United States Patent [19]

Bauer

[11] **3,890,466**

[45] **June 17, 1975**

[54] **ENCODERS FOR QUADRAPHONIC SOUND SYSTEM**

[75] Inventor: **Benjamin B. Bauer**, Stamford, Conn.

[73] Assignee: **CBS Inc.**, New York, N.Y.

[22] Filed: **July 31, 1973**

[21] Appl. No.: **384,334**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 328,814, Feb. 1, 1973, abandoned, which is a continuation-in-part of Ser. No. 251,544, April 21, 1972, abandoned, Continuation of Ser. Nos. 44,224, June 8, 1970, abandoned, Ser. No. 124,135, March 15, 1971, Pat. No. 3,821,471, and Ser. No. 288,829, Sept. 13, 1972, abandoned.

[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** ..... 179/1 GQ, 100.1 TD, 179/100.4 ST, 15 BT

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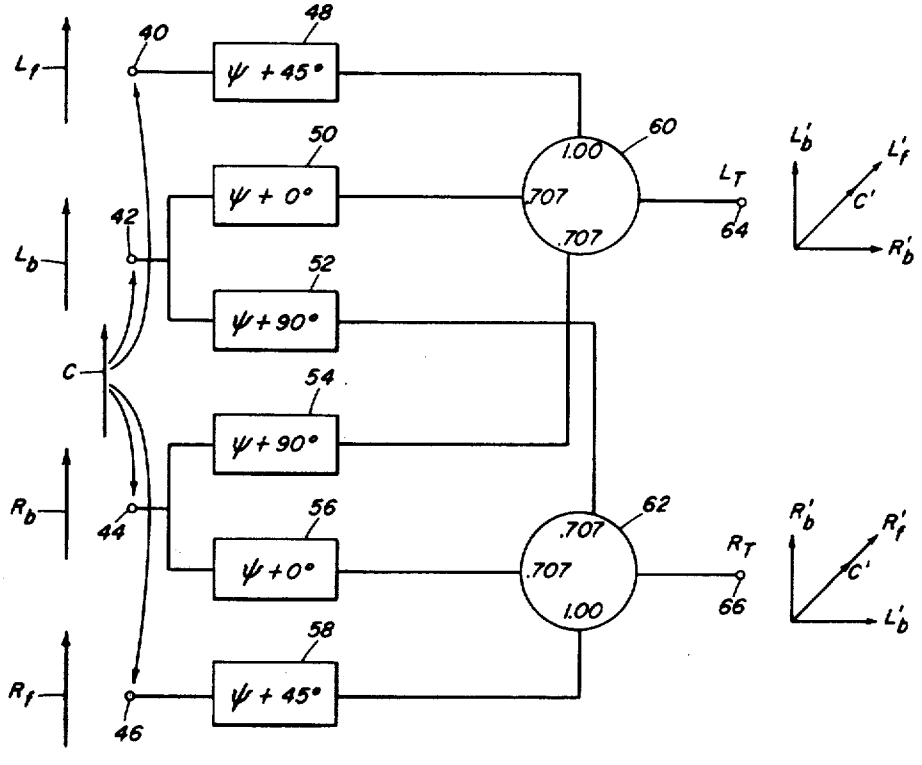
The Joke System by Michael Gerzon, Hi Fi News, June 1970, pp. 843, 847.

Primary Examiner—William C. Cooper
Assistant Examiner—Thomas D'Amico
Attorney, Agent, or Firm—Spencer E. Olson

[57] **ABSTRACT**

Methods and apparatus for combining a plurality of channels of audio program information into two composite signals suitable for recording or transmission on a medium having only two independent tracks, and for presentation over the two loudspeakers of stereophonic playback apparatus which at the same time will admit of decoding into a plurality (e.g., four) separate signals corresponding to the originally encoded signals for presentation over corresponding loudspeakers. The two composite signals respectively contain input signals intended for presentation on loudspeakers positioned at the left front and right front corners of a listening area, and both composite signals contain, at reduced amplitude, signals intended for presentation on loudspeakers positioned at the left back and right back corners of the listening area. The encoder includes all-pass phase-shifting networks designed to transmit all frequencies in the frequency range of interest which are operative to cause the left back and right back components of one composite signal to be in quadrature relationship with corresponding components in the other composite signal.

33 Claims, 37 Drawing Figures



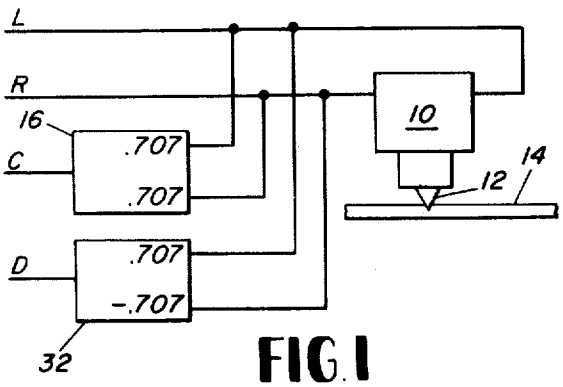


FIG. 1

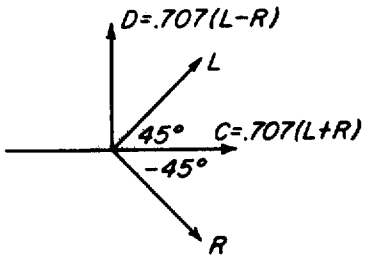


FIG. 2

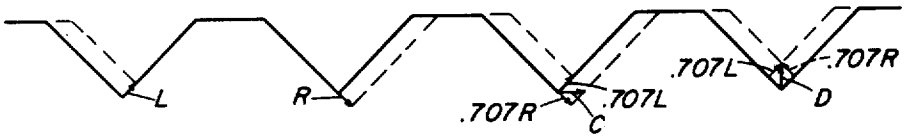


FIG. 3

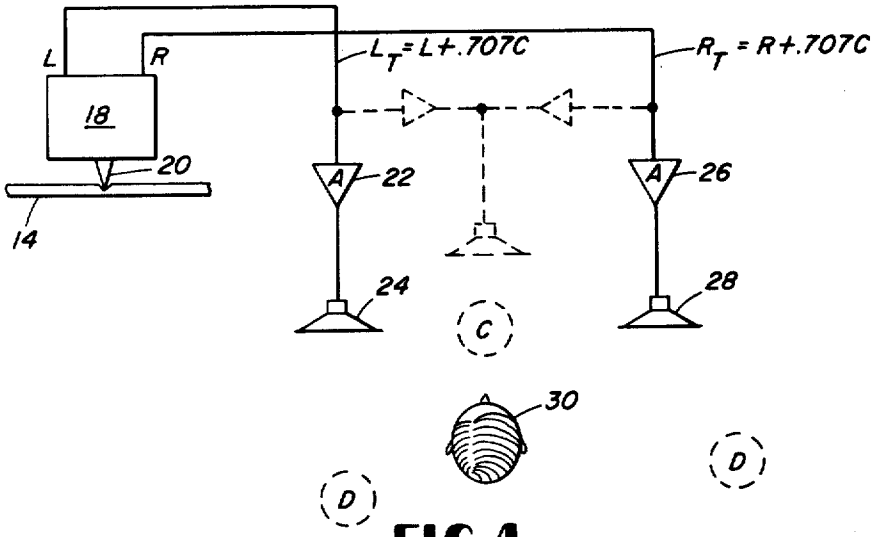


FIG. 4

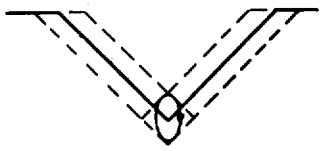


FIG. 6

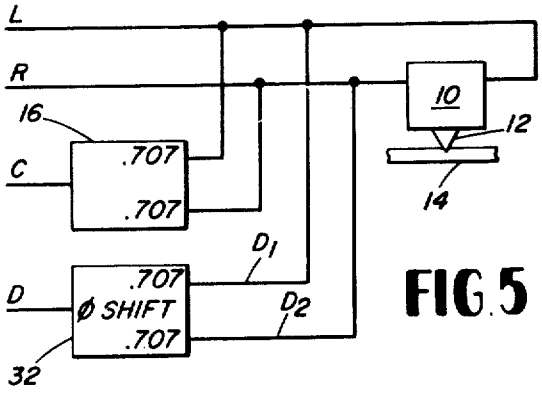


FIG. 5

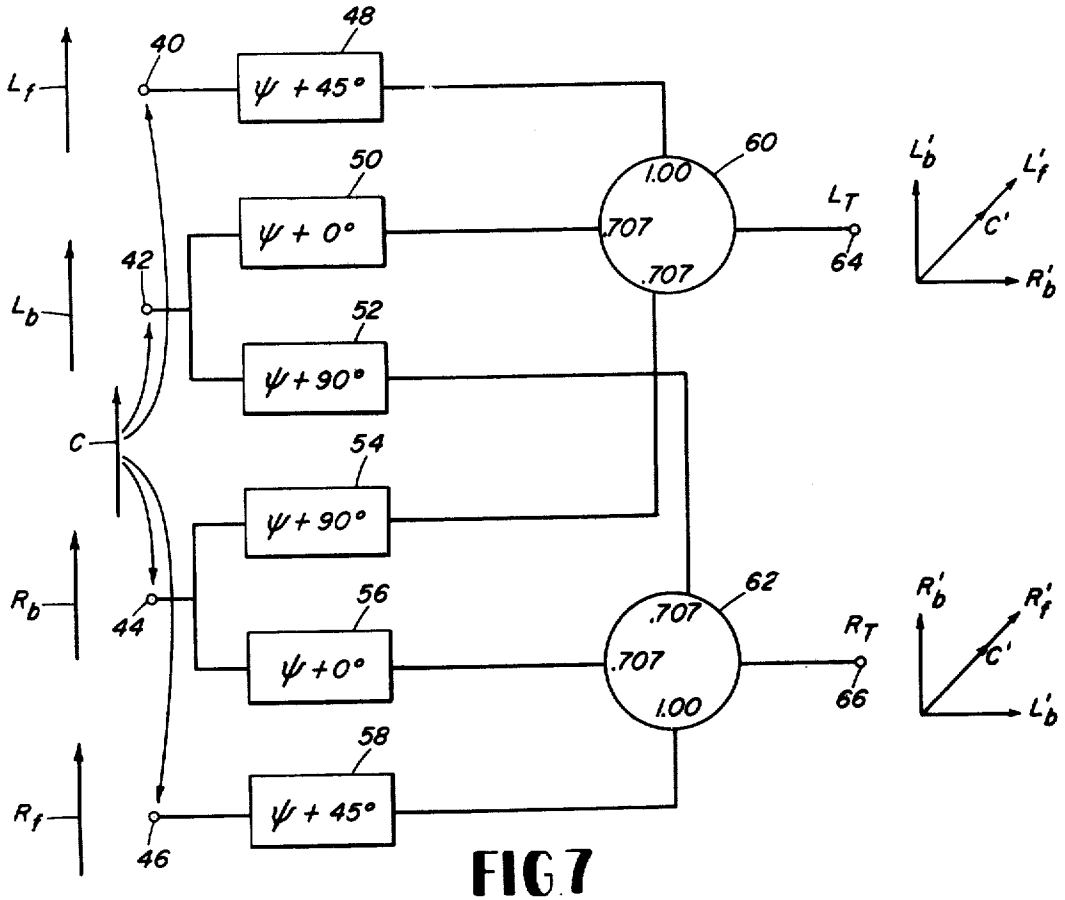

L_f
L_b
C
R_b
R_f
40
42
44
46
48
$\psi + 45°$
50
$\psi + 0°$
52
$\psi + 90°$
54
$\psi + 90°$
56
$\psi + 0°$
58
$\psi + 45°$
60
1.00
.707
.707
62
.707
.707
1.00
L_T
64
R_T
66
L'_b
L'_f
C'
R'_b
R'_b
R'_f
C'
L'_b

FIG. 7

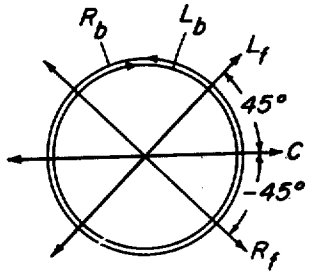

R_b
L_b
L_f
45°
C
-45°
R_f

FIG. 8

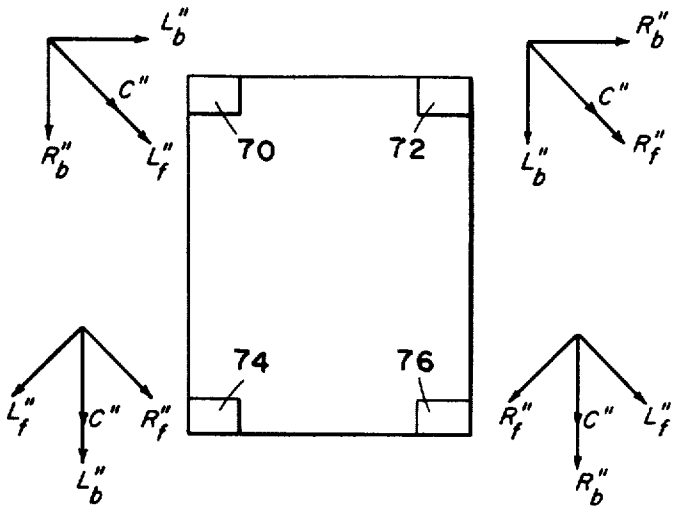

L_b''
C"
R_b''
L_f''
70
72
R_b''
C"
L_b''
R_f''
74
76
L_f''
C"
R_f''
L_b''
R_f''
C"
L_f''
R_b''

FIG. 9

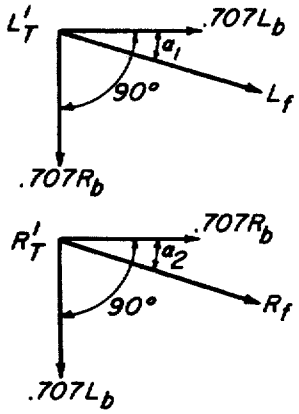

L_T'
.707L_b
a_1
90°
L_f
.707R_b
R_T'
.707R_b
a_2
90°
R_f
.707L_b

FIG. 10

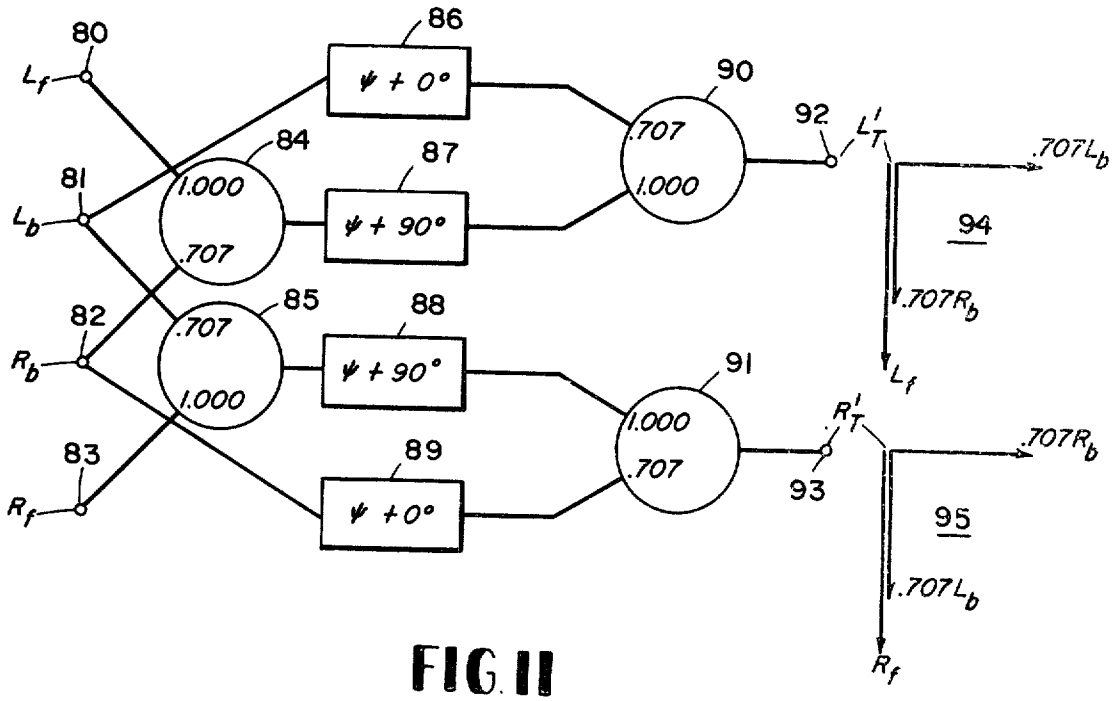

80
L_f
81
L_b
82
R_b
83
R_f
84
1.000
.707
85
.707
1.000
86
ψ + 0°
87
ψ + 90°
88
ψ + 90°
89
ψ + 0°
90
.707
1.000
91
1.000
.707
92
93
L'_T
R'_T
.707L_b
94
.707R_b
L_f
.707R_b
95
.707L_b
R_f

