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May 4, 1943. F. E. TERMAN 2,318,268

DIVERSITY RECEIVER SYSTEM

Filed Feb. 10, 1942 3 Sheets-Sheet 1

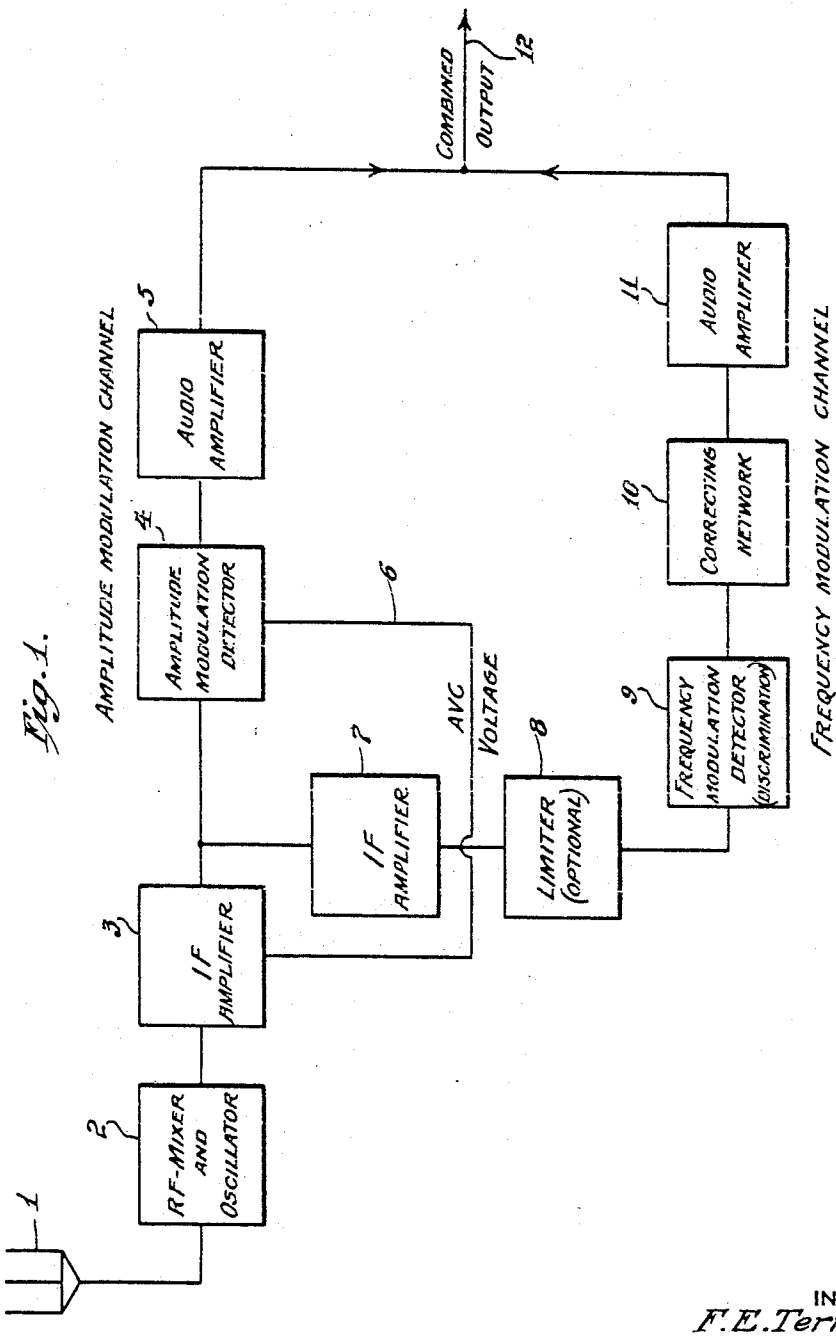


Fig. 1.

