Oct. 2, 1951 M. A. McLENNAN 2,569,485

AUTOMATIC RANGING SYSTEM

Filed May 27, 1944 3 Sheets-Sheet 1

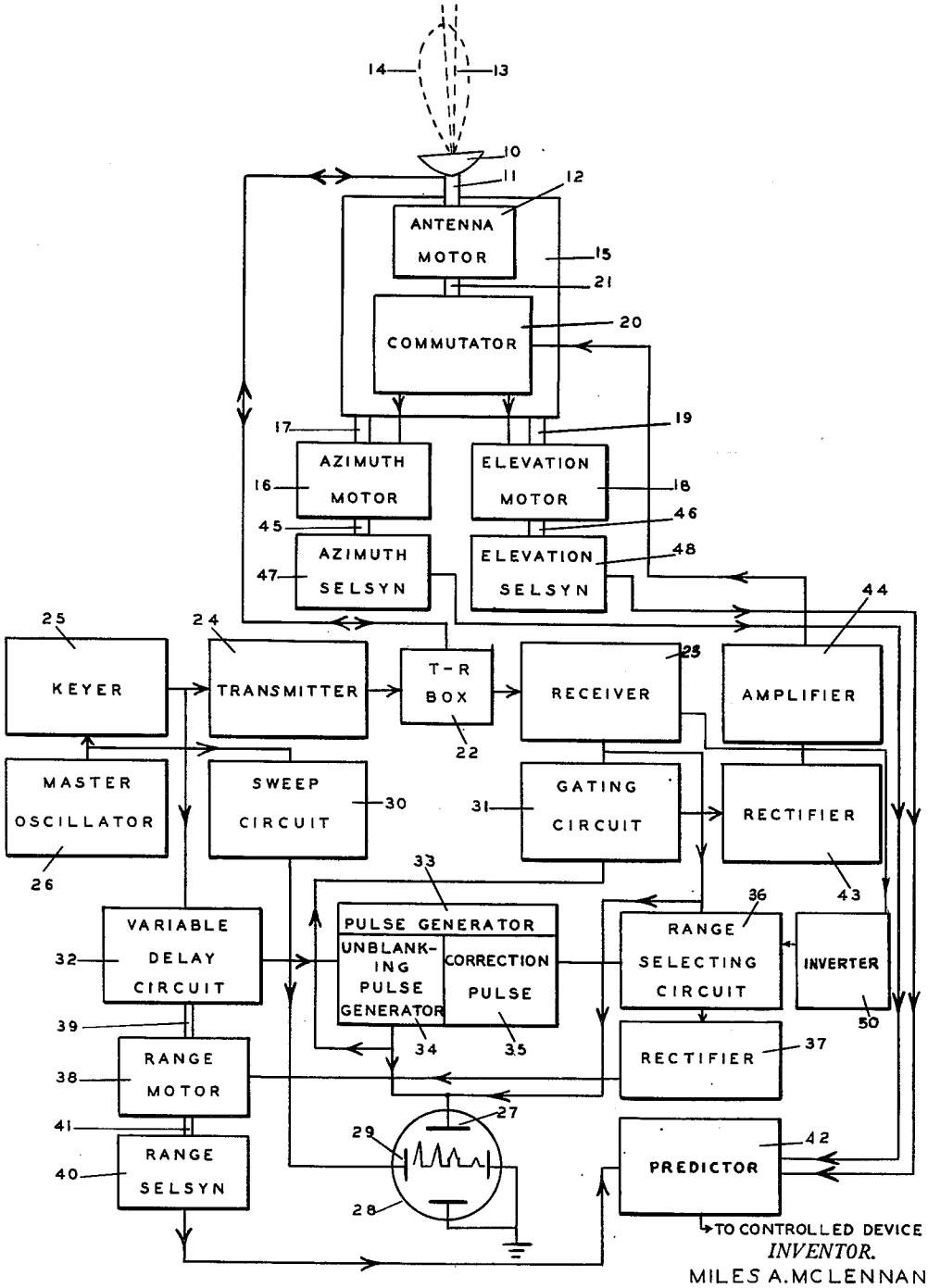


FIG.1

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AUTOMATIC RANGING SYSTEM

