

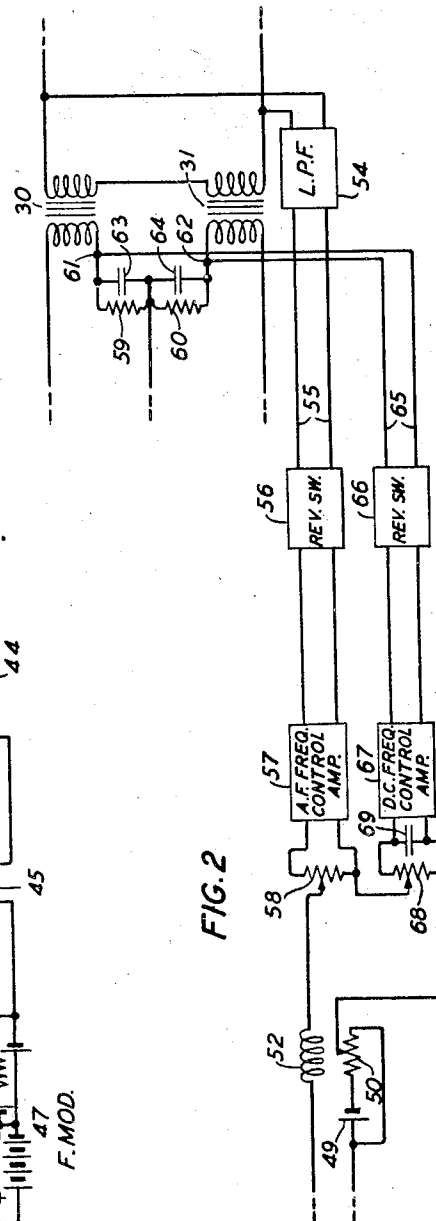
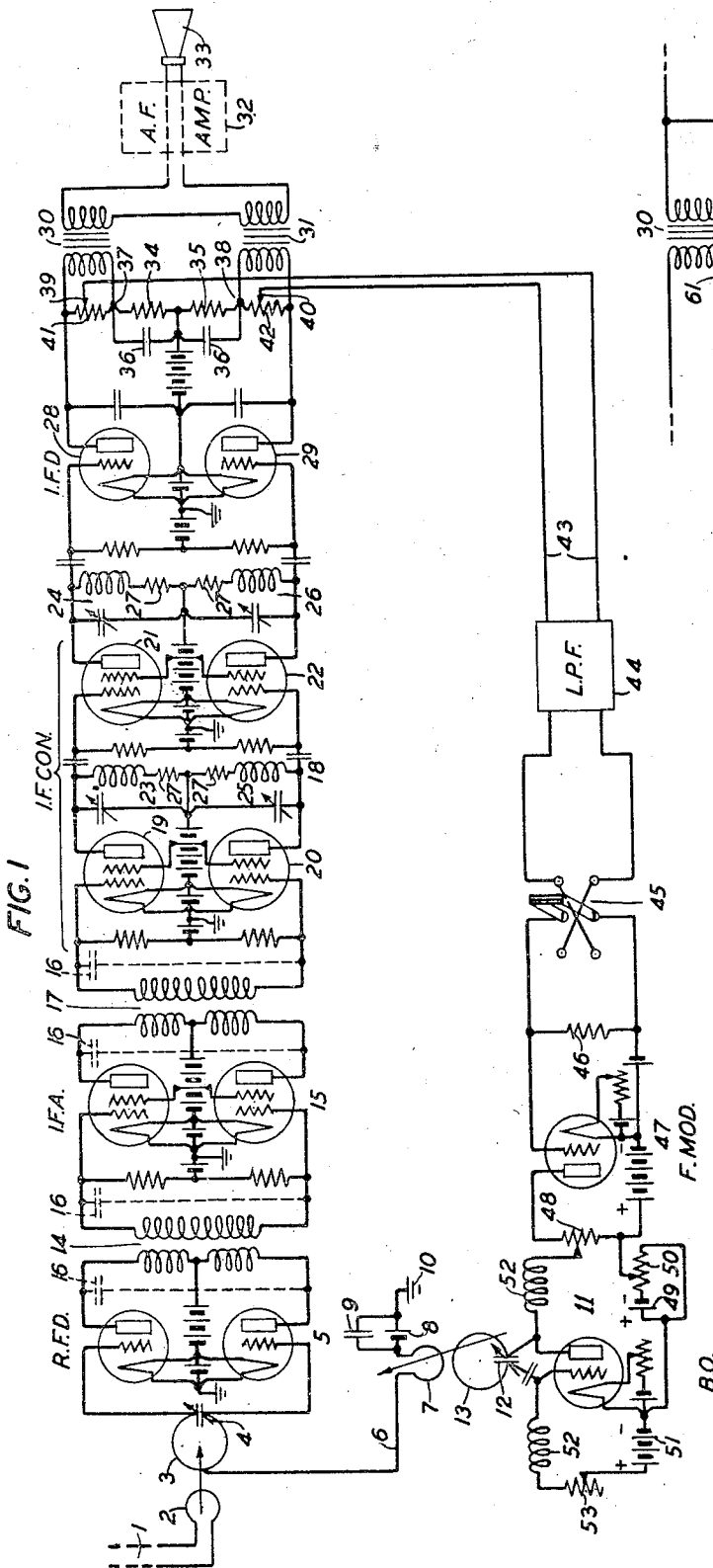
March 30, 1937.

