May 30, 1967 E. B. RENWICK, JR 3,322,899

SIMULATING STEREOPHONIC SOUND REPRODUCTION

Filed Sept. 9, 1963 2 Sheets-Sheet 1

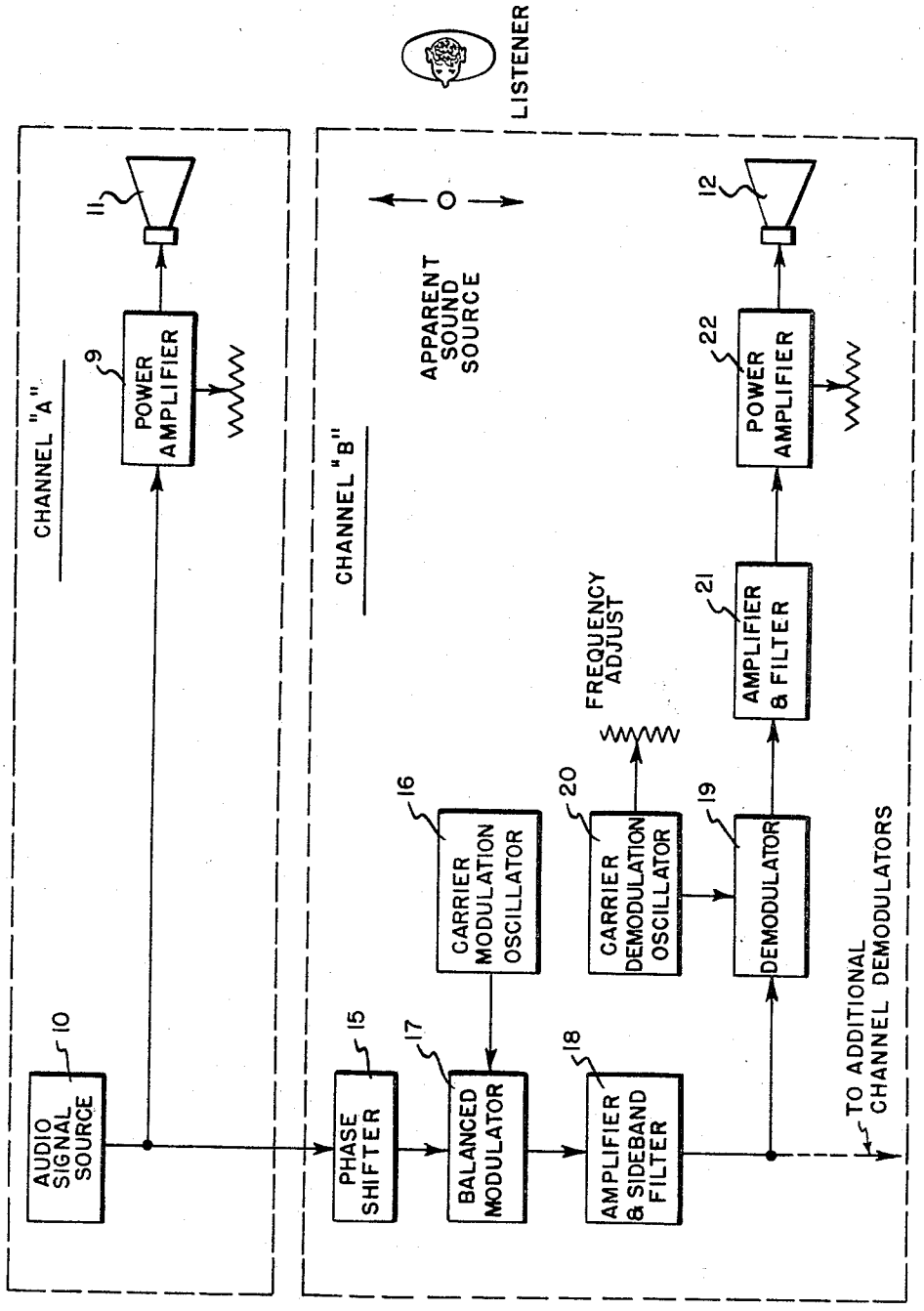


FIG. 1

INVENTOR
Erle B. Renwick, Jr.
BY Pennie, Edmonds, Morton, Taylor and Adams
ATTORNEYS