FIG. 11

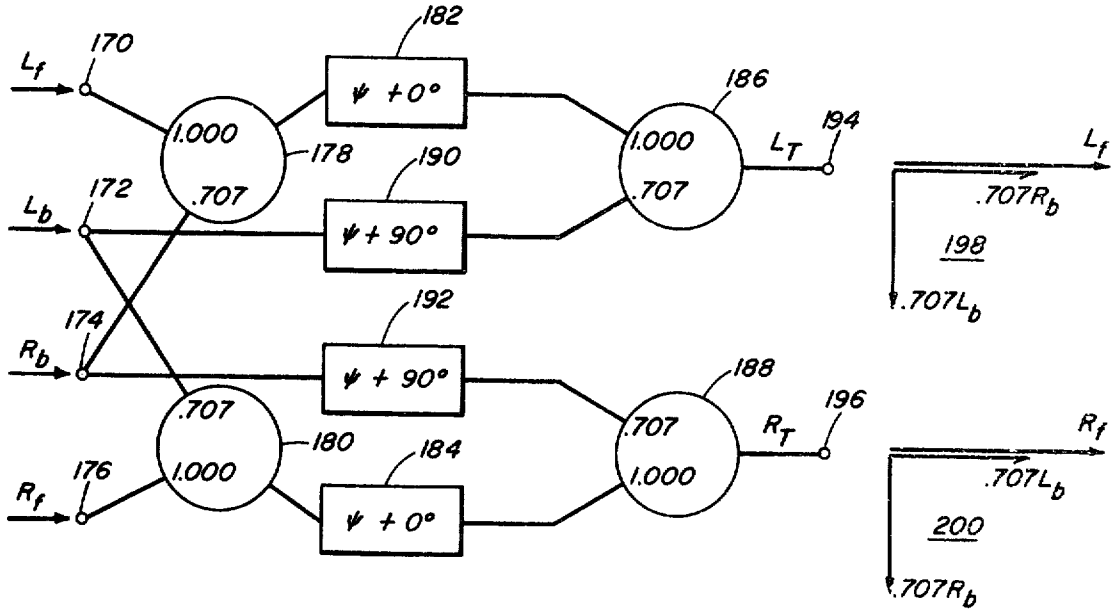

170
L_f
172
L_b
174
R_b
176
R_f
178
1.000
.707
180
.707
1.000
182
ψ + 0°
184
ψ + 0°
186
1.000
.707
188
.707
1.000
190
ψ + 90°
192
ψ + 90°
194
L_T
196
R_T
L_f
.707R_b
198
.707L_b
R_f
.707L_b
200
.707R_b

FIG. 13

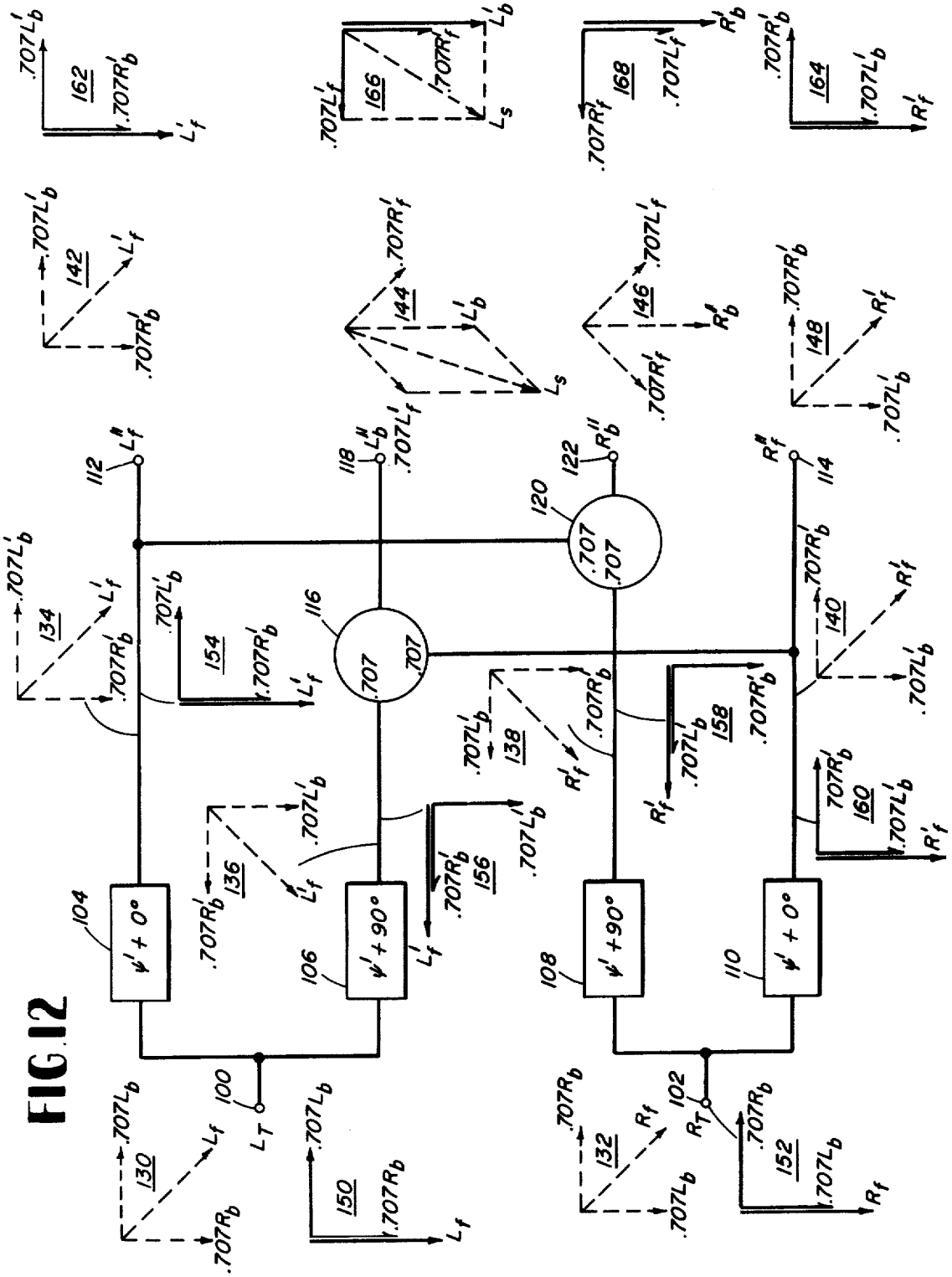

100
102
104
106
108
110
112
114
116
118
120
122
130
132
134
136
138
140
142
144
146
148
150
152
154
156
158
160
162
164
166
168
.707
.707
ψ' + 0°
ψ' + 90°
ψ' + 90°
ψ' + 0°

