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FREQUENCY MODULATION

Filed April 28, 1938

FIG. 1

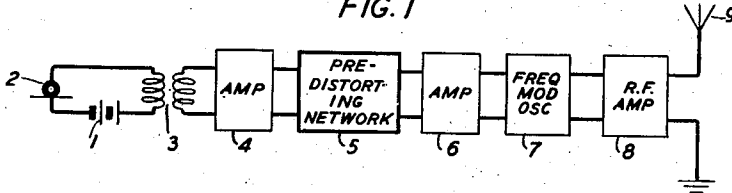


FIG. 2

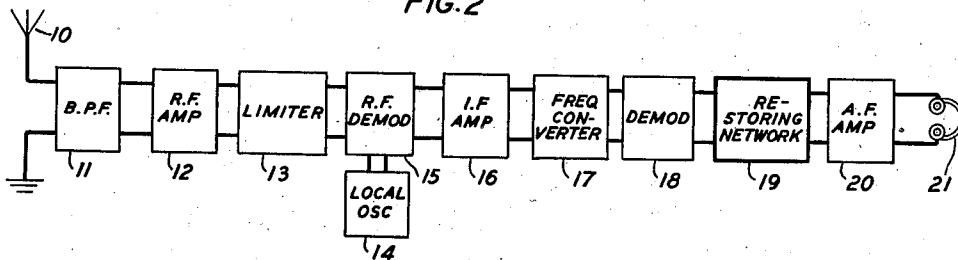


FIG. 3

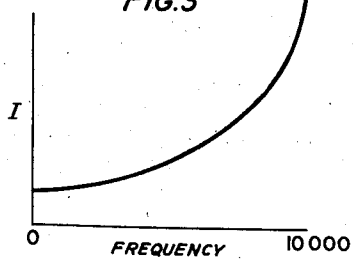
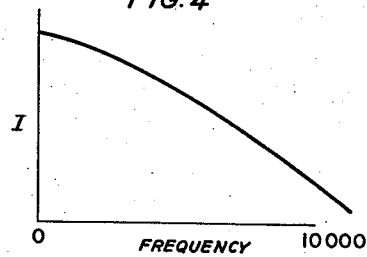


FIG. 4



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## UNITED STATES PATENT OFFICE

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## FREQUENCY MODULATION

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6 Claims. (Cl. 250—6)

This invention relates to frequency modulation and more particularly to improvements in frequency modulation systems for increasing the ratio of signal to noise.

5 In a well-known type of receiver for frequency modulated waves the incoming waves are subjected to an amplitude limiting operation to remove peaks in excess of a preassigned limit so that the resulting waves while of varying frequency are of substantially constant amplitude. The constant amplitude waves are next subjected to a frequency detection or conversion which may be effected by impressing them upon a circuit having a sharply sloping attenuation characteristic with respect to frequency. Since the amplitude response of such a circuit varies with frequency the constant amplitude waves are converted to variable amplitude waves which may be detected by an ordinary amplitude modulation detecting device. Such a system is disclosed in U. S. Patent to Demarest 2,047,312, July 14, 1936, for a Signal system.

As is well known, if the received frequency modulated waves are at all times substantially greater in amplitude at the receiving point than the noise and disturbance electromotive forces, it is possible to provide sufficient amplification at the receiver to bring the desired incoming waves during their weakest intervals up to the limiting level to which the limiter restricts them so that superimposed noise current electromotive forces are effectively eliminated so far as they may have any tendency to increase the amplitude of the received waves. It has been found in the research incident to the present invention that although the amplitude variation effects occasioned by noise electromotive forces at the radio receiver may be readily eliminated by the limiting process there is a residual phase effect occasioned by the superimposed noise electromotive forces which is not eliminated by the limiter and which therefore appears later as noise in the telephone receiver or other signal translating device. This is for the reason that a noise or disturbance electromotive force which may be of substantially the same frequency but which differs considerably in phase from the instantaneous carrier wave frequency will, when superposed upon the carrier wave electromotive force in the circuit, give rise to a vector sum electromotive force which differs materially in phase from the undisturbed carrier wave. The limiter will reduce the magnitude of the vector sum to the proper limiting value but it will not restore the phase condition of the carrier current. It transpires, there-

fore, that as a result of such noise or disturbance electromotive forces the limited or constant amplitude wave contains phase shifts which give rise to noise disturbances in the output of the final detector. An object of the invention is to reduce the resultant noise effects produced by such phase shifts.

