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Bauer

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[54] **APPARATUS FOR REPRODUCING QUADRAPHONIC SOUND**

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[52] **U.S. Cl. 179/1 GQ,** 179/100.4 ST, 179/100.1 TD

[51] **Int. Cl.** **H04r 5/00**

[58] **Field of Search** 179/15 BT, 16, 16 P, 100.4 ST, 179/100.1 TD, 1 GQ

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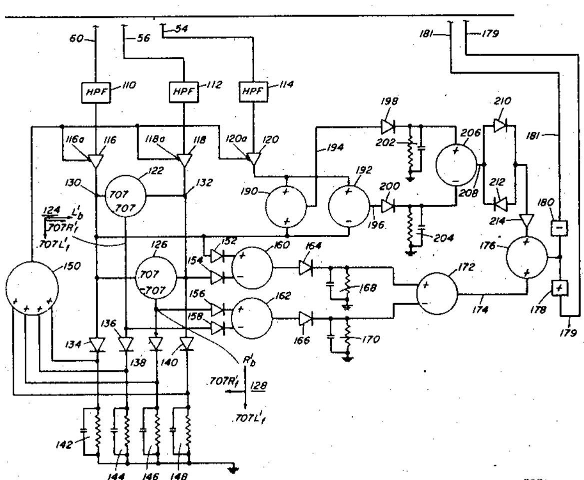
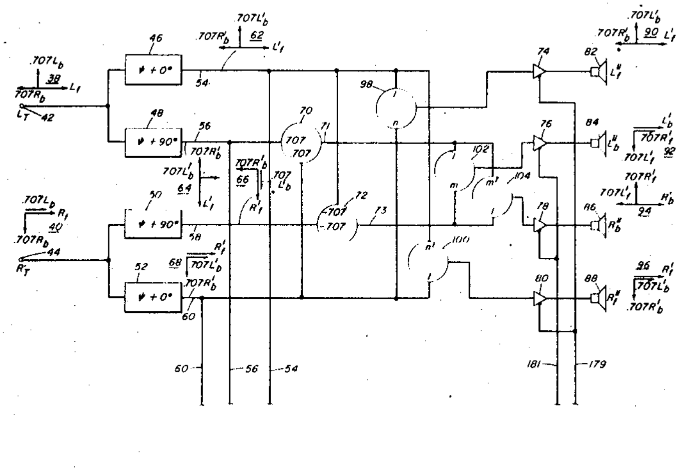
[57] **ABSTRACT**

Apparatus for decoding four separate channels of information transduced from a medium having only two separate tracks and presenting it on four loudspeakers to give the listener the illusion of sound coming from a corresponding number of separate sources. The realism is enhanced by a decoding system which accepts the two outputs from the medium, which may be a stereophonic disc record, separates them into four independent channels each carrying predominantly the information contained in the four original recorded sound signals, and, utilizing a wave-matching technique derives control signals for controlling the gains of amplifiers associated with the four loudspeakers. The control circuitry improves the separation of the four independent channels, particularly the generally "front" from the generally "back" signals. In another aspect of the encoder, the front-to-back separation is improved by intermixing some of the "left" output signal into the "right" output signal, and vice versa, at both the front and the back sets of decoder output terminals.

25 Claims, 7 Drawing Figures





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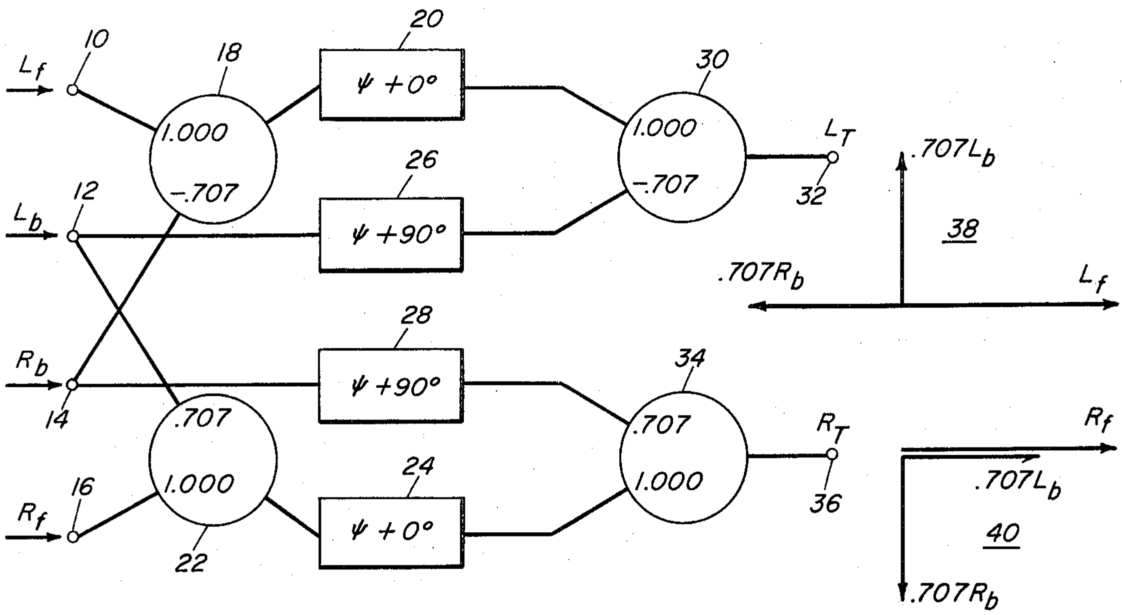

FIG. 1

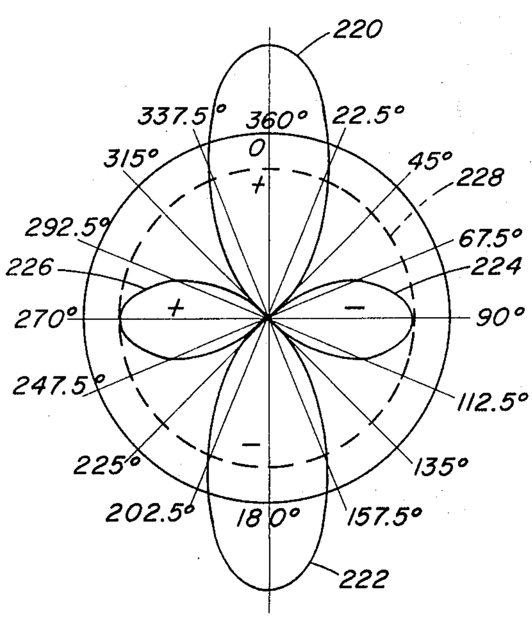

FIG. 3

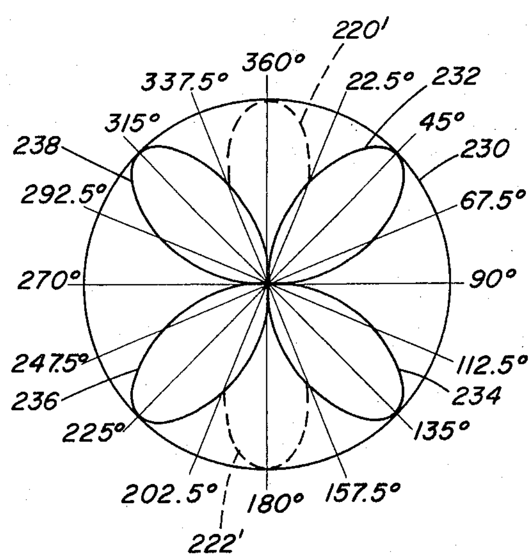

FIG. 4

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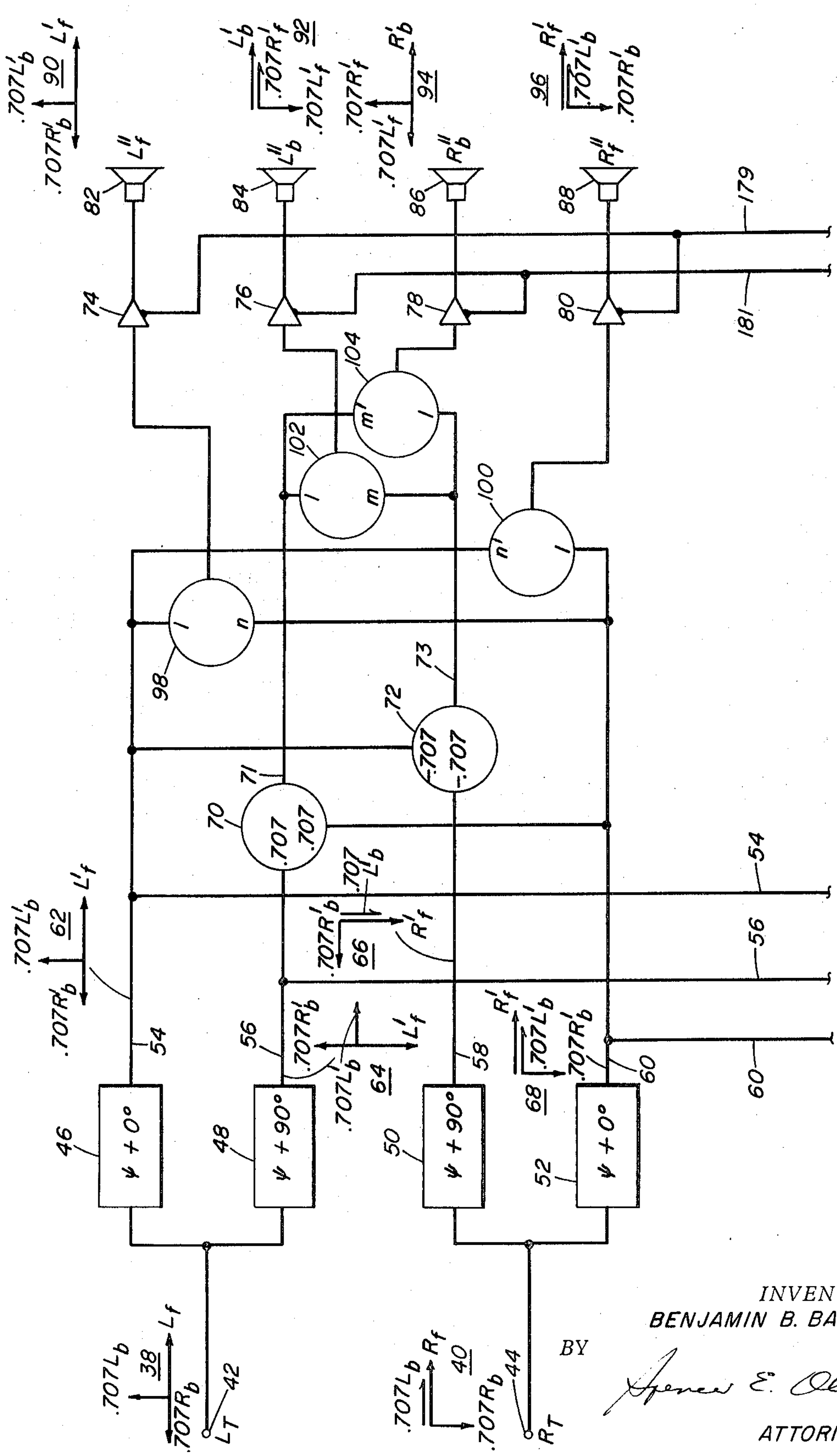

