Nov. 4, 1941. C. A. LOVELL 2,261,628

STEREOPHONIC REPRODUCTION BY CARRIER WAVE TRANSMISSION

Filed March 22, 1940

FIG. 1

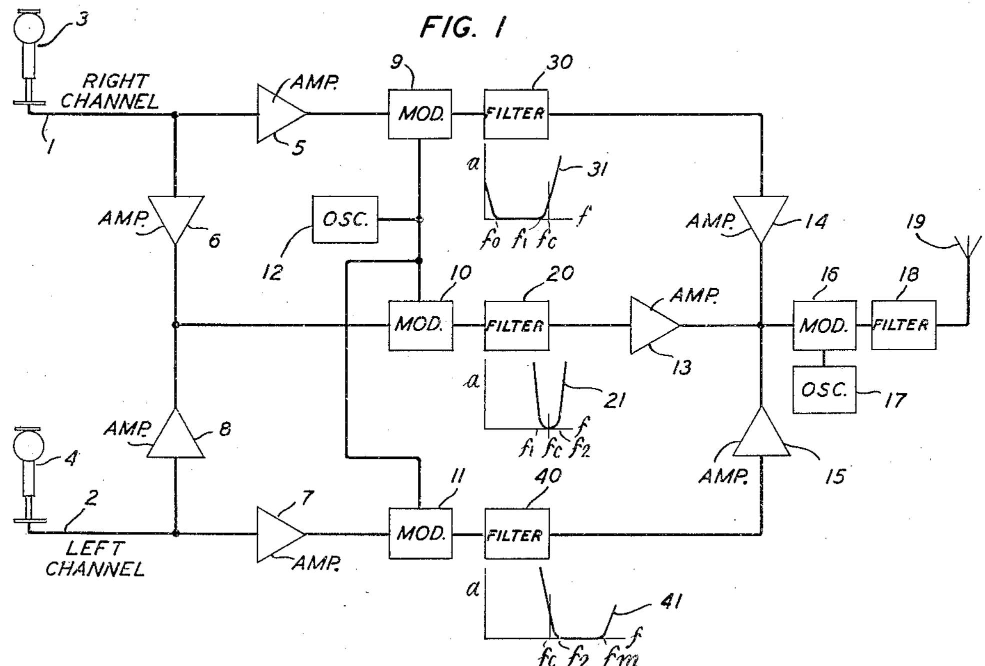

FIG. 2

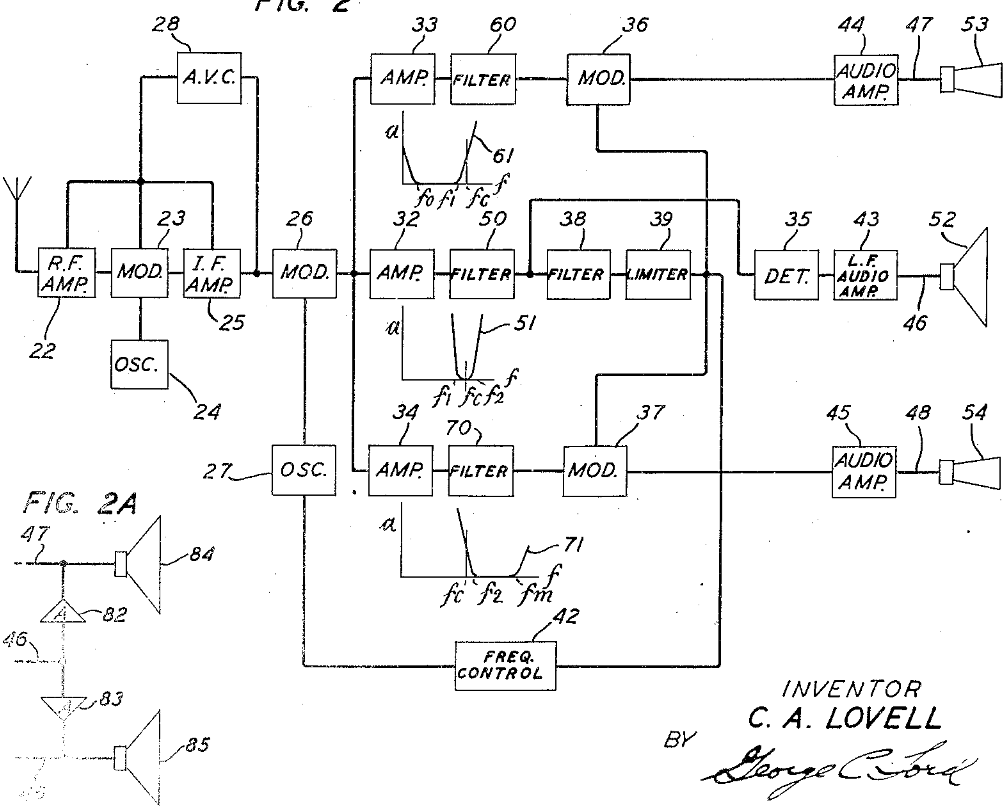

FIG. 2A

INVENTOR
C. A. LOVELL
BY George C. Ford
ATTORNEY

Patented Nov. 4, 1941 2,261,628

UNITED STATES PATENT OFFICE

2,261,628

STEREOPHONIC REPRODUCTION BY CARRIER WAVE TRANSMISSION

Clarence A. Lovell, Maplewood, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application March 22, 1940, Serial No. 325,323

14 Claims. (Cl. 250—6)

This invention relates to the reproduction of sound with spacial distribution and an object thereof is to simplify the systems for the transmission by radio or carrier of the audio signals required to produce such effects.

There are two recognized methods of transmitting and reproducing audio signals to give the spacial effect or auditory perspective experienced by a listener observing the sound directly from the source. One is binaural reproduction which aims by means of head receivers to cause the listener at a distant point to hear exactly as if he were present at the point of origin of the sound. With such a system two microphones are required for picking up the sound and separate transmission channels are required for transmitting the electrical currents from each microphone to the corresponding head receiver. The other type of system has been called a stereophonic system and also requires a multiplicity of channels each consisting of a microphone, transmission channel and a loud-speaker at the reproduction point. This system aims to reproduce in a distant hall or room, the sound field existing at the place of origin of the sound.

Both types of system require at least two separate transmission channels. In the case of transmission by guided or radiated carrier, this can be achieved by using separate carrier frequencies for each channel. However, in order to conserve space in the frequency spectrum and to simplify the receiver equipment, some method of operating on a single carrier is desirable. In the past it has been proposed to accomplish this by using the two side-bands of a single carrier for the separate