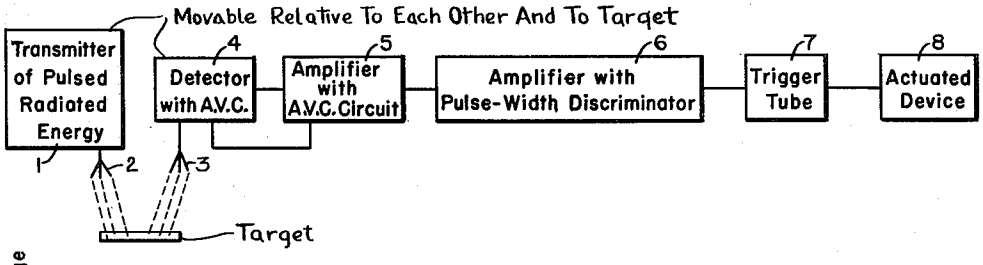
Dec. 19, 1961 A. A. MACDONALD 3,014,215

ELECTRONIC CONTROL SYSTEM

Filed Nov. 19, 1945

Fig.1.



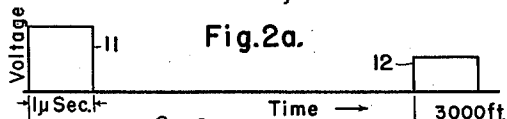


Fig.2a.

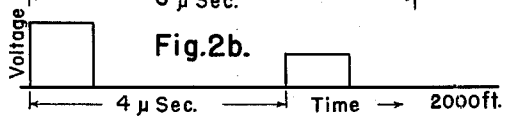


Fig.2b.

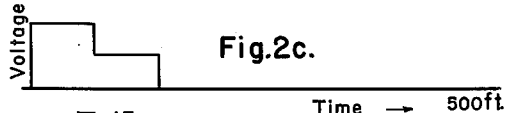


Fig.2c.

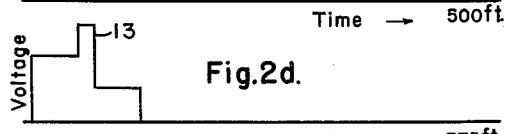


Fig.2d.

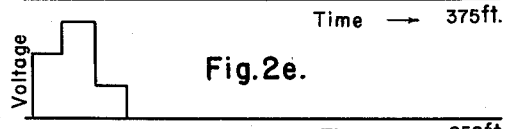


Fig.2e.

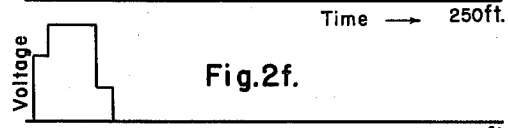


Fig.2f.

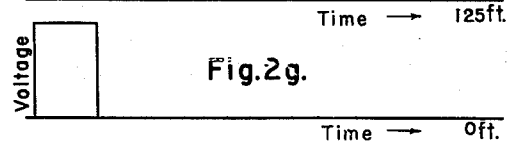


Fig.2g.

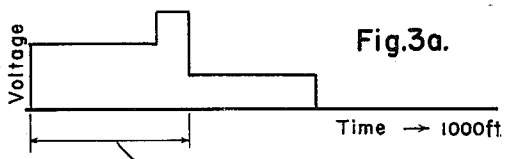


Fig.3a.

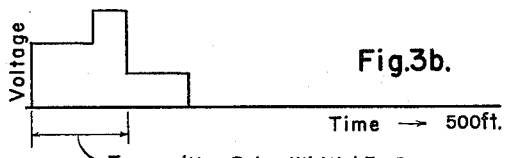


Fig.3b.

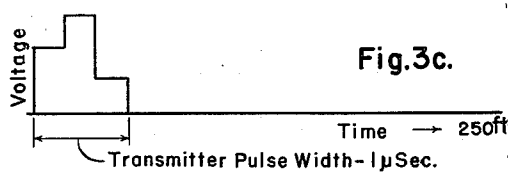


Fig.3c.

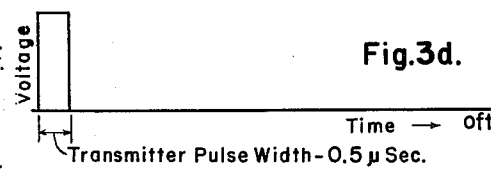


Fig.3d.

