Oct. 21, 1947. J. A. HANSEN ET AL 2,429,513

GAIN-CONTROL ARRANGEMENT

Filed Feb. 11, 1944 2 Sheets-Sheet 2

FIG. 2

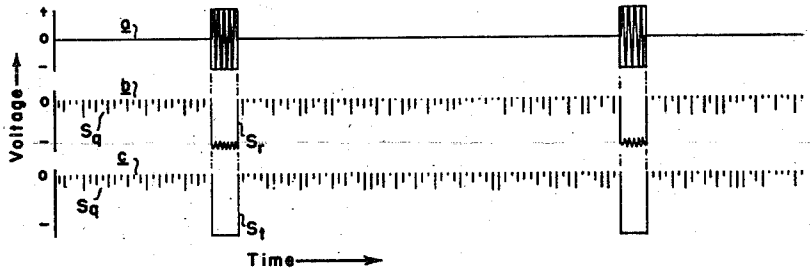


FIG. 3

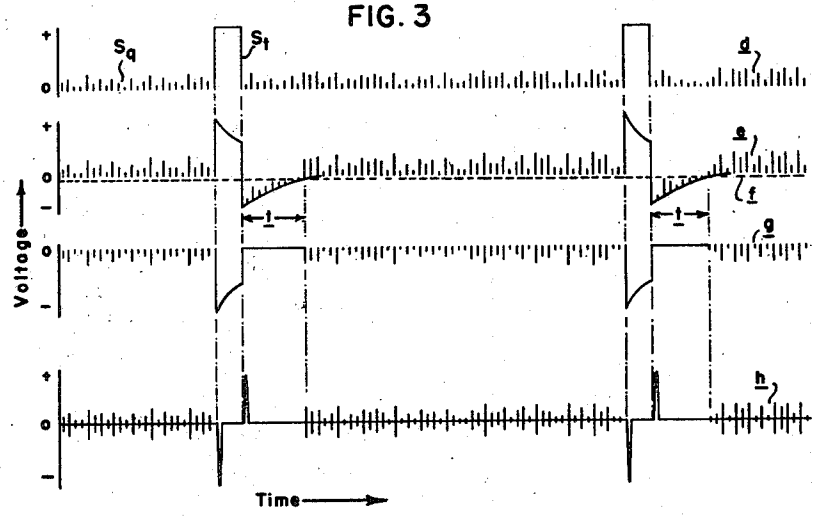
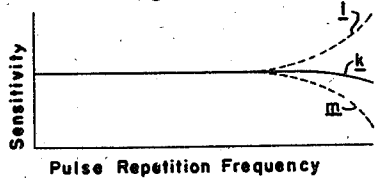


FIG. 4



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GAIN-CONTROL ARRANGEMENT

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11 Claims. (Cl. 250—20)

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The present invention is directed to a gain-control arrangement for a receiver for translating a received pulse-modulated signal having a pulse-repetition frequency which may vary over a wide frequency range. The invention is subject to a variety of applications but is especially suited for use in a wave-signal transpondor system and will be particularly described in that connection. As used throughout this specification, the term "wave-signal transpondor system" is intended to designate a wave-signal translating system including a receiver and a transmitter arranged to transmit a reply signal in response to a received interrogating signal, each such signal preferably comprising a pulse-modulated radiant-energy signal. Generally the interrogating and reply signals have carrier frequencies which are equal, or nearly so, and pulse-repetition frequencies which are either identical or integrally related.

In one prior transpondor arrangement, the receiver is of the superregenerative type having a linear mode of operation and the transmitter is triggered, or set into operation, under the control of the receiver through an amplitude-selective circuit. Optimum sensitivity of such an arrangement is obtained by adjusting the receiver gain to a compromise value between that which is required for maximum receiver sensitivity and that which is necessary to assure freedom from triggering the transmitter on the quiescent signal components of the receiver. These quiescent signal components comprise the noise signal output obtained during intervals when no desired signal is being received. In general, the quiescent signal components have a relatively low amplitude as determined by the noise signals present in the receiver circuit, but their amplitude varies with variations of the operating potentials, tube characteristics and similar factors. In order to maintain freedom from triggering the transmitter on the quiescent signal components, it is customary to embody a gain-control or gain-stabilization arrangement in the receiver for controlling the receiver gain to maintain the amplitude level of such signal components at that value required for optimum sensitivity.

