a resistor **35** to the grounded negative terminal of battery **1*a***. Emitter **34*e*** is connected to oscillator **32** at the center tap of a winding **36** on a feed-back transformer **37**.

The oscillator **32** includes two transistors **38** and **39** having emitters **38*e***, **39*e***, bases **38*b***, **39*b*** and collectors **38*c***, **39*c***, respectively. The collectors **38*c*** and **39*c*** are connected to the opposite end terminals of primary winding **36** of the feed-back transformer **37**. Feed-back transformer **37** has a secondary winding **40** whose opposite end terminals are connected to the bases **38*b***, **39*b*** of transistors **38** and **39**. The emitters **38*e*** and **39*e*** are connected to the opposite end terminals of a primary winding **41** of an output transformer **42**. Primary winding **41** has a midpoint connected to the midpoint of the secondary winding **40** of the feed-back transformer and through a wire **43** to ground.

The output transformer **42** has a secondary winding **44**. A capacitor **45** and a diode **46** are connected in series across the secondary winding **44**. A diode **47** has its anode connected to the junction between the capacitor **45** and the cathode of diode **46**. The anode of diode **46** is connected to conductor **17**. The cathode of diode **47** is connected to the other conductor **16** of the transmission line **12**.

A bleeder resistor **48**, which may be several megohms, is connected across the capacitor **8**. A movable tap **48*a*** on the resistor **48** is connected to an amplifier **49**. The output of the amplifier **49** is impressed across the resistor **35** in series with the base **34*b*** of transistor **33**.

## OPERATION OF FIG. 7

The oscillator **32** produces a square wave output which is impressed on the terminals of the primary winding **41**. The oscillator **32** is essentially a relaxation oscillator. The core of the feed-back transformer **37** is of material having a substantially rectangular hysteresis loop. Consider that the current through the transistor **38** is zero and increasing in the positive sense. As the current increases no change in flux in the core of transformer **37** takes place until the current reaches a corner of the rectangular loop. Beginning at that time, the flux reverses rapidly and at a rate of change which is substantially constant. Because of this constant rate of change the potential induced in the secondary winding **40** is substantially flat-topped, i.e., it is a square wave. When the flux in the core of transformer **37** reaches a point where the core is saturated, no potential is induced in the secondary winding **40**. Consequently, the input current to the transistors is cut off and the output current falls off, rapidly reversing due to the collapse of the magnetic field in the transformer **37** and inducing a potential in the secondary winding **40** in the opposite sense. The square wave in the windings of transformer **37** controls the output wave form. The transformer **42** has closely coupled windings and does not saturate, so that it has little effect on the wave form. The current in the windings of transformer **37** is determined chiefly by the load on the secondary winding **44** and is substantially constant during each half cycle.

During the half wave when the upper terminal of secondary winding **44** is negative, current flows from that winding through the diode **46** and charges the capacitor **45** with its right hand terminal positive. The winding **44** and capacitor **45** together act as a voltage doubler, to develop across that capacitor a transient inverse potential equal to twice the applied potential. During the opposite half waves, current flow through the diode **46** is blocked but the current can flow from winding **44** and capacitor **45**, which now act as potential sources in series aiding, through diode **47** and the transmission line **12**, thereby charging capacitor **8**.

A proportion of the potential on capacitor **8** is fed back at a low potential and substantially zero current to the amplifier **49** whose output is impressed across the resistor **35**. The potential across resistor **35** controls the current flow from battery **1*a*** through transistor **34** and thereby determines the amplitude of the oscillations of the oscillator **32**. The circuit is effective to maintain the charge on capacitor 8 at a potential determined by the setting of tap **48a** on resistor **48**.

The discharge of capacitor **8** through gap **9** and initiator **10** is controlled by a trigger signal through transformer **13**, as described above in connection with FIGS. 1 and 3.

FIG. 8

This figure illustrates an exploding bridge wire initiator typical of the prior art, and such a device may be used as the initiator **10** in any of the circuits of FIGS. 1 to 7. It consists of a wire **50** of material having a high temperature coefficient of resistance, bridging a gap between two support wires **51**, **52**. The wire **50** may be welded or soldered to the support wires. The wires **51**, **52** pass through and are supported by an insulating block **53**. Upon subjection to an electrical impulse of predetermined energy, the wire **50** vaporizes, producing heat and a shock wave in its immediate vicinity.

FIG. 9

This figure illustrates a modified form of initiator device, with which the initiator systems described above may be used. This initiator is described in greater detail and claimed in a copending application for United States Letters Patent of John V. McNulty, Louis I. Knudson and Edward L. Mooney, Serial No. 71,650, filed November 25, 1960, entitled "Initiator Devices," now Patent No. 3,196,042.

The initiator of FIG. 9 includes a hollow cylindrical metal shell **60**, open at its left-hand end and having an inwardly projecting flange opening **60a** at its right-hand end defining a central opening **60b**. An annular member **61** of semiconductive material, for example, ferrite, is inserted through the open end of the shell **60** and abuts the flange **60a**, with the central opening of the annular member **61** aligned with the opening **60b**. An electrode **62** having an enlarged head **62a** extends axially of the shell **60**, with the head **62a** inside the central opening in the annular semiconductive member **61**, but with its end spaced from the flange **60a**. An insulating member **63**, of ceramic material, is inserted through the open end of the shell **60** and abuts against the annular member **61** and head **62a**. The several parts may be held firmly together by appropriate bonding material.

