

Nov. 5, 1946.

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2,410,489

NON-LINEAR FREQUENCY MODULATION SIGNALING SYSTEM

Filed July 19, 1944

3 Sheets-Sheet 1

Fig. 3.

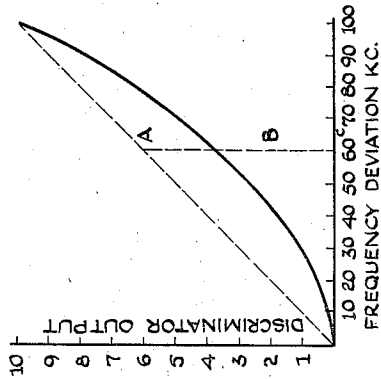


Fig. 2.

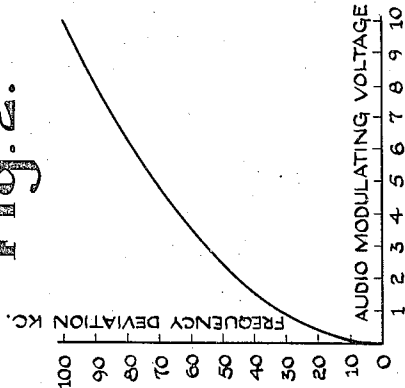


Fig. 1.

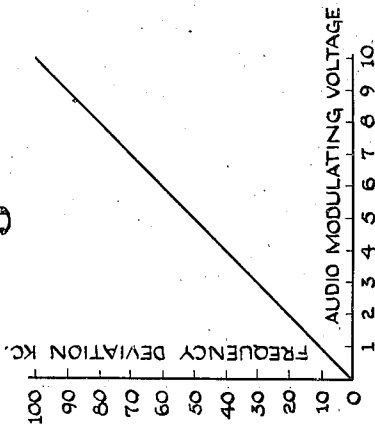
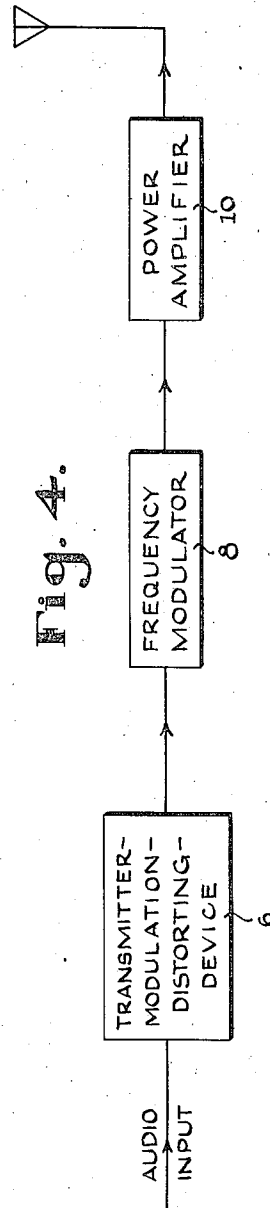


Fig. 4.



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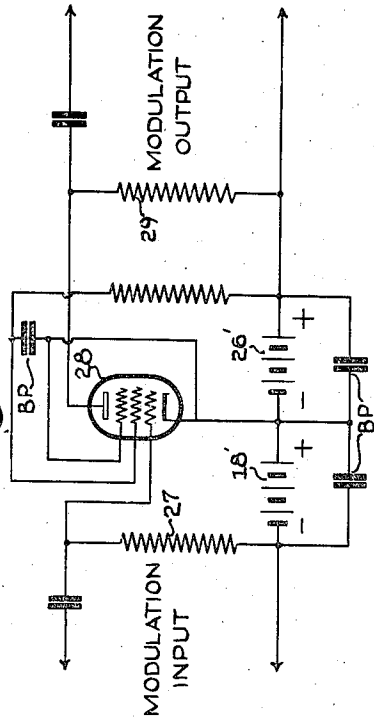
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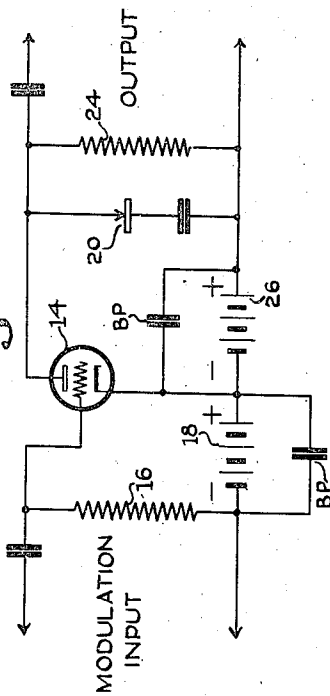
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Fig. 7.