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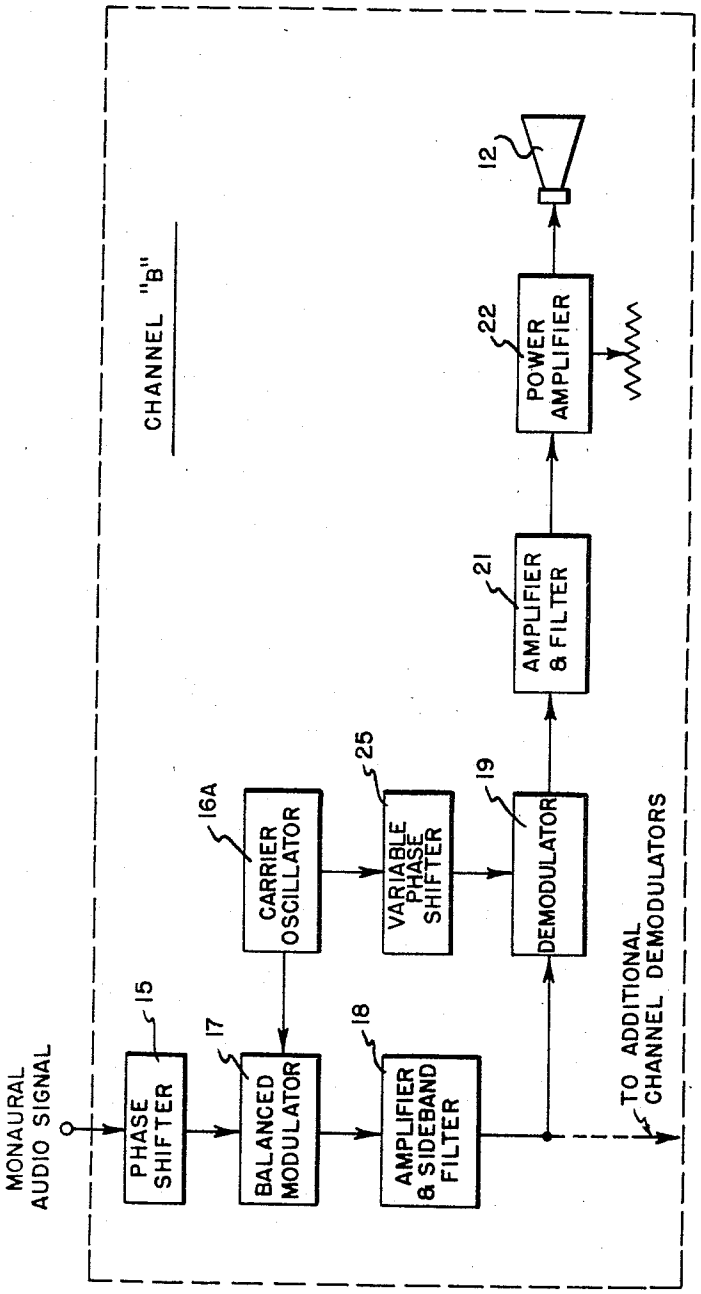


FIG. 2

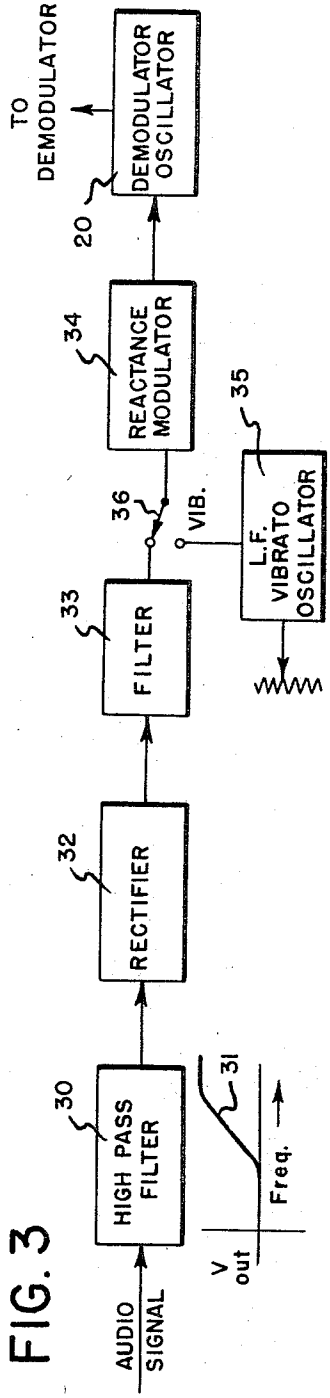


FIG. 3

INVENTOR
Erle B. Renwick, Jr.
BY Pennie, Edmonds, Morton, Taylor and Adams
ATTORNEYS

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SIMULATING STEREOPHONIC SOUND REPRODUCTION

Erie B. Renwick, Jr., Denville, N.J.
(267 Mossman Road, Sudbury, Mass. 01776)

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8 Claims. (Cl. 179—1)

The present invention relates to sound reproduction systems, and more particularly to a method and apparatus for simulating stereophonic reproduction of sound signals orginating from a monaural sound source.

