May 30, 1944. W. R. KOCH 2,349,870

FREQUENCY MODULATION SYSTEM

Filed May 27, 1942

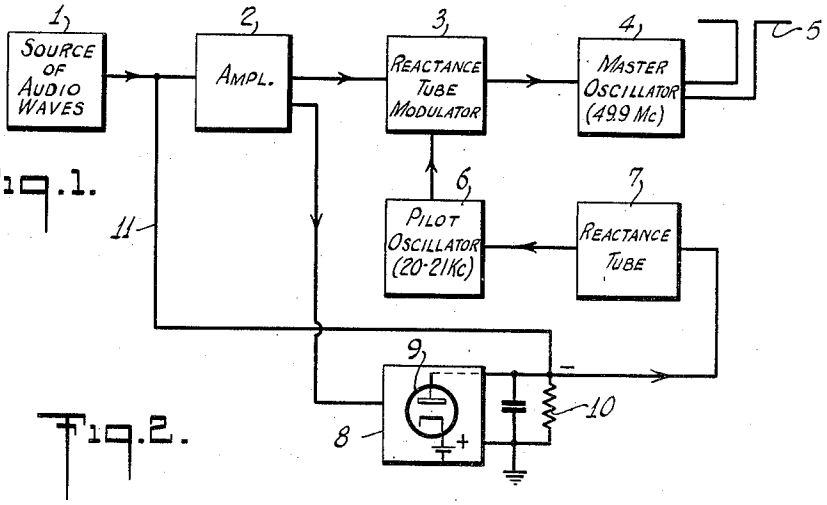


Fig. 1.

Fig. 2.

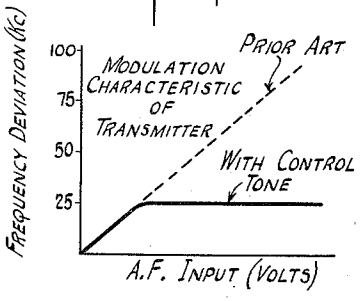


Fig. 3.

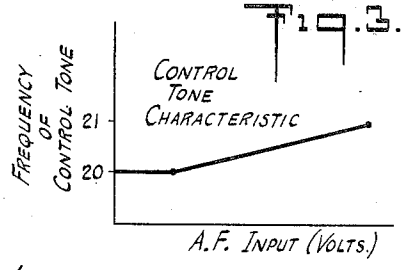


Fig. 4.

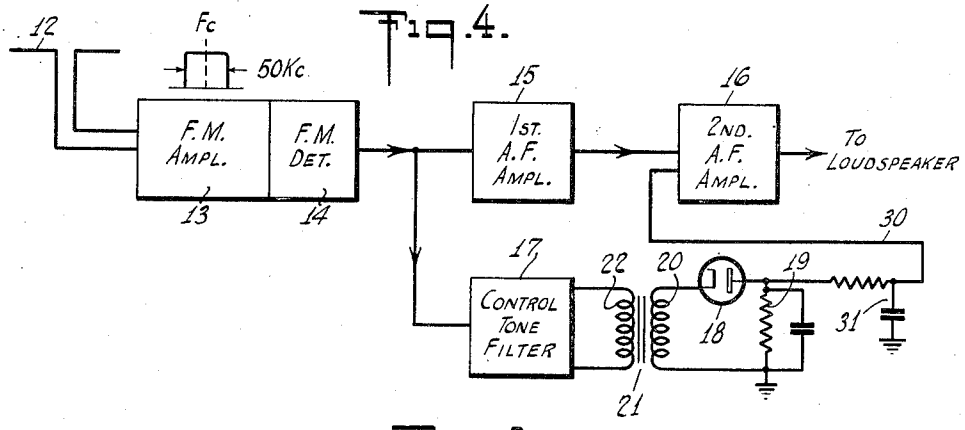


Fig. 5.