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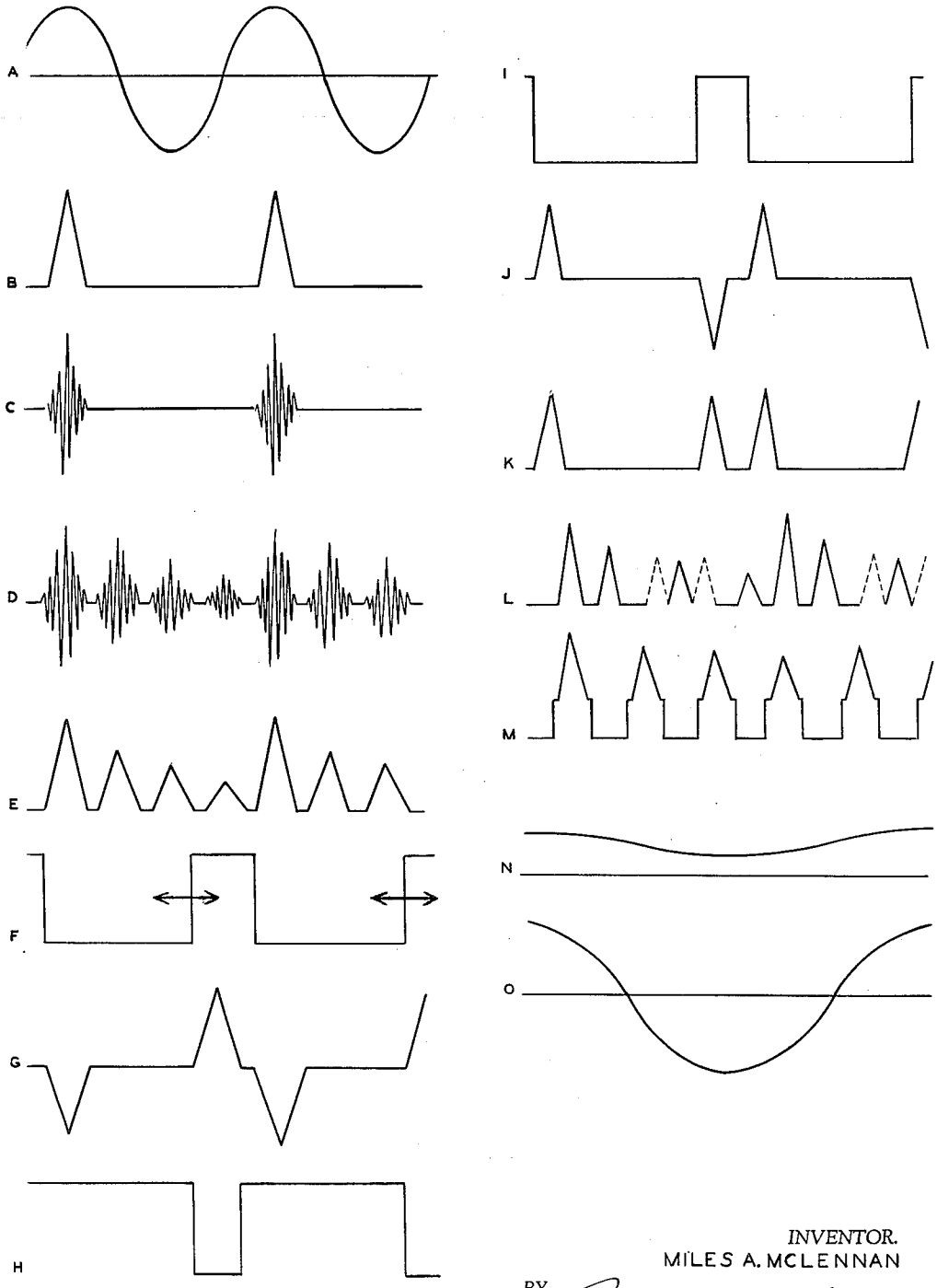


FIG. 2

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Oct. 2, 1951 M. A. McLENNAN 2,569,485