It may be seen that the initiator of FIG. 9 provides a gap between the head **62a** of the electrode **62** and the flange **60a** on the metal shell **60**, which serves as the other electrode of the gap. The gap is defined on one side by the inner surface of the annular semiconductive member **61**.

The initiator of FIG. 9 may have its gap end immersed in a solid, explosive material which it is desired to ignite or detonate. When an appropriate potential is applied across the electrodes, the gap first breaks down along the surface of the semiconductive member **61**. After that initial breakdown, a typical spark discharge occurs between the two electrodes. The spark discharge is accompanied by production of substantial heat and by a substantial shock wave in the explosive material, resulting in the initiation of combustion or explosion, depending upon the nature of the material in which it is immersed.

The semiconductor initiator of FIG. 9 has a substantial advantage over the bridge wire initiator of FIG. 8, in that the semiconductor initiator can be tested with a full scale spark discharge without destroying its effectiveness. When the bridge wire type of initiator is tested with full scale energization, the bridge wire is destroyed, and it thereafter cannot initiate an explosion. The semiconductor initiator of FIG. 9 is consequently much more reliable and dependable than the bridge wire initiator shown in FIG. 8.

The pulse forming systems described above for energizing initiators may use either the bridge wire type of initiator shown in FIG. 8 or the semiconductor initiator of FIG. 9. Other suitable types of semiconductor initiators are disclosed and claimed in the copending application of McNulty, Knudson and Mooney, Serial No. 71,650, referred to above.



We claim:

**1.** Apparatus for transmitting an electrical impulse having a steep wave front, comprising a source of electrical energy, a plurality of load devices located remotely from the source, a plurality of receiving units, one for each load device, each receiving unit comprising a capacitor and an enclosed gap connected in series with the associated load device across the capacitor terminals, and inductance means connected between the respective receiving units and the receiving end of the transmission line.

**2.** Apparatus as defined in claim **1**, in which said inductance means comprises a transformer winding having a center tap, means connecting the center tap to the receiving end of the transmission line, and means connecting the end terminals of the transformer winding to two of said receiving units.

**3.** Apparatus as defined in claim **1**, including at least four load devices, said inductance means comprising a transformer having a core with three magnetically parallel legs, a primary winding on one of the three legs having a center tap and two end terminals, secondary windings on each of the other two legs, each having a center tap and two end terminals, means connecting the center tap on the primary winding to the receiving end of the transmission line, means connecting the end terminals of the primary winding to the respective center taps of the secondary windings, and means connecting the end terminals of the secondary windings to the respective load devices.

**4.** Apparatus as defined in claim **3**, wherein the one core leg carrying the primary winding is longitudinally separated into two leg portions by an air gap, and each of said portions is connected in a magnetic circuit with one only of said other two legs.

**5.** Apparatus for transmitting an electrical pulse having a steep wave front, comprising a load, a receiving unit including said load, a first source of electrical energy, a transmission line extending between said first source and the receiving unit, a second source of electrical energy, a transformer having a secondary winding connected in series with the transmission line and a primary winding connected to the second source of electrical energy, said receiving unit comprising a capacitor connected across the line, a sealed gap connected in series with the load, means connecting the gap and load in parallel with the capacitor, and feedback means for controlling said first source of electrical energy to maintain said capacitor at a constant potential, said capacitor being chargeable above said constant potential through the line by said second source of electrical energy until the breakdown potential of the gap is reached, whereupon the gap breaks down and a steep pulse of electrical energy is delivered to the load.

**6.** Apparatus for transmitting an electrical impulse having a steep wave front, comprising a source of electrical energy, a load located remotely from the source, a receiving unit including said load, an elongated transmission line extending between the source and the receiving unit; said receiving unit comprising a capacitor connected across the line, and an enclosed gap with a predetermined breakdown potential connected in series with the load across the line, said capacitor being chargeable only through the line until the breakdown potential of the gap is reached, whereupon the gap breaks down and a steep front pulse of electrical energy is delivered to the load; said transmission line including an inductive element coordinated with the distributed inductance, resistance, and capacitance of the line and the capacitance of the capacitor in the receiving unit so as to produce a voltage increasing effect at the load, said inductive element comprising a transformer secondary winding; and said source of electrical energy comprising a second capacitor, means for charging said second capacitor, a second enclosed gap connecting the second capacitor to the transmission line and having a breakdown potential greater than the potential of the charging means, a primary winding coupled to the secondary winding, and means for supplying to the primary winding an electrical pulse effective when translated to the secondary winding to produce therein a potential effective to break down said second enclosed gap, whereupon said second capacitor discharges through said second gap and said transmission line.

7. Apparatus for transmitting an electrical impulse having a steep wave front, comprising a source of electrical energy, a load located remotely from the source, a receiving unit including said load, an elongated transmission line extending between the source and the receiving unit, said receiving unit comprising a capacitor connected across the line, and an enclosed gap with a predetermined breakdown potential connected in series with the load across the line, said capacitor being chargeable



only through the line until the breakdown potential of the gap is reached, whereupon the gap breaks down and a steep front pulse of electrical energy is delivered to the load; and said transmission line comprising two conductors, a grounded conducting shield encircling said two conductors, and means insulating the conductors from each other and from the shield, whereby the two conductors are at the same potential with respect to ground.


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