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2,075,503

RECEPTION OF FREQUENCY MODULATED WAVES

Filed March 26, 1936



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2,075,503

RECEPTION OF FREQUENCY MODULATED WAVES

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Application March 26, 1936, Serial No. 70,929

9 Claims. (Cl. 250—6)

This invention relates to reception of frequency modulated waves and more particularly to methods and circuits for reducing noise and disturbances introduced during reception of frequency modulated waves.

An object of the invention is to receive frequency modulated waves and to derive from them the signal or other control waves by which they were originally modulated, and at the same time to effect a substantial reduction in the noise currents or other disturbances occurring in the course of the reception process.

A further object of the invention is to reduce the extent to which the wave form of the signaling wave is distorted in the process of reception and detection.

According to this invention the well-known superheterodyne method for reception of frequency modulated waves is employed in which the received waves are combined with locally produced oscillations to yield intermediate frequency waves which, after amplification, are converted from frequency modulated to amplitude modulated waves and thereafter demodulated in the ordinary manner. The resulting audio frequency signals correspond to the frequency modulations of the incoming waves but are accompanied by disturbing audible waves. These may arise from tube noise generated within the receiving system, from various extraneous sources, and from distortions resulting from non-linearity in the characteristic of the receiving system. To reduce such effects, in accordance with the present invention, an opposing electromotive force is fed back from the audio frequency output of the receiver so as to produce a frequency modulation of the local oscillations which beat or combine with the received waves. The feedback component is so predetermined as to phase and so adjusted as to amplitude that the distortion components are effectively reduced leaving an audio frequency output current which more faithfully represents the modulations of the received waves.

Assume that during a non-signaling period when the frequency of the incoming or received waves is constant, the frequency of the locally produced waves is made to vary in some periodic fashion without varying the amplitude of the locally produced waves. The frequency of the intermediate frequency waves will consequently vary and the final detector will yield an audible note the intensity of which will be a function of the extent of the frequency variation introduced into the local oscillator and the pitch of which

will correspond to the periodicity of the frequency variation. In other words, by frequency modulation of the local oscillator it is possible to produce an audio frequency note of a desired pitch and intensity in the output circuit. By the same token it is possible to produce an audio frequency electromotive force that will tend to counteract an undesired audio frequency output current if a frequency modulation corresponding to such an undesired output noise current be applied to the local oscillator in such phase as to produce an effective noise counteracting electromotive force in the output circuit. Such a frequency modulation of the local oscillator may be had by applying to it as a frequency modulating electromotive force a portion of the audio frequency output current.