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DIVERSITY RECEIVER SYSTEM

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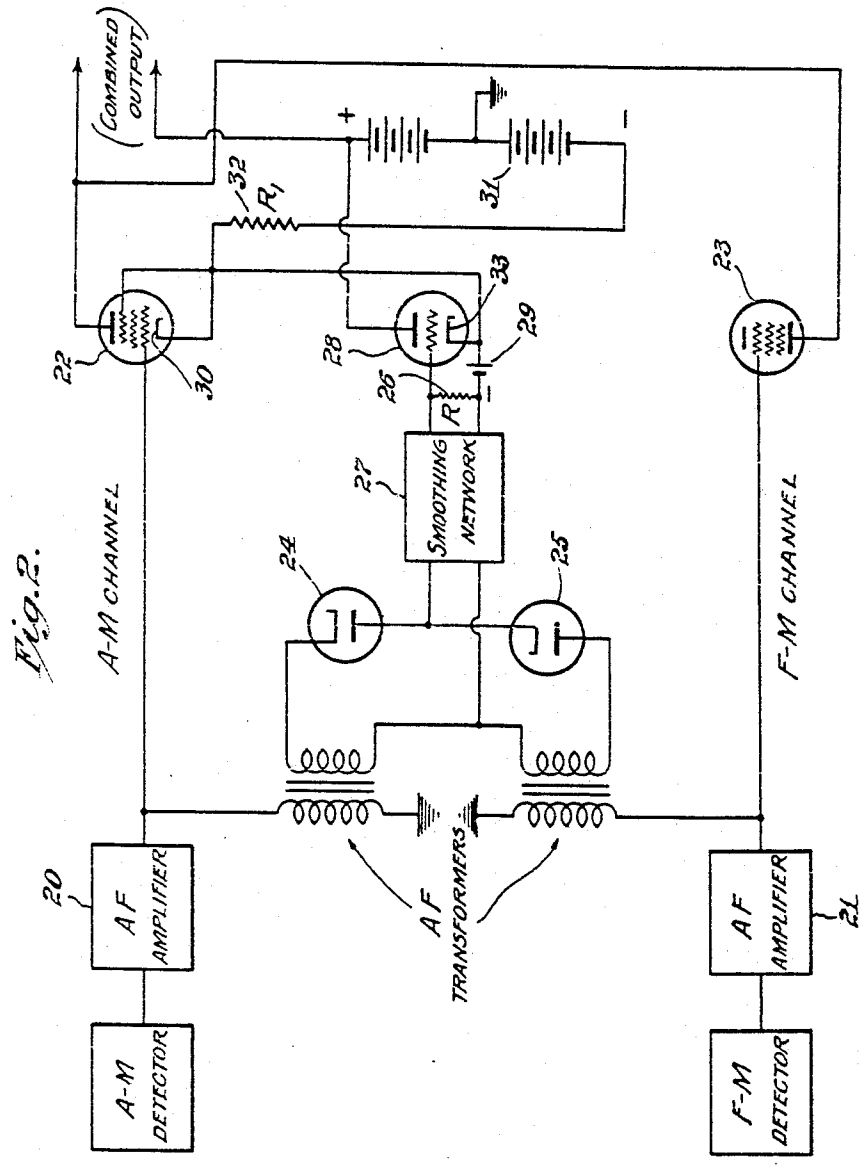


Fig. 2.

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DIVERSITY RECEIVER SYSTEM

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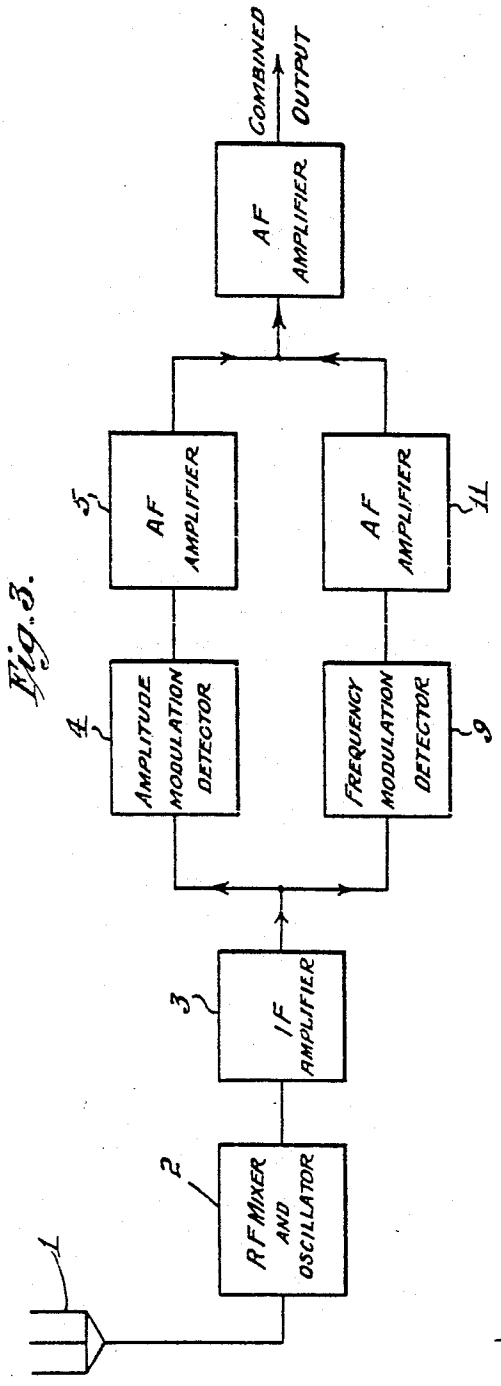


Fig. 3.

