

Aug. 18, 1931.

C. W. HANSELL

1,819,508

COMMUNICATION BY FREQUENCY VARIATION

Filed Aug. 11, 1927

2 Sheets-Sheet 1

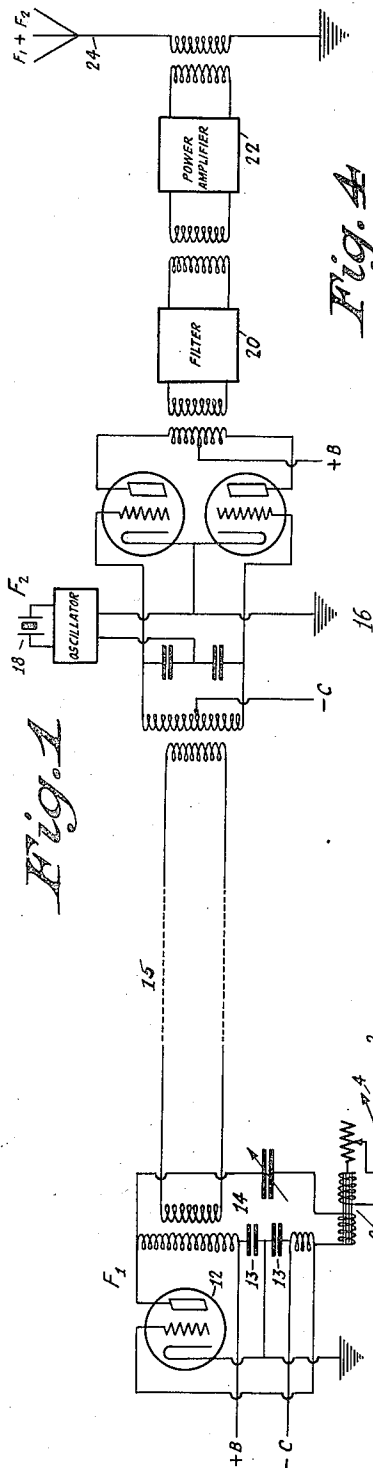


Fig. 4

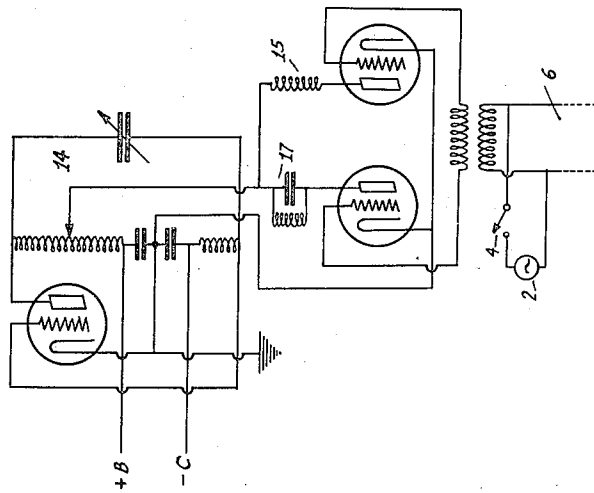


Fig. 3

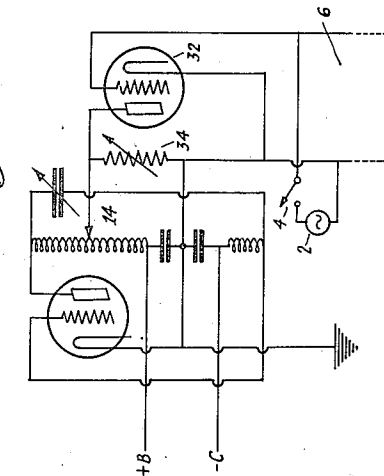
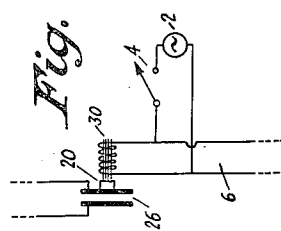


