Device for the transmission of signals by means of frequency-modulated carrier waves.

Fig. 1a

Fig. 1b

Fig. 2a

Fig. 2b

Frequencies in cycles per second.

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DEVICE FOR THE TRANSMISSION OF SIGNALS BY MEANS OF FREQUENCY-MODULATED CARRIER WAVES

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1. This invention relates to a device for the transmission of signals by means of a frequency-modulated carrier wave. It is known that in various respects the use of frequency-modulated oscillations may have great advantages over amplitude-modulated oscillations.

The invention has for its object to add to these advantages another advantage viz. a considerable decrease of the distortions which may arise when the emitted signal reaches the receiver along different paths.

The invention is based on the recognition that upon reception of frequency-modulated oscillations reaching the receiver along two paths with a difference in transit time the distortion occurring after detection depends on the frequency and is approximately inversely proportional to the frequency of the modulating oscillations. Consequently, the distortion is troublesome more particularly at the lower frequencies and for this reason a device for the transmission of frequency-modulated oscillations is, according to the invention, arranged so that at least a part of the frequency spectrum of the signals to be transmitted is heterodyned before the modulator in such a manner that the frequency spectrum of the oscillations modulating the carrier wave to be transmitted solely comprises frequencies above a definite frequency which exceeds the lowest frequency of the signal frequencies to be transmitted.

The frequency spectrum of the signals to be transmitted is preferably shifted towards the higher frequencies by an amount corresponding at least substantially to the minimum frequency which may still appear in the oscillations modulating the carrier wave and which preferably amounts to about 1000 cycles/sec.

The choice of the minimum frequency is determined on the one hand by the admissible distortion which occurs after detection due to transmission along two different paths, but on the other hand the minimum frequency should not be chosen too high, since otherwise there occur too high modulation frequencies and, as is well-known, the ratio between signal and the disturbances caused in a receiving set by other transmitters, by noise or by atmospheres becomes worse as the ratio between the frequency deviation and the highest modulation frequency decreases.

The invention will be more fully explained by reference to the accompanying drawing, given by way of example, in which Fig. 1a represents one form of construction of a transmitting device according to the invention, in which that part of the frequency spectrum of the signals to be transmitted, which lies below the lowest admissible frequency of the oscillations modulating the carrier-wave to be transmitted is heterodyned in such a manner that the transformed spectrum does not comprise frequencies below the said frequency.

Fig. 1b schematically represents a receiving arrangement for the reception of frequency-modulated oscillations transmitted by means of a device as shown in Fig. 1a.

Fig. 2a represents a device for the transmission of signals, in which the whole frequency spectrum of the signals to be transmitted is shifted by an amount corresponding to the lowest frequency which may still appear in the oscillations modulating the carrier wave.

Fig. 2b schematically represents a receiving arrangement for the reception of oscillations emitted by means of a device as shown in Fig. 2a.

In describing the executional examples illustrated in the drawing it is postulated that the frequency spectrum of the signals to be transmitted comprises a frequency range of 0 to 10,000 cycles/sec. and that the oscillations modulating the carrier wave may solely comprise frequencies below 1000 cycles/sec. In the form of construction represented in Fig. 2a the signals to be transmitted, which are generated in a microphone Q, are supplied through a low-frequency amplifier LQ to two filters F1 and F2, of which the filter F1 transmits the signal frequencies exceeding the lowest frequency which may still appear in the oscillations modulating the carrier wave, the filter F2 transmitting the signal frequencies which are lower than the said frequency.

The frequencies of 1000 to 10,000 cycles/sec. transmitted by the filter F1 are directly supplied to a frequency modulator FM, and the frequencies of 0 to 1000 cycles/sec. transmitted by the filter F2 are heterodyned, before being supplied to the frequency modulator FM, in such a manner that the frequency spectrum of the transformed oscillations no longer comprises frequencies below 1000 cycles/sec. To this end the frequencies transmitted by the filter F2 are supplied to a modulator M; having also supplied to it an oscillation generated by an oscillator O; whose frequency is higher than the highest original signal frequency to be transmitted and amounts to 10,000 cycles/sec., which oscillation is amplitude-modulated by the frequencies of 0 to 1000 cycles/sec. transmitted by the filter F2. In this way there are produced two side bands com-
prising a frequency range of 10,500 to 11,500 cycles/sec. and 10,500 to 9500 cycles/sec. respectively. In the modulator the carrier wave of 10,500 cycles/sec. is preferably suppressed, whereas the two side bands are supplied to a filter \( F_2 \), which transmits only one of the side bands and, for the chosen value of the frequency of the oscillator \( O_1 \), passes the upper side band of 10,500 to 11,500 cycles/sec. This side band, whose frequency spectrum includes the heterodyned frequency range of 0 to 1000 cycles/sec. of the signals to be transmitted, is supplied to the frequency-modulator \( FM \), in which modulator the carrier wave generated by an oscillator \( O_2 \) is frequency-modulated by the frequencies supplied to the modulator. The frequency spectrum of the oscillations modulating the carrier wave includes the frequency band of 1000 to 10,000 cycles/sec. transmitted by the filter \( F_1 \), and the frequency band of 10,500 to 11,500 cycles/sec. transmitted by the filter \( F_2 \), which frequency bands do not comprise frequencies below 1000 cycles/sec.