At the same time that the local oscillator frequency varies in such manner as to produce the noise counteracting electromotive force in the final audio output circuit, it will, during signaling periods, also undergo variations in frequency corresponding to the desired audio frequency signal waves with which the received waves were frequency modulated. This is for the reason that the feedback path is subjected not only to the noise components but also to the desired signal components of the output circuit. It follows that the frequency modulation of the oscillator also produces a signal counteracting electromotive force in the output circuit so that along with the reduction of the noise current there is a corresponding reduction of the desired signal. This may be overcome by increasing the effective modulation of the wave sent out at the remote transmitting station. In frequency modulated wave systems this result may be attained without increasing the transmitting station output power by increasing the depth of modulation at the transmitter by which is meant the absolute change in frequency that occurs at the peaks of the modulating waves. Since the change in frequency occasioned by the modulation process is a function of the amplitude of the modulating waves, it is only necessary to increase the amplitude of the modulating waves to increase the depth of modulation. Accordingly, with increased depth of modulation at the transmitter, the loss of signal strength occasioned at the audio output terminals of the receiver by the feedback frequency modulation operation may be compensated. Compensation can also be effected by additional signal frequency amplification following the detector, but the net result as far as

unwanted effects are concerned will be different as will be explained subsequently.

Various other objects and desirable features of the invention will be apparent from a consideration of the appended specification in connection with the drawing in which:

Fig. 1 shows an embodiment of the invention in a radio receiver circuit for receiving frequency modulated waves, and

Fig. 2 shows a modification of the feedback circuit of Fig. 1.

In the circuit of Fig. 1 the receiving circuit 1 in which the ultra short waves of, for example, 500 megacycles frequency and modulated in frequency in accordance with audio frequency signal waves, are impressed by an antenna or receiving conductor, is coupled by a coupling coil 2 to the inductance 3 which with the variable tuning condenser 4 constitutes an input circuit broadly tuned to the desired incoming waves. The incoming circuit is associated with a push-pull high frequency detector or combining device 5 comprising two electron discharge devices having a grid polarizing path extending from a central point in inductance 3 by way of conductor 6, coupling coil 7, grid bias source 8 and shunting condenser 9 to earth at 10. A beating oscillator 11 illustrated in the drawing as of the Barkhausen type is provided with a tuning circuit including variable tuning condenser 12 and coil 13 coupled to coil 7 so as to impress local beating oscillations in like phase on the grids of the electron discharge tubes of combining device 5. Intermediate frequency oscillations produced by device 5 are impressed by transformer 14 on the grid circuit of push-pull intermediate frequency amplifier 15. The transformer windings are preferably self-tuned, or, in other words, are so designed that with their inherent self and connected shunt capacities 16 and with sufficient coupling between the windings they are very broadly tuned to the intermediate frequency band. The use of rather low values of grid circuit resistance following these transformers is an aid in securing the desirable flat-topped characteristic. Intermediate frequency amplifier 15 increases the amplitude of the intermediate frequency waves and is coupled by a transformer 17 to two-stage intermediate frequency converter 18. The transformer 17 is similar to transformer 14 and its windings are similarly tuned and coupled. Each stage of the frequency converter comprises two electron discharge devices 19 and 20, and 21 and 22, each preferably of the screen grid type. Tubes 19 and 21 are each provided with a tuned output circuit 23, 24 tuned to a frequency considerably higher than the intermediate frequency resulting from interaction of oscillations of the local beating oscillator 11 with received waves of the normal or unmodulated carrier frequency so that the normal intermediate frequency will fall at approximately a midpoint of the most linear portion of the ascending side of the over-all amplitude response-frequency characteristic of circuits 23 and 24. Output circuits 25, 26 of tubes 20 and 22 are each tuned to a frequency correspondingly lower than the normal intermediate frequency which will therefore fall at approximately the midpoint of the descending side of the linear portion of the over-all amplitude response-frequency characteristic of circuits 25 and 26. Moreover, the circuits 23, 24 and 25, 26 each include a damping resistance element 27 to make their frequency response characteristics somewhat more linear than they would otherwise be. The tubes 19 and 20,