Fig. 2



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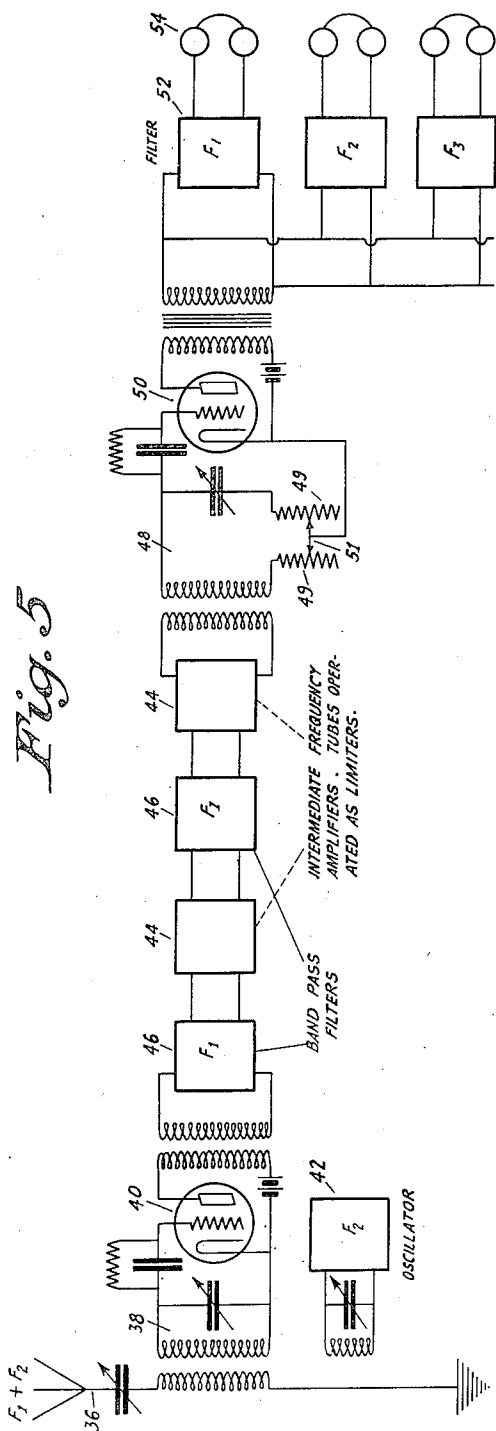


Fig. 8

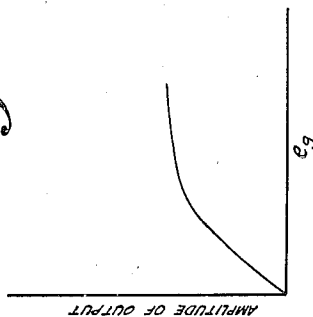


Fig. 7

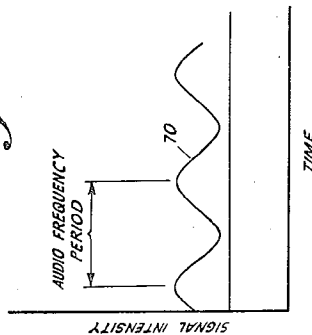
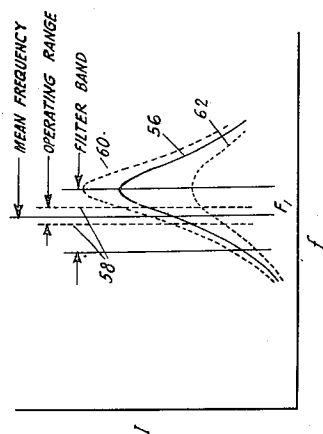


Fig. 6



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COMMUNICATION BY FREQUENCY VARIATION

Application filed August 11, 1927. Serial No. 212,192.