FIG 12

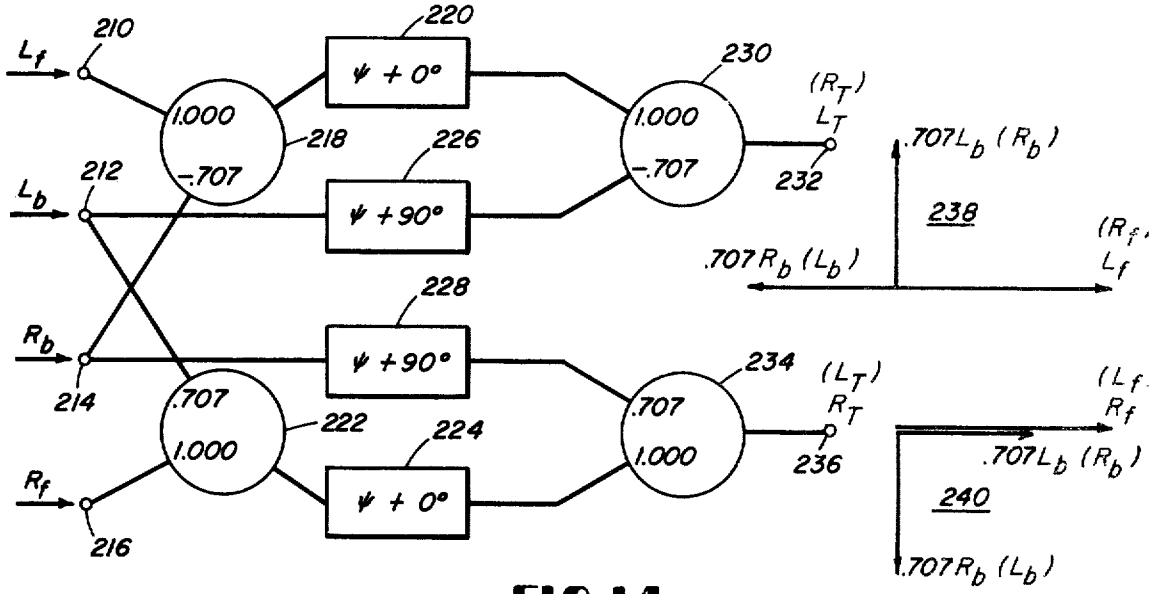


FIG. 14

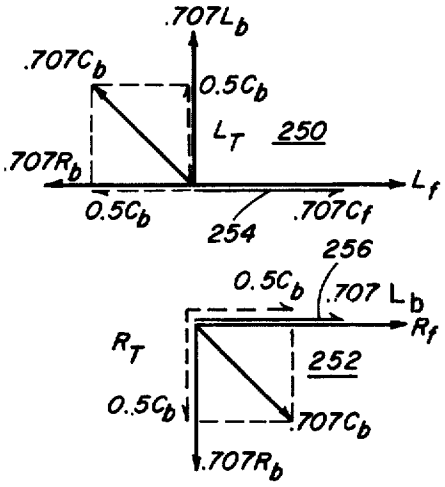


FIG. 16

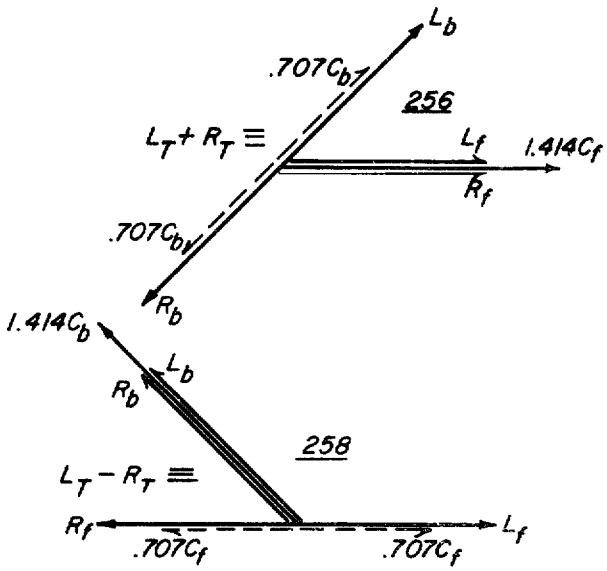


FIG. 17

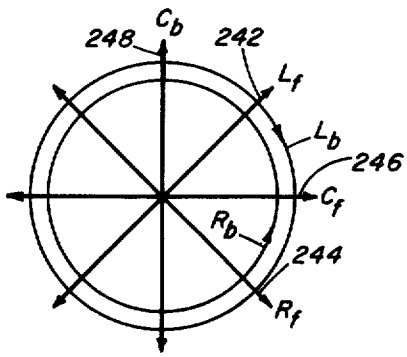


FIG. 15

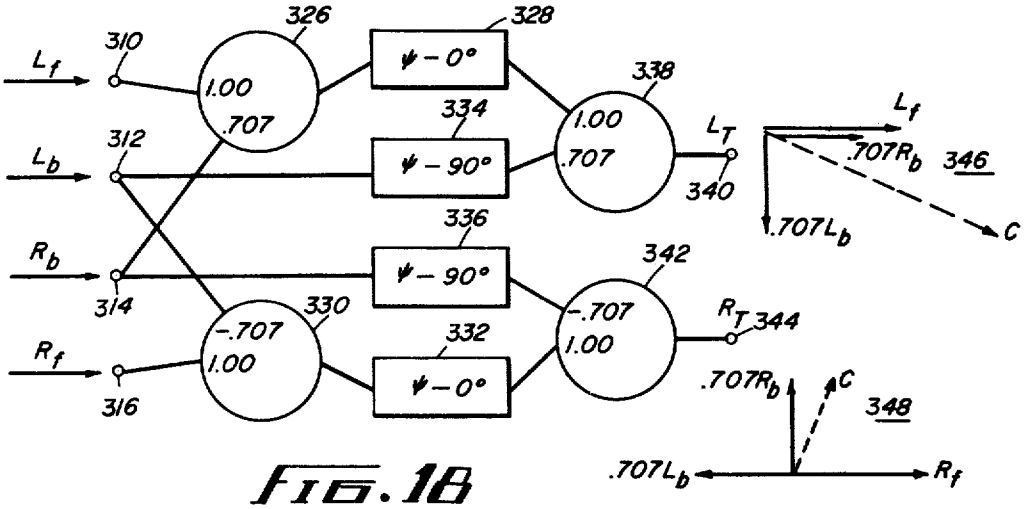


FIG. 18

FIG. 18A

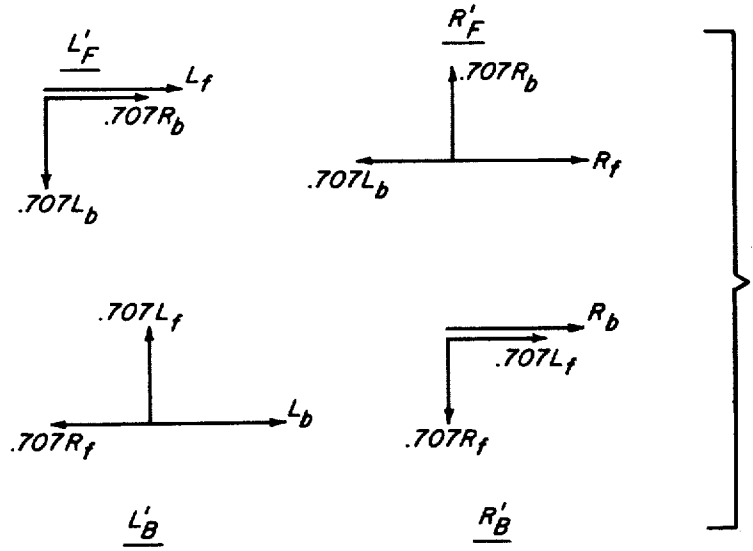


FIG. 18B

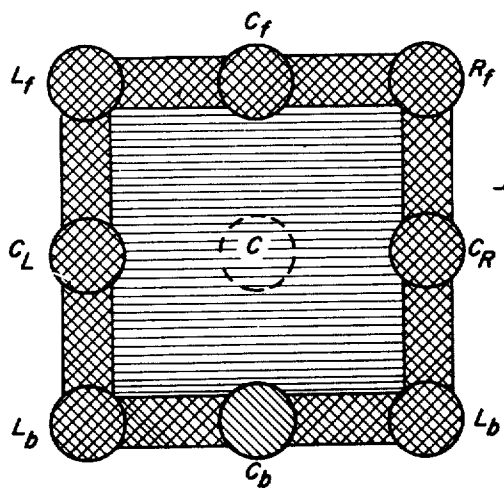


FIG. 18C

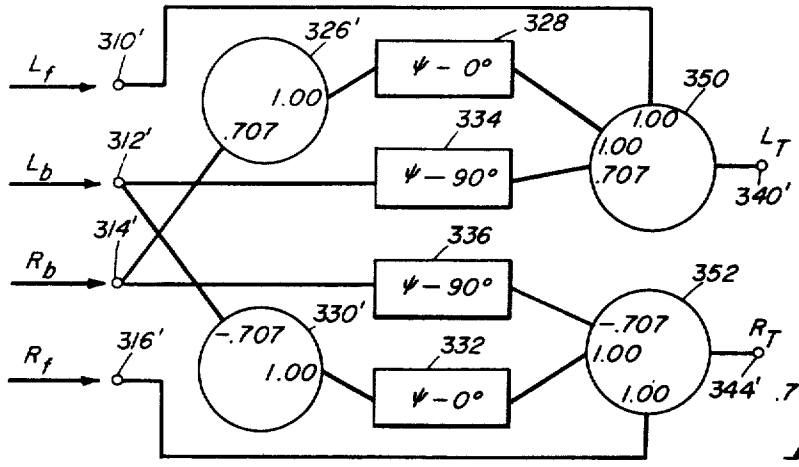


FIG. 19

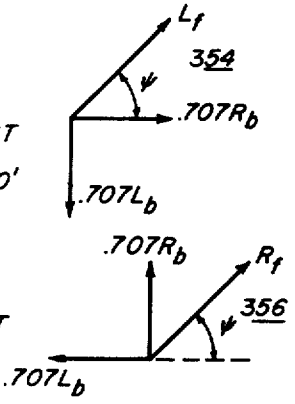


FIG. 19A

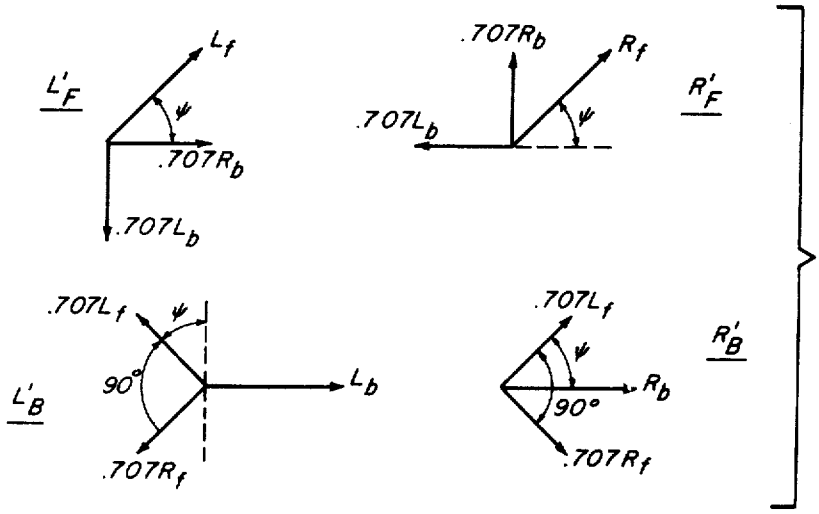


FIG. 19B

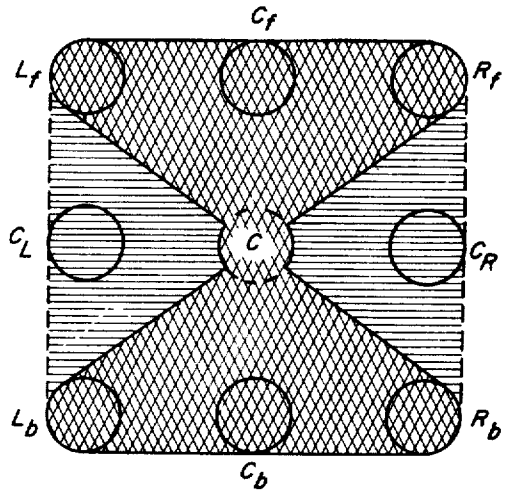


FIG. 19C

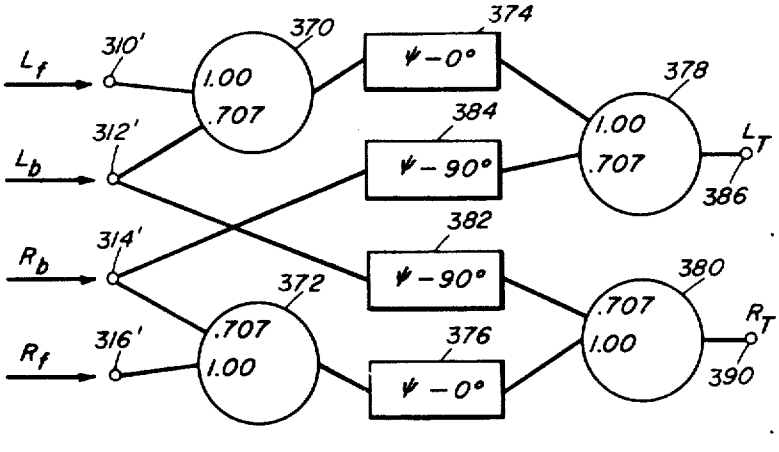


FIG. 20

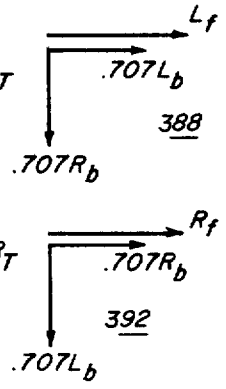


FIG. 20A

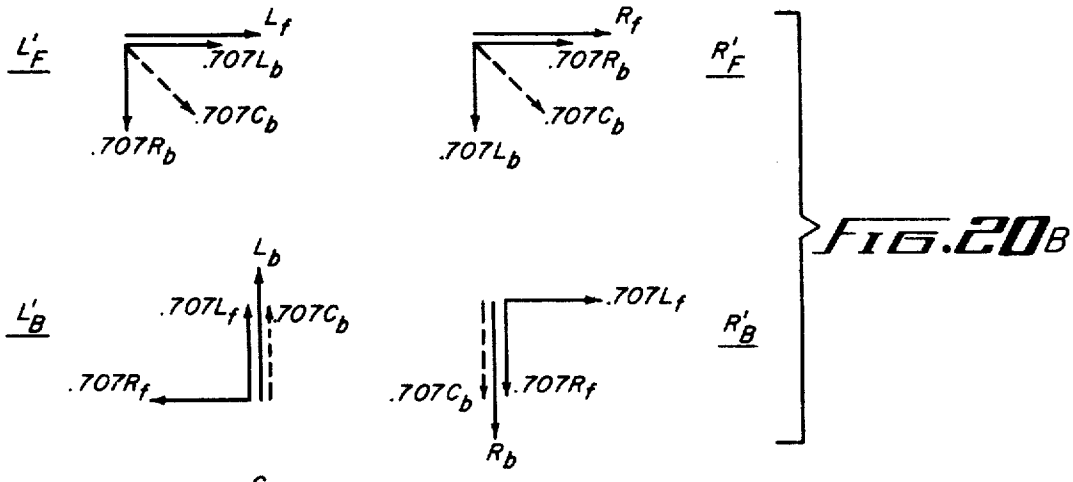


FIG. 20B

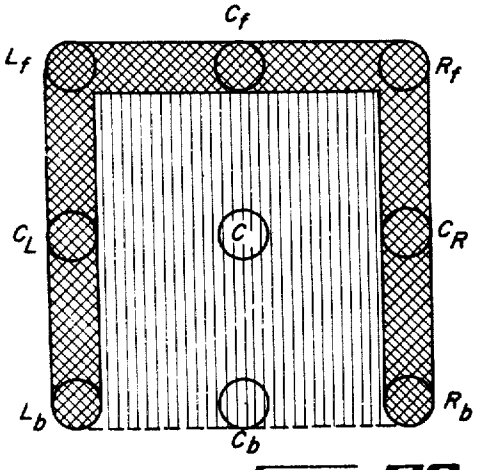


FIG. 20C

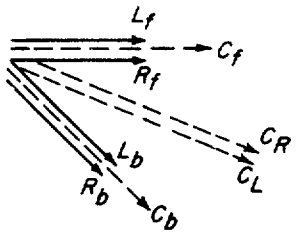


FIG. 20D

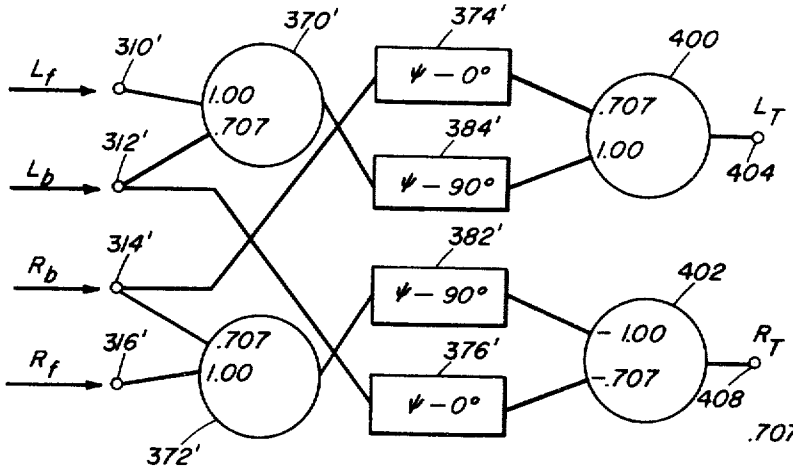


FIG. 21

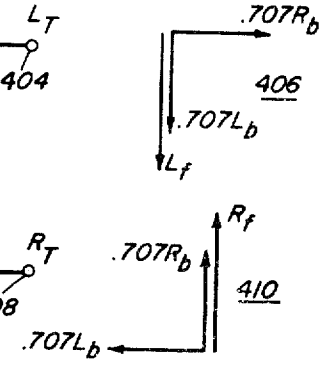


FIG. 21A

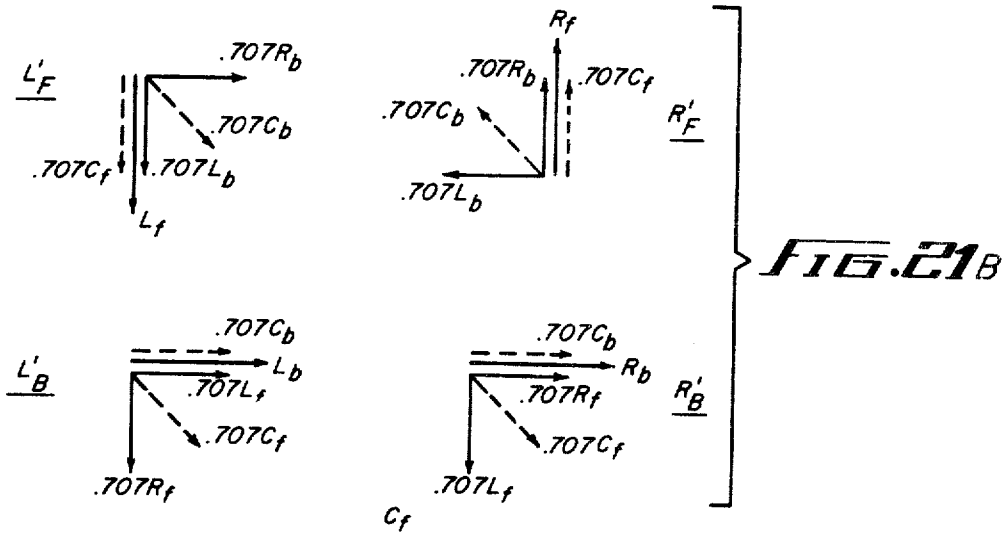


FIG. 21B

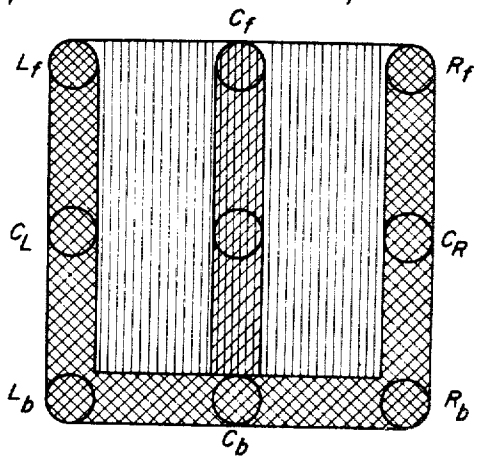


FIG. 21C

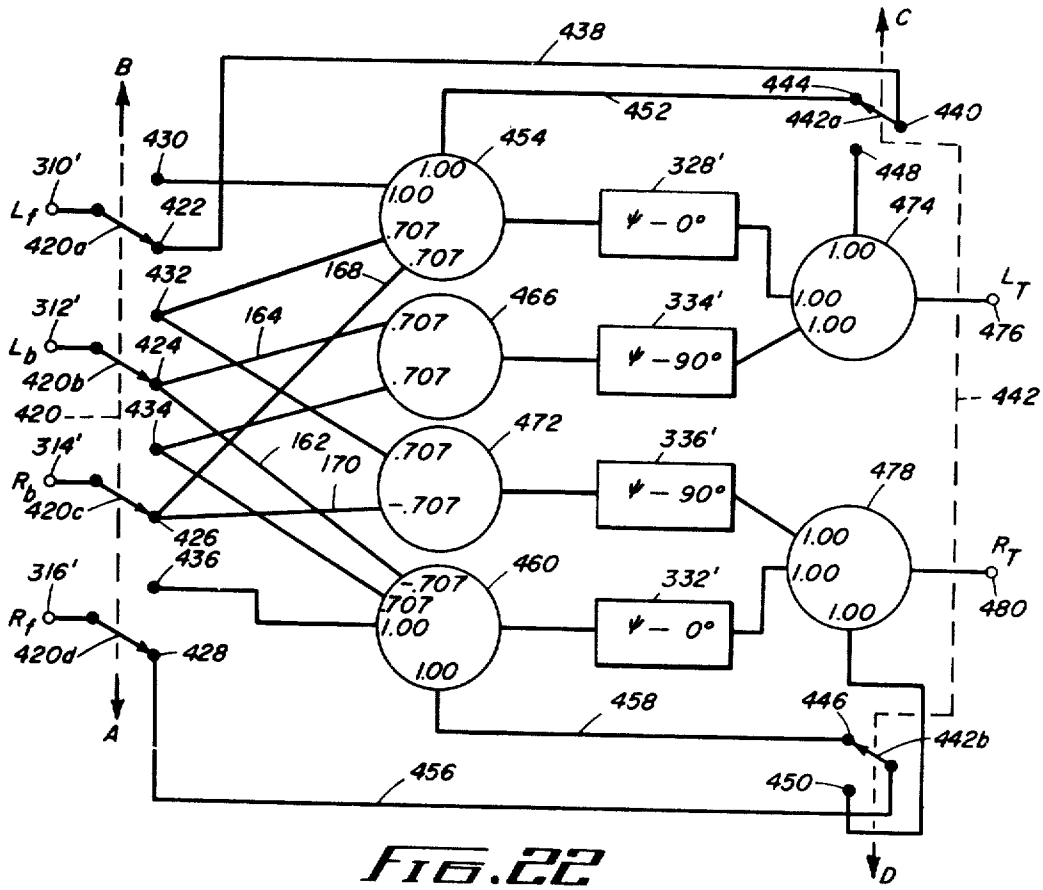


FIG. 22

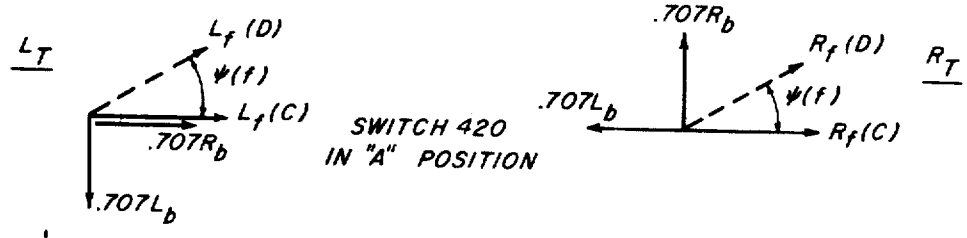


FIG. 22A

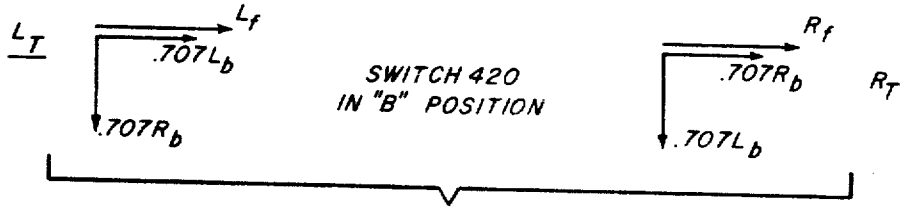


FIG. 22B

ENCODERS FOR QUADRAPHONIC SOUND SYSTEM

This is a continuation-in-part of now abandoned application Ser. No. 328,814 filed on Feb. 1, 1973 in the name of Benjamin B. Bauer (which, in turn, is a continuation-in-part of now abandoned application Ser. No. 251,544 filed on Apr. 21, 1972 as a continuation of now abandoned application Ser. No. 44,224 filed June 8, 1970, and of application Ser. No. 124,135 filed on Mar. 15, 1971, now U.S. Pat. No. 3,821,471) and of now abandoned application Ser. No. 288,829 filed on Sept. 13, 1972 in the name of Benjamin B. Bauer.

CROSS-REFERENCE TO OTHER APPLICATIONS

This invention is related to the subject matter of the following other co-pending applications, all of which are assigned to the assignee of the present invention and application: Ser. No. 164,675 filed July 21, 1971 as a continuation-in-part of now abandoned application Ser. No. 40,510 filed May 26, 1970 now also abandoned; Ser. No. 44,196 filed June 8, 1970, now U.S. Pat. No. 3,708,631; Ser. No. 271,470 filed July 13, 1972 as a division of application Ser. No. 44,196, filed June 8, 1970, now U.S. Pat. No. 3,794,780; Ser. No. 185,050, filed Sept. 30, 1971 as a division of now abandoned application Ser. No. 44,224 filed June 8, 1970, now U.S. Pat. No. 3,813,494; Ser. No. 251,636 filed May 8, 1972 as a continuation of now abandoned Ser. No. 81,858 filed Oct. 19, 1970, now U.S. Pat. No. 3,812,295; and Ser. No. 243,800 filed Apr. 13, 1972, now Pat. No. 3,761,628; Ser. No. 118,271 filed Feb. 24, 1971, now U.S. Pat. No. 3,784,744.

BACKGROUND OF THE INVENTION

There is an increasing interest in multiple-channel recording and reproduction because of the variety of sounds and music forms that can be achieved thereby. In the early days of phonograph, only single channel or monophonic recording was used, and as early as 40 to 50 years ago, investigators realized the value of recording and transmitting two separate channels of information, which in modern parlance is known as binaural or stereophonic sound. However, even two channels of information are considered insufficient for full illusion of reality. For example, when a listener is placed in front of a symphony orchestra he hears sounds arriving from many different directions and from a variety of instruments, as well as reflections from the walls and ceiling, which gives him an accustomed illusion of space perspective. However, when reproduction is accomplished by utilizing only two channels it is difficult, if not impossible, to produce true reality with respect to spatial perspective. Early experiments have demonstrated that a minimum of three independent channels are needed to convey a satisfactory illusion of reality in the reproduction of orchestral music.

The modern stereophonic phonograph is capable of recording, or encoding, modulation along two separate channels, which geometrically are at 90° to each other and at 45° to the disc surface. It is usual practice to include a third, or center, channel by "matrixing" or combining it as an in phase phantom channel to the other two, which causes it to be recorded as lateral modulation parallel to the record surface. Upon reproduction, the third (or central) channel appears on the two loudspeakers of the stereophonic phonograph with

equal loudness and in-phase relationship and an observer placed centrally between the loudspeakers perceives the illustion of the third channel being located between the other two. Although there have been attempts to reproduce the third or center channel on a separate loudspeaker, the results have not been entirely satisfactory, and most stereophonic systems, even though many stereo records carry a "center" channel, employ only two loudspeakers.

In the aforementioned co-pending application Ser. No. 164,675 of William S. Bachman there is described a system for providing third and fourth playback channels to otherwise two-channel systems by feeding third and fourth loudspeakers with signals respectively representing the sum and difference between the left and right channel signals. The left and right loudspeakers may be located, for example, on opposite sides of a listening area, with the loudspeakers for the two virtual channels positioned at opposite ends of the listening area. Each loudspeaker displays the particular information fed to its channel accompanied by half-power signals from its adjacent channels. This system provides a pseudo-four-channel effect, but does not give a complete illustion of each channel appearing independently on its corresponding loudspeaker.

A better illusion of each channel appearing independently on its corresponding loudspeaker is provided by the system described in the above-mentioned U.S. Pat. No. 3,708,631 which includes four gain control amplifiers through which the four separate channels of information are respectively applied to corresponding loudspeakers, and a logic control circuit which derives its signals from the "left" and "right" output terminals of the transducer for automatically controlling the gain control amplifiers to enhance the realism of four separate channels of information. While this system provides a significant improvement in the art of reproduction of recorded sound, it has a number of drawbacks as follows: (1) The system provides for both a single "back" channel and the information originating from this back channel, which is encoded as a difference signal or as a vertically oriented elliptical signal, has little or no component in the "lateral" or "sum" direction, and accordingly, as the record is played on a monophonic phonograph or transmitted over a monophonic radio station, the signal identified with the back direction is greatly attenuated or disappears altogether; (2) In the case of a stereophonic disc record, it is undesirable to apply information originating from the back in the vertical direction because it tends to make cutting and pressing of the record more difficult; (3) When a stereophonic disc record carrying back information as vertical modulation is played on a conventional stereophonic player, the signals corresponding to the back direction appear at the two loudspeakers out-of-phase, or significantly so, thereby causing a relatively unpleasant "pressure in the ears" sensation; (4) In conventional stereophonic practice the two loudspeakers are normally placed in two adjacent corners of the listening room, and it is conventional in the production of four-channel recordings to have the four sources originate from the four corners of the room or listening area. However, the systems described in the aforementioned co-pending applications are designed to preserve symmetry withh loudspeakers placed centrally of the four walls of the listening room. If the loudspeakers were placed in the corners, the aspect of the originally re-

corded sound would be shifted by 45°, causing an inconsistency confusing to the listener. Also, since there are practical difficulties in finding suitable locations for loudspeakers centrally of the walls in most homes, it is preferable that the reproducing system permit the placement of the loudspeakers at the corners of the listening room.

SUMMARY OF THE INVENTION

