Dec. 27, 1949 W. M. KELLOGG 2,492,363

AUTOMATIC GAIN CONTROL SYSTEM

Filed Feb. 1, 1946 3 Sheets-Sheet 1

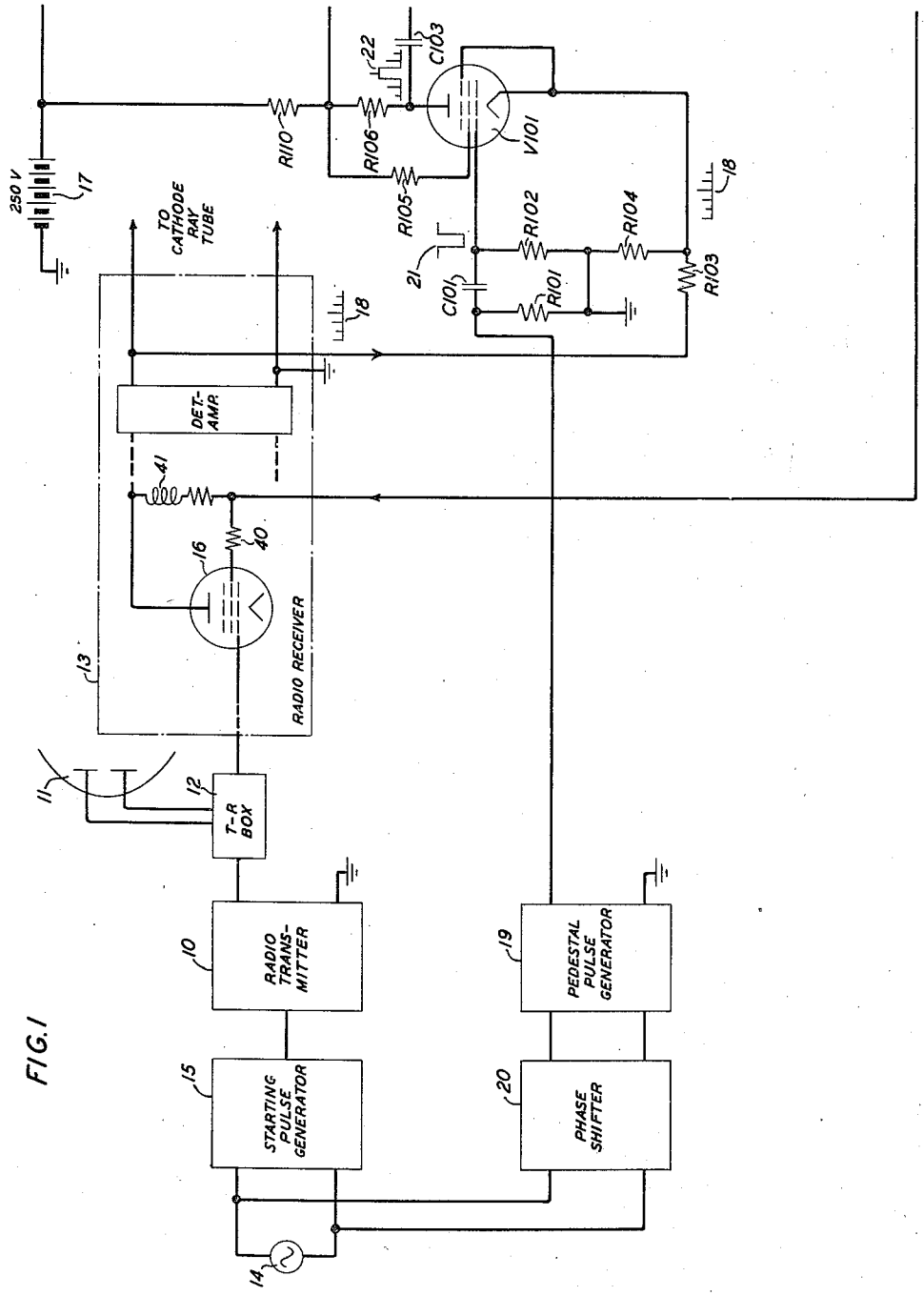