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UNITED STATES PATENT OFFICE

2,318,268

DIVERSITY RECEIVING SYSTEM

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Application February 10, 1942, Serial No. 430,203

8 Claims. (Cl. 250—20)

This invention relates to new and useful improvements in diversity reception of amplitude modulated waves.

A diversity receiving system is a system for reception in which fading is minimized by receiving the incoming signal in two or more ways that fade more or less at random, and then combining the respective outputs. The resultant signal will fade out only in the unlikely chance that the signal fades completely simultaneously on each of the several channels.

The usual diversity system used in the reception of modulated waves employs receiving antennas spaced sufficiently far apart for the fading in the individual antennas to take place more or less at random. Such an arrangement requires separate receivers and separate antennas, and where the antennas are directional the expense of the antenna system becomes quite large. It is also possible to obtain diversity by receiving the signals on vertically and horizontally polarized antennas, since the fading of the vertically polarized and horizontally polarized components are quite independent of each other. Such a system is not very practical with directional antennas, however, because from a practical point of view it is not feasible to obtain the same directional characteristic for both polarizations.

In accordance with the present invention diversity is obtained even though only a single receiving antenna is employed, and only a single especially-designed radio receiver is required. These results are achieved by the application of techniques similar to those employed in dealing with frequency-modulation systems.

The invention makes use of the fact that when short-wave signals have travelled a considerable distance, the relative phase of the carrier and of the various side-band frequencies has been shifted by passage through the ionosphere in a more-or-less random manner. Now, if the relative phase of the carrier and sidebands of an amplitude-modulated wave is shifted 90 degrees from normal, then the envelope possesses relatively little amplitude modulation, and one has what is essentially a frequency-modulated wave. In fact, when such a wave with its carrier shifted from the normal phase position is passed through a limiter, one obtains a pure frequency-modulated wave.

As a consequence of this fact, if we take a short-wave signal which has travelled a long distance under conditions such that the phase relations normally existing between carrier and sidebands in an amplitude-modulated wave have been altered, and put this signal through a limiter, we will expect to obtain from the output of the limiter a frequency-modulated wave in which the modulation index will depend upon the extent to which the normal phase relations of the various components of the original modulated wave have been disturbed. This is true even when the wave was originally radiated as an amplitude-modulated wave, and was entirely free of frequency-modulation. To achieve this result it is merely necessary that the transmission conditions be such that there be a disturbance of the normal phase relations in the various frequency components of the amplitude-modulated wave, and this condition is always realized to an appreciable extent in short-wave signals that have travelled long distances. Inasmuch as the modulation index of the frequency-modulated wave delivered by the limiter will depend upon the distortion in the normal phase relations, this will vary in a more-or-less random way with time. If the output of the limiter is then applied to a discriminator type of detector such as is used for frequency-modulated waves, then this detector's output will fluctuate or fade in a random way that can be expected to be largely independent of the fluctuations in the output obtained by rectifying the envelope of the incoming way in the usual manner. There is, accordingly, diversity action between the output obtainable by this frequency modulation action as compared with the output from reception of the same signal in the normal manner for amplitude modulation. If the two outputs obtained in this way are combined, the resultant fading will be much less than the fading with ordinary single-channel reception, thus giving diversity action.

In the drawings, Fig. 1 is a schematic diagram of an example of a diversity receiving system according to the present invention, Fig. 2 is a diagram of a channel disabling system adapted for use with Fig. 1, and Fig. 3 is a diagram of a simplified form of the system of Fig. 1.

In the schematic diagram of Fig. 1, signals picked up by antenna 1 are delivered to a radio frequency mixer and oscillator 2, then to an intermediate-frequency amplifier 3, amplitude modulation detector 4, and audo frequency amplifier 5. A second intermediate frequency amplifier 7 connects the output of amplifier 3 over a limiter 8, frequency modulation detector 9, and correcting network 10, to audio amplifier 11. The outputs of the amplitude modulation channel (4, 5) and the frequency modulation channel (9, 10, 11) are combined at 12.