A principal object of the present invention is to provide methods and apparatus for combining four channels of program information, edited for presentation on four loudspeakers placed at the corners of a listening area, into two composite signals suitable for presentation over the two loudspeakers of stereophonic sound-reproducing apparatus which at the same time will admit of decoding into four separate signals corresponding to the four signals originally encoded, for presentation over four corresponding sound-reproducing devices.

Briefly, the foregoing object is obtained by combining the four channels of information for convenience identified as L_f for "left front", R_f for "right front", L_b for "left back" and R_b for "right back", to form two composite signals L_T (left total) and R_T (right total) for recording or transmission on a two-channel medium, such as a stereophonic disc record or a two-track magnetic tape. The encoding apparatus contains all-pass phase-shift networks designed to transmit all frequencies from about 20 to about 20,000 Hz and summing networks interconnected in a manner such that upon linear matrixing of four equal-amplitude input signals designated L_f, R_f, L_b and R_b the L_T and R_T composite signals have the following characteristics:

1. The L_f signal appears only in the L_T composite signal and the R_f signal appears only in the R_T composite signal; thus the front signals are completely isolated from each other. When L_T and R_T are applied to a stereophonic cutter, L_f produces a 45° modulation, while R_f produces a −45° modulation, precisely as with conventional stereo.

2. The left back (L_b) signal appears in both the L_T and R_T composite signals at reduced amplitude, 0.707 L_b in the preferred embodiment, and in quadrature with each other, with the L_b component in the L_T composite signal preferably leading the corresponding signal in the R_T signal. This causes a stereophonic cutter stylus to describe a circular motion in the clockwise direction, which when combined with the lengthwise motion of the groove becomes a clockwise helix.

3. The right back (R_b) signal also appears in both the L_T and R_T composite signals at reduced amplitude, 0.707 R_b in the preferred embodiment, and in quadratuure with each other. The R_b component in the R_T signal leads the corresponding component in the L_T signal which causes the cutter stylus to describe a circular motion in the counterclockwise direction.

The front channel modulations are fully equivalent to the corresponding stereophonic modulations and provide the full channel separation on playback of which the pickup is capable, while the back channel modulations are of a character to cause the pickup stylus to describe a circular motion in one direction for a left back signal and in the opposite direction for a right back signal.

BRIEF DESCRIPTION OF THE DRAWING

An understanding of the foregoing and additional aspects of this invention may be gained from consideration of the following detailed description, taken in conjunction with the accompanying drawing, in which:

FIG. **1** is a schematic diagram of a prior system for recording four channels of information on a stereophonic record;

FIG. **2** is a vector diagram useful in explaining the motion of the cutter stylus in response to application of left, right, center and difference signals;

FIG. **3** is a cross-sectional view of a fragmentary portion of a record showing four record grooves on a greatly enlarged scale, to illustrate the motion of the cutter in response to various signals;

FIG. **4** is a schematic diagram of a prior art stereophonic playback system for providing the illusion of a third channel;

FIG. **5** is a schematic diagram of the system described in the aforementioned U.S. Pat. No. 3,708,631 for recording four channels on a two-track stereophonic record;

FIG. **6** is a greatly enlarged illustration of a record groove illustrating the effect of applying the "difference" signal to the left and right channels through a phase-shift network;

FIG. **7** is a schematic diagram of one embodiment of an encoder according to the invention for combining four independent signals intended for ultimate presentation on four separate loudspeakers;

FIG. **8** is a vector diagram useful in explaining the operation of the encoder of FIG. **7**;

FIG. **9** is a plan view of a listening area illustrating the location of four loudspeakers therein and the phasor diagrams of the signals appearing on the four loudspeakers;

FIG. **10** is a pair of phasor diagrams useful in explaining the principles of the invention;

FIG. **11** is a schematic diagram of another encoder according to the invention;

FIG. **12** is a schematic diagram of decoder apparatus described in U.S. Pat. No. 3,784,744, useful in explaining the efficacy of the encoder of FIG. **11**;

FIG. **13** is a schematic diagram of an alternative form of encoding apparatus embodying the invention;

FIG. **14** is a schematic diagram of still another alternative form of encoding apparatus embodying the invention;

FIG. **15** is a diagram similar to FIG. **8** illustrating the motion of the cutting or playback stylus of stereophonic recording or reproducing apparatus in response to signals encoded in accordance with the invention;

FIGS. **16** and **17** are phasor diagrams useful in explaining the operation and advantages of the encoder of FIG. **14**;

FIG. **18** is a schematic diagram of a modified form of the encoder of FIG. **14**, and FIGS. **18A**, **18B**, and **18C** are diagrams illustrating the operation thereof;

FIG. **19** is a schematic diagram of an encoder described in applicant's co-pending U.S. Pat. No. 3,761,628, and FIGS. **19A**, **19B** and **19C** are diagrams illustrating the operation thereof;

FIG. **20** is a schematic diagram of still another alternative form of encoding apparatus, and FIGS. **20A**, **20B**, and **20C** and **20D** are diagrams useful in explaining its operation;

FIG. 21 is a schematic diagram of still another encoder, and FIGS. 21A, 21B, and 21C are diagrams useful in explaining its operation; and

FIG. 22 is a schematic diagram of encoding apparatus embodying the features of the three encoders illustrated in FIGS. 18, 19 and 20, and FIGS. 22A and 22B are phasor diagrams useful in explaining its operation.

DISCUSSION OF THE PRIOR ART

By way of background for better understanding the present invention, the current method of recording stereophonic signals including a third or center channel, and a method of reproducing the signals over a stereophonic two-loudspeaker system will be described with reference to FIGS. 1–4. The currently provided left (L), right (R) and center (C) signals are applied to the two terminals of a stereophonic cutter 10 having a cutting stylus 12 which is adapted to cut a groove in the lacquer of a master disc 14, revolving on a recording turntable (not shown). The C signal is supplied through a signal splitter 16 of known configuration resulting in application of equal portions thereof, equivalent to 0.707C, to each of the L and R terminals in-phase. AS is well known in the groove cutting art, the tip of the cutter is capable of motions contained within a surface generally perpendicular to the disc in the manner portrayed by the vector diagram of FIG. 2. When a left signal L is applied, the stylus executes motions along the arrow L, which is at an angle of 45° to the horizontal, and when an R signal is applied, the stylus motion is along the arrow R, at an angle of −45° to the horizontal. Application of 0.707C to each of the L and R terminals in-phase causes motion of the stylus along the arrow C, equal in magnitude to $0.707\ (\vec{L}+\vec{R})$, which is of the same magnitude as either L or R, but directed horizontally. It will be appreciated that instead of applying the L, R and C signals directly to the cutter, as shown in FIG. 1, they may, in keeping with common practice, first be recorded on a two-track master tape recorder and the output of the tape reproducer used to drive the record cutter. Discussion of the difference signal D illustrated in FIGS. 1 and 2 will be deferred until later.

The type of groove modulation resulting from the just-described procedure is shown in FIG. 3. When only the left signal L is applied, the groove is modulated in accordance with the arrow L, which is essentially confined to one wall of the groove. Similarly, when the R signal is applied, the modulation is in the opposite wall of the groove in the direction of the arrow R, which, it will be noted, is perpendicular to the arrow L. Application of equal amounts of the center signal C to the L and R lines causes both walls of the groove to be simultaneously and equally modulated in the directions indicated by the arrows L=0.707C and R=0.707C, resulting in horizontal or side-to-side translation indicated by arrow C.

