Sept. 12, 1944. W. VAN B. ROBERTS 2,357,975

FREQUENCY MODULATION SYSTEM

Filed March 16, 1942

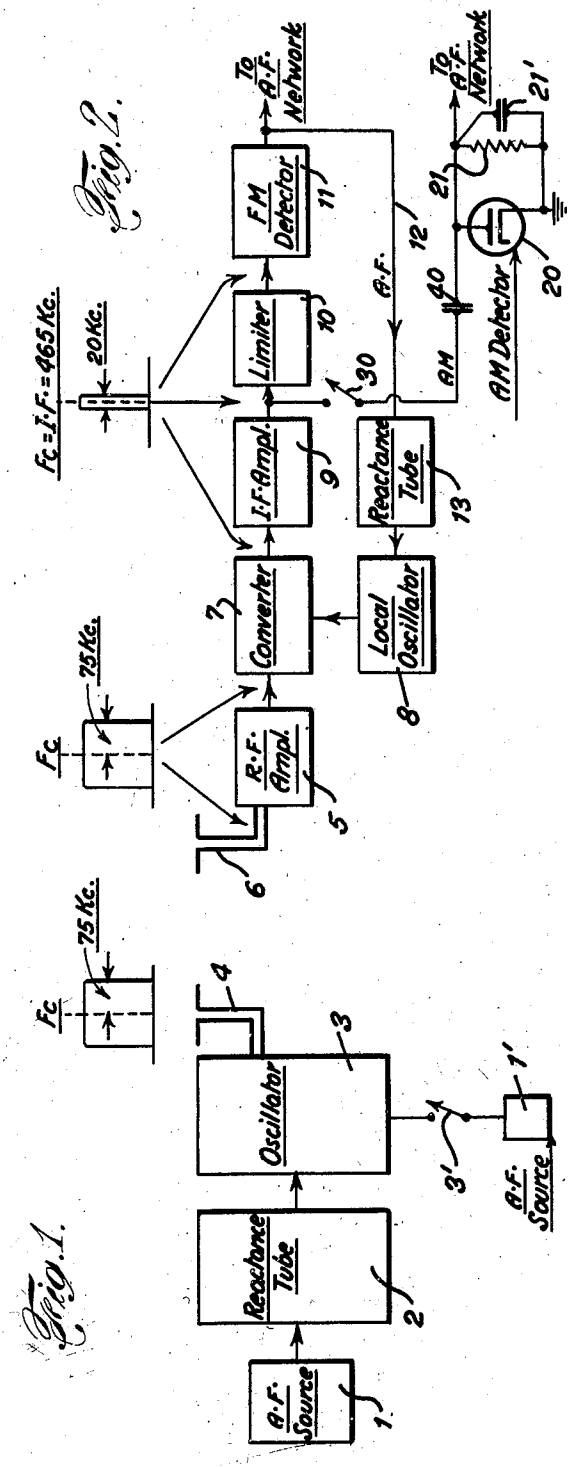


Fig. 1.

Fig. 2.

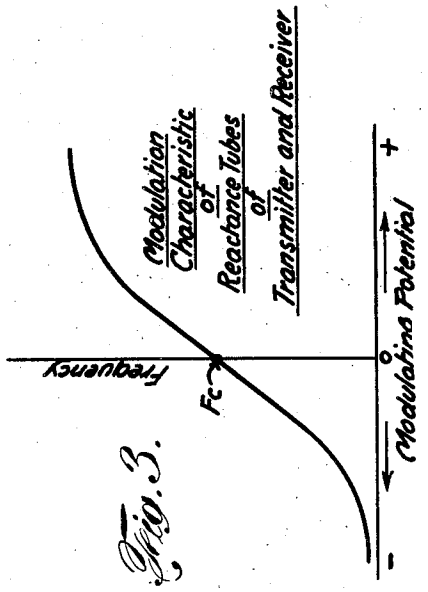


Fig. 3.

INVENTOR
Walter Van B. Roberts
BY H. G. Grove
ATTORNEY

Patented Sept. 12, 1944

2,357,975

UNITED STATES PATENT OFFICE

2,357,975

FREQUENCY MODULATION SYSTEM

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

Application March 16, 1942, Serial No. 434,881

3 Claims. (Cl. 250—6)

My present invention relates to reception of angular velocity-modulated carrier waves, and more particularly to a communication system for transmitting and receiving frequency modulated carrier waves.

