

Nov. 7, 1939.

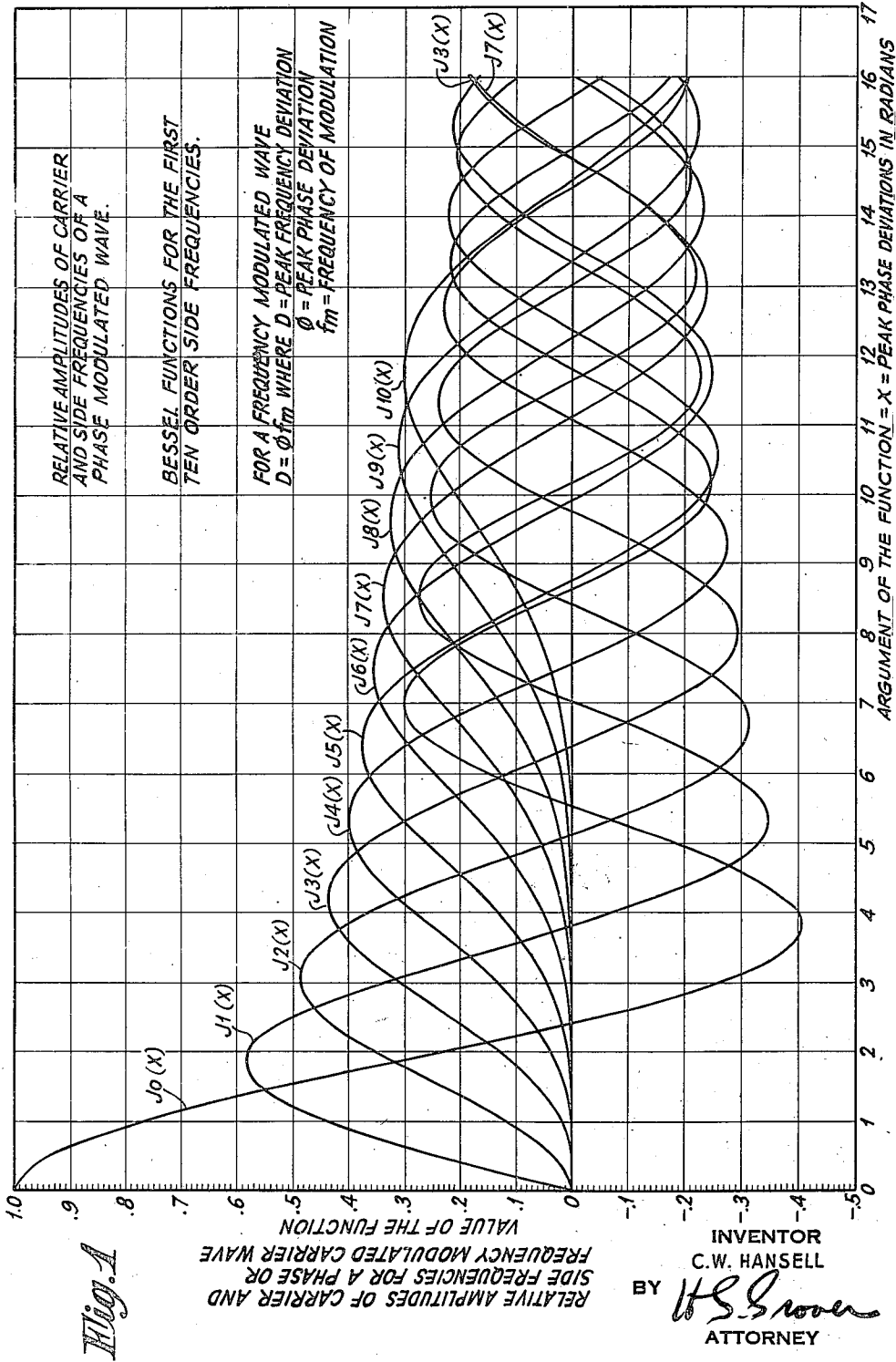
C. W. HANSELL

2,179,182

FREQUENCY MODULATION CIRCUITS

Filed Nov. 27, 1936

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C. W. HANSELL

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Fig. 2

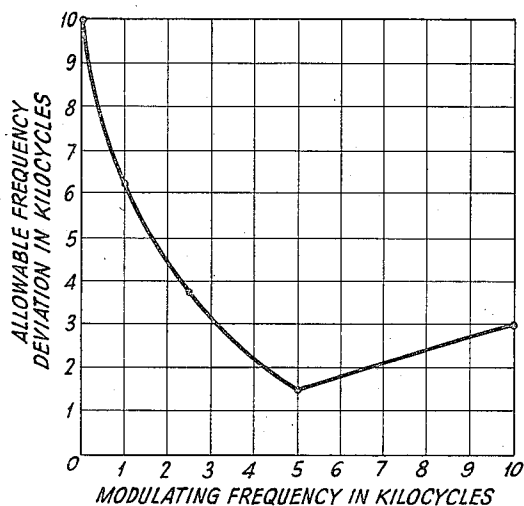


Fig. 3

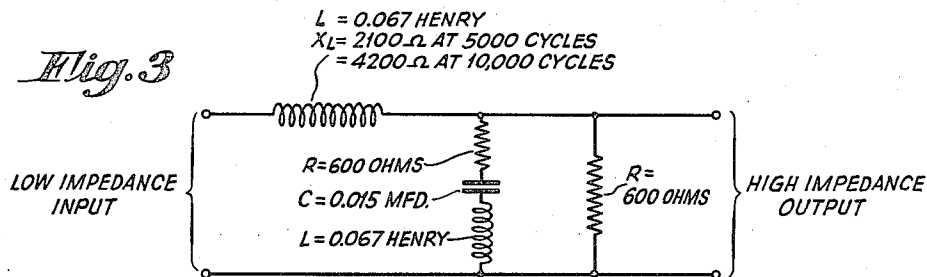


Fig. 4