This invention relates to frequency modulation, and to a method and means for multiplexing signals transmitted by frequency modulation.

6 In order to reduce fading it has been suggested that the frequency of transmission be wobbled. It is an object of my invention to transmit keyed signals by causing an intermittent frequency wobble preferably during
10 the marking periods of keying, and to detect the wobble at the receiver, thereby solving the problems of keying and of wobbling at the same time. This I do by keying relatively low frequency energy and using the
15 keyed energy to frequency modulate transmission energy, that is, the transmission energy has its frequency varied at a frequency equal to the low frequency, and this frequency variation is unaccompanied by variations in
20 amplitude of the transmission energy. At the receiver an analyzing circuit tuned to a frequency lying outside of the applied range of frequency is used to change the frequency variations to amplitude variations.

25 It is a further object of my invention to permit of multiplex communication by means of frequency variation, and this I do by separately signalling on each of a plurality of signal energies of different relatively
30 low frequencies, adding the separate signal energies to obtain a complex resultant signal wave, and using the resultant wave to frequency modulate transmission energy of relatively high frequency.

35 To receive this multiplex frequency modulated carrier my method includes impressing the received energy upon an analyzing circuit which is tuned to a frequency lying outside of the operating range of frequency
40 supplied to it in order to change the frequency modulation to amplitude modulation, rectifying the amplitude modulated energy in order to obtain a complex signal wave such as was used for frequency modulation at the
45 transmitter, separating the rectified energy into its component signal energies by means of filters, and then separately translating the component signal energies to obtain the several original signals.

50 In selecting the frequencies for the signal-

ling channels a difficulty encountered is that these frequencies must not be harmonically related. But if natural harmonics are suppressed, energy of harmonic frequency may be used in the signal channels. It is a property of balanced circuits that by their use
55 alternate harmonic frequencies are suppressed, and a further object of my invention is to provide a balanced frequency modulator, thereby permitting a much wider
60 choice of frequencies for the various signal energies. This device may be termed a push-pull wobbler, and in its broadest form comprises means for varying the tuning of a resonant circuit in one direction, means for
65 varying the tuning of said resonant circuit in the opposite direction, and a modulator circuit arranged to energize said means in phase opposition, preferably through the use of electron emission tubes the control electrodes of which are coupled in push-pull.

One of the advantages of using frequency modulation in preference to amplitude modulation is the fact that the necessary frequency band for each transmitter may be reduced to any desired minimum. In using a small frequency variation in a high frequency carrier the percentage variation may be so small as to present modulating and demodulating difficulties, both at the transmitter and receiver. Furthermore, with small frequency variations for the signal it becomes exceedingly important to keep the mean frequency as constant as possible. To overcome these difficulties is a further object of my
85 invention, which I accomplish by using the signal energy of low frequency to frequency modulate energy of an intermediate frequency, thereby increasing the percentage variation, and then utilizing the intermediate frequency energy for modulating the high frequency carrier of a single side band transmitter. In somewhat similar fashion the received wave is heterodyned to an intermediate frequency, in which the relative frequency variation may be made as great as desired, depending upon the magnitude of intermediate frequency chosen.

With a transmitter arranged as indicated the source of carrier frequency need not be 100

adapted for frequency variation at all, for the constancy of the side band amplitude results from the constant amplitude of the intermediate frequency energy. Therefore the source of carrier frequency may be constructed with the single object of obtaining constant frequency. Variations in the mean frequency of the intermediate frequency energy are then quite small with respect to the transmission frequency.

Under unfavorable atmospheric conditions it is desirable to narrow the width of the frequency band employed for communication. In such case, in order to obtain the desired amplitude of amplitude modulation at the receiver it becomes necessary to decrease the damping coefficient of the analyzing circuit of the receiver. When this is done it may be found that the signal amplitude has not increased, the reason being that the more efficient resonant circuit tends to average out the frequencies applied to it. To overcome this we must either increase the wobble range, or decrease the wobble frequency. The former, obviously, would defeat the object sought, which was to narrow the frequency range, so we must resort to the latter. Inasmuch as maximum keying speed depends upon the wobble frequency of the channel being keyed, it follows that it may further be necessary to slow up the keying speed, but this may itself be not undesirable under unfavorable atmospheric conditions.