The correcting network 10 is required because the amplitude of the sideband components in the original amplitude-modulated wave is independent of the modulating frequency. When the phase relations are distorted, the resulting wave that is obtained is then really a phase-modulated wave. When such a wave is applied to the ordinary detector or discriminator such as used in frequency modulation receivers the response to the higher modulation frequencies is excessive. This can be corrected by employing an equalizing or correcting network which develops an output voltage that is inversely proportional to frequency.

In designing the equalizing network an additional factor that should be taken into account is that the degree of randomness in the distortion of the phase relation between the various frequency components of the original amplitude-modulated wave can be expected to increase the greater the difference in frequency between these individual components. Thus if the modulation frequency is very low, the magnitude of the random distortion in phase relations of the received signal can be expected to be smaller than when the modulation frequency is large. Such an effect can be compensated by employing an equalizing network 10 in which the response decreases with frequency more rapidly than inversely proportional to the frequency, at least for the lower modulation frequencies, but which for higher modulation frequencies should presumably give an output more nearly inversely proportional to frequency.

A variety of methods may be used to combine the output of the amplitude-modulated and frequency-modulated sides of the receiving system. One procedure would be to adjust the respective audio gains so that the two outputs are, on the average, of equal amplitude, and then combine the two directly (as in Fig. 1). Under these conditions the particular signal that happened to be strongest at the moment would dominate. The automatic volume control voltage is derived from the rectified D. C. component of the amplitude-modulation detector 4, and this control voltage is applied over path 6 to the intermediate frequency amplifier 3 ahead of the point at which the intermediate frequency system is divided to provide amplitude-modulation and frequency-modulation channels, i. e., ahead of the point at which amplifier 7 is connected.

The dominance of the stronger channel over the channel which at the moment is weaker can be established with greater positiveness by auxiliary equipment designed to disable the audio system of the weaker channel. Such a disabling system is illustrated in Fig. 2. Here 20 and 21 represent ordinary audio amplifiers, while 22 and 23 represent volume-control tubes, the outputs of which are combined to give the output of the system. 24 and 25 comprise a system of diode detectors such that, when the rectified audio output of the amplitude-modulated channel is weaker than the rectified audio output of channel 2, a positive voltage is developed on the upper end of a resistance 26 bridged across the output of detectors 24, 25 over a smoothing network 27. This voltage is applied to the grid of tube 28, which is provided with an initial bias from battery 29 such that the tube is biased just to cut-off when the voltage across 26 is zero. The control tube 22 is arranged so that its cathode 30 is returned to a relatively large negative potential of battery 31 through a high resistance 32 so chosen that under normal conditions the cathode of this tube is just sufficiently positive with respect to the control grid of the tube to provide normal bias for amplifier operation. The cathode 30 is connected to the cathode 33 of tube 28.

When the audio output in channel 1 is less than that in channel 2, a positive D. C. voltage is developed across 26 that reduces the bias of tube 28 to less than cut-off. This increases the voltage developed across 32, making the cathode of tube 22 more positive than before, and quickly driving 22 to cut-off provided that the tube 28 is of a type that has a large mutual conductance, and has a much heavier plate current under normal conditions than tube 22. Thus, a signal on channel 1 slightly less than the signal on channel 2 will disable channel 1 almost completely, whereas if channel 1 has a slightly larger output than channel 2, the disabling system is inoperative. A corresponding disabling system can, of course, be added to channel 2 that will put it out of commission if its output is less than that of channel 1.

It is to be understood that many variations in the details of this system are possible. Thus the limiting system shown in Fig. 1 may be omitted as in Fig. 3. This is possible because to a first order, the discriminator responds only to differences in frequency, and not to changes in amplitude. In Fig. 3, which is similar to Fig. 1 in its general features, the intermediate frequency amplifier 7, the limiter 9, and the correcting network 10 are omitted for simplification, the output of the amplitude modulation channel 4, 5 being combined directly with that of the frequency modulation channel 9, 11. Other variations that are obviously possible are in the details of the discriminator, the method by which the two channels are ultimately combined, etc.