The present invention arose from consideration of the fact that while tube noise and circuit resistance noise which constitute an important source of troublesome noise power may be assumed to be distributed uniformly throughout the frequency spectrum, the noise power which manifests itself as a result of the phase distribution introduced by noise electromotive forces in a receiving system employing current limiting is not uniformly distributed. The amplitude of the noise current which occurs with the audio signal in the output of such a frequency modulated wave receiving system is proportional to its absolute frequency and the noise power is proportional to the square of the absolute frequency thus giving a parabolic distribution of disturbance or noise power in the finally detected signal. In accordance with the present invention, the ratio of signal to noise is arbitrarily increased in the higher range of signal frequencies by subjecting the speech current or other signal current employed to modulate the carrier wave to a discriminatory attenuation to reduce the power at low frequencies relatively to that at high frequencies or to augment the power at high frequencies relatively to that at low frequencies. This predistorted signal current is then employed in a frequency modulation system of any desired type. After the final detection at the receiving station, the intensities of the high frequency components of the signal will be disproportionately high and will, accordingly, override the noise power in the higher frequency region. The detected currents may then be subjected to a compensating attenuation to reduce the higher frequency components so as to bring them back to their proper relative levels. This operation correspondingly reduces the noise power in the high frequency region.

Other objects and features of the invention will be apparent from the following detailed description and the appended claims taken in connection with the accompanying drawing in which Fig. 1 illustrates schematically the circuits of a radio transmitting station, and Fig. 2, the circuits of a cooperating receiving station, of a system employing the novel methods and appa-

ratus of this invention for transmission and reception of frequency modulated waves;

Fig. 3 illustrates the transmission characteristic of an element of the circuit of Fig. 1, and

Fig. 4 illustrates the transmission characteristic of an element of the circuit of Fig. 2.

The radio transmitting circuit of Fig. 1 embodies a source 1 of unidirectional current, a microphone 2 and a primary winding of a transformer 3 in series therewith, a low frequency amplifier 4 connected to the secondary winding of the transformer, and a predistorting network 5, audio frequency amplifier 6, frequency modulated oscillator 7, radio frequency amplifier 8 and antenna or transmission circuit 9, connected in tandem to the output terminals of the amplifier 4. In operation of the system, speech or other signal currents originating at microphone 2 and which may encompass a range of 0 to 10,000 cycles are amplified and impressed upon the predistorting network 5 which has a transmission characteristic of the type illustrated in Fig. 3. The characteristic of Fig. 3 indicates the manner in which electromotive forces of equal intensity and of different frequencies throughout the audio frequency range give rise in the output circuit of the distorting network to currents which increase with frequency at a rising rate so that the higher frequencies are very greatly favored over the lower frequencies. The precise characteristic of the distorting network may be predetermined in any desired manner by suitable design of the network but it is preferably such as to cause the current intensities for equal impressed electromotive forces to increase at least in direct proportion to absolute frequency so that the power of these signal current will increase in accordance with the square of the frequency. In the characteristic illustrated in Fig. 3, the current intensity  $I$  increases at an even more rapid rate than the frequency. In other respects the apparatus of the circuit of Fig. 1 may consist of conventional types. It will be understood that there is radiated from the transmitting antenna 9 a frequency modulated carrier wave, the modulating current corresponding to a speech signal in which the intensities of the low frequency components are relatively depressed and the intensities of the components of the high frequencies are relatively augmented as indicated in Fig. 3.

The amplification attained by the use of amplifiers 4 and 6 is preferably sufficient to give a high index of modulation. As an example, the unmodulated carrier frequency may be of the order of 100 megacycles. The signal currents from source 2 may comprise a range of 0 to 10,000 cycles inclusive, such as may be desirable for the broadcasting of music. The modulation index may, for example, be of the order of 20 so that the frequency excursion to each side of the carrier frequency may be of the order of 200,000 cycles.

Fig. 2 shows a receiving circuit for receiving frequency modulated waves radiated from the transmitter of Fig. 1. Its circuit comprises an antenna 10, a band-pass filter or tuned circuit 11 having a sufficiently broad pass band to enable it to accept the wide range of frequencies radiated from antenna 9, a broad band radio frequency amplifier 12, a current limiter 13, a local superheterodyne oscillator 14 and radio frequency amplifier 16 which is designed to pass a broad band, frequency converter 17 for translating constant

amplitude variable intermediate frequency currents into variable amplitude currents, a demodulator 18, a restoring network 19, audio frequency amplifier 20 and a receiver, loud-speaker or other signal translating device 21.