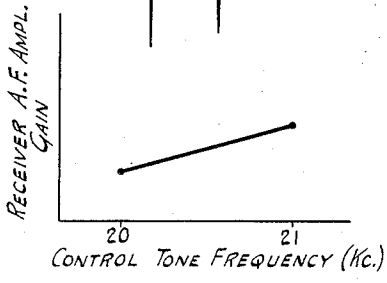
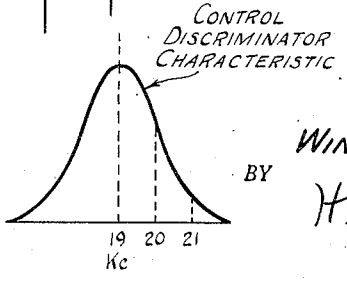


Fig. 6.



INVENTOR.
WINFIELD R. KOCH.
BY
H. S. Grover
ATTORNEY

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FREQUENCY MODULATION SYSTEM

Winfield R. Koch, Haddonfield, N. J., assignor to Radio Corporation of America, a corporation of Delaware

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12 Claims. (Cl. 250—6)

My present invention relates to frequency modulation systems, and more particularly to a novel method of, and means for, securing the benefits of high deviation modulation with a narrow band receiver.

In present frequency modulated carrier wave (FM) transmission and reception there is employed a channel width of 200 kilocycles (kc.). The FM band itself extends from 42 to 50 megacycles (mc.) The carrier is actually deviated over a range up to a maximum of 75 kc. on either side of the carrier, or center, frequency. In other words, the channel width is considerably in excess of the audible modulation range. Various proposals have been made for receiving such high deviation FM waves in a receiver whose pass band width prior to demodulation is relatively narrow. Such prior proposals have involved complex networks, and function solely at the receiver.

My present invention has as its main object the provision of an FM system wherein the benefits of high deviation modulation are secured, while utilizing a receiver having selector circuits of relatively narrow pass band width prior to the demodulator; the system generally being characterized by its utilization of a super-audible control signal in the transmitted FM wave energy.

In the past it has been proposed to utilize super-audible frequencies within the same transmission channel as employs audible signals as modulation. For example, facsimile picture signals are multiplexed in the same channel with audible signals. Hence, the presently proposed use of a super-audible control frequency which can be transmitted simultaneously without interference, is quite feasible.

Accordingly, it is another important object of my invention to provide a radio transmission system wherein at the transmitter a carrier can be deviated over a relatively narrow range by modulation signals, but a control tone of super-audible frequency is included in the channel for expanding the dynamic range of the receiver thereby to simulate the action of a receiver of wide pass band characteristics.

Another object of my invention is to provide in an FM system a method of transmission wherein the carrier deviation is increased with audio signal amplitude up to a maximum value, which value is relatively smaller than has been employed in the past; there being included in the FM energy a super-audible control tone whose frequency is a function of modulation amplitude; and at the receiver the control tone being employed to expand the dynamic range of the audio network for audio signals of high amplitude.

Still other objects are to improve generally the simplicity and efficiency of FM transmission, and more especially to provide a system of the FM type which is reliable in operation.

The novel features which I believe to be characteristic of my invention are set forth in particularity in the appended claims; the invention itself, however, as to both its organization and method of operation will best be understood by reference to the following description taken in connection with the drawing in which I have indicated diagrammatically several circuit organizations whereby my invention may be carried into effect.

In the drawing:

Fig. 1 schematically shows an FM transmitter embodying the invention,

Fig. 2 shows the modulation characteristic of the transmitter,

Fig. 3 illustrates the control tone characteristic at the transmitter,

Fig. 4 schematically shows a receiver used in my system,

Fig. 5 illustrates the effect of the control characteristic at the receiver,

Fig. 6 shows the control tone discriminator characteristic at the receiver.

