TRANSMISSION AND RECEPTION OF FREQUENCY MODULATED WAVES

Filed Aug. 24, 1938 2 Sheets-Sheet 1

FIG. 1

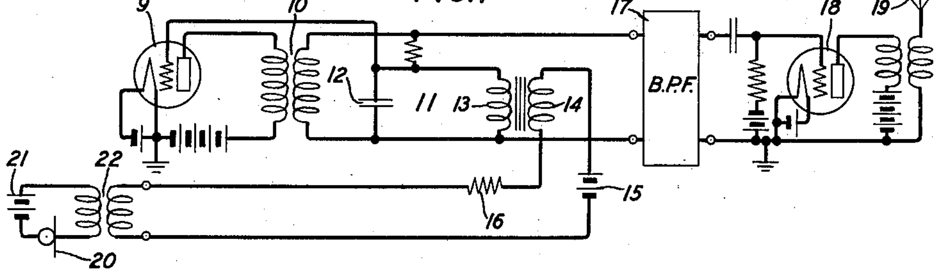



FIG. 2

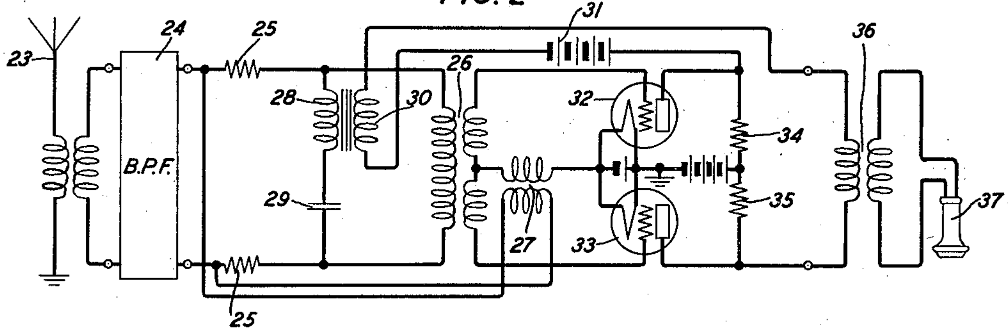



FIG. 3

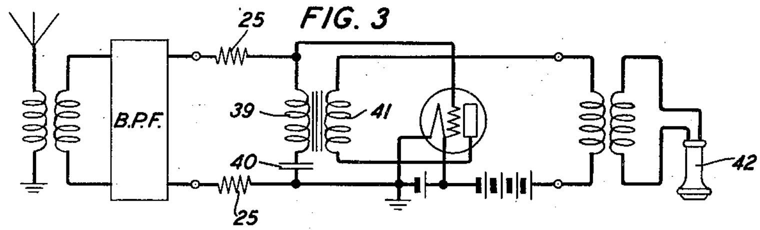
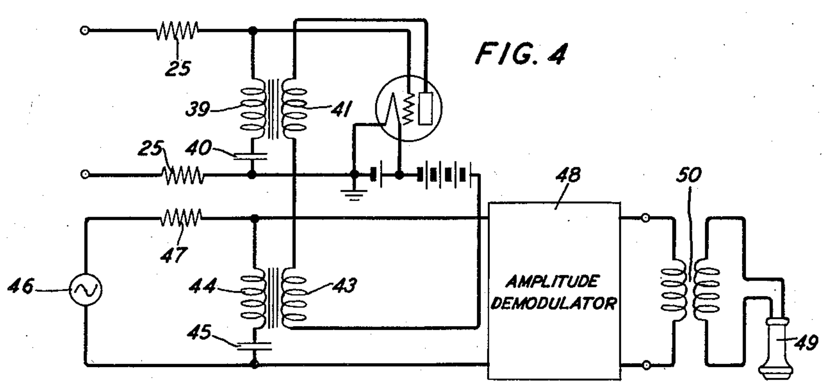



