March 26, 1946. W. VAN B. ROBERTS 2,397,157

WAVELENGTH MODULATION SYSTEM

Filed Feb. 12, 1943 3 Sheets-Sheet 1

Fig. 1.

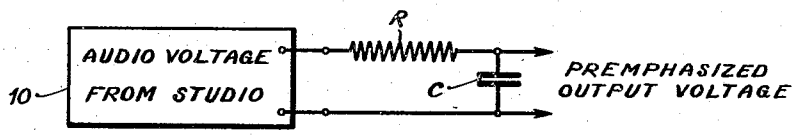


Fig. 2a.

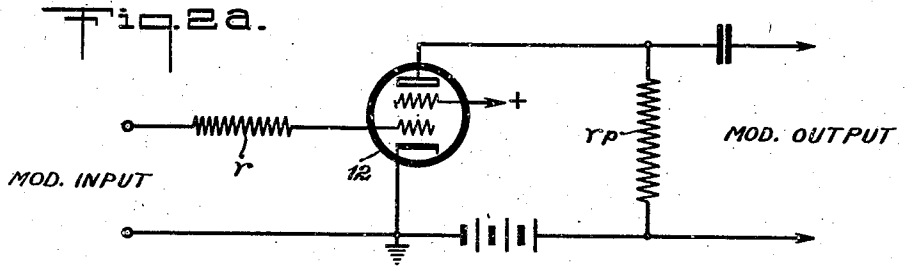


Fig. 2b.

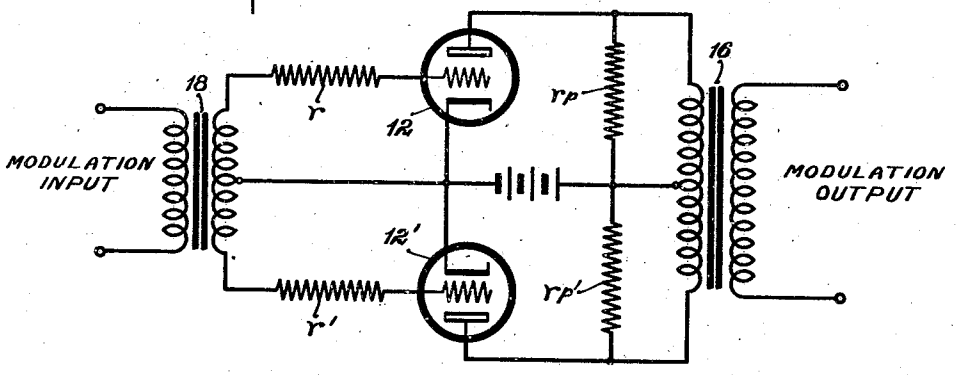
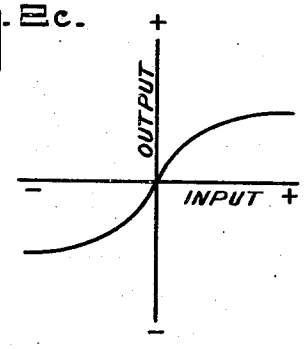


Fig. 2c.