FIG. 1

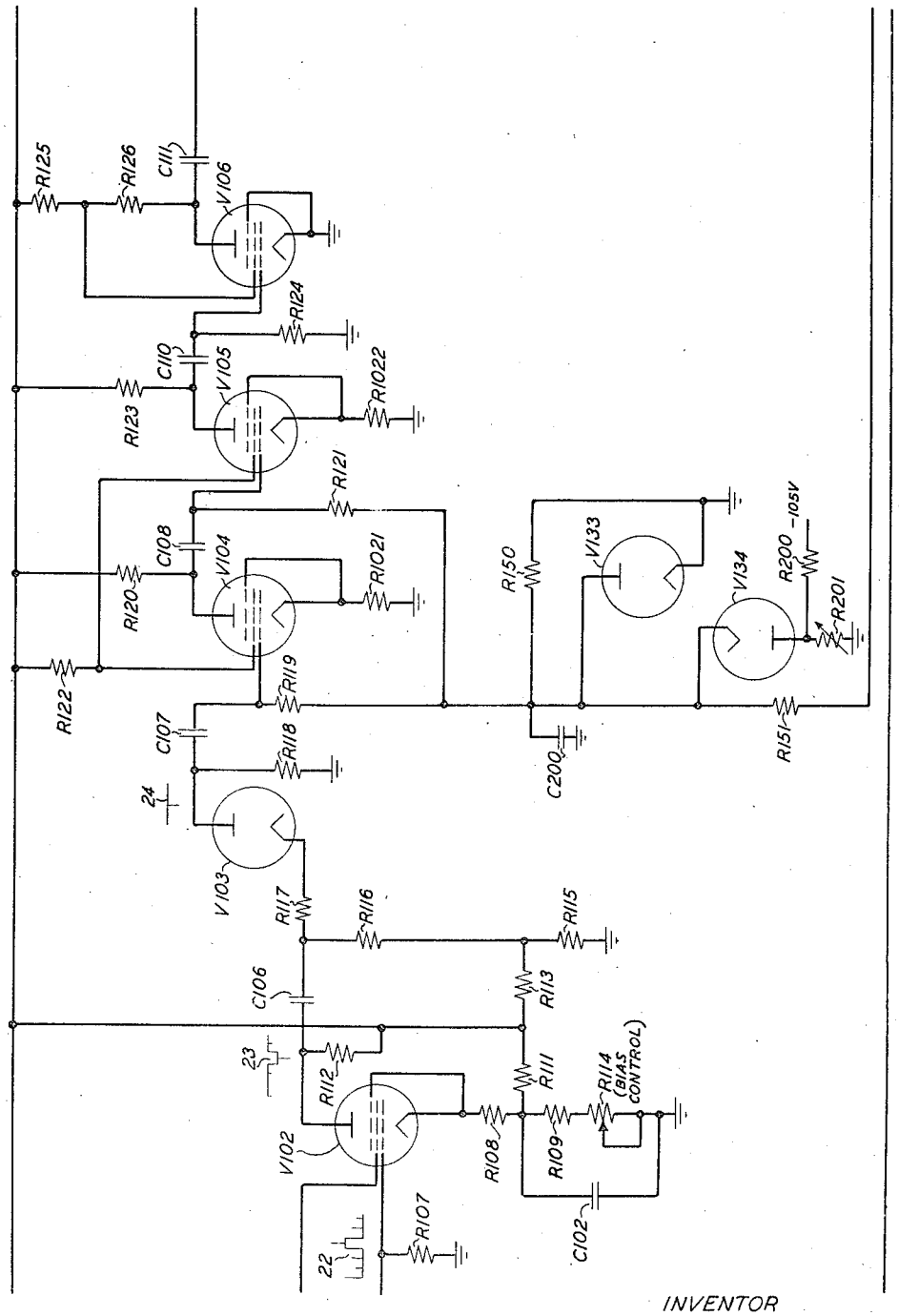
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FIG. 2