channels. However, with such a system, it is difficult to separate the two side-bands without the loss of part of each side-band representing the low frequencies of the sound. This is very disadvantageous in the case of the reproduction of music where the loss of the low frequency destroys much of the naturalness of the reproduction. The separation of the two side-bands without the loss of the low frequencies in order to achieve good quality reproduction can at best be accomplished only by the use of expensive apparatus. In the case of radio broadcast for public reception, this is, of course, a prohibitive limitation.

It has been observed that the spacial effects, particularly of direction, are determined primarily by the high frequencies of the sound and are substantially independent of the lower audio frequencies. While the dividing line is not very critical, it has been found that sound of frequencies up to about 300 cycles per second could give very little spacial effect. This applies not only to stereophonic systems employing loud-speakers but also to binaural systems.

In accordance with this invention the electrical currents produced by two spaced microphones are transmitted as modulations of the same carrier wave. High frequencies from one microphone are transmitted as one single side-band modulation and those from the other microphone as the other single side-band modulation. At the same time, lower frequencies from one or both microphones are transmitted as double side-band modulations of the same carrier. By the use of such a system, the single side-band higher frequency modulations can be readily separated by the use of simple and inexpensive apparatus in the receiver to give two separate audio channels for producing the spacial effects and at the same time the double side-band lower frequency modulations can be detected and reproduced to give high quality reproduction.

The drawing is a functional schematic of one embodiment of the present invention in a radio system for stereophonic reproduction:

Fig. 1 showing the transmitting apparatus;

Fig. 2, the receiving apparatus; and

Fig. 2A, a modification of the loud-speaker arrangement of the receiving apparatus.