INVENTOR
W. V. B. ROBERTS
BY H. S. Hoover
ATTORNEY

March 26, 1946. W. VAN B. ROBERTS 2,397,157

WAVELENGTH MODULATION SYSTEM

Filed Feb. 12, 1943 3 Sheets-Sheet 2

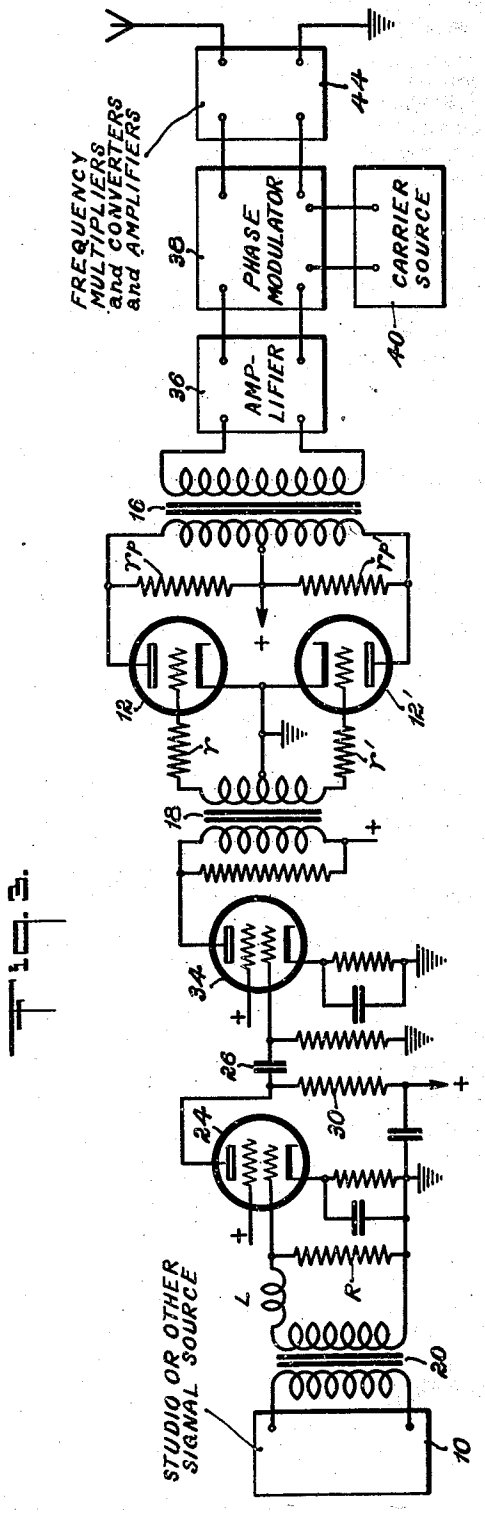


Fig. 3.

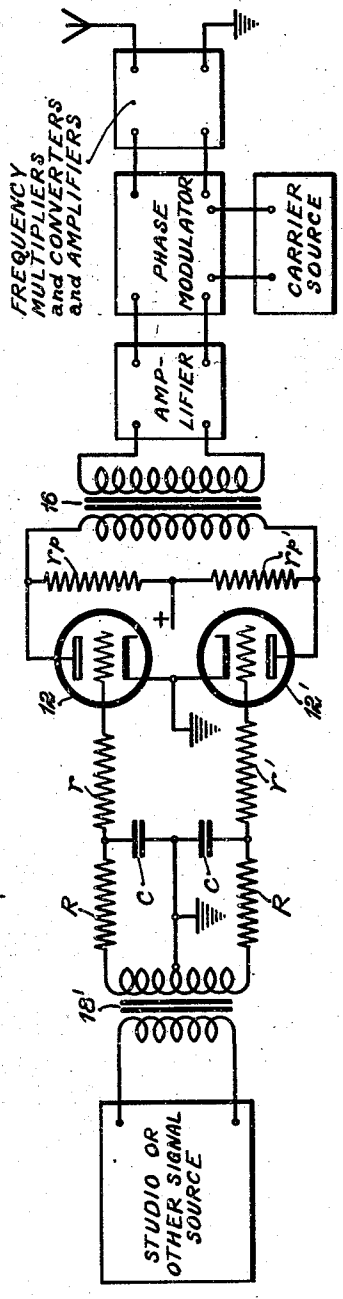


Fig. 4.