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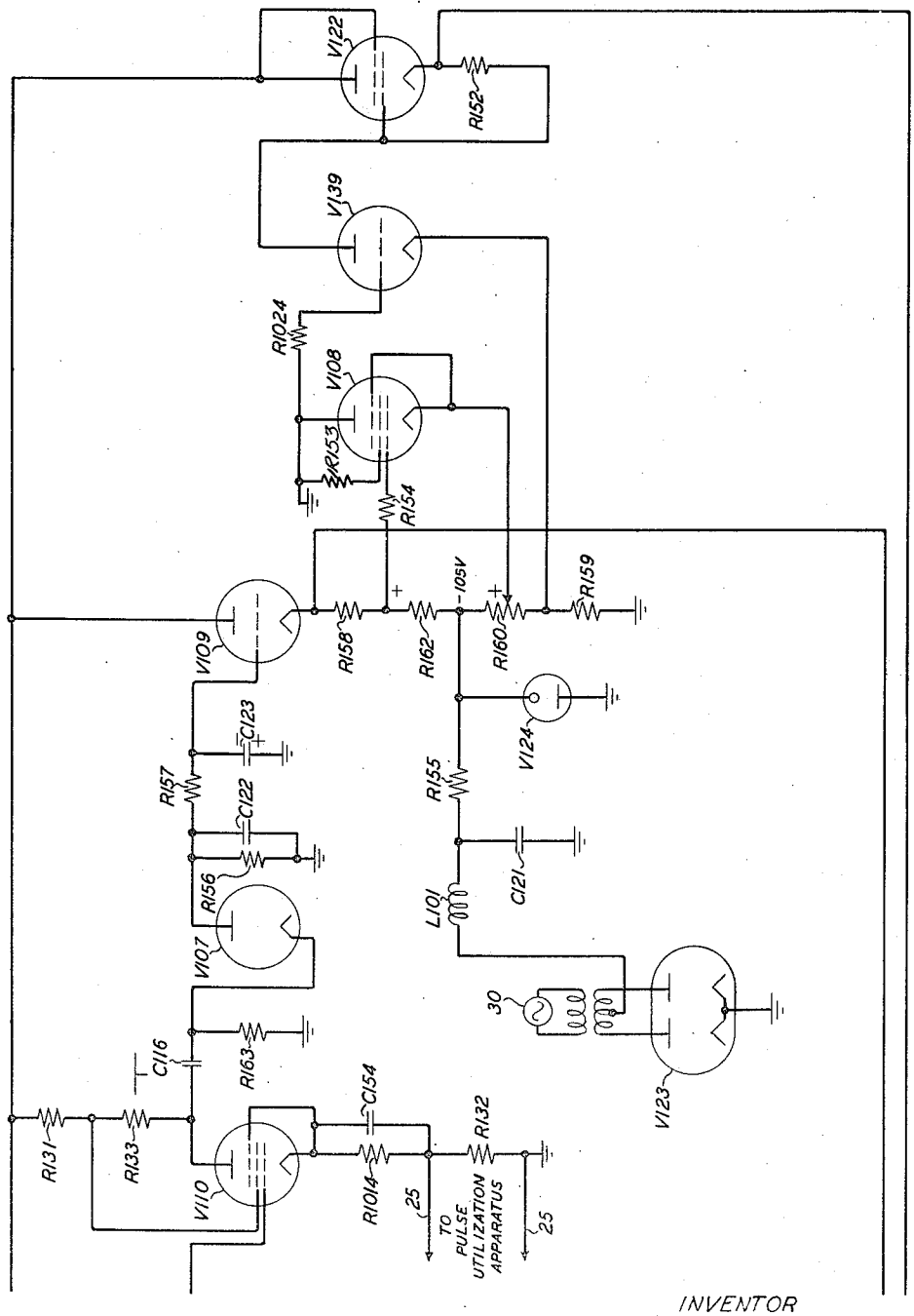


FIG. 3

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AUTOMATIC GAIN CONTROL SYSTEM

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3 Claims. (Cl. 179—171)

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This invention relates to signal transmission systems and particularly to means for controlling the energy level at desired points in a signal transmission system.

The invention is applicable, for example to a so-called "radar" system in which recurrent pulses of radio energy are transmitted toward a target and echo pulses reflected from the target are received by a radio receiver, means being provided for measuring the delay period between transmitted pulses and corresponding echo pulses received from the target and thereby indicating the range of the target. In measuring the range of the target, it is common practice to impress the output energy of the radio receiver upon a pair of deflecting plates of a cathode-ray tube to produce deflection of the beam along one coordinate, a saw-tooth wave synchronized with the transmitted pulses being provided for deflecting the beam along a second coordinate. There will also be present at the output of the radio receiver energy other than that of the selected echo signal, or so-called "noise" energy, which normally produces a smaller deflection of the cathode-ray beam than the deflection produced by the selected echo pulses so that the echo pulses are distinguishable from the noise. When fading occurs, it is desired to increase the gain of the radio receiver so that the indication produced on the cathode-ray tube screen by the echo pulses may be observed by an operator. However, excessive noise appearing on the cathode-ray tube screen becomes annoying to the operator, and it is, therefore, desirable to limit the gain of the radio receiver to a certain maximum gain such that the noise on the cathode-ray tube screen will not become excessive even if the selected echo signal completely fades out.

