

May 20, 1947.

M. G. CROSBY

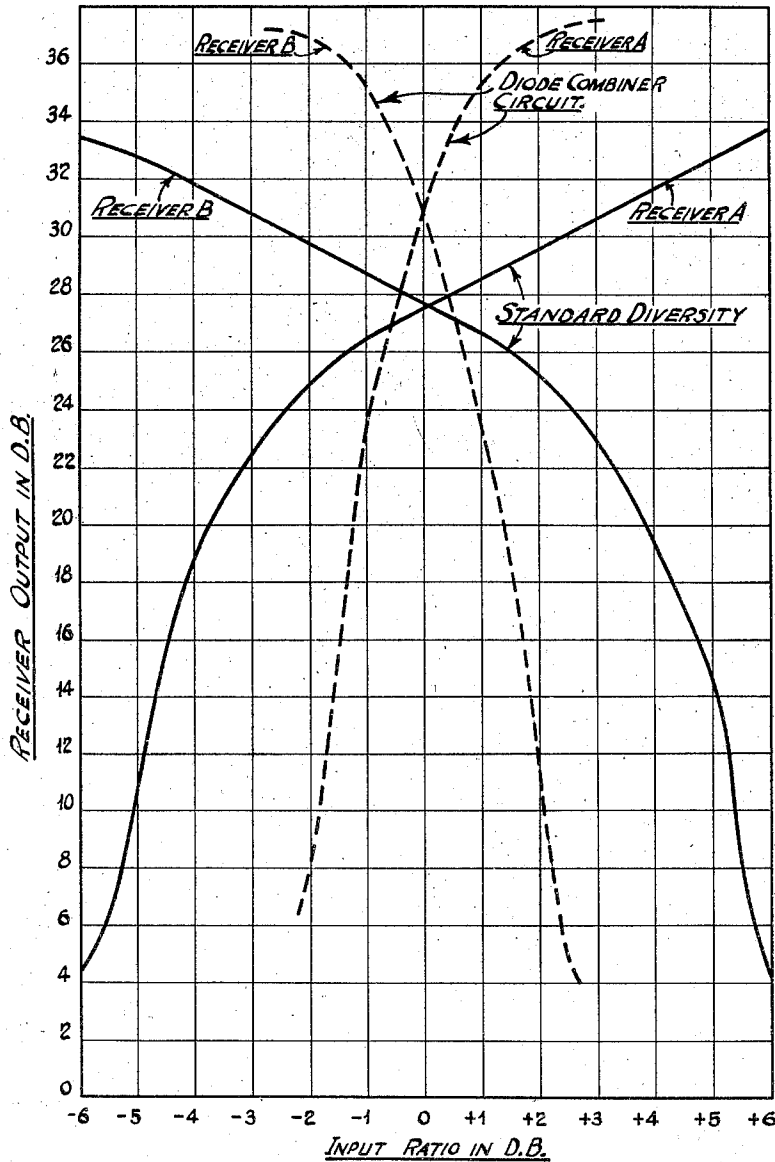
2,420,868

DIVERSITY COMBINING CIRCUIT

Filed April 22, 1943

3 Sheets-Sheet 1

Fig. 1.



