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[54] **QUADRUPHONIC DISC RECORDING SYSTEM UTILIZING SINGLE SIDEBAND MODULATION**

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[63] Continuation of Ser. No. 169,219, Aug. 5, 1971, abandoned.

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[58] **Field of Search** .... 179/100.4 ST, 100.1 TD, 179/15 BT, 15 RP, 15 FS, 15 FE, 1 GQ; 325/150, 137, 136, 65

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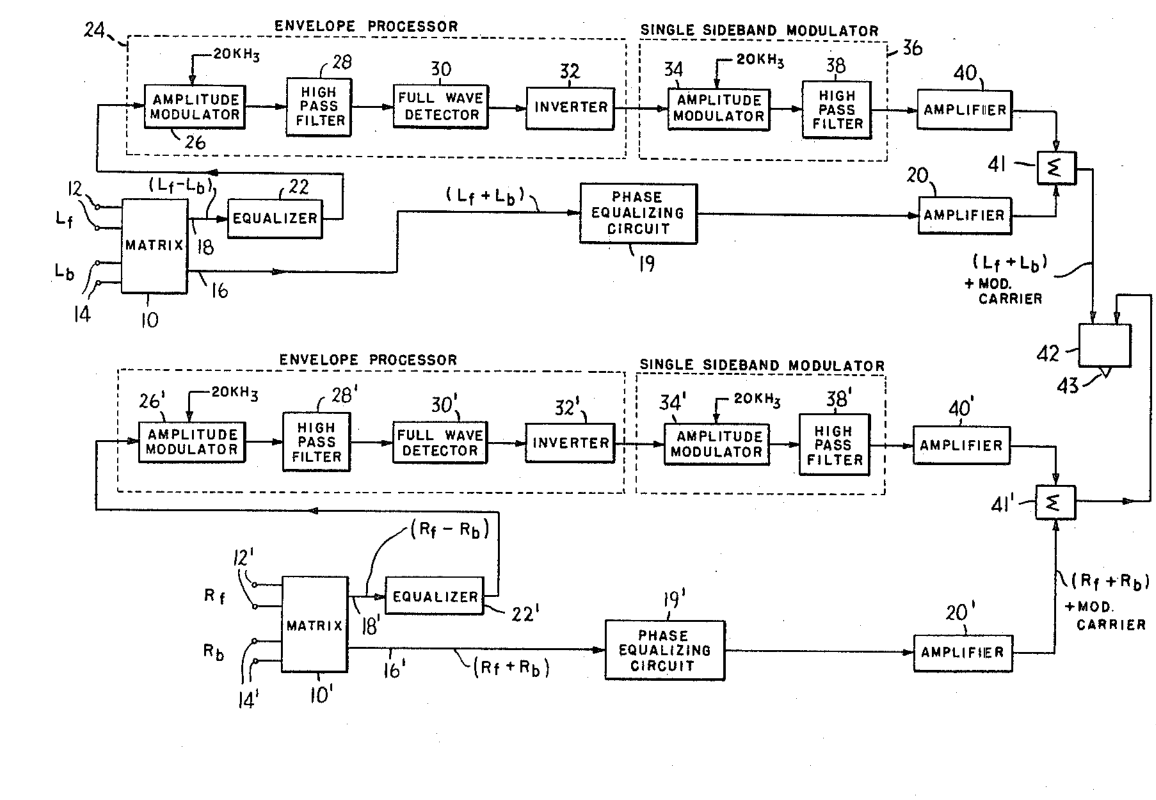
[57] **ABSTRACT**

As described hererin, sound information comprising four discrete audio signals is recorded on a single groove, two-channel record disc. To this end, two of the four signals are added to produce a sum signal and subtracted to produce a difference signal. The difference signal is employed to amplitude modulate a carrier signal and the upper sideband thereof is added to the sum signal and applied to one input terminal of a recording transducer. The transducer modulates one channel of the record groove in response to the sum signal and the upper sideband signal applied thereto. A similar operation is performed upon the remaining two signals, and the transduced modulates the second channel of the record groove in response to the sum signal and the upper sideband applied thereto.