Prior gain-control arrangements generally include a system which rectifies a selected portion of the quiescent signal output of the receiver to derive a gain-control voltage. In one such arrangement, that component of the quiescent signal which has a frequency corresponding to the quench frequency of the receiver is utilized in developing the desired gain-control voltage. Ar-

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rangements of this type are able to maintain optimum sensitivity so long as the translated pulse-modulated signals have low pulse-repetition frequencies. As the repetition frequency increases, however, there is a tendency for the gain-control circuit undesirably to reduce the receiver sensitivity. This results from the fact that each pulse of the received interrogating signal causes the signal output of the receiver to have an increased amplitude and, at high repetition frequencies, the effect is to increase the average level of the signal input to the gain-control arrangement. As a consequence, the derived control voltage varies in a sense which tends to reduce the receiver gain and sensitivity accordingly. This desensitizing effect is most pronounced where the transmitted reply signal makes its way into the receiver circuit, as for example in transpondor systems where the receiver and transmitter have common circuit elements providing a feed-back path into the receiver. In such a case, the transmitted reply signal, which has an exceedingly high energy content and signal components falling within the pass band of the gain-control system, greatly increases the level of the signal applied to the gain-control system at high repetition frequencies.

Compensating circuits have been proposed for reducing this effect. One form of compensating circuit that has been utilized consists of a differentiating circuit for eliminating some of the energy content of the high-amplitude signal components that are applied to the gain-control system each time the transmitter operates. Other compensating circuits decrease the gain of one or more amplifiers included in the gain-control system during intervals when the transmitter is operating. Such compensating circuits, however, are effective to maintain the desired receiver sensitivity for only a limited range of pulse-repetition frequencies.

It is an object of the invention, therefore, to provide an improved gain-control arrangement for a receiver for translating pulse-modulated signals and which avoids one or more of the aforementioned limitations of prior art arrangements.

It is another object of the invention to provide an improved gain-control arrangement for a receiver for translating a received pulse-modulated signal having a repetition frequency which may vary over a wide frequency range.

In accordance with the invention, a gain-control arrangement for a receiver for translating a received pulse-modulated signal having a repetition frequency which may vary over a wide frequency range comprises means for deriving from

that initiates the oscillations in succeeding quench cycles. For the no-signal condition under consideration, the exciting signal comprises the low-amplitude noise signals present in the receiver circuit so that the oscillations produced in successive quench cycles have a correspondingly small amplitude value.

The generated oscillations are detected by detector 21, producing across resistor 23 a low-amplitude periodic-signal voltage which has been referred to above as the quiescent signal of the receiver. This signal has a frequency component corresponding to the frequency of the quench voltage and includes components harmonically related to the quench frequency as well as components corresponding to the noise signals of the receiver circuit. The quiescent signal is translated through pulse amplifier 40 and applied to cathode follower 43, producing across its cathode impedance 44 a control voltage. The control voltage so developed is applied to the control electrode of transmitter tube 30 but, for the assumed condition of optimum sensitivity, has insufficient magnitude to overcome the bias voltage applied to the transmitter by bias resistor 33. Consequently, the quiescent signal components derived from the receiver have no effect on the transmitter which remains blocked.

