TRANSMISSION OF FREQUENCY MODULATED WAVES

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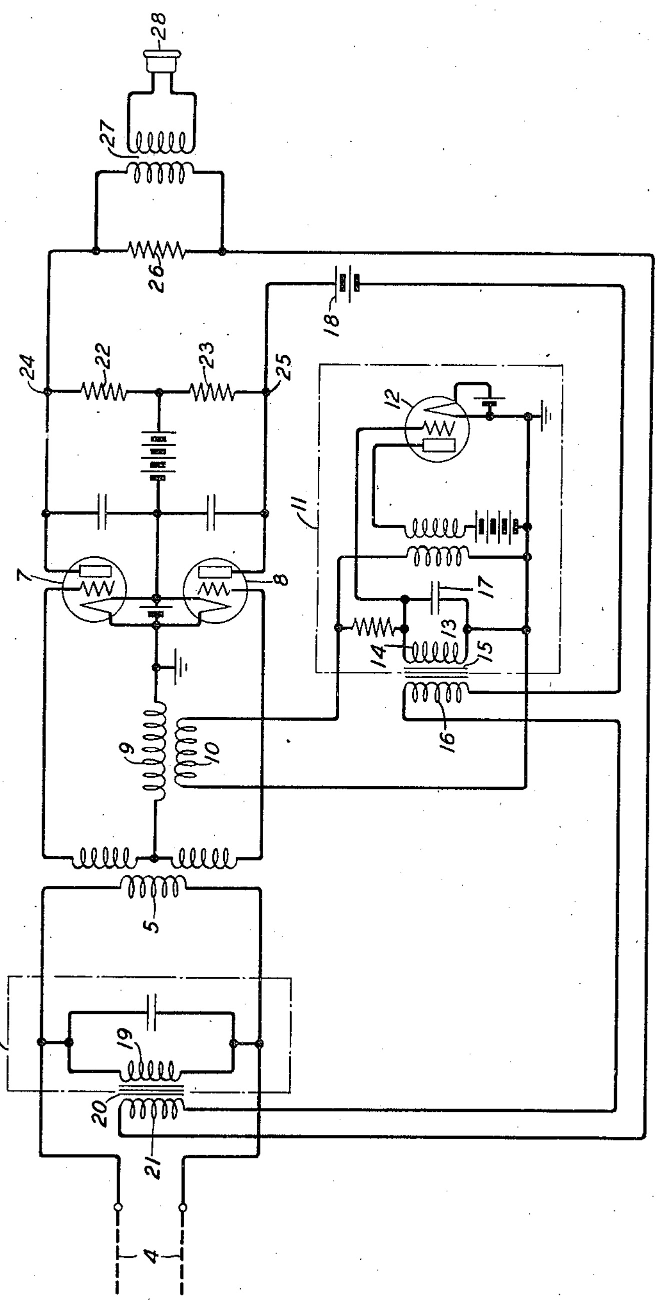