INVENTOR
W. V. B. ROBERTS
BY H. G. Grover
ATTORNEY

March 26, 1946. W. VAN B. ROBERTS 2,397,157

WAVELENGTH MODULATION SYSTEM

Filed Feb. 12, 1943 3 Sheets-Sheet 3

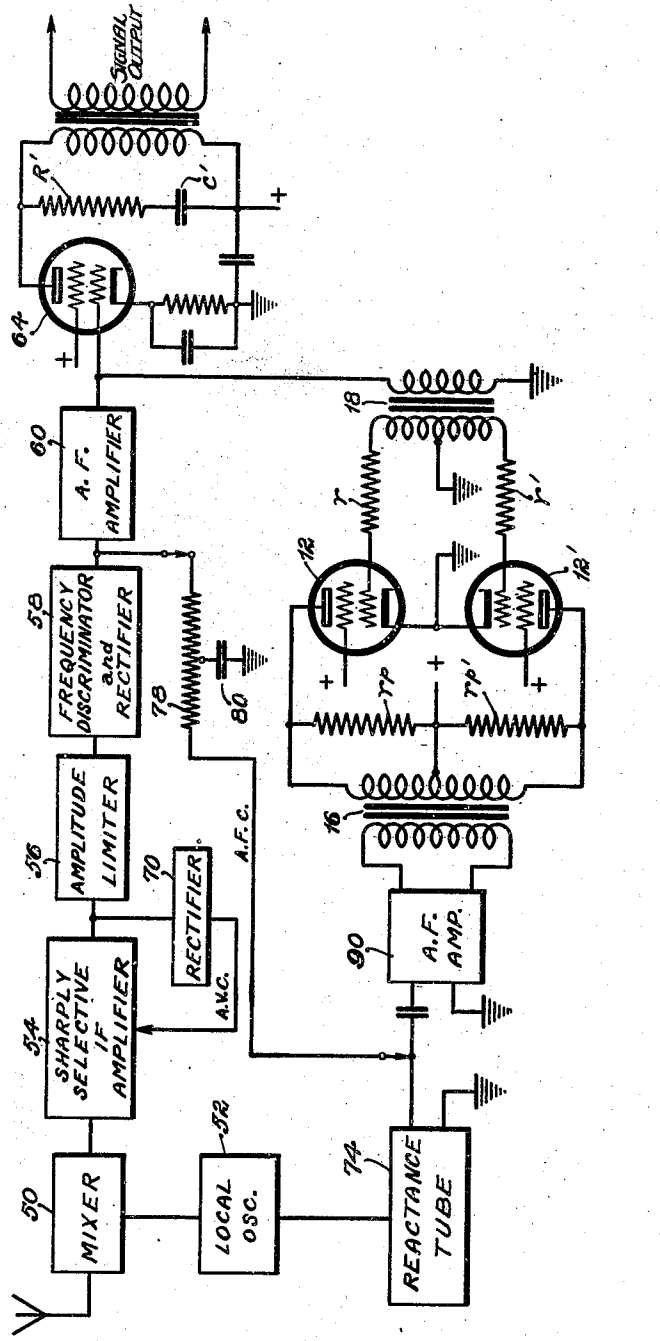


Fig. 6.

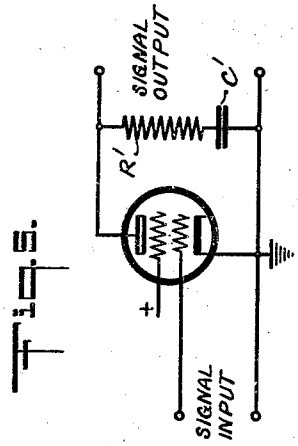


Fig. 5.

INVENTOR
W. V. B. ROBERTS
BY H. S. Glover
ATTORNEY

Patented Mar. 26, 1946

2,397,157

UNITED STATES PATENT OFFICE

2,397,157

WAVE LENGTH MODULATION SYSTEM

Walter van B. Roberts, Princeton, N. J., assignor to Radio Corporation of America, a corporation of Delaware

Application February 12, 1943, Serial No. 475,601

11 Claims. (Cl. 250—6)

This application discloses improvements in transmission from a phase modulation transmitter and in receivers of said transmission where the allowable signal channel width is sufficient to permit large phase swing.

The general object of the present invention is to reduce noise by utilizing as fully as possible the full available channel width, whether or not the original modulating voltage is of low or high audio frequency and whether or not it is of larger or smaller amplitude.

Other objects attained in the present invention and advantages derived by the use thereof will appear in the detailed description which follows and in which reference is made to the attached drawings wherein;

Fig. 1 illustrates a preemphasis circuit used to reform or modify the modulating potentials used to modulate the transmitted carrier. This preemphasis circuit is arranged and operated in accordance with my invention to modify the modulating potentials in a particular manner appropriate to the use to which I put them,

Fig. 2*a* is an amplifier or relay wherein the modulating potentials are further modified in accordance with their amplitude in such a manner that the output voltage varies substantially as the logarithm of the input voltage,

Fig. 2*b* is a modified circuit using the principle of the circuit of Fig. 2*a* in a full wave amplifier or relay of the modulating potential,

Fig. 2*c* shows qualitatively the characteristic of the circuit of Fig. 2*b*,

Fig. 3 illustrates partly by block diagram and chiefly schematically a phase modulation transmitter including the novel features of my present invention,

Fig. 4 illustrates in like manner a modified phase modulation transmission system arranged in accordance with my invention,

Fig. 5 shows a tube relay and voltage modifying circuit to be used at a receiver adapted to receive the transmission from a transmitter such as the type illustrated in Figs. 3 and 4; while,

Fig. 6 illustrates a receiver arranged and adapted to receive waves transmitted in accordance with my invention.