AUTOMATIC RANGING SYSTEM

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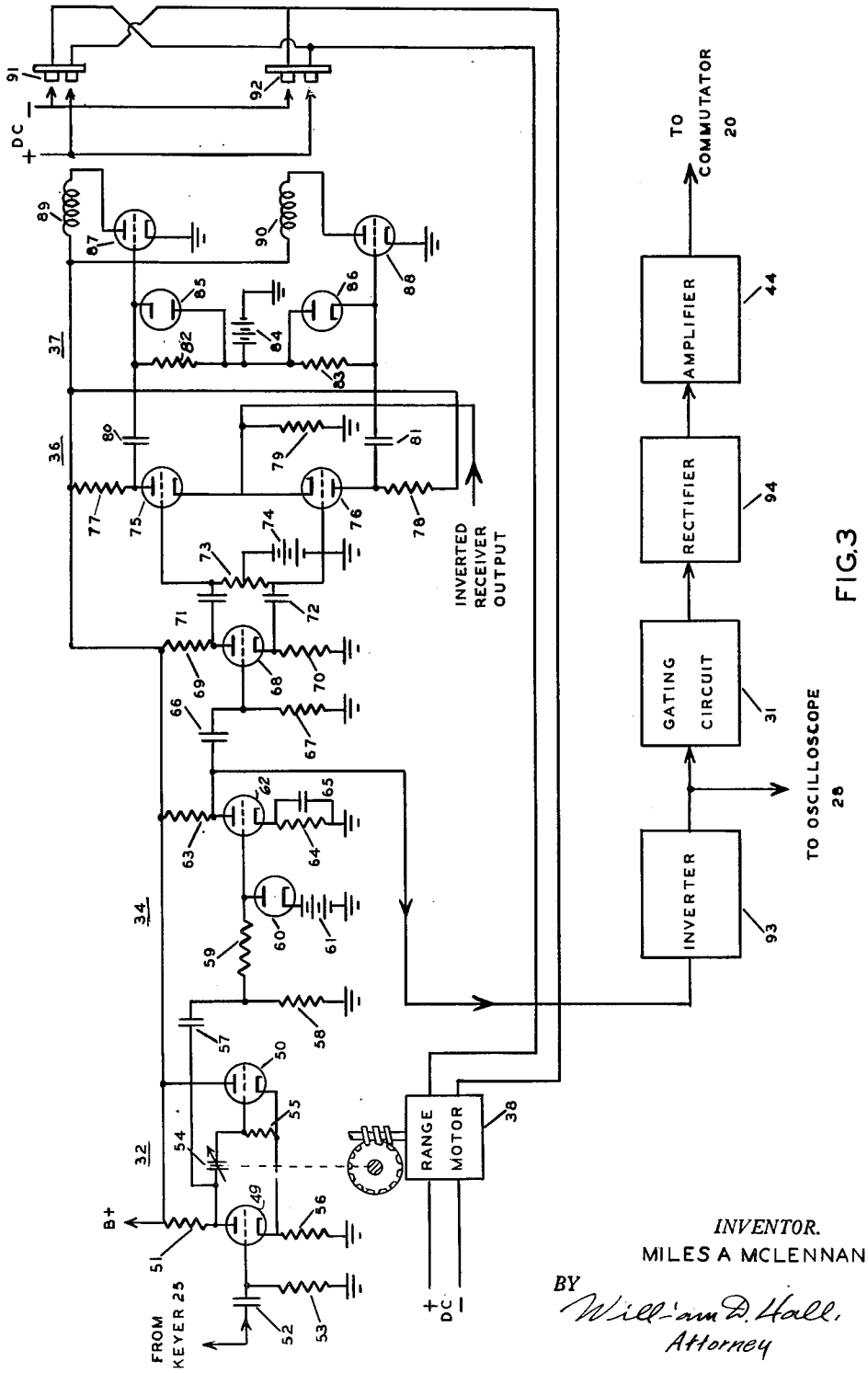


FIG.3

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Patented Oct. 2, 1951

2,569,485

UNITED STATES PATENT OFFICE

2,569,485

AUTOMATIC RANGING SYSTEM

Miles A. McLennan, Detroit, Mich.

Application May 27, 1944, Serial No. 537,670

5 Claims. (Cl. 343—7)

(Granted under the act of March 3, 1883, as amended April 30, 1928; 370 O. G. 757)

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The invention described herein may be manufactured and used by or for the Government for governmental purposes, without the payment to me of any royalty thereon.

My present invention relates to object-locating radio systems, and more particularly, to a pulse-echo radio system for following a moving target, such as an aircraft in flight, whereby equipment, for example, anti-aircraft guns, searchlights, or the like, may be continuously, automatically and accurately laid thereon.

Existing systems for the same general purposes have certain disadvantages attendant thereto. For one thing, they lack the ability to discriminate between targets differing in range but having approximately the same directional coordinates, as a result of which they hunt. In addition, they require unduly complex multiple signal channels which are costly and difficult both initially to construct, and to maintain and service in the field.

It is, therefore, one of the objects of my present invention to provide an automatic, radio tracking and ranging system of the pulse-echo type whereby the movement of a selected target may be followed to the exclusion of all others, thereby eliminating the above referred to hunting associated with existing systems.

It is another object of my present invention generally to improve object-locating systems of the character indicated by eliminating the necessity for multiple signal channels, thereby effecting substantial savings in the initial cost of the equipment, and also greatly reducing the maintenance and service problems connected therewith.

These, and other objects and advantages of my present invention, which will become apparent as the detailed description thereof progresses, are attained in the following manner:

I provide a sharply directional antenna system for radiating into space audio-frequency pulses of radio-frequency energy, the antenna system being so rotated that the beam pattern thereof generates a cone about the axis of rotation. Said antenna system is further provided with means for sweeping the cone so generated horizontally through 360° of azimuth, and independent means for scanning vertically through an appropriate angle of elevation, depending upon the sector desired to be covered.