Accordingly, my invention includes adjusting the frequency band according to atmospheric conditions. It further includes adjusting the damping coefficient of the analyzing circuit of the receiver according to the width of frequency band. It still further includes adjusting the wobble frequency to avoid loss of signal amplitude by reason of the low decrement indicated by too sharp a resonance curve. On the other hand, in the case of favorable communication conditions my invention contemplates increasing the keying speed, and in the order of their necessity, increasing the wobble frequency at the transmitter, the damping coefficient of the analyzing circuit at the receiver, and the wobble range at the transmitter.

Sometimes fading is experienced which only partially reduces the signal intensity, and which therefore might be thought not serious, but such fading may itself occur at an audible frequency and for that reason prove ruinous to reception. This type of fading may be contended with when frequency modulated signals are transmitted by taking advantage of the difference in the character of the modulations produced in order to discriminate between them, the disturbance being an amplitude variation, whereas the signal is a frequency variation. To eliminate the former and not the latter the amplifying tubes used in the receiver may be arranged as

a limiting device, preferably by over excitation of the grids of the vacuum tubes in one or more stages of the amplifier. Subsequent to the elimination of the amplitude variations the frequency modulation may be transposed to amplitude variation in order to obtain the transmitted signals.

Further objects appear in the following more detailed specification, which is accompanied by drawings in which,

Figure 1 is a multiplex transmitter;

Figures 2 and 3 indicate alternative means for obtaining frequency variation;

Figure 4 shows a push-pull frequency modulator;

Figure 5 is a multiplex receiver; and

Figures 6, 7 and 8 are explanatory of the adjustments made in the receiver.

Referring to Figure 1 there are a plurality of sources of relatively low frequency energy, 2, of frequencies f_1 , f_2 , and f_3 , which in the case of telephony signals should be super audible frequencies. These signalling energies are separately controlled by signalling means, exemplified in this case by the keys 4, but which may equally well be controlled by picture transmission relays, or microphones. The various channels are led to a common bus 6 from which the complex signalling energy is led to a suitable means for obtaining frequency modulation. This has been indicated in the present case by a magnetic wobbler 8, the sole requirement for which is that it should be operated on a linear portion of its characteristic curve in order that the signals in the various channels may not be intermodulated.

The frequency modulation may take place directly in the transmission energy, or preferably it may take place first in intermediate frequency energy which then may be used to frequency modulate higher frequency energy for transmission. The latter scheme is here shown, and the intermediate frequency oscillator comprises an electron emission tube, 12, which is regeneratively coupled through suitable blocking condensers 13 to a resonant circuit 14, part of the inductance of which is the inductance of the radio frequency portion of the magnetic wobbler 8. The energy of frequency F_1 , frequency modulated by the resultant of the frequencies f_1 , f_2 , etc., is led over a line 15 of suitable length to the low frequency input side of a single side band transmitter 16. The carrier frequency F_2 may be crystal controlled by a crystal 18, and the side bands are separated by a filter 20, the output from which may be amplified in a power amplifier 22 before being radiated from a suitable antenna system 24.

The frequency modulation may be accomplished by capacity variation, instead of inductance variation, as is indicated in Figure 2, which represents a fragment of Figure 1 in which the magnetic wobbler 8 has

been replaced by a condenser 26. One plate of this condenser is vibrated by an armature 28 under the influence of an electromagnet 30. It is more difficult to obtain linear frequency variation with this type of modulation, but the magnetic response of the armature may be so adjusted as to obtain the desired result. The variable condenser may be arranged in parallel with a fixed condenser, and their magnitudes relatively adjusted to control the extent of frequency modulation obtained.