FIG. 4

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TRANSMISSION AND RECEPTION OF FREQUENCY MODULATED WAVES

Filed Aug. 24, 1938 2 Sheets-Sheet 2

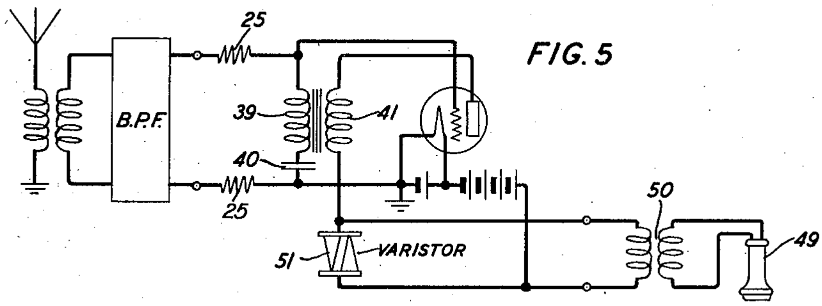



FIG. 5

FIG. 6

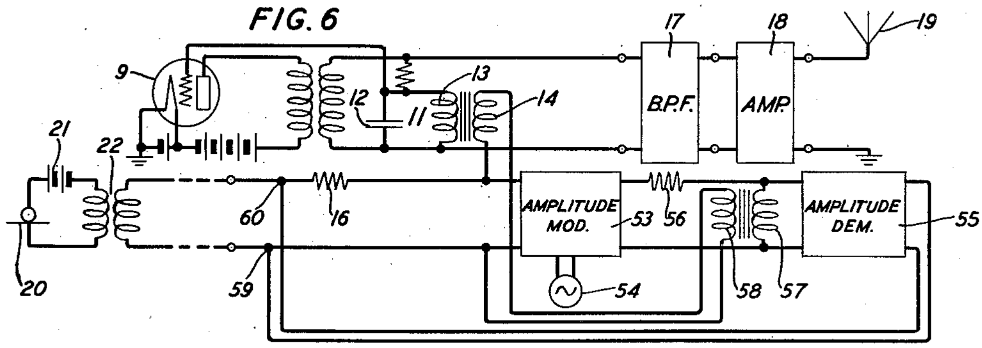



FIG. 7

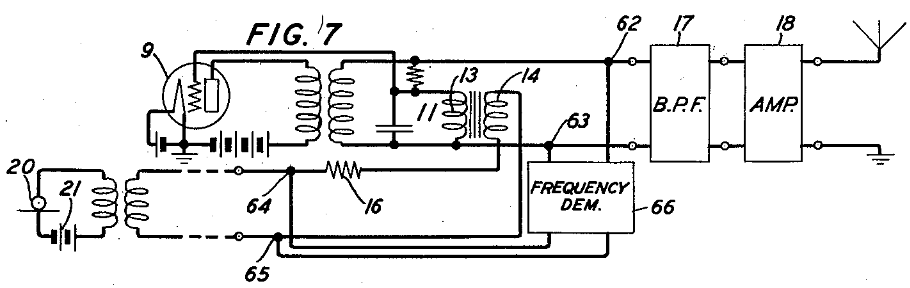
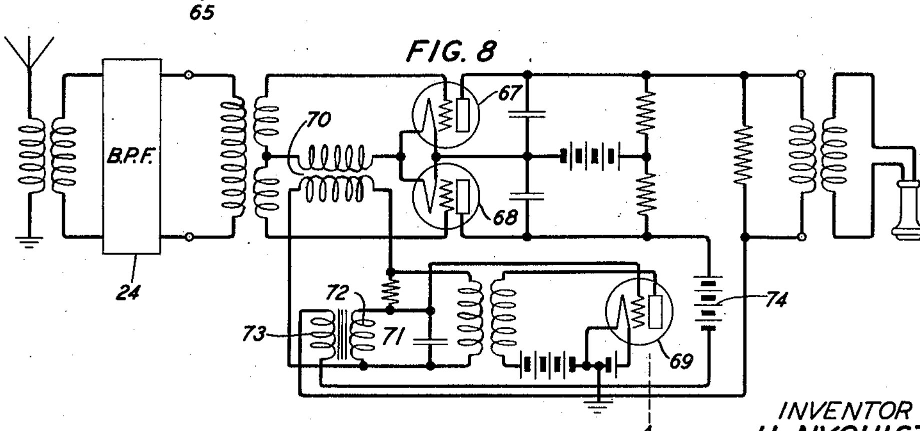



FIG. 8

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Patented Jan. 30, 1940

2,188,758

# UNITED STATES PATENT OFFICE

2,188,758

## TRANSMISSION AND RECEPTION OF FREQUENCY MODULATED WAVES

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Application August 24, 1938, Serial No. 226,444

9 Claims. (Cl. 250—20)

This invention relates to transmission and reception of frequency modulated waves.

An object of the invention is to simplify the apparatus required in frequency modulated wave systems.

Another object of the invention is to reduce the distortion incident to frequency modulation and demodulation.

Demodulation of frequency modulated waves is ordinarily effected by converting the frequency modulated waves to waves having an amplitude modulation which may be readily demodulated by amplitude demodulators of the usual types. The conversion from frequency modulated waves to waves having an amplitude modulation is accomplished by subjecting the frequency modulated waves to the action of a frequency selective path. The output current from such a path will vary in amplitude as the input electromotive force applied to the path varies in frequency.