FIG. 2A

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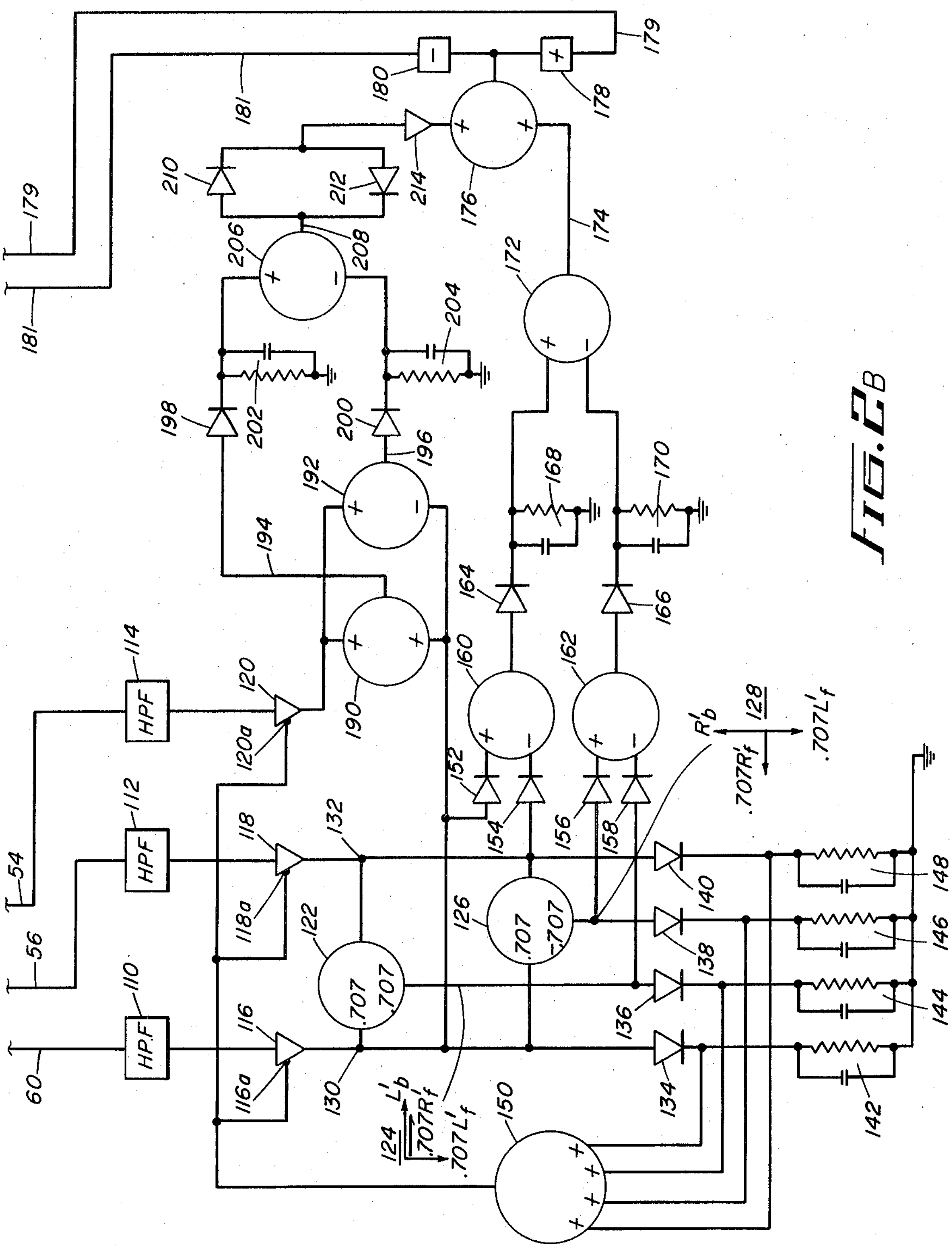

FIG. 2B

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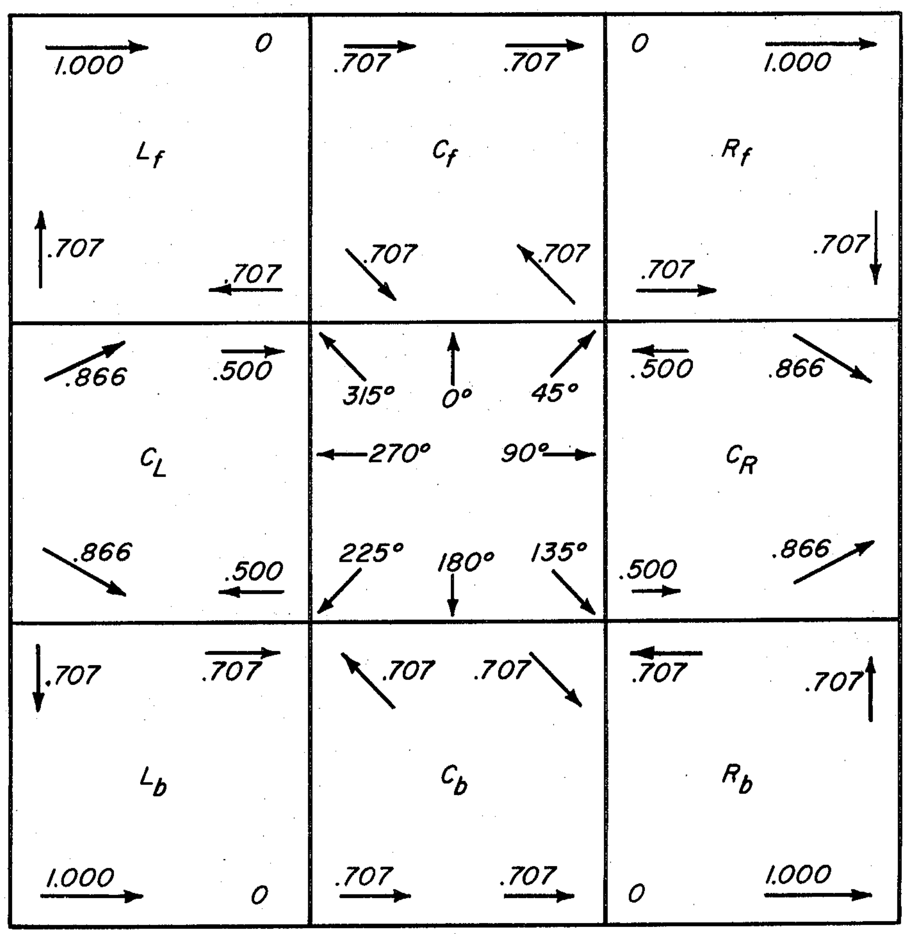

FIG. 5

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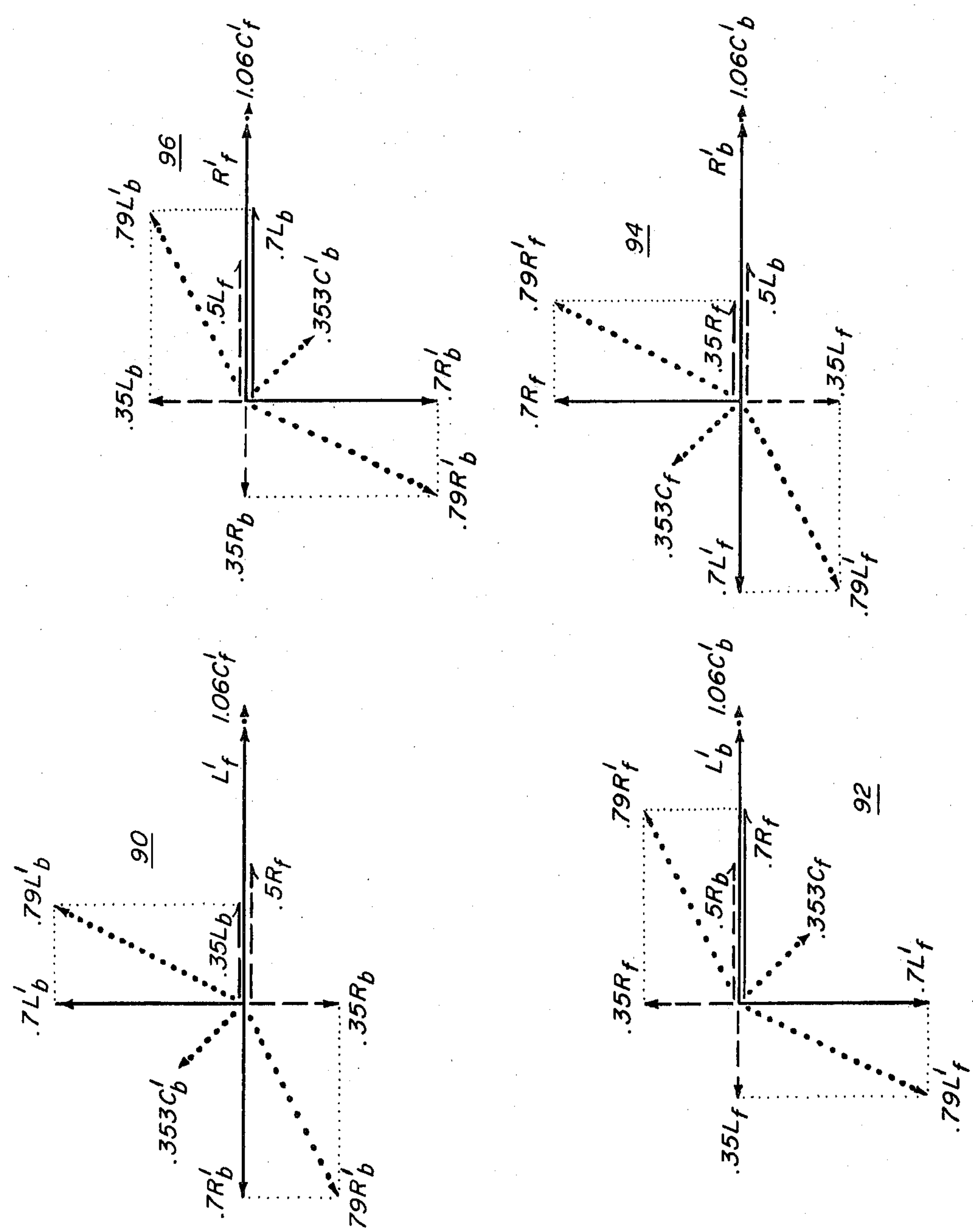