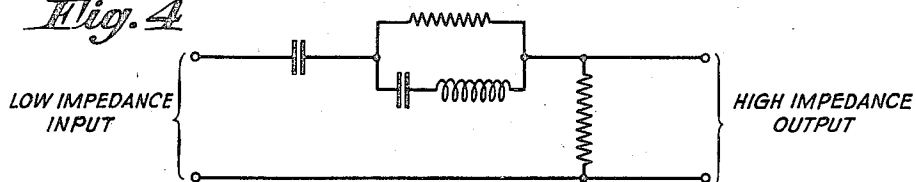
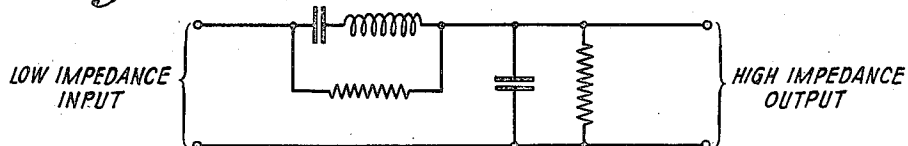


Fig. 5



INVENTOR
C. W. HANSELL
BY *H. S. Hoover*
ATTORNEY

Nov. 7, 1939.

C. W. HANSELL

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Fig. 2a

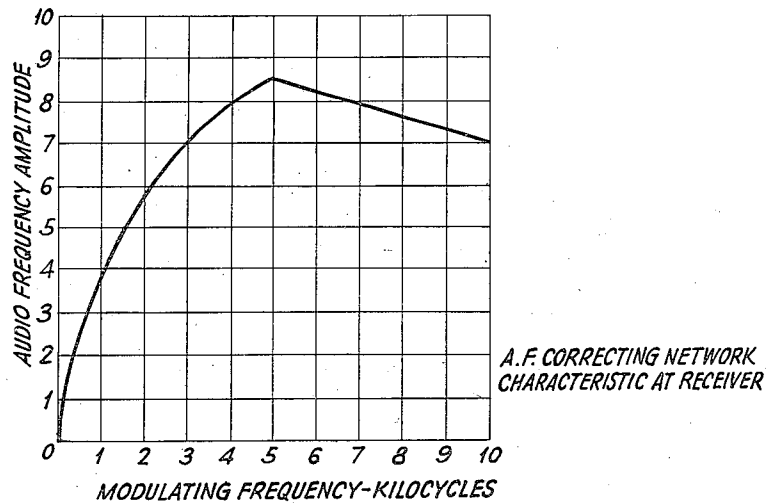


Fig. 6

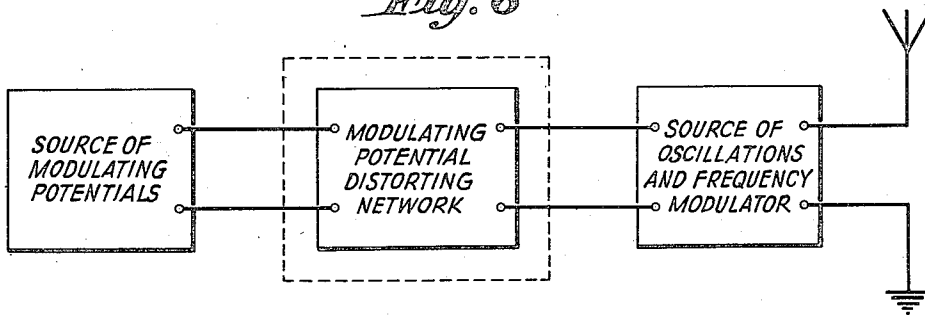
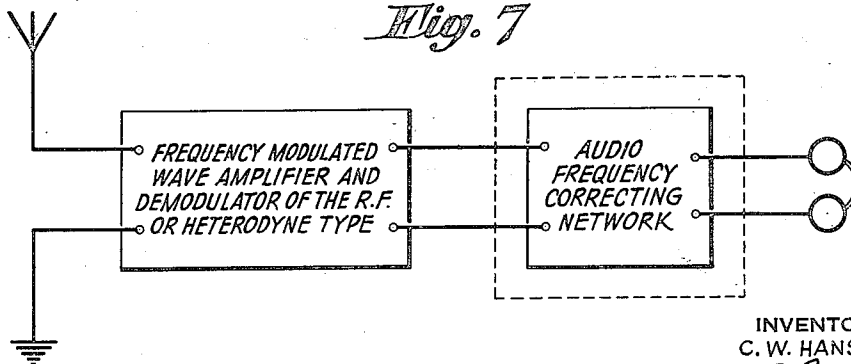