It is customary in frequency modulation systems to transmit carrier waves which vary in frequency in accordance with the modulating signals but do not vary in amplitude. However, in consequence of the superposition of extraneous fields in the transmitting medium and also some forms of fading, the frequency modulated waves upon arrival at a remote radio receiving station may exhibit amplitude modulations which appear as distortions when the frequency modulated waves are converted to amplitude modulated waves. In order to overcome distortion of that type, it is customary to introduce at the receiving station an amplitude limiter to remove such amplitude variations. See, for example, U. S. Patent to Demarest 2,047,312, July 14, 1936.

A further object of the invention is to demodulate incoming frequency modulated waves in such manner as to produce signals which are dependent on the incoming carrier frequency but are independent of amplitude fluctuations not involving frequency modulation.

One type of frequency modulation system utilizes the modulating waves or impulses to control the reactance of an element of an oscillator frequency control circuit. Ferromagnetic inductances may be so employed as the control reactance of the oscillator frequency control circuit in accordance with the method disclosed in Fig. 4 of the patent to Mertz 1,548,895, August 11, 1925. Such ferromagnetic inductances ordinarily tend to introduce a distortion because of the nonlinear relationship existing between the amplitude of the modulating or controlling current and the resulting inductance of the ferromagnetic element. Ideally, the inductance element should have such a characteristic that the resonance frequency of the oscillation circuit of which it forms a part will vary linearly with the amplitude of the modulating current. An object of the invention is to enable the ferromagnetic inductance element of such a frequency modulating system to effectively present such an ideal characteristic.

In accordance with this invention both frequency modulation and demodulation of a frequency modulated wave or either may be effected by varying the natural resonance frequency of a tuned circuit. Preferably this is accomplished by including in the tuned circuit a variable reactance as, for example, an inductance having a ferromagnetic core similar to that disclosed in the patent to Mertz No. 1,548,895 to which reference has been made. There may be associated with the magnetic core a control winding supplied with currents which by their magnetizing effect upon the core change the reactance of the inductance in well-known manner and thus vary the resonance frequency of the tuned circuit.

Modulating systems in accordance with this invention utilize the speech or other modulating waves or impulses as the control current for the variable inductance of the tuned circuit. Accordingly, if an electric wave generator be provided with a frequency-determining tuned circuit with such a magnetic control there will be produced modulated waves, the carrier frequency of which varies with the instantaneous variations in amplitude of the modulating or control waves or impulses.

Demodulating systems in accordance with this invention utilize a similar variable tuned circuit which is so controlled by locally produced control currents that its natural resonance frequency tends to follow the frequency of the incoming or received frequency modulated waves. Any departure from frequency agreement enables the incoming waves to set up in the resonance circuit an electromotive force which is applied to an associated detector. The resulting detected current is then superimposed upon the original control current which thereupon alters the tuning of the tuned circuit to bring it into harmony with the frequency of the incoming waves. Under these conditions the control currents correspond with the original modulated control currents at the remote transmitter and may, accordingly, be utilized to yield speech or other modulating signals by which the frequency modulation at the transmitter station is effected.

If the natural frequency of a tuned circuit including a magnetically controlled reactance does not vary in linear fashion with respect to the magnitude of the reactance or if the magnitude of the reactance does not vary in linear fashion with respect to the amplitude of the control currents the frequency of the tuned circuit will not bear a linear relation to the amplitude of the control current and distortion will ensue. This may be effectively eliminated by a counter-distortion in which a similar resonant circuit or a device having a complementary resonant distorting characteristic is employed. In an alternative device the distortion may be effectively eliminated by a reverse feedback operation involving the principle disclosed in the U. S. Patent No. 2,102,-671 to H. S. Black.

The nature of the invention will be apparent from the following detailed description taken in connection with the appended claims and the accompanying drawings in which:

Fig. 1 illustrates a frequency modulation transmitter;

Fig. 2, a receiver for receiving frequency modulated waves and deriving the modulated signals therefrom independently of the amplitude of the received waves;

Fig. 3, a modified form of the receiver of Fig. 2;

Fig. 4, a modification of the circuit of Fig. 3 in which provision is made to reduce distortion occurring in the demodulating process;

Fig. 5, a receiving circuit for frequency modulated waves having alternative means for reducing distortion;

Fig. 6, a frequency modulated wave transmitter including means for reducing distortion which occurs in the modulating process;

Fig. 7, a modification of the circuit of Fig. 6 comprising an alternative arrangement for reducing distortion; and

Fig. 8, a receiving system for frequency modulated waves in which a local oscillator is so controlled as to tend to remain in frequency agreement and in phase quadrature with the incoming waves.

