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COMPLETE SPECIFICATION

Signal Strength Controlling Means for Signal Receiver Systems Employing Semi-Conductor Devices

We, TEXAS INSTRUMENTS INCORPORATED, of 6000 Lemmon Avenue, Dallas, Texas, United States of America, a corporation organized and existing under the laws of the State of Delaware, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to signal strength controlling means for signal receiver systems employing semi-conductor devices automatically controlling the gain of signal-receiving systems.

In the transmission of signals, for example radio frequency signals, the amplitude diminishes rapidly after leaving the transmitting antenna so that the strength of the signals received by the antenna of a radio receiver is a function of the distance of the receiving antenna from the transmitting antenna. Thus, where a radio receiver is tuned from a distant transmitting station to a nearby transmitting station or where the receiver is moving toward a transmitting station such as in an automobile, the signals at the receiver antenna may either change from low to high amplitude or gradually increase in amplitude. Depending upon the power of the transmitting antenna and the proximity of the receiving antenna, it is possible to receive signals of such amplitude that the first amplification stage or stages of the receiver will be overloaded to the point where no recognizable output can be obtained. This signal strength factor has been solved more or less satisfactorily in vacuum-tube radios by the use of variable gain remote cut-off vacuum-tubes which are capable of handling large signals without overload at reduced gain. The problem is present to a much greater extent in transistor radios for the reason that present transistors are essentially sharp cutoff devices and, in common with sharp cutoff vacuum-tubes, cannot handle large signals at

reduced gain because of the extreme curvature of the transfer characteristics when operating near cutoff (low gain).

Various automatic gain control circuits, well-known in the prior art, such as are discussed on pages 181—192 of the book "Radio and Television Receiver Circuitry and Operation" by Alfred A. Chirardi and J. Richard Johnson, have been associated with the receiver antenna and tuning circuit to reduce the signal level input to the first or radio frequency amplifier stage of the receiver. These automatic gain control circuits, referred to hereinafter as AGC circuits, usually fall within either one or the other of two general types of circuits. In the first type, a variable resistance device whose resistance decreases with increasing signal level is connected in shunt with the tuning circuit to the first amplification stage of the receiver. The second type of circuit uses a variable resistance device whose resistance increases with increasing signal level and has this device connected in series between the receiving antenna and the tuning circuit for the receiver.

For several reasons, neither type of prior art circuit has been entirely satisfactory with transistors. The last type of AGC circuit has used such variable resistance devices as photo-electric cells and glow tubes, neon tubes, thermistors and rectifiers. Some of these variable resistance devices are subject to one or more of the objections that a considerable amount of control power is required to control the resistance, lack of ability to follow closely changes in signal level and discontinuous rather than smooth, continuous control. In the second type of AGC circuit, the variable resistance in series between the antenna and the tuning circuit for the receiver cannot be used with a loop-type antenna circuit. Perhaps most important of all, in both types of circuits, the range of signal level control available is limited by the resistance range of the variable resistance device; consequently, when the re-

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sistance range of the device has been exceeded, the AGC circuit no longer functions to control the signal level.

5 It is a principal object of this invention to provide improved means for extending the signal control range of a receiving system whereby the normal AGC circuitry controls the signal level in the receiver until a pre-determined level is reached and thereafter signal level control is accomplished or assisted by means of the non-linear resistance means.

10 According to the invention signal strength controlling means for signal receiver systems employing at least one plural electrode semiconductor device connected to amplify the signal is characterised by a first automatic gain control arrangement connected so as to continuously apply, to at least one electrode of said device, a unidirectional potential which varies in accordance with the input signal magnitude, and a second automatic gain control device which comprises a voltage sensitive arrangement having a two electrode substantially continuous non-linear resistance connected by the two electrodes in shunt with the signal path to receive from a different electrode of said semiconductor device a unidirectional bias potential which renders said non-linear resistance conductive only for input signal magnitudes above a given value at the receiver.