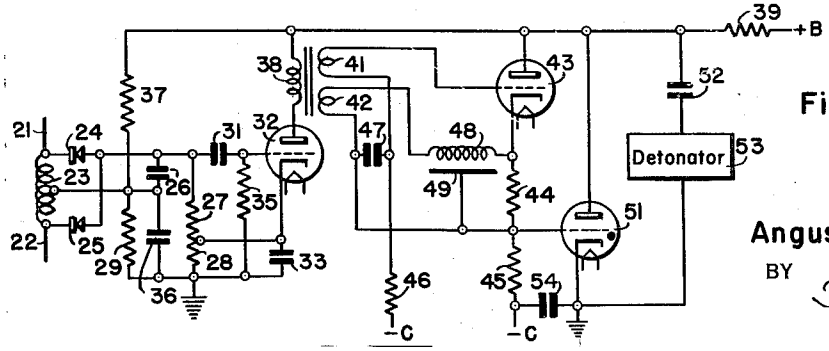


Fig.4.

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ELECTRONIC CONTROL SYSTEM

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Filed Nov. 19, 1945, Ser. No. 629,658
6 Claims. (Cl. 343—17.1)

My invention relates to radio control systems and in particular relates to such systems in which a work circuit or control device is to be actuated upon a moving vehicle or other object when the distance separating the latter from a reflecting body reaches a certain value. For example, my control system is adapted to detonate bombs when they have approached to within a predetermined distance of a target.

One of the novel features of my invention is that it employs circuits which are energized only when electric pulses of a predetermined duration are impressed upon them to control the position at which the work circuit, such as a bomb detonator, will be activated. One of the advantages of such a device is that its actuation is, over a large range of values, independent of variations in the intensity of the radio waves acting upon it and also that it is comparatively unaffected by substantial changes in the electrical characteristics of electron tubes employed in the system. It thereby avoids certain defects characteristic of other arrangements for controlling detonating operations and the like by means of reflected electromagnetic waves.

One object of my invention is accordingly to provide a system employing reflected wave pulses separated from each other by intervals long compared with the pulse duration for controlling work circuits by a system which is to a large degree independent of variations in intensity of the transmitted or reflected pulses.

Another object of my invention is to provide a system in which reflected wave pulses control a work circuit in response to energization thereof for the critical time period only.

A further object of my invention is to provide a system employing intermittent radio pulses and their reflections from a target to actuate work circuits when a moving body has attained a predetermined distance from said target and in which the actuation is controlled in response to the duration of the recurrent pulses.

Still another object of my invention is to provide a system in which the work circuit is controlled by the interfering action of pulsed radio waves and in which the control of the work circuit is responsive to a predetermined overlap in time between the transmitted and reflected waves incident upon the body.

A still further object of my invention is to provide a system in which pulsed radio waves are reflected from a target and are received by a control circuit on the body approaching the target in which the distance from the target at which the control circuit is actuated is varied by varying the duration of the transmitted pulses.

Other objects of my invention will become apparent upon reading the following description taken in connection with the drawing, in which:

FIGURE 1 is a block diagram showing the main components of a circuit employed in carrying out the principles of my invention;

FIGS. 2*a* to 2*g* inclusive are a series of curves showing the electric pulses and their effect on the receiving circuit embodied in my invention;

FIGS. 3*a* to 3*d* inclusive are a graph showing the effect of varying the duration of the electric wave pulses incident upon the receiving device embodying my invention; and

FIG. 4 is a circuit diagram illustrating one suitable

form of receiver for employing the system of my invention.

Referring in detail to FIG. 1, a transmitter **1** of the type well known today in the radio art, which is adapted to send out pulses of electromagnetic waves separated from each other by intervals large compared with the duration of the separate pulses, is positioned together with a radiating antenna **2** on a vehicle or other support from which it is desired to control the actuation of a work circuit positioned upon a vehicle or other device moving relative to said support. For example, where it is desired to control the point at which a bomb dropped by an airplane shall detonate, the transmitter **1** is located on the airplane. Since transmitters for generating intermittent pulses of high frequency waves are well known in the art, it is not believed necessary to explain the circuits of the transmitter **1** in detail here.