As is well known, upon the energy radiated as above encountering some conducting object, such as an aircraft, a portion thereof is omnidirectionally reflected or reradiated, the reflections

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or reradiations being known as echoes. A portion of the reflected or reradiated energy is received back at the ground station and there utilized to determine the location in space of the object causing the same. Various means have been developed for this purpose and need not be described in this specification.

I provide an oscilloscope with a linear time base synchronized with the above mentioned pulse transmission, and apply a portion of the originally transmitted energy, and any received echoes thereof, to said oscilloscope whereby the distances separating the deflections of the trace of said time base, corresponding to said original transmission and said echoes thereof, are proportional to the range of each echo-causing object.

I also apply the input to said oscilloscope, as aforesaid, to a gating circuit, whereby the echoes received only from a selected target are passed to the exclusion of all others, and to the exclusion of the originally transmitted energy as well. Now, in order to operate the gating circuit in this manner, I generate, in synchronism with the pulse transmission of the system, a square-wave voltage of variable width, the adjustment of the width of this square-wave voltage providing the time delay, between said pulse transmission and the instant of reception of the echoes from a particular target, necessary to operate the gating circuit for the purposes mentioned. The lagging edge of said square-wave voltage is utilized to generate a pedestal voltage of an amplitude and width slightly in excess of that of the original pulse transmission. This pedestal voltage is inverted to obtain proper polarity, and is applied to the gating circuit, which is normally nonconducting, to open the same long enough to let through only the desired echo signals.

As the target instantaneously under consideration moves with respect to the ground station, altering the range thereof, the echo indication of this target appearing upon the screen of the oscilloscope moves outside the limits of the gate, and it is therefore necessary to alter the time of the opening of the gate with respect to the time of the original pulse transmission in order to continue to follow said target. For this purpose, I differentiate the pedestal voltage generated as above and combine the resulting pulses with the output of the system receiver, with the object of maintaining the echo signals from the selected target disposed intermediate said pulses, the latter being hereinafter referred to as correction

pulses. Under these circumstances, should the selected echo pulses move into coincidence with one or the other of the correction pulses, the above mentioned means for generating the square-wave voltage of variable width, which controls the introduction of the proper time delay between the original transmission and the reception of the echo signals of the particular target, is adjusted to alter the width of said square-wave voltage, whereby the correction pulses are appropriately moved to the right or to the left in order to maintain the selected echoes in their proper relative position with respect to said correction pulses. Thus, a selected target is automatically followed notwithstanding changes in the range thereof.

In order to utilize any correction necessary to maintain the relationship described, the adjustment of the square-wave voltage generator is translated into electrical energy of appropriate amplitude and polarity, which is applied to a predictor or any other preferred mechanism capable of utilizing said energy for controlling, for example, the aiming of a gun, or a searchlight, or any other equipment which it is desired accurately to lay upon the target.

I now return to the antenna system, to describe the manner in which said system is oriented in order to follow the target in azimuth and in elevation. Because of the manner in which said antenna system is mounted with respect to its axis of rotation, causing the radiated beam to generate a cone about said axis of rotation, unless a particular target is aligned with said axis of rotation, the echo signals received therefrom vary in amplitude as the antenna pattern sweeps over the same at a frequency corresponding to the rotation period of the antenna system. The peaks of the varying amplitude output of the gating circuit are therefore rectified and the resulting output, after amplification, is utilized to alter the azimuthal and elevational angles of the axis of rotation of the antenna system until said axis of rotation is "on target." When this condition is attained, the echo pulses received from said target will all be of equal amplitude, no rectified output will be obtained, and the means controlling the azimuthal and elevational angles of the antenna system, and the axis of rotation thereof, will remain inoperative until the "on target" condition is disturbed.

Voltages, of appropriate amplitude and polarity, corresponding to any correction of the azimuthal and/or elevational angles are transmitted to the above mentioned predictor for use in correcting the aim of the controlled equipment and accurately laying the same upon the target.

In the accompanying specification, I shall describe, and in the annexed drawings show, what is at present considered a preferred embodiment of the object-locating system of my present invention. It is, however, to be clearly understood that I do not wish to be limited to the exact details herein shown and described for purposes of illustration only, inasmuch as changes therein may be made without the exercise of invention and within the true spirit and scope of the claims hereto appended.

In said drawings:

Fig. 1 is a block diagram of an automatic tracking and ranging system assembled in accordance with the principles of my present invention;

Fig. 2 shows the wave shapes resulting from the major components of the system shown in Fig. 1; and

Fig. 3 is a circuit diagram of the major components of said system.