It is desired to utilize the echo pulse signals for controlling apparatus other than the range measuring apparatus, such as apparatus for causing a directional antenna to automatically follow a moving target in elevation and azimuth so that the transmitted pulses will at all times reach and be reflected from the target. The pulses impressed upon such automatic following apparatus should preferably be brought up to a fixed normal level when fading occurs even under relatively weak signal conditions such that the radio receiver is operated at fixed maximum gain.

There are, therefore, provided in accordance with the invention, a specific embodiment of which is shown and described herein for the purpose of illustration, a signal transmission system comprising two repeaters for repeating signals

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from a source impressed upon a first of said repeaters, the second repeater repeating signals received from the first, and apparatus under the control of signaling energy from the output of the second repeater for causing the output signaling energy to be maintained at a substantially constant level, this apparatus comprising means for controlling the gain of the first repeater over a range up to a certain maximum gain, and means for controlling the gain of the second repeater to further control the gain of the system while the first repeater is set for maximum gain. When fading of the signal occurs, therefore, the gain of the repeater in the radio receiver is increased up to a predetermined maximum and, if the signal further fades, the gain of the second repeater continues to increase until, if complete fading occurs, the noise energy at the output of the second repeater is brought up to normal signal amplitude. The arrangement is such that there is supplied to the utilization apparatus connected to the output of the second repeater all the signal possible up to a desired normal amplitude, without allowing the noise deflections on the cathode-ray tube indicator to become so high as to be annoying to the operator. Constant amplitude energy at the output of the second repeater will be maintained whether the output energy is noise energy or signaling energy.

The invention will now be described in detail with reference to the accompanying drawing, Figs. 1, 2 and 3 of which when placed side by side, in order with Fig. 1 at the left, constitute a schematic view of a pulse signal transmission system embodying the invention.

Referring now to the drawing, there are provided an oscillator 14 for generating a sinusoidal wave which is impressed upon a starting pulse generator 15 for generating a series of pulses of brief duration, one for each cycle of the sinusoidal wave. The starting pulses are impressed upon a radio transmitter 10 which produces a series of corresponding brief pulses of radio frequency energy. These radio pulses are impressed through a suitable coupling arrangement or T-R box 12 upon a dipole directional antenna 11 from which the pulses are radiated toward a target. Echo pulses reflected from the target are picked up by the antenna 11 and impressed through the T-R box upon the input of radio receiver 13 comprising a plurality of intermediate frequency amplifier stages including an amplifier tube 16. The coupling arrangement 12 serves to shunt the input of the radio receiver during pulse transmitting periods so that the same antenna may be used

both for transmission and reception of pulses although separate transmitting and receiving antennas obviously may be used if desired. The T-R box is a transmit-receive switch which may be of any desired type and may conveniently be a Western Electric Company 709A space discharge tube. This tube is essentially a resonant cavity filled with an ionizable gas. During reception with the low voltages of the received energy, the gas is not ionized, the cavity is tuned to resonance and the received energy is conducted to the radio receiver 13. During the transmission of a pulse, the voltages due to the pulse ionize the gas, thus detuning the cavity and preventing the energy of the pulse from reaching the radio receiver 13.