Frequency modulation may also be obtained by variably detuning a resonant circuit through the use of a resistance shunt. This has been illustrated in Figure 3 in which a portion of the inductance of the resonant circuit 14 is shown by-passed by an electron emission tube 32, the impedance of which is varied by fluctuations of its grid potential obtained by coupling the signaling energy bus 6 to the cathode and grid of the tube. The cathode to anode circuit of the tube 32 may be shunted, if desired, by a resistance 34, adjustment of which controls the extent of frequency variation obtained for given potential variations applied to the tube grid.

In Figure 4 I have indicated a balanced frequency modulator. This comprises an inductive circuit 15 and a capacitive circuit 17 each controlled by an electron emission tube, arranged in parallel with one another and with a portion of the reactance of the resonant circuit 14. The condenser of circuit 17 is by-passed by a radio frequency choke to permit direct anode potential to reach the tube anode. The modulating energy from the bus 6 is coupled to the control electrodes of the tubes in phase opposition, and the tubes are made conductive only alternately. When the inductive circuit 15 is made effective as a shunt the reactance of the shunted portion of the tuning coil of the resonant circuit 14 is lowered, whereas during the other half cycles when the capacitive circuit 17 is connected in parallel the reactance is raised. With this balanced modulator the resonant frequency is made to fluctuate to both sides of the mean frequency of an efficient resonant circuit, which is preferable to detuning all in one direction. It is possible to obtain a more nearly linear characteristic, for only half as long a portion of each tube characteristic need be utilized, and identical portions of the characteristics of the two tubes may be chosen. A still more important advantage is the suppression of undesired harmonics of the modulating frequencies.

Figure 5 is a wiring diagram for a receiver arranged to cooperate with the transmitter shown in Figure 1. The transmitted energy of mean frequency $F_1 + F_2$ is collected on a suitable antenna circuit 36 and applied to the input circuit 38 of a combining tube 40. A local oscillator 42 is arranged to supply ener-

gy for heterodyning the receiver energy to any desired intermediate frequency. In the present case the oscillator frequency is indicated as F_2 , in which case the intermediate frequency is F_1 , and is therefore equal to the transmitter intermediate frequency, but this is not an essential condition. Heterodyne reception is useful to beat down the carrier frequency without reducing the extent of frequency variation, thereby making demodulation less difficult. It helps avoid fly-wheel effect, which is discussed later.

The energy of intermediate frequency is amplified in cascade amplifiers 44, before the stages of which there are interposed band pass filters 46, the purpose of which will be more fully explained in connection with Figure 6. The amplified intermediate frequency energy is supplied to an analyzing circuit, which in this case is the resonant input circuit 48 of the rectifying device 50. This circuit includes equal resistances 49, and a common contactor 51 for coupling the analyzing circuit symmetrically to the input circuit of the detector tube. The function of this damping resistance is to control the sharpness of the resonance curve of the circuit 48. The analyzing circuit 48 is tuned to a frequency which lies outside of the operating range of intermediate frequency, and therefore serves to change the frequency modulation to amplitude modulation. The amplitude modulated energy is rectified in a detector tube 50, the rectified output from which contains a complex wave composed of the low frequencies f_1, f_2 , etc. These may be separated by the filters 52, the outputs from which are led to separate translating devices 54, herein shown as telephone head sets, but which may obviously be tape recorders or other appropriate translating devices.

In Figures 6 the curve 56 represents the resonance curve of the analyzing circuit 48, and it will be seen that its resonance frequency lies so far outside of the mean frequency F_1 that the operating range of frequency variation lies entirely on one sloping side of the resonance curve. The band pass filters 46 are adjusted to a range about as shown, and their chief function is to preclude frequencies lying on the other side of the resonance curve, altho they incidentally will preclude certain undesired frequencies caused by interference, strays, microphonics, and noises developed in the amplifier itself. It is in order to eliminate the latter noises that it is preferable to distribute the filters between the stages of the intermediate frequency amplifier.