FIG. 1

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FIG. 2

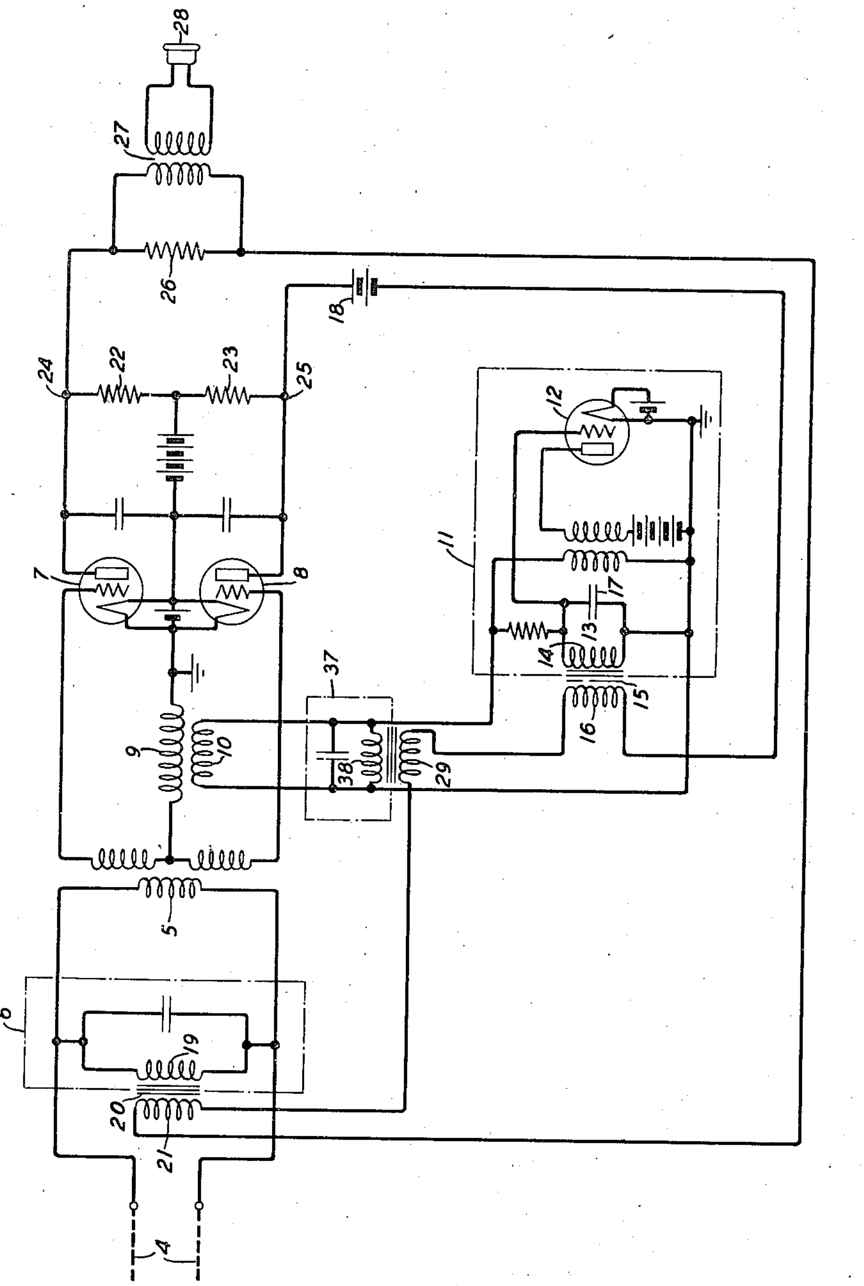

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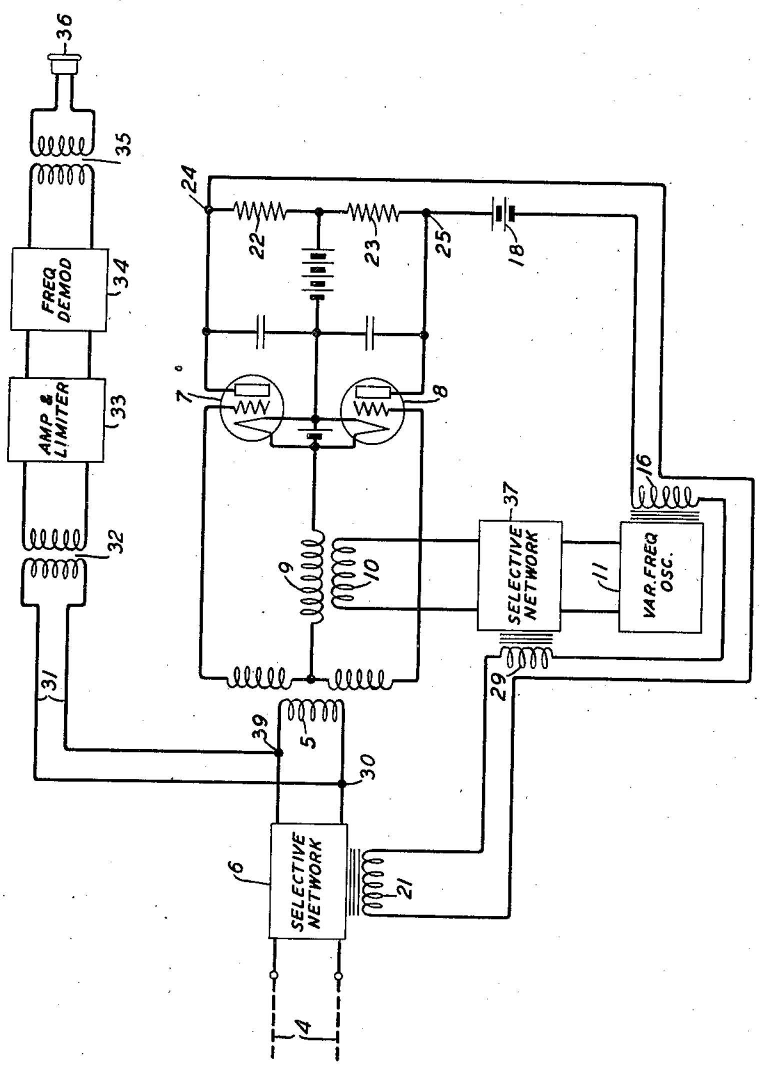
FIG. 3