FIG. 6

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APPARATUS FOR REPRODUCING QUADRAPHONIC SOUND

CROSS-REFERENCE TO OTHER APPLICATIONS

This invention is related to the subject matter of the following co-pending applications all of which are assigned to the assignee of the present application: Ser. No. 44,196, filed June 8, 1970, now abandoned in favor of continuation Ser. No. 251,544, filed Apr. 12, 1972, which in turn has now been abandoned in favor of continuation-in-part application Ser. No. 328,814 filed Mar. 10, 1973, which has also been abandoned in favor of continuation-in-part application Ser. No. 384,334 filed July 31, 1973; Ser. No. 81,858, filed Oct. 19, 1970, now abandoned in favor of continuation application Ser. No. 251,636, filed May 8, 1972; Ser. No. 112,168, filed Feb. 3, 1971, now Pat. No. 3,745,252; Ser. No. 118,271, filed Feb. 24, 1971; and Ser. No. 124,135, filed Mar. 15, 1971.

BACKGROUND OF THE INVENTION

This invention relates to systems for recording and reproducing four separate channels of information on a medium having only two independent tracks, and more particularly to apparatus for reproducing such information and presenting it on four loudspeakers to give the listener the illusion of sound coming from a corresponding number of separate sources. More particularly, the present invention is concerned with a decoder for improving the realism of sound decoded from a matrixed quadraphonic record, recorded on a two-track medium in accordance with the method described in aforementioned co-pending application Ser. No. 124,135 and similar systems.

Briefly, in a matrixed quadraphonic record, four usually independent channels, L_f, L_b, R_f and R_b, which are intended to be reproduced on respective loudspeakers positioned at the left front, left back, right front, and right back corners, respectively, of a room or listening area, are combined into two channels by a device known as a quadraphonic encoder. A suitable encoder for this purpose is illustrated in FIG. **8** of the aforementioned application Ser. No. 124,135, but it is to be understood that the decoder to be descried herein is operative to reproduce signals encoded with encoders of other configurations, for example, the encoder described in co-pending application Ser. No. 384,334. The encoder produces two composite signals that can be recorded on a two-track medium, such as magnetic tape or a disc record, utilizing conventional recording techniques. The two output channels, which for convenience will hereinafter be designated R_T and L_T (for total or transmitted left and right signal, respectively) may be recovered from a phonograph record with a conventional phonograph pickup, or alternatively, transmitted directly from the encoder, and applied to a decoder which transforms them into four new signals, predominant components of which correspond to the original signals L_f, L_b, R_f and R_b applied to the encoder, except that they may have a different phase orientation than the original signals.

An essential feature of the decoder is a combination of all-pass phase-shifting networks, usually employed in groups of two or more, for positioning the components of the two composite signals to permit combination thereof by addition and subtraction. Each network of a group has a basic phase-shift angle, Ψ, which is a function of frequency, and an incremental angle, Δ, which is essentially constant over the frequency range of interest. The angle Δ is normally zero to 90°, although it will be evident from the description to follow that other values may be used with equivalent results.

The nature of the encoded signals, and the significance of the phase-shifting networks, will be better understood from a brief description of the encoder illustrated in FIG. **8** of the aforementioned application Ser. No. 124,135, which is repeated herein as FIG. **1.** The encoder has four input terminals **10, 12, 14** and **16** to which four input signals L_f, L_b, R_f and R_b, depicted as in-phase signals of equal amplitude, are respectively applied. The total L_f signal is added in a summing junction **18** to −0.707 of the R_b signal, the output of this summing junction being applied to a phase-shifting network **20** which introduces a reference phase-shift Ψ which, as was noted earilier, is a function of frequency. The full R_f signal at terminal **16** is added in summing network **22** to .**707** of the L_b signal appearing at input terminal **12,** and the output passed through the ψ-network **24,** which also provides the reference phase-shift ψ. The L_b and R_b signals are also applied to respective ψ-networks **26** and **28,** each of which provides a phase shift of $\psi + 90°$. It should here be noted that the angular notation used refers to lagging angles, but as long as there is consistency in notation, it makes no difference to the operation of the system whether the angles are lagging or leading. The full signal appearing at the output of network **20** is added in a summing circuit **30** to −0.707 of the signal appearing at the output of network **26** to produce at its output terminal **32** a composite signal designated L_T. Similarly, the full signal from network **24** is added in summing junction **34** to 0.707 of the signal from network **28,** the latter in this case being in the positive sense. The signal appearing at the output terminal **36** is the composite signal R_T. The signals L_T and R_T may be recorded on any two-channel medium such as a two-track tape or stereophonic record for later reproduction, or may be transmitted by FM multiplex radio.

The composite signals appearing at output terminals **32** and **36** are portrayed as phasor groups **38** and **40,** respectively, which may be characterized in complex notation, as follows:

$$L_T = L_f - 0.707R_b + j0.707L_b \qquad (1)$$

and

$$R_T = R_f + 0.707L_b - j0.707R_b \qquad (2)$$

In the interest of providing better realism of image placement when the record is played on a conventional stereophonic phonograph over two loudspeakers, it is preferable that the phasor $0.707L_b$ in phasor group **40** lags behind the similarly numbered phasor in phasor group **38,** and conversely, to arrange phasor $0.707R_b$ in phasor group **38** to lag behind the corresponding phasor in group **40.**

Co-pending application Ser. No. 118,271 describes a system for decoding of the signals L_T and R_T depicted in FIG. **1,** in which they are respectively applied to a pair of phase-shifting networks, one network of each pair introducing a phase-shift of $(\psi + 0°)$, and the other network of each pair introducing a phase-shift of $(\omega + 90°)$. By reason of the relative 90° phase-shift, the two phasor groups appearing at the outputs of the ψ-networks to which the L_T signal is applied are in quadrature relationship, as are the two phasor groups appearing at the outputs of the ψ-networks to which the R_T signal is applied. Thus, the phasors at the outputs of the four ψ-networks are properly positioned for selective addition and subtraction to derive four separate output signals predominantly containing the original signals L_f, L_b, R_b and R_f, respectively, for reproduction over four corresponding loudspeakers. These decoded signals are not "pure" or discrete original signals, however, each being "diluted" by two other signals. Nevertheless, when all four channels of the original program contain musical signals in concert, and the four decoded signals are reproduced over respective loudspeakers placed in the corners of the room or listening area, then as far as the listener is concerned there is sufficient "mixing" of the sounds in the room that the resulting overall sound effect is quite similar to the sound of the original four discrete channels, and a credible simulation of the original four-channel program results.

There are situations, however, in which it is desirable to provide the illusion of greater independence or purity of the decoded signals; for example, when the original sound is present in one or two channels only, it is desirable to automatically attenuate the gain in those channels which originally are inactive, thereby to enhance the separation of the channels which are present. It is also desirable that the decoder distinguish between front and back, especially as it relates to the center front and center back signals. Three different logic and control systems for achieving signal enhancement are described in co-pending applications Ser. Nos. 384,334 and 251,636. It is a primary object of the present invention to obtain greater quadraphonic realism than that attainable with previously described methods while, at the same time, simplifying the circuitry for accomplishing it.

SUMMARY OF THE INVENTION

The foregoing and other objects of the invention are achieved according to one aspect thereof, by an improved logic for controlling the gains of the four output amplifiers of the decoder in response to signals appearing in the decoder to enhance the realism of the four-channel reproduction. It being a characteristic of the decoder that regardless of the bearing of a signal originally applied to the encoder, upon reproduction the predominant signal appears at the output of the correct loudspeaker and unwanted side effect signals from other channels associated therewith are equal and either in-phase or in quadrature phase relationship, the logic is designed to compare the voltages in adjacent channels and to derive control signals for reducing the gains of the output amplifiers for such channels whenever the voltages are in-phase or in quadrature phase condition, thereby to eliminate the side-effect signals. That is, the logic senses the presence of side-effect signals and causes the gains of the appropriate output amplifiers to be correspondingly increased so that the total accustical power contributed by the active loudspeakers resmins unchanged.