Referring to Fig. 1 there are shown two audio channels 1 and 2 which include the pick-up microphones 3 and 4, respectively, which are suitably spaced in front of a pick-up stage or other program source as is well understood in the art. The audio currents of channel 1 are transmitted through the amplifiers 5 and 6 to the modulators 9 and 10, respectively. Similarly, the audio currents of channel 2 are transmitted through the amplifiers 7 and 8 to the modulators 11 and 10, respectively.

Carrier oscillations of frequency f_c are supplied from an oscillator 12 to the three modulators 9, 10 and 11. The frequency f_c of these oscillations may be of the order of 30 kilocycles. The resulting outputs of the three modulators 9, 10 and 11 are later increased in frequency by a second modulation step to raise them to a range desirable for radio transmission. The double modulation process, in which the signals are first modulated by the lower carrier frequency of 30 kilocycles, is employed in order to facilitate the separation of the frequency bands.

The output of the modulator 10 is connected to a filter 20 having a frequency-attenuation characteristic as shown at 21 which passes all frequencies between f_1 and f_2 and attenuates other frequencies, where $f_1=f_c-300$ and $f_2=f_c+300$. The output of this filter will therefore contain the 30-kilocycle carrier along with double side-band modulations of the low frequencies (up to 300 cycles per second) from both of the audio channels 1 and 2.

The output of the modulator 9 is supplied to a filter 30 which has the frequency-attenuation characteristic shown at 31. This filter passes all frequencies between f_1 and f_0 where f_1 is again f_c-300 and f_0 a limiting frequency determined either by the audio range desired for good reproduction or the channel space available. The output of filter 30 will therefore contain the lower side-band of the modulation of the carrier oscillator f_c by the higher frequencies (above 300 cycles per second) of the current in the channel 1.

In a similar manner, the output of the modulator 11 is supplied to a filter 40 having a frequency-attenuation characteristic shown at 41. This filter passes all frequencies between f_2 and f_m where f_2 again is f_c+300 and f_m a limiting frequency determined in the same way as f_0. The output of this filter 40 therefore represents the upper side-band of the modulation of the carrier f_c by the higher frequencies in the audio channel 2.

Since the carrier frequency f_c is supplied only by the modulator 10, and no carrier is taken from the output of the modulators 9 and 11, these latter two modulators may conveniently be of balanced or push-pull type.

Since the output of the filters 20, 30 and 40 are to be paralleled to the input of the modulator 16, it is desirable that in the neighborhood of the cut-off frequencies f_1 and f_2, the attenuation and phase characteristics of the three filters should be adjusted to uniform frequency response.

The output of the three filters 20, 30 and 40 are supplied through the respective amplifiers 13, 14 and 15 to a modulator 16 in which they are combined with carrier oscillations from an oscillator 17 for the purpose of converting the intermediate carrier f_c and its associated side-bands to the higher frequency desired for radio transmission. The filter 18 connected to the output of the modulator 16 passes one side-band of this modulation process as is well understood in connection with multimodulation transmitters. This side-band represents the radio frequency carrier with a double side-band modulation of lower frequencies of the two audio channels and two single side-band modulations representing the higher frequencies of the respective audio channels and is radiated from the antenna 19.

Fig. 2 is a functional schematic of a radio receiver for receiving the signals transmitted from the transmitter of Fig. 1. In order to facilitate the separation of the various channel signals, this receiver is of the triple detection or double superheterodyne type. The received waves are selectively amplified in the radio frequency amplifier 22 and supplied to the first detector or modulator 23 in which they are combined with beating oscillations from the local oscillator 24. The resulting first stage intermediate frequency waves are selectively amplified in the intermediate frequency amplifier 25. An automatic volume control circuit 28 of the conventional type controls the gain of the radio frequency amplifier 22, the modulator 23, the intermediate frequency amplifier 25 in the well-known manner.

