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EXHIBIT
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H. E. CURTIS

2,352,254

FREQUENCY MODULATED WAVE TRANSMISSION

Filed July 23, 1943

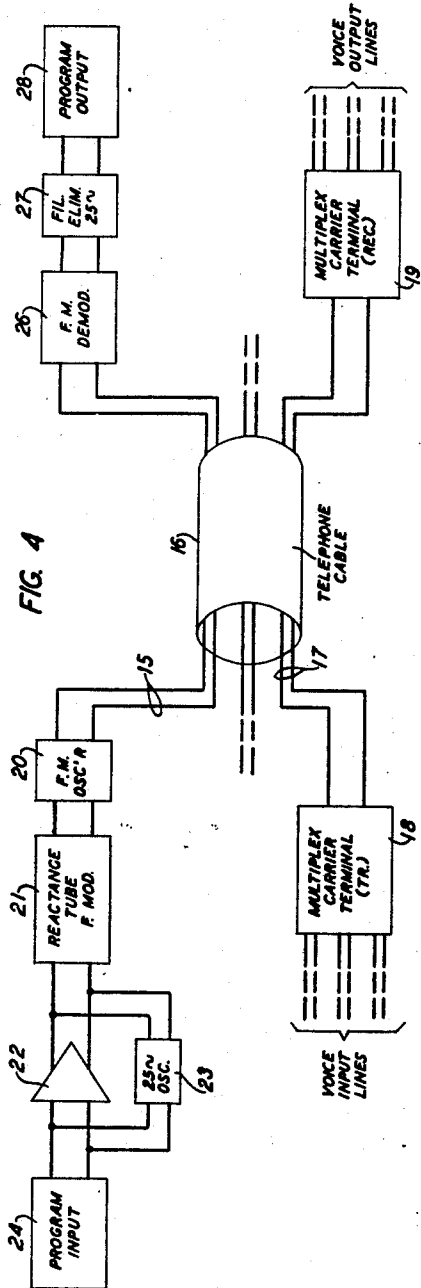


FIG. 1

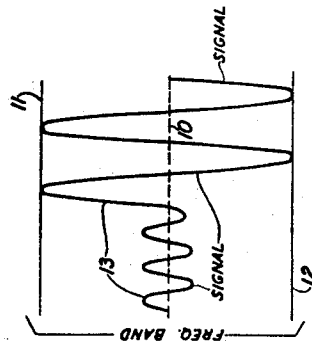


FIG. 2

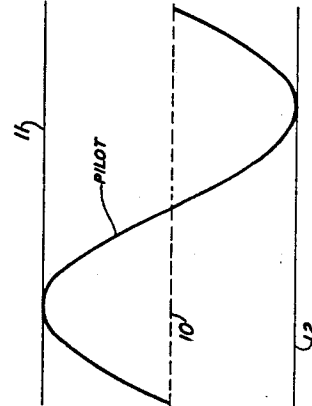
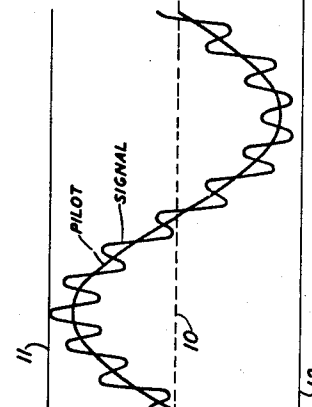


FIG. 3



INVENTOR
H. E. CURTIS
BY *H. A. Byers*
ATTORNEY

UNITED STATES PATENT OFFICE

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FREQUENCY MODULATED WAVE
TRANSMISSION

Harold E. Curtis, Madison, N. J., assignor to Bell
Telephone Laboratories, Incorporated, New
York, N. Y., a corporation of New York

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9 Claims. (Cl. 179-78)

The present invention relates to radio or carrier frequency signal transmission and more especially to such systems in which the frequency of the radio or carrier wave is varied to transmit intelligence.

A common example of such system is one employing frequency modulation, in which the rate at which a carrier wave frequency is varied is determined by the frequency of the signal or other modulating wave, and the extent of change in frequency of the carrier wave, or depth of modulation, depends upon the signal amplitude. In such a system if there is no modulating wave or signal being sent, or only a weak signal, the frequency of the carrier wave remains unchanged or is changed to only a slight extent from its normal value. In certain types of transmission this gives rise to undesired effects such as undue interference in neighboring systems or circuits.

One object of the invention is to provide for continually changing the wave frequency used for signaling whether signals are being sent or not, in order to avoid the disturbing effects that would be produced if the wave frequency were to remain fixed or were varied to only a slight extent about its mean value.