A preferred embodiment of the invention uses as a non-linear resistance a voltage-sensitive diode which unlike current sensitive resistances such as thermistors, requires nominal amounts of control power and has the ability to follow closely and smoothly changes in signal level. Since the invention is most applicable to transistor receivers, the diodes in such receivers are p-n junction semiconductor diodes in which the semiconductor material may be either germanium or silicon. In the preferred embodiment a voltage divider circuit applies a fixed reference voltage to the diode in such a direction and polarity as to bias it in the condition for conduction. A second voltage, derived from the normal AGC circuit of the radio receiver, is also applied to the diode but in such a direction and polarity as to bias the diode for non-conduction. The voltage derived from the AGC circuit is greater than the fixed reference voltage until a predetermined level is reached and, consequently, the diode has very little or no effect below this level and signal control in the radio receiver is by means of the normal AGC circuit. However, as the incoming signals increase above the predetermined level, the AGC voltage to the diode decreases below the fixed reference voltage and the diode, then being in a conductive condition, takes over the signal level control of the receiver. By affecting the impedance loading on the inductance coil of the parallel tuned circuit, the diode bypasses to ground a portion of the signals in proportion

to their amplitude and thus reduces the amplitude of the signals received in the amplification stage or stages of the receiver.

The invention will now be described by way of example with reference to the accompanying drawings in which:—

Figure 1 is a partial schematic diagram of a radio receiver illustrating principally the automatic gain control circuit of this invention; and

Figure 2 is a forward current curve of a typical p-n junction semiconductor diode plotted against voltage showing thereby its non-linear resistance characteristics.

Referring now to Figure 1, only that portion of a signal receiving system, represented as a radio receiver, necessary to describe the present invention is shown. Transistors are used in the radio receiver circuit of Figure 1 and the voltages applied to the transistors will be discussed hereinafter in terms of the voltage polarities appropriate for n-p-n transistors. However, it should be recognised that p-n-p transistors could be used in place of the n-p-n transistors by reversing the DC polarities of the voltages as discussed. The non-linear resistance diode element will be discussed in terminology appropriate for a p-n junction semi-conductor diode although a vacuum-tube diode could be suitably substituted in its place.

Radio frequency signals are received by an antenna 10, the antenna being shown as comprised of an antenna coil 10a and a ferrite core 10b. In parallel with antenna 10 is a variable capacitor 11 and a fixed capacitor 12 forming thereby a parallel tuned circuit in which the variable capacitor 11 tunes the circuit to resonance at the desired signal frequency. It should be recognised at this point that this invention is not limited to the ferrite core antenna as shown since the radio frequency signals can be received by any conventional antenna and fed, for example, to a parallel tuned circuit comprised of coil 10a and variable capacitor 11.

A second coil 13 is wound on the ferrite core 10b and voltages corresponding to the radio frequency signals received at the antenna are induced in coil 13 and fed through a blocking capacitor 14 into the base of transistor 15. Coil 13 has a smaller number of coil turns than coil 10a in order to provide an impedance match between the high impedance of the parallel tuned circuit at resonance and the low input impedance of the base of transistor 15. Transistor 15, as shown, serves as the radio frequency amplifier and mixer stage and receives at its emitter the output of an oscillator circuit through lead 16¹. As is well-known in super-heterodyne receivers, the oscillator frequency is mixed with the input signal frequency to produce an intermediate frequency, usually of 455 kilocycles although 262 kilocycles is another common intermediate

frequency. In the biasing circuit for transistor 15, a positive voltage is shown as being applied through the primary coil of the intermediate frequency transformer 16 to its collector.