Although the method and apparatus of the present invention is particularly well suited for enhancing the reproduction quality and listening enjoyment of music produced by electronic organs, which useful application will be frequently referred to in description of specific embodiments of the invention which follow, the invention may also be utilized with a wide variety of other monaural sound sources to achieve the desired effective addition of depth and stereophonic illusion.

It is known to those skilled in the art of sound and music reproduction that when two spaced sound reproducers are energized from a common sound source at the same energy level, the sound appears to a listener to originate from a point midway between the two reproducers. If both reproducers are energized by a combination of sinusoidal signals and the electrical phase angles of the signals supplied to one reproducer are gradually shifted in phase with respect to the signals supplied to the other reproducer, the listener no longer gains the impression that the sound originates from a point midway between the two reproducers; on the contrary, the apparent source gradually moves in space in a direction toward the sound reproducer which is energized with the signal that leads the signal supplied to the second reproducer.

The above described stereophonic motion effect is readily recognized by the listener of pipe organ music when two or more spaced pipes of an organ are sounded at the same pitch. In practice, the several pipes are normally slightly out of tune with one another and, accordingly, create audible notes which are substantially the same in pitch but which continually shift in phase relationship through 360° at a rate equal to the beat frequency or difference frequency of the two pipes. Since the source direction depends upon phase relationship as described above, the effective sound source for the two spaced pipes appears to the listener to move back and forth from one pipe to the other. This illusion of motion provides a very desirable dynamic impression to the listener, an impression which is totally lacking in electronic organs utilizing a single tone generator for each keyboard note.

It is a principal object of the present invention to provide a method and apparatus for simulating stereophonic reproduction of audio signals derived from a monaural sound source.

In accordance with the method of the present invention, sound signals from an audio source that are normally supplied through a power amplifier to a loudspeaker are additionally supplied to a second loudspeaker through an appropriate power amplifier after having been translated in frequency or frequency and phase by a predetermined amount. The translated signal is supplied to the second reproducer which is placed in spaced relationship with the first reproducer. Since the second reproducer is energized by an audio signal that changes slowly in phase relationship with respect to the signal supplied to the first loudspeaker, it will be appreciated that the listener gains the impression that the apparent sound source is dynamically shifted back and forth between the two speakers.

In accordance with one preferred embodiment of the invention, the desired frequency shift of the audio signals supplied to the second loudspeaker system is produced by modulating a carrier oscillator to produce a double sideband suppressed carrier signal, followed by filtering to provide a single sideband signal and demodulating the single sideband signal with a product detector energized by an oscillator that is offset in frequency from the original carrier oscillator by a desired beat frequency difference (e.g., .25 c.p.s. to 1 c.p.s.). The resultant audio output signal from the detector is thereby translated or changed in frequency by the same amount (i.e., 0.25 c.p.s. to 1 c.p.s.).

In accordance with a further preferred embodiment of the invention, the desired phase-shift of the audio signals supplied to the second loudspeaker system is produced by modulating a carrier oscillator to produce a double sideband suppressed carrier signal, followed by filtering to provide a single sideband signal and demodulating the single sideband signal with a product detector energized with a signal from the carrier oscillator that is dynamically shifted in phase. The resultant audio output signal from the detector is thereby shifted dynamically in phase with respect to the audio input signal.

In accordance with one aspect of the invention the monaural audio signal applied to the single sideband modulator is passed through a phase-shift network to add fixed phase-shift to the audio signal that varies as a function of audio signal frequency. The added frequency-proportional phase-shift produces a very desirable illusion in that certain frequencies will lead others in the criss-crossing motion between the two speakers. In fact certain frequencies will appear to be moving from left to right while others are moving from right to left.

In accordance with a further aspect of the invention, the frequency of the above described demodulation oscillator is frequency modulated by a control signal which varies as a function of the amplitude and/or the frequency of the incoming audio signal. Accordingly, the frequency of the output audio signal from the product detector is translated differentially as a function of the amplitude and/or the frequency of the incoming audio signal.