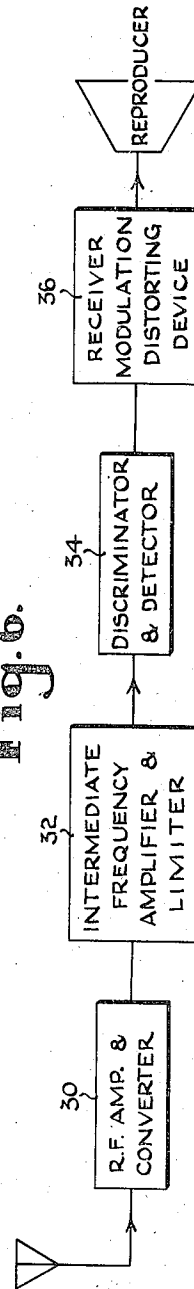
MODULATION DISTORTING
DEVICE AT RECEIVER

Fig. 5.



MODULATION DISTORTING
DEVICE AT TRANSMITTER

Fig. 6.



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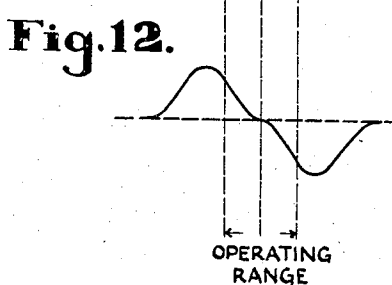
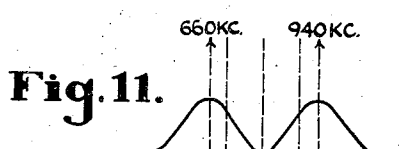
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NON-LINEAR FREQUENCY MODULATION SIGNALING SYSTEM

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3 Sheets-Sheet 3

[illegible]

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NONLINEAR FREQUENCY MODULATION
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Application July 19, 1944, Serial No. 545,576

13 Claims. (Cl. 250-6)

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This application relates to signaling systems wherein the timing of oscillatory energy is modulated in accordance with potentials or currents representing signals of any type, such as voice, television, facsimile, etc.

The general object of the present invention is the reduction of noise in the system, so that at the receiver output little or no noise appears.

In its broadest aspect my invention then is a method of and means for reducing the noise output in the response of a frequency modulation receiver by means of a distortion of the conventional frequency characteristic of the receiver discriminator, and the utilization of an opposite or counter distortion of the discriminator characteristic of the transmitter to give perfect fidelity.

The manner in which the noise reduction is accomplished in my improved system will not be described in detail. In this description reference will be made to the attached drawings, wherein

Fig. 1 illustrates the relation of the audio modulating voltages to frequency deviation in known frequency modulation systems.

Fig. 2 illustrates the relation of the audio modulating voltages to the frequency deviation in a timing modulation system arranged and operated in accordance with my invention.

Fig. 3 illustrates by a curve the characteristic of the counter-correction used at the receiver, and also shows the improvement in noise reduction gained by the use of my system.

Fig. 4 illustrates by block diagram the essential features of a frequency modulation transmitter system, arranged in accordance with my invention.