Referring now more in detail to the aforesaid preferred embodiment of my present invention, with particular reference to the block diagram of Fig. 1 and the wave shapes shown in Fig. 2, the numeral 10 generally designates any appropriate antenna system for radiating into space a sharply directional beam of electromagnetic energy; for example, a suitable dipole array arranged at the focus of a parabolic reflector.

The antenna system is mounted for rotation upon the shaft 11 of a motor 12, the system being so angularly disposed with respect to said shaft, and the axis of rotation thereof, that, when rotated, the beam pattern 14 generates a cone about said axis of rotation. The antenna system 10 and motor 12 are mounted upon a suitable platform 15 adapted to be rotated, horizontally, through 360° of azimuth, by a motor 16 coupled thereto, as at 17, and vertically, through the angle of elevation intended to be covered by the system, by a motor 18 coupled thereto, as at 19. Also mounted upon the platform 15 is a distributing commutator 20 which is coupled to the antenna motor 12, as at 21, and which is adapted to feed correction voltages, generated as hereinafter described in detail, to the azimuth and elevation motors 16 and 18, in order to adjust the azimuthal and elevational angles of the system to correspond to an "on target" position. Further details of the orienting mechanism for the antenna system are not thought necessary to be described herein inasmuch as the same are adequately disclosed in my abandoned application entitled, "Radiation Directional Indicating Apparatus and Method," Serial No. 433,925, filed March 9, 1942, particularly the embodiments disclosed in Figures 4 and 6 of the drawings of said application.

The energy radiated by the antenna system 10 is fed thereto through a T-R box 22 containing any appropriate protecting circuit to prevent the receiver 23 from being subject to undue shock during the periods when the transmitter 24 is "on the air." The transmitter 24 includes a radio-frequency generator which is normally biased to cut-off and which is periodically keyed into operation by short, sharp voltage pulses generated in a keyer 25 under the control of a master audio-frequency oscillator 26. The frequency of the oscillator 26 depends, in a well-known manner, upon the desired maximum effective range of the locating system. The respective outputs of the oscillator 26 and keyer 25, and the A.-F. pulses of R.-F. energy radiated by the antenna system 10 are shown in Figure 2 (A, B and C).

As already stated, upon the transmitted energy encountering a conducted object, such as an aircraft in space, a portion thereof, in the form of an echo, is reflected or reradiated, and the resulting echo signals are picked up by the antenna system 10 and applied, through the T-R box 22, to the receiver 23. The input to the receiver may, for example, be as shown in Figure 2 (D), which illustrates two of the originally transmitted pulses, each of which is followed by three echo signals originating at three objects at different distances from the ground station.

The received signals are demodulated in the re-

ceiver 23 and the demoduated output, shown in Figure 2 (E), is applied to the vertically deflecting plates of an oscilloscope 28, said oscilloscope having applied to the horizontally deflecting plates 29 thereof a horizontal, linear sweep, generated in a sweep generator 30 under the control of and in synchronism with the output of the master oscillator 26. There therefore appears upon the screen of the oscilloscope 28, at the commencement of the base line thereof, a relatively large deflection corresponding to the transmitted pulses, and along the length thereof, at spaces corresponding to different time intervals, progressively lesser deflections corresponding to echoes received from objects at different distances from the ground station.

In order to select a particular target for tracking to the exclusion of all others whose echo indications may appear upon the oscilloscope screen, I also supply the output of the receiver 23 to a normally nonconducting gating circuit 31 which, in order to pass the desired echo signals, must be rendered periodically conducting for a period of time corresponding to the duration of the transmitted pulse, commencing at a time just in advance of the instant of reception of the desired echo. For this purpose I apply a portion of the output of the keyer 25 to a variable-delay circuit 32 which consists of a slave square-wave voltage generator provided with means for varying the duration of the duty cycle thereof to obtain a negative-going square-wave voltage of controllable width, as shown in Figure 2 (F). This controls the instant at which the gating circuit 31 is opened, but the description of the manner in which this is accomplished will be reserved for a later portion of this specification.

The square-wave voltage obtained as above is applied to a pulse generator 33 consisting of two components 34 and 35, the former for generating an unblanking pulse for opening the gating circuit 31, as aforesaid, and the latter for generating correction pulses for maintaining the proper time relationship between the shifting echo signals, as the target causing the same moves, and the time of operation of said gating circuit. In the unblanking pulse generator 34 the square-wave output of the variable-delay circuit 32 is differentiated, as shown in Figure 2 (G), and the positive-going pulse resulting from the adjustable trailing edge of said square-wave voltage is clipped, shaped and amplified to obtain a rectangular, negative-going voltage, as shown in Figure 2 (H), of an amplitude in excess of that of the transmitted pulse in the output of the receiver 23 and of a width slightly in excess of that of said transmitted pulse. This rectangular voltage is then inverted to obtain a positive-going pedestal voltage, as shown in Figure 2 (I). The pedestal voltage thus obtained is applied to the gating circuit 31 to periodically unblock the same and permit the selected echo signals to pass therethrough. The manner of using these echo signals to control the orientation of the antenna system 10 will be described in a later portion of this specification.