INVENTOR
MURRAY G. CROSBY.
BY *H. G. Snow*
ATTORNEY

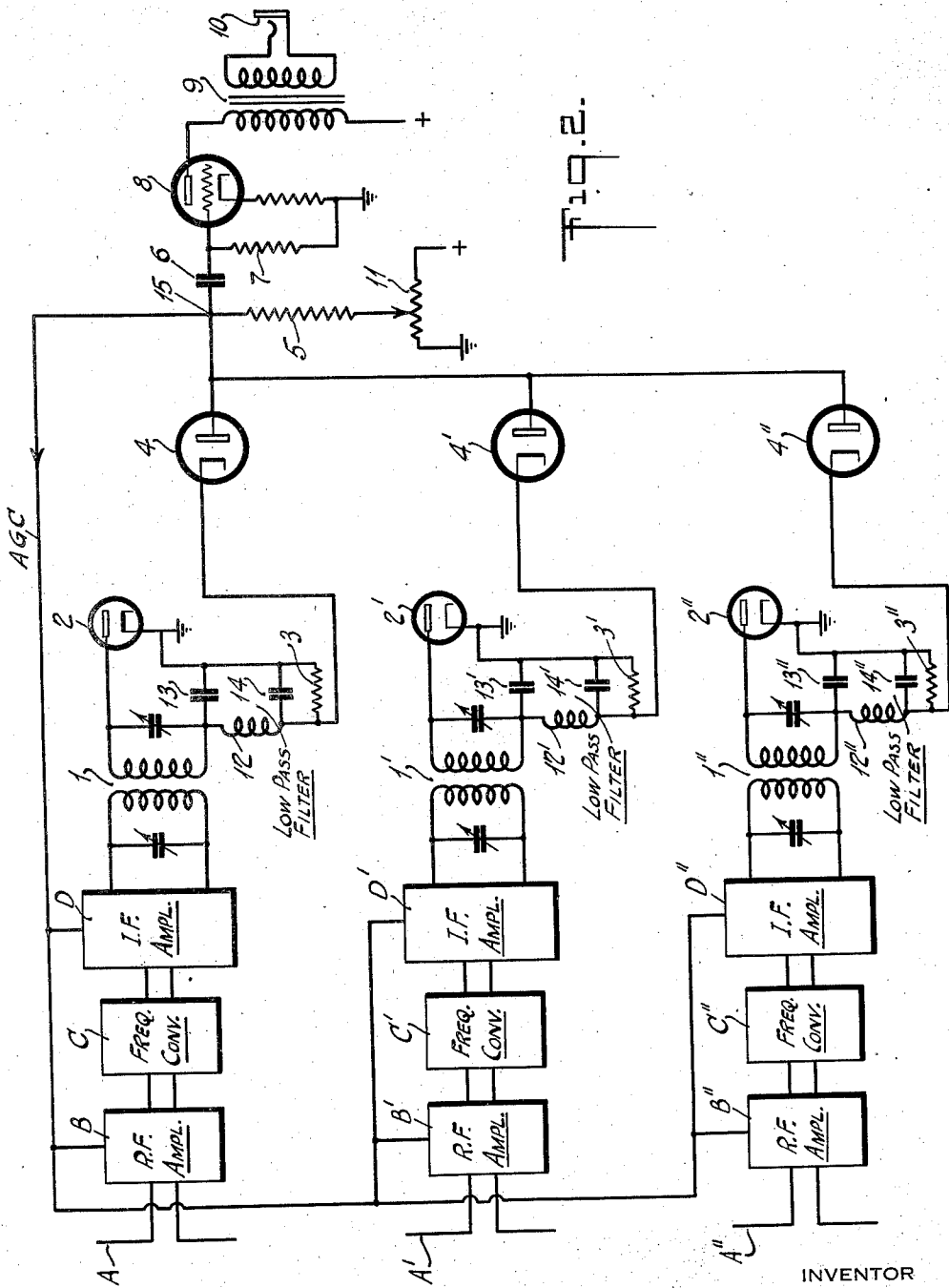
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M. G. CROSBY
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3 Sheets-Sheet 2



INVENTOR
MURRAY G. CROSBY.
BY *H. Brown*
ATTORNEY

May 20, 1947.