The oscillations frequency-modulated in the modulator are emitted by an antenna \( A \).

The choice of the frequency of the oscillator \( O_1 \) determines the width of the frequency spectrum of the oscillations modulating the carrier wave. This frequency is preferably so chosen that the frequency spectrum of the modulating oscillations is but slightly broader than the frequency spectrum of the signals to be transmitted. In fact, it is advantageous in the receiver that the frequency spectrum should not be broader than is strictly necessary, since the energy of the disturbances produced in the receiver increases with an increasing width of the frequency spectrum of the oscillations frequency-modulating the carrier wave. In fact, the energy of the disturbances occurring is proportional to

\[
\left( \frac{f_m}{s} \right)^2
\]

wherein \( s \) represents the amplitude of the variation of the momentary frequency and \( f_m \) represents the maximum frequency of the modulating oscillations.

With an extension of the frequency spectrum, consequently at a higher value of \( f_m \), the energy of the disturbance appearing in the receiver is larger than will be the case upon reception of a frequency-modulated carrier wave, in which case the frequency spectrum of the modulating oscillations is as broad as the frequency spectrum of the signals to be transmitted.

The receiver represented in Fig. 1b which is adapted for the reception of the frequency-modulated oscillations emitted by means of a device as shown in Fig. 1a comprises a high-frequency amplifier \( HP \) to which are supplied the oscillations picked up by an antenna \( A \). The amplified oscillations set up in the output circuit of the amplifier \( HP \) are preferably supplied through a frequency transformer or modulator \( M_2 \), to which are supplied oscillations locally generated by an oscillator \( O_2 \), to a detector \( D \), in which the frequency variations of the carrier wave are transformed into amplitude variations which are subsequently rectified. The oscillations supplied by the detector comprise a frequency spectrum which corresponds to the frequency spectrum of the oscillations modulating the incoming carrier wave, and extends from 1000 to 10,000 cycles/sec. and from 10,500 to 11,500 cycles/sec. In order to transform this frequency spectrum into the frequency spectrum of the signals to be received, the oscillations in the output circuit of the detector \( D \) are supplied to two filters \( F_3 \) and \( F_4 \), of which the filter \( F_3 \) transmits the frequency band of 1000 to 10,000 cycles/sec., and the filter \( F_4 \) transmits the frequency band of 10,500 to 11,500 cycles/sec. The frequencies transmitted by the filter \( F_3 \) are directly supplied to a low-frequency amplifier \( LF_1 \), and the frequencies transmitted by the filter \( F_4 \) are so heterodyned that they are being supplied to the low frequency amplifier \( LF_2 \), that the frequency spectrum of the heterodyned oscillations corresponds to the frequency spectrum of that part of the signals to be transmitted which is transmitted by the filter \( F_4 \) in the transmitter. For this purpose the frequencies of 10,500 to 11,500 cycles/sec. transmitted by the filter \( F_4 \) are supplied to a modulator \( M_3 \), which has also supplied to it an oscillation which is generated by the oscillator \( O_3 \) and has a frequency of 10,500 cycles/sec. In the modulator \( M_3 \) there are supplied two frequency bands of 21,000 to 22,000 cycles/sec. and of 0 to 1000 cycles/sec., respectively, of which the lower side band including the frequencies of 0 to 1000 cycles/sec. is transmitted by a filter \( F_5 \) and supplied to the low frequency amplifier \( LF_3 \). In the low-frequency amplifier are amplified the frequency band of 1000 to 10,000 cycles/sec. transmitted by the filter \( F_4 \) and the frequency band of 0 to 1000 cycles/sec. transmitted by the filter \( F_5 \), which bands jointly comprise the frequency spectrum of the signals to be transmitted, the oscillations set up in the output circuit being supplied to a loud-speaker \( LS \), in which the amplified oscillations are transformed into the sound vibrations to be received.