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Patented Oct. 14, 1941

2,259,000

UNITED STATES PATENT OFFICE

2,259,000

TRANSMISSION OF FREQUENCY MODULATED WAVES

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Application May 21, 1938, Serial No. 209,183

14 Claims. (Cl. 250—20)

This invention relates to systems for transmission of frequency modulated waves and more particularly to methods of and apparatus for reducing the effects of interference in such systems.

An object of the invention is to enable transmission of frequency modulated waves with a relatively high index of modulation without correspondingly increasing the interference or noise introduced because of the relatively wide range of frequencies employed.

Another object of the invention is to reduce the relative effect with respect to the desired signal of interference which consists of very sudden impulses.

In accordance with the invention, incoming frequency modulated waves are demodulated in any desired manner after first being subjected to the selective action of a network having the general characteristics of a band-pass filter. In order to exclude the major portion of the interference energy to which the ordinary frequency modulation receiving system is subjected the network is given a transmission range only wide enough to readily accommodate essential bands which are required at the moment to give a good quality detected signal. In order to permit the network to continue to transmit the received waves as their frequency shifts over a wide range the network is made variable and is controlled by the detected currents to cause its transmission band while remaining narrow to shift up and down in the frequency scale in step with the frequency of the incoming waves. This may be accomplished by causing the demodulated waves to control the effective reactance of an element of the network such as an inductance winding associated with an iron core.

In the drawings, Fig. 1 illustrates a high frequency station for reception of frequency modulated waves;

Fig. 2 shows a modification of the circuit of Fig. 1 provided with means for counteracting the distortion occasioned by the variable magnetic inductance; and

Fig. 3 illustrates another modification in which the automatically varying selective network of Figs. 1 and 2 is employed in a frequency modulated wave detection system of otherwise conventional type.

Referring to Fig. 1, the incoming antenna or receiving circuit 4 is connected by transformer 5 to the input circuits of two detectors each of which may be of the electron discharge type. Shunted across the transformer input circuit is a selective network indicated generally within the broken line rectangle 6. As illustrated, it may take the form of an anti-resonant circuit tuned to have its resonance frequency at approximately the unmodulated carrier frequency of the incoming carrier wave. The circuit may be so designed that it will offer substantially infinite impedance to currents of the normal unmodulated carrier frequency but will reduce by about 3 decibels the voltage of components which differ from the normal frequency by the maximum essential frequency of the speech or other signal wave by which the carrier wave is modulated at the remote transmitter. For example, in the case of high quality speech in which it may be desirable to transmit components of all frequencies extending up to 3,000 cycles the circuit 6 may be tuned to the normal unmodulated carrier frequency and may introduce a loss of 3 decibels for electromotive forces which depart 3,000 cycles from the normal carrier frequency.

The detectors 7 and 8 have input circuits connected in opposite phase to the secondary winding of transformer 5 and a common input winding 9 inductively connected with the winding 10 in the output circuit of a variable frequency oscillator designated generally by the broken line rectangle 11. The oscillator 11, as illustrated, comprises an electron discharge device 12 which may be of the well-known three-electrode type having its anode and grid circuits inductively coupled in well-known feedback relation to produce oscillations. The grid circuit includes a tuned loop 13 comprising an inductance element 14 associated with the magnetic core 15 and a controlling winding 16, together with a capacity element 17. The oscillator 11 produces oscillations of substantially the natural resonance frequency of the circuit 13. The tuning of circuit 13 is, of course, dependent upon the magnitude of the inductance element 14. In order to set this at such a normal magnitude that the oscillations produced will be of the normal or unmodulated carrier frequency of the incoming waves a source 18 is included in series with biasing or controlling winding 16 to determine the normal magnetomotive force to which the core 15 is subjected.