Fig. 7



INVENTOR
C. W. HANSELL
BY *H. S. Sower*
ATTORNEY

UNITED STATES PATENT OFFICE

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FREQUENCY MODULATION CIRCUITS

Clarence W. Hansell, Port Jefferson, N. Y., assignor to Radio Corporation of America, a corporation of Delaware

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19 Claims. (Cl. 250-6)

In operating a frequency modulation communication circuit it is possible to eliminate a considerable amount of the noise that would be heard in an equivalent amplitude modulation system. This is because a balanced frequency modulation receiver, particularly one with amplitude limiting of the energy input to its frequency modulation detector, tends to suppress the effect of all incoming noise in side frequencies near the frequency of the carrier wave. Noise frequency components which would normally give low audio frequency beats with the carrier tend to balance out in the output of the balanced frequency modulation receiver. The balance is substantially perfect for those noise components which would give nearly zero frequency audio output from the receiver but the balance decreases to nearly zero for noise components lying at the extreme limits of the spectrum for which the receiver is designed. As a result, a frequency modulation receiver of the balanced type designed to accommodate zero to 10,000 cycles modulation has its maximum noise output at 10,000 cycles, but at 5,000 cycles the noise is reduced to half amplitude. At 1,000 cycles the noise is reduced to 10%, at 100 cycles to 1%, etc., down to zero at zero frequency.

Frequency modulation receivers of the balanced type referred to above are known in the art and examples of such receivers have been shown and claimed in Usselman Patent #1,794,932 dated March 3, 1931, and in Crosby application #45,409 filed October 17, 1935, Patent #2,071,113 dated February 16, 1937. Other balanced frequency modulation receivers, in addition to those mentioned above are known in the art. See, for example my Patents #1,867,567, #1,922,290, and #1,938,657.

The balanced frequency modulation receiver also discriminates against useful side frequencies produced at the transmitter by the lower frequency modulations which lie near the carrier. However, this discrimination is balanced out by the greater number and spectrum width of side frequencies produced by low frequency modulation compared to that which would be obtained in the amplitude modulation system. The final result is an average gain, due to the balancing, of about 3 to 1 in power with respect to signal-to-noise ratio which would be obtained in receiving wave energy from an amplitude modulated transmitter of equal carrier power. There is an additional gain of about 5 to 1 due to the possibility of increasing the output from a given transmitter when we change from amplitude to frequency

modulation. Thus, using frequency modulation instead of amplitude modulation and maintaining substantially equivalent conditions, may make an improvement in signal-to-noise power ratio as high as 15 to 1.

It is known in the radio art that a still greater improvement in signal-to-noise ratio may be obtained by increasing the frequency deviation at the transmitter in response to the modulating potentials, while, at the same time, making correspondingly wider frequency pass band adjustments at the receiver. In fact, so long as the signal is considerably stronger than the noise, the signal to noise power ratio will be improved about in proportion to the square of frequency band used.

My present invention is an improvement on the methods and means for frequency modulation and frequency demodulation by balanced receivers known in the art and on the wide frequency deviation systems known in the art. The latter systems require a transmitter to occupy greater space in the ether and so will lead to an increase in interference or a reduction in the number of transmitters which may be operated without mutual interference. My present invention may be applied without widening the frequency band required for a transmitter or it may be used in combination with moderate widening of the band. In effect, it permits one to use the minimum frequency spectrum required by the modulation or a chosen band of greater width, more effectively than has been heretofore possible and in a manner to increase the signal-to-noise ratio.

In describing in detail the outstanding features of my novel method of and means for signalling by frequency modulated wave energy, reference will be made to the attached drawings. In the drawings

Figure 1 is a chart showing the relative amplitudes of a carrier and side frequencies produced by phase modulation of the carrier;

Figure 2 is a curve illustrating the manner in which the relative amplitudes of modulating potentials at various frequencies may be distorted to obtain the operating characteristics desired in the frequency modulator;

Figure 2a is a curve illustrating the manner in which the audio frequencies at the receiver must be distorted to obtain an overall linear output;

Figures 3, 4, and 5 illustrate audio frequency potential correcting or distorting networks;

Figure 6 illustrates diagrammatically the essential elements of a frequency modulator which includes an audio frequency potential correcting

network such as those shown in Figure 3; while

Figure 7 illustrates diagrammatically by rectangles the essential elements of a frequency modulation receiver including an audio frequency potential correcting network such as illustrated in Figures 4 and 5.