Referring to Fig. 1, there is illustrated a vacuum tube oscillation generator comprising a tube 9 which may be of the well-known three-element type having its plate circuit coupled inductively to its grid circuit by a transformer 10 to produce oscillations of a frequency determined by the tuned circuit 11. The natural frequency of circuit 11 is, of course, determined by the magnitudes of the capacity element 12 and the inductance element 13. Element 13 comprises a winding associated with a magnetic core and a control winding 14. The normal current through the control winding 14 is determined by the electromotive force of the source 15 and by the magnitude of the resistance 16 in series with winding 14. It is, therefore, possible to subject the magnetic core to any desired magnetomotive force to predetermine the normal inductance of the winding 13 as will be readily understood. Accordingly, during non-modulating intervals the oscillation source will produce oscillations of the frequency determined by the tuned circuit 11 and will transmit them by way of band-pass filter 17 and power amplifier 18 to the transmitting antenna circuit 19. A microphone or other signal transmitter 20 is associated with an electric current source 21 in a series circuit coupling by means of the transformer 22 to the magnetizing current circuit of the control winding 14. Whenever, therefore, sound waves are impressed upon microphone 20 an electromotive force will be induced in the secondary winding of transformer 22 to alternately augment and decrease the magnetizing current through the control winding 14. The varying magnetomotive force which ensues changes the magnetization of the magnetic core and the magnitude of the effective inductance of the element 13. It follows that the tuning of circuit 11 and, therefore, of the oscillations generated by the vacuum tube oscillator and transmitted from the antenna 19 will rise and fall as the speech current varies the carrier frequency rising with one polarity of speech current and falling with the opposite polarity. In this manner, the system of Fig. 1 serves to produce and radiate oscillations which are modulated as to frequency in accordance with speech currents. As is well known the result of frequency modulation is to produce a very wide band of different frequencies. In order to avoid the radiation of a broad band at the third harmonic of the carrier frequency or more generally bands arising from non-linearity, the band-pass filter 17 is provided. In general, the filter will have its mid-frequency at about the frequency of the unmodulated carrier wave and will readily transmit all frequencies at either side of the central frequency over a range several times that of the essential audio frequencies employed in ordinary speech. The power amplifier 18 may be employed to augment the energy within the desired band for radiation.

Fig. 2 illustrates a receiving system for use in receiving frequency modulated waves such as are transmitted from the system of Fig. 1. The antenna circuit 23 which, like the transmitting antenna circuit 19, is preferably broadly tuned so as to accept a very wide range of oscillations, without substantial discrimination, and is coupled to band-pass filter 24 which may be of the same type as the transmitting filter 17. The high frequency energy received and selected by the filter 24 is supplied to two parallel paths one of which includes the series resistances 25 and the primary winding of transformer 26, the other of which includes the primary winding of transformer 27. Shunted across the first path at points electrically adjacent the primary winding of transformer 26 is a circuit consisting of an inductance element 28 and a capacity 29 in series therewith, the circuit being normally tuned to the unmodulated carrier frequency. Inductance 28 resembles the inductance 13 of the transmitter in that it is associated with a similar ferromagnetic core and a control winding 30, the normal current of which is determined by a source 31 of magnetizing current. Associated with the secondary winding of transformer 26 are the input circuits of two vacuum tube detectors 32 and 33 which are so connected that an electromotive force in the primary winding of transformer 26 which induces a positive potential on the grid of one tube will simultaneously induce a corresponding negative potential on the grid of the other tube. The space current paths of the tubes include resistors 34 and 35 which are connected in the magnetizing path of winding 30 in series with the primary winding of output transformer 36. The secondary winding of transformer 27 is connected in a common portion of the input circuits of devices 32 and 33 in such manner that an electromotive force in the primary winding acting in such direction as to make the grid of one tube positive, tends simultaneously to impress an equal positive potential upon the grid of the other tube.

During non-modulating intervals the transmitting system of Fig. 1 will radiate unmodulated oscillations of the normal carrier frequency. These normal carrier frequency oscillations received by antenna 23 and selected by the band filter 24 will be supplied to the two parallel paths connected to its output terminals. Oscillations appearing in the primary winding of transformer 27 will cause equal electromotive forces of the same polarity to be applied to the input circuits of tubes 32 and 33. Assuming for the moment that the original space currents of the tubes 32 and 33 have been made equal so that without source 31 there is no potential difference between the outer extremities of resistances 34 and 35 in consequence of these space currents, the similar changes which the space currents undergo as a result of electromotive forces from transformer 27 will leave the electrical situation undisturbed. Since the tuned circuit 28, 29 is normally resonant at the unmodulated carrier wave frequency it will short-circuit the primary winding of transformer 26 for that frequency to prevent any effect upon detectors 32 and 33 from the other parallel path. Consequently, the receipt of oscillations of the normal carrier frequency regardless of their amplitude which may be small or large, constant or variable, will not affect the detector output circuit. It will be apparent that the magnitude of the source 31 is determined solely by the criterion that the normal magnetizing current should maintain inductance 28 at such a magnitude that the circuit 28, 29 will be resonant to the normal carrier frequency.