The negative-going voltage of Figure 2 (H), from which the pedestal voltage of Figure 2 (I) was obtained, is applied to the correction pulse generator 35, where it is differentiated, as shown in Figure 2 (J), to obtain correction pulses, as shown in Figure 2 (K), spaced by an interval of time slightly in excess of the width of the transmitted pulse.

These correction pulses are fed to a range-selecting circuit 36 where they are mixed with an

inverted portion of the output of the receiver 23 from inverter 50 to obtain a combined output, as shown in Figure 2 (L), wherein the correction pulses are illustrated in dotted lines, flanking the echo signals of the target it is desired to track.

This combined output is, after passing through a rectifier 37, utilized to operate a range motor 38 coupled, as at 39, to the means for adjusting the width of the square-wave voltage with which the variable-delay circuit 32 is provided. The range-selecting circuit 36 is so designed that if the desired echo signals should coincide with the earlier correction pulses, the range motor 38 is operated to adjust the variable-delay circuit to generate a square-wave voltage of lesser width, thus shifting the correction pulses nearer in time to the originally transmitted pulses. If, on the other hand, the desired echo signals should coincide with the later correction pulses, the range motor 38 operates in reverse to cause generation of a wider square-wave voltage. The tendency, therefore, is to keep the desired echo signals positioned, with respect to time, midway between the correction pulses.

Of course, as the width of the square-wave voltage of the variable-delay circuit becomes altered, so, too, the time of generation of the unblanking pedestal voltage which is applied to the gating circuit 31 becomes altered, always to allow only the desired echo signals to pass therethrough. A portion of the inverted output of the unblanking pulse generator 34 is also applied to the vertically deflecting plates 27 of the oscilloscope 28, so that the operator can select any one of the echo indication appearing upon the screen of said oscilloscope.

In the oscilloscope display illustrated in the drawings, it will be noted that the center echo indication is the one which is set upon the pedestal and is, therefore, to be tracked. In order to permit such selection, the variable-delay circuit 32 is, in addition to being operable by the range motor 38, provided with a manual control for adjusting the width of the square-wave voltage output thereof.

The angle through which the range motor 38 must rotate to adjust the circuit 32 so as to follow the selected target is translated into electrical energy of proper amplitude and polarity by a conventional self-synchronizing motor system 40, coupled to the motor 38, as at 41, and said electrical energy is transmitted to a predictor 42, or any other suitable mechanism for utilizing the intelligence received thereby for controlling a gun, searchlight or the like.

Now, unless the target which it is desired to automatically track is aligned with the axis of rotation 13 of the antenna system 10, the amplitude of the echo signals from a particular target will vary as said target is swept by the antenna beam pattern, and the output of the gating circuit 31 will, under these conditions, appear as shown in Figure 2 (M). This output is applied to a rectifier 43 by means of which the greatly varying amplitude input thereto becomes transformed into a smoothly varying output of a frequency corresponding to the rotational period of the antenna system 10. Such an output is shown in Figure 2 (N). This output is applied to an amplifier 44 to obtain the output shown in Figure 2 (O), and this, in turn, is applied to the commutator 20, as described in the earlier portions of this specification.

The commutator distributes the energy applied thereto to the azimuth and elevation motors 16

and 18 which causes reorientation of the antenna system until the axis of rotation 13 thereof becomes aligned with the target selected for tracking. The azimuth and elevation motors 16 and 18 have respectively coupled thereto, as at 45 and 46, conventional self-synchronizing motor systems 47 and 48, similar to the range self-synchronizing system 40, and adapted to transform the angles of rotation of said motors 16 and 18 into electrical energy of appropriate amplitude and polarity, which is supplied to the predictor 42 or other similar mechanism for controlling the aiming of the gun, searchlight or the like.

This completes the description of the object-locating system of my present invention insofar as the general functioning of the components thereof is concerned, and I shall now describe some specific circuits which may be used in some of the major components of the system as a whole.