The selective network 6 is similar to the tuned circuit 13 and includes an inductance element 19 similar to the inductance element 14 and which is controlled in the same way by a magnetic core 20 and a control winding 21 connected in series with the control winding 16.

When normal unmodulated carrier frequency waves are received over circuit 4, selective networks 6 and 13 are both tuned to the received wave frequency. Consequently, the full electromotive force of the received waves is impressed upon the primary winding of transformer 5 and a corresponding electromotive force is applied from the secondary winding of the transformer 5 to the input circuits of detectors 7 and 8. The oscillator 11 produces oscillations of the same frequency, namely, normal unmodulated carrier frequency, and applies them to the common portion 9 of the input circuits in phase quadrature with the incoming oscillations transmitted by transformer 5. The result of the combination of the two electromotive forces of this same frequency and in phase quadrature by the detectors is to produce no response in the output circuits of the detectors so that the circuit of source 18 and the series windings 16 and 21 is unaffected. The circuit 6 which, as previously explained, is anti-resonant at the unmodulated carrier frequency waves serves as a by-pass to substantially divert from the transformer 5 other disturbing electromotive forces which may be of substantially more than 3,000 cycles frequency difference from the received unmodulated carrier wave.

Whenever frequency modulation begins at the remote transmitting station the incoming wave at the receiving station will depart from the normal unmodulated carrier frequency by an amount determined by several factors including the modulation index of the transmitting system, the intensity of the modulating signal and the rate at which the intensity of the modulating signal is changing. The tendency will be for the frequency of the band of essential incoming components to shift to such an extent that it will depart from the range which the circuit 6 is normally set to exclude. However, as the frequency of the incoming wave departs from that of the normal unmodulated carrier, the initial condition of phase quadrature at the input circuit of detectors 7 and 8 between the received wave and the locally produced wave will no longer subsist. The change in frequency of the incoming wave will cause the electromotive force impressed by transformer 5 to fall more nearly in phase with the local oscillation in one detector and to increase the phase difference angle in the input circuit of the other detector. Consequently, the space current in one detector as, for example, in detector 7 will tend to rise with a consequent increase in the potential difference across the resistance 22 in the output circuit of that detector. In converse manner, the space current of detector 8 will diminish as will the potential difference across the resistance 23 associated with that detector. Whereas points 24 and 25 at the outer extremities of the two resistances were originally at equal potentials so far as the effect of space current is concerned, they now tend to assume different potentials and consequently there is effective in the circuit of the source 18 an additional electromotive force which may either aid or oppose the source 18 according to the polarity of the latter. In accordance with the invention the source 18 is so poled that the effect of the additional electromotive force set up between the points 24 and 25 by the unbalance in the detector circuits is to so change the bias or control current through the winding 16 as to cause the reactance of the element 14 to change the tuning of the loop 13 in the same direction that the frequency of the incoming waves has changed. In other words, if the instantaneous effect of the frequency modulation is to increase the frequency of the incoming waves, the effect of the unbalance potentials between points 24 and 25 is to correspondingly increase the frequency of the oscillations from the source 11. As will be readily understood, the ideal relationship for balance requires that the phase quadrature between the incoming waves and the locally produced waves be maintained. This condition may be specified if at all times the locally produced oscillations faithfully follow the frequency of the incoming waves with no delay. When the frequency of the incoming waves shifts in the opposite direction from that which has been previously considered, the tendency will be for an unbalanced potential to be set up between the points 24 and 25 in the opposite direction thus influencing the reactance 14 to change in such manner that the oscillations produced by the source 11 keep in step with the frequency of the incoming waves. It will therefore be apparent that the system is one in which there is a tendency to automatically maintain the phase quadrature relation and hence an equality of frequency between the locally produced oscillations and the incoming waves.