Apparatus for reproducing a stereophonic record carrying L, R and C signals recorded in this manner, schematically illustrated in FIG. 4, includes a stereophonic pickup having a cartridge 18 and a stylus 20 which enters the groove in the record and is actuated by the groove modulations to deliver output voltages on the L and R terminals. If only L signal modulation is present in the groove, an output signal appears only at the L terminal and is amplified by a suitable power amplifier 22 and reproduced by a loudspeaker 24. Similarly, when only R signal modulation is present in the groove, an output voltage appears at only the R terminal of the pickup, which is amplified by power amplifier 26 and applied to its respective loudspeaker 28. When the groove has lateral modulation consisting of the presence of equal amounts of left and right signal, then equal signals, namely, 0.707C, appear at both the left and right loudspeakers, resulting in the appearance of a phantom source C (shown surrounded by a dashed line circle) midway between loudspeakers 24 and 28. However, this illusion is preceptible only to the centrally located observer 30; when he moves to either side, the C signal is heard over the nearest loudspeaker unless special precautions are made to adjust the directional characteristics of the loudspeakers with respect to the position of the observer.

It will be noted that the described three-channel record is "compatible" because the L, R and C signals all have a horizontal component and thus will be heard when played on a monophonic player, which is sensitive only to lateral modulation, albeit their relative intensities will not be in the exact balance initially intended by the recording director since the horizontal components of L and R are 0.707 of C. In reality, in spite of the introduction of a third channel, the above-described system reproduces only two independent channels of information. The third channel, C, is contained in both the left and right channels and the listener will, therefore, usually hear it reproduced from the loudspeaker nearest to him. This center channel may be presented on a separate loudspeaker system, as shown in dotted lines in FIG. 4, and amplifiers are commercially available for this purpose. This permits the observer to percieve the center information without having to locate himself equidistant from the left and right speakers, although such a center channel loudspeaker tends to cause the sounds of the other two loudspeakers to appear to be pulled in toward the center.

Reverting to FIGS. 1–3, a fourth channel, D, may be introduced to the two-channel stereophonic system by dividing it into equal parts by a signal splitter 32 and applying them in phase-opposition to the left and right channels. As shown in FIG. 2, application of the D signal in this manner causes motion of the stylus in the vertical direction, along the arrow D, to an extent specified as 0.707 times the amount of D contained in the left and right channels subtracted from each other; i.e., 0.707 (L-R). As seen in FIG. 3, this causes the left and right motions of the stylus to be out-of-phase relative to each other, resulting in up and down motion. When vertical modulation is reproduced by the system of FIG. 4, the loudspeaker cones are driven in opposite directions, resulting in out-of-phase sound pressures applied to the ears of the listener, and since this condition of pressure on the ears does not correspond to any known normal listening experience, the observer is unable to localize the sound. The difference signal D appears at some indefinite point in space, shown as D in a dashed circle, and the listener is unable to locate its whereabouts. Furthermore, some listeners of such out-of-phase sound have complained of a peculiar pressure in the ears sensation. This is in part overcome, however, by the system described in the aforementioned Bachman application Ser. No. 164,675 wherein the difference signal, as well as the center signal, are reproduced on separate loudspeakers.

To afford better compatibility with monophonic and conventional stereophonic players, while at the same time improving the illusion of four separate channels during playback, the difference signal D may be applied in the manner suggested in applicant's article entitled "Some Techniques Toward Better Stereophonic Perspective", *IEEE TRANSACTIONS OF AUDIO*, Vol. AU-11, No. 3, May–June, 1963. In keeping therewith, and as is illustrated in FIG. **5**, instead of applying the difference signal equally and oppositely to the left and right channels as in the circuit of FIG. **1**, the D signal is applied through an acoustical phase shift network **32** which splits the incoming signal into two equal amplitude signals D_1 and D_2, each containing all of the frequencies of the D signal, but displaced in phase with respect to each other. Relative phase displacements in the range of 110° to 170° have been successfully used, with an angle of 135° being particularly suitable. It can be readily demonstrated that when the two signals are thus displaced relative to each other, the tip of the stylus instead of undergoing a purely up and down motion as shown in FIG. **3**, executes the elliptical motion illustrated in FIG. **6**. The limits of stylus motion are shown by the dashed lines and the direction of motion of the ellipse depends on whether D_1 leads D_2, or vice versa. The important consideration is that the groove has a horizontal component defined by the horizontal width of the ellipse, whereby both monophonic and stereophonic phonographs will reproduce all four signals; that is, the record with four separate channels will be fully compatible with the older playback systems, albeit with monophonic systems the signal D is attenuated by about 8 db.

The realism of reproduction of four separate channels of information recorded as described above is enhanced by the control system described in the aforementioned U.S. Pat. No. 3,708,631 which derives signals from the left and right terminals of the transducer, separates the composite signals into their respective components, compares the magnitudes of these components, and actuates gain control amplifiers in the respective loudspeaker circuits in concert with the loudness of the respective components in a manner to give a realistic illustion of four separate independent sources of sound.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIG. **7**, there is shown in schematic form a first embodiment of an encoding or matrixing system for combining four independent signals, intended for ultimate display on four separate loudspeakers, into two composite signals for recording or transmission on a two-track medium, such as a stereophonic disc record or a two-track tape. The encoder includes four input terminals **40, 42, 44** and **46** for receiving four separate input signals which, for convenience, will be designated left front (L_f), left back (L_b), right back (R_b) and right front (R_f), respectively. These designations signify the locations in a listening area of the four loudspeakers on which the signals are intended for ultimate presentation. These signals are identified by vertical arrows of equal length which signify, for purposes of the analysis to follow, that the incoming signals are assumed to be of equal magnitude and referred to the same phase reference. The encoding matrix includes six all-pass phase-shift networks **48, 50, 52, 54, 56** and **58** designed to introduce a substantially constant phase shift to the applied signal over the frequency range of interest without altering their magnitudes. Each of the networks has a reference phase shift ψ, which is a function of frequency, the two phase shifters **50** and **56** introducing only the reference phase shift. Phase shifters **48** and **58** provide a phase shift equal to $(\psi+45°)$, and networks **52** and **54** provide a phase shift equal to $(\psi+90°)$. It is to be noted that according to the convention used herein the phase-shift angles produced by phase-shifters **48–58** are lagging angles. In other words, a network with phase-shift of $(\psi+90°)$ produces an output lagging 90° behind that produced by a network with phase shift $(\psi+0°)$.

The signals L_f and R_f, respectively identified with the left front and right front loudspeakers are applied via their respective terminals **40** and **46** through their associated all-pass networks **48** and **58** to respective summing circuits **60** and **62**. The left back signal L_b is applied to both of phase-shift networks **50** and **52**, the output signal from the former being applied to summing circuit **60** with attenuation corresponding to the multiplicand 0.707, and the output signal from network **52** is applied to summing circuit **62** with the same attenuation. The right back signal R_b is similarly applied to both of phase-shift networks **54** and **56**, the output signals from which are respectively applied with 0.707 attenuation to summing circuits **60** and **62**. The summing circuits **60** and **62**, which are of conventional design and well known to ones skilled in the art, are operative to produce respective composite signals L_T and R_T at their corresponding output terminals **64** and **66**. These signals may be applied to the left and right terminals of a stereophonic disc record cutter, for example, or to the two recording heads of a two track tape recording apparatus, or to any other known two-track medium, in a manner which will be apparent to ones skilled in the art.

Although the encoding apparatus has been thus far described in terms of four input signals, if it is desired to have a signal appear centrally in the reproducing system, a center signal designated by the arrow labeled C, may be applied equally and in phase to terminals **40** and **46**, or to the terminals **42** and **44**, or to all four terminals simultaneously, as indicated by the curved arrows. It will be evident that the C signal will be subjected to the phase shift of those of networks to which it is applied, in the example of FIG. **7** to networks **48–58**, and will become part of the composite signals L_T and R_T.

The nature of the composite signals appearing at terminals **64** and **66** will be seen from the phasor diagrams adjacent the terminals. It is seen that each of these signals contains a predominant front loudspeaker signal, L_f' and R_f', respectively, both of which are shifted in phase relative to input signals L_f and R_f by $(\psi+45°)$. The L_T signal further includes signals L_b' and R_b' at 90° to each other, with the L_b' signal leading, and in a 45° relationship with L_f'. The C signal appears as C' in both composite signals in the same relative phase position as the signals L_f' and R_f'.

It is significant to note that the R_T signal contains in addition to the signal R_f', the two signals L_b' and R_b' at 90° to each other. It will be seen, however, that they are reversed in phase relative to the L_T signal, with R_b' leading and signal L_b' lagging relative to the corresponding signals on terminal **64**. As noted earlier, how-

ever, the signal C′ is again in the same relative position with respect to the corresponding signal on terminal **64.**

Another significant feature of the composite signal is that the L_b and R_b components in one composite signal are in quadratuure with the corresponding components in the other composite signal, and that the L_b component in the L_T composite signal leads the corresponding component in the R_T signal and that the R_b component in the R_T signal leads the R_b component in the L_T signal.

Since the signals L_f' and R_f' usually will be incoherent signals, if recorded on a stereophonic disc record they will appear independently as separate modulations of the left and right channels. The signals C′ being in phase at both terminals **64** and **66** will cause lateral modulation of the disc record. The fact that signal L_b' at terminal **64** leads the L_b' signal at terminal **66** by 90° will cause modulation of the record groove in a clockwise advancing spiral, in the manner of a right-hand screw thread. Similarly, because signal R_b' at terminal **64** lags behind signal R_b' at terminal **66** by 90° will result in a counter-clockwise helix, in the manner of a left hand thread. Thus, it is seen that the five signals applied to the matrix system of FIG. **7** may be applied to a stereophonic disc record as five distinct types of modulations, namely, modulation of the left and right walls of the groove, lateral modulation, and clockwise and counter-clockwise helical modulation.

The form of modulation on the disc record, as viewed from the point of view of the cutter tip, looking in the direction of motion of the groove, is illustrated in FIG. **8.** The L_f' signal causes motion at 45° to the horizontal, the R_f' signal causes motion at −45° to the horizontal, and the C′ signal causes lateral or horizontal modulation. These three modulations, it will be recognized, are identical with those which obtain in the cutting of a conventional stereophonic record. As a significant departure from conventional practice, there is, additionally, clockwise circular modulation L_b, corresponding to the left back loudspeaker signal, and counter-clockwise circular modulation R_b, corresponding to the right back loudspeaker signal. Since the L_b and R_b modulations have a significant horizontal component (as projected on the line C) it is evident that they will produce equivalent signal components in the horizontal mode, therefore assuring full compatability with a monophonic phonograph player. An important advantage of this method of combining the input signals is that the stereophonic record or tape can be replayed over any stereophonic or monophonic player with full and complete reproduction of all of the sounds recorded on the record.

Upon playback, the composite signals L_T and R_T depicted by the phasor diagrams of FIG. **7** may be decoded by the decoder described in above-mentioned U.S. Pat. No. 3,813,494 to produce four output signals for display on four loudspeakers **70, 72, 74** and **76** positioned, as illustrated in FIG. **9,** at the left front, right front, left back and right back corners, respectively, of a listening area. Phasor diagrams of the signals appearing on each of these loudspeakers as produced by the referenced decoder are presented adjacent their respective loudspeaker. It will be observed that the signals L_f'', R_f'', L_b'' and R_b'' predominate in loudspeakers **70, 72, 74** and **76,** respectively. The signals from other channels appearing in each of the main channels are about 3 dB lower in level than the principal signals and, accordingly, tend not to be prominent in the mind of the listener; rather, he will hear primarily the four independent channels being presented on the four loudspeakers.

While it is important in the encoding process to maintain a 90° relationship between the phasors 0.707 L_b and 0.707 R_b, it will be seen from FIG. **10** that the positions of the phasors L_f and R_f relative to the L_b and R_b components may be arbitrarily chosen insofar as decoding is concerned. That is, any decoder designed to decode the composite signals L_T and R_T shown in FIG. **7** will also satisfactorily decode the signals L_T' and R_T' shown in FIG. **10,** regardless of the size of the angles α_1 and α_2 between phasors L_f and 0.707 L_b, and between phasors R_f and 0.707 R_b, respectively. Since the α's (45° in FIG. **7**) are established by ψ-networks **48** and **58,** by suitable design of these networks it is possible to place phasors L_f and R_f at any desired position with respect to the other two phasors in the group. An especially beneficial relationship is established by making both the angles α=90° so that in the phasor group portraying L_T', the phasor L_f coincides with phasor 0.707 R_b, and in the other phasor group, the phasor R_f coincides with phasor 0.707 L_b. This relationship is readily obtained by modifying ψ-networks **48** and **58** so that instead of providing a phase-shift (ψ+45°) they provide a phase-shift (ψ+90°). An important benefit of this modification is that the encoding function can be performed with only four ψ-networks, instead of the six required in the encoder of FIG. **7.**

Referring now to FIG. **11,** an encoder embodying this improvement has four input terminals **80, 81, 82** and **83** to which input signals L_f, L_b, R_b and R_f represented by phasors corresponding to the same signals depicted in FIG. **7,** are respectively applied. Rather than being applied directly to a ψ-network as in the system of FIG. **7,** input terminals **80** and **82** are connected to a summing junction **84** which is operative to add a unity measure of signal L_f to 0.707 of signal component R_b. Similarly, terminals **81** and **83** are connected to a second summing junction **85** which is operative to add a unity measure of signal R_f to 0.707 of signal L_b. Terminal **81** is also connected to the input of a ψ-network **86** which introduces a relative phase-shift of ψ to the L_b signal, and terminal **82** is connected to the input of a second (ψ+0°) network **85.** The output signals from summing junctions **84** and **85** are respectively applied to the input terminals of ψ-networks **87** and **88,** both of which introduce a relative phase-shift of (ψ+90°).

The full output of -network **87** is added in summing junction **90** to 0.707 of the output of network **86,** and similarly, the full output of ψ-network **88** is added at summing junction **91** to 0.707 of the output of ψ-network **89.** As a consequence of this phase-shifting and combining of signals, there appears at output terminal **92** a composite signal L_T' depicted by phasor group **94,** and at output terminal **93** a composite signal R_T', depicted by phasor group **95.** It will be observed that there is a one-to-one correspondence between phasor groups **94** and **95** and the corresponding phasor groups in FIG. **10** if the angle α in the latter group is set at 90°.

That the encoder of FIG. **11** is compatible with decoders intended for use with the signals encoded in accordance with the system of FIG. **7** is demonstrated by the comparative analysis presented in FIG. **12,** as applied to the decoder described in U.S. Pat. No. 3,784,744. This decoder includes a pair of input termi-

nals **100** and **102** to which the composite signals L_T and R_T are respectively applied. The signal applied to terminal **100** is applied to both and is phase-shifted by a pair of ψ-networks **104** and **106**, and the composite R_T signal applied to input terminal **102** is applied to both of ψ-networks **108** and **110**. These ψ-networks are of the type previously described, the networks **104** and **110** introducing a phase-shift of $(\psi'+0°)$ and networks **106** and **108** introducing a phase-shift of $(\psi'+90°)$. It will be noted that the reference angle is designated ψ' instead of ψ, as used in the encoder; this is to call attention to the fact that the reference phase-shift in the decoder need not be the same as in the encoder, provided the same reference phase-shift is used in all four of ψ-networks **104, 106, 108** and **110**. The output signals from networks **104** and **110** are applied directly to the left-front output terminal **112** and to the right-front output terminal **114**, respectively. Equal portions of the output signals from networks **106** and **110** are summed in a summing junction **116**, the output of which is applied to the left-back output terminal **118**, and equal portions of the outputs of networks **104** and **108** are summed in a second summing network **120**, the output of which is applied to the right-back output terminal **122**.