21 and 22 and their circuits are so matched that at the normal intermediate frequency the amplitude of their response is equal.

In passing through the two stages of intermediate frequency converter 18, the intermediate frequency waves are further amplified and at the same time their frequency modulations are converted into amplitude variations by virtue of the sloping characteristics of circuits 23, 24, 25, and 26. Since the slopes of the characteristics of circuits 23 and 24 are opposite to those of the characteristics of circuits 25 and 26 when viewed at the intermediate carrier frequency, the envelope of the modified wave impressed upon the detector tube 28 will vary in opposite sense to that of the wave applied to the other detector 29. These envelope variations correspond to the modulating voltage applied to the transmitter. Upon detection in tubes 28 and 29 there will result voice frequency currents in the plate circuits of these tubes which will be of opposite phase. Hence output transformers 30 and 31 must be so arranged that their output windings will deliver currents of like phase to audio frequency amplifier 32 and indicating or translating device 33.

Connected in series in the space current paths of detectors 28 and 29 are resistances 34 and 35, each shunted by a large by-pass condenser 36. If, as a resultant of a slow drift of the intermediate frequency from normal frequency, the space current rises in resistance 34 in consequence of the increasing amplitude of intermediate frequency waves applied to the upper detector 28 and simultaneously falls in resistance 35, the potential between points 37 and 38 slowly drifts from its normal zero value to some definite magnitude which is a function of the frequency drift. This slowly drifting potential difference between points 37 and 38 give rise to a frequency correcting potential which is applied by sliders 39 and 40 of potentiometers 41 and 42, over conductors 43, low-pass filter 44 and the contacts of the reversing switch 45 to a resistance 46 in the input path of an electron discharge amplifier 47, the plate circuit of which includes a potentiometer resistance 48 which is also included in the anode biasing circuit of Barkhausen oscillator 11. There is thus impressed at the terminals of resistance 48 a bias potential which operates effectively in series with the bias electromotive force impressed from source 49 through its potentiometer 50. Accordingly, the frequency of the oscillations produced by source 11 may be made to slowly drift in the same manner and to practically the same extent as the frequency of the incoming wave (and hence of the intermediate frequency) varies. It follows that so long as the frequency drift of the incoming wave and of the local oscillations are equal and in the same direction, that is, both increasing or both decreasing, the resultant central intermediate frequency which is the numerical difference of the incoming wave frequency and the locally generated oscillation frequency will remain of substantially constant value. It will, therefore, be apparent that slow drifts in the frequency of the incoming oscillations or of the local beating oscillations will be automatically compensated by a correction of the frequency of the beating oscillator such as to bring the central intermediate frequency practically back to its normal value.

Alternating potentials corresponding to signal, distortion, and random disturbances will appear across potentiometers 41 and 42, but not across resistances 34 and 35 since the latter elements