Whenever the carrier frequency of the incoming waves either rises or falls in consequence of modulation by speech currents at the transmitting station the operation of the circuit of Fig. 2 will change for the reason that the circuit 28, 29 no longer serves as a short circuit for the primary winding of transformer 26. Under these conditions oscillations induced in the secondary windings of transformer 26 will aid the oscillations induced in the secondary winding of transformer 27 in the input circuit of one detector tube at the same time opposing those in the other. Accordingly, space current in one tube will rise and that in the other will simultaneously fall so that the changes in space current will occasion differences in potential in the resistances 34 and 35 and these differences in potential are additive with respect to the outer terminals of the resistances. Because of the detecting action of the tubes these output circuit variation potentials will correspond to the original modulating speech frequency currents. It follows that detected speech frequency currents will be supplied by the transformer 36 to the telephone receiver or other indicating device 37. At the same time, the current in the magnetizing circuit of winding 30 will undergo variations in consequence of the superposed detected speech frequency electromotive force which will at times aid the normal magnetizing current from source 31 and at times oppose it. The winding 30 is preferably so arranged that the speech current impulses which ensue upon rise of the received carrier frequency from its normal value will tend to increase the resonant frequency of the circuit 28, 29. If the circuit be properly adjusted the circuit 28, 29 will be retuned to the increased carrier frequency and its tuning will thus tend to follow that of the incoming waves. In its attempt to automatically hold the tuned circuit 28, 29 at the frequency of the incoming waves the current of the magnetizing circuit of the winding 30 will correspond effectively to that in the magnetizing circuit of the winding 14 to the extent that it is a faithful copy of the original speech current. It will, therefore, be seen that in its operation to demodulate the frequency modulated waves, the circuit of Fig. 2 serves to produce from the incoming frequency modulated waves a variable magnetizing current which tends to control the reactance 28 so as to short-circuit the primary winding of transformer 26 and thus restore the normal zero output or balance condition of the detectors. In this manner it produces a magnetizing current which is a replica with respect to frequency and wave form of the speech frequency magnetizing current in the circuit of Fig. 1.

The circuit of the magnetizing winding in Fig. 2 constitutes a species of negative feedback and for best results should be so arranged that there is a high degree of feed back. As an indication of the adjustment and design of this circuit it may be stated that if the feedback circuit is disconnected from the magnetizing winding and a current is supplied to the magnetizing winding by some auxiliary source and the magnetizing current is changed, the resulting change in the output current should preferably be of the order of 10 to 100 times as great. Under these conditions of feedback and with the circuit connected as shown in Fig. 2, the circuit stabilizes itself to a new value of output current for each new frequency and the output current is a faithful copy of the modulating current at the remote transmitter.

The receiving circuit of Fig. 3 resembles that of Fig. 2 but has been simplified by the omission of one of the detector tubes and the parallel path leading to transformer 27. The resonant circuit 39, 40, instead of being normally tuned to the mid-frequency of the transmitted band is made resonant near one extremity of the desired band either above or below the mid-frequency. Consequently, during the non-modulating interval when the normal carrier frequency wave is being received the circuit 39, 40 presents a relatively large impedance to the incoming wave and an effective electromotive force of the incoming carrier frequency is applied to the detector input circuit. The resulting space current is preferably such as to attain the normal magnetizing current in winding 41 which is required to hold inductance 39 at the desired normal magnitude. Assume that the normal tuning of the path 39, 40 is such that its resonance frequency lies at the upper extremity of the wave band to be received. If now, as the modulation begins, the incoming carrier frequency at the receiver rises so as to approach the normal resonance frequency of the path 39, 40, the shunting effect of the resonance circuit will increase and the effective voltage applied to the input circuit of the detector tube will fall. The resulting decrease in the current in the magnetizing and space current path of the detector operates to so change the inductance of element 39 that the resonance frequency of the path 39, 40 becomes still higher thus receding from the frequency of the incoming waves. In this manner, the detector circuit tends to maintain the instantaneous tuning of the path 39, 40 at a frequency above the simultaneously received incoming waves. The varying magnetizing current to which the detection of the incoming waves gives rise and which, in turn, controls the tuning of the path 39, 40 corresponds to the speech controlled magnetizing current at the transmitting station and is, therefore, interpretable in the telephone receiver 42 as the reproduced speech signal. In both Figs. 2 and 3 it is desirable that the inductance should be a linear function of the unidirectional current traversing it, or preferably that the resonance frequency of the tuned circuit should be a linear function of the unidirectional magnetizing current.