On the moving body, e.g., the bomb, which it is desired to control, is positioned an antenna **3** adapted to received radiations from the transmitter **1** and also radiations reflected from a third body such as a target. The antenna **3** controls a detector **4** which is arranged for automatic volume control by the circuits of an amplifier in an automatic control device **5** fed from the output of the detector. Numerous types of detectors and amplifiers embodying automatic volume control are known in the art, and a particular type which now seems to me well suited for the purposes of this invention is shown in detail in FIG. 4. The output of the amplifier **5** is fed to a second amplifier **6** which is provided with a circuit adapted to cause a marked change of current flow in its output in response to the transmission from the amplifier **5** of a current pulse of at least a predetermined duration. That is to say, current pulses from the output of amplifier **5** having a length substantially less than said predetermined value, leave unchanged the current magnitude in the output of the amplifier **6**. The amplifier **6** may be referred to as embodying a pulse-width discriminator and such a discriminator is described in detail in FIG. 4.

The output of the amplifier **6** is supplied to a trigger tube **7** of which many types are well known in the art, one such being shown in FIG. 4 hereof, and causes energization of the output circuit of said trigger tube in response to the above mentioned substantial change in the output current of amplifier **6**. The output circuit of the trigger tube **7** actuates any desired control device **8**; for example, the detonator of a bomb on which the elements **3** through **8** are carried.

Referring to FIG. 2, the antenna **3** will, in general, receive a pulse of energy from transmitter **1** each time the latter emits a pulse; and will also, an instant later, receive a second pulse comprising the energy reflected from the target when struck by the emitted pulse just mentioned. In this figure, **11** represents the envelope of the pulse received directly from the transmitter **1** by the antenna **3** carried on the bomb or moving object, and **12** represents the envelope of the wave pulse received by that same antenna as a result of the reflection from the target of the pulse producing envelope **11**. When the bomb or moving object is 3000 feet distant from the target, as will be seen from FIG. 2*a*, the pulse **12** does not occur in the antenna **3** until about 6 microseconds after the pulse **11**.

In FIG. 2*b*, the pulses **11** and **12** have the same significance as the corresponding number of pulses in FIG. 2*a* and represent conditions when the bomb or moving object is 2000 feet distant from the target. It will be seen by comparing FIGS. 2*a* and 2*b* that the time separating pulses **11** and **12** decreases in proportion to the distance separating the moving body and the target.

FIG. 2*c* represents the pulses **11** and **12** and shows that when the moving body is separated from the target

by 500 feet, the pulse **12** follows the pulse **11** without a break.

FIG. 2*d* represents the effect of the pulses **11** and **12** when the distance separating the body from the target has been reduced to 375 feet and shows that the two pulses overlap to produce a portion **13** having an amplitude equal to the sum of the amplitudes of the pulses **11** and **12**.

FIGS. 2*e* and 2*f* represent, respectively, the pulses **11** and **12** when the distances separating the body from the target are 250 feet and 125 feet, and it is evident from them that the overlap **13** increases in width as the distance separating the body from the target decreases.

Finally, FIG. 2*g* shows that when the distance separating the target from the body is reduced to zero, the pulses **11** and **12** overlap completely, coalescing to form by their overlap a single rectangular wave form.

In accordance with one feature of my invention, I cause the trigger tube **7** to be actuated only when the overlap **13** has a predetermined duration. By reason of the fact that the detector **4** and amplifier **5** are provided with automatic valume control the output of the amplifier **5** is unaffected over a wide range, by variations from time to time in the amplitude of the pulses **11** and **12**; however, in accordance with the well known properties of automatic volume control circuits, the output current of the amplifier **5** responds to the comparatively short-time fluctuations of energy represented by the overlap **13**. Thus the automatic volume control prevents the amplitude of the output-pulses from amplifier **5** from varying with distance of the target from the transmitter or from the receiver antenna **3**. Interference beating between the direct and reflected radio waves at the receiver may be rendered unimportant by making the pulse repetition rate at least several times this beat frequency.

It will be noted that a circuit may be embodied in the amplifier **6** which will cause the output current of the latter to vary only in response to an overlap **13** of a given width. For example, the output circuit of the amplifier **6** may be constructed to fluctuate only in response to the pulse width represented by the overlap **13** in FIG. 2*e*. Under such conditions there would be no energization of the trigger tube **7** while the moving body was separated from the target by the 3000 feet represented in FIG. 2*a* because there would be no overlap between the pulses. Similar statements apply to the 2000 feet distance and the 500 feet distance covered, respectively, by FIGS. 2*b* and 2*e*. While there would be an overlap in the 375 feet distance represented by FIG. 2*d*, the overlap would be too short to cause fluctuation of the output current of amplifier **6** inasmuch as the latter is arranged to fluctuate only in response to an overlap of the length of **13** in FIG. 2*e*.