2 Claims, 3 Drawing Figures



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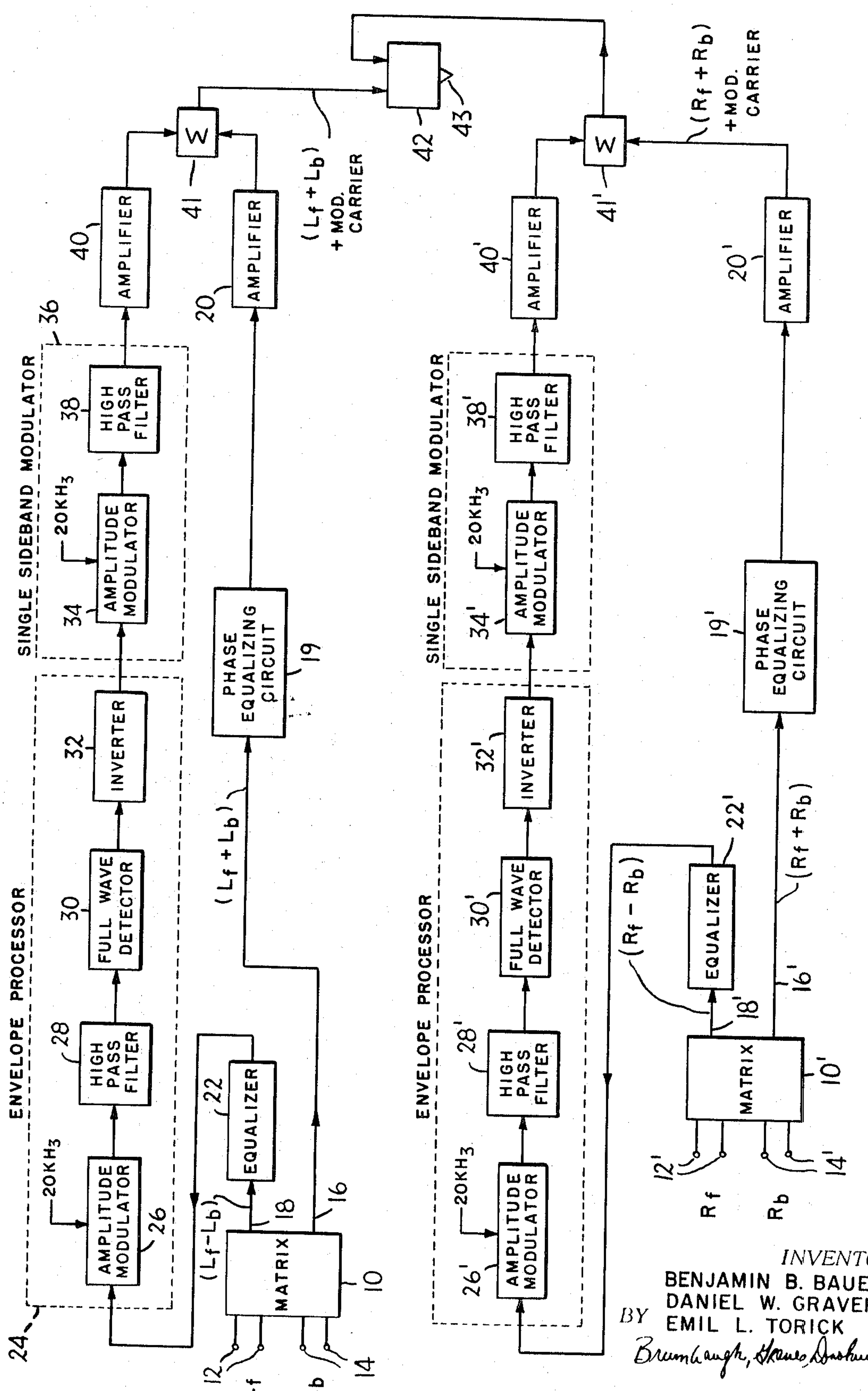