For this purpose, reference is made to Figure 3 of the drawings. As there shown, the variable-delay circuit 32 is a standard flip-flop circuit, including a pair of vacuum tubes 49 and 50, the plate of the former being connected to the positive side of a "B" voltage supply through a dropping resistor 51, and the plate of the latter being directly connected to said "B" voltage supply. The input to the tube 49 includes a coupling capacitor 52 and a grounded grid resistor 53. The plate output of the tube 49 is applied to the tube 50, through a variable capacitor 54, across a grid resistor 55, the time constant of the capacitor-resistor combination 54—55 controlling the width of the square-wave output of the circuit. The cathodes of both tubes are grounded through a common resistor 56. The variable capacitor 54 is manually adjustable and, in addition, is mechanically coupled, as shown, for operation by the range motor 38.

The plate output of the tube 49 is also applied to the unblanking pulse generator 34, which includes a differentiating network consisting of a series connected capacitor 57 and resistor 58, the drop across the latter being applied, through a current-limiting resistor 59, to a diode limiter 60, so biased, by means of a battery 61, as to be normally nonconducting.

The positive-going pulse resulting from the differentiated trailing edge of the square-wave output of the tube 49 is applied to a vacuum tube amplifier 62, plate voltage to which is supplied from the "B" voltage supply through a resistor 63, and the cathode of which is grounded through a resistor 64, by-passed by a capacitor 65.

The amplified output thus obtained is, in part, differentiated by application across a series connected capacitor 66 and resistor 67, the drop across the latter being applied to a vacuum tube 68. The plate of said tube 68 is connected to the "B" voltage supply through a resistor 69, and the cathode thereof is grounded through a resistor 70.

Plate and cathode outputs, consisting of pairs of oppositely disposed pulses resulting from the output of the last-mentioned differentiating network, are applied, respectively, through capacitors 71 and 72, to the opposite ends of a resistor 73, which is center-tapped and connected to ground through a bias battery 74. The drops across the two halves of the resistor 73 are applied to the range-selecting circuit 36.

The latter includes a pair of vacuum tubes 75 and 76 which are biased beyond cutoff, by the battery 74, an amount equal to the amplitude of the positive-going portions of the respective inputs thereto. Plate potentials from the "B" voltage supply are applied to the tubes 75 and 76, respectively, through resistors 77 and 78, and the cathodes thereof are grounded through a common resistor 79. The cathodes of said tubes are receptive of the inverted output of the receiver 23 of Fig. 1. The plate outputs of the tubes 75 and 76 are applied to the rectifier 37 through capacitors 80 and 81, said rectifier including two resistors 82 and 83 connected through a bias battery 84 to ground, the resistors being shunted by inverted diodes 85 and 86.

The rectified outputs thus obtained are applied to vacuum tube amplifiers 87 and 88, the cathodes of which are grounded directly, and the plates of which are connected, respectively, through relay coils 89 and 90 to the "B" voltage supply. The relay coils are adapted, when the average plate currents of their respective control tubes 87 and 88 reach predetermined amplitudes, to close contacts 91 and 92, as the case may be, to convey direct current of appropriate polarity to the armature of the range motor 38, the field of said motor being constantly energized.

A portion of the output of the unblanking pulse generator 34 of Fig. 1 is applied to an inverter 93 (circuit not shown because conventional) and the output of the inverter is applied, in part, to the vertically deflecting plates of the oscilloscope 26 and, in part, to the gating circuit 31. The latter, too, is conventional, and therefore no circuit diagram has been shown. The output of the gating circuit is applied to the conventional rectifier 43 and the rectified output thus obtained, after passing through the amplifier 44 (also conventional), is conveyed to the distributing commutator 20.

This completes the description of one form of circuit which may be utilized, in the object-locating system of my present invention, for selecting a particular target for tracking and automatically following the movements of the same when once selected.

It will be noted from all of the foregoing that I have provided a relatively simple and inexpensive means for automatically and accurately laying equipment, such as anti-aircraft guns, searchlights, or the like, upon a selected target, and it will further be noted that I attain this result without the necessity of complicated multiple signal channels, which have heretofore been incorporated in apparatus designed for similar purposes.

Other objects and advantages of my present invention will readily occur to those skilled in the art to which the same relates.

I claim:

1. In combination with a radio object-locating system, including means for scanning a selected area of space with pulses of radio-frequency energy, means for receiving echoes of said energy reflected from any targets within the scanned area, and means for indicating the relative positions of said targets in said scanned area; means for selecting and automatically following the movements of a particular target comprising: a first means for generating unblanking pulses in synchronism with the reception of the echoes from a particular one of said targets, a second means for applying said unblanking pulses to said receiving means to permit the echoes from said particular target to pass therethrough, a third means operable under the control of said first means for generating normally ineffective

correction voltages, said normally ineffective correction voltages consisting of two pulses of the same polarity one of which occurs immediately prior to the time of occurrence of the echoes from said particular target and the other of which occurs immediately subsequent to the time of occurrence of the echoes from said particular target, a fourth means for combining said correction voltages with the output of said receiving means, and a fifth means rendered effective in response to said receiving means output for restoring the time relationship existing between said normally ineffective correction voltages and the echoes from said particular target to maintain the system automatically following the movements of said particular target in range.