Let it be assumed now that an aircraft desiring direction-finding information from the transpondor transmits thereto an interrogating signal having a wave form as represented by curve *a* of Fig. 2. The interrogating signal is a pulse-modulated radio-frequency signal having a carrier frequency substantially equal to the operating frequency of the receiver and a predetermined pulse-repetition frequency. In general, this signal will have a high intensity with reference to the noise signals in the receiver so that the oscillations generated in each quench cycle occurring within the interval of a received pulse have a relatively high amplitude. If the operation of the transmitter be neglected, the detected output signal of the receiver obtained in response to the received interrogating signal may have the wave form of curve *b* of Fig. 2. This output signal has low-amplitude quiescent signal components S_q occurring at the quench frequency and high-amplitude components S_r determined by the pulse modulation of the received signal and occurring at a frequency which corresponds to the pulse-repetition frequency thereof. The high-amplitude components S_r, after translation through pulse amplifier 40 and cathode follower 43, produce across cathode impedance 44 a control voltage of sufficient magnitude to overcome the blocking potential normally applied to tube 30 and initiate oscillations in the transmitter.

The oscillations generated in the transmitter are also applied to detector 21 through the common tuned circuit and are fed back to the input circuit of tube 30 through a regenerative circuit including diode detector 21, pulse amplifier 40 and cathode follower 43, which augments the inherent feedback of the transmitting oscillator. For this reason, the generated oscillations of the transmitter reach saturation amplitude value early in the transmitter cycle, causing the transmitted pulse to have full power irrespective of the power of the interrogating signal. As the oscillations of tube 30 continue, condenser 34 included in its cathode circuit becomes charged, raising the cathode potential thereof and tending to terminate transmission. The value of condenser 34 is so chosen that the transmitted pulse has a predetermined pulse duration which may be equal to that of the pulse duration of the received interrogating signal. Condenser 34 in discharging through resistor 33 determines the recovery time of the transmitter. The wave form of the transmitted reply signal will be substantially as represented in curve *a* of Fig. 2. The reply comprises a pulse-modulated radio-frequency signal having substantially the same carrier frequency and modulation as the interrogating signal but being, in the usual case, of very much greater intensity.

Noting that the transmitted signal is also applied to detector 21, it will be seen that as far as the signal output of the detector is concerned the transmitted signal is equivalent to and may be considered as a received signal. Therefore, when the transmitter operation is taken into consideration, the output signal obtained from detector 21, in response to an interrogating signal, may be as represented by curve *c* of Fig. 2, in which the high-amplitude signal components S_t represent the detected transmitted pulses. These components have a much greater relative intensity than the components S_r of curve *b* than can be conveniently represented in the drawing. Also, for convenience of representation, the high-amplitude signal components S_r derived by detector 21 in response to a received pulse for triggering the transmitter are represented as merged into the transmitted pulse. This representation is substantially accurate since the transmitter is triggered into operation by the leading edge of the triggering pulse.

Reference is now made to unit 50 provided in the transpondor system in accordance with the teaching of the present invention to control the gain characteristic of the receiver. This unit is coupled to detector 21 through pulse amplifier 40 and comprises means for deriving from the output signal of the receiver a second signal. Unit 50 includes amplitude-responsive means responsive to the high-amplitude components of the receiver output signal for eliminating from the derived second signal an energy content which is at least substantially equal to that of the energy content contributed by such high-amplitude components to the second signal. More specifically, unit 50 includes a vacuum-tube signal repeater or amplifier 51 having a self-bias resistor 52 and coupled to the output circuit of pulse amplifier 40 by means of a condenser 53 and grid resistor 54. The operating potentials applied to tube 51 and the values of bias resistor 52 and condenser 53 are so chosen that high-amplitude signal components of positive polarity applied to the input circuit of the tube produce grid current limiting in which the control electrode and cathode of the tube function, respectively, as anode and cathode elements of a diode rectifier. Grid resistor 54 is selected to have a high value of impedance for a purpose to be described presently. A second amplifier 55 is coupled to the output circuit of amplifier 51 and includes in its input circuit a condenser-resistor combination, comprising a condenser 56 and a resistor 57, arranged to form a conventional differentiating circuit. The output circuit of amplifier 55 includes the primary circuit of a double-tuned transformer 58 damped by a resistor 59. Transformer 58 is tuned to the quench frequency of the receiver, thereby to derive in unit 50 the above-mentioned second signal.