FIG. 1

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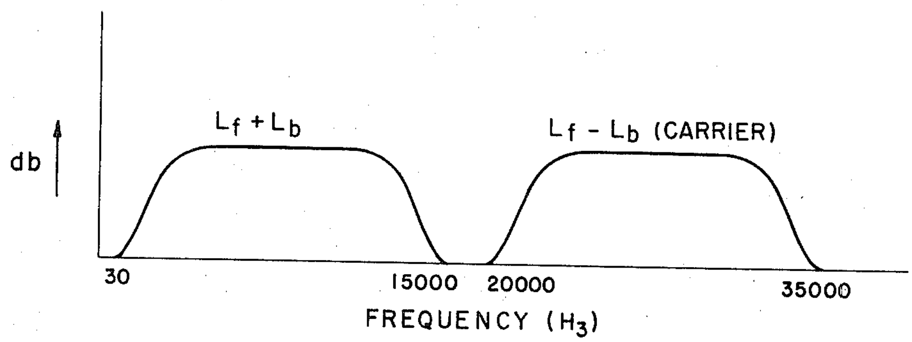

FIG. 2

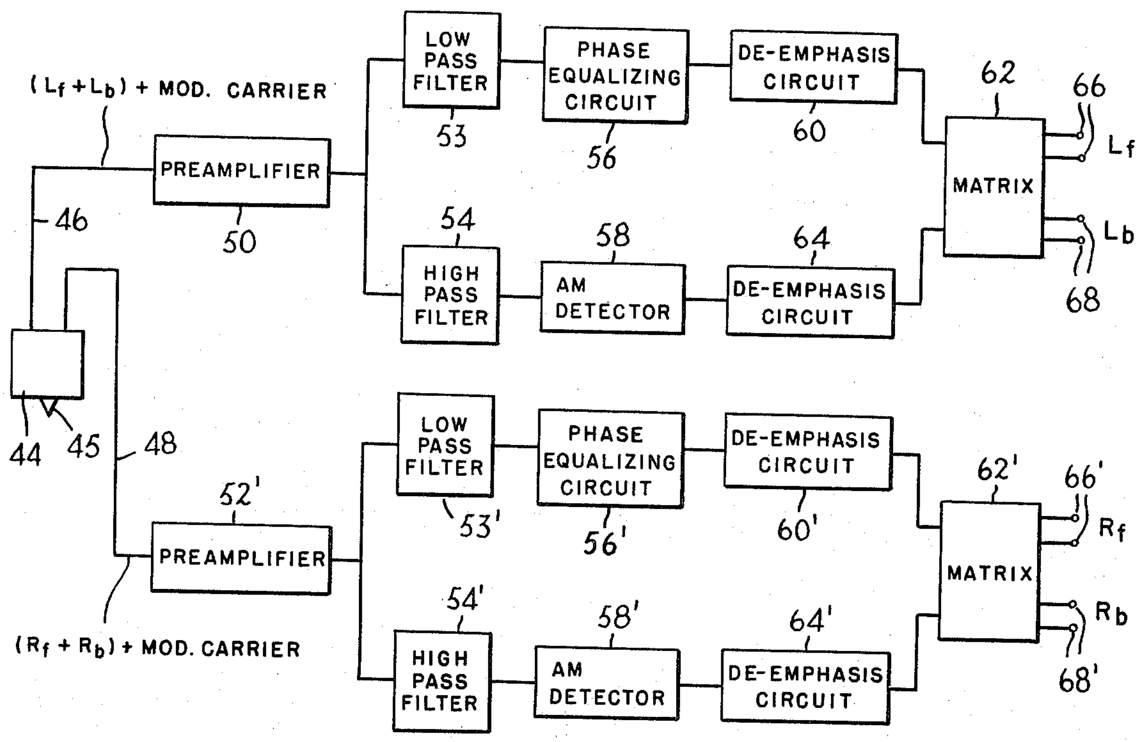

FIG. 3

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QUADRUPHONIC DISC RECORDING SYSTEM UTILIZING SINGLE SIDEBAND MODULATION

This is a continuation, of application Ser. No. 169,219, filed August 5, 1971, now abandoned.

BACKGROUND OF THE INVENTION

This invention relates to stereophonic disc recording systems and, more particularly, to a new and improved recording system adapted to record four independent channels of audio information on a two-channel disc record.