There is provided a pulse transmitting system comprising space discharge devices V101, V102, V103, V104, V105, V106 and V110 for transmitting the selected echo pulses received from a target to a pulse utilization apparatus. A circuit comprising resistors R103 and R104 is connected to the output of radio receiver 13 so that the echo pulse voltages 18 appearing across resistor R104 will be impressed upon the input circuit of tube V101. A typical form of the video output of the receiver is shown by 18. The vertical axis shows the voltage amplitude of the target echo pulses and the horizontal axis shows their time relationship with respect to the leakage signal from the transmitter or "direct" pulse at the left of the diagram. A pedestal pulse generator 19 is provided for producing pedestal pulses, one for each cycle of the sinusoidal wave from source 14 impressed thereon through an adjustable phase shifter 20. By adjusting the phase shifter 20, the pedestal pulses may be delayed or advanced until each echo pulse from a desired target occurs during the period of the corresponding pedestal pulse in order that the desired echo pulse may be selected or separated from other echo pulses. The pedestal pulses from the generator 19 are impressed across a circuit having a resistor R101 in one of the two parallel branches and, in the other branch path, a condenser C101 and a resistor 102 in series. The control grid-cathode circuit of tube V101 comprises resistors R102 and R104 in series and having their common terminal grounded so that a negative pedestal pulse potential 21 is impressed upon the control grid with respect to ground and a positive echo pulse potential is impressed upon the cathode with respect to ground. A 250-volt direct current source, shown as the battery 17, having its negative terminal grounded, is provided for supplying operating voltages to the screen grid of tube V101 through resistors R110 and R105 and to the anode of the tube through resistors R110 and R106. In order to simplify the drawing, filter condensers used in various parts of the system, such as one in a path connecting the common terminal of resistors R110 and R105 to ground, are not shown.

The echo pulse and the pedestal are thus added by the circuit of tube V101 so that the pedestal and the echo pulse each have a positive polarity at the anode of the tube. The amplitude of the pedestal is greater than that of any signal including the selected echo pulse which is superposed upon the pedestal as shown at 22. The pedestal pulse with the echo signal superposed is impressed upon the input circuit of amplifier V102. For this purpose the anode of tube V101 is connected through condenser C103 and resistor R107 to ground, the control grid of tube

V102 being connected to the common terminal of condenser C103 and resistor R107. The cathode of tube V102 is connected through resistors R108, R109 and variable resistor R114, all in series, to ground, condenser C102 being connected across resistors R109 and R114. The anode of tube V102 is connected through a condenser C106 and resistor R117 to the cathode of a diode V103, the anode of the diode being connected through resistor R118 to ground. Current from the positive terminal of battery 17 flows through resistors R111, R109 and R114 to ground. Current also flows from the positive battery terminal through resistors R113 and R115 to ground. Condenser C106 is charged to the voltage across R113 through a circuit comprising resistors R112, R113 and R116. When no anode current is flowing in tube V102, the anode-cathode voltage is equal to the voltage drop across resistor R111. Screen grid voltage is applied to tube V102 from source 17 through resistor R110. The bias voltage across resistors R109 and R114 is set so that the pedestal voltage drives the tube V102 from cut-off to a value of anode current above which there is adequate operating range to handle the signal superposed upon the pedestal voltage. When anode current flows, the potential at the anode of tube V102 is reduced due to the voltage drop across resistor R112 and the condenser C106 discharges through a circuit comprising resistors R112, R113 and R116. Tube V102 thus acts as a partial clipper and the voltage across R116 contains the pedestaled echo pulse and the tips of other high amplitude pulses as shown at 23. The resistance of resistor R114 may be varied to control the bias of tube V102 and thus to control the amplitude of the pedestal appearing at the anode of tube V102. A pedestal of just sufficient amplitude to overcome the bias voltage across resistor R115 permits the pedestaled echo pulse current to flow through resistor R118 and the diode V103. The desired echo pulse is thus completely selected and appears as a voltage across resistor R118 as shown at 24.

The gain of amplifier stages comprising variable gain tubes V104 and V105 is automatically controlled in response to the variable voltage drop produced across a resistor R150 which is shunted by a diode V133, as will be explained below. The control grid-cathode signal circuit of tube V104 comprises resistor R119 and condenser C200 to ground and resistor R1021 connecting the cathode to ground. The signal voltage across resistor R118 is applied to the input circuit of tube V104 by means of the coupling circuit of resistors R118 and R119 and condensers C107 and C200. Screen grid voltage is applied to tube V104 from source 17 through resistor R122 and to the anode through resistor R120. The anode of tube V104 is connected to the control electrode of tube V105 through a condenser C108. A circuit connecting the control electrode and cathode of tube V105 comprises resistor R121 and condenser C200 to ground and thence through resistor R1022 to the cathode. Screen grid voltage for tube V105 is applied from source 17 through resistor R122 and anode voltage is applied thereto through resistor R123.