It will be noted that the invention provides means of obtaining diversity action in a receiving system that from antenna to detector is identical in every respect to the ordinary, single channel amplitude-modulation receiver. It is especially to be noted that only a single antenna is required, and that only a single (although especially designed) receiver is needed. Even the intermediate-frequency stages of the receiver (except those stages which follow a limiter in the second channel) should have only the normal band width required for amplitude modulation, and do not require the unusually wide band of conventional frequency modulation systems. The system has the merits of compactness and flexibility, can be made portable, and when connected up to any antenna will immediately function as a diversity system.

What I claim is:

1. In a diversity radio receiving system, an antenna for receiving waves originally amplitude modulated with a given desired signal, an amplitude modulation detector, a frequency modulation detector, connections from said detectors to said antenna, and means for combining portions of said desired signal from the outputs of the two detectors.

2. In a diversity radio receiving system, an antenna for receiving waves originally amplitude modulated with a given desired signal, an amplitude modulation channel connected with the antenna and including an amplitude modulation detector, a frequency modulation channel including a frequency modulation detector and a correcting network, said network having an output voltage inversely proportional to frequency,

a connection from the frequency modulation detector to said antenna, and means for combining portions of said desired signal from the outputs of the two channels.

3. In a diversity radio receiving system, an antenna for receiving amplitude modulated waves, an amplitude modulation channel connected with the antenna and including an amplitude modulation detector and an audio amplifier, a frequency modulation channel including a frequency modulation detector, and an audio amplifier, a correcting network in the frequency modulation channel between said detector and amplifier and having a response which for the lower modulation frequency as compared to higher modulation frequencies decreases with frequency more rapidly than inversely proportional to frequency, said network having an output voltage inversely proportional to frequency at high modulation frequencies, a connection from the frequency modulation detector to said antenna including a limiter which delivers a frequency modulated wave having a modulation index which depends on the distortion in the normal phase relations of the carrier and sidebands in the amplitude modulated waves received to produce in the last mentioned detector an output which fades at random, and means for combining the outputs of the two amplifiers.

4. In a diversity radio receiving system, an antenna for receiving waves originally amplitude modulated with a given desired signal, an amplitude modulation channel including an amplitude modulation detector, a frequency modulation channel including a frequency modulation detector, connections from said channels to said antenna, means for adjusting the respective gains of said channels so that their outputs are on the average of equal amplitude, and means for combining portions of said desired signal from the outputs of the two detectors.

5. In a diversity radio receiving system, an antenna for receiving amplitude modulated waves, an amplitude modulation channel connected with the antenna and including an amplitude modulation detector and an audio amplifier, a frequency modulation channel including a frequency modulation detector and an audio amplifier, a correcting network in the frequency modulation channel between said detector and amplifier and having an output voltage inversely proportional to frequency, a connection from the frequency modulation detector to said antenna, means for adjusting the gains of the two channels so that the outputs of the two audio amplifiers are on the average of equal amplitude, and means for combining the outputs of the two amplifiers.

6. In a diversity radio receiving system, an antenna for receiving amplitude modulated waves, an amplitude modulation channel including an amplitude modulation detector and an audio amplifier, a connection between said detector and antenna including an intermediate frequency amplifier, a path for applying automatic volume control voltage from said detector to said intermediate frequency amplifier, a frequency modulation channel including a frequency modulation detector and an audio amplifier, a correcting network in the frequency modulation channel between said detector and amplifier and having an output voltage inversely proportional to frequency, a connection from the frequency modulation detector to said intermediate frequency amplifier at a point nearer the amplitude modulation detector than the point where the volume control voltage is applied, and means for combining the outputs of the two amplifiers.

7. In a diversity radio receiving system, an antenna for receiving amplitude modulated waves, an amplitude modulation channel connected with the antenna and including an amplitude modulation detector, a frequency modulation channel including a frequency modulation detector, a connection from the frequency modulation detector to said antenna, a control tube associated with each channel, a combined output for said control tubes, and means for disabling a control tube when the output of its associated channel is less than the output of the other channel.

8. In a diversity radio receiving system, an antenna for receiving amplitude modulated waves, an amplitude modulation channel connected with the antenna and including an amplitude modulation detector and a first audio amplifier, a frequency modulation channel including a frequency modulation detector and a second amplifier, a connection from the frequency modulation detector to said antenna, two volume control tubes, one connected with the first and the other with the second amplifier, a combined output circuit for said tubes, a diode detector associated with the first and a diode detector associated with the second amplifier, a common output circuit for the diode detectors, means for producing a variable bias in the last mentioned circuit depending on the relative strengths of the outputs of said channels and for applying said bias to one of said volume control tubes.

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