Fig. 5 illustrates details of the distorting or modulation potential modifying circuit which may be used in my system to obtain the desired modification of the modulating potentials used for timing modulating the carrier.

Fig. 6 illustrates by block diagram a receiver arranged in accordance with my invention and including counter-distorting means, while

Fig. 7 illustrates a modulation distorting device for use at the receiver to accomplish counter-distortion of the modulation to correct the distortion used at the transmitter for noise reduction purposes.

In Fig. 8 I have shown an arrangement for producing the counter-distortion in the intermediate frequency circuit of the receiver, for example, the frequency discriminator circuit.

Figs. 9, 10, 11 and 12 comprise characteristic curves of the circuit of Fig. 8. These curves are used in explaining the manner in which the

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counter-distortion is obtained in the arrangement of Fig. 8.

In the conventional frequency modulation transmitter the antenna current may be represented by the following expression.

$$(1) \quad i = A_0 \sin(\omega_0 t + m_f \sin \omega t)$$

$$m_f = \frac{K_f f_0}{f_\infty}$$

k_f = modulation factor

$k_f f_0$ = frequency deviation

f_0 = the radio frequency

f_∞ = the audio frequency

The modulation factor in the typical frequency modulation transmitter varies linearly with the strength of the audio modulating voltage. Hence the frequency deviation varies linearly with the strength of the audio modulating voltage. Thus to take a typical example assume

$$f_0 = 40,000,000 \text{ cycles}$$

$$k_f(\text{max}) = .0025$$

From the values given above the maximum deviation is seen to be 100 kc. Assume that 10 volts of audio voltage at the output to the modulator gives this deviation of 100 kc. A chart showing the frequency deviation versus modulating voltage amplitude for the typical frequency modulation transmitter is as shown in Fig. 1. Note that the deviation is substantially directly proportional to modulation voltage amplitude.

In my improved system the deviation does not vary linearly with the audio modulation voltage but follows a curve such as, for example, the curve of Fig. 2. In this curve it is again assumed the maximum deviation is 100 kc. and occurs at 10 volts modulation voltage at the modulator input. The deviation for all intermediate values of modulation, however, is greater than in usual systems. The modulation factor k_f is no longer linear with respect to the modulation strength. The deviation varies at a rate higher than linearly with respect to the modulation rate. Assuming deviation to be plotted on the "Y" axis and modulation voltage on the "X" axis, the second derivative of "Y" with respect to "X"

$$\left(\text{i. e. } \frac{d^2 Y}{dX^2} \right)$$

should be negative.

At the receiver then, I use a modulation correction network having a characteristic opposite to that of Fig. 2. Such a characteristic is shown

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in Fig. 3 by curve B. Here the audio output does not vary linearly with respect to the frequency deviation; it varies at a rate that is less than linearly with respect to the deviation. Assuming deviation to be plotted on the "Y" axis and modulation voltage on the "X" axis, the second derivative of "Y" with respect to "X"

$$\left(\text{i. e. } \frac{d^2Y}{dX^2} \right)$$

should be positive.

Inspection of these curves shows that an advantage of the receiver discriminator characteristic shown at B in Fig. 3, is that for noise having a low frequency deviation the signal to noise ratio is improved by the ratio AC/BC, which is an improvement of the order of 2 to 1.

My improved signaling method, as described hereinbefore, and means for carrying out the same, will be apparent to those skilled in the art without further description.

However, in Fig. 4 I have illustrated by rectangles the essential features of a timing modulation system arranged in accordance with my invention.

The input which for convenience has been designated audio input, but may be inputs of other types and of frequencies other than audio, is supplied to a modulation distorting device 6, which has a characteristic as illustrated in Fig. 2. The so-modified modulation current or potentials is then applied to a frequency modulator 8, wherein a carrier is modulated as to timing in accordance with the modified modulating potentials. The carrier is then amplified or frequency multiplied, etc., as desired, in a power amplifier 10 and utilized. The frequency modulator in 8 may be of the type illustrated, for example, in Crosby U. S. Patent #2,279,659, dated April 14, 1942, or of the type wherein the phase of a carrier of fixed frequency is modulated by potentials corrected in such a manner that the output derived by frequency multiplying the phase modulated carrier has the characteristics of frequency modulation or similar characteristics.