The intermediate frequency output of the amplifier 25 is supplied to a modulator 26 and therein combines with oscillations from the fixed frequency oscillator 27 to produce the second intermediate frequency wave which may be, for example, 30 kilocycles (f_c). This second intermediate frequency is supplied to three parallel paths comprising the amplifiers 32, 33 and 34. The outputs of these amplifiers are connected to suitable filter circuits for separating the various signals or channels.

Thus, filter 50 connected to the output of amplifier 32 has a frequency-attenuating characteristic shown at 51 similar to the filter 20 in the transmitter and selects the carrier and low frequency double side-band modulations. Filter 60 connected to the output of the amplifier 33 has a frequency-attenuation characteristic shown at 61 and selects the lower side-band modulation representing the high frequencies of one stereophonic channel. The filter 70 connected to the output of the amplifier 34 has a frequency-attenuation characteristic shown at 71 and selects the upper side-band representing the high frequencies of the other stereophonic channel.

The filters 50, 60 and 70 used in the radio receivers do not have to meet the requirements for the similar filters in the transmitter. For example, no phase correction is required for these filters for the reason that their outputs are connected to independent sound radiators as will be described. Also some slight cross-talk between channels can be tolerated. When the system is used for program broadcasting to the public, it is economical to have the separation between channels made as stringently as possible in the transmitter, thus permitting the use of simpler and therefore cheaper filters in the larger number of receivers which will be used.

The output of filter 50 is connected to an ordinary detector 35 which may be of the diode type, for example, and will provide satisfactory detection of the double side-band low frequency signals. This detected signal is then amplified in the low frequency audio amplifier 43, the output of which is connected through the line 46 to the low frequency loud-speaker 52.

Since the outputs of the filters 60 and 70 contain only single side-band signals with no carrier, it is necessary to provide carrier for the detection of these signals. This is accomplished by the selection of some of the carrier energy from the output of filter 50. For this purpose there is provided a highly selective filter 38 and an amplitude limiter 39. The use of the limiter 39 smooths out or removes the modulations from the carrier and thus makes less stringent the requirements for filter 38.

The carrier output of the limiter 39 is supplied to the modulators 36 and 37 to which are also supplied the side-band outputs of the filters 60 and 70, respectively. The output of these modulators, therefore, contains the detected audio signals which are amplified in the audio amplifiers 44 and 45, respectively and supplied through the lines 47 and 48 to the respective high frequency loud-speakers 53 and 54.

The low frequency speaker 52 may, for example, be mounted in a cabinet containing the radio receiver apparatus including the audio amplifiers. The high frequency speakers 53 and 54 may then be symmetrically placed on either side of the main cabinet to give the desired spacial distribution of the sound or stereophonic effect. Since the speakers 53 and 54 are required to reproduce only the higher frequencies, they can be small in structure and may be readily arranged in an inconspicuous manner.

There is also shown a frequency control **42** of the well-known type for controlling the frequency of the second beating oscillator **27**. This control is operated by the carrier output of the limiter **39**. While it is not essential to the operation of the system, it may be found very desirable in order to maintain the second intermediate frequency output of the modulator **26** constant which is desirable for the purpose of separating the channels, i. e., so that the intermediate frequency will always be constant with respect to the characteristics of filters **50**, **60** and **70**.

Fig. 2A shows an alternative circuit for the speaker arrangement. In this circuit, two wide frequency range loud-speakers **84** and **85** are used. These are mounted in the well-known manner for giving the spacial sound distribution. With this arrangement, the spaced loud-speakers **84** and **85** not only reproduce the high frequencies from the stereophonic channels **47** and **48**, but they also reproduce the low frequencies from the double side-band channel **46**. These low frequency signals are supplied through the respective amplifiers **82** and **83** to the two speakers **84** and **85**. An essential function of the amplifiers **82** and **83** is to isolate the two channels so as to prevent cross-talk therebetween. Other methods of accomplishing the same purpose, for example, the use of a hybrid coil may be employed.

While in the circuit of Fig. 2, the carrier for the detection of the side-band channels in the modulators **36** and **37** is obtained from the double side-band output of the filter **50**. This carrier might also be obtained from a separate oscillator. U. S. Patent No. 2,041,855 to R. S. Ohl, May 26, 1936, shows a radio receiver in which the carrier for demodulation is obtained by either of these two methods, namely, separate amplification of the received carrier or local generation of a carrier oscillation. This and other modifications can readily be made in the system.