The amplifiers and local oscillator are preferably of the well-known thermionic electron discharge type. As is well known, such devices involve a certain amount of so-called tube noise which consists of the random disturbances which are always to be found in circuits of high resistance such as are necessarily associated with thermionic discharge devices and the random variations which occur in the space currents of electron discharge devices because of the lack of uniformity in electron discharge from the cathodes of such devices. Moreover, there are additional static effects occasioned by lightning and other transient electrical disturbances which are picked up by the antenna 10 and impressed upon the receiving circuit.

In the operation of the receiving system of Fig. 2, incoming frequency modulated waves received by the antenna 10 and accepted by the selective filter unit 11 are amplified by amplifier 12 to such an extent that the level of the weakest passages is brought up to the limiting level at which the current limiter 13 "cuts off." The operation of the radio frequency demodulator in cooperation with local oscillator 14 is to effectively shift the band of constant amplitude waves to an intermediate frequency range which is of the same band width but which is lower in frequency by the amount of the frequency of the local oscillator 14. The intermediate frequency waves are amplified by amplifier 16 and are then impressed on the frequency conversion unit 17 which corresponds in its nature and function to the unit TR of the Demarest Patent 2,047,312. The operation of the frequency conversion device is to produce output currents which vary in amplitude and which may therefore be demodulated by an amplitude modulation demodulator 18 of the usual type. The output currents delivered by the demodulator 18 are accordingly of audio frequency and correspond in their frequency and amplitude characteristics to the output currents of the predistorting network 5 at the transmitting station.

The effect of tube noise and other disturbing electromotive forces at the radio receiver is to produce a gamut of components the power of which is distributed substantially uniformly throughout the frequency spectrum. Such of these disturbances as fall within the range of frequencies of the modulated carrier electromotive forces may combine with the carrier electromotive forces to produce resultant electromotive forces, the magnitude and phase of which are indicated by the vector sum of the combined electromotive forces. If such a noise electromotive force by chance happens to agree in phase with the carrier wave at a particular instant its principal effect, when superimposed thereon, will be to increase the magnitude of the carrier wave. Consequently, since limiter 13 restricts the transmitted carrier electromotive force to a magnitude somewhat less than that of the minimum which would exist in the absence of the noise electromotive force, the limiter effectively wipes out the noise electromotive force increment and leaves the carrier wave unaffected. If, however, the noise electromotive force while agreeing in frequency with the carrier wave is displaced from it in phase by a considerable

angle, the vector sum will likewise be displaced in phase from the undisturbed carrier wave. The current limiter 16 will restrict the magnitude of the vector sum electromotive force to the pre-assigned limiting value but it will not alter the phase relation so that the limited wave now carries with it a phase distortion. As is well known a sinusoidal phase modulation is equivalent to a sinusoidal frequency modulation with the modulating frequency 90 degrees displaced. It transpires therefore, that the phased distortion introduced by the superposition of noise electromotive forces and carrier electromotive forces gives rise to noise currents in the final output current of such a frequency demodulation system. The energy of these noise currents unlike the noise power of the original superimposed noise is not uniformly distributed in the frequency spectrum. In fact, the resultant noise current is found to be proportional to absolute frequency and the noise power is therefore proportional to the square of the absolute frequency. Accordingly, with the usual frequency modulation transmission system, the noise tends to override the desired signal components in the upper frequency portion of the signal band. It will be recalled, however, that at the transmitting station the modulating signal has been predistorted by device 5 in advance of the modulating operation so as to accentuate the higher frequency components of the signal as to cause them to increase relatively to the lower frequency components at a rate higher than the increase of absolute frequency. Consequently, the demodulated signal current at the output terminals of demodulator 18 increases with frequency at a rate in excess of the absolute frequency and the power increases at a rate in excess of the square of the absolute frequency. It will, therefore, be evident that the signal currents in their higher frequency ranges have been so favored by the system that they readily override the noise in the same higher frequency range. In order to restore the proper relative levels of the different frequency components of the demodulated signals, these demodulated signals are subjected to the action of restoring network 19, the transmission characteristic of which, as illustrated in Fig. 4, has been so designed as to be complementary to that of the predistorting device 5 which is illustrated in Fig. 3. The demodulated signals are, therefore, restored to the normal frequency relation of the signals occurring in the output circuit of amplifier 4 at the transmitter. At the same time the noise currents at the higher frequencies are also reduced by the network 19 with the result that the final signal greatly exceeds the noise currents at all frequencies in its frequency band. The system has, therefore, enabled the full advantage of the current limiter to be had without reduction of the signal to noise ratio at the higher signal frequencies.