Fig. 2a represents one form of construction of a device according to the invention, in which the frequency spectrum of the signals to be transmitted is shifted as a whole towards the higher frequencies by an amount corresponding to the lowest frequency that may still appear in the oscillations modulating the carrier wave and preferably amounts to 1000 cycles/sec. In this form of construction the width of the frequency spectrum of the oscillations modulating the carrier wave consequently corresponds to the width of the frequency spectrum of the signals to be transmitted. In Fig. 2a the arrangement corresponding to the arrangement shown in Fig. 1b bears the same reference numerals; furthermore, it is assumed again that the frequency spectrum of the signals to be transmitted includes the frequency range of 0 to 10,000 cycles/sec.

In the form of construction represented in Fig. 2a the oscillations generated in the microphone \( Q \), which comprise the frequency spectrum of 0 to 10,000 cycles/sec., are supplied through the amplifier \( LF_1 \) to a modulator \( M_4 \), which has also supplied to it an auxiliary oscillation supplied by an oscillator \( O_4 \) whose frequency at least corresponds to the highest signal frequency to be transmitted plus the lowest frequency which may still appear in the oscillations modulating the carrier wave to be transmitted and amounts to say 30,000 cycles/sec., which oscillation is amplitude-modulated by the amplified signals to be transmitted. In this way there arise two side bands comprising a frequency range of 30,000 to 40,000 cycles/sec. and 30,000 to 20,000 cycles/sec. respectively.

Preferably the oscillation of 30,000 cycles/sec. is suppressed in the modulator \( M_4 \), the two side bands being supplied to a filter \( F_6 \), which solely transmits the upper side band, and supplies it to a modulator \( M_5 \), which has also supplied to it a second auxiliary oscillation supplied by an oscil-
The oscillator $O_x$, whose frequency is 1000 cycle/sec, higher than the highest frequency of the upper side band and consequently has a frequency of 41,000 cycles/sec. In the modulator $M_s$, also, there ensue two side bands, which comprise a frequency range of 71,000 to 81,000 cycles/sec, and of 11,000 to 1000 cycles/sec, respectively. This last-mentioned side band, whose frequency spectrum is shifted by 1000 cycles/sec, towards the higher frequencies with respect to the frequency spectrum of the signal in the transmitted and consequently does not comprise frequencies below 1000 cycles/sec, is supplied, through a filter $F_s$, solely transmitting this lower side band, to a modulator $FM$, wherein the carrier wave produced by the generator $O_s$ is frequency-modulated by these side-band frequencies.

In the described form of construction the frequency spectrum of the signals to be transmitted is not only shifted as a whole by 1000 cycles/sec, but also the frequency spectrum is reversed, as a result of which the low and high frequencies respectively of the signals to be transmitted are high and low frequencies respectively in the frequency spectrum of the oscillations modulating the carrier wave.

This reversal of the frequency spectrum does not take place if the auxiliary oscillation supplied by the oscillator $O_s$ has a frequency which is 1000 cycles/sec, lower than the lowest frequency of the frequency band of 30,000 to 41,000 cycles/sec, transmitted by the filter $F_s$ and consequently supplies an oscillation having a frequency of 20,000 cycles/sec. In this case there ensue in the modulator $M_s$ two side bands comprising a frequency range of 59,000 to 70,000 cycles/sec, and of 1000 to 11,000 cycles/sec, respectively, the frequency spectrum of the lower side band being shifted by an amount of 1000 cycles/sec, with respect to the frequency spectrum of the signals to be transmitted.

However, it is preferable that the oscillator $O_s$ should produce oscillations whose frequency lies beyond the side bands produced in the modulator $M_s$, in order to achieve the desired displacement of the frequency spectrum of the signals to be transmitted the oscillator $O_s$, provided the filter $F_s$ transmits the upper side band of the side bands obtained in the modulator $M_s$, which comprises a frequency range of 30,000 to 41,000 cycles/sec, will consequently be tuned to a frequency which exceeds by 1000 cycles/sec, the highest frequency of this frequency band, but if the filter $F_s$ transmits the lowest side band of 30,000 to 20,000 cycles/sec, the oscillator $O_s$ will be tuned to a frequency which is 1000 cycles/sec, lower than the lowest frequency of the lower side band. In both cases the desired displacement of the frequency spectrum is accompanied by reversal of the frequency spectrum.