The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description of preferred embodiments of the invention, as illustrated in the accompanying drawings in which:

FIG. 1 is a block diagram showing apparatus provided by the present invention wherein the desired effective phase-shift between the audio signals supplied to the sound reproducers is produced by shifting the frequency of one signal;

FIG. 2 is a block diagram illustrating a second embodiment of the invention wherein the audio signals supplied to the two sound reproducers have the same frequency but one signal is dynamically shifted in phase at a predetermined rate; and

FIG. 3 is a block diagram illustrating means for differentially varying the frequency offset of the audio signals supplied to one sound reproducer with respect to that signal supplied to a first sound reproducer.

Referring to the drawings and particularly to FIG. 1, there is shown a conventional audio reproducing system

dentified as channel A and comprising monaural audio signal source **10** energizing loudspeaker **11** through power amplifier **9** as shown. In accordance with the present invention, the audio signal from source **10** is also supplied to an additional channel B which includes loudspeaker **12** separated in space from loudspeaker **11** and circuit apparatus for offsetting or shifting the frequencies of the audio signal supplied to reproducer **12** with respect to those frequencies supplied to speaker **11**. The monaural audio signal from **10** is supplied to phase shifter **15** which introduces a frequency-dependent phase-shift in the audio signal which is then superimposed on a carrier frequency from oscillator **16** supplied to balanced modulator **17**. The double sideband suppressed carrier signal from balanced modulator **17** is supplied to an amplifier and sideband filter **18** which removes one of the sideband signals and feeds the remaining single sideband signal to demodulator **19** as shown. Demodulator **19** may comprise any one of a number of well-known product detectors.

The desired frequency offset in the audio signal supplied to loudspeaker **12** is obtained by offsetting the frequency of carrier demodulation oscillator **20** with respect to the operating frequency of carrier modulation oscillator **16**. Since the oscillators **16** and **20** are free running and completely independent of one another, it is apparent that an offset in frequency of the demodulation oscillator **20** of, for example, one cycle per second will result in a shift in frequency in the audio signals produced at the output of demodulator **19** by the same one cycle per second. In practice, the inventor has found that the frequency of oscillator **20** should be made adjustable and should preferably be offset with respect to the frequency of oscillator **16** by a small amount, for example, from between 0.25 cycle per second up to several cycles per second.

The audio output signal from demodulator **19** is fed to amplifier and filter **21** which is adapted to remove all undesired harmonics produced in demodulator **19**. The output signal from **21** is then supplied to a conventional power amplifier **22** which, in turn, energizes loudspeaker **12**. Normally the gains of power amplifiers **9** and **22** are set to substantially the same level so that absent a difference in frequency (and hence phase) between the two signals supplied to **11** and **12**, a listener would gain the impression that the sound source is located substantially midway between the two speakers. However, when the audio signal frequencies supplied to loudspeaker **12** differ from those frequencies supplied to loudspeaker **11** by, for example, one cycle per second, then the apparent sound source will shift back and forth between the loudspeakers at a one cycle per second rate and in a direction towards that speaker which is energized by the audio signals leading in phase. Thus the listener gains the impression that he is listening to stereophonic reproduction since the apparent sound source moves back and forth in space periodically in much the same manner as it does with pipe organs.

Since each audio frequency signal from source **10** is phase shifted by a different angle through phase shifter **15**, it will be understood that the high pitched signals from violins, for example, will be positioned differently in space than the lower frequency signals from cellos, for example, and will in fact at times be moving in opposite directions.

Although only a two channel system has been illustrated in FIGS. 1 and 2, it should be understood that the output signal from sideband filter **18** may be supplied to additional demodulators and separate power amplifier and loudspeaker systems. It will also be understood that the frequency offset in the additional demodulator channels may be adjusted to provide a different value and a corresponding different effect for the listener as desired.

A second embodiment of the invention, as shown in block diagram form in FIG. 2, will now be described in detail. In this embodiment of the invention, the monaural

audio signal is processed in the same manner by phase shifter **15**, balanced modulator **17** and amplifier-sideband filter **18** as described above in connection with FIG. 1. However, demodulator **19** and modulator **17** are driven by the same oscillator **16A** and the desired phase shift in the audio output signal from demodulator **19** is obtained by introducing a dynamic phase-shift at carrier frequency in the oscillator signal supplied to demodulator **19** through variable phase shifter **25**. Phase shifter **25** may be any one of a variety of well known types of variable reactance phase shifters and preferably should be of the type that is continuously variable from 0° to 360°. Additionally, phase shifter **25** should preferably be of the type that can be either manually operated or motor driven at a variable speed in either direction. Thus the phase angle of the carrier oscillator signal supplied to demodulator **19** may be variably shifted in either a negative or a positive direction and at any desired rate so that the phase angle of the audio signals produced at the output of demodulator **19** may be advanced or retarded as desired with respect to the phase angle of the audio signals supplied to loudspeaker **11** (not shown in FIG. 2).