Substantially constant amplitude signals for comparison of the voltage in adjacent channels, regardless of changes in level of the program, are obtained by applying a pair of signals derived from the decoder respectively corresponding to the composite input signal R_T and the composite signal L_T shifted by 90° from its input phase condition, to respective gain control amplifiers which include means for maintaining the amplitude of their outputs substantially constant. The output signals from these auxiliary gain control amplifiers are selectively added and subtracted to produce two additional signals, also of substantially constant amplitude, resembling two signals produced in the decoder and ultimately applied to two of the four loudspeakers. The four signals thus produced are separately rectified and the resulting wave forms compared in pairs in a pair of subtracting junctions, for example, the outputs of the junctions again rectified, and one of the rectified outputs subtracted from the other two produce a signal of one polarity or the other indicative of the presence of side-effect signals. Signals of one polarity control in unison the gains of the gain control amplifiers associated with the two "front" loudspeakers, and signals of opposite polarity control the two "back" loudspeakers in unison.

The ability of the logic to discriminate between generally front and generally back signals is enhanced by comparing the substantially constant amplitude signal from one of the above-described gain control amplifiers, preferably the one to which the R_T composite signal is applied, with the output of a third auxiliary gain control amplifier (which also has a substantially constant amplitude output) to which the L_T composite signal is applied. The comparison is made by obtaining the sum and the difference of the two outputs, separately rectifying the sum and difference signals, and obtaining the difference of the two rectified signals. That portion of the latter difference signal which exceeds a predetermined level is added to the control signal generated by the wave-matching logic described in the preceding paragraph for application to the output gain control amplifiers.

In accordance with another aspect of the invention, the front-to-back discrimination of the decoder is enhanced, without the use of a logic and control circuit, by blending or mixing the signals in some of the output channels of the matrix decoder with signal in some of the other channels. More particularly, a fraction of the signal in the "left front" channel is added to the "right front" signal, and a like or different fraction of the signal in the "right front" channel is muxed with the "left front" signal. Similarly, fractions of the signals in each of the "left back" and "right back" channels are intermixed with the full signal in the other.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects, features and advantages of the invention, and a better understanding of its construction and operation, will be had from the following detailed description, taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a schematic diagram of an encoder for encoding four original sound signals into two composite signals, to which reference has already been made in discussing the background of the invention;

FIGS. 2A and 2B taken together is a schematic diagram of decoding apparatus embodying the invention;

FIG. 3 is a plot of the output of the front-back logic circuitry of the system of FIG. 2 as a function of "panning" a constant signal around a circle;

FIG. 4 is a plot of the output of the wave-matching logic of the system of FIG. 2 as a function of "panning" a constant signal throughout a circle;

FIG. 5 is a plot of the values of the phasors for the four channels as a function of the bearing angle for eight positions of a panned signal; and

FIG. 6 is a series of phasor diagrams useful in explaining the operation of the channel intermixing feature of the decoder of FIG. 2.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The decoder of the present invention, illustrated in FIG. 2, is similar in many respects to the decoder described in aforementioned application Ser. No. 384,334 certain details of which, in turn, are described in application Ser. No. 118,271. The input signals to the decoder, designated L_T and R_T and depicted by the phasor groups **38** and **40**, respectively, are applied to respective input terminals **42** and **44**. The L_T signal is applied in parallel to a pair of all-pass phase shifting networks **46** and **48** which introduce phase shifts of ($\psi + 0°$) and ($\psi + 90°$), respectively, and the R_T signal is similarly applied to a pair of all-pass networks **50** and **52** which provide phase shifts of ($\psi + 90°$) and ($\psi + 0°$), respectively. The four phase-shift networks are operative to produce four signals at the output terminals or leads **54, 56, 58** and **60**, depicted by the phasor groups **62, 64, 66** and **68**, respectively. To distinguish these signals from the encoded input signals, and to signify that they have passed through a set of phase-shift networks with a common phase-shift ψ, the designations of the components of the phase-shifted signals are primed.

The signals appearing on conductors **56** and **60** are each multiplied by the coefficient 0.707 and added together at a summing junction **70** to produce a new signal at the output terminal **71** thereof, while the signals on conductors **54** and **58** are multiplied by the coefficient −0.707 and added together in a summing junction **72** to produce a second new signal at its output terminal **73**. In the decoder described in application Ser. No. 118,271, the signals on conductors **54, 71, 73** and **60** are amplified by amplifiers **74, 76, 78** and **80**, respectively, and applied to corresponding loudspeakers **82, 84, 86** and **88** where they are reproduced as sounds which correspond to the configuration of phasor groups **90, 92, 94** and **96**, respectively.

In accordance with one aspect of the present invention, applicant has recognized that quadraphonic realism can be improved by blending or mixing the outputs of some of the channels with the outputs of other channels before amplification. This blending operation is accomplished be means of four summing junctions **98, 100, 102** and **104** each of which is operative to add the signal from one channel to a fraction of the signal of another channel. More specifically, junction **98** adds a fraction, designated n, of the signal appearing on conductor **60** to the signal appearing on conductor **54**, the output of the summing junction being applied to amplifier **74**. Similarly, the junction **100** adds a fraction, n', of the signal on conductor **54** to the signal on conductor **60**, the sum being applied to amplifier **80**. Similarly, summing junction **102** adds a fraction, designated m, of the signal appearing on conductor **73** to the signal appearing on conductor **71** and applies the sum to amplifier **76**, and summing junction **104** adds a fraction, m', of the signal appearing on conductor **71** to the signal appearing on conductor **73** prior to application to amplifier **78**. It is convenient, and satisfactory in many circumstances, to make the fractions n, n', m and m' equal, but they may be of differing values in others. In general, it has been found that beneficial results are obtained by choosing values for the fractions m and n between 25 and 50 percent, it being understood, however, that other fractional amounts may be used. It should be pointed out at this juncture that the phasor groups **90, 92, 94** and **96** are, for clarity, shown for the condition where the fractions m and n are zero, that is, for a matrix without "blend", and that the logic and control circuitry to be described hereinbelow, which is an extension of the control circuitry described in co-pending applications Ser. Nos. 118,271 and 124,135, can be used with a decoding matrix with or without "blend"; the effect on the corresponding phasor groups of intermixing some of the left output into the right channel and vice versa, in both the front and back sets of loudspeakers, will be described later with reference to FIG. 6, following a description of the balance of the system of FIG. 2.

It will be noted that the phasor groups **90, 92, 94** and **96** which characterize the sounds emanating from the four loudspeakers **82, 84, 86** and **88**, respectively, and which are usually placed in a listening room or area so that the signals L_f', L_b', R_b'' and R_f'' are localized at the left front, left back, right back and right front corners, contain dominant signals L_f', L_b', R_b' and R_f'; however, they each also contain diluting or side-effect signals from two other channels. Although these side-effect signals are relatively unobjectionable in the thus far described matrix configuration, the perfection of quadraphonic sound reproduction is enhanced if the gains of those channels which contain only side-effect signals are controllably diminished. This can be accomplished by using gain controlled amplifiers instead of fixed gain amplifiers for amplifiers **74, 76, 78** and **80** and varying the gains thereof in response to a control voltage derived by an electronic logic system. A number of different forms of electronic logic for this purpose are described in certain of the above-mentioned co-pending applications. The present invention, in another aspect thereof, is concerned with an improved and simplified logic which will now be described in the environment of the improved matrix illustrated in FIG. 2A.

Referring now to FIG. 2B, the electronic logic according to the present invention is operative to develop control signals for the gain control amplifiers by operating on three signals developed in the matrix of FIG. 2A, preferably the signals appearing on conductors **60, 56** and **54**. The reasons for selecting these three in preference to others will become evident as the description proceeds. To insure that the signals to be operated upon by the logic are relatively uniform regardless of the signal strength of the program being reproduced, the signals from conductors **60, 56** and **54** are first coupled through respective, substantially identical high pass filters **110, 112** and **114** designed to reject frequencies below about 50Hz-frequencies which normally should not be involved in the logic action. The transmission characteristic of the filters above the cut-off point is preferably adjusted so as to optimize the logic control action in accordance with the sensitivity of the ear to the loudness of various sounds. The signals delivered by the filters are applied to the input terminals of respective gain control amplifiers **116**, **118** and **120** which have identical or closely similar gain versus control voltage characteristics. It will be observed that the signals from conductors **60** and **56** applied to amplifiers **116** and **118**, respectively, are obtained from the outputs of all pass phase-shift networks **52** and **48**, respectively, whereby corresponding components of the R_T and L_T composite signals are shifted in phase relative to each other by 90°. This phase relationship permits the signals delivered by gain control amplifiers **116** and **118** to be added and subtracted to derive two new signals having properties advantageous to the desired performance of the logic. Specifically, 0.707 of each of the signals from amplifiers **116** and **118**, appearing at terminals **130** and **132**, respectively, are added in a summing junction **122** to produce at its output a new signal represented by the phasor group **124**, in which the component L_b' is predominant. Similarly, −0.707 of the signal from amplifier **118** is added in another summing junction **126** to 0.707 of the signal from amplifier **116** to produce at its output terminal another new signal represented by the phasor group **128**, in which the component R_b' is predominant. At the same time, the predominant component of the signals appearing at terminals **130** and **132** are R_f' and L_f', respectively.

The four signals just described are rectified by respective rectifiers **134**, **136**, **138** and **140**, which are preferably full-wave rectifiers, each of which includes respective time constant circuits **142**, **144**, **146** and **148**, each designed to provide a rapid attack time, of the order of about 1 millisecond, and a relatively slower decay time, of the order of about 20 milliseconds. The four rectified signals are added together in a summing junction **150** and the sum signal is applied to the control electrodes **116a**, **118a** and **120a** of gain control amplifiers **116**, **118** and **120**. Application of the sum of the rectified signals in the illustrated feedback relationship automatically and simultaneously adjust the gains of the amplifiers in response to changes in the strength of the signals being processed, thereby to maintain the amplitude of the rectified signals essentially constant.

It will be noted that although only the signals from amplifiers **116** and **118** are used to develop the gain control voltage, the same gain control voltage applied to the control electrode **120a** of amplifier **120** also maintains its output level essentially constant.

Although a particular circuit arrangement has been described for feeding information back to the gain control amplifiers **116**, **118** and **120** so as to obtain a constancy of output signals, it will be understood that other techniques can be used for this purpose without departing from the spirit of the invention. For example, it is possible to use a single time constant element for all four of the rectified signals, and/or an OR gate may be used to select the strongest of the four signals for application to the control electrodes of the three gain control amplifiers.