One of the main objects of my present invention is to provide a novel method of transmitting and receiving modulated carrier waves of the type generically referred to as timing modulated, or angular velocity-modulated, carrier waves. For example, the transmission and reception of frequency modulated (FM) carrier waves is an example of such communication. As is well known today, the carrier wave employed in frequency modulation communication has a frequency located in the ultra-high frequency range. In the frequency band assigned to FM broadcasting the frequency band covers a range of 42 to 50 megacycles (mc.). The practice in such broadcasting is to swing the carrier wave about a mean frequency located in the aforesaid band, and the frequency deviation, or swing, which is permissible may be as high as 75 kilocycles (kc.) to either side of the mean, or carrier, frequency. To employ a modulated carrier wave of such frequency deviation, it is necessary to design the receiver as well as the transmitter in a special manner.

It is another object of my present invention to provide an FM receiver which is of the superheterodyne type, and wherein the intermediate frequency (I. F.) network may employ a relatively narrow response band despite the relatively wide frequency deviation of the radiated modulated carrier wave.

Another important object of the invention is to provide an FM receiver of the superheterodyne type, wherein the same I. F. network may be employed for the reception of FM waves or amplitude modulated (AM) carrier waves, whether independently of each other or even concurrently.

Still another important object of this invention is to provide a method of transmitting and receiving FM waves wherein a lack of linearity between the audio, or modulation, voltage applied at the transmitter and the output frequency of the transmitter is compensated for by a similar action at the receiver.

Yet another object of my invention is to provide a method of radio communication employing frequency, or phase, modulated carrier waves, wherein the reactance tube employed at the transmitter is a non-linear modulating device, and at the receiver there is utilized a superheterodyne system whose local oscillator is frequency modulated by the modulation voltage output of the receiver, the receiver using a reactance tube having a non-linear modulating characteristic which is a replica of the transmitter reactance tube characteristic.

Still other objects of my invention are to improve generally the efficiency and reliability of FM communication systems, and more especially to provide an FM signalling system which is efficient in operation and is economically manufactured and assembled.

The novel features which I believe to be characteristic of my invention are set forth with 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 a transmitter embodying the present invention,

Fig. 2 is a schematic representation of the receiver employed in the present system,

Fig. 3 shows the preferred modulating characteristic for the reactance tubes of the transmitter and receiver.

Referring to Figs. 1 and 2 of the drawing, there is shown a radio communication system employing the present invention. Since the invention resides in the entire system, rather than in the specific construction of the individual transmitter and receiver networks, the present disclosure is greatly simplified by schematic representations of the individual networks. Those skilled in the art of radio communication with FM waves are fully aware of the specific construction of the individual networks of the system to be disclosed.

Fig. 1 shows the networks usually employed in an FM transmitter. The transmitter generally comprises a source of modulation signals 1, and the signals may be in the audio frequency range. For example, the source 1 may be a microphone. The modulation signals from source 1 are applied to a modulating reactance tube 2. There are many various types of reactance tubes available for this purpose. Generally, such a reactance tube comprises an electron discharge device whose circuit connections are so arranged that the plate to cathode impedance of the tube simulates a reactance such as an inductance, or a capacity. On the other hand, the grid to cathode impedance of the reactance tube may be utilized as the simulation reactance. In either case, the simulated reactance is provided across the tank circuit of the transmitter oscillator 3. In this way the mean frequency, or the carrier frequency, of the oscillator is varied in accordance with the modulation signals of source 1. The oscillator 3 produces oscillations of constant amplitude, but due to the action of the modulating source 1 on the reactance tube 2 the oscillations produced at

source 3 are varied in frequency in accordance with the amplitude of the modulating signals.

The modulated carrier waves are radiated from antenna 4 which may be of any desired construction useful in the ultra-high frequency range. The radiator is shown, by way of example, as a dipole. Above the radiator 4 there is graphically shown the spectrum of the wave which is radiated. It will be observed that the frequency is deviated up to 75 kc. on either side of its mean value. In Fig. 3 there is shown the referred modulating characteristic of the reactance device. It will be noted that the characteristic relates audio frequency amplitudes in the form of modulation potential as abscissae to frequency deviation as ordinates. The characteristic is non-linear, since for the extremes of the positive and negative audio amplitudes the deviation is less than proportional to amplitude. In other words, there is a lack of linearity between audio frequency applied to the reactance tube and the output frequency of the oscillator 3. Of course, the modulation characteristic can be made linear if desired. The reason for preferring the non-linear characteristic shown is that the signal to noise ratio at low modulation levels is improved by the steeper-than-average modulation characteristic at low levels.