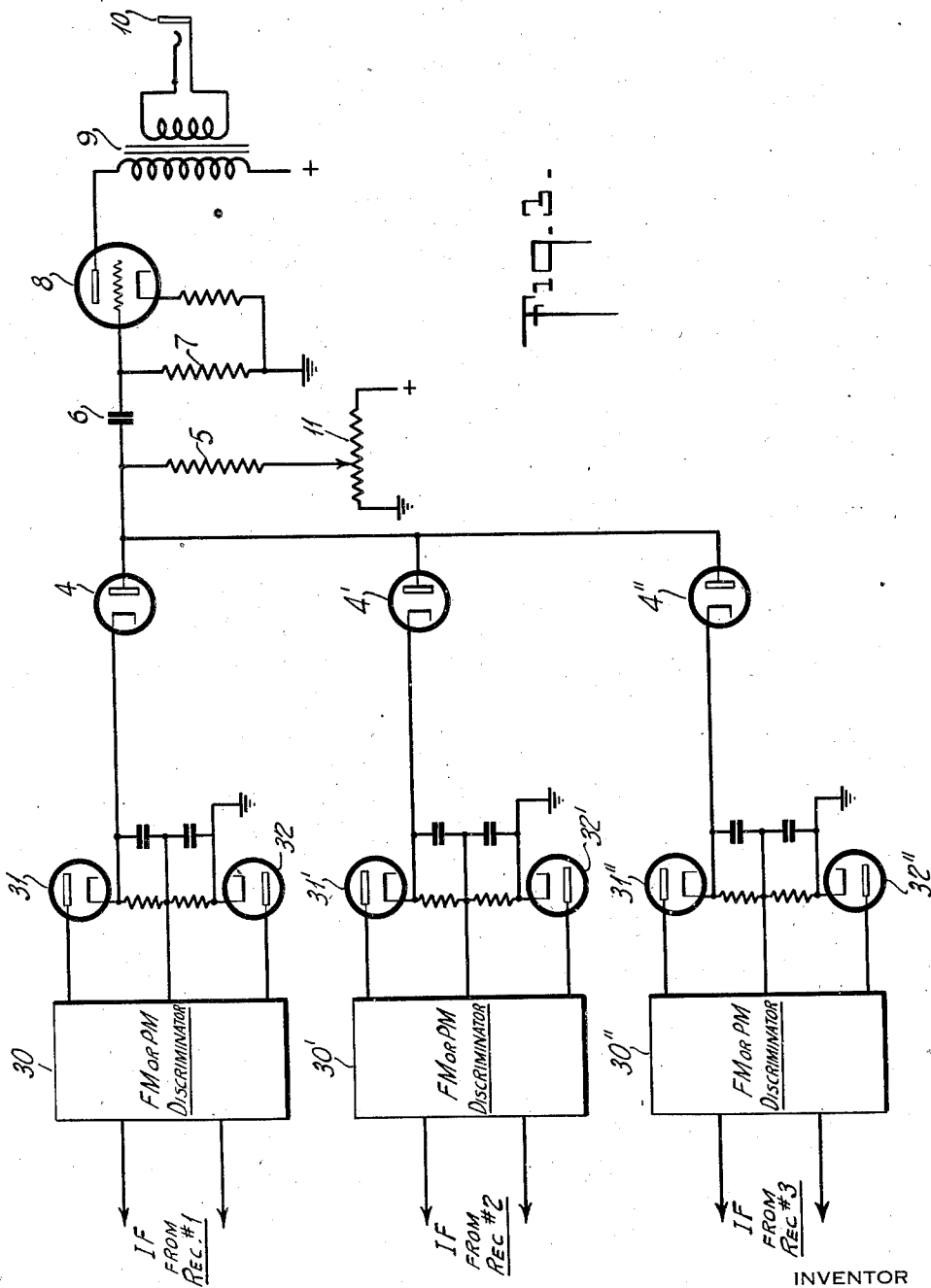
M. G. CROSBY

2,420,868

DIVERSITY COMBINING CIRCUIT

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3 Sheets-Sheet 3



INVENTOR
MURRAY G. CROSBY.
BY *H. B. Grover*
ATTORNEY

UNITED STATES PATENT OFFICE

2,420,868

DIVERSITY COMBINING CIRCUIT

Murray G. Crosby, Riverhead, N. Y., assignor to
Radio Corporation of America, a corporation
of Delaware

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17 Claims. (Cl. 250—20)

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This invention concerns diversity reception in which the outputs of several radio receivers are combined to reduce the effects of fading. In the system of the present invention, the individual receiver outputs are combined in a common output circuit in such manner that the stronger signal overcomes the weaker signal more rapidly than in prior systems. This feature of the present invention reduces the possibility of more than one receiver in the diversity system contributing to the common output at one time and producing distortion.