The anode-cathode circuit of tube V105 is coupled to the control grid-cathode circuit of tube V106 through coupling condenser 110 and resistor R124, one terminal of this resistor and the cathode of tube V106 being grounded. Anode voltage is supplied from source 17 to this tube through

resistors R125 and R126 in series and screen grid voltage is supplied from the common terminal of these resistors. The anode of tube V106 is connected through a condenser C111 to the control electrode of output amplifier tube V110. The cathode of tube V110 is connected through resistors R1014 and R132 in series to ground, resistor R1014 being shunted by condenser C154. Voltage from source 17 is applied to the screen grid of tube V110 through resistor R131 and to the anode of this tube through resistors R131 and R133 in series.

The output pulses of tube V110 produced across resistor R132 are supplied to a desired utilization apparatus, not shown, by way of the leads 25. These output pulses may be used, for example, for controlling the antenna 11 to cause it to follow or track a moving target so that the transmitted pulses will reach the target, be reflected therefrom and picked up by the antenna after reflection.

The circuit arrangement for generating the control voltages for automatically controlling the gain of the intermediate frequency amplifier of the radio receiver 13 and of the amplifier stages V104 and V105 comprises the space discharge devices V107, V109, V108, V139, V122, V124 and V123. The anode of tube V110 is connected through a condenser C116 and resistor R163 to ground, the common terminal of the condenser and resistor being connected to the cathode of a diode V107. The anode of diode V107 is connected through a circuit comprising a resistor R156 shunted by a condenser C122 to ground and is connected through a second circuit comprising a resistor R157 in series with a condenser C123 to ground. The common terminal of resistor R157 and condenser C123 is connected to the control electrode of tube V109. When tube V110 is quiescent, condenser C116 is charged by current from source 17 through resistors R131, R133 and R153 in series. When the selected pulse of positive polarity is impressed upon the input of tube V110 the anode current increases and condenser C116 discharges through a circuit comprising the anode-cathode path of tube V110, condenser C154, resistor R132, condenser C122 and the anode-cathode path of diode V107. Condenser C122 is thereby charged during each selected pulse duration with a charge proportional to the pulse voltage applied to the grid of V110. A condenser is used to store the pulse energy so that a maximum of energy can be stored without requiring excessive pulse voltage amplitudes to be developed by V110. To avoid build up of voltage across C122 by accumulation of charge from the succession of echo pulses corresponding to each transmitted pulse, such that the proportionality of each charge to the selected pulse amplitude is continuously maintained in spite of signal fading or other erratic changes in signal amplitude, most of the pulse charge on condenser C122 is permitted to leak off through resistor R156 during periods between successive pulses. Resistor R157 and condenser C123 comprise a resistance-capacity filter for suppressing alternating components of the voltage across condenser C122 so that the voltage across condenser C123 is a relatively steady voltage having an amplitude corresponding to the average amplitude, taken over a period such as one-tenth second, for example, of the selected echo pulses during normal operation. There is provided a rectifier comprising a double diode V123, transformer coupled to an alternating current source 30 for supplying current to a load

comprising potentiometer R160 and resistor R159 in series, the positive terminal of the rectifier and one terminal of resistor R159 being grounded. The supply circuit includes a ripple filter comprising a series choke coil L101 and a shunt condenser C121 and a voltage regulator comprising a series resistor R155 and a cold cathode, gaseous discharge tube V124 which maintains the ungrounded load terminal at substantially 105 volts negative with respect to ground. The anode of tube V109 is directly connected to the positive terminal of battery 17. The cathode of tube V109 is connected through resistors R158 and R162 in series to a terminal of resistor R160. The voltage across resistors R158 and R162 and the anode-cathode path of tube V109, all in series, is therefore 355 volts. The voltage across potentiometer R160 and resistor R159 in series is opposed to the voltage drop across resistors R158 and R162 in series, thus permitting tube V109 to operate at a proper bias.