Unit 50 also includes means, comprising a di-

ode rectifier 60, for rectifying this second signal to derive a control effect which is utilized to control the gain of the receiver. The load circuit of rectifier 60 includes the tuned secondary winding of transformer 58, a resistor 61 and a by-pass condenser 62. The rectified signal voltage produced across resistor 61 is applied with negative polarity to the input circuit of a direct current amplifier 63 through a low-pass filter provided by series resistors 64 and 65 and a shunt condenser 66. Amplifier 63 is a conventional amplifier except that its load impedance 67 is located in the cathode circuit. A gain-control voltage of adjustable magnitude is obtained from a voltage tap 68 of impedance 67 and is applied by way of a resistor 69 to the control electrode of receiver tube 10.

In considering the operation of the described control arrangement, it will be assumed initially that no signals are being intercepted by antenna system 46. For the assumed conditions, the low-amplitude quiescent signal output of the receiver derived in the circuit of detector 21 as described above is amplified in pulse amplifier 40 and applied with positive polarity to the input circuit of unit 50. This signal is translated through amplifiers 51 and 55 and a second signal is derived therefrom in the output circuit of amplifier 55, this second signal comprising the quench-frequency component of the quiescent signal output of the receiver. The derived second signal is rectified by diode rectifier 60, producing across resistor 61 a signal voltage which is applied with negative polarity to direct current amplifier 63. The input circuit of amplifier 63 is such that the direct current component of the rectifier output signal is applied directly between its control electrode and cathode, while the alternating current components thereof are effectively applied between the control electrode of tube 63 and ground. Therefore, tube 63 is a cathode follower with reference to alternating current signals so that the gain-control voltage developed across impedance 67 and applied to the control electrode of receiver tube 10 is substantially a pure direct current voltage. The magnitude of this gain-control voltage is directly proportional to the amplitude of the quiescent signal output of the receiver. The circuit parameters and operating potentials of unit 50 are so selected that under normal conditions of operation this control voltage has such magnitude as to establish optimum sensitivity of the receiver circuit. If a change in the operating conditions of the receiver causes the amplitude of the quiescent signal output to be increased, the negative-polarity signal voltage applied to amplifier 63 is increased proportionately, rendering tube 63 less conductive. The magnitude of the gain-control voltage developed across impedance 67 is decreased accordingly, reducing the gain of the receiver and restoring the amplitude of the quiescent signal output to that value which is required for optimum sensitivity. Conversely, a decrease in the amplitude of the quiescent signal components produces an increase in the magnitude of the gain-control potential applied to tube 10, whereby the receiver gain is increased to maintain optimum sensitivity.

In considering the operation of the gain control arrangement during intervals when the transpondor system replies to a received interrogating signal, reference is made to the curves of Fig. 3. The output signal of detector 21 during such intervals is applied through amplifier 40 to the input circuit of unit 50 with a wave form as represented by curve *d*. This signal includes the low-amplitude quiescent signal components S_q of the receiver and the high-amplitude components S_t which correspond to the pulses of the transmitted reply signal. The high-amplitude components S_t which are effective to cause the gain-control arrangements of the prior art undesirably to reduce the sensitivity of the receiver as mentioned above, are effectively suppressed in unit 50 to a controlled degree in order that the receiver may have a desired sensitivity-pulse repetition-frequency characteristic. The manner in which this is accomplished is illustrated by the remaining curves of Fig. 3.