Under adverse conditions the width of the frequency band may be narrowed, thereby decreasing the horizontal distance between lines 58. In order to obtain the same variation in current amplitude as is indicated by

the vertical spacing between the points of intersection of the lines 58 with the resonance curve 56 it then is necessary to steepen the side of the resonance curve, by obtaining a new resonance curve, indicated by the curve 60. With a high wobble frequency the expected increase in current variation will not be realized because of the averaging out or fly-wheel effect of the more efficient resonant circuit, and therefore, as before explained, it may be necessary to decrease the wobble frequency at the transmitter. On the other hand, under conditions more favorable than the average, the keying speed may be so far increased as to necessitate an increase of wobble frequency, and then in order to avoid fly-wheel effect the resistance 49 in Figure 5 may be increased, causing a less sharp resonance curve, such as the curve 62 in Figure 6. To again obtain full current variation the extent of frequency variation or wobble range may be increased by the operator at the transmitter, who in practice may change wobble range and wobble frequency simultaneously in the same direction.

In Figure 7 the curve 70 indicates how a received signal may fade to a small extent but with sufficient rapidity to itself constitute a disturbing wave. This type of fading may be overcome by introducing limiting means in the intermediate amplifier tubes so that saturation will occur at a signal level slightly below the lowest fading intensity. In Figure 8 a characteristic curve for a vacuum tube is indicated, the flattening of the top of which shows the type of limiting which is introduced for a given anode potential. I prefer to overexcite the tubes, but this is merely for economy of apparatus, and I may instead use a reduced anode potential, or a limited filament emission. Obviously, in case fading reduces the signal to zero the expedient here suggested is futile.

It should be understood that altho I consider the use of a heterodyne to beat the transmission frequency down to an intermediate frequency exceedingly desirable, yet it is not essential for the operation of the receiver, the only requirement of which is that it include an analyzing circuit for changing frequency modulation to amplitude modulation. It is also to be understood that while I have indicated the input circuit of the detector tube as the analyzing circuit this also is optional, and in cases where an exceedingly steep resonance curve is desired it may prove preferable to use all of the successive resonant circuits of the intermediate frequency amplifier for the analyzing circuit.

The system here described has the advantage, in the case of code signals, that there are no key clicks to interfere with broadcast receivers, in addition to the advantages of reduced fading and reduced requisite frequency range. The power amplifier of the

transmitter runs at constant load, thereby increasing the life of the vacuum tubes. Furthermore the signalling is relatively secret, for the range of frequency variation may be made so small as to be incapable of reproducing signals in an ordinary receiver, and is especially so in the case of multiplex signals because the apparent signal, even if made audible, is unintelligible unless properly separated into its component signals.

I claim:

1. The method of transmitting intelligence which includes keying relatively low frequency energy and using the low frequency energy to vary the frequency of high frequency transmission energy at a frequency equal to the low frequency, and with substantially no variation in amplitude of the transmission energy thereby eliminating keying clicks in apparatus within the range of transmission.

2. The method of transmitting multiplex signals by frequency variation which includes signalling on each of a plurality of different relatively low frequency energies, adding the signal energies, and using the resultant complex wave to frequency modulate transmission energy according to a linear characteristic.

3. The method of analyzing a multiplex frequency modulated constant amplitude carrier wave which includes impressing the received wave on a resonant circuit which is tuned to a frequency which lies outside of the operating frequency range, thereby amplifying the different frequency portions of the impressed wave unequally, rectifying the resulting wave, separating the rectified wave into its constituent signal channels, and translating the energy of each channel.