The circuit of tube V109 serves as an impedance transformer. When the received signal fades with the result that the charge on condenser C123 decreases, the anode current of tube V109 increases and the potential at the cathode of tube V109 will become less negative with respect to ground. The resistance connected in the cathode path of tube V109 is sufficiently large to cause a change of potential at the cathode to be substantially equal to a change of potential at the control electrode. Thus the direct voltage at the output of the averaging circuit which has a high impedance is available across the cathode resistance of tube V109 at a relatively low impedance. The resultant voltage measured between the cathode of tube V109 and ground is impressed upon a voltage divider circuit comprising resistors R150, one terminal of which is grounded, and R151 in series. A diode V133 is connected across resistor R150 to provide a shunt path across resistor R150 and thereby to prevent the potential at the cathode of tube V109 from becoming positive with respect to ground. The voltage drop across resistor R150 is applied as a bias voltage to tube V104 by way of a circuit comprising resistors R119 and R1021 and to the tube V105 by way of resistors R121 and R1022. Thus, as signal fades and therefore the charge on condenser C123 decreases, the variable gain tubes V104 and V105 are biased less negatively to increase the gain of the amplifier.

In order to restrain the action of this automatic control of amplifier gain the limiting diode V134 is provided. The limit to which the negative bias voltage and hence the amplifier gain reduction can attain is determined by diode V134. The cathode of V134 is connected to the junction of resistors R151 and R150 and the anode is connected to the junction of resistors R200 and R201 which are connected between ground and a negative source of current such that the anode is negative with respect to ground by the voltage drop across R201. R201 is adjustable to permit adjustment of the anode bias voltage. When the negative voltage drop across R150 becomes greater than the drop across R201 the diode V134 becomes conductive and of low resistance as compared with R151. It acts as a limiter and prevents further increase of the voltage drop across R150. The low limit of the gain of the amplifier is thus controllable by means of R201. This adjustment serves to restrain the gain control actions of the variable gain tubes V104 and V105 in the region of signal level where the automatic gain

control of the intermediate frequency amplifier is active. As will be described later the automatic gain control of the intermediate frequency amplifier is made effective at signal levels only above a chosen level. At this chosen level, by means of R201 the voltage drop across R201 is made equal to the voltage drop across R150 and as the signal increases the gain of amplifier stages V104 and V105 remains constant, thereby placing the full automatic gain control function in advance of the cathode-ray oscilloscope indicating system.

As previously stated, the gain of the intermediate frequency amplifier of the radio receiver is controlled over a range up to a predetermined maximum. This maximum may be adjusted by changing the setting of the movable contact of potentiometer R160 which is connected to the cathode of space discharge tube V108. The control grid of tube V108 is connected through a resistor R154 to the common terminal of resistors R158 and R162. The anode of tube V108 is connected directly to ground and its screen grid is connected through a resistor R153 to ground. The anode of tube V108 is connected through resistor R1024 to the control electrode of a triode V139, the cathode of tube V139 being connected to the ungrounded terminal of resistor R159. There is also provided a space discharge tube V122 having its anode and its screen grid connected to the voltage source 17 and having its cathode connected through a resistor R152 to the anode of tube V139 and to the control grid of tube V122. The cathode of tube V122 is connected to the screen grid and anode of one stage 16, at least, of radio frequency amplification of radio receiver 13 through a resistor 40 and an impedance element 41, respectively.

The intermediate frequency amplifier of the receiver includes a manual gain control not shown in the drawing. This manual gain control enables adjustment of the cathode bias voltages of the amplifier stages and therefore, in conjunction with the automatic control of the anode and screen grid voltages, serves to control the gain of the receiver. The maximum anode and screen grid voltage of the intermediate frequency amplifier and hence the maximum gain for a given setting of the manual gain control is adjusted by means of the top of potentiometer R160.

If the grid of tube V108 is biased relatively more negatively by moving the potentiometer tap toward ground, the space current of tube V108 is decreased. As a result the current flowing through a portion of potentiometer R160 and resistor R159 is increased and the cathode of tube V139 becomes more negative with respect to ground. The space current of tube V139 flowing from source 17 through a circuit comprising the anode-cathode path of tube V122, resistor R152, the anode-cathode path of tube V139 and resistor R159 is therefore increased. The resulting increased voltage drop across resistor R152 causes the control grid of tube V122 to become more negative to increase the impedance of the anode-cathode path of tube V122 and therefore to increase the voltage drop across the anode-cathode path. The potentials impressed upon the screen grids and anodes of the intermediate frequency amplifier tubes of the radio receiver are therefore reduced to cause the gain of the radio frequency amplifier to be reduced. Moving the tap of potentiometer R160 in the reverse direction so as to make the grid of tube V108 less negative will cause the maximum gain of radio receiver 13 to be increased.