Heretofore, in the art of diversity reception, the detected outputs of the receivers have been combined by connecting the diode outputs to a common resistor. The strongest signal therefore appearing in any one receiver of the diversity system develops a bias across the common resistor as a result of which those diodes of the other receivers which are fed the weaker signals are biased in such manner that they draw a reduced current. Consequently, the stronger signal of the various receivers of the diversity system takes control of the common output and biases the weaker signals so that they contribute less energy to this common output. While this selecting action effected by the use of a common diode resistor in prior art diversity systems is effective, there is room for improvement because there is a considerable range over which the stronger signal received by a receiver in the diversity system does not completely switch off the weaker signal simultaneously received by the other receivers in the same system. Measurements have indicated that with such an arrangement as known in the art, the stronger signal must be approximately 1.8 times stronger than the weaker signal before the contribution from the weaker signal is made to be negligible. Hence, over this range in which both the strong and the weak signals contribute to the common output, there is the possibility of distortion and other fading effects since the modulations received on both the strong and weak signals may arrive out of phase and cancel.

In the system of the present invention, this range over which both the stronger and weaker signals contribute to the common output is considerably reduced. The possibility of cancellation distortion in the common output is therefore reduced. Measurements have indicated that with the system of the invention, the contribution by the weaker signal is negligible when the stronger signal is only 1.16 times the weaker, as compared

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to the 1.8 figure required in prior diversity systems.

A better understanding of the invention may be had in the following description, which is accompanied by a drawing wherein:

Fig. 1 graphically illustrates, for comparison purposes, the input-output characteristics of the individual receivers of a diversity system as arranged both conventionally and in accordance with the invention; and

Figs. 2 and 3 illustrate, schematically, two diversity receiving systems embodying the principles of the present invention.

Fig. 1 shows, in solid line curves, measured characteristics of the conventional standard diversity system using the common diode resistor and the corresponding selection characteristics, and shows in dash line curves, measured characteristics of the combining circuit of the present invention. The curves of Fig. 1 were obtained by applying carriers modulated with different modulating tones to the two receivers of a two-receiver diversity system. The different tones were selected in the common output circuit by means of audio filters. Hence, the relative amplitudes of the tones gave an indication of the relative amount of output signal contributed by each receiver. For instance, when the input carriers had an amplitude ratio of -2 decibels, receiver B of the conventional diversity system contributed a 29.8 decibel signal to the output, as indicated, while receiver A of the conventional diversity system contributed 24.8 decibels. At this same input carrier ratio, the diode combiner circuit of the present invention gave an output of 37 decibels for receiver B and 8 decibels for receiver A. Thus, in the case of the conventional diversity receiver combination, the stronger signal had overcome the weaker signal by a difference of $29.8 - 24.8 = 5.0$ decibels. In the case of the diode combiner circuit of the present invention, however, the corresponding difference is $37 - 8 = 29$ decibels. It is thus apparent that the selecting action of the diversity system of the invention is much more rapid and positive than the conventional diversity system.