Referring now to the accompanying drawing, wherein like reference characters are used to designate similar circuit elements in the different figures, Fig. 1 schematically shows the various networks of a frequency modulation transmitter. This invention is in no way restricted to FM, since it can be readily applied to phase modulation. The expression "angular velocity-modulated carrier wave" is to be understood as generically denoting either a frequency or phase modulated carrier wave. The source of audio waves 1 may be a microphone, phonograph record pick-up, line or any other type of audio modulation source. Further, the modulation need not be audio; since modulation frequencies of a super-audible frequency range can be used. The control tone in that case may be at some frequency above the modulation range.

The modulation energy is applied to an amplifier 2. The amplified modulation energy is used to vary the reactive effect of a reactance tube modulator 3. The latter, as is very well known in the FM art, may be a tube connected to have its anode to cathode impedance simulate a reactance whose sign depends on the circuit connections. The applied modulation, usually applied to a control grid, varies the simulated reactance. The latter is connected across the tank circuit of the master oscillator 4. The tank circuit is tuned so

that the oscillations, in the absence of modulation, have a carrier frequency in the 42 to 50 megacycle (mc.) band. The latter is the presently assigned FM broadcast band.

Of course, the invention is not restricted to operation in the 42–50 mc. band. Any higher, or lower, band may be utilized. What is important is that the carrier frequency (say 49.9 mc. for illustration) be deviated in proportion to the amplitude of the modulation. The rate of carrier, or center, frequency deviation is a function of the modulation frequencies per se. In the present FM band of 42–50 mc., it is the practice to deviate the carrier frequency a maximum of 75 kilocycles (kc.) to each side. The FM channel itself has a width of 200 kc. The FM wave energy is radiated from the radiator; the latter may be a dipole 5.

The reception of FM wave energy having an overall deviation width of 150 kc. requires specially designed transformers prior to the demodulator. It is, in fact, highly desirable to be able to radiate the high deviation band energy, but to receive the same with a receiver whose selector circuits need not have excessively wide response characteristics. My solution of this problem depends upon the inclusion of a super-audible control tone (assuming the modulation is at audio frequency) in the FM wave energy and in the concurrent compression of the carrier frequency deviation. At the transmitter this is easily and effectively accomplished in the manner now to be described.

A pilot oscillator 6 is provided. The frequency thereof may be varied over a range of 20 to 21 kc. A reactance tube 7 is employed to vary the frequency of the pilot oscillator tank circuit. It will be understood that the circuit of reactance tube 7 may be constructed and arranged as was described in connection with circuit 3. The reactive effect due to network 7 is controlled in accordance with the amplitude of the modulation energy. Thus, amplifier 2 feeds a portion of its modulation energy to a rectifier circuit 8. The latter may include a diode 9 whose cathode may be positively biased to provide delayed rectification of modulation currents.

The rectified modulation current flows through output resistor 10, which is properly bypassed for alternating current components, and develops a direct current control voltage. The voltage may be applied, for example, with an increasingly negative polarity as the modulation amplitude increases. Thus, the gain of reactance tube 7 decreases, and the circuits of network 7 will be chosen to provide a reactive effect which acts to increase the pilot oscillator frequency. For example, if network 7 simulated a capacity effect, smaller values of capacity effect would act to increase the pilot frequency. Hence, up to a predetermined value of modulation input level to rectifier 8 no effect on pilot frequency takes place. Thereafter, the pilot frequency increases up to 21 kc. as the modulation amplitude rises. The pilot oscillator output energy is applied to modulator 3, so that the current variation of the latter will include the pilot frequency as a component. Fig. 3 shows the control tone frequency variation as a function of modulation amplitude.

The modulator output is concurrently varied in the manner suggested in Fig. 2. In the prior art, and as indicated by the dotted line in Fig. 2, the frequency deviation of the carrier increased linearly with the modulation amplitude. According to my invention, the frequency deviation is not permitted to rise above a certain maximum frequency value. Thus, in Fig. 2 the full line curve shows how the deviation is maintained substantially at 25 kc., to each side of the carrier, or center, frequency value above a predetermined modulation amplitude. This is accomplished by having the rectifier 8 reduce the gain of modulation amplifier 2 as the voltage applied to diode 9 overcomes the delay bias. The voltage across resistor 9 is used to decrease the gain of amplifier 2.