Phase modulators have the advantage over frequency modulators in that crystal control circuits may be employed to stabilize the transmitted carrier. However, in the case of a phase modulating transmitter it is also known that for a given amplitude of modulating voltage the radiated spectrum is the wider, the higher the frequency of the modulating voltage. If the modulating voltage were to reach the same maximum amplitude at all frequencies a simple voltage "preemphasis" of the various modulating frequencies inversely in accordance with their frequencies would result in a full utilization of the available channel or frequency spectrum regardless of the frequency of the modulating voltage. However, in ordinary speech or music the low frequencies are likely to reach maximum amplitudes considerably in excess of the maximum amplitude of any of the higher frequencies. Hence a simple preemphasis such as mentioned above would result in the low audio frequency components of speech or music creating a wider than allowable spectrum if the transmitter were adjusted to cause the higher frequency components to utilize the allowable channel substantially fully.

In accordance with one aspect of the present invention I therefore provide a preemphasizing network for the voice or music, which network transmits the higher frequencies with output amplitudes substantially inversely proportional to their frequencies but which provides lessening preemphasis as the frequency becomes lower so that only a limited amount of preemphasis is imposed on the lowest modulation frequencies. The exact constitution of this network may be varied somewhat in accordance with the nature of the signals to be transmitted, but for the purpose of illustrating as simply as possible a network which is capable of realizing to a large extent the advantages of the present invention Fig. 1 may be discussed.

In Fig. 1, 10 is the signal or control potential source such as current or voltages representing voice, music or pictures originating in a studio. R and C respectively represent circuit resistance and capacity which modify the voltages from the studio in accordance with their frequency but as will be seen later not necessarily in inverse proportionality to their frequency.

It is easily shown that the output voltage of Fig. 1 for a given input amplitude to R, C, is proportional to

$$\frac{1}{1+jWRC}$$

where W equals 2π times the frequency of the input. In accordance with the present invention, R and C are so chosen that at the higher frequencies WRC is much greater than 1 whereby for high frequencies a simple preemphasis substantially inversely proportional to frequency results. However, R and C are further so chosen that at very low audible frequencies WRC is less

than 1 so that at very low frequencies there is a substantially lessened preemphasis. This choice of R and C distinguishes the network of Fig. 1 from previously used networks of similar diagrammatic compositions wherein R and C were so chosen as to make WRC less than 1 throughout the entire audible range, thus producing in these known networks a simple preemphasis, namely, inversely proportional to frequency, throughout the whole signal range.

To recapitulate the foregoing, the preemphasizing network of Fig. 1 alters the relative amplitudes of the various component frequencies of speech or music etc. in such a fashion that the radiated spectrum of a wide phase deviation transmitter (modulated by the output of Fig. 1) more fully and uniformly utilizes the available channel at all modulation frequencies than would be the case in the absence of Fig. 1.

Quite distinct from the foregoing considerations there is another reason why full utilization of the allowable channel in either wide phase or wide frequency modulation has not been attained in the past. This reason is the great variation of signal intensity level from time to time in both speech and music. It is obvious that only during periods of high intensity of the modulating voltage will the allowable channel be fully utilized. Attempts have been made in the past to improve this situation by subjecting the modulating voltage to what is called "compression of the dynamic range." However, this sort of treatment introduces other difficulties and it is therefore an object of the present invention to provide an improved means, other than compression, for widening the radio spectrum resulting from low intensity modulating voltage relative to that resulting from high intensity voltage. This means provided may be illustrated by one suitable device shown in Fig. 2*a* although it will be understood that other devices having similar characteristics may be employed alternatively.

In Fig. 2*a* is shown a relay or amplifying tube 12 having a resistance *r* in its grid circuit to which the modulating potentials are applied and a resistance *rp* in its plate circuit from which the modified modulating potentials are derived.

Referring now to 2*a* it is known that if a positive voltage of variable amplitude is impressed through *r* on the grid of tube 12 by way of the input terminals and, if *r* is very large while the plate resistance *rp* is small, then the output voltage will vary substantially as the logarithm of this input voltage. This is because the large value of *r* makes the grid current substantially proportional to the input, in combination with the fact that for small positive grid potentials the grid current varies exponentially with respect to grid potential. Hence, the grid voltage varies as the logarithm of the grid current and thereby as the logarithm of the input voltage. The plate current varies linearly with grid voltage for small variations, so that finally we have a plate current which varies as the logarithm of the input voltage.