The high-amplitude signal components S_t are rectified in the input circuit of amplifier 51 thereby charging condenser 53. The charge on condenser 53, which can be dissipated only through the high-impedance resistor 54, applies a transient signal voltage of negative polarity to the control electrode of amplifier 51 which decays in accordance with an exponential function determined by the time constant of condenser 53 and the resistor 54. The resulting signal voltage established on the control electrode of amplifier 51 is represented by the curve *e* of Fig. 3. Assuming amplifier 51 to have a cut-off level as indicated by broken-line curve *f*, it will be seen that the high-amplitude components S_t of the signal output from detector 21 are effective periodically to block amplifier 51 for intervals *t* which are short with reference to the period corresponding to the pulse-repetition frequency of the received and transmitted signals. The effect of such blocking is to eliminate from the signal translated by amplifier 51 those quiescent signal components S_q which occur during the intervals *t*. Therefore, the signal produced in the output circuit of amplifier 51 has a wave form represented by curve *g*. The energy content of the high-amplitude components included in this signal is materially reduced by the differentiating circuit associated with amplifier 55, establishing on the control electrode thereof a signal voltage represented by curve *h*. The quench-frequency component of this signal is selected in the output circuit of amplifier 55, as described above, to comprise a second signal which is rectified in rectifier 60 to derive a gain-control voltage. Where it is desired to maintain substantially optimum sensitivity of the receiver with variations of the pulse-repetition frequency of the interrogating and reply signals, unit 50 is to be adjusted in the following manner. The blocking arrangement associated with amplifier 51 and the differentiating circuit coupled to amplifier 55 are adjusted to eliminate from the above-mentioned second signal a portion of the energy content contributed thereto by the high-amplitude components S_t and a portion of the energy content contributed to the second signal by the quiescent signal components S_q which is substantially equal to the remaining portion of the energy content contributed to the second signal by the high-amplitude components. Expressed differently, these circuit arrangements are to be so adjusted that the second signal, derived in the output circuit of amplifier 55, has substantially only the energy content contributed thereto by the quiescent signal components S_q of the receiver even during intervals when the transpondor system is replying to a received interrogating signal.

The curves of Fig. 4 represent the sensitivity-pulse repetition-frequency characteristic of the receiver obtained by appropriate adjustments of

unit 50. Curve *k* indicates a substantially flat sensitivity characteristic obtained by adjusting unit 50 in the manner recited above. By increasing the discharge time constant of condenser 53, a greater portion of the energy content contributed to the second signal by the quiescent signal components is removed, resulting in the rising characteristic of curve *l*. On the other hand, a reduction of this time-constant may produce the drooping characteristic of curve *m*.

It will be understood that the quench voltage utilized to provide superregeneration may have a rectangular or other suitable wave form instead of the described sinusoidal wave form. Also, control arrangement 50 need not necessarily select the quench-frequency component of the receiver quiescent signal output as the above-described second signal for rectification by rectifier 60. If desired, the selector circuits of unit 50 may be arranged to select, as the second signal, a portion of the noise-signal components of the quiescent signal output.

In the described transpondor system the receiver and transmitter share a common frequency-determining circuit. It will be understood that the invention is equally applicable to other transpondor arrangements as, for example, one wherein a single regenerative oscillatory circuit is utilized for both receiving and transmitting. Likewise, the invention may be utilized in a transpondor system having completely independent receiver and transmitter portions but including some arrangement, such as an antenna system, through which the transmitted signal may be fed back to the receiver.

It will also be understood that the invention may be applied to a superheterodyne, as distinguished from a superregenerative, receiver. In such a case the gain-control system of the invention likewise comprises an arrangement for deriving a control voltage from the noise signal output of the receiver which is utilized to maintain the receiver noise signal at a predetermined level.

While there has been described what is at present considered to be the preferred embodiment of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is, therefore, aimed in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. A gain-control arrangement for a receiver for translating a received pulse-modulated signal having a repetition frequency which may vary over a wide frequency range comprising, means for deriving from said receiver an output signal having low-amplitude quiescent signal components and high-amplitude components determined by the pulse modulation of said received signal, means for translating said output signal to produce a second signal and including means responsive to said high-amplitude components for effectively eliminating from said output signal during the translation thereof an energy content which is at least substantially equal to all of the energy content contributed by said high-amplitude components to said output signal, means for rectifying said output signal to derive a control effect, and means for utilizing said control effect to control the gain of said receiver.