The embodiment shown in FIG. 2 has the outstanding advantage that the phase angle of the audio signal supplied to **12** can be accurately and precisely programmed in any desired manner by programming the control of variable phase shifter **25**. Frequency stability is excellent since the modulator and demodulator are driven by a common carrier oscillator. It will be appreciated that the dynamic phase-shift in the audio signal supplied to loudspeaker **12** through amplifier and filter **21** and power amplifier **22** is controlled by controlling the drive rate of variable phase shifter **25**. Thus where it is desired to have a one cycle per second cyclic shift between reproducers **11** and **12**, variable phase shifter **25** is continuously driven through 360° of phase-shift at a rate of 1 c.p.s.

Although the present invention is illustrated in FIGS. 1 and 2 may be used advantageously to enhance listening quality of audio signals from any one of a variety of monaural sound sources, the method and apparatus provided herein has been found to be particularly useful with electronic musical instruments such as electronic organs. As indicated above, the embodiment shown in FIG. 2 may also be used with a plurality of demodulator circuits. When so used, the inventor has found that excellent synthesis of celestial chimes, celestial bells, celestial flutes, celestial tibia and string celeste may be effected.

Referring now to FIG. 3, there is shown therein in block diagram form apparatus adapted to variably shift the frequency of incoming audio signals from a monaural source as a function of the incoming audio frequency and amplitude. As shown audio signals from the monaural source are supplied to high-pass filter **30** having a frequency pass characteristic as indicated at **31** which increases in amplitude with increase of input frequency. The output signal from high-pass filter **30** is then rectified by **32** and the resultant output signal supplied to smoothing filter **33**. The variable D.-C. voltage developed across filter **33** is utilized to control reactance modulator **34** which is provided to vary the frequency of demodulation oscillator **20** in FIG. 1. In accordance with this aspect of the invention, the audio signals supplied to loudspeaker **12** are variably shifted in frequency as a function of the audio input frequency. The demodulation oscillator is frequency modulated to produce beat frequencies between the outputs of speakers **11** and **12** that vary with the frequency content and amplitude of the input music signal. The over-all effect is similar to that obtained with a pipe organ using several ranks of pipes simultaneously wherein several beat frequencies are produced at different rates. Where desired, the input audio signal may be obtained from the output of an automatic gain control amplifier so that the signal level is substantially constant and the frequency of the audio output

signal is then varied only as a function of the frequency of the input audio signal. The filter **30** operating in combination with rectifier **32** functions as a slope type FM discriminator. Where desired, a low pass filter having a negative slope characteristic may be utilized to produce a D.-C. control signal which increases in amplitude as the frequency of the incoming audio signal is decreased. In this manner, it will be appreciated that the frequency of the audio signal delivered to loudspeaker **12** is increased in frequency more at the low end of the spectrum and less at the high end of the spectrum.

Reactance modulator **34** may also be controlled by the output signal from low frequency vibrato oscillator **35** by switching circuit switch **36** to the vibrato position. Output frequency of demodulation oscillator **20** is thereby frequency modulated at a predetermined frequency by the adjustable output frequency of oscillator **35** and the audio signal supplied to loudspeaker **12** is also frequency modulated at the same rate.

In accordance with a further aspect of the present invention, the apparatus shown in FIGS. 1 and 2 may be utilized to produce an effective tremolo. The desired effect may be obtained by locating the speakers adjacent the one another to effect amplitude modulation of the two signals by acoustic mixing in the listener's ears. In the alternative, the tremolo effect may be obtained by electrically mixing two audio signals supplied to a single loudspeaker (i.e., 12). The desired result is obtained by utilizing a sideband filter at **18** which passes both the upper and lower sideband signals from modulator **17**. The resultant output audio signal supplied to speaker **12** is amplitude modulated at a frequency equal to twice the difference between the modulator oscillator frequency and the demodulator oscillator frequency.

While several preferred embodiments of the invention have been described, it will be appreciated by those skilled in the art that various modifications may be made within the scope of the present invention as defined in the appended claims.