In systems for recording stereophonic information comprising two signals in a single groove record disc, it is customary to modulate the two channels (left and right) of the record groove in two perpendicular directions. Thus, the groove variations in one channel represent one function of the two signals and those in the other channel represent another function of the two signals. Typically, the groove is cut with modulation in each channel of the groove representing each signal and with lateral modulation representing the sum of the signals and vertical modulation representing the difference between the signals.

Since the commercialization of stereophonic phonograph sound reproduction in about 1958, efforts have been made to record three or more signals on a two-channel record for the obvious reason that the sound distribution of the reproduced information will improve as the number of signal sources increases. For example, three channel disc recording systems have been proposed in which a selected fraction of a third signal corresponding to the sound detected by a centrally disposed microphone is added to the two signals corresponding to the sound detected by spaced left and right microphones to record a dependent sum, or center, channel on the stereophonic record. Alternatively, it has been proposed to subtract a selected fraction of the third signal from each of the other two signals and to record a dependent difference channel on the stereophonic record. However, such a difference channel is not compatible with monophonic players because the vertical groove modulation cancels for monophonic reproduction, nor with stereophonic players which produce an unnatural sound during reproduction.

SUMMARY OF THE INVENTION

It is a principal object of the present invention to provide a method and apparatus for recording four discrete channels of audio information on a two-channel disc record, and for reproducing the four discrete channels upon playback of the record.

Another object of the invention is to provide a system for recording four discrete channels of audio information on a two-channel disc record which may be reproduced on a conventional stereophonic phonograph without loss of any sound contained in the original four signals.

These and other objects of the invention are accomplished by processing four discrete audio signals and modulating each channel of a two-channel disc record of the conventional 45°–45° modulation type in accordance with separate functions of two of the signals. For convenience of description, the four discrete signals correspond to the positions in a listening area at which four loudspeakers would be placed to respectively reproduce the four signals; that is, they may be characterized as left front (L_f), right front (R_f), left back (L_b) and right back (R_b). In particular, selected pairs of the audio signals, for example, L_f and L_b and R_f and R_b, are added to produce sum signals and subtracted to produce difference signals. The difference signals are employed to amplitude modulate carrier signals and the resultant carrier signals are combined with their respective sum signals. The combined sum signals and amplitude modulated carrier signals are then recorded on the separate channels of a two-channel stereophonic record.

In a preferred embodiment of the invention, only the upper sidebands of the difference signal modulated carrier signals are combined with their respective sum signals and recorded on the separate channels of the record. To compensate for the envelope distortion of the single sideband carrier signals, envelope processing circuits are provided to process or predistort the difference signals prior to developing the single sideband. In addition, equalizing networks are provided to maximize the modulation in the upper frequency ranges of the difference signals.

In a preferred embodiment of a record reproducing system, the sum signals are separated from the difference signal modulated carrier signals, the difference signals are detected, and the sum and difference signals are again added and subtracted to produce four audio signals corresponding to the original four channels for application to four appropriately positioned loudspeakers.

BRIEF DESCRIPTION OF THE DRAWINGS

In the Drawing:

FIG. **1** is a block diagram illustrating a preferred embodiment of a recording system arranged according to the invention for recording four discrete channels of audio information on a two-channel disc record;

FIG. **2** is a diagram illustrating the frequency distribution of the sum and the single sideband carrier signals recorded on one channel of a two-channel stereophonic record; and

FIG. **3** is a block diagram illustrating a preferred embodiment of a reproducing system arranged according to the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In a preferred embodiment of a four-channel recording system arranged according to the present invention, as shown in FIG. **1**, a pair of matrix circuits **10** and **10′** receive four audio signals from a suitable four-channel source, such as a master tape, (not shown) via input terminals **12**, **14** and **12′**, **14′**, respectively. As illustrated, the four input signals are designated left front (L_f), left back (L_b), right front (R_f) and right back (R_b) and each corresponds to the location in a listening area in which they are to be reproduced. The processing circuitry for the L_f and L_b signals will be described in detail. As will be apparent hereinafter, the L_f and L_b signals are recorded in the left channel of a sterophonic record and the R_f and R_b signals are recorded in the right channel. The components of the processing circuitry for the R_f and R_b signals corresponding to the components of the L_f and L_b signal processing circuitry are designated by prime numbers.