are effectively by-passed as shown. Hence, if sliders 39 and 40 are moved, preferably symmetrically, away from points 37 and 38 a portion of the receiver output energy is applied to the feedback system via leads 43. The frequency correcting potentials derived from resistances 34 and 35 will not be substantially altered by this process if resistance 46 is given a rather high value. Thus the amount of feedback of signal frequency may be adjusted to any desired value, while the frequency control feature will remain fully effective at all times. This latter feature of the system is similar to that disclosed and claimed in my copending application, Serial No. 56,017 filed December 24, 1935. As the frequency of the received incoming waves rises in consequence of signal modulations at the remote transmitter, the similar signal modulations imposed upon the beating oscillator will cause its frequency also to rise. The intermediate frequency waves will therefore also experience a rising frequency but the frequency rise will be of less extent than that of the incoming waves. Assume, for example, that on the positive peak of the low frequency signal wave the incoming waves are increased in frequency by 100,000 cycles and at the same time the modulations of the beating oscillator by signal waves fed back over path 43 cause its frequency to increase 60,000 cycles. The resulting intermediate frequency will rise by the difference frequency or 40,000 cycles. This means, of course, that the effective frequency modulation of the incoming waves has been reduced by 60% by the feedback operation. The extent of this reduction will be determined by the extent of the signal frequency feedback, which is in turn controlled by the setting of potentiometer sliders 39 and 40.

Reversing switch 45 is thrown to such a position that the signal frequency and noise impulse electromotive forces transmitted to potentiometer resistance 48 will tend to increase the frequency of the beating oscillator when the frequency of the incoming wave increases in response to signal modulations at the transmitter, and decrease it when the frequency of the incoming waves decreases in response to transmitter signal modulations. Reversing switch 45 may be opened to cut off the feedback path during intervals in which the Barkhausen oscillator is being initially adjusted.

The effect of the degenerative feedback is to reduce audio frequency noises and distortions in the output current which have been introduced in the receiving process and thus to impart to the receiver as a whole more nearly the characteristics of a distortionless or linear circuit in so far as the modulations of the received waves are concerned. As has been explained this result is secured at the cost of a considerable amount of amplification or "gain" as it is commonly designated. Compensation for this loss may be effected in two ways: (1) a voice frequency amplifier as indicated at 32 by dotted lines may be inserted between output transformers 30, 31 and transducer device 33, and (2) the degree of modulation to which the transmitter is subjected can be increased until the received signal is restored to its former value. In the first case, since both signal and noise outputs will have been reduced to the same extent by feedback no improvement in signal to noise ratio will have been effected. An improvement in the ratio of signal to distortion will be realized as will be explained subsequently.

In the second case wherein the degree of modulation applied to the transmitter is increased an improvement in the ratio of signal to noise will be realized since the background level of noise which is observed during the periods of zero modulation will remain at a reduced value. Any increase in noise which may be brought about by the process of modulation will merely bring about an increase in the noise energy fed back to oscillator 11, and will therefore give rise to a correspondingly greater noise counteracting electromotive force in the output of the intermediate frequency detector.

The effect of the signal frequency feedback action upon the signal distortion products generated within the receiver may be understood from the following considerations. These distortion products represent harmonics of the fundamental components of the signaling wave applied at the transmitter and are generated as the result of any non-linearity in the frequency-response characteristics of the conversion device 18. Additional distortion can also arise in the intermediate frequency detectors. This latter form of distortion can be minimized by the use of detectors having a linear rather than a parabolic characteristic. All of these harmonics are functions of the degree of modulation for a given conversion circuit and detector, and in general will increase more rapidly with increased modulation or frequency variation the greater the order of the harmonic. All harmonic levels approach zero as the degree of modulation is reduced.

Considering again the effect of feeding back voice frequency output energy so as to produce a frequency modulation of the local oscillator of the same phase as that originally produced at the transmitter, this process can be viewed as bringing about a reduction in the degree to which the intermediate frequency wave is modulated. It is possible to define the equivalent percentage of modulation in a frequency modulation system in the same terms as are commonly used in describing a system employing amplitude modulation. Thus, it is possible to use the term 100% modulation in the former system to describe the condition obtaining when the variations in the frequency of the transmitter are sufficient to embrace the useful portion of the conversion circuit characteristic. This concept differs from that commonly employed in that in frequency modulation systems the percentage of equivalent modulation is determined in the receiver and not at the transmitter.