The correction network in 8 may be arranged in various manners. For example, this network may comprise an arrangement as illustrated in Fig. 5. In Fig. 5, the modulation input is supplied to the input electrodes of a tube 14. The input electrodes are shunted by a resistance 16 of high impedance which supplies grid bias due to grid rectification. The bias supplied by 16 may be supplemented by the source 18 shunted by modulation potential by-pass condenser BP. The output electrodes are shunted by a non-linear impedance 20 and a high resistance 24. The impedance 20 has a characteristic such that its resistance varies inversely with the applied voltage. A material known as "Thyrte" has such a characteristic. The output thus is loaded lightly at low levels and heavy at high levels. The anode source 26 is shunted by a modulation frequency by-pass condenser BP. The output from the system is supplied to the frequency or phase modulator in 8.

There are a number of materials which may be used for the non-linear impedance 20. The device should have a high resistance with low values of current, and a low resistance for high values of current. Copper oxide rectifiers have a characteristic like this. The operation of this non-linear impedance is as follows. Tube 14 is an amplifier having an audio output voltage which is practically linear with audio input volt-

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age when the non-linear impedance 20 is disconnected. When the non-linear impedance 20 is connected in the circuit, the output voltage is practically the same as above for small values of audio voltage input. However, for large values of audio voltage input, the impedance which tube 14 works into decreases due to the characteristics of non-linear impedance 20 and hence the output is reduced. Of course the change in resistance of 20 with current is gradual. By adjusting the value of resistor 24 the shape of curve, Fig. 2, may be changed as desired.

The receiver may be arranged as illustrated in Fig. 6, wherein the distorting device is connected between the discriminator and detector and the output. The receiver may include a radio frequency amplifier and converter including a source of oscillations at 30, and intermediate frequency amplifier and limiter in 32, a discriminator and detector in 34, and the receiver modulation distorting correcting device in 36. As to the discriminator and detector, it may be of any well known approved type. Preferably a discriminator and detector of the type illustrated in Crosby U. S. Patent #2,229,640, dated January 28, 1941, or Seeley U. S. Patent #2,121,103, dated June 21, 1938, or Conrad U. S. Patent #2,057,640, dated October 13, 1936, is used here.

The distorting device in 36 may be as illustrated in Fig. 7. The modulation distorting device illustrated in Fig. 7 is essentially an audio amplifier using a pentode tube 28 of the remote cutoff type. These tubes are commonly used for automatic volume control and have an output characteristic similar to Fig. 3. By adjusting the value of resistor 24 (Fig. 5) curve, Fig. 2, may be made complementary to the curve of Fig. 3. In operation the input of tube 28 is coupled to the detector output of unit 34 (Fig. 6), and the output of tube 28 is supplied to a utilization circuit. The counter-distortion may be accomplished by modifying the response of radio frequency circuits, as, for example, the characteristic of the discriminator circuit. The essential feature is that the relation between the modulation and deviation be changed in the transmitter, as I have disclosed, and a compensating or restoring change made at the receiver.

In Fig. 8 I have shown a frequency discriminator circuit arranged to accomplish this counter-distortion. This circuit consists of two resonant series circuits A and B, one tuned above and the other below the frequency modulated carrier band. The two series circuits are in parallel across the tuned stage 42, which may be coupled to the tuned stage 40 of the intermediate frequency amplifier. Tuned circuit 42 then supplies the frequency modulated I. F. to the series circuits A and B. Each of the circuits A and B comprises an inductance and a capacity in series. Each circuit also contains a series resistance, 44 and 46, which is of high value as compared to the maximum reactance of the circuit within the band.