It will be understood that the flat portion of the curve of Fig. 3 corresponds to the rising linear portion of the full line curve of Fig. 2. This means that over the horizontal portion of the modulation characteristic of the transmitter the control frequency will have a rising course. The negative bias applied to amplifier 2 may be impressed on the control grid over lead 11. As the modulation amplitude level rises, the gain of amplifier 2 is caused to decrease thereby to prevent any increase in the reactive effect due to network 3 affecting the master oscillator frequency. However, as pointed out previously, simultaneously there is embodied in the FM energy a component for determining the mode and extent of dynamic expansion to be employed at the receiver. The magnitude of the delay bias applied to rectifier 8 predetermines the extent of the linear rise in Fig. 2, and the horizontal section length in Fig. 3.

Considering, now, the receiving system shown in Fig. 4, the collector 12 feeds the collected FM wave energy to usual networks up to the demodulator designated as "FM det." The demodulator may be preceded by the customary amplifiers. Where the receiver is of the superheterodyne type, as is universally the case, the amplifier section 13 may embody the usual amplifiers feeding a converter whose intermediate frequency (I. F.) output is passed through one or more I. F. amplifiers followed by a limiter. The limited I. F. energy is fed to the FM detector 14 to provide the modulation signals applied at 1 to the transmitter.

Each of the tuned selector circuits up to the detector 14 need have a pass band of only 50 kc. This is due to the fact that the oscillator frequency at the transmitter has been deviated up to a maximum of 25 kc. to each side of center frequency. Hence, above the network 13 there has been depicted a response curve representing the pass band of 50 kc., as well as the fact that the midband frequency is F_c. The latter will have a value depending upon whether it is in the ultra-high frequency range, or whether it is of intermediate frequency, for example 4.3 mc. The detected FM wave energy is passed through successive audio amplifiers 15 and 16 which may be of conventional construction. Any desired type of reproducer may be employed following the last audio amplifier 16. The FM detector may be of any desired construction. For example, the type of detector shown by S. W. Seeley in U. S. Patent 2,121,103, granted June 21, 1938, may be used.

In order to properly reproduce the audio signals applied from source 1, the dynamic range of the receiving system is expanded. Since there has been embodied in the radiated FM energy a component whose super-audible frequency varies from 20 to 21 kc. depending upon the audio signal amplitude, there is provided a simple and effective method for securing higher receiver output for the higher amplitude audio notes. It is only necessary to filter out at some appropriate

point in the demodulated signal network the component corresponding to the control tone. The numeral 17 represents such a control tone filter capable of passing energy of 20 kc. and higher. That is, filter 17 is a high-pass filter having a cut-off below 20 kc.

The control tone energy is transmitted to a rectifier 18, of the diode type, whose anode is connected to ground by a properly bypassed load resistor 19. The cathode of the diode is connected back to ground by the secondary winding 20 of discriminator-transformer 21. The primary of transformer 21 is denoted as 22; the transformer primary is connected across the output terminals of the filter 17. The transformer 21 is resonant to a mid-frequency of 19 kc. Fig. 6 shows the resonance curve of the transformer. It will be seen from the resonance curve that maximum control energy is applied to the rectifier 18 when the filter output is 20 kc. As the filter output energy rises in frequency to 21 kc., the input to the rectifier 18 decreases.

When the control tone frequency is at 20 kc., which is the value corresponding to the horizontal section of the curve of Fig. 3, there will be supplied maximum energy to rectifier 18. As a result the drop across resistor 19 will be a maximum, and there will be supplied a large negative bias to audio amplifier 16. The negative bias across resistor 19 would be supplied over lead 30 through the filter network 31. The bias may be supplied to a control grid of the audio amplifier tube. As a result, and as shown in Fig. 5, the receiver audio amplifier gain will not rise above the level corresponding to the lower end of the curve in Fig. 5. However, should the control tone frequency rise towards 21 kc., as it will for audio amplitude above the horizontal section of the Fig. 3 curve, then the input energy to the rectifier 18 will decrease. This causes the direct current voltage across the resistor 19 to decrease. Hence, the gain of the controlled audio amplifier 16 will rise, as indicated in Fig. 5.