Suppose that in a frequency modulation system the modulating voltage at the transmitter is reduced to the extent of, say, 10 decibels. At the receiver the output voltage of fundamental frequency will likewise be reduced to the extent of 10 decibels. The second harmonic of the modulating frequency generated within the receiver will be reduced to the extent of 20 decibels. If, instead, a voltage derived from the output of the receiver is fed back to produce frequency modulation of the local beating oscillator and in such phase and magnitude as to reduce the signaling frequency output of the receiver by the factor of 10 decibels as before, the equivalent percentage modulation of the intermediate frequency wave will have been reduced as though the modulation at the transmitter had been decreased 10 decibels. This follows from the fact that the modulation applied locally to the beating oscillator has caused its frequency to shift in synchronism with

the variations induced at the transmitter and to approximately 68% of their extent, when viewed from the standpoint of the fundamental frequency only. This reduction in modulation will reduce the second harmonic distortion produced in the conversion and detection process to the extent of 20 decibels as before. In addition, the feedback action, through the generation of second harmonic counteracting electromotive forces as previously described, will further reduce the output distortion product an additional 10 decibels, resulting in a net reduction of 30 decibels. There is thus obtained an improvement in signal to second harmonic distortion amounting to 20 decibels. Since the noise output has been reduced to the same extent as the fundamental signal, no improvement in their ratio will be realized.

While the above reasoning has been applied to the second harmonic distortion only it will be seen that higher harmonics will also be modified but to an extent depending upon the order of the harmonic in question. The above method of operation is therefore useful in cases in which distortion is more troublesome than noise, as, for example, in multiplex systems where cross-talk is more disturbing than background noise.

In cases where it is desired to improve the signal to noise ratio by increasing the modulation limit at the transmitter, the reduction in distortion will not be so great, as will be seen from the following. If, after having applied feedback as before to the extent of 10 decibels, the modulating voltage at the transmitter is now increased by the same factor, the incoming signaling wave will be modulated to approximately three times its former extent. If the modulation level had been originally set at its maximum level, this increase would result in severe over-modulation were it not for the action of the feedback system. However, as a result of this action the effective fundamental frequency modulation of the intermediate frequency wave will remain the same as before. This will result in the same distortion products as were originally generated. The feedback action will produce counteracting electromotive forces which will tend to reduce the net distortion output to the extent of 10 decibels. While this result is usually obtained in the case of second harmonic distortion, higher order effects often make it impossible to realize the full improvement in the case of the higher harmonics.

Since, as has been stated previously, an increase in the degree of modulation at the transmitter to offset the reduction in signal level occasioned by feedback will result in a corresponding improvement in signal to noise ratio, this method of operation makes it possible to improve the received signal both with respect to noise and to distortion.

The Barkhausen oscillator 11 is of conventional type with a high positive electromotive force grid bias source 51, a plate bias source 49 which may be either positive or negative, but in any event is of a low electromotive force, radio frequency choke coils 52 and a variable high grid circuit resistance 53 for adjusting the grid bias potential. Although Barkhausen oscillators readily adapt themselves to frequency modulation, the invention is in no way limited to sources of this type but may utilize any type of oscillator in which the desired frequency modulation may be obtained. It is desirable that the frequency modulation of the transmitting station and of the local oscillator be linear with respect to modulating signal amplitudes. It is also advantageous to effect

frequency modulation of the beating oscillator without unduly large amplitude modulations since the less the distortions which the feedback must correct the more satisfactory will be the final result.

As described the circuit 43 which includes a low-pass filter 44 to guard against possible singing as a result of feedback for currents of high or intermediate frequency, operates to feed back slow changes in unidirectional potential differences between points 37 and 38 which are occasioned by slow drifts in the frequency of the remote transmitting or the local beating oscillator, and also operates to feed back audio frequency currents to such an extent as to partially counteract and wipe out noise and other audible disturbances, and to reduce signal distortion introduced at any point in the receiving circuit between the point at which the received waves are combined with the local oscillations and the points of connection of the sliders 39 and 40.