4. The method of analyzing a constant amplitude carrier wave which has been frequency modulated by a plurality of keyed signal energies which includes heterodyning the received wave to obtain frequency modulated energy of intermediate frequency, impressing the received wave on a resonant circuit which is tuned to a frequency which lies outside of the operating range of intermediate frequency, thereby amplifying the different frequency portions of the impressed wave unequally, rectifying the resulting wave, separating the rectified wave into its constituent signal energies, and separately translating the signal energies.

5. The method of transmitting intelligence which includes signalling on relatively low frequency energy, frequency modulating intermediate frequency energy with the signal energy, modulating high frequency energy with the intermediate frequency energy, and transmitting a side band of the modulated high frequency energy.

6. The method of transmitting multiplex signals by frequency variation which in-

cludes signalling on each of a plurality of signal energies of different relatively low frequencies, adding the signal energies, frequency modulating intermediate frequency energy with the resultant signal energy, modulating high frequency energy with the intermediate frequency energy, and transmitting a side band of the modulated high frequency energy.

7. The method of communicating multiplex signals which includes signalling on each of a plurality of signal energies of different relatively low frequencies, adding the signal energies, frequency modulating transmission energy with the resultant signal energy, receiving the transmission energy, changing the frequency modulation to amplitude modulation, rectifying the amplitude modulated energy to obtain the resultant signal energy, separating the rectified energy into its constituent signal energies, and separately translating the signal energies.

8. The method of frequency modulating the tuning of a resonant circuit by means of modulating energy of lower frequency which includes utilizing alternate half cycles of the modulating energy to connect inductive reactance in parallel with a portion of the resonant circuit, and the other half cycles of the modulating energy to connect capacitive reactance in parallel with a portion of the resonant circuit.

9. In communication by frequency modulation the method which includes decreasing the extent of frequency variation during unfavorable atmospheric conditions, and increasing the extent of frequency variation during favorable atmospheric conditions.

10. In communication by frequency modulation the method which includes widening or narrowing the frequency band to obtain most favorable communication, and increasing or decreasing the damping coefficient of a circuit of the receiver according as the frequency band is wider or narrower.

11. In communication by frequency wobble, the method of improving communication during unfavorable atmospheric conditions which includes, at the transmitter decreasing the range and frequency of wobble, and at the receiver decreasing the damping coefficient of an analyzing circuit.

12. The method of eliminating the effect of partial fading of frequency modulated signals which includes discriminating between amplitude and frequency variation by limiting the received signal to the low signal level, and thereafter changing frequency modulation to amplitude modulation for detection.

13. A transmission system for eliminating keying clicks and reducing fading comprising an oscillator having controlling means to determine the oscillation frequency of the oscillator, a source of relatively low fre-

quency energy, means to vary the frequency controlling means in response to the low frequency energy, and means to key the low frequency energy.

14. A multiplex transmission system comprising a plurality of sources of energy of different low frequencies, signalling means to control the energy of each frequency, means to add the signal energies, a source of high frequency energy, and means to frequency modulate the high frequency energy in response to the resultant signal energy in accordance with a linear characteristic.

15. A transmission system comprising a single side band transmitter, a source of intermediate frequency for modulating the transmitter carrier energy, a source of relatively low frequency energy, means for frequency modulating the intermediate frequency energy in response thereto, and signalling means for controlling the low frequency energy.

16. A multiplex transmission system comprising a single side band transmitter, a source of intermediate frequency for modulating the transmitter carrier energy, a plurality of sources of energy of different relatively low frequencies, means to add the low frequency energies to obtain their resultant, means for frequency modulating the intermediate frequency energy in response to the resultant, and signalling means for separately signalling on each of the low frequency energies.

17. A multiplex receiving system for constant amplitude frequency modulated energy including an analyzing circuit for changing frequency modulation to amplitude modulation comprising a resonant circuit tuned to a frequency lying outside of the operating range of frequency supplied to it, a rectifying circuit, and means to separate the rectified wave into its component energies of different frequency.