If now I employ a pair of tubes 12 and 12' each arranged in a full wave circuit as shown in Fig. 2*a*, I obtain the push-pull arrangement as illustrated in Fig. 2*b*. The overall relation derived between secondary of transformer 16 and the instantaneous input voltage applied to the primary of transformer 18 of Fig. 2*b* is shown qualitatively in Fig. 2*c*.

Imagine now that modulating voltages are applied to a phase or frequency modulating transmitter through the arrangement of Fig. 2*b*. It will be seen from Fig. 2*c* that small amplitudes of modulating voltage will produce relatively much larger phase or frequency deviation, than large amplitudes. Thus even during weak passages of music for example, the radiated spectrum may utilize a substantial portion of the allowable channel while strong passages are prevented from exceeding this channel by virtue of the saturating or limiting property of the device of Fig. 2*b*.

Fig. 3 shows schematically a complete transmitter arranged to utilize the allowable channel more fully than has been the case in prior transmitters, both with respect to varying frequency and varying amplitude of the components of speech or music to be transmitted.

In Fig. 3, 10 represents the signal source. 20 is a transformer feeding the signal voltage to a preemphasis circuit comprising L and R and to an amplifier tube 24, the anode of which is coupled by a condenser 26 and resistance 30 to the input electrodes of a second amplifier tube 34, the anode of which is coupled to the primary winding of transformer 18 the secondary winding of which feeds the pair of tubes 12 and 12' connected as illustrated in Fig. 2*b* to modify the voltages as illustrated in Fig. 2*c*. The output transformer of the tubes 12 and 12' feeds an amplifier 36 which in turn supplies the modulating voltage to a phase modulator of any approved type in 38 to modulate therein carrier wave oscillations from a source 40. The source 40 may comprise a stabilized oscillator and/or frequency multiplier. These modulated waves are fed to a unit 44 wherein they are frequency multiplied, converted in frequency and amplified as desired.

In the arrangement of Fig. 3 the combination of L and R is shown as an alternative to the network of Fig. 1. The ratio

$$\frac{L}{R}$$

plays the same role as the product CR of Fig. 1. The network of Fig. 2*b* is as is shown incorporated without alteration in Fig. 3. The signals from 10 are modified in L, R as described hereinbefore, amplified in tubes 24 and 34 and further modified in accordance with their amplitude in tubes 12 and 12', amplified in 36 and finally used to phase modulate the carrier in 38 the high frequency output of which is increased in amplitude and frequency as desired in 44 for utilization.

In the modification illustrated in Fig. 4 a push-pull preemphasis network of the type of Fig. 1 is combined with the full wave or pushpull intensity preemphasis circuit of Fig. 2*b*. This circuit, it is believed, needs no further discussion at this point.

Having now shown how to improve the efficiency of channel utilization in a phase modulating transmitter, there remains the question of reception of signals from such a transmitter, and it is a further object of the present invention to provide a receiver capable of producing, from such transmission, the original studio signal without the amplitude and frequency distortions imposed on it during transmission.

Let us suppose we start with a simple FM receiver and that the amplitude distorting device of Fig. 2 is absent from the transmitter. The output of an FM receiver is proportional to the rate of change of phase of the received signal, and the latter is equal to W where W is defined

as before. But on account of the preemphasis network the phase deviation is proportional to

$$\frac{1}{1+jWRC}$$

as noted in connection with Fig. 1. Hence the output of the FM receiver is proportional to

$$\frac{W}{1+jWRC}$$

Since we wish the output of the receiver to be determined only by the amplitude of the studio voltage, a correction network must be applied to the output of the FM receiver and this correction network must have an output to input ratio given by

$$\frac{1+jWRC}{W}$$

so as to offset the undesired frequency dependence just mentioned. Such a correction network may be constituted as shown schematically in Fig. 5, in which a choke feed for D. C. is assumed. The transmission ratio in Fig. 5 is proportional to

$$R'+\frac{1}{jWC'}$$

and hence to

$$\frac{1+jWR'C'}{W}$$

Therefore, if R'C' is made equal to RC, the output of the simple FM receiver will be corrected for frequency distortion. Next we may consider the correction of amplitude distortion. This may best be explained by reference to the partly schematic diagram Fig. 6.