Within the matrix circuit **10**, which may be of conventional construction and, accordingly, need not be described herein, the L_f and L_b signals are added together to supply a sum signal (L_f+L_b) to a channel **16** and subtracted to supply a difference signal (L_f-L_b) to a channel **18.** As described hereinafter, the sum signal (L_f+L_b) is recorded in the left channel of a stereophonic record and the upper sideband of a carrier signal modulated by the difference signal (L_f-L_b) is also recorded in the left channel of the stereophonic record. In like manner, the sum signal (R_f+R_b) developed in the matrix **10'** and the upper sideband of a carrier signal modulated by the difference signal (R_f-R_b) are recorded in the right channel of the stereophonic record.

The sum signal (L_f+L_b) is applied via a phase-equalizing circuit **19** to a buffer amplifier **20,** whereas the difference signal (L_f-L_b) is applied initially to an equalizer circuit **22.** The phase equalizer circuit **19** is provided to maintain coincidence between the sum signal and the difference signal, which is phase-altered by reason of the processing to which it is subjected, as will be apparent hereinafter.

The equalizer circuit **22** attenuates the components of the difference signal (L_f-L_b) ranging in frequency from about 20 to about 1 kHz to compensate both for the fact that some of the lower sideband signal is transmitted to the output of the processing circuitry because of the method employed for producing single sideband. The signal-to-noise ratio of the composite signal is improved by pre-emphasizing the high frequency components of the difference signal (in which the spectral energy is less than for mid-range frequencies) and correspondingly de-emphasizing the signal during playback so that a flat frequency response is attained and the record noise subsequently attenuated. The method utilized to generate single sideband is to pass a double sideband signal with carrier through a high-pass filter having a cutoff frequency equal to the carrier frequency. Consequently, the audio level for low frequencies must be attenuated with respect to the high frequencies so that the modulation percentage in the double sideband region is the same as in the single sideband region for constant level input. These signals ranging in frequency from about 17 to 20 kHz will be transmitted, albeit with attenuation.

From the equalizer circuit **22** the difference signal is supplied to an envelope processor circuit **24** which includes an amplitude modulator **26,** a highpass filter **28,** a full wave detector **30** and an inverter **32.** The present invention utilizes a single sideband modulator to record the difference signal (L_f-L_b) on the same channel (left) of the stereophonic record groove that the sum signal (L_f+L_b) is recorded. As is understood in the art, when a sideband is removed from an amplitude modulated carrier signal to develop a single sideband signal with carrier, the envelope of the single sideband signal is in the shape of a "poid" and thus represents a distorted replica of the difference audio signal. In order to compensate for such distortion of the envelope of the single sideband signal, it is a feature of the present invention to predistort the difference signal (L_f-L_b) in the processor **24.**

Within the processor **24,** therefore, the difference signal (L_f-L_b) is applied to one input terminal of the amplitude modulator **26** wherein the signal modulates a carrier signal having a frequency of 20 kHz. The developed modulated carrier signal is then applied to the highpass filter **28** having a cutoff frequency of 20 kHz which rejects at rapid rate frequencies below 20 kHz and passes without attenuation the upper sideband of the modulated carrier signal. The transmitted sideband signal is then applied to the full wave detector circuit **30** which comprises, for example, a full wave rectifier and lowpass filter and, accordingly, detects only the envelope of the transmitted sideband signal. As above described, the detected signal constitutes a distorted replica of the difference signal (L_f-L_b).

The inverter **32** inverts the detected and distorted difference signal and applies the inverted signal to one input terminal of an amplitude modulator **34,** composing the first component in a single sideband modulator **36.** In the modulator **34,** the inverted and distorted difference signal modulates a 20 kHz carrier signal applied to the other input terminal of the modulator. A highpass filter **38** having a cutoff frequency of 20 kHz transmits only the upper sideband of the difference signal amplitude modulated carrier signal. By virtue of the inherent distortion in the modulation and filtering process, the envelope of the transmitted upper sideband signal is distorted with the result that the previous distortion is cancelled and the envelope of the resultant signal is an exact replica of the difference signal (L_f-L_b).