It may sometimes be preferred to separate the two feedback effects by providing parallel but otherwise separate paths for each. This may be accomplished by a circuit similar to that of Fig. 1 but having the feedback modified as indicated in Fig. 2. As illustrated in Fig. 2 the audio frequency feedback energy is derived from the secondary windings of transformers 30 and 31. This energy is fed through low-pass filter 54, leads 55, reversing switch 56, audio frequency control amplifier 57 and potentiometer 58 by which, as will readily be understood, audio frequency waves corresponding to the signal and noise current waves appearing in the output circuit of the detectors 28 and 29 will be impressed upon the anode biasing circuit of oscillator 11. Resistances 59 and 60 in series respectively with the input windings of transformers 30 and 31 are traversed by the unidirectional current flowing in the output circuits of the detectors 28 and 29 and serve to set up between the points 61 and 62 differences of potential corresponding to the slow drifts which transpire in the effective intermediate frequency. By-pass capacity elements 63 and 64 divert from the resistances 59 and 60, all variations of the signal frequency range and those of higher frequency. Slowly drifting potential variations are therefore impressed by way of path 65, reversing switch 66, unidirectional frequency control amplifier 67 and potentiometer 68 to the anode bias path of Barkhausen oscillator 11. A by-pass condenser 69 diverts from potentiometer 68 all except low frequency drift effects of the order of a few cycles and which are, in general, considerably below audibility.

It will be appreciated that the circuit of Fig. 2 enables entirely separate control of the amplitudes of the audio frequency and the slow drift effects and simplifies the design of the feedback paths since each may then be constructed with a view only to transfer of its individual effects.

While there has been illustrated an intermediate frequency converter of the two-path type in which one path including circuits 23 and 24 is tuned above the normal unmodulated incoming carrier frequency and the other including circuits 25 and 26 is tuned below that frequency, it is to be understood that the signal frequency feedback feature of the invention is not limited thereto but is equally applicable to any type of conversion circuit whether two or more paths or one path be employed and irrespective of whether electron discharge devices are utilized or not. However, the use of push-

pull conversion circuits is to be preferred since they make it possible to secure a balance against even order harmonics arising from curvature of the conversion circuit characteristics, as well as a balancing out of the amplitude effect of noise originating ahead of the conversion stages during the non-signaling intervals. Furthermore, when separate feedback paths for the signal frequency waves and the frequency correcting potentials are provided as in Fig. 2, the signal frequency feedback energy may also be derived from potentiometers connected across the primary windings of the output transformers as in Fig. 1.

As an aid to the better understanding of the process by which it is possible to improve the ratio of signal to noise at the output of a radio system incorporating the feedback feature of this invention, a useful analogy is the method often employed to reduce the effect of noise on telephone lines. By the simple expedient of increasing the transmitted speech level and attenuating the received signal and noise by a like amount, a corresponding reduction in noise level is effected while the signal level remains as before. An analogous action takes place when, as a result of feeding back the receiver output so as to frequency modulate the beating oscillator, both signal and noise levels at the output of the receiver are decreased by an amount equal to the degree of feedback. The equivalent percentage of modulation of the intermediate frequency wave is decreased by a like amount. Since the intermediate wave is now greatly under-modulated it becomes possible to increase the degree of modulation at the distant transmitter by this same factor so as to restore the signal to its former level. Noise resulting from disturbances both within and external to the receiver will remain at a reduced value. The use of frequency modulation rather than amplitude modulation makes this procedure possible since the equivalent percentage of modulation is, in the former system, determined at the receiver and not at the transmitter. This assumes, of course, that the amplitude modulated transmitter in question is fully modulated.