Referring, now, to Fig. 2 which shows the receiving network of the communication system, it is first pointed out that it is of well known superheterodyne construction. For the sake of illustration, let it be assumed that the communication system employs a receiver which is continually tuned to the transmitter shown in Fig. 1. For example, such a system is of utility in the case of police radio car communication, air transport systems, mobile military systems and the like. In such case, the usual radio frequency amplifier 5, which may comprise one or more stages of tuned radio frequency amplification, has its input terminals connected to the signal collector device 6. The latter may be a dipole.

It will be understood that the tuned circuit or circuits of amplified 5 will be resonated to the mean, or carrier, frequency of the waves radiated from the transmitter antenna. Hence, above the rectangle denoting the radio frequency amplifier circuit, there is shown the response characteristic of the various transmission circuits employed throughout the amplifier network, as well as at the network coupling amplifier 5 to the converter 7. It will be seen that the response curve is such that the entire frequency deviations are efficiently passed. As is well known in the art, band pass networks having a flat top and an overall width of 150 kc., are best employed for this purpose.

The numeral 8 designates the local oscillator which is employed to produce oscillations whose frequency differs from the mean frequency of the received modulated carrier waves by the value of the operating I. F. The operating I. F. value is preferably chosen of the order of 465 kc. This choice is made in accordance with common practice in broadcast receivers. The I. F. amplifier is denoted by numeral 9. It may include one or more I. F. amplifier stages. A limiter 10 follows the I. F. amplifier network 9. Any well known type of FM detector circuit 11 follows the limiter 10. The coupling networks, usually tuned transformers, employed between the successive stages following the converter need only have a narrow pass band width. By way of example, it is shown in Fig. 2 that these coupling networks have a pass band width of 20 kc. In other words, there may be employed I. F. transformers, in successive stages following the converter, which are well known in sound broadcasting superheterodyne receivers. Each of these coupling networks may consist of an I. F. transformer whose primary and secondary circuits are each tuned to an I. F. of 465 kc., and each of which transformers has a substantially flat top response curve whose frequency width is 20 kc.

Those skilled in the art are fully aware of the manner of constructing a limiter network. Briefly, the network functions to remove any amplitude modulation components which may exist on the I. F. signal carrier energy fed to the input circuit of detector 11. The detector 11 may be of any well known form. Its function is to derive from the applied FM energy the modulation voltage. In this case the modulation output is of audio frequency, and the audio frequency energy is transmitted to any type of audio frequency amplifier network. The required reduction of the frequency swing of the received FM waves is secured by frequency modulating the local oscillator 8 with the modulation voltage output of the FM detector 11. This is readily accomplished by taking some of the audio frequency energy output of detector 11, and transmitting it over a path 12 to a reactance tube 13. The latter reactance tube is to be constructed in the same manner as the reactance tube 2 of the transmitter. Similarly, it is desirable that the local oscillator 8 of the receiver be constructed in the same manner as the transmitter oscillator 3.

In general, the modulation network comprising lead 12, reactance tube 13 and oscillator 8 at the receiver is an exact replica of the network comprising audio source 1, reactance tube 2 and oscillator 3 at the transmitter. The effect of modulating the oscillator 8 in accordance with the audio input applied from lead 12 is to cause the I. F. energy output of converter 7 to have a mean frequency deviation swing so reduced that the spectrum of the I. F. currents is held within a band of some 20 kc. in width. It is not believed necessary to go into detail concerning the theoretical reasons for the production of this reduction in frequency deviation of the converter output. Reference is made to U. S. Patent 2,273,-110, granted February 17, 1942, to Charles N. Kimball and George C. Sziklai, for a disclosure of an audio feedback system which can be employed to produce the inverse modulation of oscillator 8 thereby to secure the reduction in frequency deviation of the I. F. energy output of converter 7.

It will be recognized that the network 12—13—8 is essentially an automatic frequency control circuit (AFC) which holds the I. F. value relatively stiffly toward its mean frequency. The pass band width that may be employed subsequent to the converter can thus be relatively narrow, but, of course, it should not be chosen so narrow that amplitude modulation applied to the carrier is not efficiently transmitted. It will now be seen that the modulation voltage applied to the local oscillator reactance tube must be substantially a replica of the audio voltage applied to the transmitter reactance tube, since both of these audio voltages produce nearly equal frequency swings. This is particularly true if similar reactance tube and oscillator assemblies are employed in both transmitter and receiver. One of the advantages of the present system is that a

lack of linearity between the audio frequency signals applied to the transmitter reactance tube and the transmitter output frequency is neutralized by a similar action at the receiver. Of course, if the transmitter uses a linear modulating characteristic, then the modulation characteristic for oscillator **8** must be similarly linear.