Figure 1 of the drawings shows the relative amplitudes of carrier and side frequencies produced when the carrier is modulated in phase. In this drawing the ordinates indicate the relative amplitudes of the carrier and various side frequencies. The abscissa indicates phase deviation of the carrier and side frequencies in radians. The carrier has been designated $J_0(X)$, while the side frequencies produced by any one modulating frequency have been indicated by $J_1(X)$, $J_2(X)$, $J_3(X)$, etc., in the order of their remoteness from the carrier. This chart also shows the relative amplitudes of a carrier and side frequencies of a frequency modulated wave, if we remember that the scale marked "Argument of the function= X " is the phase deviation of the carrier in radians, which we may call ϕ . Also the angle $\phi = D/f$ where f is any one modulating frequency and D is the frequency deviation of the carrier wave produced by the energy of frequency f .

For further information concerning the analysis of frequency modulated waves into component frequencies reference may be made to a paper in Proceedings of the Institute of Radio Engineers by Bolth Van Der Pol entitled "Frequency Modulation". This paper appears in vol. 18, No. 7, July, 1930. See also a paper by Hans Roder entitled "Amplitude, Phase and Frequency Modulation", in Proceedings of the Institute of Radio Engineers, vol. 19, No. 12, December, 1931. Each of the foregoing papers lists additional references.

If we have a frequency modulated transmitter and intended to handle modulating frequencies from 0 to 10,000 cycles, and we wish to specify that no one modulating frequency, giving full modulation, can produce side frequencies outside the normal band exceeding 1% in voltage of the carrier wave, we can see immediately from the curves in Figure 1 that at 5,000 cycles the phase deviation must be limited to 0.3 radian, because the second order side frequencies (of amplitude $J_2(X)$) produced by the 5,000 cycles modulating frequency reaches 1% and falls at the limit of the permissible band, i. e., plus the minus 10,000 cycles. This limitation on phase deviation corresponds to a limitation of peak frequency deviation of $D = 5,000 \times 0.3$ or 1,500 cycles for a modulating frequency of 5,000 cycles.

An equal modulating voltage at 1,000 cycles will also produce 1,500 cycles frequency deviation in the usual frequency modulator and the corresponding phase deviation will be $\phi = 1500/1000$ or 1.5 radians. However, in the case of 1,000 cycles modulation we need not be concerned about exceeding our permissible plus and minus 10,000 cycle band until the tenth order side frequency $J_{10}(X)$ is reached and by inspection of Figure 2 we see that $J_{10}(X)$ reaches an amplitude of 1% of the carrier for a phase deviation of about 6.2 radians corresponding to a frequency deviation of $D = \phi F = 6.2 \times 1,000 = 6,200$ cycles. Therefore, the 1,000 cycle modulation will not produce out of band side frequencies exceeding 1% up to a frequency deviation of about plus and minus 6,200 cycles. From this it will be seen that in the ordinary frequency modulator, we are not using all the deviation permissible, i. e., plus or minus

6,200 cycles instead of plus and minus 1,500 cycles.

If we again refer to the chart of Figure 1 we will see that the 10th or higher order side frequencies do not exceed 1% of the carrier amplitude in case ϕ —the peak deviation is equal to or less than 6.2 radians. Thus we may increase the phase deviation at 1,000 cycles up to 6.2 radians, or more than 4 to 1, as compared to the deviation produced at 1,000 cycles by modulating potentials of the same amplitude as the permissible limit at 5,000 cycles, before we exceed our allowable 1% for any side frequency outside the band of plus and minus 10,000 cycles.

At all modulation frequencies between 5,000 and 10,000 cycles all but the first order of side frequencies will fall outside the permissible band, that is, carrier plus and minus 10,000 cycles. If we limit out of band frequency amplitudes to 1% of the carrier power then the phase deviation, ϕ , may be allowed to reach but must not exceed .3 radian for any modulating frequency in the upper half of the modulation band. The permissible frequency swing or frequency deviation in the 5,000 to 10,000 cycle band may therefore be $D = \phi F = 0.3F$ and increases from 1,500 to 3,000 cycles as the modulation frequency increases from 5,000 to 10,000 cycles. That is, the permissible frequency swing for modulating potentials between 5,000 and 10,000 cycles is proportional to the modulation frequency and if the modulation frequency potentials are increased in proportion to the modulation frequency from 5,000 cycles to 10,000 cycles, the desired correction is obtained. This is illustrated in Figure 2 of the drawings where the curve slopes upward in a positive direction substantially linearly from 5,000 cycles to 10,000 cycles.