It is also to be understood that the expression "signal waves" as used in the specification and the appended claims is intended to be generic to waves used for communication, control systems, or any other teledynamic operation and that the term "waves" of the expression is intended to connote impulses of electromotive forces of any wave form and frequency whatever and regardless of their continuity or discontinuity. The term "noise" is to be construed to include not only what is ordinarily known as tube noise but also noise producing influences arising at any point subsequent to the transmitter itself.

What is claimed is:

1. The method of receiving frequency modulated waves which comprises converting the received waves to amplitude modulated waves, demodulating the amplitude modulated waves to reproduce the modulating signal waves and utilizing energy of the resulting signal waves to introduce a frequency modulation component in the received waves which will yield in the finally demodulated output a component which reduces noises and distortions introduced in the receiving process.

2. The method of reducing extraneous effects introduced during reception of the incoming frequency modulated waves which comprises fre-

quency modulating beating oscillations in accordance with the signal frequency output waves derived from the incoming waves and combining the modulated beating oscillations with the incoming waves.

3. The method according to claim 2 in which the incoming frequency modulated waves are given a modulation of sufficient extent to compensate for the loss occasioned by frequency modulation of the beating oscillator.

4. The method of signal transmission comprising imparting to unmodulated carrier waves a frequency modulation in accordance with the signals of greater extent than that desirable in the usual frequency to amplitude conversion operation, transmitting the modulated waves over a transmitting medium to a remote reception point, combining the transmitted waves with beating oscillations similarly modulated but to a somewhat lesser degree with the reproduced signals and also with noise impulses generated in the reception process whereby the effects of noise and distortion in the reception process are substantially reduced.

5. A frequency modulated wave receiver comprising means for converting received frequency modulated waves to amplitude modulated waves and for demodulating the amplitude modulated waves to recover modulating signal waves, and means for combining with the received frequency modulated waves other waves frequency modulated by some of the recovered signal modulation energy to counteract distortions and extraneous noises which are introduced in the receiver and which would otherwise appear as disturbances in the recovered signal wave output.

6. A receiving system for frequency modulated waves which comprises means for converting received frequency modulated waves to amplitude modulated waves, means for demodulating the amplitude modulated waves to reproduce signal waves by which the received waves were modulated, means for causing energy of the reproduced signal waves to generate a counter-electromotive force, and means for causing the counter-electromotive force to introduce a modulation into the received frequency modulated waves which will reduce noise and distortion currents which the receiving system tends to superimpose upon the reproduced signal waves.

7. A receiving system for frequency modulated waves comprising a source of locally generated beating oscillations, means for combining the beating oscillations with the received waves, means for deriving audio frequency signal waves from the resultant of the combination and means for frequency modulating the beating oscillations by the derived audio frequency signal wave energy.

8. A system for transmission of signals by frequency modulated carrier waves comprising a source of carrier waves, a source of modulating waves and means for modulating the frequency of the carrier waves to cause the modulated waves to extend over a greater frequency range than the feasible intermediate frequency range of a superheterodyne receiver, means for transmitting the signal modulated waves to a remote point, means thereat for combining the transmitted waves with locally generated beating oscillations to produce intermediate frequency waves, means for converting the intermediate frequency waves from frequency modulated waves to amplitude modulated waves, means for

deriving signal waves from the amplitude modulated waves, and means for frequency modulating the locally generated beating oscillations in accordance with derived signal wave energy to reduce the range of the intermediate frequency waves to a band for which the response frequency characteristic of the converting means is substantially linear.

5 9. A receiving system for frequency modulated waves comprising a source of locally generated
10 beating oscillations, means for combining the

beating oscillations with the received waves, means for deriving from the resultant of the combination both signal waves and lower frequency electromotive forces representing drifts in the unmodulated carrier wave frequency of the received waves, and means for modifying the frequency of the beating oscillations in accordance with both the derived signal wave energy and with the lower frequency electromotive forces.

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