Reverse feedback circuits of the stabilized amplifier type are very well known in the electrical transmission art. It may perhaps be appreciated that the circuit of detectors 7 and 8, biasing circuit of source 18 and control winding 16 and oscillator 11 is a species of reverse feedback circuit in which the audio frequency detected components are fed back from the outputs of the detectors 7 and 8 through frequency modulation of the oscillator 11 in such manner as to reduce the resultant detected component. If the amplification which the energy undergoes in the reentrant loop involving the detectors and the feedback circuit is made very high the tendency of the circuits to introduce distortion is reduced and the effective detected audio frequency electromotive force between the points 24 and 25 will tend to faithfully reflect the variations in frequency of the incoming wave. Accordingly, there will be produced between the terminals of the series resistance 26 an electromotive force corresponding in its wave form and frequency to the modulating waves at the remote transmitter. These demodulated signal waves may therefore be transferred through transformer 27 to a telephone receiver 28 or other indicating device.

In the foregoing discussion of the operation of the receiving circuit of Fig. 1, the effect of the unbalance potential between points 24 and 25 in tending to maintain phase quadrature relation between the incoming and the locally produced oscillations has been described. There is an additional effect which the unbalance potential produces through the agency of the selective circuit 6. As the frequency of the incoming wave departs from the normal unmodulated carrier frequency there is a tendency for the selective network 6 to increasingly attenuate the incoming wave because of its frequency discriminatory characteristics. However, the unbalance potential causes the current in control winding 21 to change with a consequent readjustment of the reactance 19 in such direction as to shift the resonance frequency of the resonant circuit 6 in the same manner that the resonance frequency of the resonant circuit 13 is shifted. Accordingly, as the tuning of the circuit 19 changes with the change of frequency of the incoming carrier the desired band of essential frequencies is excluded by the circuit 6 and is effectively transmitted to the transformer 5 while frequency components which were previously transmitted to the transformer 5 are now attenuated. In this manner the selective network 6 follows the incoming wave frequency accepting a relatively narrow band of essential frequencies and suppressing components of frequencies outside that band. As the noise energy is distributed throughout the entire range which the incoming wave traverses only a small portion of it will fall within the passed band at any particular instant, the major portion falling within the suppressed or highly attenuated portion of the range. This expedient therefore enables the receiver to accept the essential frequencies of the desired signal even though these frequencies vary from instant to instant and at the same time to exclude the major portion of extraneous waves occurring in the over-all range of the incoming signal.

Assuming that in the course of modulation the incoming waves and the transmission band of the selective network or vario-filter 6 will traverse a range of frequencies extending 60,000 cycles at each side of the normal unmodulated carrier frequency and assuming that the effective range of frequencies unsuppressed by the selective network is 6,000 cycles, the average interference will be reduced so that the improvement amounts to about 10 decibels. However, the most common form of interference is not usually a steady form but one which consists of very sudden impulses. When a very sudden impulse is passed through a band filter having a 6,000-cycle band-pass range instead of through a band filter of the same general type having 60,000-cycles band-pass range not only is the power in the narrower filter one-tenth of that in the wider filter but in addition the duration of the disturbance in the narrower filter is ten times as great as in the wider filter. Consequently, the voltage power for the duration of the disturbance is reduced one hundredfold. For this reason the narrow range filter of applicant's invention effects a particularly important result in reduction of noise produced by very sudden impulses.

Although the filter is very effective in reducing noise it may in some instances introduce certain forms of distortion in the wave which would not otherwise be present. In order to counteract the effects of such distortion, the circuit of Fig. 2 may be employed. In this circuit similar elements are designated as in the circuit of Fig. 1. The circuit of Fig. 2 differs from that of Fig. 1 in the introduction between the output terminals of the oscillator 11 and the transformer 9, 10 of a vario-filter 37, made as nearly like the vario-filter 6 as is practicable and similarly controlled by a control winding 29 associated with the vario-magnetic reactance winding 38 serves to nullify the distortion effects produced by the filter 6 by causing the variable shunting and distorting action of network 37 upon the local oscillations to correspond at all times to the variable shunting and distorting action of network 6 upon the received waves so that the phase quadrature condition is maintained.