From the filter **38,** the upper sideband signal with carrier is supplied to a buffer amplifier **40** having its output terminal connected to one input terminal of a summing network to the other input terminal of which the output terminal of buffer amplifier **20** is applied. In the summing network **41,** the sum signal (L_f+L_b) and the (L_f-L_b) single sideband signal with carrier are added together and supplied to one input terminal of a recording transducer **42.** In this case, the transducer **42** is arranged to modulate the left channel of the record groove by means of a stylus **43** in response to the sum signal (L_f+L_b) and the (L_f-L_b) single sideband signal with carrier supplied thereto.

In like manner, the sum signal (R_f+R_b) and the upper sideband signal with carrier having an envelope representative of the difference signal (R_f-R_b) are added together in a summing network **41'** and then applied to the other input terminal of the recording transducer **42.** The transducer **42** is arranged to modulate the right channel of the record groove in accordance with the sum signal (R_f+R_b) and the (R_f-R_b) single sideband signal with carrier supplied thereto.

Referring now to FIG. **2,** there is shown the frequency distribution of the sum signals (L_f+L_b) and the difference signals (L_f-L_b). The sum signal is recorded as a regular audio signal in the respective channel of the record groove and the difference signal is recorded as single sideband modulation with carrier in the same channel of the record groove. The total bandwidth extends from 30 to 35 kHz. The distribution of the frequency components of the right channel signal is identical to that shown for the left channel.

In a preferred embodiment of a four-channel record reproducing system arranged according to the present invention, as shown in FIG. **3,** a two-channel disc phonograph pick-up transducer **44** includes a stylus **45** that responds to the modulations in the left and right channels of a record disc recorded in the above-described manner to supply the sum signal and the (L_f-L_b) single sideband signal with carrier, and the sum signal (R_f+R_b), together with the (R_f-R_b) single sideband signal with carrier, along a pair of conductors **46** and **48,** respectively, to a pair of preamplifiers **50** and **52,** respectively. Like the recording system, the components of the processing circuitry for the left and right channels are identical, and accordingly, only the processing circuitry for the left channel information will be described herein. The corresponding components in the right channel are designated by prime numbers.

The preamplifier **50** amplifies the sum signal ($L_f + L_b$) and ($L_f - L_b$) single sideband signal with carrier and applies the amplified signal to both a lowpass filter **53** and to a highpass filter **54**. The filters **53** and **54** separate the sum and single sideband signals and supply the separated signals to a phase equalizing circuit **56** and to an AM detector circuit **58**, respectively. The phase equalizing circuit **56** is provided to maintain coincidence between the sum signal and the ($L_f - L_b$) single sideband signal with carrier which is altered in phase by virtue of the additional circuits to which it is subjected, as will be apparent hereinbelow. From the circuit **56**, the sum signal is applied by way of a de-emphasis circuit **60**, conventional in stereophonic record reproducing systems, to one input terminal of a matrix **62**.

In the AM detector circuit **58**, which may comprise, for example, a diode network and a lowpass filter, the envelope of the ($L_f - L_b$) single sideband signal with carrier is detected, the detected signal being an exact replica of the (L_f −]L_b) signal produced by the matrix **10** in the recording process (FIG. 1). The difference signal ($L_f - L_b$) is then applied by way of a de-emphasis circuit **64** to the other input terminal of the matrix **62**. In the matrix **62**, the sum signal ($L_f + L_b$) is combined with the detected difference signal ($L_f - L_b$) in the conventional manner to reproduce at two pairs of output terminals **66** and **68** the left front (L_f) signal and the left back signal (L_b). The right front (R_f) signal and the right back (R_b) signal are reproduced in like manner at the two pairs of output terminals **66'** and **68'** of the matrix **62'**. Although not shown, these signals may then be supplied through power amplifiers to four spaced loudspeakers positioned at the left front, right front, left back and right back corners of the listening area, so that the spatial relation of the original four-channel sound is reconstructed during reproduction.