At a modulating frequency of 10 cycles, we may produce a frequency deviation very close to plus and minus 10,000 cycles, whereas normally our deviation would be only about plus and minus 1,500 cycles, the same as at 5,000 cycles. This is because, as may be found by inspecting a table of Bessel functions representing the relative amplitudes of carrier and side frequencies, only phase deviations above

$$\frac{10,000}{10}$$

produce side frequencies which fall outside the permissible band and they are so weak that they can be entirely disregarded if the phase swing does not exceed the value

$$\frac{10,000}{10}$$

But a phase swing of

$$\frac{10,000}{10}$$

gives a frequency deviation=

$$10 \times \frac{10,000}{10} = 10,000 \text{ cycles}$$

as mentioned above. Similar reasoning shows that a frequency swing of approximately 10,000 cycles is allowable for all extremely low modulating frequencies.

At 2,500 cycles modulating frequency only the 4th order of side frequencies fall at the limit of the permissible band of plus and minus 10,000 cycles and to maintain the amplitudes of these side frequencies below 1% of the carrier we may have a peak deviation of about $\phi = 1.5$ radians

which gives a permissible frequency swing of $2,500 \times 1.5$ or 3,750 cycles.

From this it will be seen that in order to use our whole permissible frequency band for each modulating frequency we should increase the amplitude of the lower modulating frequencies with respect to the amplitude of the mean frequency. This has been illustrated in Figure 2 of the drawings. It will be noted here however, that the amplitude of the modulating potentials as they leave 5,000 cycles and decrease towards zero cycles should not be increased linearly. At nearly zero modulating frequency we may have a peak frequency deviation of plus and minus 10,000 cycles, at 1,000 cycles modulation we may have a peak frequency deviation of 6,000 cycles, at 2,500 cycles we have a peak frequency deviation of 3,750 cycles, at 5,000 cycles modulation we may have a peak frequency deviation of 1,500 cycles and for higher modulating frequencies up to 10,000 cycles, we may increase the frequency deviation linearly up to 3,000 cycles again.

The curve in Figure 2 shows approximately the way in which I may distort the frequency characteristics of the transmitter in the assumed case without exceeding 1% amplitude on any side frequency more than 10,000 cycles removed from the carrier. Obviously, preferably, I distort the frequency characteristics of the transmitter in this way in order to maintain a better signal-to-noise ratio at the receiver. I may then distort the receiver response characteristic oppositely to the frequency distortion in the transmitter, as illustrated in Figure 2a, and thus end up with a correct reproduction of the audio frequency modulation at the output of the receiver with a greatly reduced noise level. In the assumed case I have shown that the improvement in signal-to-noise ratio amounts to about 17 to 1 in power at 1,000 cycles, where the ear is quite sensitive, compared to the ratio obtainable with ordinary frequency modulation. The improvement at various frequencies will be about as follows:

Modulation frequency	Allowable deviation	Voltage gain	Power gain
0 cycles.....	10,000	6.67	44.5
1,000 cycles.....	6,200	4.13	17.1
2,500 cycles.....	3,750	2.5	6.25
5,000 cycles.....	1,500	0	0
10,000 cycles.....	3,000	2	4

The mean or overall improvement in signal-to-noise ratio in the foregoing example will depend upon the normal frequency distribution of modulation energy and of noise but will tend to range above and below about 10 to 1 in power. If noise is predominantly low in frequency the overall gain may range up to about 45 to 1.

If I distort the frequency response characteristic of a transmitter in accordance with the invention to take full advantage of the permissible maximum frequency deviations at each modulating frequency and also take advantage of the proposal to add additional frequency response distortion in accordance with the inverse of the peak values of modulating voltages at different modulating frequencies then I may expect to obtain an overall gain in signal-to-noise ratio ranging up to perhaps 100 to 1 in power.

It should be noted that, in addition to reducing ordinary noise the scheme brings about a great relief from the effects of hum in transmitters. Practically all transmitters have the power potentials supplied to the electrodes of the vacuum

tubes from rectifiers fed with 50 or 60 cycle A. C. current. As a result we have had much difficulty in eliminating hum at say, 60, 120, 180, 240, 360, and 720 cycles. Of these, hum at 120 cycles has been most troublesome. The present scheme, in the assumed case, would reduce the effects of 120 cycle frequency modulation hum by about 37 to 1 in power.

Of course, the fundamental reason for the possibility of distorting the frequency characteristic of the transmitter on frequencies below the mid frequency lies in the decreasing spacing between side frequencies as the modulating frequency is decreased. The possibility of distorting the characteristic above the mid frequency arises from the setting of a definite limit on side frequency energy outside the prescribed band and the discontinuous way in which the limit is approached.

If the various modulating frequencies to be transmitted are not of equal maximum amplitudes I may modify the frequency distortion response characteristics of Figure 2 so that the maximum value of any one modulating frequency component will reach the maximum allowable frequency deviation. Speech, for example, usually has maximum peak values at about 800 cycles and progressively lower value at higher and lower values. I contemplate also modifying the relative amplitudes of modulation inputs to the transmitter to fit the frequency distribution of peak amplitudes in the modulation in order to obtain maximum permissible frequency deviation for each modulating frequency.

In practice we may prefer to leave the frequency characteristic undistorted in the upper half of the frequency band but to use distortion in the lower half very roughly in the proportions shown in Figure 2.