In the receiver in Fig. 6, **50** is a radio frequency amplifier and mixer such as of a heterodyne receiver. **52** represents the source of oscillations for beating with the received wave in the mixer or converter in **50**. **54** is an intermediate frequency amplifier. **56** is an amplitude limiter. **58** is a frequency discriminator and rectifier system. **60** is an audio frequency amplifier while amplifier tube **64** has in its output a resistance R' and a condenser C' the purpose of which will be described hereinafter.

The output from the intermediate frequency amplifier **54** is supplied to a rectifier **70** wherein potentials for automatic volume control purposes are developed and fed to one or more of the stages in **54**. Audio frequency and direct current is taken from the output of **58** and fed back to a reactance tube modulator in **74** to stabilize the local oscillator in **52** in a manner described hereinafter. The audio variations in this automatic frequency control potential are filtered out by resistors **78** and condenser **80**.

The modulation output of the amplifier in **60** is supplied to the primary winding of a transformer **18**, the secondary winding of which is connected to the control grids of a pair of tubes **12** and **12'**, the anodes of which are coupled by a transformer **16** to an audio amplifier in **90**. The amplifiers **12** and **12'** and their couplings are similar to the arrangement in Fig. 2b and operate in the same manner. The output of the amplifier in **90** is also fed to the reactance tube and is used along with the direct current automatic frequency control potential supplied from **58** to control the operation of the reactance tube modulator coupled to the oscillator in **52**.

Basically this is a superheterodyne receiver whose mixer input system (including R. F. stages if any) is broad enough to admit the full spectrum of the transmitter of Fig. 3, for example 100 kc. However, intermediate frequency system **54** is preferably much narrower for reasons which will appear later. The intermediate frequency output feeds a rectifier in **70** which produces AVC voltage in the usual way, and the intermediate frequency output also excites a limiter in **56**. The limiter output is impressed on a sharply responsive discriminator of any of the well known types in unit **58**, that is, any discriminator which yields, upon a small change of the intermediate frequency from its nominal value, a large direct current potential whose sign and amplitude are in accordance with the direction and amount of said change. The average discriminator output may be separated from audio variations by the "RC" filter **78** and **80** shown in the connection between **58** and the reactance tube in **74** and used as "AFC" voltage to keep the mean intermediate frequency equal to the zero-output frequency of the discriminator.

The audio frequency output of the discriminator is amplified in unit **60** and corrected for frequency distortion by the coupling network R'C' as described in connection with Fig. 5 and then impressed on the loud speaker or other utilization device.

Some of the audio frequency output of the discriminator is also impressed, without frequency distortion correction, upon a logarithmic output device **18**, *r*, *r'*, **12**, **12'**, *rp*, *rp'* and **16** like the circuit of Fig. 2b. The output of this device is then amplified in **90** and impressed on the reactance tube in **74**. The insertion of the logarithmic device as described accomplishes correction of amplitude distortion as follows:

In accordance with the invention, the governing action of the circuit connecting the discriminator output to the reactance tube is so strong that the frequency departure of the intermediate frequency from its mean value is at all times kept very small compared with the variation of instantaneous frequency of the signal received upon the mixer in **50**. This requires, however, that the local oscillator frequency from **52** must vary about its mean frequency in the same way and almost as much as the instantaneous frequency of the received signal varies. But this in turn requires that the voltage input to the logarithmic device **12**, **12'** should differ from the transmitter studio voltage only to the extent that the performance of the preemphasizer of Fig. 3 or 4 differs from simple inverse variation with frequency. This difference between discriminator output and studio voltage is what is corrected by the network R'C' of Fig. 6. It should be emphasized that the exactness of compensation for frequency and amplitude distortions introduced at the transmitter in order to improve signal to noise ratio by more fully utilizing the available channel, depends upon the exactness with which network R'C' of the receiver is matched to the transmitter network time constant R/L of Fig. 3 (or RC of Fig. 4), and upon the exactness with which the performance of the logarithmic device of the receiver matches that of the transmitter.