It should be noted that not only is the system of this invention adapted for giving the advantages of stereophonic reception, but also that it can be readily fitted into the present type of broadcast system. Thus, the signals transmitted from the transmitter **51** may be received by an ordinary broadcast receiver. In this case, of course, no stereophonic effect is produced. The only effect will be similar to that of mixing the outputs of the microphones **3** and **4** in a single channel system. Similarly, the radio receiver of Fig. 2 may be used for the reception of ordinary double side-band broadcast waves as well as the stereophonic transmission. In this case, of course, no stereophonic effects will be produced at the receiver as the two side-bands reproduced by the separate high frequency loud-speakers are identical.

However, it can be seen that the use of stereophonic broadcasting in accordance with this invention would not remove from a station that group of listeners who have single channel receivers, while on the other hand the purchase of a stereophonic receiver would not eliminate single channel stations from the list of stations which could be tuned in by the listener.

While the modulation system, as described and shown herein, has been applied to a stereophonic system, it is adaptable to other uses. For example, a single high quality audio channel could be transmitted by employing double side-band modulations for the low frequencies and single side-band modulations of the same carrier for the high frequencies at the same time utilizing the other side-band for an auxiliary purpose, for example for the transmission of pilot or control currents. The entire band of modulations would occupy only the same space as the ordinary double side-band broadcast channel at the same time avoiding the limitations and complicated receiving equipment of single side-band systems just as with the stereophonic system described in detail herein.

These and other modifications of the specific embodiment shown herein may be made without departing from the invention as defined in the appended claims.

What is claimed is:

1. In a modulated carrier transmission system for the reproduction of sound with special distribution, two sources of audio frequency oscillations representing sound fields at points spaced with respect to the sound source, a source of carrier oscillations, means for producing a double side-band modulation of said carrier oscillations by the lower frequency oscillations from at least one of said two sources, means for producing an upper side-band modulation of said carrier oscillations by the higher frequency oscillations from one of said two sources, and means for producing a lower side-band modulation of said carrier oscillations by the higher frequency oscillations from the other of said two sources.

2. In a system according to claim 1, means for producing a double side-band modulation of said carrier oscillations by the lower frequency oscillations from both of said two sources of audio frequency oscillations.

3. A radio system for producing stereophonic effects comprising two sources of electrical oscillations representing sound fields at points spaced with respect to the sound source, a source of carrier oscillations, means for producing an upper side-band modulation of said carrier oscillations by the higher frequency oscillations from one of said two sources, means for producing a lower side-band modulation of said carrier oscillations by the higher frequency oscillations from the other of said two sources, means for producing a double side-band modulation of said carrier oscillations by the lower frequency oscillations from said two sources, and the means for simultaneously transmitting said double side-band modulations and said upper and lower side-band modulations.

4. A radio telephone system according to claim 3 including a radio receiver for receiving the transmitted modulations and comprising means for separately detecting the double side-band modulations, the lower side-band modulations, and the upper side-band modulations, two spaced loud-speakers, means for supplying the signal oscillations resulting from the detection of said lower side-band modulation to one of said loud-speakers, means for supplying signal oscillations resulting from the detection of the upper side-band modulation to the other of said loud-speakers, and means for producing sound waves corresponding to the signal oscillations resulting from the detection of the double side-band modulations.

5. A radio telephone system according to claim 3 including a radio receiver for receiving the transmitted modulations and including means for separately detecting the double side-band modulations, the lower side-band modulations

and the upper side-band modulations, two spaced loud-speakers, means for supplying the signal oscillations resulting from the detection of said lower side-band modulations to one of said loud-speakers, means for supplying the signal oscillations resulting from detection of the upper side-band modulations to the other of said loud-speakers, a third loud-speaker, and means for supplying the signal oscillations resulting from the detection of said double side-band modulation to said third loud-speaker.