2. A gain-control arrangement for a superregenerative receiver having a given quench frequency and for translating a received pulse-modulated signal having a repetition frequency which may vary over a wide frequency range comprising, means for deriving from said receiver an output signal having low-amplitude quiescent signal components occurring at said quench frequency and high-amplitude signal components determined by the pulse modulation of said received signal, means for translating said output signal to produce a second signal and including means responsive to said high-amplitude components for effectively eliminating from said output signal during the translation thereof an energy content which is at least substantially equal to all of the energy content contributed by said high-amplitude components to said output signal, means for rectifying said second signal to derive a control effect, and means for utilizing said control effect to control the gain of said receiver.

3. A gain-control arrangement for a superregenerative receiver having a given quench frequency and for translating a received pulse-modulated signal having a repetition frequency which may vary over a wide frequency range comprising, means for deriving from said receiver an output signal having low-amplitude quiescent signal components occurring at said quench frequency and high-amplitude signal components determined by and occurring at the repetition frequency of the pulse modulation of said received signal, means for translating said output signal to produce a second signal and including means responsive to said high-amplitude components for effectively eliminating from said output signal during the translation thereof an energy content which is at least substantially equal to all of the energy content contributed by said high-amplitude components to said output signal, means for rectifying said second signal to derive a control effect, and means for utilizing said control effect to control the gain of said receiver.

4. A gain-control arrangement for a receiver for translating a received pulse-modulated signal having a repetition frequency which may vary over a wide frequency range comprising, means for deriving from said receiver an output signal having low-amplitude quiescent signal components and high-amplitude components determined by the pulse modulation of said received signal, means for translating said output signal to produce a second signal and including means responsive to said high-amplitude components for effectively eliminating from said output signal during the translation thereof an energy content which is substantially equal to all of the energy content contributed by said high-amplitude components to said output signal, means for rectifying said second signal to derive a control effect, and means for utilizing said control effect to control the gain of said receiver.

5. A gain-control arrangement for a receiver for translating a received pulse-modulated signal having a repetition frequency which may vary over a wide frequency range comprising, means for deriving from said receiver an output signal having low-amplitude quiescent signal components and high-amplitude components determined by the pulse modulation of said received signal, means for translating said output signal to produce a second signal and including amplitude-responsive means responsive to said high-amplitude components for effectively eliminating from said output signal during the translation thereof an energy content which is at least substantially equal to all of the energy content con-

tributed by said high-amplitude components to said output signal, means for rectifying said second signal to derive a control effect, and means for utilizing said control effect to control the gain of said receiver.

6. A gain-control arrangement for a receiver for translating a received pulse-modulated signal having a repetition frequency which may vary over a wide frequency range comprising, means for deriving from said receiver an output signal having low-amplitude quiescent signal components and high-amplitude components determined by the pulse modulation of said received signal, means for translating said output signal to produce a second signal and including means responsive to said high-amplitude components of said output signal for effectively eliminating from said output signal during the translation thereof a portion of the energy content contributed thereto by said high-amplitude components and a portion of the energy content contributed to said output signal by said quiescent signal components which is at least substantially equal to the remaining portion of said energy content contributed to said output signal by said high-amplitude components, means for rectifying said second signal to derive a control effect, and means for utilizing said control effect to control the gain of said receiver.

7. A gain-control arrangement for a receiver for translating a received pulse-modulated signal having a repetition frequency which may vary over a wide frequency range comprising, means for deriving from said receiver an output signal having low-amplitude quiescent signal components and high-amplitude components determined by the pulse modulation of said received signal, means for translating said output signal to produce a second signal and including means responsive to said high-amplitude components of said output signal for effectively eliminating from said output signal during the translation thereof a portion of the energy content contributed thereto by said high-amplitude components and means responsive to said high-amplitude components of said output signal for eliminating from said output signal during said translation a portion of the energy content contributed thereto by said quiescent signal components which is at least substantially equal to the remaining portion of said energy content contributed to said output signal by said high-amplitude components, means for rectifying said second signal to derive a control effect, and means for utilizing said control effect to control the gain of said receiver.