Fig. 2 diagrammatically shows the diversity system of the invention as it was used in obtaining the curves in dash lines of Fig. 1. The system of Fig. 2 shows three similar receivers. Since the apparatus at the three receivers are similar and similarly arranged, the units of the second and third receivers have been given the same reference numerals as the first receiver, with the addition of prime designations. The operation

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of all three receivers is the same. Each receiver includes an antenna A, A' or A'', a radio frequency amplifier B, B' or B'', a frequency converter C, C' or C'', and an intermediate frequency amplifier D, D' or D''. Each receiver may have its own local beating oscillator (not shown) connected to the frequency converter; or, if desired, there may be used a common beating oscillator for all three receivers. The output circuits of the intermediate frequency amplifiers have been designated by transformers 1, 1' and 1'', and these transformers respectively feed diodes 2, 2' and 2''. Transformers 1, 1' and 1'' pass the intermediate frequency outputs of the three receivers to be combined. These intermediate frequency outputs are rectified by diodes 2, 2' and 2'' so that the respective detected outputs appear on resistors 3, 3' and 3''. Coupled to the output of each intermediate frequency amplifier in each receiver there is provided a low pass filter 12, 13 and 14 which removes intermediate frequency energy from the detected output and also acts as a by-pass capacitor across the diode resistor 3.

The rectified outputs from the three receivers are connected through diode tubes 4, 4' and 4'' to a common point 15 which is the high potential side of resistor 5. The low potential side of resistor 5 is supplied with positive potential by means of potentiometer 11. The combined output from the three receivers, which appears across resistor 5, is fed to the control grid of audio amplifier 8 through blocking condenser 6 and is made available at jack 10 for utilization by any suitable translation device, such as a loud-speaker or head set, or a recorder. Automatic gain control potentials are taken from the high potential side of resistor 5 and fed over lead AGC to bias the grids of the radio frequency and intermediate frequency amplifiers. In effect, the diode tubes 4, 4' and 4'' function as variable resistors since the diode which passes the signal is biased to such a point on its anode current characteristic that it passes current for both positive and negative applied input voltages.

In the operation of the diversity system of the invention, let it be assumed for the sake of simplicity that signals are present in only the first two of the receivers and appear in transformers 1 and 1'. When these two signals are equal in amplitude, equal currents will flow through diodes 4 and 4' so that both receivers will contribute an equal amount to the common output. If the amplitude of the signal in transformer 1 rises above that of the signal in transformer 1', the negative voltage fed from resistor 3 through diode 4 to resistor 5 will be greater than that fed from resistor 3' through diode 4' to 5. This will raise the negative voltage appearing across resistor 5, due to the increased current flow therein, so that the plate of diode 4' is relatively more negative than its cathode. Such a condition will cut off the current through diode 4'. Hence diode 4' will act as an open circuit and will not pass energy from resistor 3' to the common output resistor 5. Thus, the stronger signal from transformer 1 is left to furnish the output for the audio frequency amplifier 8, while the weaker signal is switched off.

The operation of the system of the invention with signals present in all of the receivers is the same as that described above for two signals present. The stronger signal assumes control of the voltage on the output resistor 5 and automatically switches off the current fed

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through the diodes which do not have enough negative voltage on their cathodes to overcome the negative voltage on their anodes.

By experimentation, I have found that the positive voltage fed to the low potential side of resistor 5 by means of potentiometer 11, removes distortion. Without this positive bias voltage on the potentiometer, a negative peak clipping (a form of distortion) occurred which was similar to the negative peak clipping which occurs when a diode is operated as a detector feeding into an audio load which is too low. The adjustment of this positive voltage on the potentiometer 11 is not critical to remove this type of distortion, and thus requires no voltage regulator. Comparison measurements made of distortion in the apparatus of the diversity system of the invention without connection to the antennas show the relative same low value of about 2% distortion which is present in the conventional diversity method of combination. Such measurements were made by a signal generator to determine the linear characteristics of the system, and should not be confused with fading distortion which occurs during reception of radio signals.

In the experimental set up, diode resistors 3, 3' and 3'' were 13,000 ohms. Diodes 4 were of the RCA 6H6 type. Output resistor 5 was one megohm. Potentiometer 11 was 40,000 ohms and was adjusted to apply a positive bias of about 20 volts to the low potential side of resistor 5.