Summarizing the function of the control circuit thus far described, it selects for the logic operation the signals represented by phasor groups **68**, **64** and **62** and maintains them all at a relatively constant level. It will be observed that in two of these phasor groups, namely, in groups **68** and **64**, the signal components 0.707 L_b' and 0.707R_b' are either in phase coincidence or in phase opposition; consequently, as taught in applicant's co-pending application Ser. No. 118,271, the disclosure of which is hereby incorporated by reference, these signals can be utilized in a wave-matching arrangement to ascertain if either an L_b' or an R_b' signal component is present. Also, as has already been noted when these two signals are added and subtracted in junctions **122** and **126**, two new signals, represented by phasor groups **124** and **128**, are obtained in which the components 0.707L_f' and 0.707R_f' are also either in phase coincidence or in phase opposition, and thus can be used to ascertain if an L_f' or an R_f' signal component is present in the circuit.

Following the principles of the wave-matching technique described in application Ser. No. 118,271 for ascertaining the presence in the circuit of L_b', R_b', L_f' or R_f' signal components, four signals that are applied to rectifiers **134**, **136**, **138** and **140** to develop the gain control signal are also applied to rectifiers **152**, **154**, **156** and **158**, respectively, which are preferably full-wave rectifiers and the rectified outputs therefrom then subtracted in pairs in subtracting junctions **160** and **162**. Specifically, the rectified signal appearing at terminal **132** is subtracted in junction **160** from the rectified signal appearing at terminal **130** and the rectified signal represented by phasor group **124** is subtracted in junction **162** from the rectified signal corresponding to phasor group **128**.

It will be noted that rectifiers **152–158** are shown as not having resistor and capacitor time constant circuits; this is deliberate to indicate that these rectifiers desirably have a short time constant. In fact, if ideal phase-shift networks were available, no time constant elements would be required because the waves to be matched would be in perfect alignment with each other; however, because of circuit imperfections, these rectifiers may be designed to have a relatively short time constant, of the order of a fraction of a millisecond to a few milliseconds, which may, in fact, be provided by the capacitance of the circuit leads.

The output signals from junctions **160** and **162** are again rectified by rectifiers **164** and **166**, respectively, (which preferably are also full-wave rectifiers) having associated time constant circuits **168** and **170** the resistance and capacitance values of which are selected to provide a rise time of the order of 1 millisecond and a decay time of the order to 20 milliseconds. It should be understood, however, that wide variations in these values may be used without substantially affecting the operation of the invention. The output signal from rectifier **166** is subtracted in a subtracting junction **172** from the output signal from rectifier **164** and the difference signal appearing at its output terminal **174**, which represents the contribution of the wave-matching logic to the control signals for the gain control amplifiers **74–80** in FIG. **2A**, is applied as one input to a summing junction **176**.

To briefly review the action of the wave-matching logic (which is decribed in detail in co-pending application Ser. No 118,271), if, for example, either or both of the L_f or R_f signals are present, since they would be present in precisely equal amounts at the outputs of junctions **122** and **126**, the wave-matching of the rectified signals in junction **162** would result in a zero signal output. At the same time, since the L_f and R_f signals at the terminals **130** and **132** are completely different and incoherent, wave-matching of the rectified signals applied to junction **160** will not cause cancellation, and an output would be produced. For this signal condition, then, rectification of the outputs of junctions **160** and **162**, and subtraction thereof in junction **172**, will produce a positive signal at terminal **174**. Other signal conditions may result in correlation and cancellation in junction **160** so as to produce zero output therefrom, while at the same time the signals applied to junction **162** may be incoherent and thus produce an output signal, with the consequence that the output signal from junction **172** would be of negative polarity. The signal delivered by junction **172** (which may be positive or negative) applied to one input of summing junction **176** (the second input to which will be subsequently described) and the output thereof is applied in parallel to transmission elements **178** and **180**.

Transmission element **178** is a network that is operative to transmit a control signal therethrough without change in sign and has a transfer function designed to avoid overloading the controls of the gain control amplifiers **74–80**. Transmission element **180** is similar to transmission element **178** except that it includes means for inverting the sense of signals applied to it. Therefore, the signals delivered by transmission element **178** and **180** in response to a given input signal are of the same magnitude but of opposite polarity. The output signal from transmission element **178** is applied via conductor **179** to the control electrodes of gain control amplifiers **74** and **80**, and the output of transmission element **180** is applied over conductor **181** to the gain control electrodes of amplifiers **76** and **78**. Thus, a positive signal appearing at the output of junction **176** passes through transmission element **178** without change of sign, and upon application to the control electrodes of amplifiers **74** and **80** increases their gains and enhances the signals L_f' and R_f'' emanating from loudspeakers **82** and **88**, respectively. At the same time, the positive signal at the output of junction **176** is inverted by transmission element **180** with the consequence that when it is applied to the control electrodes of amplifiers **76** and **78**, the gains thereof are decreased, thereby to attenuate the side-effect signals in their associated loudspeakers **84** and **86**. Conversely, when either one or both of signals L_b' or R_b' are present, there is a net control voltage at the output of rectifier **166**, and a zero voltage at the output of rectifier **164**, resulting in a negative control signal at the output terminal **174** of junction **172** (and **176**). The positive control signal resulting from inversion in transmission element **180** when applied to the control electrodes of amplifiers **76** and **78** increases their gains and enhances the signals L_b'' and R_b'' reproduced by loudspeakers **84** and **86**. At the same time, the negative control signal from junction **176**, applied without change of sign through transmission element **178** to the control electrodes of amplifiers **74** and **80**, reduces the gain of the front loudspeakers.

The gain control amplifiers **74–80** preferably have time constants such as to permit relatively rapid increase in gain in response to application of positively going control signals and a relatively slow decrease in gain when the gain control signal decreases, in accordance with the teaching of applicant's aforementioned co-pending application Ser. No. 118,271.

The action of the present wave-matching logic is as described in application Ser. No. 118,271 except for the utilization of automatic gain control amplifiers **116** and **118** to provide signals of substantially constant amplitude for wave-matching, and the manner in which the output signal from the wave-matching logic interacts with the output of a second logic circuit for providing improved separation between front and back signals, now to be described.

The front-back logic utilized in the present system is similar in some respects to the front-back logic described in applicant's aforementioned co-pending application Ser. No. 124,135, and the disclosure thereof is hereby incorporated by reference. The signals for the front-back logic are derived from the outputs of automatic gain control amplifiers **116** and **120**, one of which it will be noted is common with one of those used to derive the signals for the wave-matching logic, and which provide relatively constant level output signals corresponding to the phasor groups **68** and **62**, respectively. It will be noted that L_f' and R_f' signals in these two phasor groups are in phase with the consequence that if a front center signal is applied to the L_f and R_f terminals of the encoder of FIG. **1**, equal amounts of such a front center signal would appear coincident with the L_f' and R_f' component signals in these phasor groups. As described in co-pending application Ser. No. 124,135, addition and subtraction of these phasor groups, under the circumstance in which there is a center front signal present, causes a greater total signal upon addition and a smaller total signal upon subtraction. In contrast, if a center back signal were to be applied to the terminals L_b and R_b of the encoder of FIG. **1**, such signals would appear out of phase in phasor groups **62** and **68** with the result that a smaller total signal results upon addition and a larger total signal is obtained upon subtraction. These differences in the magnitude of the output signals are utilized, in keeping with the teachings of application Ser. No. 124,135 to ascertain whether there is a center front or a center back signal in the composite signals R_T and L_T to be decoded.

To this end, the output signals from gain control amplifiers **116** and **120** are applied to the two inputs of an adding junction **190**, and also to the two inputs of a subtracting junction **192** in which the signal from the amplifier **116** is subtracted from the signal appearing at the output of amplifier **120**. The sum signal appearing at the output terminal **194** of the summing junction, and the difference signal appearing at the output **196** of the subtracting junction, are rectified by respective rectifiers **198** and **200** (which are preferably full-wave rectifiers) which may be provided with time constant circuits **202** and **204**, respectively. The outputs of rectifiers **198** and **200** are applied to the positive and negative terminals, respectively, of subtracting junction **206** which produces a difference signal at its output terminal **208** which is available to perform a logic function.

The front-back logic circuit and its function thus far described is similar to that in co-pending application Ser. No. 124,135 with one important exception. In the earlier application the voltage input control of the front-back logic was provided with logarithmic amplifiers which, because of the limitations of practical amplifiers of this type limited the sensitivity and range of control that could be exercised with signals of widely varying levels. The use of automatic gain control amplifiers **116** and **120** to keep the signal level at a high, substantially constant value greatly enhances the action of the front-back logic.

The present embodiment of the front-back logic also differs from the previously described embodiment in the significant respect that the output of subtracting junction **206** is applied to a parallel back-to-back junction of rectifiers **210** and **212**, and the output of this junction after suitable amplification by an amplifier **214**, applied to the other terminal of summing junction **176**. The rectifiers **210** and **212** are appropriately biased (not shown) to function as a "slicer" to permit only front-back control signals exceeding a predetermined amplitude to be applied to the junction **176**. The purpose and operation of this "slicing" action will now be explained.