8. A gain-control arrangement for a receiver for translating a received pulse-modulated signal having a repetition frequency which may vary over a wide frequency range comprising, means for deriving from said receiver an output signal having low-amplitude quiescent signal components and high-amplitude components determined by the pulse modulation of said received signal, means for translating said output signal to produce a second signal and including means responsive to said high-amplitude components of said output signal for effectively eliminating from said output signal during the translation thereof a portion of the energy content contributed thereto by said high-amplitude components and a signal repeater having means responsive to said high-amplitude componnts of said output signal for periodically blocking said repeater to eliminate from said output signal during said translation a portion of the energy content contributed thereto by said quiescent signal components which is at least substantially equal to the remaining portion of said energy content contributed to said output signal by said high-amplitude components, means for rectifying said second signal to derive a control effect, and means for utilizing said control effect to control the gain of said receiver.

9. A gain-control arrangement for a receiver for translating a received pulse-modulated signal having a repetition frequency which may vary over a wide frequency range comprising, means for deriving from said receiver an output signal having low-amplitude quiescent signal components and high-amplitude components determined by the pulse modulation of said received signal, means for translating said output signal to produce a second signal and including means responsive to said high-amplitude components of said output signal for effectively eliminating from said output signal during the translation thereof a portion of the energy content contributed thereto by said high-amplitude components and a vacuum-tube signal repeater having means responsive to said high-amplitude components of said output signal for periodically blocking said repeater to eliminate from said output signal during said translation a portion of the energy content contributed thereto by said quiescent signal components which is at least substantially equal to the remaining portion of said energy content contributed to said output signal by said high-amplitude components, means for rectifying said second signal to derive a control effect, and means for utilizing said control effect to control the gain of said receiver.

10. A gain-control arrangement for a receiver for translating a received pulse-modulated signal having a repetition frequency which may vary over a wide frequency range comprising, means for deriving from said receiver an output signal having low-amplitude quiescent signal components and high-amplitude components determined by the pulse modulation of said received signal, means for translating said output signal to produce a second signal, said last-named means including means responsive to said high-amplitude components of said output signal for effectively eliminating from said output signal during the translation thereof a portion of the energy content contributed thereto by said high-amplitude components and a signal repeater having means responsive to said high-amplitude components of said output signal for periodically blocking said repeater for intervals which are short with reference to the period corresponding to said repetition frequency of said received signal to eliminate from said output signal during said translation a portion of the energy content contributed thereto by said quiescent signal components which is at least substantially equal to the remaining portion of said energy content contributed to said output signal by said high-amplitude components, means for rectifying said second signal to derive a control effect, and means for utilizing said control effect to control the gain of said receiver.

11. A gain-control arrangement for a wave-signal transpondor system which is responsive to a received pulse-modulated signal having a predetermined carrier frequency and a repetition frequency which may vary over a wide frequency range for transmitting a pulse-modulated reply signal having a carrier frequency substantially equal to that of said received signal and a repe-

tition frequency related to that of said received signal comprising, means for deriving from said transpondor system an output signal having low-amplitude quiescent signal components and high-amplitude components determined by the pulse modulation of said reply signal, means for translating said output signal to produce a second signal and including means responsive to said high-amplitude components for effectively eliminating from said output signal during the translation thereof an energy content which is at least substantially equal to all of the energy content contributed by said high-amplitude components to said output signal, means for rectifying said second signal to derive a control effect, and means for utilizing said control effect to control the gain of said transpondor system.