A comparison will now be made of the performance of the decoder of FIG. **12** in response to signals encoded with the encoder of FIG. **7**, and to composite signals encoded in accordance with the encoder of FIG. **11**. Phasor groups corresponding to signals encoded with the encoder of FIG. **7** are shown in dotted lines, and the phasor groups encoded by the encoder of FIG. **11** are shown in solid lines. Phasor groups **130** and **132** portray the two input signals L_T and R_T which, upon being shifted in phase by the all-pass networks **104**, 106, 108 and **110** appear as new phasor groups **134**, 136, 138 and **140**. The phasors in these latter four groups are labeled with a prime to differentiate them from the corresponding phasors prior to introduction of the relative phaseshifts. The signal represented by phasor group **134** appears at output terminal **112** as phasor group **142** and contains a dominant component L_f' together with the smaller components $0.707L_b'$ and $0.707R_b'$. The phasor groups **136** and **140** after summing in junction **116** result in a signal at output terminal **118** represented by phasor group **144** containing a dominant phasor L_b' and subsidiary phasors $0.707L_f'$ and $0.707R_f'$. The sum of phasors **134** and **138** appearing at the output of summing junction **120** (output terminal **122**) is a composite signal represented by phasor group **146** having a dominant phasor R_b' accompanied by subsidiary signals $0.707R_f'$ and $0.707L_f'$. Finally, the phasor group **140** appears at output terminal **114** as phasor group **148**, and contains a dominant signal R_f' together with subsidiary signals $0.707R_b'$ and $0.707L_b'$. Thus, the decoded signals appearing at output terminals **112, 118, 122** and **114** each contains its appropriate dominant signal together with signals from two other channels reduced in amplitude by the factor 0.707. It will be noted that the two principal front channel phasors, namely L_f' in group **142** and R_f' in group **148** are in phase, and that the two principal back channel vectors, L_b' in phasor group **144** and R_b' in group **146**, are also in phase with each other, but not in phase with the L_f' and R_f' phasors.

It will now be demonstrated that this favorable phase relationship is also achieved when signals encoded with the encoder of FIG. **11** are decoded in the decoder of FIG. **12**. It will be remembered from the description of FIG. **11** that the encoded signals L_T and R_T are as portrayed by phasor groups **150** and **152**, the former after being acted upon by ψ-networks **104** and **106** appearing as phasor groups **154** and **156**, respectively, and the R_T signal after transmission through ψ-networks **108** and **110** appearing as phasor groups **158** and **160**, respectively. Phasor group **154** appears at output terminal **112** as phasor group **162**, and phasor group **160** appears at output terminal **114** as phasor group **164**. These output signals contain predominant signals L_f' and R_f', respectively, which are in phase with each other, and each includes subsidiary signals $0.707R_b'$ and $0.707L_b'$.

The phasor groups **156** and **160** upon being summed in summing junction **116** produces at output terminal **118** the composite signal portrayed by phasor group **166**, and the sum of the signals represented by phasor groups **154** and **158** appearing at the output terminal **122** of summing junction **120** is as portrayed by phasor group **168**. It will be noted that phasor groups **166** and **168** contain predominant phasors L_b' and R_b', respectively, which are in phase with each other, and also in phase with the predominant phasors in groups **162** and **164**, and each accompanied by two subsidiary signals $0.707R_f'$ and $0.707L_f'$. Comparison of phasor groups **162** and **142, 166** with **144, 168** with **146**, and **164** with **148** reveals that they contain the same respective subsidiary signals in the same magnitude and in the same intergroup phase relationships. Therefore, the respective signals are capable of properly activating the enhancing logic and control circuits described in U.S. Pat. No. 3,784,744.

Another advantage of the encoder of FIG. **11** will be seen from a comparison of phasor groups **144** and **146**, for example, in each of which there is shown in dotted line a side signal L_s, which results from applying equal amplitude signals to the left-front and left-back terminals of the encoder. Because of the angular relationship between phasors $0.707L_f'$ and $0.707L_b'$ in phasor group **144** as compared to the quadrature relationship between the corresponding phasors in group **166**, the resulting phasor L_s in group **144** is of greater magnitude than the corresponding phasor in group **166**. The absence of exaggeration of the L_s signal is of significant advantage, and by symmetry, it will be recognized that exaggeration of an R_s signal which would result from application of equal amplitude signals to terminals **82** and **83** of the encoder of FIG. **11** is likewise avoided.

In summary, the encoder of FIG. **11** offers the following significant advantages over the encoder of FIG. **7**: (1) it provides encoding with four, instead of six ψ-networks, with an attendant reduction in the cost of the encoder; (2) it produces encoded signals which, upon decoding, cause the predominant signals to all be in phase; and (3) it avoids exaggeration of output signal intensity from the decoder when equal signals are applied to the side terminals of the encoder.

FIG. **13** illustrates a modification of the encoder of FIG. **11**, differing therefrom in the manner in which the four input signals are added and phase-shifted. In this case, the full L_f signal applied to terminal **170** is added in a summing junction **178** to 0.707 of the R_b signal applied to input terminal **174**, and the full R_f signal applied at input terminal **176**, is added in summing junction **180** to 0.707 of the L_b signal applied at input termi-

nal **172.** The sum signals from summing junctions **178** and **180** are transmitted by respective ψ-networks **182** and **184** and are added in respective summing junctions **186** and **183** to 0.707 of signals L_b and R_b, respectively, after being shifted in phase by (ψ+90°) in respective ψ-networks **190** and **192.** The L_T and R_T signals appearing at output terminals **194** and **196,** represented by phasor groups **198** and **200,** respectively, are similar to the corresponding phasor groups **94** and **95** in FIG. **11** except that in group **198** the $0.707R_b$ phasor leads the $0.707L_b$ phasor, whereas in group **94** the L_b phasor leads the R_b phasor; the positions of the L_b and R_b phasors in groups **200** and **95** are similarly interchanged. While this decoder provides perfectly consistent signals, it has the slight disadvantage stemming from the fact that the $0.707R_b$ phasor in group **198** leading the corresponding signal in phasor group **200** tends to cause this right-back signal to appear to lean slightly toward the left-front channel when the record is replayed stereophonically over two loudspeakers. By symmetry, the left-back signal likewise will tend to lean slightly to the right when the record is replayed stereophonically. Thus, while the alternative encoder of FIG. **13** produces acceptable composite signals for reproduction over four loudspeakers, it is inferior to the encoder of FIG. **11** if the record carrying the encoded signals is to be played over a two-channel stereophonic playback apparatus.

By seemingly slight modifications of the encoder of FIG. **13,** and of the decoder shown in FIG. **12** (which is fully described in U.S. Pat. No. 3,784,744), the performance of the overall system can be significantly improved, particularly in its ability to resolve ambiguities in cases when the sound signals are "panned"; that is inserted into adjacent channels in an in-phase relationship. The cause of such ambiguities will become apparent from analysis of the decoded signals delivered by the decoder of FIG. **12** which, it will be remembered, contain predominant signals L_f, L_b, R_f and R_b, respectively, together with two "contaminating" signals from other channels. Actually, the contaminating signals are not noticed when all four predominant signals are simultaneously present, as when four different performers produce four parts of a musical selection in all four channels, since there is sufficient mixing of sound in the room or listening area that the presence of the contaminating signals in the individual channels is inconsequential. They are noticeable, however, when sound is present in only a single channel, or in at most two channels, because in these instances, when the sound should be coming from a single loudspeaker or from two loudspeakers, it is instead heard from all four, which is readily noticeable and sometimes objectionable. This situation is improved, and the realism of four channel reproduction enhanced by the logic and control systems described in the aforementioned U.S. Pat. No. 3,784,744 which recognize the presence of sounds in individual channels and generate signals for controlling the gain of gain control amplifiers in the individual loudspeaker circuits in response to the instantaneous presence of the predominant signals. Thus, if a signal appears only in the left-front channel, for example, (and which, because of the protocol of the decoder, also appears at reduced level in both of the back channels) the logic functions to enhance the gain of the front loudspeaker amplifiers and to turn down the gain of the back loudspeaker amplifiers thereby to cause the sound to appear to originate at the left-front loudspeaker only. The logic and control circuitry operates similarly with respect to the other three loudspeakers with the consequence that when artists are performing in concert in all four channels the gains of the respective amplifiers are increased and decreased to instantaneously enhance the channel or channels in which signals are predominant at a particular instant to give a highly realistic replication of the original four channel program.

The above-described methods of encoding four signals into two and decoding them back into four works very well in the majority of circumstances, one exception, however, being when the sounds are panned, and then only in two specific instances: namely, when the sound is panned exactly between the two front channels by application of equal amplitude signals to the L_f and R_f encoder terminals, or when it is panned precisely between the two back channels L_b and R_b. It can be shown that in these two circumstances the modulation produced on the stereophonic disc is the same when the two front channels are panned as it is when the two back channels are panned. Consequently, the logic and control system used with the decoder is unable to distinguish whether such panned sound signal belongs to the front channels or to the back channels, resulting in an ambiguity. In accordance with another aspect of this invention, this ambiguity is resolved by another embodiment of the encoder and modification of the decoder so as to provide a significant improvement in performance of the system.

The alternative encoder, illustrated in FIG. **14,** has four input terminals **210, 212, 214** and **216** to which the four signals L_f, L_b, R_b and R_f, depicted as in-phase signals of equal amplitude, are respectively applied. The total L_f signal is added in a summing junction **218** to −0.707 of the R_b signal, the output of the summing junction being applied to a phase-shifting network **220** which introduces a reference phase-shift ψ. The full R_f signal at terminal **216** is added in summing network **222** to 0.707 of the L_b signal appearing at input terminal **212,** and the output is passed through the ψ-network **224,** which also provides the reference phase-shift ψ. The L_b and R_b signals are also applied to respective ψ-networks **226** and **228,** each of which provides a phase-shift of (ψ+90°). The full signal appearing at the output of network **220** is added in a summing circuit **230** to −0.707 of the signal appearing at the output of network **226** to produce at its output terminal **232** a composite signal designated L_T. Similarly, the full signal from network **224** is added in summing junction **234** to 0.707 of the signal from network **228,** the latter in this case being in the positive sense. The signal appearing at the output terminal **236** is the composite signal designated R_T. As in the case of the other encoders, the signal L_T and R_T may be transmitted by FM multiplex radio, or they may be recorded on any two-channel medium such as a two-track tape or stereophonic record for later reproduction.

The significance of the modifications to the encoder of FIG. **13** to provide the encoder of FIG. **14** (namely, the reversal of the phase of the 0.707 terminals of the two summing circuits in the upper half of the diagram) will be appreciated from an analysis of the phasor relationship of the L_T and R_T composite signals portrayed as phasor groups **238** and **240,** respectively. It will be observed that phasor group **238** consists of the signal

L_f (which although shown in the same phase relationship as the input signal L_f has a ψ-as-a-function-of-frequency angle difference between them), a signal $0.707R_b$ in a negative sense with respect to its corresponding input phasor, and a $0.707L_b$ signal which lags phasor $0.707R_b$ by 90° because of the action of network **226.** Phasor group **240** consists of the original signal R_f in the same relative phase position as its corresponding input signal, a signal $0.707L_b$ in phase with the R_f signal, and a $0.707R_b$ signal lagging the $.707L_b$ signal by 90° due to the action of ψ-network **228.** As has been pointed out hereinabove, in the interest of providing better realism of image placement when the record is played in conventional stereophonic mode over two loudspeakers, it is preferable to arrange the phasor $0.707L_b$ in phasor group **240** to lag behind the corresponding phasor in phasor group **238,** and conversely, to arrange the phasor $0.707R_b$ in phasor group **238** to lag behind the corresponding phasor in group **240.** Alternatively, the positions of phasor groups having its component phasors oriented as depicted at **238** and **240** can be interchanged and still enjoy the benefits of the invention. For example, simply by reversing the order in which the input signals are applied to the encoder—that is, R_f to terminal **210,** R_b to terminal **212,** L_b to terminal **214** and L_f to terminal **216**—the composite signal R_T having the components shown in parentheses in phasor group **238** will appear at output terminal **232** and the composite signal L_T having the components shown in parenthesis in phasor group **240** will appear at output terminal **236.**

Referring now to FIG. **16,** the effect of panning is to divide the signal (as by means of two coupled attenuators) between two channel inputs. At the mid-point of the panned operation, the signal becomes divided evenly between the front channels L_f and R_f, or between the back channels L_b or R_b; this condition will now be examined. The phasor groups **238** and **240** from FIG. **14** are repeated here as phasor groups **250** and **252,** respectively, and the panned center signals have been added. The front center signal, C_f, is placed in the proportion $0.707C_f$ and in-phase in the phasor groups **250** and **252,** appearing as phasors **254** and **256.** Since these phasors are equal and in-phase the signals L_T and R_T combine to produce a horizontal motion of the cutter stylus; accordingly, the center front signal C_f appears as a horizontal arrow **246** in FIG. **15.** From the discussion thus far, it is seen that FIG. **15** depicts the left front channel phasor, L_f, the center channel phasor, C_f, and the right-front channel phasor, R_f, in a relationship which those skilled in the art will recognize as portraying the modulation of a conventional stereophonic record.

Reverting now to FIG. **16,** it will be noted that the center-back signal, C_b, is divided in the proportion 0.707 in the left back and right back channels, and since these two phasors already appear as a 0.707 fraction, the corresponding fraction of the C_b signal is 0.5 in phase with the $0.707L_b$ phasor and 0.5 in phase with the $0.707R_b$ phasors in both phasor groups. With this convention in mind, it is seen that the two phasors in each group add to the larger phasors $0.707C_b$ in each of the phasor groups **250** and **252**; however, it should also be observed that the phasor $0.707C_b$ in phasor group **250** is out-of-phase with the corresponding phasor in group **252.** This is an important quality of the encoder of FIG. **14** because now the center back signal, C_b, is of an entirely different character than the center front signal C_f. It will be recognized that the signal, C_b, having an out-of-phase relationship in the two channels will result in a vertical modulation of the record groove, which is depicted by the arrow **248** in FIG. **15.** It will be realized that any signal recorded in this manner cannot be reproduced by a monophonic phonograph pick-up, nor by the monophonic section of an FM multiplex transmitting station; consequently, when using the encoder of FIG. **14** the center-back location should preferably be used for occasional sounds such as reverberation, motion during panning, etc., and not for the placement of an important artist, because he would not be heard when the signal is broadcast over AM radio or over monophonic FM radio. Such signals would, however, be fully audible with stereophonic or quadraphonic modes or reproduction, and all other locations of the artist would be transmitted satisfactorily.

Another significant feature of the FIG. **14** encoder is illustrated by the phasor groups **256** and **258** in FIG. **17,** the former depicting the situation which results when the phasor groups **250** and **252** of FIG. **16** are added and the latter depicting the situation when the composite signal R_T (phasor group **252**) is subtracted from L_T (phasor group **250**). It will be noted that when L_T and R_T are added the phasors L_f, L_b, R_b and R_f all have an amplitude equal to unity, whereas the front center signal, C_f, is augmented by a factor 1.414, which is exactly what happens when a stereophonic record is played over a monophonic player. The back center signal, C_b, is cancelled, however, because of the aforementioned out-of-phase relationship. When the phasor groups are subtracted, the phasors L_f, L_b, R_b and R_f again all appear with unity amplitude, but this time the center back signal, C_b, is augmented by the factor 1.414 while the center front signal, C_f, is canceled. The relationship portrayed by phasor groups **256** and **258** are extremely important since they indicate that if only a center front signal is present (i.e., no center back signal) the phasor group **256** will be greater than group **258,** and, conversely, if there is only a center back signal but no center front signal, the phasor group **258** will be larger. This interesting property is used to advantage to enhance the operation of the decoder to be utilized with the encoder of FIG. **14,** all as fully described in U.S. Pat. No. 3,821,471.