Obviously the example I have used to illustrate my invention is not the only condition which might be assumed or met with in practice. I might have assumed that conditions permitted as much as 5% or 10% peak amplitudes of side frequencies outside the transmitter band. Then the values of permissible frequency deviation at various modulating frequencies would have been different but could readily be determined with the aid of Figure 1. Also, I might have assumed that a transmitter to handle modulating frequencies of 0 to 10,000 cycles could be allowed to occupy a normal band width of plus and minus 20,000 cycles, 50,000 cycles, 100,000 cycles, etc. Then, by setting a limit on out of band side band strength, the permissible distortion in frequency response, of the character illustrated in Figures 2 and 2a, could readily be determined, with the aid of Figure 1, in the same manner as in the example given.

I have not attempted to work out frequency distorting networks for carrying out my invention with nearest possible perfection since there already exists a very well known art on this subject in connection with wire line telephone practice. However, as a rough approximation to one type of frequency distorting circuit for use at the transmitter I have drawn a schematic diagram of a circuit in Figure 3 and indicated relative values of the component parts very approximately.

Figures 4 and 5 represent types of circuits which may be used at the receiver to counterbalance the distortion introduced in the transmitter frequency characteristic. In practice somewhat more complicated circuits may be used to obtain more exactly the characteristics required just as

more complicated circuits are arrived at and used in the well known wire line telephone art in correcting the frequency characteristics of lines and apparatus. It is my belief that one skilled in the art, having been instructed in respect to the frequency distorting characteristics required; having been shown simple examples of suitable distorting networks, and having been told to consult the voluminous telephone wire line art on similar devices, will require only ordinary diligence and persistence in approaching as nearly as necessary to the ideal performance of my invention. The limitations of circuits for application of my invention will make it substantially impossible to obtain exactly the frequency distortion characteristics illustrated in Figure 2 and Figure 2a but exact matching of the theoretically optimum characteristic is not necessary in order to obtain the greater part of the advantages offered by my invention.

The method and means of the present invention may be applied to any frequency modulation system known in the art today. For example, I may use a frequency modulator as illustrated in any of the many United States patents disclosing frequency modulators or as disclosed in the many applications of myself and my associates now on file in the United States Patent Office. As examples, frequency or phase modulators such as disclosed in:

Hansell, United States application #681,945, July 24, 1933, Patent #2,121,737, dated June 21, 1938; Chireix, United States application #585,489, Jan. 8, 1932, Patent #2,076,264, dated April 6, 1937; Crosby, United States application #588,309, Jan. 23, 1932, Patent #2,081,577, dated May 25, 1937; Lindenblad, United States application #13,886, Mar. 30, 1935, Patent #2,143,891, dated Jan. 17, 1939; Hansell Patent #2,027,975, dated January 14, 1936; Hansell Patent #1,830,166, dated November 3, 1931; Hansell Patent #1,819,508, dated August 18, 1931; Hansell Patent #1,803,504, dated May 5, 1931; and Hansell Patent #1,787,979, dated January 6, 1931.

The limitations of circuits for the application of my invention makes it desirable or necessary to use a distortion characteristic somewhat modified from that shown in Figure 2 but my scheme may still be applied and combined with frequency modulators of any type including sideband frequency modulators or over-modulated frequency modulators or phase modulators such as, for example, disclosed in the Chireix and Crosby patents mentioned above. By "frequency modulation" as employed in describing and defining my invention, I mean modulating the instantaneous frequency of wave energy as any function of signals to be transmitted.

In describing my invention I have given an example in which the output amplitude of any one frequency lying outside the minimum transmitter band is limited to 1% of the carrier amplitude. Although this 1% value is a good practical value to set as a limit there may be many cases in which a lower or a higher limit are desirable. If we change the limit then the optimum frequency distortion characteristic illustrated in Figure 2 will be modified. I have shown how the characteristic of Figure 2 was arrived at so that, with a table of Bessel functions or curves such as Figure 2, anyone practicing this invention may readily obtain optimum distortion characteristic curves for any assumed limit. For additional information concerning Bessel functions see the book, Bessel Functions for Engineers, by

N. W. McLachlan, published by the Oxford University Press in 1934 and the references cited in the back of the book.

The frequency modulator system per se may comprise as shown in Figure 6, a source of modulating potentials connected by way of a modulating potentials distorting network to a frequency modulator which as well known, includes a source of oscillations to be modulated and with a load circuit such as for example, an antenna. The distorting network may be of any suitable type and for example may be as illustrated in Figure 3.

Any type of frequency modulated receiver known in the art today may be used. Preferably I use a demodulator of the balanced type as illustrated in Usselman Patent #1,794,932 or in Crosby application #45,409 filed October 17, 1935, Patent #2,071,113, dated February 16, 1937. The essential features of a demodulator are illustrated in Figure 7 wherein wave energy pick-up means such as a line or an antenna, feeds a receiving, amplifying, and demodulating means of either the radio frequency or heterodyne type. The output of the demodulating means is connected by a correction circuit of any type such as, for example, the type illustrated in Figures 4 and 5 to the indicating means.