The intermediate frequency signals from transistor 15 are coupled into the base of transistor 17, the first intermediate frequency amplifier stage of the receiver, through the double tuned intermediate frequency transformer 16. Transistor 17, like transistor 15, has a low input impedance and thus, the input lead to the base is tapped on the secondary coil of transformer 16 to provide an impedance match with the output of transistor 15. In order to bias the n—p—n transistor 17 for amplification, the emitter-base diode is biased in the forward direction and the collector-base diode is biased in the reverse direction. Therefore, to obtain the proper bias conditions, the DC emitter voltage of transistor 17 is negative with respect to the base and the DC collector voltage is positive with respect to the base. The amplifier intermediate frequency signals are fed from transistor 17 through one or more succeeding stages of intermediate frequency amplification and from there to a detector. In the detector, the audio-frequency signals are first detected and then coupled into a conventional audio-frequency amplifier and sound reproducer. In addition, the detector produces a negative DC voltage proportional to the signal level received, which voltage is fed back as a negative AGC voltage to the base of transistor 17 through line 18 and the series-connected secondary of transformer 16. Bypass condenser 19 is connected into line 18 to provide a low impedance path to ground for AC signals, both audio frequency from the detected signal and radio frequency from transformer 16.

To form the second AGC circuit, according to the present invention, a p—n junction semiconductor diode 22 is connected in shunt across the antenna 10 and thus across the parallel tuned circuit comprised of coil 10a and capacitor 11. A fixed reference voltage E_2 is obtained by feeding the B_+ battery voltage through a voltage divider network consisting of resistors 24 and 25. A line 26 is tapped in between resistors 24 and 25 and feeds the reference voltage E_2 developed across resistor 24 through coil 10a to the diode 22. A second voltage E_1 to diode 22 is developed across resistor 20 and connected in series with the emitter of transistor 17 to ground. The voltage E_1 , produced by the emitter current through resistor 20, is fed through lead 27 and the series-connected resistor 21 to the other side of diode 22 from the E_2 voltage connection.

Although a circuit arrangement has been described for providing the bias voltages E_1 and E_2 to diode 22, it is possible to provide these voltages in other ways. For example, E_2 can be derived from some other point of fixed

voltage in the circuit and thus the voltage divider network of resistors 24 and 25 eliminated. Similarly, the variable bias voltage E_1 need not necessarily come from the emitter of transistor 17 since the voltage E_1 could be developed across a suitable resistor (not shown) in the collector DC return, provided suitable adjustments were made in the fixed reference voltage E_2 . This latter connection has the added advantage that considerable amplification of the normal AGC control voltage may be obtained in transistor 17, and thus a greater control of diode 22 is possible.

In operation, the circuit provides improved AGC control in the following described manner. With low level signal inputs to the antenna, there is little AGC voltage developed and the emitter of transistor 17 remains considerably negative with respect to the base. In this condition, the emitter current is normally 0.5 to 1.0 milliamps and, since resistor 20 may have a typical value of from 470 ohms to 2200 ohms, the voltage E_1 developed is equal to the emitter current times the resistance of resistor 20. The voltage E_2 is set by the voltage divider network of resistors 24 and 25 to be somewhat less than E_1 , the exact value not being critical. However, it is desired for the p—n junction diode 22 to have no effect on the input signals until a predetermined signal level has been reached and so the diode connection is such that the n-type side of the junction is connected with the voltage E_1 and the p-type side of the junction is connected with E_2 . Since E_1 is then positive with respect to E_2 , the p—n junction diode will be biased in the reverse direction for current flow and thus has substantially no effect on the antenna coil.

Then, as the signal level in the receiver increases, the larger amount of negative AGC voltage to the base of transistor 17 reduces the bias between the base and the emitter and the emitter current drops. As the emitter current drops, voltage E_1 drops and the bias existing across 22 is reduced. At a predetermined amplitude of input signal level, the voltage E_1 drops to a point below the fixed voltage E_2 and diode 22 will then be biased in the forward direction. Depending upon the strength of the signal and the amount of voltage E_2 , diode 22 will be set to operate around some point along the current-voltage curve shown in Figure 2. As can be seen from the curve of Figure 2, the current is not a linear function of the voltage and, therefore, when diode 22 is biased only slightly in the forward direction, the diode will operate in the higher resistance portion of the curve. However, as the signal level increases and the operating point of diode 22 is shifted to a higher point on the curve, its resistance will be lower thus permitting a greater amount of current to flow.