The wave distorting network 5 at the transmitting station and the restoring network 19 at the receiving station may comprise only static networks for variably attenuating the waves impressed upon them by the circuit elements to which they are connected. They may, however, also comprise amplifiers so designed as to produce non-linear amplification. Accordingly, it is to be understood that when reference is made in the specification or claims to "discriminatory transmission" or to "discriminatory attenuation" that the expressions are used in a generic

sense to describe the operations of both types of apparatus.

It is to be understood that various modifications may be made in the system without departing from the principle of the invention provided only that the signal modulation of the modulated carrier waves which are limited at the receiver has been accentuated in the range for which the limiter introduces the greatest phase disturbance noise. Accordingly, both the method and the system of the invention are to be understood as limited only by the scope of the appended claims.

What is claimed is:

1. The method of signaling in which carrier waves are modulated in frequency in accordance with the amplitude of modulating signal waves which comprises accentuating the degree of modulation for the higher signal wave frequencies by predistorting the modulating signal waves in such manner as to cause the higher frequency components thereof to be relatively increased in magnitude with respect to the lower frequency components in accordance with a characteristic which rises at a much more rapid rate than does the frequency of the signal wave components, limiting the amplitude of the resulting frequency modulated waves to a substantially constant magnitude and thereafter frequency demodulating the modulated carrier waves whereby the increased energy of signal waves at higher signal wave frequencies may override at those same frequencies the increased noise introduced by the limiting action.

2. The method of frequency modulation which comprises subjecting modulating waves to a discriminating action by predistorting the entire band of modulating waves in such manner as to cause a relative increase in magnitude throughout the band as the frequency increases in accordance with a characteristic which rises at a much more rapid rate than does the frequency of the modulating wave components utilizing the resulting modulating waves to frequency modulate a carrier wave, transmitting the frequency modulated carrier wave to a remote receiving point, subjecting the frequency modulated waves received at the receiving point to an amplitude limiting action, causing the limited waves to undergo frequency demodulation to reproduce waves of the modulating frequency and varying the relative intensities of the components of the demodulated wave to restore the original intensity relationships of the different frequency components of the modulating signal.

3. The method of signaling which comprises predistorting signals to be transmitted in such fashion as to greatly augment each frequency component with respect to all lower essential frequency components, frequency modulating a carrier wave by the resulting energy, transmitting the modulated carrier wave to a remote point and subjecting it to a frequency demodulation, and thereafter causing the demodulated signal to undergo a compensating transmission to restore its various frequency components to their original relative intensity levels.

4. A transmitter for frequency modulation comprising a source of modulating waves, means for subjecting said waves to a discriminatory transmission of such character that the levels of the intensities of the higher frequency components are increased relatively to those of the lower frequency components to a degree which increases much more rapidly than does the frequency of

the components to produce signal waves of altered amplitude frequency characteristic having a greatly accentuated effect in the upper portion of the modulating signal frequency range, a carrier wave source, and means for modulating the frequency of carrier waves produced by said source in accordance with the signal waves of altered amplitude frequency characteristic.

5. A receiver for carrier waves which have been frequency modulated by speech currents predistorted to increase the amplitudes of each of the speech frequency components with respect to all lower frequency speech components in such manner as to discriminate in favor of the higher frequency components comprising a path upon which such waves may be impressed, an amplifier connected thereto, a wave amplitude limiter connected to the amplifier, means connected to the amplitude limiter for receiving the constant amplitude waves which it delivers and for frequency demodulating them to produce audible signal waves, and means for subjecting the audible signal waves to a discriminatory attenuation which increases with frequency throughout the entire speech frequency range and has such a charac-

teristic as to cause their various frequency components to attain their proper relative levels.

6. A carrier wave transmission system comprising a source of audio frequency signal waves, means for augmenting the higher frequency components relatively to the lower frequency components to a degree which increases much more rapidly than does the frequency of the components, a source of carrier waves, means for frequency modulating the carrier waves in accordance with the augmented signal waves, means for transmitting the modulated carrier waves to a remote receiving point, means at the receiving point for subjecting the incoming waves to a limiting action to render their amplitude substantially constant, means for frequency demodulating the resulting limited amplitude waves, and means for augmenting the lower frequency components of the demodulated waves in such manner as to compensate for the discrimination between these components and the higher frequency components which occurred prior to the frequency modulating operation whereby waves corresponding to the original audio frequency signal waves may be derived.

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