I claim:

1. A method of improving the signal-to-noise ratio in a frequency modulation system operating in a predetermined frequency spectrum which includes, producing at each modulating frequency substantially the maximum frequency swing permissible without producing side frequencies outside said spectrum the amplitudes of which are greater than a small fraction of the carrier amplitude.

2. A method of improving the signal-to-noise ratio in a frequency modulation system operating in a limited frequency spectrum which includes, producing substantially the maximum frequency swing of a carrier wave for each frequency of the modulating potentials permissible without producing higher order side frequencies outside said spectrum the amplitudes of which are greater than 1% of the carrier wave amplitude.

3. A method of improving the signal-to-noise ratio in a frequency modulation system operating in a predetermined frequency spectrum which includes, producing potentials frequency ranges of which have amplitudes sufficient to produce substantially the maximum frequency swing permissible without producing higher order side frequencies outside said spectrum the amplitudes of which are greater than a small fraction of the carrier amplitude, and modulating wave energy in accordance with said produced potentials.

4. The method of improving the signal-to-noise ratio in a frequency modulation system operating in a predetermined frequency spectrum which includes the steps of, producing potentials, the amplitudes of which are different for the different modulating frequencies and distorted relative to the amplitudes of the modulating frequencies sufficient to produce the maximum frequency swing of carrier wave energy for each of the various modulating frequencies without producing side frequencies outside said spectrum the amplitudes of which are greater than a small fraction of the carrier amplitude, modulating the frequency of carrier wave energy in accordance with said produced potentials, transmitting said modulated carrier wave energy, demodulating the transmitted wave energy and distorting the mod-

ulation components in a manner inverse to the distortion produced at the modulator.

5 The method of improving the signal-to-noise ratio in a frequency modulation system operated in a limited frequency spectrum, by being modulated in frequency through said spectrum in accordance with modulating potentials covering a predetermined band which includes the steps of producing potentials the amplitude of which is maximum for a low modulating potential frequency and of decreasing amplitude for modulating potentials of increased frequency up to a predetermined frequency depending on the channel width and the modulating potential frequency band and of increasing amplitude as the modulating potential frequency increases from said predetermined frequency, and producing oscillatory energy the frequency of which varies substantially linearly in accordance with the amplitude of said modulating potentials.

6. The method of improving the signal-to-noise ratio in a frequency modulation system comprising a modulator operated in a limited frequency spectrum, by being modulated in frequency through said spectrum in accordance with modulating potentials covering a predetermined band and a demodulator which includes the steps of, producing potentials the amplitude of which is maximum for a low modulating potential frequency and of decreasing amplitude for modulating potentials of increased frequency up to a predetermined frequency depending on the channel width and the modulating potential frequency band, producing oscillatory energy the frequency of which varies substantially linearly in accordance with the amplitude of said modulating potentials, transmitting said oscillatory energy, demodulating said transmitted oscillatory energy to derive the modulation components, and producing potentials corresponding to said modulation components the amplitude of the produced potential corresponding to the modulation component of lowest frequency being reduced a maximum amount relative to the amplitude of the said corresponding modulation component, the amount of reduction of the amplitudes of the produced potentials relative to the amplitude of the corresponding modulation components decreasing with increase of frequency up to said predetermined frequency.

7. In a frequency modulator, a source of oscillations, a source of modulating potentials, a frequency modulator coupled with said source of oscillations, a circuit having a characteristic such that the amplitude of the modulating potentials increases with increase or decrease of frequency from a selected frequency, coupled between said source of modulating potentials and said frequency modulator, transmitting means coupled with said modulator, receiving and demodulating means energized by the transmitted energy, and a circuit having a characteristic such that demodulated components passed thereby are reduced in amplitude with increase or decrease in frequency of said components from a selected modulation component frequency, coupled with said means.

8. The method of reducing the effect of variations in potential of filament or electrode heating sources in the frequency modulated output of a frequency modulator using electron discharge devices having electrodes energized by said sources and operating to swing a carrier wave within a given frequency spectrum which includes

the steps of, producing substantially the maximum frequency swing of said carrier wave permissible for the various modulation frequencies without producing side frequencies outside said given frequency spectrum the amplitudes of which exceed a given value to thereby increase the degree of modulation of said carrier wave by signal potentials as compared to the degree of modulation of said carrier wave by the said variations of said sources.

9. The method of signalling by frequency modulation, within a given frequency spectrum, by means of a carrier wave of a frequency substantially equal to the mean frequency of said spectrum and a band of modulating potentials characteristic of signals having a peak amplitude at a given frequency which includes the steps of, modulating the frequency of said carrier wave in accordance with said modulating potentials and modifying the relative amplitudes of said modulating potentials non-linearly on both sides of said frequency of maximum amplitude to produce the maximum frequency swing of said carrier for each modulating frequency without producing wide frequencies outside of said permissible spectrum which exceed a small fraction of the amplitude of said carrier.