The operation of the simplified circuit of Fig. 3 is attended with an increased tendency toward distortion as a result of any casual amplitude modulations of the incoming waves. For that reason it may be desirable in such single detector systems to insert current limiters at either the transmitting or receiving station or both.

The circuit of Fig. 4 corresponds in the tuning of the path 39, 40 and in the function of the magnetizing winding 41 to the circuit of Fig. 3. Circuits of this general type in which electrical tuning is a function of variable ferromagnetic inductances are subject to distortions occasioned by non-linearity in the relationship existing between the frequency of the circuit and the amplitude of the magnetizing current which controls the ferromagnetic inductance. In order to reduce such distortion there is introduced into the magnetizing circuit of Fig. 4 an additional series magnetizing winding 43 associated with a magnetic core and with a resonant path 44, 45, similar to the path 39, 40. As the magnetizing current varies thus varying the resonance frequency of the path 39, 40 it serves through winding 43 to likewise vary the resonance frequency of path 44, 45. The path 44, 45 is connected in shunt across a local circuit including a source 46 of constant frequency oscillations, a series resistance 47 corresponding in general to the series resistances 25 and an amplitude demodulator 48 of the usual type to the input circuit of which a receiver 49 is connected through transformer 50. The local source 46 is constructed and adjusted to produce oscillations of the normal resonance frequency of the path 44, 45. Consequently, during non-modulating intervals the path 44, 45 serves as a short circuit, preventing oscillations from the source 46 from reaching the detector 48. As the resonance frequency of the path 44, 45 varies in response to the variable magnetizing currents its impedance likewise varies with the result that there are transmitted from the source 46 to the demodulator 48 oscillations having amplitude modulations which may be readily demodulated by the demodulator. Since the operation of the magnetizing circuit 43 on the path 44, 45 is the converse of the operation of the path 39, 40 upon the magnetizing circuit at 41, it follows that the distortion introduced in the original conversion is counteracted. Accordingly, the amplitude of the modulated waves impressed upon the demodulator 48 will vary substantially in accordance with the frequency of the incoming carrier waves which in turn varies in accordance with the amplitude of the modulating currents at the remote radio transmitter. The output of detector 48 will, therefore, transmit to receiver 49 demodulated currents which correspond in frequency and wave form to the original modulating signals.

The receiving system of Fig. 5 involves an alternative expedient for counteracting distortion which may occur in consequence of energy translation by the control of a ferromagnetic inductance. The elements similarly designated correspond to those of Fig. 4. In series with the control winding 41 in the output circuit of the detector tube is a device 51 comprising a non-linear resistance which may be of the well-known copper-oxide varistor type. The device is preferably so designed as to have a characteristic such that the voltage across it is the same function of the current through it as the frequency of the resonant circuit is of the current through the ferromagnetic coil. Since the same current traverses the ferromagnetic coil 41 and the varistor 51, the voltage across the varistor 51 will vary in accordance with the frequency of the resonant circuit. Inasmuch as the frequency of the resonant circuit changes from instant to instant to follow the carrier frequency of the incoming received waves, the intensity of the electromotive force across the varistor 51 will likewise follow the carrier frequency of the incoming waves and there will be supplied to the transformer 50 and the receiving instrument 49 a current which is a replica of the modulating wave at the remote transmitting station.

At the transmitting station, the same problems as to non-linearity arise in connection with the use of variable frequency circuits including ferromagnetic inductances controlled by the modulating current. One method of reducing such non-linearity in a circuit like that of Fig. 1 is to utilize as the resistance element 16 of that circuit a non-linear resistance so designed as to compensate for non-linearity of the tuned circuit characteristic with respect to modulating current. The non-linear resistance 16 should be so designed that the resonant frequency of the tuned circuit 11 is a linear function of the modulating electromotive force impressed on the magnetizing circuit at the terminals of the secondary winding of transformer 22.