Although the receiving system of Fig. 2 (as shown) is designed for receiving amplitude modulated waves, the principles of the invention are equally applicable to frequency and phase modulation diversity receivers, provided that in the last two systems the signals are detected by suitable apparatus including frequency or phase modulation discriminators, without limiters preceding the discriminators. Fig. 3 shows only the essential features of such frequency or phase diversity receivers. The antennas, frequency converters and intermediate frequency amplifiers of the three receivers have not been shown since they may follow the illustration of the system of Fig. 1 and their illustration is not necessary to an understanding of the system of Fig. 3. If a frequency modulation discriminator is employed, it may be of the type described in my United States Patent 2,295,092, granted September 15, 1942, or 2,243,417, granted May 27, 1941. If a phase modulation discriminator is employed, it may be of the type described in my United States Patent 2,233,773, granted March 4, 1941, or 2,204,575, granted June 18, 1940. The discriminators of the different receivers are labeled, respectively, 30, 30' and 30'' and respectively feed differential type detectors 31, 32; 31', 32' and 31'', 32''. When diversity reception is used with frequency modulation or phase modulation detectors, there should be no limiter in the receivers. The elimination of the limiters allows the detected outputs to vary in accordance with the signal strengths so that the combining system may choose the strongest signal. Were limiters used, the detected outputs would all be equal and the combining circuit would not be able to choose the best signal.

The term "angular velocity modulated waves" employed in the claims is deemed to include both frequency and phase modulated waves.

What is claimed is:

1. A diversity receiving system comprising a plurality of spaced antennas, a receiver coupled

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to each antenna and including an amplifier, a rectifier coupled to the output of said amplifier, a low pass filter in the space current path of the rectifier, a resistor in shunt to said filter, a diode tube having its cathode connected to a point on said resistor for deriving a negative voltage therefrom during the passage of current through the rectifier, direct connections between the anodes of the diode tubes in circuit with the different receivers, a resistor having one terminal directly connected in common to the anodes of said diode tubes and its other terminal connected to a source of positive potential, and an audio frequency amplifier having its input circuit coupled to said resistor.

2. In a diversity receiving system having a plurality of receivers feeding a common utilization circuit, each of said receivers including a radio frequency amplifier, a frequency converter, an intermediate frequency amplifier and a rectifier for rectifying the output of said intermediate frequency amplifier, said rectifier including a cathode connected directly to ground, a low pass filter shunted by a resistor in the space current path of said rectifier, said filter being located between the cathode and another electrode of said rectifier, a diode for each rectifier having a cathode directly connected to that terminal of said resistor which is farthest away from the cathode of said rectifier, means for directly connecting together the anodes of the diodes associated with the different receivers, a common load resistor having one terminal directly connected to the anodes of said diodes and another terminal connected to a potentiometer, a connection from one end of said potentiometer to ground, and a connection from the other end of said potentiometer to a positive polarizing potential, and an automatic gain control connection from the diode anode terminal of said common load resistor to the radio frequency and intermediate frequency amplifiers of said receivers.

3. A diversity receiving system comprising a plurality of receivers, an antenna coupled to the input side of each receiver, the several antennas being geographically spaced from one another, a common utilization circuit for the different receivers, selective means controlled by a predominant value of signal energy fed through any one receiver for instantly rendering that energy predominantly effective in said utilization circuit, said means being simultaneously and selectively effective to prevent the transfer of signal energy from the remaining receivers to said utilization circuit, said means comprising a rectifier and an electron discharge tube serially connected between the output of each receiver and the common utilization circuit, said electron discharge tubes each having an output electrode, a direct conductive connection between the output electrodes of said electron discharge tubes, whereby the passage of the strongest signal through one of said rectifiers and its associated electron discharge tube provides a bias which prevents current from passing through the other electron discharge tubes.