10. The method of swinging the frequency of a carrier wave within a given frequency spectrum in accordance with a band of modulating potentials the amplitudes of which normally increase with frequency to reach a peak value at a given frequency and then decrease with frequency, which includes the steps of, swinging the frequency of said carrier about its mean frequency in accordance with said modulating potentials, and modifying said modulating potentials to obtain substantially the maximum swing of said carrier within said given spectrum without producing side frequencies without said spectrum of appreciable amplitude as compared to said carrier amplitude.

11. The method of improving the ratio of signal-to-noise in the energy produced by a frequency modulator operated in a frequency spectrum of limited width, by modulating a carrier wave in frequency through said spectrum in accordance with modulating potentials covering a predetermined band which includes the steps of, producing potentials the amplitudes of which are maximum for a low modulating potential frequency and of decreasing amplitude for modulating potentials of increased frequency up to a predetermined modulation frequency depending on the width of the frequency spectrum and the modulating potential frequency band, and producing oscillatory energy the frequency of which varies substantially linearly in accordance with the amplitude of said modulating potentials.

12. In a frequency modulation system, a source of oscillations to be modulated, a source of modulating potentials including a band of frequencies, a frequency modulator coupled with said source of oscillations to be modulated, and modulation potential transferring means having a characteristic such that the amplitude of the modulating potentials increases with increase of frequency from a selected frequency intermediate the limits of said band coupled between said source of modulating potentials and said frequency modulator to transfer modulation potentials of modified form from the former to the latter.

13. In a frequency modulation system, a source of oscillations to be modulated, a source of mod-

ulating potentials including a band of frequencies, frequency modulating means connected with said source of oscillations to be energized by oscillations therefrom, and circuit means having a characteristic such that the amplitude of the modulating potentials decreases with increase of frequency from a low modulating potential frequency to a selected frequency intermediate the limits of said band, connected between said source of modulating potentials and said frequency modulating means to transfer modulating potentials from the former to the latter and modify the transferred potentials.

14. In a frequency modulation communication system, means for modulating wave energy in accordance with modulating potentials, means for modifying the relative amplitudes of all of the component modulating potential frequencies used by said first means to give more equal maximum frequency spectrum band widths in the modulation output, detecting means to be excited by said modulator, and means, for modifying back to normal the relative amplitudes of all of the component modulation potentials, connected with said detecting means.

15. In a frequency modulation communication system, means for modulating wave energy in accordance with modulating potentials which cover a band of modulating frequencies, means for modifying the relative amplitudes of the modulating frequency potentials so that the maximum amplitudes of all component modulation frequencies will give substantially equal carrier frequency band widths, means for transmitting the energy resulting from said modulation, receiving and demodulating means energized by said transmitted energy, and means connected with said demodulating means for modifying the relative amplitudes of the potentials in said demodulating means in a manner opposite to the modification of the modulating potentials at the transmitter, to substantially reproduce the original unmodified band of modulating frequency potentials.

16. In a transmission system wherein the instantaneous frequency of a wave is varied in dependence upon a modulating voltage whereby to create side frequencies of various orders, of which the lowest order side frequency that both lies without a given channel surrounding the mean frequency of said wave and also exceeds a

predetermined fraction of the amplitude of the unmodulated wave is a function of both amplitude and frequency of said modulating voltage, the method of modulation which comprises distorting signalling voltage as a function of its frequency and utilizing said distorted voltage as the modulation voltage, said function being so chosen that for each signalling frequency the resulting modulation voltage is approximately sufficient to create side order wave frequencies outside said channel the strongest of which is said predetermined fraction of the amplitude of said unmodulated wave.

17. A method as recited in claim 16 wherein the function decreases, as the frequency increases, for frequencies below $\frac{1}{2}$ the frequency difference between the carrier and the limits of said channel.

18. The method of signalling by frequency modulation, within a given frequency band, by means of a carrier wave of a frequency substantially equal to the center frequency of said band, and a band of modulating frequency potentials, characteristic of signals, within which will be a frequency component having a normal maximum strength which produces side frequencies of the carrier wave, due to frequency modulation, with significant amplitudes at frequencies extending throughout but not beyond the given frequency band, together with other modulation frequency components which require smaller band widths, which includes the steps of, modulating the frequency of said carrier wave in accordance with said modulating potentials and modifying the relative amplitudes of said modulating frequency potentials to produce the maximum frequency swing of said carrier permissible at each modulating frequency without producing side frequency energy components outside the given frequency band which exceed a maximum permissible amplitude.

19. The method of receiving a wave modulated in frequency in accordance with the method recited in claim 18 which includes the steps of, receiving and amplifying said frequency modulated wave, demodulating said amplified wave to derive the modulation components and modifying the modulation components amplitudes in a sense opposite to the manner in which they were modified during said modulation process.

CLARENCE W. HANSELL.