To better understand the need for the slicer and its proper adjustment, it should be kept in mind that the front-back control logic should act properly not only with center front and center back signals, but also must not introduce undesirable actions for other types of signals that might be present in the composite signals L_T and R_T applied to the decoder. Consider, for example, a signal panned around the four corner terminals of the encoder of FIG. **1**. The effect of such a signal can be calculated by taking into account the fact that a center front (or 0° bearing) signal C_f appears as $0.707C_f$ at both the left front (L_f) and right front (R_f) input terminals of the encoder. As the signal is panned to the right, the left front signal drops to zero and the right front signal increases to unity, following the cosine and sine laws, respectively. As panning continues from front right to back right, the signal input into the front channel of the encoder decreases according to the cosine law, while the input to the right back channel increases following the sine law, and so forth, as the signal is panned from back right to back left to front left. The total signal power into the encoder remains constant, since the sum of sine squared and cosine squared equals one. The amplitudes of the signals developed at the terminals L_T and R_T of the encoder for an input signal panned in this way have been calculated; this information permits the output voltage produced by the front-back logic to be calculated. The results of these calculations are presented in the following TABLE I in which:

a. The first column is the bearing angle of panning in degrees, with 0° corresponding to center front; 45° to right front; 135° to right back; and 180° to center back, etc.

b. The second column gives the relative signal voltage at the L_T terminal and its phase position.

c. The third column gives the relative signal voltage at the R_T terminal and its phase position.

d. The fourth column gives the absolute value of the phasor sum of the left and right signals L_T and R_T.

e. The fifth column gives the absolute value of the phasor difference of L_T and R_T (absolute values are used in the computation since the phasors are rectified prior to subtraction, this being tantamount to obtaining an absolute value.

f. The sixth column gives the difference between the sum and difference columns (this corresponds to the signal at the output of subtracting junction **206** in FIG. **2B**).

TABLE I

Bearing angle	L_T output	R_T output	$\lvert L_T+R_T \rvert$	$\lvert L_T-R_T \rvert$	$\lvert L_T+R_T \rvert - \lvert L_T-R_T \rvert$
0°	.707 at 0°	.707 at 0°	1.414	0.00	+1.414
22.5	.383 - 0	.924 - 0	1.307	.54	+.766
45	0 - 0	1.000 - 0	1.000	1.000	.0
67.5	.271 - 180	.963 - 16.3	.707	1.225	−.518
90	.500 - 180	.866 - 35.2	.542	1.305	−.763
112.5	.635 - 180	.757 - 59.6	.707	1.225	−.520
135.0	.707 - 180	.707 - 89.9	1.000	1.000	0
157.5	.707 - 202.6	.707 - 67.4	.540	1.305	−.765
180	.707 - 225.1	.707 - 44.9	0	1.414	−1.414
202.5	.707 - 247.6	.707 - 22.5	.540	1.305	−.768
225	.707 - 270.1	.707 - 0	1.000	1.000	0
247.5	.757 - 300.5	.653 - 0	1.225	.707	+.518
270.0	.866 - 324.8	.500 - 0	1.305	.541	+.764
292.5	.963 - 343.7	.271 - 0	1.225	.707	+.518
315.0	1.000 - 0	.000 - 0	1.000	1.000	0
337.5	.924 - 0	.383 - 0	1.307	.541	+.766
360.0	.707 - 0	.707 - 0	1.414	0	+1.414

The data presented in TABLE I are plotted in FIG. **3**, in which the solid-line circle represents signals of unity amplitude. It is seen that the plot contains two large lobes **220** and **222** centered about 0° and 180°, respectively, and two smaller lobes **224** and **226** centered about 90° and 270°, respectively. The two larger lobes, which have maxima of 1.414, are properly positioned to act in a logical manner to emphasize respective front or back center signals; however, the smaller lobes at 90° and 270° are undesirable and, in fact, deleterious to front-back logic action since they would tend to displace a side signal to the front or rear, depending upon the direction of arrival of the signal, obviously an undesirable result. Accordingly, the influence of the side lobes **224** and **226** is desirably eliminated, this being accomplished by the slicer arrangement of diodes **210** and **212** in which the diodes are properly biased to form a voltage barrier operative to suppress all signals which are equal to or smaller in amplitude than the maximum amplitude of the side lobes. The action of the slicer is depicted by the dash-line circle **228**, which signifies that all signals lower in amplitude than that represented by the circle are suppressed. Since the slicing action also reduces the amplitude of the desired main lobe signals, it may be necessary to amplify the output from the slicer in amplifier **214** before application to the summing junction **176**.

By a similar calculation, the voltage generated at the output terminal **174** of the wave-matching logic has been calculated and the results plotted in FIG. **4**. As in the FIG. **3** plot, the solid line circle **230** represents unity voltage, and it is seen that there are four symmetrical lobes **232**, **234**, **236** and **238** each having a maxima of unity and centered at 45°, 135°, 225° and 315°, respectively. Superimposed on the plot, in dash-lines, are those portions of the lobes **220** and **222** (FIG. **3**) not suppressed by the slicer, identified by reference numerals **220'** and **222'**, respectively. It will be noted that the latter lobes effectively "fill" the null spaces between the lobes of the signals from the wave-matching logic for front and back signal orientations. It may here be noted that the gain of amplifier **214** is adjusted so that the coaction of the wave matching logic with the front back logic is properly matched. Thus, the sum of the signal produced by the wave-matching logic (the action of which on the gain control amplifiers **74–80** has been described previously) has added to it in junction **176** the signals from the front-back logic represented by lobes **220'** and **222'**. The resulting sum signal is applied through transmission elements **178** and/or **180** to the control electrodes of the gain control amplifier to achieve enchanced separation between front and back signals.

It will be noted from the phasor diagrams **90–96** in Fig. **2A** that the matrix decoder system is completely symmetrical. This symmetry helps to preserve the balance, say, between the primary sound energy on a concert stage and the perceived energy of the hall. This important aspect of symmetry can also be noted when the signals from TABLE I are applied to the decoder. The following TABLE II gives the relative voltages and phase angles of the signals appearing at the outputs of the four loudspeakers **82–88.** Not shown in the table is the fact that the total power level remains completely constant at 3dB level regardless of the bearing angle of the panned signal.

TABLE II

Bearing angle	Left front output	Left back output	Right front output	Right back output
0	.707 at 360°	.707 at 315.4°	.707 at 360°	.707 at 134.6°
22.5	.383 - 360	.707 - 337.7	.924 - 360	.707 - 112
45	.000 - 360	.707 - 360	1.000 - 360	.707 - 269.5
67.5	.271 - 180	.653 - .0	.963 - 343.8	.757 - 59.2
90	.500 - 180	.500 - .0	.866 - 325.1	.866 - 35
112.5	.653 - 180	.271 - .0	.757 - 301.1	.962 - 16.3
135	.707 - 180	.001 - .0	.707 - 270.9	1.000 - .1
157.5	.707 - 157.1	.383 - .0	.707 - 293.3	.923 - .0
180	.707 - 134.4	.707 - .0	.707 - 315.6	.706 - .0
202.5	.707 - 111.7	.924 - .0	.707 - 337.8	.381 - .0
225	.707 - 89.1	1.000 - 360	.707 - 360	.001 - 180
247.5	.757 - 58.9	.962 - 343.8	.653 - 360	.272 - 179.9
270	.866 - 34.8	.866 - 325	.500 - 360	.501 - 179.9
292.5	.963 - 16.1	.757 - 300.8	.271 - 360	.654 - 179.9
315	1.000 - 360	.707 - 270.6	.000 - 360	.707 - 180
337.5	.924 - 360	.707 - 293.1	.383 - 360	.707 - 157.3
360	.707 - 360	.707 - 315.4	.707 - 360	.707 - 134.6

It will be noticed that for 45°, 135°, 225° and 315° bearings, which correspond to the R_f, R_b, L_b and L_f inputs, respectively, the relative voltages at the corresponding loudspeakers are unity, while those in the opposite loudspeakers are at 0.707, which corresponds with the values shown in phasor diagrams **90–96** in FIG. **2A**.

Amplitudes the phasors of the signals from TABLE II are depicted in FIG. **5** for eight positions of the panning control, spaced 45° apart. The direction of the arrows in the central square refer to the panning position (that is, the arrow labeled 0° represents a center front signal, which would be applied equally to the left front and right front channels, and the 180° position would represent a center back signal which would be applied equally to the left back and right back channels), and the arrows appearing in each of the eight surrounding squares, reading clockwise from the upper left-hand corner of each square, represent the relative amplitude and phase of the left front, right front, right back and left back signal components. Thus, in the square labeled R_f, with the panning position at 45° the left front signal at the output terminal of the right front channel is zero, the right front signal is of unity amplitude, the right back signal is at right angles to the right front signal and has a relative amplitude of 0.707, and the left back signal also has a relative amplitude of 0.707 and is in phase with the right front phasor and at right angles to the right back phasor. It will be noted that this phase relationship between the component signals is the same as shown in phasor group **96** in FIG. **2A**, and that the phasors appearing in the squares labeled R_b, and L_b and L_f correspond to phasor groups **94, 92** and **90,** respectively. Starting, for example, with the 0° position, (corresponding to the center front signal) it is seen that the desired signals at the front loudspeakers are equal and in phase, while the undesired side-effect signals are equal and out-of-phase. If the latter two signals are attenuated, then only the desired front signals remain. Moving next to the 45° position, which corresponds to input to the right front channel, it is noticed that the side-effect signals are equal and at 90° to each other. At the 90° positions, the desired signals are of equal amplitude (0.866) and are within 70° of each other, while the side-effect signals in both cases are equal and out-of-phase. Upon examination of the remaining positions it will be seen that in every case the unwanted signals are equal and either in quadrature or out-of-phase relationship. This diagram illustrates, then, that a logic designed to compare the voltages in adjacent channels and to control the gain of the output amplifiers for such channels to be attenuated whenever these voltages are in quadrature or in an out-of-phase condition, side-effect signals will be completely eliminated, while at the same time the wanted signals are properly emphasized. This is precisely the action of the combined wave-matching logic and the front-back logic described above.