In Fig. 3 the system for controlling the vario-filter 6 and for varying the frequency of the local oscillator 11 and of its output vario-filter 37 is identical with that shown in Fig. 2. It will be observed therefore that across points 30 and 39 between the vario-filter 6 and the transformer 5 there may be derived a narrow band of the essential frequencies of the incoming frequency modulated wave which has been largely freed from the normally attendant extraneous noise pulses and other interfering waves by the action of the vario-filter. It is, therefore, possible to connect a circuit such as 31 to these points and to associate it with a frequency demodulation receiver of conventional type, as indicated. The demodulating system in this instance involves the transformer 32, the combined amplifier and limiter 33 of well-known type, the frequency demodulator 34, audio frequency transformer 35 and a signal indicator 36. It will be apparent that in this system, as in those of Figs. 1 and 2, the advantage of the automatically controlled vario-filter feature is fully attained.

What is claimed is:

1. The method of receiving carrier waves which are frequency modulated in accordance with non-periodic signals and of reducing the effect of disturbing energy of frequencies differing from the instantaneous frequency of the received carrier waves which comprises highly attenuating all received components differing in frequency by more than a preassigned value from the instantaneous frequency of the received modulated waves so as to leave relatively unattenuated a band of substantially fixed width but the limiting frequencies of which constantly change and at any instant are determined by the instantaneous frequency of the received waves and frequency demodulating the unattenuated frequency band components whereby signals corresponding to the original modulations may be derived and noises incident to the attenuated frequency ranges may be eliminated.

2. The method of receiving carrier waves frequency modulated by non-periodic waves which comprises accepting only a limited band of frequencies essential for demodulation and varying the limits of the accepted band in the same frequency direction and to the same frequency extent as the instantaneous frequency of the received modulated waves varies so as to derive at all times a band of accepted waves capable upon frequency modulation of yielding non-periodic waves corresponding to those by which the incoming modulated waves are frequency modulated.

3. The method of reception of waves frequency modulated in accordance with non-periodic signals for reducing the effects of disturbing energy of frequencies differing from the instantaneous frequency of the received carrier waves which comprises suppressing all received frequencies outside of a band of those essential for detection lying between the instantaneous frequency and upper and lower limiting frequencies both of which continually vary so as to remain at relatively fixed frequency separations from the instantaneous received frequency, detecting the band of unsuppressed waves and causing the detected waves to shift the band which is sunsuppressed so that the limiting frequencies of the band effectively follow the instantaneous frequency of the incoming frequency modulated waves.

4. The method of receiving carrier waves which have been frequency modulated in accordance with signals comprising selecting from the carrier waves a limited band of frequencies, the band extent of which remains substantially constant and the limiting frequencies of which follow the frequency of the incoming waves, combining with the selected wave band local oscillations which

are in frequency agreement and in phase quadrature with the instantaneous frequency of the incoming waves, utilizing energy of any component resulting from lack of frequency agreement and phase quadrature agreement to change the frequency of the local oscillations to restore the phase quadrature relation, and utilizing a portion of the energy of the same component to reproduce the signals by which the received waves are frequency modulated.

5. A system for receiving waves frequency modulated in accordance with non-periodic signals comprising a selective network having an effective transmission band of sufficient width to accept the components of incoming waves of the essential frequencies required for detection, means connected thereto for detecting the waves transmitted by the network, and means under the control of the detected waves for varying characteristics of the network to change the frequency limits of the band which it transmits in the same direction and to the same extent as the instantaneous frequency of the incoming waves varies without changing the width of the band thus causing the central frequency of the transmission band of the network to follow the instantaneous frequency of the incoming waves.

6. A system for receiving waves frequency modulated in accordance with signals comprising a receiving circuit, an attenuating network connected thereto to suppress all components outside a band of preassigned frequency extent centering at the instantaneous received frequency and to select the preassigned band, a frequency demodulating system connected to the receiving circuit to demodulate the selected band of frequencies, and means responsive to the resulting demodulated energy to vary the selective characteristics of the network to cause the central frequency of the selected band characteristic of the attenuating network to follow the instantaneous frequency of the received frequency modulated waves.

7. In combination, a receiving circuit for frequency modulated carrier waves, a balanced demodulator having input terminals connected thereto and ontput terminals, an indicating circuit connected to the output terminals, a local oscillator having output terminals connected to the demodulator to impress local oscillations thereon for combination with the frequency modulated waves received by the receiving circuit, a tuned circuit having a magnetic core inductance shunted across the receiving circuit, a similar tuned circuit connected to the oscillator to determine the frequency of the oscillations produced, and a control circuit also connected to the output terminals of the demodulator and to the inductances of both tuned circuits to control the magnitudes of the inductance and to cause the tuning of each tuned circuit to follow the instantaneous carrier frequency of the received carrier waves.