In one particular application of the invention to be disclosed herein for illustration, the frequency modulated waves are sent over a channel in such relation to neighboring channels that undesired interference is produced in the neighboring channels if the energy in the one channel is concentrated into a narrow range in the vicinity of the normal carrier frequency. This would occur in the case of a frequency modulation channel when the carrier wave is unmodulated, or is modulated to only a small extent so that the frequency swing is small. In the embodiment of the invention to be disclosed, this is prevented by supplying a pilot wave having a frequency either above or below the signal frequency range, which pilot wave fully modulates the carrier frequency in the absence of any input signal or partially modulates the carrier frequency in the presence of a signal of less than maximum strength, to such extent that the pilot wave and signal together produce full excursions of the carrier frequency corresponding to complete modulation. Since the pilot wave has a different frequency from the signal, it can be separated from the signal in the process of reception, its purpose having been achieved in so modulating the carrier in the absence of maximum amplitude of signal as to insure an average distribution of carrier wave energy throughout

the entire frequency band represented by complete modulation by the signal.

A more complete understanding of the invention together with its objects and features will be had from the following detailed description in connection with the attached drawing in which Figs. 1, 2 and 3 are graphs to be referred to in explaining the principle of operation of the invention, while Fig. 4 is a diagram of a complete system incorporating the invention in one form.

Referring to the drawing in Figs. 1, 2 and 3, the lines 11 and 12 represent the full extent of swing of the carrier when modulated by a signal of maximum strength, the normal (unmodulated) frequency of the carrier being indicated by the dotted line 10. The graph 13 indicates how the frequency of the carrier may be varied by a sine wave, representing the signal, under the two conditions of a weak signal (at the left) and a maximum strength signal (at the right).

In Fig. 2 it is assumed that the signal is zero but that a pilot wave of low frequency is, in accordance with this invention, supplied to the modulator of sufficient amplitude to swing the carrier frequency throughout the full extent bounded by the lines 11 and 12.

Fig. 3 shows one condition in which both the pilot and the signal are present. The signal is relatively weak and the pilot in this case has just sufficient amplitude so that when it is supplemented by the signal the carrier frequency is swung to the full extent bounded by the lines 11 and 12. If the signal had been assumed stronger, the pilot wave would have had to be represented as weaker by a corresponding amount, and if the signal itself has sufficient amplitude to modulate the carrier to the full extent indicated by the bounds 11 and 12, the pilot amplitude is reduced to zero.

It will be noted that in Fig. 1 when the signal is weak, the energy is principally confined to a narrow frequency range near the normal carrier frequency. If the signal is zero, all of the carrier energy is concentrated at one frequency, of course. Only when the signal has maximum strength, in the absence of a pilot wave as assumed in Fig. 1, is the energy distributed approximately evenly over the entire frequency band devoted to the assumed channel.

Under the conditions represented in Figs. 2 and 3, however, where a pilot wave is used, it is seen that whether the signal is zero (Fig. 2) or has any value less than maximum, the energy is still distributed over the entire band by the aid

of the pilot wave which is always sufficient to insure full modulation of the carrier frequency.

In Fig. 4 a program channel is sent over one of the pairs 15 of a multipair cable 16 the other pairs of which may be devoted to any types of service, such as voice transmission and carrier transmission, one pair 17 being indicated as being used for multiplex carrier telephony. For example, the transmitting terminal 18 and receiving terminal 19 connected to opposite ends of line 17 may be standard cable carrier terminals providing twelve carrier channels occupying the total frequency range from 12 kilocycles to 60 kilocycles. Only three voice lines are represented at each terminal but in reality there would be twelve such lines. It will be understood that the cable 16 would in practice be hundreds or thousands of miles long and would include repeater stations at intervals along its length. Many of the pairs can be used for the same or different kinds of service.

The program channel that is on pair 15 is assumed to use the total frequency band from 12 kilocycles to 60 kilocycles also. At its transmitting terminal it includes a frequency modulated oscillator 20 of normal frequency 36 kilocycles, the frequency of which is modulated in any suitable manner, illustrated as modulated by means of a reactance tube circuit 21 when modulating potentials are impressed on it. Such a modulating system is disclosed, for example, in De Lange Patent 2,278,063, granted March 31, 1942, to which reference is made for complete disclosure. The frequency band of the program signal itself may extend from near zero to 8 kilocycles by way of illustration.

Ahead of the modulator 21 and following the program input 24 is an amplifier 22 provided with a feedback coupling 23 which causes the amplifier to generate a pilot wave of low frequency, such as 25 cycles, the amplitude of which depends upon and is complementary to the amplitude of the impressed program signal. This amplifier may be constructed as disclosed in Bollman Patent 2,231,558, dated February 11, 1941.

Thus there is produced and sent into the line 15 a wave having an average or normal frequency of 36 kilocycles which is frequency modulated by the program signals and pilot wave together in such manner as always to cause the frequency to be swung over the entire 12-kilocycle to 60-kilocycle range as described previously in connection with Figs. 2 and 3.