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RADIANT-ENERGY SIGNAL DIRECTION FINDER

Filed Sept. 20, 1943 4 Sheets-Sheet 1

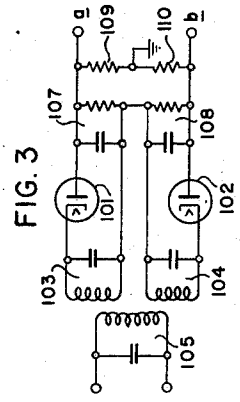


FIG. 3

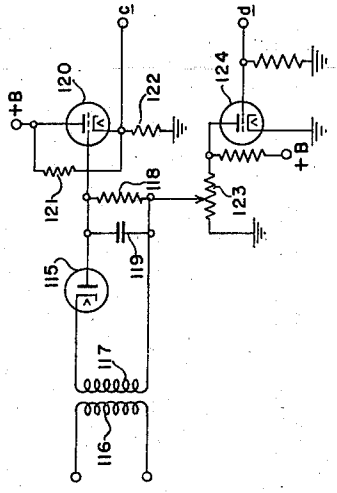


FIG. 4

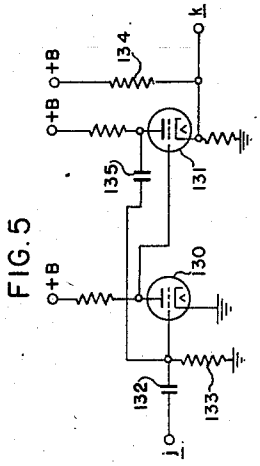


FIG. 5

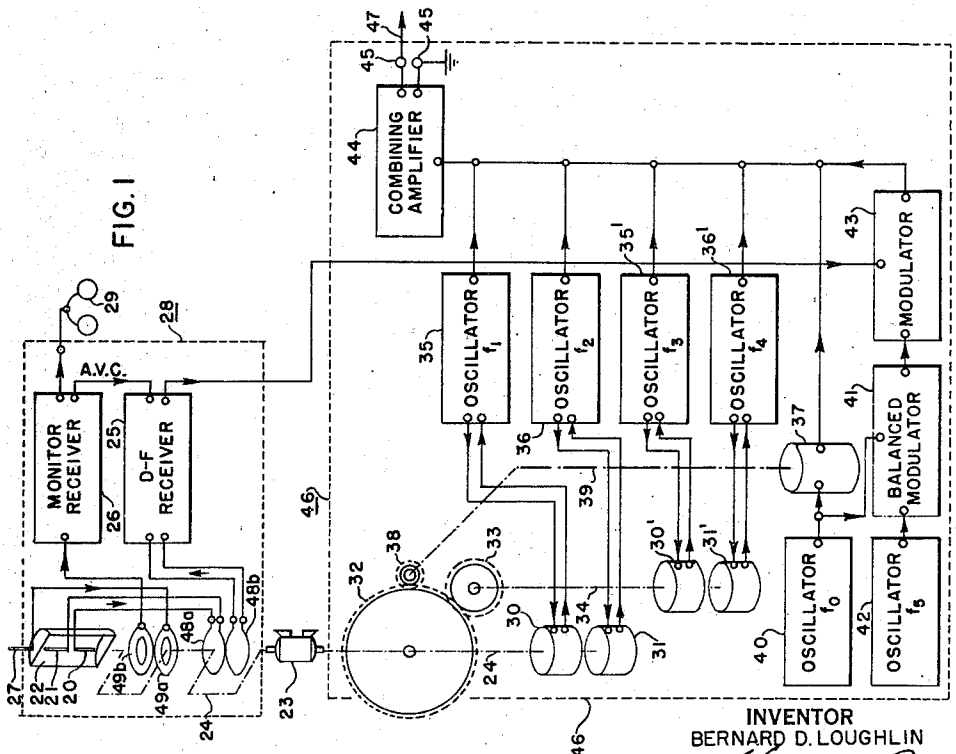


FIG. 1

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