6. In a modulated carrier wave transmission system for the reproduction of sound with spacial distribution, two sources of electrical oscillations representing sound fields at points spaced with respect to a sound source, a modulator connected to each of said sources, a third modulator connected to both of said sources, a source of carrier oscillations connected to all of said modulators, filter means in the output of one of the first two modulators for selecting a portion of the upper side-band of the modulation process to the exclusion of the carrier and all other frequencies below a fixed frequency above said carrier frequency, a second filter means in the output of the other of said first two modulators for selecting a portion of the lower side-band of the modulation process to the exclusion of the carrier and all other frequencies above a fixed frequency below the carrier frequency, and a third filter means connected to the output of said third modulator for selecting the carrier frequency and that portion of both of said side-bands of the modulation process between the limits of said fixed frequency below the carrier and said fixed frequency above the carrier to the exclusion of frequencies outside said limits.

7. In a modulated carrier wave transmission system for the reproduction of sound with spacial distribution, two sources of electrical oscillations representing sound fields at points spaced with respect to a sound source, a modulator connected to each of said sources, a third modulator connected to both of said sources, a source of carrier oscillations connected to all of said modulators, filter means in the output of one of the first two modulators for selecting that portion of the upper side-band of the modulation process above a limiting frequency f_c+f where f_c is the frequency of the carrier and f is of the order of 300 cycles per second to the substantial exclusion of all frequencies below said limiting frequency, a second filter means in the output of the other of said first two modulators for selecting that portion of the lower side-band of the modulation process below a limiting frequency f_c-f to the substantial exclusion of all frequencies above said limiting frequency, and a third filter means connected to the output of said third modulator for selecting the carrier frequency and that portion of both side-bands of the modulation process between the limiting frequencies f_c-f and f_c+f to the substantial exclusion of frequencies below and above said limiting frequencies.

8. In a modulated carrier wave transmission system according to claim 7, a second source of carrier oscillations and means for subjecting the output of the three filter means to modulations with carrier oscillations from said second source.

9. In a stereophonic reproduction system, a source of modulated carrier waves having double side-band modulations representing the lower audio frequencies from a sound source and two single side-band modulations each representing the high frequency sound field at points differently spaced with respect to said sound source, means for separately demodulating the double side-band modulations and the two single side-band modulations, means for establishing a sound field corresponding to the low frequency audio oscillations resulting from the demodulation of the double side-band modulations, and the means for establishing two spaced sound fields each corresponding to the high frequency audio oscillations resulting from the demodulation of a different one of the single side-band modulations.

10. A stereophonic reproducing system comprising a loud-speaker for reproducing low frequency audio signals from a sound source and a plurality of spaced high frequency loud-speakers each reproducing high frequency audio signals representing sound fields at points spaced with respect to said sound source.

11. A stereophonic reproducing system comprising two audio channels representing high frequency sound fields at points spaced with respect to a sound source, a third audio frequency channel representing low frequencies from the same source, a loud-speaker for reproducing the low frequencies in said third channel, and two loud-speakers symmetrically spaced with respect to the first-mentioned loud-speaker, one of said two loud-speakers being connected to each of said two audio channels.

12. The method of transmitting and reproducing sound to give a reproduction of the spacial distribution of the sound from a sound source which comprises transmitting the low frequency sounds from said source as double side-band modulations of a carrier wave, transmitting the higher frequency sounds produced by said sound source at one point as lower side-band modulations of the same carrier wave, transmitting the higher frequency sounds produced by said sound source at a different point in space as upper side-band modulations of the same carrier, establishing a sound field from one point corresponding to said higher frequency lower side-band modulations, establishing a sound field from another point spaced with respect to the first point and corresponding to said higher frequency upper side-band modulations, and establishing a sound field corresponding to said low frequency double side-band modulations.

13. The method of transmitting and reproducing sound according to claim 12 in which the low frequency sound field is set up from a point symmetrically spaced with respect to the points from which the high frequency sound fields are set up.

14. The method of transmitting and reproducing sound according to claim 12 in which the low frequency sound field is established by the simultaneous production of sounds from both points from which the high frequency sound fields are set up.

CLARENCE A. LOVELL.