At the receiving terminal this wave is demodulated in a frequency modulation demodulator 26 of suitable and known type, the output of which will contain the program signals and the pilot wave. The latter is eliminated by the high-pass filter 27 which passes the program currents but suppresses the 25-cycle pilot wave. The program currents are impressed on a suitable type of receiver or program circuit 28.

In a system of the type disclosed in Fig. 4 the invention permits an increase to be realized in the signal-to-noise ratio in the program channel as compared with the case where the pilot wave is not used. The permissible level in the program channel is determined by the crosstalk or interference set up in the other cable pairs especially in the multiplex carrier circuits which use the same frequency range as the program channel. During the times of zero or weak program current, if the carrier wave in the program channel were allowed to remain at one frequency or within a narrow band, the crosstalk would be con-

fined to one or two channels of the multiplex carrier system and the total program energy could not be allowed to rise higher than the crosstalk tolerance under these conditions. If, however, this energy is spread over the entire transmission band, in accordance with the invention, the crosstalk into each channel of the multiplex system is reduced and the total program energy can, therefore, in this case, be higher. The permissible increase in program level for the type of system disclosed is of the order of 5 decibels, and the improvement in signal-to-noise ratio is in the same order.

What is claimed is:

1. In a carrier wave signal transmission system, means to produce frequency modulated waves for transmission, said means including modulating means controlled jointly by the signal that is to be transmitted and by a pilot wave having a different frequency from the signal and having an amplitude varying in complementary fashion to the signal amplitude.

2. In a frequency modulated wave transmission system, means to generate high frequency waves, and means to modulate the frequency of said waves simultaneously in accordance with a signal of varying strength and with a pilot wave of strength varying in opposite manner to said signal.

3. In a frequency modulated wave transmission system, a source of carrier waves, a signal input circuit, the signal varying in strength, means to generate a pilot wave having a frequency different from the signal, means to control the strength of said pilot wave by the signal to keep the sum of the maximum amplitudes of the pilot and signal waves constant, and means to modulate the frequency of said carrier waves in accordance with the summation of said signal and pilot wave.

4. In combination, a circuit for generating a pilot wave of given frequency, a source of signal variations having changing maximum amplitudes, means to control the amplitude of said pilot wave in accordance with the changes in maximum amplitude of said signal variations to provide a summation signal-plus-pilot wave of constant maximum amplitude, a source of carrier waves, and means to modulate the frequency of said carrier waves in accordance with said summation wave.

5. In a frequency modulated wave system, means to modulate the frequency of a carrier wave in accordance with a signal of varying strength to produce a maximum swing of given amount in the frequency of said carrier wave, and means operative whenever the signal is of less than maximum strength to produce said given amount of swing in the carrier wave frequency at a frequency different from the signal frequency.

6. In a frequency modulated wave system, means to modulate the frequency of a carrier wave in accordance with the instantaneous amplitude of a signal the maximum amplitude of which varies, said signal when at its greatest maximum amplitude causing the frequency of the carrier wave to undergo frequency excursions of given extent, and means to cause said carrier wave to undergo frequency excursions of said given extent when the signal has relatively small maximum amplitudes including zero comprising means to vary the frequency of the carrier wave by an amount that is complementary to the max-

imum amplitude of the signal and at a frequency different from signal frequencies.

7. In a frequency modulated wave system, means for modulating the frequency of a carrier wave in accordance with a signal of varying strength, to produce a frequency swing of a certain amount when the signal strength is maximum, and means to modulate the frequency of said carrier wave in accordance with an auxiliary wave in such manner that whenever the signal strength falls to zero the auxiliary wave alone swings the frequency of the carrier wave by said certain amount and whenever the signal has strengths intermediate between zero and maximum said signal and auxiliary wave together produce a carrier frequency swing of said certain amount.

8. In a signaling system comprising adjacent channels for carrying different signals, one of which channels uses a frequency modulated carrier wave for transmission, means for reducing the interference into the other channels that would occur when the carrier frequency is unmodulated or is only weakly modulated com-

prising means operating whenever the signal has less than its maximum strength or is zero for producing variations in the carrier frequency sufficient to cause the frequency to swing over as wide a range as it does when modulated by maximum strength of signal.

9. In a carrier cable system, a cable containing separate pairs of wires, means to impress frequency modulated waves on one pair for the transmission of signals thereover, said waves occupying a total frequency range overlapping the range used for signaling on certain of the other pairs, and means to reduce interference into such other pairs comprising an auxiliary wave input to said one pair for modifying the frequency modulation involved in signal transmission such that the frequency of the carrier wave is varied continually over said total frequency range whether the signal modulation is strong, weak or zero, and means at the opposite terminal of said one pair for receiving the signals and suppressing said auxiliary wave.

HAROLD E. CURTIS.