It is realized that the particular devices here shown for limited low frequency and low amplitude preemphasis in the transmitter may be replaced by others which accomplish similar results, and that the correction for these distortions may be accomplished in other than the particular manner shown. However, the present invention is believed to cover all such modifica-

tions as fall within the scope of the following claims:

I claim:

1. In a system of the nature described, a source of carrier wave energy, a source of modulation potentials covering a band of frequencies, connections between said sources for modulating the phase of the carrier by the modulation potentials of said band, means in said connections for modifying the modulation potentials substantially in accordance with the logarithm of their amplitudes, a receiver including a frequency discriminator and detector excited by currents the modulations on which correspond to the carrier modulations, an amplifier coupled to said detector for amplifying detected components in accordance with the logarithm of their amplitude and connections for modulating said currents in accordance with the output of said amplifier.

2. The method of modifying the form of signals to be used in a system wherein the instantaneous frequency of a carrier is to be modulated in accordance with the said modified signals which includes these steps, modifying the amplitude of currents representing the signals as a function of their frequency to derive resultant amplitude modified currents and modifying the resultant currents as a function of their modified amplitude.

3. The method of modifying the form of signals to be used in a system wherein the instantaneous frequency of a carrier is to be modulated in accordance with the said modified signals which includes these steps, modifying the amplitude of voltages representing the signals substantially inversely in accordance with their frequency to derive resultant amplitude modified voltages and modifying the resultant voltages substantially in accordance with the logarithm of their amplitudes.

4. The method of signalling by wave length modulated carrier energy and improving the signal to noise ratio during the signalling process which includes these steps, modifying modulating potentials as a function of their frequency and also as a function of their amplitudes as modified in accordance with their frequencies, modulating the carrier in accordance with the modified voltages, transmitting the carrier, demodulating the transmitted carrier and restoring the voltages to their original form.

5. The method of signalling by wave length modulated carrier energy and improving the signal to noise ratio during the signalling process which includes these steps, modifying modulating potentials substantially inversely in accordance with their frequency and substantially in accordance with the logarithm of their amplitudes as modified in accordance with their frequencies, modulating the carrier in accordance with the modified voltages, transmitting the carrier, demodulating the transmitted carrier and restoring the voltages to their original form.

6. The method of increasing the signal to noise ratio of signals wherein a carrier has its instantaneous frequency modulated in accordance with voice which includes these steps, modifying the signals substantially in accordance with their frequency and substantially in accordance with their voltages as modified in accordance with their frequency, modulating the instantaneous frequency of carrier energy in accordance with the modified voltages, transmitting the modulated carrier, demodulating the transmitted carrier to derive the signal voltages, modifying the signal voltages in accordance with their frequencies for utilization purposes, modifying the signal voltages in accordance with their amplitude as demodulated and controlling the carrier being demodulated in accordance with the modified voltages.

7. The method of increasing the signal to noise ratio of signals wherein a carrier has its instantaneous frequency modulated in accordance with voice which includes these steps, modifying the signals substantially inversely in accordance with their frequency and substantially in accordance with the logarithm of their voltages as modified in accordance with their frequency, modulating the instantaneous frequency of carrier energy in accordance with the modified voltages, transmitting the modulated carrier, demodulating the transmitted carrier to derive the signal voltages, modifying the signal voltages in accordance with their frequencies for utilization purposes, modifying the signal voltages in accordance with the logarithm of their amplitude as demodulated and controlling the carrier being demodulated in accordance with the last mentioned modified voltages.

8. The method of correcting signalling currents for use in angle modulation systems which includes these steps, modifying the amplitudes of signalling currents substantially inversely in accordance with their frequency and also modifying the signalling currents substantially in accordance with the logarithm of their amplitudes.

9. The method of signalling including these steps, modifying the amplitude of modulation currents as a function of their amplitude, further modifying the amplitude of the said modulation currents as a function of their frequency, and modulating the instantaneous frequency of wave energy of carrier wave frequency in accordance with the modified currents.

10. In a wide band phase modulation system, the method of improving signal to noise ratio in transmitted energy which comprises more and more increasing the phase deviation of carrier current per volt of studio signal both as signal amplitude and signal frequency diminish, transmitting the resultant energy, receiving the resultant energy for deriving therefrom the signal, and correcting both the amplitude and frequency distortion introduced by said method of transmission.

11. In a signalling system, a source of oscillations of carrier wave frequency, a source of modulating currents, a coupling between said last named source and said first named source to modulate the instantaneous frequency of the oscillations by the modulating currents, elements in said coupling for modifying the modulating currents substantially inversely in accordance with their frequency, and elements in said coupling for modifying the modulating currents substantially in accordance with their amplitude.

WALTER VAN B. ROBERTS.