When diode 22 is biased in the forward

direction for conduction, the diode in effect represents a low impedance shunt across the parallel tuned circuit. The effect of this low shunt impedance is to load the coil 10a in an amount inversely related to the impedance of the diode. Depending upon the diode loading on coil 10a, a proportionate part of the signal received at the antenna is bypassed to ground through diode 22, resistor 21, line 27 and the bypass capacitor 23 around resistor 20. To illustrate the effectiveness of the circuit of this invention, the typical increase in signal amplitude before the overload point is reached is 26 db over the same receiver without this circuit. By choosing the value of resistor 21 and tapping diode 22 down on the antenna coil 10a, various increases in overload characteristics may be obtained with great smoothness in operation.

The circuit of this invention also helps to overcome the sharpening of tuning which occurs with transistor receivers in the presence of strong signals as automatic gain control is applied. Sharpening of the bandpass frequency occurs since the input impedance of the intermediate frequency transistor amplifier is raised as current and gain is reduced by the action of the automatic gain control. This, in turn, has a tendency to narrow the bandpass characteristics of the intermediate frequency transformer, because of the reduced loading on the transformer. The diode 22, however, as a shunt resistance, increases the loading on the antenna coil and broadens the bandpass characteristic of the tuned input circuit. Thus, these two opposing factors act to cancel each other and the bandpass tends to remain constant.

WHAT WE CLAIM IS:—

1. Signal strength controlling means for signal receiver systems employing at least one plural electrode semiconductor device connected to amplify the signal, said means being characterized by a first automatic gain control arrangement connected so as to continuously apply, to at least one electrode of said device, a unidirectional potential which varies in accordance with the input signal magnitude, and a second automatic gain control device which comprises a voltage sensitive arrangement having a two electrode substantially continuous non-linear resistance connected by the two electrodes in shunt with the signal path to receive from a different electrode of said semiconductor device a unidirectional bias potential which renders said non-linear resist-

ance conductive only for input signal magnitudes above a given value at the receiver.

2. Means according to Claim 1, characterized by the fact that the voltage sensitive arrangement with the non-linear resistance is connected in parallel to a tuned input circuit of the receiver system and varies the load impedance of the input circuit by an amount related to the bias across the arrangement.

3. Means according to Claim 1 in which the second automatic gain control device is characterized by a signal receiving circuit to which the voltage-sensitive arrangement having a non-linear resistance is connected in parallel, to which a fixed voltage is applied and to which as a function of the input signal level at the receiver system a variable voltage is applied, these two voltages biasing the arrangement in such a manner that is non-conductive below a given signal level and conductive above said level, so that this arrangement, while it is conductive, maintains the output signal level of the receiving system substantially constant.

4. Means according to Claim 2 or 3, characterized by the fact that the voltage-sensitive arrangement of non-linear resistance is a diode.

5. Means according to Claim 2 or 3, characterized by the fact that the voltage-sensitive arrangement is a p—n junction semiconductor diode.

6. System as claimed in Claim 1 in which the second automatic gain control device is characterized by a tuned parallel signal input circuit to which there is connected in parallel a diode to which a fixed voltage is applied and to which a variable voltage is applied as a function of the input signal to the receiving system, these voltages so biasing the arrangement that it is non-conductive below a given signal level and is conductive above said level, whereby the diode, while it is conductive, maintains the output signal level of the receiving system substantially constant.

7. Means according to Claim 6, characterized by the fact that the parallel tuned signal input circuit is formed of a loop antenna and a variable capacitor.

8. Means according to Claim 7, characterized by the fact that the loop antenna contains a ferrite core.

9. Means according to Claim 3, 6, 7 or 8, characterized by the fact that the fixed voltage is supplied by a voltage divider.