What is claimed is:

1. In a sound reproducing system having a monaural audio reproducer energized with an audio signal by a power amplifier, apparatus for simulating stereophonic reproduction of said signal comprising,

a second sound reproducer separated in space from said monaural reproducer,

circuit means for translating the frequencies of said audio signal by a predetermined amount in frequency with respect to the frequencies of the audio signal supplied to said monaural reproducer,

and means for supplying the audio signal having translated frequencies to said second sound reproducer.

2. Apparatus in accordance with claim **1** characterized in that said circuit means includes a phase-shift network for shifting the phase angle of the incoming audio signal by a fixed predetermined amount proportional to the incoming signal frequency.

3. In a sound reproducing system having a monaural audio reproducer energized with an audio signal by a power amplifier, apparatus for simulating stereophonic reproduction of said signal comprising,

a second sound reproducer separated in space from said monaural reproducer,

a phase-shift network for shifting the phase angle of the incoming audio-frequency signal by a predetermined amount proportional to the incoming audio signal frequency,

circuit means provided to dynamically shift the phase of the output signal from said phase-shift network,

and means for supplying the dynamically phase-shifted audio signal to said second sound reproducer.

4. In a sound reproducing system having a monaural audio reproducer energized with an audio signal by a power amplifier, apparatus for simulating stereophonic reproduction of said signal comprising,

a second sound reproducer separated in space from said monaural reproducer,

and circuit means for receiving said audio signal as an input and delivering an output signal to said second sound reproducer the frequencies of which are translated by a predetermined amount with respect to the frequencies of the audio signal supplied to said monaural reproducer, said means comprising a carrier oscillator, balanced modulator and sideband filter for translating said audio signal to a single sideband signal, and a demodulation oscillator and product detector for translating the sideband signal to an audio frequency signal, the frequency of said demodulation oscillator being offset by said predetermined amount with respect to the frequency of said carrier oscillator.

5. In a sound reproducing system having a monaural audio reproducer energized with an audio signal by a power amplifier, apparatus for simulating stereophonic reproduction of said signal comprising,

a second sound reproducer separated in space from said monaural reproducer,

and circuit means for receiving said audio signal as an input and delivering an output signal to said second sound reproducer which is dynamically shifted in phase with respect to the audio signal supplied to said monaural reproducer,

said means comprising a carrier oscillator, balanced modulator and sideband filter for translating said audio signal to a single sideband signal, and a product detector energized by said carrier oscillator for translating the sideband signal to an audio frequency signal including means for dynamically shifting the phase angle of the carrier oscillator signal supplied to said detector with respect to the phase angle of the carrier signal supplied to said modulator.

6. In a sound reproducing system having a monaural audio reproducer energized with an audio signal by a power amplifier, apparatus for simulating stereophonic reproduction of said signal comprising,

a second sound reproducer separated in space from said monaural reproducer,

and circuit means for receiving said audio signal as an input and delivering an output signal to said second sound reproducer the frequencies of which are translated by a predetermined amount with respect to the frequencies of the audio signal supplied to said monaural reproducer,

said means comprising a carrier oscillator, balanced modulator and sideband filter for translating said audio signal to a single sideband signal, with a demodulation oscillator and product detector for translating the sideband signal to an audio frequency signal,

and means for modulating the frequency of said demodulation oscillator.

7. In a sound reproducing system having a monaural audio reproducer energized with an audio signal by a power amplifier, apparatus for simulating stereophonic reproduction of said signal comprising,

a second sound reproducer separated in space from said monaural reproducer,

and circuit means for receiving said audio signal as an input and delivering an output signal to said second sound reproducer the frequencies of which are translated by a predetermined amount with respect to the frequencies of the audio signal supplied to said monaural reproducer,

said means comprising a carrier oscillator, balanced modulator and sideband filter for translating said audio signal to a single sideband signal, with a demodulation oscillator and product detector for translating the sideband signal to an audio frequency signal,

and means for modulating the frequency of said de-

modulation oscillator as a function of the input audio signal frequency.

8. Apparatus for frequency modulating an electrical audio signal to produce a vibrato effect, said apparatus comprising a carrier oscillator, balanced modulator and sideband filter for translating said audio signal to a single sideband signal, with a demodulation oscillator and product detector for translating the sideband signal to an audio frequency signal,

and means for periodically modulating the frequency of said demodulation oscillator.

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KATHLEEN H. CLAFFY, *Primary Examiner.*

RICHARD MURRAY, *Examiner.*

S. J. BOR, A. H. GESS, *Assistant Examiners.*