When, however, the moving body had reached the 250 feet distance represented by FIG. 2*e*, the overlap of the right duration would be present on the input circuit to amplifier **6**; trigger tube **7** would be energized and the actuated device **8**, for example, the bomb detonator, would be actuated.

It will be noted from the observation of FIGS. 2*d*, 2*e*, 2*f* and 2*g* that the time interval separating the front (i.e. left-hand) edge of pulse **11** from the front edge of overlap **13** is proportional to the distance separating the moving body from the target. If now the duration of the pulse **11** is increased (i.e. pulses **11** and **12** become wider in FIG. 2), but the amplifier **6** remains unaltered so that it produces a current pulse in its output circuit only in response to overlap of the width shown in FIG. 2*e*, the distance between the body and the target at which the trigger tube **7** will be energized will still be proportional to the time separating the front edge of pulse **11** from the front edge of pulse **13**. From this it follows that the distance separating the body from the target at which trigger tube **7** is energized can be varied at will by varying the duration of the pulses from transmitter **1**. In particular by reducing the length of the transmitted pulses **11** to equality with the critical value of the overlap pulse **13** at which the amplifier **6** produces a current fluctuation in its output circuit, the distance separating the moving body from the target when the trigger **7** is actuated can be reduced to zero.

The foregoing relationships between pulse width and distance from the target at which the overlap **13** attains the predetermined critical value are illustrated in FIGS. 3*a* to 3*d* inclusive. These figures cover operation with the trigger tube **7** becoming energized by an overlap **13** of one-half a microsecond. FIG. 3*a* shows a transmitter pulse duration of 2.5 microseconds and represents conditions at which the pulse **11** and the pulse **13** would have an overlap just sufficient to energize trigger tube **7**, i.e. an overlap equal to one-half a microsecond. The distance separating the body from the target under the conditions represented by FIG. 3*a* would be approximately 1000 feet. Hence, at 1000 feet separating the body from the target, the actuated device **8** would be operated by transmitting from the transmitter **1** a pulse having a width of 2.5 microseconds.

If now the transmitted pulse duration is decreased to one and one-half microseconds, the conditions in antenna **3**, when the overlap is one-half a microsecond, are represented by FIG. 3*b*. Since the trigger tube is actuated when such a one-half microsecond overlap occurs and the distance separating the moving body from the target at which the pulses **11** and **12** overlap by a one-half microsecond is 500 feet, it is obvious that the actuated device **8** will be operated at 500 feet distance by reducing the intermediate pulse with to one and one-half microseconds.

FIG. 3*c* corresponds to a pulse width of one microsecond with a one-half microsecond overlap, and represents conditions occurring when the separation between the target and the moving body is 250 feet.

FIG. 3*d* represents conditions existing at the receiver when the transmitter pulse is reduced to one-half a microsecond and is correspondingly equal to the critical overlap. Such overlap occurs when the distance separating the target from the moving body is zero.

Turning now to FIG. 4, the latter represents one form of receiver circuit which I believed to be well adapted to carry out the principles of my invention, as above outlined. A receiving antenna **21**, **22**, which may be a dipole or other type suited to the wave length employed, is carried by the bomb or other moving body and energizes an inductive winding **23** having the similar electrodes of a pair of rectifiers **24**, **25** connected to its opposite ends. The remaining terminals of the rectifiers **24**, **25** are respectively connected to one terminal of a capacitor **26** having its other terminal connected to the midpoint of the winding **23**. It will be seen that the winding **23** and rectifiers **24** and **25** will charge the capacitor **26** to a potential proportional to the amplitude of the radio waves incident upon the antenna **21**, **22**. The terminals of capacitor **26** are bridged by three serially connected resistors **27**, **28** and **29**, which are of suitable value so that the members **23**, **24**, **25**, **26**, **27**, **28** and **29** constitute a detector producing current pulses in resistor **27** corresponding in wave form to the envelope of the above mentioned pulses of radio waves. One terminal of the resistor **27** is connected through a capacitor **31** to the control electrode of a suitable electron discharge amplifier tube **32**, the cathode of which is connected to the other terminal of the resistor **27**. The cathode of the tube **32** is likewise connected through a condenser **33** to the terminal of the resistor **28** which is remote from resistor **27**, and a resistor **35** connects the control electrode of tube **32** to that same terminal. A capacitor **36** shunts the terminals of the resistor **29**, and a resistor **37** connects the midtap of the winding **23** with the anode circuit of the tube **32**.