18. A balanced frequency wobbler comprising a resonant circuit tuned to the mean frequency, means responsive to modulating energy for varying the tuning of the resonant circuit in one direction, means responsive to modulating energy for varying the tuning of the resonant circuit in the opposite direction, and a modulating circuit coupled to said means in phase opposition.

19. A balanced frequency modulator including a resonant circuit tuned to the mean frequency, a plurality of electron emission tubes having control electrodes, means controlled by one tube for varying the tuning of the resonant circuit in one direction, means controlled by another tube for varying the tuning of the resonant circuit in the opposite direction, and a modulating circuit coupled to the control electrodes of said tubes in phase opposition.

20. A balanced frequency modulator com-

- prising a resonant circuit tuned to the mean frequency, a plurality of electron emission tubes having control electrodes, a capacitive circuit including one of said tubes connected in parallel with a portion of the resonant circuit, an inductive circuit including another of said tubes connected in parallel with a portion of the resonant circuit, and a modulating circuit coupled to the control electrodes of said tubes in phase opposition.
21. In a transmitter for signalling by frequency wobble, in combination, a source of carrier energy, a source of low frequency energy, means to frequency wobble the carrier energy in response to the low frequency energy, means to key the low frequency energy in accordance with a signal to be transmitted, means to control the frequency of the low frequency energy, and means other than the signalling means to control the wobble range.
22. In a system for communication by frequency modulation, in combination, a transmitter having means other than the signalling means to control the width of the frequency band, and a receiver having an analyzing circuit means to control the sharpness of tuning of the analyzing circuit.
23. In a system for signalling by frequency wobble, in combination, a transmitter having means other than the signaling means to control the range and frequency of wobble, and a receiver having an analyzing circuit and means to control the sharpness of tuning of its analyzing circuit.
24. In a frequency modulation receiver arranged to eliminate the effect of partial fading of frequency modulated signals, the combination of means to limit the signal energy to the low signal level, and means to thereafter change the frequency modulation of the limited signal energy to amplitude modulation for detection.
25. A receiving system for frequency modulated energy comprising a receiving circuit, a local oscillator, means to combine the received and local energies to produce energy of intermediate frequency, an intermediate frequency amplifier coupled to the combining means and arranged to limit the signal transferred therethrough to the low signal level, an analyzing circuit coupled to the intermediate frequency amplifier and tuned to a frequency lying outside of the operating range of intermediate frequency, rectifying means, and means to translate the rectified energy.
26. A receiving system for energy of constant amplitude, frequency modulated with relatively low frequency energy comprising a receiving circuit, a local oscillator, means to combine the received and local energies to produce energy of intermediate frequency, a band pass filter and an intermediate frequency amplifier coupled to the combining means for amplifying only the desired band of frequencies, an analyzing circuit coupled
- to the intermediate frequency amplifier and tuned to a frequency lying outside of the desired band of frequencies for changing frequency modulation to amplitude modulation, means to rectify the amplitude modulated energy, and means to translate the rectified energy.
- CLARENCE W. HANSELL.

DISCLAIMER

1,819,508.—*Clarence W. Hansell*, Rocky Point, N. Y. COMMUNICATION BY FREQUENCY VARIATION. Patent dated August 18, 1931. Disclaimer filed December 11, 1935, by the assignee, *Radio Corporation of America*.

Hereby enters this disclaimer with respect to claims 12 and 24 of the said patent, to wit:

"12. The method of eliminating the effect of partial fading of frequency modulated signals which includes discriminating between amplitude and frequency variation by limiting the received signal to the low signal level, and thereafter changing frequency modulation to amplitude modulation for detection."

"24. In a frequency modulation receiver arranged to eliminate the effect of partial fading of frequency modulated signals, the combination of means to limit the signal energy to the low signal level, and means to thereafter change the frequency modulation of the limited signal energy to amplitude modulation for detection."

[*Official Gazette January 14, 1936.*]