The receiver represented in Fig. 2b, which is adapted for the reception of the frequency-modulated oscillations emitted by means of a device as shown in Fig. 2a, comprises a high-frequency amplifier $HP$, to which are supplied the oscillations picked up by the antenna $A_n$, the frequency transformer or modulator $M_s$ and the detector $D$, the latter transforming frequency variations of the carrier wave into amplitude variations which are subsequently rectified. The oscillator supplied by the detector comprise a frequency spectrum which corresponds to the frequency spectrum of the oscillations modulating the incoming carrier wave and extends from 11,000 to 1000 cycles/sec. In order to transform this frequency spectrum into the frequency spectrum of the signals to be received the oscillations in the output circuit of the detector $D$ are supplied to a modulator $M_s$, having supplied to it an auxiliary oscillation supplied by an oscillator $O_s$ whose frequency amounts to say 41,000 cycles/sec. In the modulator $M_s$ the oscillations generated by the oscillator $O_s$ are amplitude-modulated by the oscillations comprising the frequency spectrum of 1000 to 11,000 cycles/sec, the carrier wave being preferably amplified and the lower side band of 30,000 to 40,000 cycles/sec of the two side bands thus produced being transmitted by a filter $F_s$ and supplied to a modulator $FM$, in which this frequency is modulated on the auxiliary oscillation supplied by the oscillator $O_s$, whose frequency corresponds to the lowest frequency of the transmitted side band and consequently amounts to 30,000 cycles/sec. In this case two side bands ensue again, of which the lower, which includes the frequencies of 0 to 10,000 cycles/sec, corresponds to the frequency spectrum of the signal to be received. This lower side band is supplied through a filter $F_s$, which stops the carrier wave and the upper side band, to the low-frequency amplifier $LF$ and subsequently to the loudspeaker $LS$, in which the incoming oscillations, comprising a frequency band of 0 to 10,000 cycles/sec, are transformed again into the incoming sound vibrations.

In the form of construction represented in Fig. 2b the frequency of the oscillations supplied by the oscillators $O_s$ and $O_s$ corresponds to the frequency of the oscillations produced in the transmitter by the oscillators $O_s$ and $O_s$ respectively. This, however, is not imperative; in the receiver transformation of the incoming frequency-modulated oscillations into oscillations comprising a frequency spectrum of 0 to 1000 cycles/sec, may also take place by making the oscillators $O_s$ and $O_s$ generate oscillations whose frequency is different from the frequency of the auxiliary oscillations in the transmitter. As an alternative the desired transformation may be obtained by tuning the oscillator $O_s$ to a frequency of 31,000 cycles/sec and the oscillator $O_s$ to a frequency of 20,000 cycles/sec.

However, in the form of construction under view, in which the whole frequency spectrum is shifted by an amount of 1000 cycles/sec, and conversely, the frequency difference between the oscillators $O_s$ and $O_s$ in the transmitter and the oscillators $O_s$ and $O_s$ in the receiver is equal to the minimum admissible modulation frequency of 1000 cycles/sec. In the transmitter plus the highest signal frequency of 10,000 cycles/sec, to be transmitted. In the present numerical example the difference between the oscillators $O_s$, $O_s$ and $O_s$, $O_s$ respectively consequently corresponds to 11,000 cycles/sec.

We claim:

1. In a frequency modulation system, a source of wave energy of carrier wave frequency to be modulated, a source of modulating potentials coupled to said source of wave energy to modulate the frequency of the latter in accordance with the modulating potentials, and means in said coupling for increasing the frequencies of a band of lower frequency modulation potentials by selected equal amounts which exceed the lowest modulation frequency to reduce any receiving point distortion at said lowest frequency modulation potentials due to multipath transmission comprising filter circuits for separating a band of modulating potentials in the lower frequency range of said modulating potentials from the
remaining modulation potentials, separate paths coupling said filter circuits to said frequency modulator for supplying the modulating potentials to said frequency modulator and heterodyning means in the path supplying said band of lower frequency modulating potentials.

2. In apparatus for receiving wave energy of carrier wave frequency which has been frequency modulated directly by a band of modulated potentials falling within a band of frequencies in the higher frequency end of the modulating frequency spectrum and by a subcarrier which has been modulated by the remaining modulating potentials found within a band of frequencies in the lower end of the modulating frequency spectrum to reduce at the receiving point distortion at said frequencies in the lower end of the modulating frequency spectrum due to multipath transmission, modulated wave energy amplifying means, a frequency converter including a source of oscillations coupled to said amplifier, a frequency responsive detector coupled to said converter, means for selecting from said detector the modulation components corresponding to the components used to directly modulate said carrier in the transmitter, means for selecting from said detector the modulation components corresponding to the modulated subcarrier used at said transmitter, a demodulator for deriving from said modulated subcarrier the original modulation components in said band in the lower end of the modulation frequency components, and means at said receiver for recombining said modulation components.

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