4. A diversity receiving system for angular velocity modulated waves, comprising a plurality of similar receivers each of which includes in the order named a radio frequency amplifier, a frequency converter, an intermediate frequency amplifier, a discriminator and a differential type detector for rectifying the output of said discriminator, a common utilization circuit for all said

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receivers, means for passing to said utilization circuit the signal from only that receiver having the largest incoming voltage, said means including electron discharge tube units for the different receivers for passing the rectified currents from the different differential type detectors, and a common load resistor for said electron discharge tube units, whereby the passage of current through any one electron discharge tube unit produces a direct component of voltage drop in said load resistor which appears as a negative bias on the other electron discharge tube units.

5. A diversity receiving system comprising a plurality of receiver channels each of which includes a rectifier for rectifying the output thereof, an electron discharge device resistor for each channel in circuit with the output of the rectifier of that channel and adapted to pass the rectified current thereof, a common direct current impedance element connected to the outputs of said electron discharge device resistors of all of said channels, and means for supplying a unidirectional potential to said common impedance element, whereby the flow of current through said impedance element caused by the flow of rectified current passing through one of said rectifiers and the discharge device resistors in circuit with its output produces a bias on the other discharge device resistors in such direction as to reduce their responsiveness.

6. A diversity receiving system comprising a plurality of spaced antennas, a receiver coupled to each antenna and including an amplifier and a rectifier following said amplifier, said rectifier deriving energy from the output of said amplifier, a tube connected to operate as a diode coupled to the output of the rectifier of each receiver, a common receiving circuit coupled to the outputs of said tubes, an impedance in the space current path of each rectifier, and means for biasing each said tube over a path including in series the said impedance of the rectifier in circuit with the same receiver, whereby the flow of current through a rectifier causes a direct current to flow through the impedance in its space current path and through the said tube coupled to its output and produces a change in the bias of the tubes in circuit with the outputs of the other rectifiers.

7. A diversity receiving system comprising a plurality of receiver channels each of which includes a rectifier for rectifying the output thereof, electron discharge device resistors respectively in circuit with the rectifiers of said different receiver channels and adapted to pass the rectified currents of the different receivers, each of said electron discharge device resistors having an output electrode, a common resistor having one terminal connected to the output electrodes of said electron discharge device resistors, and means for supplying a positive polarizing potential to the other terminal of said common resistor as a result of which polarizing potentials are supplied through the common resistor to all of said electron discharge device resistors, whereby the flow of current through said common resistor caused by the flow of rectified current passing through one of said rectifiers and the electron discharge device resistor in circuit therewith produces a bias on the other discharge device resistors in such direction as to reduce their responsiveness.

8. In a diversity receiving system having a plurality of receiver channels feeding a common utilization circuit, means for passing to said utilization circuit the signal from only that receiver channel having the largest incoming voltage, said

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means including a rectifier in each receiver channel for rectifying the alternating current in that channel, and also including an electron discharge device resistor for passing the rectified current from the rectifier, and a common load resistor for all of the discharge device resistors of said channels, whereby the passage of current through any one of said discharge device resistors produces a direct component of voltage drop in said load resistor which appears as a negative bias on the other discharge device resistors.

9. In a diversity receiving system having a plurality of receivers feeding a common utilization circuit, said receivers including amplifier stages, means for passing to said utilization circuit the signal from only that receiver having the largest incoming voltage, said means including a rectifier in circuit with each receiver for rectifying the alternating current signal in each receiver and an electron discharge resistor for each receiver for passing the rectified current therefrom, a common load resistor for said electron discharge resistors connected thereto by a direct current connection, whereby the passage of current through any one discharge device resistor produces a direct component of voltage drop in said load resistor which appears as a negative bias on the other discharge device resistors, and an automatic gain control connection from a point on said common load resistor to the amplifier stages of said receivers.

10. A receiving system for angular velocity waves, comprising in the order named a radio frequency amplifier, a frequency converter, an intermediate frequency amplifier, a discriminator and a differential type detector for rectifying the output of said discriminator, an electron discharge device resistor coupled to said differential type detector, a load resistor connected to the output of said discharge device resistor, and a utilization circuit coupled to said load resistor.