An alternative circuit for eliminating distortion at the transmitter is that of Fig. 6. In this circuit corresponding elements are designated as in Fig. 1. The modulating input circuit is connected through a series high resistance 16 to the input terminals of an amplitude modulator 53 with which is associated a carrier frequency oscillator 54. Although the precise frequency of the oscillations produced by oscillator 54 is immaterial it is preferably of the same order as the frequency of the principal oscillator 9. It is desirable that oscillator 54 be highly stable with respect to both amplitude and frequency so as not to introduce additional distortion for which the correcting circuit must correct. Modulated oscillations delivered at the output terminals of modulator 53 are impressed upon the input terminals of an amplitude demodulator 55 over a path including a series resistance 56 and a shunt inductance 57 with which is associated a ferromagnetic core and an inductance control winding 58. The output circuit of demodulator 55 is connected back directly to the points 59 and 60. If, in accordance with the well-known principle of reversed or negative feedback amplifier circuits, the gain of the units 53 and 55 and of their incidental amplifiers is made sufficiently high, the resultant electromotive force fed back to points 59 and 60 will be such as to reduce or counteract any distortion occurring in modulator 53, demodulator 55 or the connecting circuit of the feedback loop including the series resistance 56 and the shunt inductance 57 so that the output of the demodulator 55 is substantially free from distortion. In the same manner as in the circuit of Fig. 1, the speech input circuit impresses a speech input electromotive force upon a path leading to reactance control winding 14 associated with the ferro-magnetic inductance 13. The path of the control winding 14 also includes in series with the control winding a ferromagnetic reactance 58 so associated with the shunt inductance 57 as to be controlled thereby. The cores of the ferromagnetic reactances 58 and 13 are constructed of the same material and the reactances of both are therefore variable with current amplitude. The variable amplitude audio frequency current in the output or space current circuit of modulator 53 induces in winding 58 an audio frequency electromotive force which is distorted by the action of the variable reactance 58. The distorted electromotive force induced in winding 58 is superposed upon an undistorted speech electromotive force derived from points 59, 60, and the resulting distorted speech current traverses control winding 14. The variable reactances are preferably so designed that the distortion in the speech current applied to the control winding is of such character and magnitude as just to counteract the distortion which occurs in inductance 13. More precisely stated, the current traversing winding 14 is so predistorted that the resonant frequency of the circuit 11 will vary directly and proportionately in accordance with the undistorted speech electromotive force between points 59 and 60. The control circuit including windings 14 and 58 is designed to transmit audio frequency currents and the transfer of high frequency is precluded by the character of winding 58 which has such high distributed capacity as to effectively short-circuit any carrier frequency electromotive force that might otherwise be induced therein.

Fig. 7 shows the circuit of an alternative type of frequency modulation transmitter which also employs a reverse feedback path to maintain linearity between the outgoing carrier frequency and the amplitude of the modulating waves. The circuit may be considered as a modification of Fig. 1 with a reverse feedback circuit connected between the input terminals 62, 63 of band-pass filter 17 and the speech input terminals 64 and 65 in the modulating path. Included in the reverse feedback path is a frequency demodulating element 66 which includes sufficient incidental or additional amplification to enable the distortion correcting action of reverse feedback to be attained. If a speech or other modulating electromotive force is impressed between points 64 and 65 the carrier frequency of the modulated carrier wave as presented at output terminals 62 and 63 should faithfully follow the intensity of the modulating electromotive force. Consequently, frequency-demodulating device 66 which may, for example, be of the types disclosed in Figs. 2, 4 or 5 will yield an undistorted speech frequency electromotive force. If, however, there is any tendency for distortion to occur in the modulation process because of the characteristics of the ferromagnetic inductance or of the tuned circuit there will be a corresponding tendency for the speech frequency current in the output path of demodulator 66 to exhibit a corresponding distortion. Any such tendency is counteracted by the operation of the negative feedback path which insures that such a modulating or control current is applied to control winding 14 as will overcome the distorting tendency.

Fig. 8 presents a frequency modulated wave receiving system in which two detectors are connected like detectors 32 and 33 of Fig. 2 with their input terminals in push-pull relation to the receiving circuit and their output terminals in opposition. Any demodulated components resulting from amplitude modulations of the incoming waves passed by band-pass filter 24 will accordingly be balanced out in the output circuit. A local oscillator comprising an electron discharge device 69 and its associated circuits is connected to the common input path of the two detectors by a transformer 70 and serves to impress on the input path oscillations of the normal unmodulated carrier frequency to which the tuned loop 71 is resonant, the impressed electromotive force being in phase quadrature to the incoming wave unmodulated carrier frequency electromotive force applied to the same path. The tuned loop includes a ferromagnetic reactance winding 72 with which is associated a control winding 73 connected to the output circuit of the two detectors in the same manner as is control winding 30 of Fig. 2. A biasing source 74 corresponds in its function to source 31 of Fig. 2. In operation, the local source tends to remain in frequency agreement and in phase quadrature with the central frequency component of the incoming frequency modulated waves. Any departure from that condition gives rise to an increase in the space current of one detector and a decrease in the space current of the other to produce a control electromotive force which is applied to the winding 73 in such direction as to cause a compensating change in the reactance of element 72 so that the conditions of frequency agreement and phase quadrature are maintained.

What is claimed is:

1. A receiving system for frequency modulated carrier waves comprising a tuned circuit, means for impressing received frequency modulated waves upon the tuned circuit, means connected to the tuned circuit for producing a low frequency current corresponding in its amplitude to the carrier frequency potential set up across the tuned circuit by the received waves impressed thereupon, and means controlled by the low frequency current to shift the tuning of the tuned circuit in such direction as to tend to reduce the carrier frequency potential thereacross.