The anode of the tube **32** is connected through the primary winding **38** of a transformer and a resistor **39** to the positive terminal of a direct current source having its nega-

tive terminal connected via ground to the common terminals of resistors 28 and 29.

The connections of the tube 32 thus described constitute it a combined amplifier and automatic volume control device for signals incident upon the antenna 21, 22. An automatic control voltage is developed across the resistor 28 and capacitor 33 and is impressed both upon the tube 32 and upon the detector comprising rectifiers 24, 25 and capacitor 26. The resistors 29 and 37 are so proportioned as to produce a potential drop in resistor 29 equal and opposite to that produced in resistor 28 when no signal is impressed on the control circuit of tube 32. As a result of this arrangement, the detector comprising rectifiers 24, 25 and capacitor 26 remains unbiased when no signal is being received by the antenna 21, 22. The output voltage of the detector appears across the resistor 27 and is impressed thereby on the tube 32.

Associated with the winding 38 to constitute an efficient pulse transformer are a pair of windings 41, 42. The winding 41 has one terminal connected to the control electrode of an electron discharge tube 43 of a type suitable to amplify high frequency pulses and having its anode connected to receive current through the above mentioned resistor 39. The cathode of the tube 43 is connected through a resistor 44 in series with a second resistor 45 to the negative terminal of a suitable direct current voltage source having its positive terminal grounded. The other terminal of the winding 41 is connected through a resistor 46 to the negative terminal of another direct current voltage source having its positive terminal connected to ground.

One terminal of the winding 42 is connected to the common terminal of resistors 44 and 45 and also through a pulse by-pass capacitor 47 to the last mentioned terminal of the winding 41. The other terminal of winding 42 is connected through a distributed inductance 48 to the cathode of the tube 43. The distributed inductance 48 is associated with a similarly distributed capacitance 49 which is connected to the common terminal of the resistors 44 and 45.

The elements 48, 49 constitute a well known type of time delay circuit which produces a voltage at its output terminal of substantially similar wave form to that impressed on its input terminal but delayed by a predetermined time interval with reference thereto.

The common terminal of the resistors 44 and 45 is connected to the control electrode of a gaseous electric discharge tube 51 having its anode connected to receive current through the resistor 39 or alternatively to the positive terminal of another direct current voltage source having its negative terminal grounded. Tube 51 has its cathode grounded. A capacitor 52 connected in series with an actuated device or work circuit 53, which may, for example, be the control of a bomb detonator, is bridged between the anode and cathode of the tube 51. A pulse by-pass capacitor 54 grounds the negative terminal of the resistor 45.

The elements 21 through 42 above mentioned correspond to the antenna 3 and detector 4 in FIG. 1; the elements 43 through 49 in FIG. 4 correspond to the amplifier and pulse width discriminator 6 of FIG. 1; the tube 51 corresponds to the trigger tube 7 of FIG. 1; and the detonator 53 corresponds to the actuated device 8 of FIG. 1.

The resistor 28 and the remaining elements energizing tube 32 are initially given such values that in the absence of energy incident upon the antenna 21, 23, the tube 32 is biased nearly to cut off; and the values of the potential impressed through resistor 46 on tube 43 and through resistor 45 on tube 51 are made such that tubes 43 and 51 are biased below cutoff.

The operation of the arrangement just described is believed to be as follows. When a wave pulse is incident upon the antenna 21, 22 from transmitter 1 a voltage pulse corresponding in form to the envelope of said incident pulse is impressed by winding 41 upon tube 43. However, the volume control for the detector 24, 25 and amplifier 32 is so adjusted that the pulse impressed on tube 43 by winding 41 is insufficient to overcome the negative bias impressed through resistor 46 to a sufficient degree to render the tube 43 conductive.

The above mentioned incidence of a pulse on antenna 21, 22 will likewise impress a voltage across the resistor 44 in the cathode circuit of tube 43, but this pulse will be delayed relative to the pulse impressed on tube 44 by winding 41 in virtue of the action of the time delay device 48, 49; hence, the voltage pulses respectively impressed on the control electrode of tube 43 will not occur simultaneously and neither alone will suffice to render trigger tube 43 conductive.