The receiving system is readily utilized in such cases where the carrier has applied to it modulation signals which act to amplitude modulate the carrier concurrently with its frequency modulation. At the transmitter there is shown a second source of modulation signals **1'** which may be applied in any well known manner to the oscillator **3**. A switch **3'** may be provided to permit amplitude modulation of the carrier, or to discontinue such multiplexing. At the receiver it is necessary to take off the AM signals from the carrier. For this purpose, it is only necessary to provide any usual type of amplitude modulation detector, such as a diode **20** provided with a load resistor **21**. The latter is by-passed for I. F. currents by shunt condenser **21'**. The AM modulation path is designated by the lead "AM." A switch **30** is included in the AM lead. When the switch **30** is closed the I. F. energy will be taken off from a point between the converter output circuit and the limiter input circuit. In this way the I. F. energy is transmitted through coupling condenser **40** to the demodulator diode, with its signals existing as modulation on the carrier. The rectified signals developed across resistor **21** may be then transmitted to any desired audio network.

Of course, when the switch **30** is closed both the FM signals and the AM signals will concurrently be reproduced in their respective audio output networks. Alternatively, the switch **30** may be open, and solely the FM signals can be reproduced. The AM components on the carrier are efficiently transmitted through the I. F. circuit, because the latter has a pass band readily capable of handling such AM components as voice or music.

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. In a frequency modulation communication system, a transmitter comprising a carrier oscillator, a reactance tube coupled to said oscillator to vary the frequency thereof, a source of modulation signals connected to said reactance tube to vary the effect thereof on said oscillator, said reactance tube having a non-linear modulation characteristic whereby the signal to noise ratio at low modulation amplitudes is improved, a receiver comprising a converter stage provided with an input circuit having a pass band sufficiently wide to pass the frequency modulated carrier waves radiated from said transmitter, a local oscillator constructed in the same manner as said transmitter oscillator, said oscillator being connected to said converter to apply thereto local oscillations whose frequency differs from the carrier frequency by a predetermined intermediate frequency, a frequency modulation detector, a coupling network between the converter output circuit and said detector input circuit, said latter coupling network having a pass band which is relatively narrow with respect to the pass band of the converter input circuit, a reactance tube connected to said local oscillator to vary the frequency thereof, said reactance tube having a modulating characteristic which is a replica of that of the transmitter reactance tube, and means for varying the effect of the receiver reactance tube with the modulation signal output of said receiver detector.

2. In a frequency modulation communication system, a transmitter comprising a carrier oscillator, a reactance tube coupled to said oscillator to vary the frequency thereof, a source of modulation signals connected to said reactance tube to vary the effect thereof on said oscillator, said reactance tube having a non-linear modulation characteristic, a receiver comprising a converter stage provided with an input circuit having a pass band sufficiently wide to pass the frequency modulated carrier waves radiated from said transmitter, a local oscillator constructed in the same manner as said transmitter oscillator, said oscillator being connected to said converter to apply thereto local oscillations whose frequency differs from the carrier frequency by a predetermined intermediate frequency, a frequency modulation detector, a coupling network between the converter output circuit and said detector input circuit, said latter coupling network having a pass band which is relatively narrow with respect to the pass band of the converter input circuit, a reactance tube connected to said local oscillator to vary the frequency thereof, said reactance tube having a modulating characteristic which is a replica of that of the transmitter reactance tube, means for varying the effect of the receiver reactance tube in accordance with the modulation signal output of said receiver detector, said transmitter including a second source of modulation signals adapted to modulate the radiated oscillations as to the amplitude thereof, and a second detector at said receiver for detecting amplitude modulation signals on the received carrier waves, said second detector having an input path connected to a point between the converter output circuit and said frequency modulation detector input circuit.

3. In a radio communication system, the method which includes generating carrier oscillations of substantially constant amplitude at a transmitter, varying the frequency of said oscillations with modulation signals according to a non-linear modulating characteristic which produces low amplitude level emphasis, radiating the resulting modulated carrier waves, collecting the modulated carrier waves at a receiver, producing local oscillations at the receiver of a frequency differing from the mean frequency of the received modulated carrier waves by a predetermined beat frequency value, heterodyning the received modulated carrier waves with said local oscillations to produce modulated carrier waves whose mean frequency is equal to said beat frequency, detecting the heterodyne waves to produce the modulation signals, and frequency modulating said local oscillations with said detected modulated signals in exact accordance with said transmitter non-linear modulating characteristic, and carrying out said modulation of said local oscillations to an extent such as greatly to reduce the frequency deviation of said heterodyne energy.

WALTER VAN B. ROBERTS.