The two series circuits in parallel are connected to one end of circuit 42 by resistances 44 and 46. The high frequency circuit is completed by connecting the other end of the tuned circuit 42 through resistance 45 to a resistance divider in shunt to the anodes 52 and 54 of the diode 50. The anode 52 of the diode is coupled to a point on the series circuit A by a radio frequency coupling condenser 51 and a series resistance 53 to include a portion of the series resonant circuit A in shunt to the electrodes of this diode. The anode 54 of

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the other diode is similarly coupled to a point on the series circuit B by a radio frequency coupling condenser 55 and resistance 57.

Due to the preponderance of resistance in the circuits, the currents in the two branches A and B are essentially constant and equal, regardless of frequency. Hence, across the reactive part of each branch appears a voltage which varies almost linearly with frequency, reaching zero on the frequency midway between the resonant frequencies of the branches A and B and rising from zero value on either side of the said midway frequency. These two voltages are separately detected in the double diode 50 and the outputs of the detectors are fed in phase opposition to the resistances 60 and 62, one end thereof being grounded. The corrected output is taken from these resistances. Thus, at the center of the band the detectors are producing equal direct current voltages across the load resistances 60 and 62, and the direct current potential across the total load is zero since these equal outputs oppose. If the frequency increases, the output of one detector increases and the output of the other detector decreases, causing the total output voltage to go negative by an amount proportional to the frequency deviation. In similar manner a decrease of frequency will cause the output voltage to go positive. This pushpull type of detector not only balances out the harmonic distortion which would occur due to the departure from linearity in the series resonant circuit, but also causes any amplitude modulation to be bucked out.

The customary adjustment for the two series resonant circuits A and B is shown in Fig. 9. When the outputs of the two diodes are combined, and bucking, the output curve is linear with frequency, as illustrated in Fig. 10.

In accordance with my invention, adjustment is made such as to introduce counter-distortion. To do this I adjust the resonant frequencies of the two series resonant circuits further apart so that the resonance curves are situated as illustrated in Fig. 11. This is done by tuning the reactances and/or resistances of the series circuits A and B. Now when the outputs of the detectors are combined bucking in the double diode the output will appear as in Fig. 12. This will result in a discriminator output similar to that shown in Fig. 3 of the drawings. In this arrangement abscissas designate frequency deviation, while the ordinates represent discriminator output.

As an example of the frequencies involved, it may be assumed that the mean frequency of the intermediate frequency fed to tuned circuit 40 and thence to tuned circuit 42 is about 800 kc. Then circuit A might, if conventional, be tuned to about 690 kc. and circuit B might be tuned to about 910 kc., as indicated in Fig. 9. In accordance with my invention, however, A is series tuned to about 660 kc. and B to about 940 kc., as indicated in Fig. 11. Then the circuit elements of A and B may be of the values indicated in Fig. 8. It will be understood that for other I. F. input frequencies, other circuit values may be used, and also at the input frequency used as an example the element values given may be varied considerably in practice without altering the results obtained in accordance with my invention.

I claim:

1. The method of signaling which includes these steps, amplifying modulating potentials to a degree such that they vary in amplitude greater than linearly with respect to their initial ampli-

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tude, and modulating the timing of oscillatory energy in accordance with the modified modulating potentials.

2. The method of signaling which includes these steps, generating oscillations of carrier wave frequency, generating currents of a predetermined amplitude range characteristic of signals, deviating the timing of the oscillations in accordance with the signal currents, and modifying the amplitude of the signal currents intermediate the upper and lower ends of the amplitude range thereof in such a manner that the timing deviation of the oscillations is expanded throughout a corresponding range.

3. The method of signaling which includes these steps, generating oscillations of carrier wave frequency, generating currents representing signals the amplitude of which vary from a minimum to a maximum value, deviating the timing of the oscillations in accordance with the signal, modifying the amplitude of the signal currents in such a manner that the timing deviation of the oscillations is expanded for signal amplitudes intermediate said minimum and maximum values, transmitting said oscillations so modulated, and subjecting the same to an amplification and demodulation process wherein the resulting signal current amplitude is compressed with respect to timing deviations intermediate maximum and minimum deviations.