10. Means according to any one of the preceding claims, characterized in that the re-

direction for conduction, the diode in effect represents a low impedance shunt across the parallel tuned circuit. The effect of this low shunt impedance is to load the coil 10a in an amount inversely related to the impedance of the diode. Depending upon the diode loading on coil 10a, a proportionate part of the signal received at the antenna is bypassed to ground through diode 22, resistor 21, line 27 and the bypass capacitor 23 around resistor 20. To illustrate the effectiveness of the circuit of this invention, the typical increase in signal amplitude before the overload point is reached is 26 db over the same receiver without this circuit. By choosing the value of resistor 21 and tapping diode 22 down on the antenna coil 10a, various increases in overload characteristics may be obtained with great smoothness in operation.

The circuit of this invention also helps to overcome the sharpening of tuning which occurs with transistor receivers in the presence of strong signals as automatic gain control is applied. Sharpening of the bandpass frequency occurs since the input impedance of the intermediate frequency transistor amplifier is raised as current and gain is reduced by the action of the automatic gain control. This, in turn, has a tendency to narrow the bandpass characteristics of the intermediate frequency transformer, because of the reduced loading on the transformer. The diode 22, however, as a shunt resistance, increases the loading on the antenna coil and broadens the bandpass characteristic of the tuned input circuit. Thus, these two opposing factors act to cancel each other and the bandpass tends to remain constant.

WHAT WE CLAIM IS:—

1. Signal strength controlling means for signal receiver systems employing at least one plural electrode semiconductor device connected to amplify the signal, said means being characterized by a first automatic gain control arrangement connected so as to continuously apply, to at least one electrode of said device, a unidirectional potential which varies in accordance with the input signal magnitude; and a second automatic gain control device which comprises a voltage sensitive arrangement having a two electrode substantially continuous non-linear resistance connected by the two electrodes in shunt with the signal path to receive from a different electrode of said semiconductor device a unidirectional bias potential which renders said non-linear resist-

ance conductive only for input signal magnitudes above a given value at the receiver.

2. Means according to Claim 1, characterized by the fact that the voltage sensitive arrangement with the non-linear resistance is connected in parallel to a tuned input circuit of the receiver system and varies the load impedance of the input circuit by an amount related to the bias across the arrangement.

3. Means according to Claim 1 in which the second automatic gain control device is characterized by a signal receiving circuit to which the voltage-sensitive arrangement having a non-linear resistance is connected in parallel, to which a fixed voltage is applied and to which as a function of the input signal level at the receiver system a variable voltage is applied, these two voltages biasing the arrangement in such a manner that is non-conductive below a given signal level and conductive above said level, so that this arrangement, while it is conductive, maintains the output signal level of the receiving system substantially constant.

4. Means according to Claim 2 or 3, characterized by the fact that the voltage-sensitive arrangement of non-linear resistance is a diode.

5. Means according to Claim 2 or 3, characterized by the fact that the voltage-sensitive arrangement is a p—n junction semiconductor diode.

6. System as claimed in Claim 1 in which the second automatic gain control device is characterized by a tuned parallel signal input circuit to which there is connected in parallel a diode to which a fixed voltage is applied and to which a variable voltage is applied as a function of the input signal to the receiving system, these voltages so biasing the arrangement that it is non-conductive below a given signal level and is conductive above said level, whereby the diode, while it is conductive, maintains the output signal level of the receiving system substantially constant.

7. Means according to Claim 6, characterized by the fact that the parallel tuned signal input circuit is formed of a loop antenna and a variable capacitor.

8. Means according to Claim 7, characterized by the fact that the loop antenna contains a ferrite core.

9. Means according to Claim 3, 6, 7 or 8, characterized by the fact that the fixed voltage is supplied by a voltage divider.

10. Means according to any one of the preceding claims, characterized in that the re-



ceiving system employs at least one transistor.

11. A signal receiving system having automatic gain control means substantially as described and as shown in the accompanying drawings.

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