If fading of the signal, with the accompanying reduction of charge of condenser C123, occurs, the potential of the common terminal of resistors R158 and R162 becomes less negative, thereby causing an increase of space current through the tube V108. The current flowing through resistor R159 is reduced to make the cathode of tube V139 less negative and thereby causing a decrease of current through the circuit comprising resistor R152 and the anode-cathode path of tube V139. The tube V122 is therefore biased less negatively to decrease the impedance of the anode-cathode path of tube V122. The voltage applied to the anodes and screen grids of the intermediate frequency amplifier tubes of the radio receiver 13 is therefore increased to increase the gain of the radio receiver.

The maximum anode and screen grid voltage is obtained when the signal has decreased to a point where the control grid-cathode bias of tube V108 is equal to zero. If the signal decreases further, the potential at the common terminal of resistors R158 and R162 will become positive with respect to the movable tap of potentiometer R160. Tube V108 will then draw grid current with the result that a voltage drop is produced across resistor R154 which counteracts the voltage drop across resistor R162 and the portion of potentiometer R160 in the grid-cathode circuit. The grid bias of tube V108 therefore remains substantially equal to zero and the gain of the radio receiver remains substantially constant at its maximum gain.

When no echo pulse is being received, the noise energy output from the radio receiver will be limited to a maximum amplitude as determined by the setting of potentiometer R160. However, the gain of the amplifier comprising tubes V104 and V105 will be further increased after the radio receiver has been brought up to maximum gain. The output energy across resistor R132 supplied to pulse utilization apparatus is thus automatically maintained at a substantially constant amplitude. This output energy will be the recurring echo pulses corresponding to those received from a target or, if the selected pulse signal fades completely, the output energy will be noise energy of the same substantially constant amplitude. This arrangement permits all the signal possible to be supplied to the utilization apparatus without allowing the noise energy applied to the cathode-ray indicator connected to the output of the radio receiver to become so high as to be annoying to the operator.

What is claimed is:

1. In combination, voltage responsive means for controlling the gain of a transmission system for transmitting electric signals, comprising a first space current device having an anode, a cathode and a control electrode, a first, a second and a third resistor, a first circuit connecting said anode and said cathode comprising in series a source of space current and said first resistor for causing a unidirectional voltage to be set up across said first resistor, a second circuit connecting said control electrode and said cathode, means for impressing upon said second circuit signals derived from said transmission system, a third circuit comprising said second and third resistors in series, means for supplying unidirectional current to said third circuit for causing voltages to be set up across said second and third resistors, means for connecting the negative terminals of

said first and second resistors, a second space current device having an anode, a cathode and a control electrode, a fourth circuit connecting the anode and cathode of said second device comprising said third resistor and a portion of said second resistor, a fifth circuit connecting the control electrode and cathode of said second device comprising said first resistor and the remaining portion of said second resistor, and means under control of a voltage derived from the anode-cathode circuit of said second device for controlling said voltage responsive means.

2. A combination in accordance with claim 1 in which said means for controlling said voltage responsive means comprises a fourth resistor, a third and a fourth space current device each having an anode, a cathode and a control electrode, a sixth circuit comprising in series a source of unidirectional current, the anode-cathode paths of said third and fourth devices, respectively, and said third and fourth resistors, a seventh circuit connecting the control electrode and cathode of said third device comprising said third resistor, and an eighth circuit connecting the control electrode and cathode of said fourth device comprising said fourth resistor.

3. An electric signal transmission system comprising a first portion and a second portion each having an input an an output, a first and a second gain control means for controlling the gain of said first and second portions, respectively, means for impressing upon the input of said first portion electric energy including recurring pulses which it is desired to utilize, means connected to the output of said first portion for selecting said recurring pulses, means for impressing said selected

pulses upon the input of said second portion, means for setting up a first voltage having an average amplitude proportional to the amplitude of said selected pulses derived from the output of said second portion, means under control of said first voltage for setting up a second voltage proportional to said first voltage over a first amplitude range of said first voltage and having a substantially fixed amplitude for amplitudes of said first voltage less than a certain predetermined amplitude, means for utilizing said second voltage to control said first gain control means, means under control of said first voltage for setting up a third voltage proportional to said first voltage over a second amplitude range of said first voltage and having a substantially fixed value for amplitudes of said first voltage greater than said certain predetermined amplitude, and means for utilizing said third voltage to control said second gain control means.

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