With the background provided by the diagram of FIG. **5,** reference is again made to FIG. **2A** for explanation of the function of the blending or adding junctions **98, 100, 102** and **104.** It has been seen from FIG. **5** that the magnitudes of signals in all four loudspeakers are the same for the 0° and 180° panning positions, which correspond to the center front and center back signals into the encoder, respectively. This is not of consequence when logic circuitry is used with the matrix decoder to suppress the unwanted side-effect out-of-phase signals, but in the interest of providing a lower cost decoder (one not having logic and control circuitry), it is desirable to improve the front-to-back discrimination of the matrix itself. The manner in which this is accomplished may be seen from FIG. **6** where the phasors **90–96** are reproduced, in solid lines, and enlarged to show more detail, and the dash-line phasors are the ones resulting from cross-blending portions of the phasors from L_f'' into R_f'', and vice versa, and from cross-blending portions of the phasors from L_b'' into R_b'', and vice versa. The amount of cross-blend illustrated in FIG. **6** is 50 percent, primarily for clarity of illustration, the usual amount of blending being in the vicinity of 25 and 30 percent for *m* and *n*. Thus, considering the upper left-hand phasor diagram, it will be seen that the phasors $.35R_b$ and $0.35L_b$ and $0.5\ R_f$, each representing 50 precent of its corresponding phasor in phasor group **96**, have been superimposed in the same relative phase relationship. The phasors resulting from adding the solid and dash-line phasors are shown in dotted lines. For example, when solid line phasor $.7L_b'$ is added to dash-line phasor $.35L_b$, the dotted line phasor $.79L_b'$ results. It will be seen, also, that the cross-blending causes a center front signal to be increased to a value of $1.06C_f'$ in the two front channels, and a center back signal in the two front channels to be greatly diminished, namely, to $0.353C_b'$. Conversely, a center back signal is increased to $1.06C_b'$ in the back channels, and a center front signal C_f' is reduced in the back channels to $0.353C_f$. Thus it is seen that the intermixing of signals between channels by the junctions **98–104** establishes a front-to-back information differential even without the use of logic control circuitry. Moreover, the initial favorable positioning of the front and back phasors resulting from intermixing simplifies the task to be performed by logic circuitry and thus serves an important purpose whether used simply as a feature of the matrix decoder, or as a feature of a matrix decoder combined with more sophisticated, and consequently more expensive, logic and control circuitry.

It will be observed that since the matrix of FIG. **2A** is a linear additive device, and the cross-blending operation but another additive operation, the circuitry of the matrix may be simplified somewhat without degrading the above-described operation. For example, since the input to gain control amplifier **76** is composed of

$$0.707E_{56} + 0.707E_{60} - 0.707mE_{54} - 0.707mE_{58} \quad (3)$$

and the input to amplifier **78** is

$$-0.707E_{54} - 0.707E_{58} + 0.707mE_{56} + 0.707mE_{60} \quad (4)$$

junctions **70** and **72** can be designed to perform the required operations thereby to eliminate the need for junctions **102** and **104.**

Although a preferred embodiment of the invention has been illustrated and described, various modifications will now be suggested to ones skilled in the art. For example, although the front-back logic of FIG. **2B** is best carried out with signal voltages derived from conductors **60** and **54**, and the wave-matching logic is best performed with signals derived from conductors **60** and **56**, somewhat less adequate wave-matching action can be obtained from voltages also taken from conductors **60** and **54**. It follows, therefore, that it is possible to operate both the wave-matching logic and front-back logic with but a single pair of gain control amplifiers, for example, amplifiers **116** and **120**, thereby to reduce the cost of the system. Although there would be some degradation in performance, this implementation might be commercially attractive for use in the less expensive sound reproducing systems.

I claim:

1. In apparatus for reproducing on separate loudspeakers four individual audio information signals contained in first and second composite signals each of which contains up to three of said audio information signals, two of which are common in said first and second composite signals and said common signals in said first composite signal being in substantially quadrature phase relationsiip with corresponding common signals in said second composite signal, the combination comprising:

matrix decoding means including

first and second input circuits to which said first and second composite signals are respectively applied, said input circuits including means for shifting the phase of one of said composite signals relative to the other by substantially 90° for positioning said common signals in one of said relatively phase-shifted composite signals either in phase coincidence of in phase opposition with corresponding ones of said common signals in the other of said relatively phase-shifted composite signals,

first, second third and fourth output channels,

means for coupling said first and second composite signals to said first and second output channels, respectively,

means for selectively combining predetermined proportions of said relatively phase-shifted first and second composite signals to produce third and fourth composite signals each containing a different one of said common signals as its predominant component, and

means for coupling said third and fourth composite signals to said third and fourth output channels, respectively;

means for combining predetermined fractions of the composite signals in said first and second output channels with the composite signals in said second and first output channels, respectively, operative to produce first and second composite output signals respectively containing different ones of two of said audio information signals as predominant components, and

means for combining predetermined fractions of the composite signals in said third and fourth output channels with the composite signals in said fourth and third output channels, respectively, operative to produce third and fourth composite output signals repsectively containing different ones of the other two of said audio information signals as predominant components.

2. Apparatus according to claim **1**, wherein the said fractions are equal.

3. Apparatus according to claim **1**, wherein the said fractions are unequal.

4. Apparatus according to claim **1**, wherein at least some of the said fractions have a value in the range of 0.25 and 0.35.

5. In apparatus for reproducing on separate loudspeakers four individual audio information signals L_f, R_f, L_b and R_b, respectively, to the extent they are contained in first and second composite signals L_T and R_T respectively containing dominant L_f and R_f component signals and each containing to the extent they are present sub-dominant L_b and R_b signal components with a phase-shift angle of substantially 90° between said L_b components and between said R_b components and with the L_b component in one of said composite signals leading the L_b component in the other and with the R_b component in said one composite signal lagging the R_b component in the other, the combination comprising:

matrix decoding means including

first and second input circuits to which said L_t and R_t composite signals are respectively applied, said first and second input circuits respectively including first and second pairs of all-pass phase-shifting networks to both of which the corresponding input signals is applied, a first phase-shifting network of each pair being operative to shift the phase of the applied signal by a predetermined reference angle and the second phase-shifting network of each pair being operative to shift the phase of the applied signal by an angle differing from said reference angle by substantially 90°,

first, second, third and fourth output channels adapted to be coupled to the loudspeakers positioned at the left front, right front, left back and right back corners, respectively, of said listening area,

means for coupling the composite signals from the first network of said first and second pairs, respectively containing said L_f and R_f components as predominant components, to said first and second output channels, respectively,

first means for combining substantially equal proportions of the composite signals from the second network of said first pair and from the first network of said second pair and for coupling to said third channel a composite signal containing said L_b component as its predominant component, and

second means for combining substantially equal proportions of the composite signals from the first network of said first pair and from the second network of said second pair and for coupling to said fourth channel a composite signal containing said R_b component as its predominant component;

means for combining predetermined fractions of the composite signals in said first and second channels with the composite signals in said second and first channels, respectively, to produce first and second composite output signals respectively containing said L_f and R_f components as predominant components; and

means for combining predetermined fractions of the composite signals in said third and fourth channels with the composite signals contained in said fourth and third channels, respectively, for producing third and fourth composite output signals respectively containing said L_b and R_b components as predominant components.

6. Apparatus according to claim **5**, wherein the said fractions are equal.

7. Apparatus according to claim **5**, wherein the said fractions are unequal.

8. Apparatus according to claim **5**, wherein at least some of the said fractions have a value in the range between 0.25 and 0.35.

9. Apparatus according to claim **5**, wherein said first, second, third and fourth output channels respectively include first, second, third and fourth gain control amplifiers connected for respectively coupling said first, second, third and fourth composite output signals to a respective loudspeaker, and further including a control circuit for controlling the gains of said gain control amplifiers to enhance the realism of the four channel sound reproduced by the loudspeakers, said control circuit comprising:

control signal generating means connected to receive composite signals from the second network of said first pair and from the first network of said second pair and operative to derive therefrom first, second, third and fourth auxiliary composite signals of substantially constant amplitude regardless of the amplitudes of said composite signals and respectively containing the information contained in the composite signals in said first, second, third and fourth channels,

first circuit means for comparing said first and second auxiliary composite signals and operative to produce a first signal indicative of whether they contain substantially equal amplitude signals in phase coincidence or in phase opposition,

second circuit means for comparing said third and fourth auxiliary signals and operative to produce a second signal indicative of whether they contain substantially equal amplitude signals in phase coincidence or in phase opposition, and

means for combining said first and second signals and operative to produce and apply to said gain control amplifiers a control signal for enhancing the gain of said first and second gain control amplifiers relative to said third and fourth gain control amplifiers when said first and second auxiliary signals do not contain said signal components L_b and R_b, and to enhance the gain of said third and fourth gain control amplifiers relative to said first and second gain control amplifiers when said third and fourth auxiliary signals do not contain said signal components L_f and R_f.

10. Apparatus in accordance with claim **9**, further including

means for comparing the sum and the difference of said first auxiliary signal and the composite signal from the first network of said first pair and operative to produce a second control signal of a given polarity or opposite polarity depending on whether the sum exceeds the difference, or vice versa, and

means for combining said second control signal with the control signal from said control signal generating means for application to said gain control amplifiers to enhance the separation between signals contained in said first or said second channels, or in both of said first and second channels, relative to signals contained in said third and said fourth channels, or in both of said third and fourth channels.

11. Apparatus according to claim **10**, wherein said last-mentioned combining means includes means for limiting the amplitude of said second control signal to a predetermined amplitude.

12. Apparatus according to claim **11**, wherein said control signal generating means includes

first and second auxiliary gain control amplifiers each having input and output terminals and a control electrode,

means coupling the composite signals from the second network of said first pair and from the first network of said second pair to the input terminals of said first and second auxiliary gain control amplifiers, respectively, said first and second auxiliary gain control amplifiers being operative to produce first and second auxiliary composite signals, respectively, at their respective output terminals corresponding to the composite signals applied thereto,

means connected to the output terminals of said first and second auxiliary gain control amplifiers for selectively combining the auxiliary composite signals appearing thereat and operative to produce third and fourth auxiliary composite signals containing the information contained in the composite signals in said third and fourth channels, respectively, and

circuit means connected to the control electrodes of said auxiliary gain control amplifiers and operative in response to at least one of said first, second, third and fourth auxiliary composite signals to maintain substantially constant the amplitude of said firt, second, third and fourth signals regardless of changes in amplitude of said L_T and R_T signals.

13. Apparatus according to claim **12,** further including a third auxiliary gain control amplifier for coupling the composite signal from the first network of said first pair to said means for comparing the sum and difference of it and said first auxiliary signal, said third auxiliary gain control amplifier having input and output terminals and a control electrode, and means coupling the composite signal from the first network of said first pair to the input terminal of said third auxiliary gain control amplifier, and wherein said last-mentioned circuit means is connected to the control electrode of said third auxiliary gain control amplifier and operative to maintain substantially constant the amplitude of the amplified composite signal appearing at the output terminal of said third auxiliary gain control amplifier regardless of changes in amplitude of said L_T signal.