8. The method of receiving frequency modulated waves carrying signal modulations while at the same time reducing the effect of undesired disturbances caused by components of frequencies remote from the instantaneous received frequency comprising selectively transmitting a band of the received waves lying between two limiting frequencies which are separated from each other by a substantially fixed amount and both of which vary in frequency in like manner so as at any instant to be separated from the varying received carrier frequency by respective frequency differences which remain substantially constant of sufficient width to include the essential frequencies required for detection and suppressing frequencies outside the limiting frequencies of the band, detecting the selected band of received waves and causing the detected waves to control the limiting frequencies of the band of waves selected in such manner as to cause the central frequency of the selected unsuppressed band to follow the instantaneous frequency of the incoming waves.

9. The method of receiving frequency modulated waves free from the effects of undesired disturbances occurring in the neighborhood of the instantaneous received frequency comprising selection of a band of frequencies of preassigned frequency extent centering at the instantaneous carrier frequency and the limiting frequencies of which vary in consonance with the instantaneous received frequency so as to remain at substantially fixed separations therefrom, demodulating the selected band of frequencies and utilizing the demodulated waves to vary the limits of the selected band in order to cause its central frequency to follow the instantaneous carrier frequency of the incoming waves.

10. The method of receiving carrier waves which are frequency modulated in accordance with signals which comprises selecting from the incoming waves a band of preassigned frequency extent, the limiting frequencies of which are constantly changing so as to maintain the central frequency of the band at substantially the instantaneous carrier frequency of the incoming waves, combining the selected waves with locally produced waves of substantially the instantaneous carrier frequency and in phase quadrature therewith and deriving from the combined waves correcting energy to control the limiting frequencies of the selected band and the phase quadrature agreement between the local oscillations and the instantaneous incoming carrier frequency waves.

11. A system for receiving carrier waves which are frequency modulated in accordance with non-periodic modulating forces comprising a receiving circuit to which electromotive forces corresponding to the frequency modulated waves may be applied, a frequency selective network capable of transmitting a range of frequencies constituting only a small portion of the frequency range throughout which the frequency modulated carrier wave shifts during its frequency excursions, a wave detector connected to the output terminals of the network to receive from the receiving circuit waves of the limited range of frequencies passed by the selective network and means for causing the pass band of the network to vary in such manner as at all times to accept and transmit to the wave detector the incoming frequency modulated wave.

12. A system for receiving carrier waves which are frequency modulated in accordance with modulating forces comprising a receiving conductor upon which electromotive forces corresponding to the frequency modulated waves may be impressed, a detecting device and a selective network having input terminals connected to the conductor and output terminals connected to the detecting device, the selective network having a transmission band extending over a small fraction only of the range throughout which the frequency modulated wave varies during its frequency excursion and means responsive to waves

yielded by the detecting device for varying the frequency position of the transmission band of the network to enable it at all times to accept waves of the instantaneous frequency of the frequency modulated carrier wave.

13. A system for receiving frequency modulated waves comprising an incoming conductor on which energy of the waves may be impressed, a selective pass network for passing a band of a frequency extent which is a small fraction only of the extent of the band through which the frequency modulated wave ranges during the course of the frequency modulation, a network having input terminals connected to the incoming conductor and output terminals, a receiver for frequency modulated waves connected to the output terminals and means for automatically controlling the frequency position of the band passed to the receiver by the network without substantially varying its width whereby the network at all times accepts the incoming frequency modulated wave irrespective of the character of the modulation involved and of the manner in which the frequency of the incoming wave varies.

14. The method of reception of carrier waves which are frequency modulated in accordance with non-periodic modulating forces which comprises selecting from the received frequency modulated carrier waves components falling within a band adjacent to and including the instantaneous frequency of the frequency modulated carrier wave, the width of the selected band being small relative to the width of the band encompassing the frequency excursions of the modulated carrier wave, causing the selected band to vary in frequency position but not substantially in frequency extent in such manner that at each instant it encompasses the incoming frequency modulated wave and deriving from the selected components waves representing the non-periodic modulating forces.

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