2. In combination with a radio object-locating system including means for scanning a selected area of space with pulses of radio-frequency energy, means for receiving echoes of said energy reflected from any targets within the scanned area, and means for indicating the relative positions of said targets in said scanned area; means for selecting and automatically following the movements of a particular target comprising: a first means for generating a square-wave voltage of controllable width in synchronism with the radiation of said pulses of radio-frequency energy, a second means for adjusting the width of said square-wave voltage to correspond to the time elapsing between the radiation of said pulses of radio-frequency energy and the instants of reception of the echoes from a particular one of said targets, a third means for differentiating said square-wave voltage, a fourth means for transforming one of the pulses of each pair of pulses resulting from the differentiation of the trailing edge of said square-wave voltage into unblanking pulses, a fifth means for applying said unblanking pulses to said receiving means to permit the echoes from said particular target to pass therethrough, a sixth means operable under the control of said fourth means for generating normally ineffective correction voltages, and a seventh means for combining said correction voltages with the output of said receiving means whereby coincidence between said correction voltages and said receiving means output renders the former effective to maintain the system automatically following the movements of said particular target in range.

3. In combination with a radio object-locating system including means for scanning a selected area of space with pulses of radio-frequency energy, means for receiving echoes of said energy reflected from any targets within the scanned area, and means for indicating the relative positions of said targets in said scanned area; means for selecting and automatically following the movements of a particular target comprising: a first means for generating unblanking pulses in synchronism with the reception of the echoes from a particular one of said targets, a second means for applying said unblanking pulses to said receiving means to permit the echoes from said particular target to pass therethrough; a third means operable under the control of said first means for differentiating the output of the latter, thereby generating normally ineffective correction voltages, and means for combining said correction voltages with the output of said receiving means whereby coincidence between said correction voltages and said receiving means output generates an error voltage, and means for utilizing said error voltage to maintain the system automatically following the movements of said particular target in range.

4. In combination with a radio object-locating system including means for scanning a selected area of space with pulses of radio-frequency energy, means for receiving echoes of said energy reflected from any targets within the scanned area, and means for indicating the relative positions of said targets in said scanned area; means for selecting and automatically following the movements of a particular target comprising: a first means for generating a voltage of controllable duration, a second means for adjusting the duration of said voltage to correspond to the time elapsing between the radiation of said pulses of radio-frequency energy and the instants of reception of the echoes from a particular one of said targets, a third means under the control of said first means for generating unblanking pulses and applying the same to said receiving means to permit the echoes from said particular target to pass therethrough, a fourth means operable under the control of said third means for differentiating the output of the latter, thereby generating normally ineffective correction voltages, and means for combining said correction voltages with the output of said receiving means whereby coincidence between said correction voltages and said receiving means output generates an error voltage, and means for utilizing said error voltage to maintain the system automatically following the movements of said particular target in range.

5. In combination with a radio object-locating system including means for scanning a selected area of space with pulses of radio-frequency energy, means for receiving echoes of said energy reflected from any targets within the scanned area, means for detecting said received signals and amplifying them to form signal voltage pulses and means for indicating the relative positions of said targets in said scanned area; means for selecting and automatically following the movements of a particular target comprising: a first means for generating a square-wave voltage of controllable width in synchronism with the radiation of said pulses of radio-frequency energy, a second means for adjusting the width of said square-wave voltage to correspond to the time elapsing between the radiation of said pulses of radio-frequency energy and the instants of reception of the echoes from a particular one of said targets, a third means for differentiating said square-wave voltage, a fourth means for transforming one of the pulses of each pair of pulses resulting from the differentiation of the leading and trailing edges of said square-wave voltage into unblanking square wave pulses, a fifth means for applying said unblanking pulses to said receiving means to permit the echoes from said particular target to pass therethrough, a sixth means operable under the control of said fourth means for differentiating the output of the latter, thereby generating normally ineffective correction voltage pulses at each edge of said unblocking square wave pulse, and means for combining said signal voltage pulse with either of said correction voltage pulses whereby coincidence between either of said correction voltage pulses and said signal voltage pulse generates a corresponding error voltage, and means for utilizing said error voltage to change the width of said square wave in said first means, thereby maintaining said signal voltage pulse between

said correction voltage pulses and automatically following the range movements of a particular target.

MILES A. McLENNAN.

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