14. Apparatus according to claim **12,** wherein said comparing circuit means comprises,

means for separately rectifying said first, second, third and fourth auxiliary composite signals, and

first and second signal subtracting junctions to which said rectified first and second and said rectified third and fourth signals are respectively applied and which are respectively operative to produce said first and second signals respectively proportional to the difference between said first and second rectified signals and between said third and fourth rectified signals.

15. Apparatus according to claim **13** wherein said means for comparing the sum and difference of said first auxiliary signal and the composite signal from the first network of said first pair comprises

a summing junction and a subtracting junction, each having first and second input terminals and an output terminal,

means connecting the auxiliary composite signals from said first and said third auxiliary gain control amplifiers to the first and second input terminals, respectively, of both of said summing and subtracting junctions,

means for separately rectifying the signals appearing at the output terminals of said summing and subtracting junctions,

means for comparing said rectified signals and operative to produce said second control signal with said given polarity when said L_T and R_T composite signals contain generally "front" signals and to produce said second control signal with opposite polarity when said L_T and R_T composite signals contain generally "back" signals, and

means for limiting the amplitude of said second control signal before combination with the control signal from said control signal generating means to a predetermined amplitude.

16. Apparatus according to claim **5,** wherein said first, second, third and fourth output channels respectively include first, second, third and fourth gain control amplifiers for respectively coupling said first, second, third and fourth composite output signals for a respective loudspeaker, and further including a control circuit for producing a control signal for selectively controlling the gains of said gain control amplifiers to enhance the front-to-back channel separation, said control circuit comprising:

means for comparing the sum and the difference of the composite signals from the first network of each of said pairs and operative to produce a control signal of a given polarity or of opposite polarity depending on whether the sum exceeds the difference, or vice versa, and

means for applying said control signal with said given polarity to said first and second gain control amplifiers and with said opposite polarity to said third and fourth gain control amplifiers and operative to increase the gain of said first and second amplifiers relative to the gain of said third and fourth amplifiers when said L_T and R_T composite signals contian generally front signals and to increase the gain of said third and fourth amplifiers relative to said first and second amplifiers when said L_T and R_T composite signals contain generally back signals.

17. Apparatus according to claim **16,** wherein said sum and difference comparing means comprises

a summing junction and a subtracting junction, each having first and second terminals and an output terminal,

means connecting the composite signals from the first network of each of said pairs to the first and second input terminals, respectively, of both of said summing and subtracting junctions,

means for separately rectifying the signals appearing at the output terminals of said summing and subtracting junctions, and

means for comparing said rectified signals.

18. In apparatus for reproducing on four sound-reproducing devices four directional audio information signals respectively designated L_f, R_f, L_b and R_b contained in said first and second composite signals respectively containing to the extent they are present dominant L_f and R_f component signals and each including to the extent they are present sub-dominant L_b and R_b component signals, with the L_b and R_b component signals in one of said composite signals in quadrature relationship with the corresponding component signals in the other composite signal, the combination comprising:

decoding circuit means including first and second pairs of all-pass phase-shifting networks connected to receive said first and second composite signals, respectively, a first phase shifting network of each pair being operative to shift the phase of the applied signal by a predetermined reference angle and a second phase-shifting network of each pair being operative to shift the phase of the applied signal by an angle differing from said reference angle by substantially 90°, and means for selectively combining predetermined portions of said relatively phase-shifted first and second composite signals to produce third and fourth composite signals respectively containing said L_b and said R_b component signals as its predominant component,

signal-coupling means connected to receive and operative to couple composite signals respectively containing said L_f, R_f, L_b and R_b component signals as its predominant signal to respective ones of said sound-reproducing devices said signal-coupling means including signal amplitude-modifying means for separately adjusting the amplitude of the composite signal applied thereto, and

a control circuit for producing and applying to said signal amplitude-modifying means a control signal to enhance the amplitude of the signal or signals applied to said sound-reproduction devices which instantaneously contain audio information signals which predominate relative to the other signals applied to said sound-reproduction devices, said control circuit including:

means for deriving a first set of control-signal-producing signals from like phase-shifting networks of said first and second pairs,

means for deriving a second set of control-signal-producing signals including the output signal from the other phase-shifting network of one of said pairs and one of the composite signals of said first set of control-signal-producing signals,

means connected to receive said second set of control-signal-producing signals and operative to derive therefrom first, second, third and fourth auxiliary composite signals respectively containing the signal information contained in said first, second, third and fourth composite signals,

first circuit means for comparing said first and second auxiliary composite signals and operative to produce a first signal indicative of whether they contain substantially equal amplitude signals in phase coincidence or in phase opposition,

second circuit means for comparing said third and fourth auxiliary signals and controlling to produce a second signal indicative of whether they contain substantially equal amplitude signals front phase coincidence or in phase opposition, and

means for combining said first and second signals and operative to produce and apply to said signal-amplitude-modifying means a control signal for enhancing the gain of said first and second signal amplitude-modifying means relative to said third and fourth signal amplitude-modifying means when said first and second auxiliary signal do not contain L_b and R_b signal components and to enhance the gain of said third and fourth signal amplitude-modifying means relative to said first and second signal amplitude-modifying means when said third and fourth auxiliary signals do not contain L_f and R_f signal components.

19. Apparatus in accordance with claim **18**, further comprising

means for summing and differencing the signals of said first set of control-signal-producing signals to produce sum and difference signals, and

means for comparing the absolute magnitudes of said sum and difference signals to produce and apply to said signal amplitude-modifying means a second control signal of a given polarity or opposite polarity depending upon whether the sum exceeds the difference, or vice versa.

20. Apparatus according to claim **19**, wherein said last-mentioned means includes means for limiting the amplitude of said second control signal to a predetermined amplitude.

21. Apparatus according to claim **18** wherein said control signal generating means includes

first and second auxiliary gain control amplifiers each having input and output terminals and a control electrode and connected to receive at their respective input terminals the signals of said second set of control-signal-producing signals, said first and second auxiliary gain control amplifiers being operative to produce first and second auxiliary composite signals at their respective output terminals corresponding to the composite signals applied thereto,

means connected to the output terminals of said first and second auxiliary gain control amplifiers for selectively combining the auxiliary composite signals appearing thereat and operative to produce third and fourth auxiliary composite signals containing the information contained in the composite signals in said third and fourth channels, respectively, and

circuit means connected to the control electrodes of said auxiliary gain control amplifiers and operative in response to at least one of said first, second, third and fourth auxiliary composite signals to maintain substantially constant the amplitude of said first, second, third and fourth auxiliary signals regardless of changes in the amplitude of said first and second composite signals.

22. Apparatus according to claim **21**, including a third auxiliary gain control amplifier to the input terminal of which one of the control signal-producing signals to said first set is applied, and wherein said last-mentioned circuit means is operative to maintain substantially constant the amplitude of the output composite signal from said third auxiliary gain control amplifier regardless of changes in amplitude of said first and second composite signals.

23. Apparatus according to claim **22**, wherein said means for comparing the absolute magnitudes of said sum and difference signals comprises

a summing junction and a subtracting junction, each having first and second input terminals and an output terminal,

means connecting the composite output signals from said first and third auxiliary gain-control amplifiers to the first and second input terminals, respectively, of both said summing junction and said subtracting junction,

means for separately rectifying the signals appearing at the output terminals of said summing and subtracting junctions,

means for comparing said rectified signals and operative to produce said second control signal with said given polarity when said first and second composite signals contain generally "front" signals and to produce said second control signal with opposite polarity when said first and second composite signals contain generally back signals, and

means for limiting the amplitude of said second control signal to substantially the amplitude of said first control signal.

24. In apparatus for reproducing four individual audio information signals respectively designated L_f, R_f, L_b and R_b contained in first and second composite signals respectively containing to the extent they are present dominant L_f and R_f component signals and each including to the extent they are present sub-dominant L_b and R_b component signals with a phase-shift angle of substantially 90° between said L_b component signals and between said R_b component signals, the combination comprising:

decoding circuit means connected to receive said first and second composite signals and operative in response thereto to produce third and fourth composite signals respectively containing predominant L_b and R_b component signals and each including sub-dominant L_f and R_f component signals, said decoding circuit means including first and second pairs of all-pass phase-shifting networks to which said first and second composite signals are respectively applied, a first phase-shifting network of each pair being operative to shift the phase of the applied signal by a predetermined reference angle and the second phase-shifting angle of each pair being operative to shift the phase of the applied signal by an angle differing from said reference angle by substantially 90°,

signal amplitude-modifying means connected to receive and operative to couple said first, second, third and fourth composite signals to respective ones of said sound-reproducing means,

control signal generating means for producing a control signal for selectively controling the transmission characteristic of said signal amplitude-modifying means to enhance the separation between frnt and back channel signals, said control circuit including:

means for comparing the sum and the difference of the composite output signals from the first network of each of said pairs and operative to produce a control signal of a given polarity or of opposite polarity depending on whether the sum exceeds the difference, or vice versa, and

means for applying said control signal with said given polarity to said first and second signal amplitude-modifying means and with said opposite polarity to said third and fourth gain signal amplitude-modifying means and operative to increase the gain of said first and second signal amplitude-modifying means relative to the gain of said third and fourth signal amplitude modifying-means when said first and second composite signals contain generally front signals and to increase the gain of said third and fourth signal amplitude-modifying means relative to said first and second signal amplitude-modifying means when said first and second composite signals contain generally back signals.

25. Apparatus according to claim **24**, wherein said sum and difference comparing means comprises

a summing junction and a subtracting junction each having first and second input terminals and an output terminal,

means for coupling the composite signals from the first network of each of said pairs of phase-shifting networks to the first and second input terminals, respectively, of both said summing junction and said subtracting junction,

means for separately rectifying the signals appearing at the output terminals of said summing and subtracting junctions, and

means for comparing said rectified signals.

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