4. The method of demodulating timing modulated oscillations of the character recited in claim 2 which includes these steps, amplifying the timing modulated oscillations and deriving from the amplified oscillations signal currents the amplitudes of which are compressed with respect to deviations intermediate the maximum and minimum deviations.

5. In a communication system, the method of signaling which includes these steps, expanding the amplitudes of modulating potentials for amplitudes intermediate minimum and maximum values thereof, modulating the timing of oscillatory energy in accordance with the modified modulating potentials, transmitting the timing modulated energy, amplifying and demodulating the timing modulated carrier energy while distorting the character thereof in a sense opposite to the modification of the same at the transmitter.

6. The method of signaling which includes these steps, generating oscillatory energy, generating modulating currents, modifying the amplitude of the modulation currents in such a manner that the modified modulation amplitude is substantially zero for minimum modulation amplitude and a fixed value for maximum modulation amplitude but is expanded for modulation amplitudes intermediate said minimum and maximum values, and modulating the timing of oscillatory energy in accordance with the modified modulating potentials.

7. The method of receiving timing modulated oscillatory energy of the character described in claim 6 which includes these steps, amplifying the said timing modulated oscillatory energy, detecting the modulations thereon to derive the modulation components, and subjecting the modulation components to a modification which counteracts the modification of the modulation at the transmitter.

8. In a communication system, the method of signaling which includes these steps, at the transmitter expanding the amplitudes of modulation potentials through a range intermediate

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the minimum and maximum amplitude values, modulating the timing of oscillatory energy in accordance with the so-expanded modulating potentials, transmitting the timing modulated oscillatory energy, receiving amplifying and demodulating the timing modulated oscillatory energy to derive the modulation components, and compressing the derived modulation components throughout a range intermediate the minimum and maximum amplitude values of the derived modulation components.

9. A modulation system comprising apparatus wherein oscillatory energy the timing of which is to be modulated in accordance with signals appears, a source of signal current covering a predetermined range of intensities coupled by modulating means to said apparatus, and signal current modifying means in said coupling such that the timing modulation of the oscillatory energy is expanded with respect to intermediate values of signal current intensity.

10. A system as recited in claim 9, wherein said last named means comprises an electron discharge device having input electrodes coupled with said source of signal current and output electrodes associated with said apparatus, and a non-linear resistance in shunt to said output electrodes.

11. A receiver for timing modulated oscillatory energy wherein the timing is modulated greater than linearly for signal amplitudes intermediate minimum and maximum signal amplitudes, a timing modulated oscillation amplifier circuit excited by said modulated oscillatory energy, and

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a frequency discriminator and detector circuit coupled to said amplifier, the detector and discriminator having a characteristic such that the demodulation components vary less than linearly in amplitude with respect to deviations of said oscillatory energy intermediate maximum and minimum deviations thereof.

12. A receiver for timing modulated oscillatory energy wherein the timing is modulated greater than linearly for a range of amplitudes of signaling currents, a frequency discriminator and detector circuit excited by said oscillatory energy, an output circuit, and a modulation amplifier coupling said output circuit to said detector, the modulation amplifier having a characteristic such that the demodulation components in the output circuit vary less than linearly in amplitude with respect to deviations of said oscillatory energy corresponding to said range of amplitudes.

13. The method of signaling which includes these steps; generating oscillations of carrier wave frequency, generating currents of a predetermined amplitude range characteristic of signals, amplifying the generated currents to a degree such that they vary in amplitude linearly with respect to their original minimum and maximum amplitude values and greater than linearly for amplitude values intermediate said minimum and maximum values, and modulating the timing of oscillatory energy in accordance with the modulating potentials so amplified.

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