2. A receiving system for frequency modulated carrier waves comprising a circuit tuned to a predetermined frequency having a definite relation with respect to the frequency of the unmodulated carrier waves, means for impressing received frequency modulated waves upon the tuned circuit, means for deriving from the tuned circuit an electromotive force proportional to the potential difference across its terminals, and means responsive to the derived electromotive force for varying the tuning of the tuned circuit.

3. The method of receiving frequency modulated waves which comprises initially suppressing from the received waves components of the normal unmodulated carrier frequency, combining the resultant unsuppressed waves with energy of the received waves from which no component has been suppressed to obtain demodulated waves which vary in amplitude as the frequency of the incoming waves departs from the normal carrier frequency and utilizing the demodulated waves to vary the frequency of the component which is being suppressed.

4. A receiver for frequency modulated waves comprising an input circuit having a shunt path

tuned to the normal unmodulated carrier frequency and including a variable reactance element, a detector having input terminals connected to the terminals of the shunt tuned path whereby waves impressed upon the input circuit are shunted from the detector in accordance with the proximity of their frequency to the normal carrier frequency to which the shunt path is tuned, an output circuit connected to the detector to receive the detected waves and means connected to the output circuit coupled to the variable reactance element and controlled by the detected waves therein for varying the reactance of the variable reactance element to cause the tuning of the shunt path to tend to follow the varying frequency of the received frequency modulated waves.

5. A frequency modulation system comprising a pair of demodulating devices having input circuits and output circuits, the input circuits having a portion in common and other portions connected at one terminal, the output circuits being connected in series opposition, means for applying a received modulated carrier wave to the common portion of the input circuits, and means for applying a portion of the same received carrier wave to the other portions of the input circuit in opposite phase with respect to the two demodulating devices and with an intensity which is zero at the unmodulated carrier frequency and which is generally proportional to the frequency departure of the carrier wave from the normal frequency whereby the differential output electromotive force of the output circuits connected in series opposition corresponds in its amplitude to the frequency variation of the received carrier wave.

6. A receiving system for frequency modulated carrier waves comprising a tuned circuit, means for impressing the received modulated waves upon the tuned circuit, demodulating means connected to the tuned circuit for producing a low frequency current corresponding in its amplitude to the carrier frequency potential set up across the tuned circuit by the received waves impressed thereupon, and means for causing the low frequency current to shift the tuning of the tuned circuit in such direction as to tend to reduce the carrier frequency potential thereacross.

7. In a wave transmission system, an input circuit upon which received energy may be impressed a series tuned circuit connected in shunt across the input circuit to short-circuit received currents of the frequency for which the series circuit is resonant, an electron discharge device having an output circuit and an input circuit, means coupling the tuned circuit to the input circuit, the tuned circuit comprising an inductance having a ferromagnetic core, and means coupled to the output circuit to derive control currents therefrom and to impress a corresponding magnetomotive force upon the core to cause the resonance frequency of the tuned circuit to vary in accordance with the amplitude of the control currents whereby the frequency of the component of the received waves short-circuited from the input circuit by the tuned circuit varies in accordance with the amplitude of the control currents.

8. In combination, a receiving circuit upon which received waves are impressed a tuned path comprising an inductance element having a ferromagnetic core in series with a capacitance, the tuned path being connected in shunt across the receiving circuit to divert therefrom and suppress oscillations of the resonance frequency of the tuned path, a control circuit including a control winding electromagnetically coupled with the inductance element to impress magnetomotive forces thereon whereby the resonance frequency of the tuned path varies as the electromotive forces applied to the control circuit vary, and means responsive to a departure from a linear relationship between the resonance frequency and the impressed control circuit electromotive forces to so affect the current in the control winding of the inductance element as to tend to restore the relation of linearity between the resonance frequency and the electromotive force impressed on the control circuit whereby the frequency of the oscillation component suppressed from the received waves is substantially proportional to the amplitude of the control winding current.

9. In a frequency modulation system, a receiving circuit over which high frequency waves are received, a series tuned path connected in shunt to the receiving circuit to short-circuit therefrom waves of the resonant frequency of the tuned path, the path comprising a capacity element and an inductance element having a ferromagnetic core, a control circuit having a control winding electromagnetically coupled to the inductance element to impress magnetomotive forces on the core whereby the inductance is varied and the resonance frequency of the tuned circuit is caused to vary as the electromotive force applied to the control circuit varies, and means in circuit with the control winding to so affect the current in the winding as to tend to maintain a linear relationship between the resonance frequency of the tuned circuit and the intensity of the electromotive force impressed upon the control circuit.

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