In operation, the matrices **10** and **10'** receive signals L_f, L_b, R_f and R_b and convert the signals into sum signals ($L_f + L_b$) and ($R_f + R_b$) and difference signals ($L_f - L_b$) and $R_f - R_b$), respectively. The sum signal ($L_f + L_b$), together with a ($L_f - L_b$) single sideband signal with carrier, is recorded in the left channel of a stereophonic record and the sum signal ($R_f + R_b$), together with a ($R_f - R_b$) single sideband carrier, is recorded in the right channel of the record. In the reproduction of the record, the sum and difference signals in each channel are separated and the difference signal detected. Thereafter, the signals are combined in the matrices **62** and **62'** and reproduced as the original four audio signals, L_f, L_b, R_f and R_b.

Although the invention has been described herein with reference to a specific embodiment, many modifications and variations therein will be readily apparent to those skilled in the art. Accordingly, all such variations and modifications are included within the intended scope of the invention as defined by the following claims.

We claim:

1. Apparatus for recording four channel signals in a single groove cut in a record disc, said apparatus comprising:

matrix circuit means for producing first and second signals representative of the sum and the difference, respectively, of the first and second channel signals and also third and fourth signals representative of the sum and difference, respectively, of the third and fourth channel signals,

first and second envelope processor means to which the second and fourth difference signals produced by said matrixing circuit means are respectively applied,

each of said envelope processor means including amplitude modulator means for modulating a carrier signal in accordance with the amplitude of the applied difference signal,

filter means for transmitting the upper sideband of the amplitude modulated signal, and

detector means for detecting the envelope of the upper sideband with carrier signal to produce a distorted replica of the difference signal,

first and second equalizing circuit means for respectively attenuating the low frequency components of the second and fourth difference signals prior to application to the amplitude modulator means of their respective envelope processor means to compensate for the presence of lower sideband signal information in the output of said filter means,

first and second output single sideband modulator means for modulating a respective carrier signal in accordance with the distorted replica of the difference signal produced by said first and by said second envelope processor means, respectively, to produce single sideband with carrier signals having envelopes corresponding to their respective difference signals, said carrier signals each having a frequency such as to cause the upper sidebands of said modulated signals to be outside the frequency range of said first and third sum signals,

first means for combining the first sum signal with the upper sideband of the single sideband with carrier signal produced by said first output single sideband modulator means,

second means for combining the third sum signal with the upper sideband of the single sideband with carrier signal produced by said second output single sideband modulator means, and

means for simultaneously recording the output signal of said first combining means on one wall of a single groove of the record disc and the output signal of said second combining means on the other wall of the groove.

2. A system for recording first, second, third and fourth channel signals in a single groove cut in a record disc, said system comprising:

matrix circuit means for producing a first sum signal and a first difference signal representative of the sum and difference, respectively, of the first and second channel signals and also a second sum signal and a second difference signal representative of the sum and difference, respectively, of the third and fourth channel signals,

first and second single sideband modulator means respectively responsive to said first and to said second difference signals for modulating a respective carrier signal in accordance with the amplitude of said first and second difference signals, respectively, said carrier signals each having a frequency such as to cause the upper sidebands of said amplitude modulated signals to be outside the frequency range of said first and second sum signals,

said first and second single sideband modulator means each including output single sideband modulator means, envelope processor means responsive to the applied difference signal for producing a modulating signal for the output single sideband modulator, and means for transmitting as an output signal the upper sideband of the amplitude modulated carrier signal produced by the output single sideband modulator means,

said envelope processor means comprising second amplitude modulator means for modulating a carrier signal in accordance with the amplitude of the applied difference signal, filter means for transmitting the upper sideband of the amplitude modulated carrier signal from said second amplitude modulator means, means for detecting the envelope of the transmitted upper sideband with carrier signal for producing a distorted replica of the difference signal, and means for applying said distorted replica of the difference signal to the output single sideband modulator as a modulating signal,

first and second equalizing circuit means for attenuating the low frequency components of the first and second difference signals prior to application to their respective second amplitude modulator means and operative to compensate for the presence of lower sideband signal information in the output of said filter means thereby to make substantially equal the modulation percentage in the output single sideband modulator means for all frequency components,

first means for combining the first sum signal with the output signal of the first single sideband modulator means,

second means for combining the second sum signal with the output signal of the second single sideband modulator means, and

means for simultaneously recording the output signal of said first combining means on one wall of the single groove of the record disc and the output signal of said second combining means on the other wall of the groove.

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