Additional features and attributes of the above-described encoders will now be described in connection with FIG. **18** which illustrates the encoder of FIG. **14** modified as described above to produce the composite signals L_T, R_T having the components shown in parentheses in phasor groups **238** and **240** of FIG. **14.** More specifically, in the encoder of FIG. **18** the full L_f signal is added in a summing junction **326** to 0.707 of the R_b signal, the output signal from the summing junction **326** being applied to an all-pass phase-shifting network **328** which introduces a reference phase-shift ψ which varies as a function of frequency. The full R_f signal at terminal **316** is added in a second summing junction **330** to −0.707 of the L_b signal appearing at input terminal **312,** and the sum signal is passed through a second ψ-network **332** which also provides the reference phase-shift ψ. The L_b and R_b signals are applied to respective ψ-networks **334** and **336,** each of which provides a phase shift of (ψ-90°) and wherein the ψ-functions are essentially the same. The full signal appearing at the output terminal of network **328** is added in a

summing circuit **338** to 0.707 of the signal appearing at the output terminal of network **334** to produce at its output terminal **340** a composite signal designated L_T. Similarly, the full signal from network **332** is added in summing junction **342** to −0.707 of the signal from network **336** to produce at its output terminal **344** a composite signal designated R_T.

The composite signals L_T and R_T are characterized by the phasor groups **346** and **348**, respectively, in FIG. **18A**, from which it will be observed that in the composite signal L_T the L_f signal has unity amplitude and the signal 0.707 L_b is in quadrature with L_f and in a lagging relationship thereto. The signal 0.707R_b is in phase with the L_f signal and consequently is also in quadrature with the signal 0.707L_b. In the R_T composite signal the R_f signal has unity amplitude, the 0.707R_b signal appears in leading quadrature relationship therewith, and the 0.707L_b signal is out-of-phase with respect to the R_f signal. The 0.707L_b in phasor group **346** is in quadrature and leads the corresponding signal in phasor group **348**, while the 0.707R_b signal in phasor group **348** is in quadrature with and leads the corresponding signal in phasor group **346**.

When the composite signals depicted by phasor groups **346** and **348** are decoded with decoders of the type in current commercial use, namely, those of the type described in applicant's U.S. Pat. No. 3,821,471, four output signals represented by the phasor groups designated L_F', R_F', L_B' and R_B' in FIG. **18B** are obtained. These four output signals respectively contain the signal components L_f, R_f, L_b and R_b as predominant components, each accompanied by lower level signals from two other channels.

The encoder of FIG. **18** allows the signal to be panned around the periphery of the quadraphonic area while retaining omnidirectional power fidelity, and specifically, it permits any set of incoherent signals to be placed, as by means of a panning potentiometer, anywhere around a circle, especially at any of the cardinal points L_f, C_f, R_f, C_R, R_b, C_b, L_b and C_L represented by the circular areas in FIG. **18C**. The signals at all of the doubly cross-hatched areas are transmitted by monophonic transmission; however, signals are not monophonically transmitted to the position C_b, which is singly cross-hatched, because such a signal would be represented by vertical stylus motion on a stereophonic disc record and therefore not reproducible on monophonic playback apparatus.

It is suggested by the horizontal shade lines in FIG. **18C** that the center part of the quadrangle should be avoided, not that this in itself produces unacceptable results, but it does result in improper image placement. For example, if a signal is panned to the center position, represented by the dashed-line circle labeled C, it would be applied equally to the four input terminals **310**, **312**, **314**, and **316** of the encoder. It will be seen from the phasor diagrams of FIG. **18A** that the encoder action causes the center signal C (represented by the dashed line phasor) to be relatively large, this because it represents the phasor sum of the three fundamental phasors L_f, 0.707R_b and −0.707L_b. However, in the R_T composite signal, represented by phasor group **348**, the center signal C, again the phasor sum of the three fundamental phasors R_f 0.707R_b and −0.707L_b, is relatively smaller. Thus, instead of obtaining two generally equal amplitude signals, two signals of unequal magnitude are produced, with the consequence that a center signal, when the record is played on a stereophonic player, will tend to appear shifted toward the left in the stereophonic sound field. By similar analysis of the phasor diagrams of FIG. **18B** it can be shown that upon decoding of the L_T and R_T signals to produce four output signals, the center signal would cause the signals in the L_F' and R_B' reproduced channels to be relatively larger, than the signals in the R_F' and L_B' channels to be relatively smaller. Other inconsistencies also appear when one attempts to position the signals along the diagonals of the quadraphonic area.

A solution for the just-described inconsistencies in reproduction which occur when certain types of signals are combined with the encoder of FIG. **18** is described in applicant's aforementioned U.S. Pat. No. 3,761,628 but will be reviewed here for the sake of completeness of the background of, and need for other alternative encoders, the description of which follows. The encoder of U.S. Pat. No. 3,761,628, which provides a mode of encoding characterized as "internal", is illustrated in FIG. **19**, and although differing little from the encoder of FIG. **18** provides significant improvement in the subsequent reproduction of signals encountered in recording environments of the kind discussed above. In this case, the full left-front (L_f) and right-front (R_f) signals appearing at input terminals **310'** and **316'**, respectively, are applied directly to an input terminal of respective output summing networks **350** and **352**, thus by-passing their respective ψ-networks **328** and **332**. The L_b and R_b signals, appearing at input terminals **312'** and **314'**, respectively, are each applied as before through respective ψ-networks **334** and **336**, which introduce a relative phase-shift of 90°, to the summing junctions **350** and **352** at an amplitude level of 0.707; in the case of the R_b signal, in a negative sense relative to the L_b signal. The L_b and R_b signals, with their amplitudes reduced by 3db by the summing junctions **330'** and **326'**, are also transmitted through ψ-networks **332** and **328**, respectively, to summing junctions **352** and **350** for addition to the other signals applied thereto.

The effect of this modification is illustrated by the phasor groups **354** and **356** in FIG. **19A** which respectively represent the composite signals appearing at output terminals **340'** and **344'**. It will be seen that the relative phase relationship between the L_f and R_f components remains unchanged, because all that has happened is that the reference phase shift function ψ has been removed equally from both of these signals. Also, the relative positions of phasors 0.707R_b and 0.707L_b are the same as they are in FIG. **18A**. In essence, the above-described modification introduces a differential reference function ψ between the back signals R_b and L_b and the front signals L_f and R_f. The introduction of this frequency-dependent function ψ causes any coherent signals panned between the front and the back channels to become largely incoherent with the result that the signals are appropriately distributed between the front and back of the decoder in a manner such that a signal panned to the center position appears to the listener to be directly above him; or the signal can be panned between the respective diagonals. (This action refers, of course, to voice and music signals, rather than to steady-state sine-wave signals.) Because of the relatively unchanged position of the phasors in the two composite signals, they are readily decoded by the decoder described in U.S. Pat. No. 3,821,471; phasor diagrams of the four decoded signals are illustrated in FIG.

19B. It will be noted that the predominant L_f and R_f signals in the front channels are in-phase with each other, and that the predominant L_b and R_b signal components in the back channels are also in phase with each other, but that they are not in phase with the predominant front channel signals as they are in FIG. **18B**.

The doubly cross-hatched area of the quadrangle illustrated in FIG. **19C** shows the preferred operation of a panning potentiometer with the encoder of FIG. **19**. The horizontally cross-hatched area is less desirable, especially for signals panned to the C_L and C_R positions, in that they suffer a certain amount of coloration because the power in either the L_f or R_b signal, as the case may be, is not uniform with frequency. Also, with certain stereophonic arrangements and listener position, some C_L and C_R signals appear not to be symmetrically placed in the stereophonic field. While these relatively insignificant oddities occur so infrequently as not to be of serious importance, since they have been the subject of some criticism, it is desirable that they be remedied.

The deficiency of the encoder of FIG. **19** in reproducing center-left and center-right signals in the stereophonic format, is overcome by the encoder of FIG. **20** which has four input terminals **310'**, **312'**, **314'** and **316'** to which input signals L_f, L_b, R_b and R_f originating with the quadraphonic program are respectively applied. The full L_f signal is added in a summing junction **370** to 0.707 of the L_b signal, and the full R_f signal is similarly added to $0.707R_b$ in a summing junction **372.** The resulting sum signals from summing junctions **370** and **372** are coupled via respective ψ-networks **374** and **376** to respective summing junctions **378** and **380.** The L_b signal appearing at input terminal **312'** is also applied directly to ψ-network **382,** which introduces a relative phase-shift of (ψ-90°), and thence to the summing junction **380** where 0.707 of the signal is added to the signal from ψ-network **376.** Similarly the R_b signal appearing at input terminal **314'** is transmitted through ψ-network **384,** which also introduces a relative phase-shift of (ψ—90°), and 0.707 of the resulting signal is added in summing junction **378** to the output of ψ-network **374.**

As a consequence of this relative phase-shifting and combining of signals, there appears at output terminal **386** a composite signal L_T depicted by phasor group **388,** and at the output terminal **390** a composite signal R_T depicted by phasor group **392.** It will be observed that the L_f and R_f components of the respective composite signals are in phase and that the L_b and R_b components in the two composite signals are in quadrature relationship. The phasor groups **388** and **392** closely resemble the phasor groups produced by the encoder illustrated in FIG. **13,** except that the positions of the back components of the two composite signals are interchanged so as to be better decoded with current commercial stereo-quadraphonic decoders, namely, of the type described in U.S. Pat. No. 3,761,628.

When the four program signals are recorded in this manner, center-left and center-right signals are flawlessly reproduced when a stereophonic record carrying the composite signals is reproduced in the stereophonic mode, and also insures that all in-phase signals, no matter how they are panned among the four channels, are portrayed in both the stereophonic and the monophonic formats. This occurs because of the complete symmetry of the phasor groups depicting the composite signals L_T and R_T which, in turn, insures that when the two composite signals are summed (as occurs in monophonic reproduction), as shown in FIG. **20D**, all of the cardinal signals, L_f, C_f, R_f, C_R, C_L, L_b, C_b and R_b are reproduced at about the same level; i.e., within 3db of each other, the C_f, C_b, C_R and C_L signals being larger than the rest. Thus, the encoder of FIG. **20** overcomes the complaint levied against the encoder of FIG. **18** that a center-back signal disappears in the monophonic mode.

On the other hand, it is seen from analysis of the phasor diagrams of FIG. **20B**, which depict the decoded signals delivered by a decoder of the kind described in U.S. Pat. No. 3,761,628, that while all the signals around a circle (other than the C_b signal) are correctly reproduced, the C_b signal (and, as a matter of fact, all center signals within the vertically cross-hatched area of FIG. **20C**), is displayed in phase at the front channels and in antiphase at the back channels; that is, precisely as if they were center-front signals. It is because of this tendency of all center signals, upon decoding, to be conveyed toward the center front that the encoder of FIG. **20** is termed a forward oriented encoder.

It will be apparent that the encoder of FIG. **20** is not intended as a replacement for the encoder of FIG. **18** for quadraphonic environments requiring display of panned-around signals or center-panned signals, but, rather, it would be used selectively when the user wishes to preferentially display center-left or center-right signals. Such signals decode very well with the decoder of U.S. Pat. No. 3,761,628, providing a left-right separation of 7.6db as compared to the 4.8db separation that is obtained for such signals when they are encoded with the apparatus of FIG. **18.** The encoder of FIG. **20** would also be used if one wished to display front signals, such as orchestral signals, which normally spill beyond the confines of the L_f and R_f channels.

FIG. **21** illustrates another encoder, which may be termed a backward oriented encoder because it places all signals appearing along the center axis of the quadraphonic area into a back orientation upon decoding. In common with the other disclosed encoders, four audio information signals from a quadraphonic program, L_f, L_b, R_b and R_f, are applied to input terminals **310'**, **312'**, **314'** and **316'**, respectively. As in the encoder of FIG. **20,** the full L_f signal is added in summing junction **370'** to 0.707 of the L_b signal, and the full R_f signal is added to 0.707 of the R_b signal in summing junction **372'**. The sum signal from summing junction **370'** is coupled through ψ-network **384'**, which introduces a relative phase-shift of (ψ-90°), and is added in summing junction **400** to 0.707 of the R_b signal after being phase-shifted by the angle ψ by ψ-network **374'**. Similarly, the sum signal from summing junction **372'**, after being subjected to a relative phase-shift of (ψ—90°) in ψ-network **382'**, is added, in the negative sense, to —0.707 of the L_b signal after being phase-shifted by the reference angle ψ by ψ-network **376'**. Thus, there are produced at output terminals **404** and **408** a pair of composite signals L_T and R_T depicted by phasor groups **406** and **410,** respectively (FIG. **21A**).

It will be observed that the composite signals delivered by the encoder of FIG. **21** are similar to the composite signals produced by the encoder of FIG. **18,** except that the left-front signal is shifted into a lagging quadrature relationship with respect to the back-channel signals, while the right-front signal is shifted into a leading quadrature relationship with respect to

the back-channel signals. Upon decoding in a decoder of the kind described in U.S. Pat. No. 3,761,628, the output signals depicted by the phasor groups of FIG. **21B** are derived; it will be noted that the predominant L_b and R_b signals (the back channels) are in phase for either center-front (C_f) or center-back (C_b) signals, and that these signals are in anti-phase relationship at the front channels. Thus, while all of the signals for the cardinal points L_f, C_L, L_b, R_f, C_R and R_b will be properly reproduced, any signals present along the center line of the quadraphonic area will, upon decoding, be shifted to the back and, moreover, will not be reproduced on a monophonic reproducer. Thus, the backward oriented encoder of FIG. **21** is not as useful as the forward oriented encoder; its main utility consists in its ability to pan signals somewhat to the left and somewhat to the right of the back channels L_b and R_b.

It will be evident from the foregoing discussion that of the several encoders disclosed herein, the ones of FIG. **18** (and the closely similar encoder of FIG. **14**) have the most universal application, and that the encoders of FIGS. **19, 20** and **21** are intended for use in recording environments in which signal conditions may be present which, if the signals were encoded with the encoder of FIG. **18,** would not be optimally reproduced, particularly in the stereophonic and monophonic formats. Since such unusual signal conditions may be only occasionally present, it is desirable that the recording engineer be able to conveniently select the encoding mode which best suits his requirements at any given time. Inspection of the encoders of FIGS. **18, 19** and **20** reveals that they all employ only four ψ-networks, which are the same in all three encoders. Each also has four summing networks or junctions, but their characteristics differ from encoder to encoder. However, with proper selection of alternative summing junctions and an appropriate arrangement of switches, the features of all three encoders may be incorporated into one encoding system which permits the user to select a desired encoding mode.

A preferred circuit arrangement for accomplishing this, illustrated in FIG. **22,** has four input terminals **310'**, **312'**, **314'** and **316'** adapted to respectively receive the four input signals L_f, L_b, R_b, and R_f of a quadraphonic program. Each of the input terminals is connected to the input terminal of a respective section of a four-pole, double-throw switch **420,** the switch contact blades of which are designated **420***a*, **420***b*, **420***c* and **420***d*, respectively. The switch is operable from the position shown (designated position A) at which the switch contact blades respectively engage terminals **422, 424, 426** and **428,** to a position B at which the contact blades engage terminals **430, 432,** 434 and **436.** The dashed line drawn through the switch contact blades indicates that they are operated in unison.