11. A receiving system for angular velocity waves, comprising in the order named a radio frequency amplifier, a frequency converter, an intermediate frequency amplifier, a discriminator and a differential type detector for rectifying the output of said discriminator, an electron discharge device resistor coupled to said differential type detector, a load resistor having one terminal connected to the anode electrode of said discharge device resistor and its other terminal connected to a source of positive potential, and an electron discharge device utilization circuit having its input coupled to the first terminal of said load resistor.

12. In a diversity receiving system having a plurality of receivers feeding a common utilization circuit, each of said receivers including a radio frequency amplifier, a frequency converter, an intermediate frequency amplifier and a rectifier for rectifying the output of said intermediate frequency amplifier, said rectifier including a cathode connected directly to ground, a low pass filter shunted by a resistor in the space current path of said rectifier, said filter being located between the cathode and another electrode of said rectifier, a diode for each rectifier having a cathode directly connected to that terminal of said resistor which is farthest away from the cathode of said rectifier, means for directly connecting together the anodes of the diodes associated with the different receivers, a common load resistor having one terminal directly connected to the anodes of said diodes and another terminal connected to a potentiometer, a connection

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from one end of said potentiometer to ground, and a connection from the other end of said potentiometer to a source of positive polarizing potential.

13. In a diversity receiving system having a plurality of receivers feeding a common utilization circuit, a rectifier in circuit with the output of each receiver for rectifying the alternating current signal in each receiver, an electron discharge device resistor in the output of each rectifier for passing the rectified signal, and a common load resistor for said discharge device resistors, whereby the passage of current through any one said discharge device resistor produces a component of voltage drop in said load resistor which appears as a negative bias on said other discharge device resistors.

14. In a diversity receiving system having a plurality of receivers feeding a common utilization circuit, a rectifier in circuit with each receiver for rectifying the alternating current signal in each receiver, a variable resistor in the form of an electron discharge tube coupled to the output of each rectifier for passing the rectified signal, and a common load resistor for said electron discharge tubes, whereby the passage of current through any one of said electron discharge tubes produces a component of voltage drop in said load resistor which appears as a negative bias on the other of said electron discharge tubes.

15. A diversity receiving system comprising a plurality of receivers, an antenna coupled to the input side of each receiver, the several antennas being geographically spaced from one another, a common utilization circuit for the different receivers, selective means controlled by a predominant value of signal energy fed through any one receiver for instantly rendering that energy predominantly effective in said utilization circuit, said means being simultaneously and selectively effective to prevent the transfer of signal energy from the remaining receivers to said utilization circuit, said means comprising a rectifier and an electron discharge tube serially connected between the output of each receiver and the common utilization circuit, each of said electron discharge tubes being connected to operate as a diode, said electron discharge tubes each having an output electrode, a direct conductive connection between the output electrodes of said electron discharge tubes, whereby the passage of the strongest signal through one of said rectifiers and its associated electron discharge tube provides a bias which prevents current from passing through the other electron discharge tubes.

16. A diversity receiving system for angular velocity modulated waves, comprising a plurality of similar receivers each of which includes in the order named a radio frequency amplifier, a frequency converter, an intermediate frequency amplifier, a discriminator and a differential type detector for rectifying the output of said discriminator, a common utilization circuit for all said receivers, means for passing to said utilization circuit the signal from only that receiver having the largest incoming voltage, said means including individual electron discharge device resistors coupled to the different differential type detectors for passing the rectified currents from said detectors, and a common load resistor for said electron discharge device resistors, whereby the passage of current through any one electron discharge device resistor produces a direct component of voltage drop in said load resistor which

appears as a negative bias on the other electron discharge device resistors.

17. A receiving system for angular velocity waves, comprising in the order named a radio frequency amplifier, a frequency converter, an intermediate frequency amplifier, a discriminator and a differential type detector for rectifying the output of said discriminator, a diode having a cathode coupled to said detector and an anode coupled to a load resistor, and a utilization circuit coupled to said load resistor.

MURRAY G. CROSBY.

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