It will now be seen that the receiver output energy level is expanded in accordance with the increase in frequency of a super-audible control component in the received modulated wave energy. Furthermore, the frequency increase of the control component is dependent upon the modulation amplitude value above a predetermined level. In this way the transmitter frequency may be deviated over a smaller range than is usual, while the benefit of wide deviation systems is secured. It will be understood that the super-audible tone can be added to channels of the present width, if desired, of 200 kc. It is desirable to keep the control tone at low amplitude relative to the audio voltage.

While I have indicated and described several systems for carrying my invention into effect, it will be apparent to one skilled in the art that my invention is by no means limited to the particular organizations shown and described, but that many modifications may be made without departing from the scope of my invention, as set forth in the appended claims.

What I claim is:

1. A method of signalling which includes generating oscillations, varying the frequency of the oscillations in accordance with the amplitude of modulation signals, preventing variation of said frequency in response to modulation signals above a predetermined modulation amplitude, concurrently producing a control tone whose frequency is varied in an increasing sense for modulation signal amplitudes above said predetermined amplitude, varying the frequency-variable oscillations with said control tone, and transmitting the resultant frequency-variable oscillations.

2. A method of signalling which includes generating oscillations, varying the frequency of the oscillations in accordance with the amplitude of modulation signals, preventing variation of said frequency in response to modulation signals above a predetermined modulation amplitude, concurrently producing a control tone whose frequency is varied in an increasing sense for modulation signal amplitudes above said predetermined amplitude, varying the frequency-variable oscillations with said control tone, transmitting the resultant frequency-variable oscillations, detecting the transmitted oscillations, amplifying the detected energy, deriving from the detected energy said control tone energy, and controlling the said amplification in an increasing sense with increase of control tone energy.

3. A method of receiving frequency modulated waves whose mean frequency has a maximum deviation range corresponding to a predetermined modulation signal amplitude, and which waves include as a component a super-audible control tone whose frequency is a function of modulation amplitude above said predetermined amplitude; said method including demodulating the received waves to produce modulation signal voltage and also voltage of said super-audible control tone, and controlling utilization efficiency of the modulation signal voltage in accordance with the frequency of the control tone.

4. A system of frequency modulation communication wherein the following steps are effected: modulating a carrier frequency by varying the value of the latter in accordance with modulation signal amplitude, limiting the frequency variation to correspond to a predetermined amplitude value of signal, concurrently varying said carrier frequency in accordance with a super-audible tone and in response to modulation thereon by signal amplitudes above said predetermined value, radiating the modulated carrier energy, collecting the radiated energy at a receiver, demodulating the received energy to produce voltage of the original modulation signals, rectifying the component of the demodulated energy corresponding to said super-audible tone, amplifying the demodulated signal energy, and expanding the amplification of the latter energy in accordance with the rectified super-audible tone energy.

5. A system of frequency modulation communication wherein the following steps are effected: modulating a carrier frequency by varying the value of the latter in accordance with modulation signal amplitude, limiting the frequency variation to correspond to a predetermined amplitude value of signal, concurrently varying said carrier frequency in accordance with a super-audible tone and in response to modulation thereon by signal amplitudes above said predetermined value, radiating the modulated carrier energy, collecting the radiated energy at a receiver, demodulating the received energy to produce voltage of the original modulation signals, rectifying the component of the demodulated energy corresponding to said super-audible tone, amplifying the demodulated signal energy, and expanding the amplification of the latter energy in accordance with the rectified super-audible tone energy.