It will however be evident that the reflection from the target of the above-mentioned pulse emitted from transmitter 1 will cause tube 32 to impress a pair of successive voltage pulses through windings 42 and 41 on tube 43; but this reflected pulse will follow the directly-incident pulse already mentioned by a time interval sufficient for radio waves to travel from antenna 3 to the target and back. The adjustment of the amplifier 32 will again be such that this pulse will of itself be insufficient to cause tube 43 to conduct current. Each of these time-separated pulses corresponds to pulse 12 in FIG. 2*a*.

When the timing of pulses 11 and 12 is right the pulses 11 and 12 overlap to form an overlap pulse 13 equal to their sum in amplitude; but tube 43 is so adjusted that even the overlap pulse 13 impressed by winding 41 alone, or by winding 42 alone, does not suffice to make tube 43 conduct. It will be evident that unless the pulse 13 has a duration equal to the time delay interposed by the time delay elements 48, 49, the voltage pulses impressed respectively by the windings 41 and 42 on the tube 43 can never overlap, and accordingly tube 43 will not be rendered conductive when the overlap 13 has a value less than the critical value set by time delay network 48, 49. However, once the overlap 13 exceeds in duration the time-delay due to network 48, 49, the voltage pulse impressed by windings 41 and 42 overlap in time and add their effects thereby rendering tube 43 conductive. Fluctuations in the output current of tube 43 flow through the resistor 45 and capacitor 54 and thereby impress a positive pulse on the control electrode of trigger tube 51 causing the latter to become conductive. The sudden pulse of current in the output circuit of tube 51 energizes detonator 53 through the capacitor 52 to operate the control device.

While I have described specific types of automatic volume control for the detector 24, 25, 26 and amplifier 32, and have described a specific type of time delay network 48, 49 for rendering the amplifier 43 responsive only to pulses of a predetermined duration, there are other types of automatic volume control circuits and time delay networks known to those skilled in the art which may be substituted for the elements I have described in detail in ways evident to those skilled in the art.

I claim as my invention:

1. In combination with a transmitter of pulsed radiant energy, a first body adapted to reflect said energy, a second body movable relative to said first body, means on said second body for receiving radiant energy both from said transmitter and from said first body, a circuit which is responsive to the output of said means for receiving, and means for rendering said circuit unresponsive where there is overlap of less than a predetermined duration in pulses received from said transmitter and said first body but responsive when said overlap is greater than said duration.

2. An arrangement as specified in claim 1 in which said second body carries an explosive which has a detonator controlled by said circuit.

3. In combination with a transmitter of pulsed radiant energy, a first body adapted to reflect said energy, a sec-

ond body movable relative to said first body, means on said second body for receiving radiant energy both from said transmitter and from said first body, a circuit which is responsive to the output of said means for receiving, and means for rendering said circuit unresponsive where there is overlap of less than a predetermined duration in pulses received from said transmitter and said first body but responsive when said overlap is greater than said duration, said transmitter being provided with means for varying the duration of said pulses, in accordance with the will of the operator.

4. An arrangement as specified in claim 3 in which said second body carries an explosive which has a detonator controlled by said circuit.

5. In combination with a transmitter of pulsed radiant energy mounted on a first body, a target, and a second body movable relative to said target and to said first body, means on said second body for receiving radiant energy directed from said transmitter and reflected from said target, a detector which is responsive to the output of said means for receiving and provided with an automatic volume control circuit, amplification means connected to receive the output of said detector, and means for preventing variations in the output current of said amplification means except when direct and reflected radiant energy originating at said transmitter are incident upon said receiving means during an overlap of predetermined duration.

6. In combination a transmitter of pulsed radiant energy mounted on a first body, a target, and a second body movable relative to said target and to said first body, means on said second body for receiving radiant energy directed from said transmitter and reflected from said target, a detector which is responsive to the output of said means for receiving and provided with an automatic volume control circuit, amplification means connected to receive the output of said detector, and means for preventing variations in the output current of said amplification means except when direct and reflected radiant energy originating at said transmitter are incident upon receiving means during an overlap of predetermined duration, said transmitter being provided with means for varying the duration of its output pulses.

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