6. A system of communication with angular velocity-modulated carrier waves wherein the following steps are effected: modulating a carrier frequency by varying the value of the latter in accordance with modulation signal amplitude, limiting the frequency variation to correspond to a predetermined amplitude value of signal, concurrently varying said carrier frequency in accordance with at least one super-audible tone and in response to modulation thereon by signal amplitudes above said predetermined value, demodulating received carrier energy modulated in the aforesaid manner to produce voltage of the original modulation signals, rectifying the component of the demodulated energy in accordance with the rectified super-audible tone energy.

7. A system of radio communication wherein the following steps are effected: frequency modulating a carrier frequency by varying the value of the latter in accordance with modulation signal amplitude, concurrently varying said carrier frequency in accordance with a control tone and in response to modulation thereon by signal amplitudes above a predetermined value, transmitting the modulated carrier energy, demodulating the transmitted energy to produce voltage of the original modulation signals, rectifying the component of the demodulated energy corresponding to said control tone, and controlling the utilization of the demodulated energy in accordance with the rectified tone energy.

8. A method of reception wherein waves are received whose mean frequency has a maximum deviation range corresponding to a predetermined modulation signal amplitude and which include as a modulation component a super-audible control tone whose frequency is a function of modulation signal amplitude above said predetermined amplitude; said method including demodulating the received waves to produce modulation signal voltage and energy of said super-audible control tone, and controlling amplification of the modulation signal voltage in accordance with the frequency of the control tone.

9. A system of radio communication wherein the following steps are effected: varying a carrier frequency in accordance with modulation signal amplitude, limiting the carrier frequency variation to correspond to a predetermined amplitude value of signal, concurrently varying said carrier frequency in accordance with a control tone and in response to modulation thereon by signal amplitudes above said predetermined value, transmitting the variable-frequency energy, demodulating the transmitted energy to produce voltage of the original modulation signals, rectifying the component of the demodulated energy corresponding to said control tone, amplifying the demodulated signal energy, and expanding the amplification of the latter energy in accordance with the rectified tone energy.

10. A system of frequency modulation communication wherein the following steps are effected: modulating a carrier frequency by varying the value of the latter in accordance with audio modulation signal amplitude, limiting the frequency variation from center frequency to about 25 kilocycles, preventing frequency variation in response to modulation signal amplitude above a predetermined value, concurrently varying said carried frequency over a range of 20 to 21 kilocycles in response to modulation thereon by signal amplitudes above said predetermined value, radiating the resultant modulated carrier energy, collecting the radiated energy at a receiver, demodulating the received energy to produce voltage of the original modulation signals, rectifying the component of the demodulated energy corresponding to said super-audible variation, amplifying the demodulated signal energy, and expanding the amplification of the latter energy in accordance with the rectified super-audible energy.

11. A method of receiving angular velocity-modulated carrier waves which are deviated over a relatively narrow range by modulation signals and which include as a component a super-audible control tone whose frequency is a direct function of modulation signal amplitude above a predetermined value, the method including detecting the modulated waves to derive modulation signal voltage, amplifying the modulation voltage, deriving from the detected voltage a control tone corresponding to said component, rectifying the latter control tone energy, and controlling the amplification of the modulation signal voltage in direct accordance with the rectified control tone energy, thereby to expand the dynamic range and simulate the action of a receiver of wide pass band characteristics.

12. A method of communicating with frequency modulated carrier waves wherein the benefits of high deviation modulation are secured while utilizing a receiver having selector circuits of relatively narrow pass band prior to the demodulator; said method including transmitting said waves with a mean frequency which has a maximum deviation range corresponding to a predetermined modulation signal amplitude and which includes as a modulation component a super-audible control tone whose frequency is a direct function of modulation signal amplitude above said predetermined amplitude, demodulating the waves at the receiver to produce modulation signal voltage and energy of said super-audible control tone, and controlling the amplification of the modulation signal voltage in direct accordance with the frequency of the control tone.

WINFIELD R. KOCH.