With the switch **420** in the position shown, the L_f channel signal is conducted from terminal **422** via a conductor **438** to the input terminal **440** of one section of a double-pole, double-throw switch **442,** the switch contact blades **442***a* and **442***b* of which are operable in unision from the illustrated position C at which they respectively engage contacts **444** and **446,** to a position D at which they engage contacts **448** and **450,** respectively. Thus, with switch **442** in the position shown, the L_f signal is conducted from terminal **440** through contact **444** of the switch and a conductor **452** to an input terminal of a summing junction **454** for addition to 0.707 of the R_b signal also applied thereto via a conductor **468.** Similarly, the full R_f signal is conducted from terminal **428** via conductor **456,** through switch contact blade **442***b*, contact **446,** and a conductor **458** to an input terminal of another summing junction **460** where it is added to $-$ 0.707 of the L_b channel signal also applied thereto via conductor **462.** The L_b channel signal is also applied via conductor **464** to a third summing junction **466** which is operative to reduce its amplitude by 3*db*, and the R_b signal is also applied via conductor **470** to a fourth summing junction **472** which reduces its amplitude by 3*db* and effectively inverts it.

The output signal from summing junction **454,** which is the sum of the full L_f signal and 0.707 R_b, is transmitted through a ψ-network **328'**, which introduces a reference phase-shift of ψ, to one input terminal of a fifth summing junction **474.** The output signal from junction **466,** namely, 0.707 L_b, is coupled through ψ-network **334'**, which introduces a relative phase-shift of (ψ—90°), and applied to another input terminal of junction **474.** Thus, there is produced at the output terminal **476** of junction **474** a composite signal L_T containing the L_f signal with unity amplitude, 0.707 R_b in phase therewith, and 0.707 L_b in quadrature with the L_f and R_b components.

The output signal from junction **460,** namely, the sum of the full R_f signal and $-$0.707 L_b, is transmitted through ψ-network **332'** to one input terminal of summing junction **478** in which it is added to $-$0.707 R_b following its transmission through ψ-network **336'**, in which it undergoes a phase-shift of (ψ—90°). Thus, there is produced at the output terminal **480** of summing junction **478** a composite signal R_T containing the R_f signal with unity amplitude, 0.707 L_b in anti-phase relationship with respect to R_f, and 0.707 R_b in quadrature with L_b.

It will be evident that with switches **420** and **442** in the positions shown, the combination of summing junctions and ψ-networks of FIG. **21** functions to produce a pair of composite signals identical to those produced by the encoder of FIG. **18.**

If the switch **442** is operated to the D position, with switch **420** left in the illustrated position, the full L_f and R_f channel signals will be applied via switch contacts **448** and **450,** respectively, to respective input terminals of output summing junctions **474** and **478** for addition to the other two signals applied thereto; in the case of junction **474,** the signals from ψ-networks **328'** and **334'**, and in the case of junction **478,** the signals from ψ-networks **336'** and **332'**. Thus, with the switch **442** in the D position the L_f and R_f channel signals by-pass the ψ-networks, and recalling from the description immediately preceding the operation of the encoder on the back channel signals, it will be seen that the composite signals produced will have the same characteristics as those produced by the encoder of FIG. **19.**

The nature of the composite signals L_T and R_T produced by the two just-described modes of operation (with the switch **420** in the A position in both cases) is depicted in FIG. **22A.** When the switch **442** is in the C position the phasor groups are as indicated in solid lines, and when the switch **442** is in the D position the phasor groups are the same except that the L_f and R_f components are displaced by the angle ψ, which is frequency dependent, as shown by the dashed-line phasors.

With the switch **442** in the position shown, and the switch **420** operated to its D position, the encoder of FIG. **22** operates in the forward mode, like the encoder of FIG. **20**. Specifically, in this case the full L_f signal is added to 0.707 L_b in summing junction **454**, and the sum signal transmitted through ψ-network **328'** to the summing junction **474** in which it is added to 0.707 R_b (by virtue of the action of junction **456**) following transmission through ψ-network **334'**. Similarly, the full R_f signal, following transmission through ψ-network **332'**, is added in junction **478** to 0.707 L_b (by virtue of the action of junction **472**) following transmission through ψ-network **336'**. Thus, it is seen that the operative portions of the system of FIG. **22** functionally correspond exactly to the encoder of FIG. **20** and, as depicted in FIG. **22B**, produce composite signals L_T and R_T corresponding to the signals depicted by phasor groups **88** and **92** in FIG. **20A**.

Thus, the system of FIG. **22** permits the user to select either of the encoders of FIGS. **18, 19** or **20** which best suits his requirements. While these three encoding modes will satisfy the requirements of the majority of recording situations, the producer or artist seeking greater perfection may wish to connect the encoder of FIG. **21** in parallel with the system of FIG. **22** to give him the added flexibility of operation in the backward mode. Such parallel operation of encoders is possible as long as the signals applied to the encoders are incoherent, and provides the possibility of simultaneously placing the applied signals in the positions shown in FIGS. **18A, 19A, 20A** and **21A**.

Although the invention has been described in terms of combining signals in specific proportions, namely, 1.00 and 0.707, and in terms of specific relative phase angles, it is to be understood that minor departures from these specific values may be made without affecting system operation, and it is intended that the claims shall encompass such departures from the indicated values.

I claim:

1. Apparatus for transforming a multi-channel program including at least first, second, third and fourth program signals into two composite signals, said apparatus comprising:

first, second, third and fourth input terminals to which said first, second, third and fourth signals to the extent they are present are respectively applied,

first and second output terminals,

means connected between said first and fourth input terminals and said first and second output terminals, respectively, operative to transfer substantially equal amplitude proportions of said first and fourth signals to said first and second output terminals, respectively, and

means connected between both said second and third input terminals and both said first and second output terminals operative to transfer substantially equal reduced amplitude proportions of said second and third signals to both said first and second output terminals and including phase-shifting networks operative to provide a substantially constant differential phase-shift angle between said second and third signals at one of said output terminals and said second and third signals, respectively, at the other of said output terminals over the frequency range of interest.

2. Apparatus in accordance with claim **1** wherein said first-mentioned means is operative to transfer said first and fourth signals to said first and second output terminals, respectively, with the same relative phase relationship they exhibit at their respective input terminals.

3. Apparatus in accordance with claim **1** wherein said differential phase-shift angle has a value of substantially 90° and said second signal at one of said output terminals leads said second signal at the other of said output terminals and said third signal at said one output terminal lags said third signal at said other output terminal.

4. Apparatus in accordance with claim **1** wherein the proportions of said second and third signals transferred to said output terminals are substantially 3*db* down in amplitude from the proportions of said first and fourth signals transferred to said output terminals.

5. Apparatus in accordance with claim **1** wherein said second signal at one of said output terminals leads said second signal at the other of said output terminals and said third signal at said one output terminal lags said third signal at said other output terminal.

6. Apparatus for transforming a multi-channel program including two or more signals identified as L_f, R_f, L_b and R_b into two composite signals, said apparatus comprising:

first, second, third and fourth input terminals to which said L_f, L_b, R_b and R_f signals to the extent they are present are respectively applied,

first and second output terminals,

means connected between said first and fourth input terminals and said first and second output terminals, respectively, operative to transfer said L_f signal to said first output terminal and to transfer said R_f signal to said second output terminal, and

means connected between both said second and third input terminals and both said first and second output terminals operative to transfer reduced amplitude proportions of said L_b and R_b signals to both of said output terminals with a 90° relative phase shift angle and to cause said L_b signal at one of said output terminals to lead said L_b signal at the other of said output terminals and said R_b signal at said one output terminal to lag said R_b signal at said other output terminal.

7. Apparatus according to claim **6** wherein said means connected between said input terminals and said output terminals includes first and second summing circuits each having first, second and third output terminals and an output terminal, the output terminal of said first and second summing circuits being connected to said first and second output terminals, respectively, each of said summing circuits being operative to produce at its output terminal a composite signal including predetermined proportions of signals applied to its first, second and third input terminals,

first and second all-pass phase-shifting networks each operative to shift the relative phase of signals applied thereto by an angle differing from a reference phase angle by 45°, said first and second phase-shifting networks being respectively connected between said first input terminal and the second input terminal of said first summing circuit and between said fourth input terminal and the second input terminal of said second summing circuit,

third and fourth all-pass phase-shifting networks each operative to shift the relative phase of signals ap-

plied thereto by an angle differing from the aforesaid reference phase angle by 90°, said third and fourth phase-shifting networks being respectively connected between said second input terminal and the first input terminal of said second summing circuit and between said third input terminal and the first input terminal of said first summing circuit, and

fifth and sixth all-pass phase-shifting networks each operative to shift the relative phase of signals applied thereto by the aforesaid reference phase angle, said fifth and sixth phase-shifting networks being respectively connected between said second input terminal and the third input terminal of said first summing circuit and between said third input terminal and the third input terminal of said second summing circuit.

8. Apparatus according to claim **7** wherein said first and second summing circuits are each operative to produce at its output terminal a composite signal including a first signal corresponding in amplitude to a signal applied to its second input terminal and second and third signals each having an amplitude corresponding to 0.707 of the amplitude of signals applied to its first and third input terminals.

9. Apparatus for transforming a multi-channel program including two or more signals identified as L_f, R_f, L_b and R_b intended for reproduction by loudspeakers positioned at the left front, right front, left back and right back corners, respectively, of a listening area into two composite signals, said apparatus comprising,

first, second, third and fourth input terminals to which said L_f, L_b, R_b and R_f signals to the extent they are present are respectively applied,

first and second output terminals,

means connected between said first and fourth input terminals and said first and second output terminals, respectively, operative to transfer substantially equal amplitude proportions of said L_f and R_f signals to said first and second output terminals, respectively, with the same relative phase relationship they exhibit at their respective input terminals, and

means connected between both said second and third input terminals and both said first and second output terminals operative to transfer substantially equal reduced amplitude proportions of said L_b and R_b signals to both of said output terminals with a substantially 90° phase-shift angle between said L_b signals and between said R_b signals at said output terminals and to cause the L_b signal at one of said output terminals to lead the L_b signal at the other of said output terminals and to cause the R_b signal at said one output terminal to lag the R_b signal at said other output terminal.

10. Apparatus in accordance with claim **9** wherein the proportion of said L_f and R_f signals transferred to said output terminals is related to the proportion of said L_b and R_b signals transferred to said output terminals by substantially the ratio 1:0.707.

11. Apparatus in accordance with claim **10** wherein substantially the full L_f and R_f signals applied to said first and fourth input terminals are transferred to said first and second output terminals, respectively.

12. Apparatus for transforming a multi-channel program including up to four audio information signals identified as L_f, L_b, R_b and R_f into two composite signals, said apparatus comprising:

first, second, third and fourth input terminals to which the L_f, L_b, R_b and R_f signals, to the extent they are present, are respectively applied,

first and second output terminals,

a first summing circuit connected to add the L_f signal from the first input terminal to a reduced amplitude proportion of the R_b signal from the third input terminal,

a second summing circuit connected to add the R_f signal from the fourth input terminal to a reduced amplitude proportion of the L_b signal from the second input terminal,

a third summing network connected to add the signal from the first summing network to a reduced amplitude proportion of the L_b signal from the second input terminal and first phase-shifting means operative to cause the signal received by said third summing network from the second input terminal to be substantially in phase quadrature with the signal received from said first summing network,

a fourth summing network connected to add the signal from the second summing network to a reduced amplitude proportion of the R_b signal from the third input terminal and second phase-shifting means operative to cause the signal received by said fourth summing network from the third input terminal to be substantially in phase quadrature with the signal received from said second summing network, and

means connecting the output terminals of said third and fourth summing networks to said first and second output terminals, respectively.

13. Apparatus in accordance with claim **12** wherein said first and second summing circuits are operative to add the signals from the first and third input terminals and from the fourth and second input terminals, respectively, substantially in the ratio 1:0.707.

14. Apparatus in accordance with claim **13** wherein said third and fourth summing networks are operative to add the signals from the first summing network and the second input terminal and the signals from the second summing network and the third input terminal, respectively, substantially in the ratio 1:0.707.

15. Apparatus in accordance with claim **13** wherein said first summing network is operative to add the signals from the first and third input terminals substantially in the ratio 1:—0.707, and the second summing network is operative to add the signals from the fourth and second input terminals substantially in the ratio 1:0.707.

16. Apparatus in accordance with claim **15** wherein said third summing network is operative to add the signals from the first summing network and the second input terminal substantially in the ratio 1:—0.707 and the fourth summing network is operative to add the signals from the second summing network and the third input terminal substantially in the ratio 1:0.707.

17. Apparatus for transforming a multi-channel program including up to four audio information signals identified as L_f, R_f, L_b and R_b into two composite signals, said apparatus comprising:

first, second, third and fourth input terminals to which said L_f, L_b, R_b and R_f signals to the extent they are present are respectively applied,

first and second output terminals, and

signal transfer means connected in circuit between said input terminals and said output terminals for transferring signals from said input terminals to said output terminals, said signal transfer means including

first, second, third and fourth summing circuits each having first and second input terminals and an output terminal,

means connecting said third and first input terminals to the first and second terminals, respectively, of said first summing circuit, said first summing circuit being operative to add unequal portions of said L_f and R_b signals,

means connecting said second and fourth input terminals to the first and second input terminals, respectively, of said second summing circuit, said second summing circuit being operative to add unequal portions of said L_b and R_f signals,

first and second like all-pass phase-shifting networks connected between the output terminal of said first summing circuit and the first input terminal of said third summing network and between the output terminal of said second summing circuit and the first input terminal of said fourth summing circuit, respectively,

third and fourth like all-pass phase-shifting networks connected between said second and third input terminals and the second input terminal of said third and fourth summing circuits, respectively, said third and fourth phase-shifting networks being operative to cause a phase-shift to signals applied thereto differing by 90° to the phase-shift introduced by said first and second phase-shifting networks,

said third and fourth summing circuits being operative to add unequal portions of signals applied to their first and second input terminals, and

means connecting the output terminals of said third and fourth summing circuits to said first and second output terminals, respectively.

18. Apparatus according to claim **12** wherein said first and second phase-shifting networks are operative to shift the relative phase of signals applied thereto by a predetermined reference angle and said third and fourth phase-shifting networks are operative to shift the relative phase of signals applied thereto by an angle differing from said reference angle by 90°.

19. Apparatus according to claim **18** wherein said first and second summing circuits are each operative to add 0.707 of a signal applied to its first input terminal to 1.00 of a signal applied to its second input terminal.

20. Apparatus according to claim **19** wherein said third and fourth summing circuits are each operative to add 1.00 of a signal applied to its first input terminal to 0.707 of a signal applied to its second input terminal, whereby in the composite signal appearing at said first output terminal said L_f signal is in phase with the 0.707 R_b signal component thereof, and in the composite signal appearing at said second output terminal said R_f signal is in phase with the 0.707 L_b signal component thereof.

21. Apparatus according to claim **18** wherein said first summing circuit is operative to add −0.707 of a signal applied to its first input terminal 1.00 of a signal applied to its second input terminal, said second summing circuit is operative to add 0.707 of a signal applied to its first input terminal to 1.00 of a signal applied to its second input termrinal, said third summing circuit is operative to add 1.00 of a signal applied to its first input terminal to −0.707 of a signal applied to its second input terminal, and said fourth summing circuit is operative to add 1.00 of a signal applied to its first input terminal to 0.707 of a signal applied to its second input terminal, whereby in the composite signal appearing at said first output terminal said L_f signal is in phase opposition with the 0.707 R_b signal component thereof, and in the composite signal appearing at said second output terminal said R_f signal is in phase with the 0.707 L_b signal component thereof.

22. Apparatus according to claim **17** wherein said third and fourth phase-shifting networks are each operative to shift the relative phase of signals applied thereto by a predetermined reference angle and said first and second phase-shifting networks are each operative to shift the relative phase of signals applied thereto by an angle differing from said reference angle by 90°.

23. Apparatus according to claim **22** wherein each of said first and second summing circuits is operative to add 0.707 of a signal applied to its first input terminal to 1.00 of a signal applied to its second input terminal, and wherein each of said third and fourth summing circuits is operative to add 1.00 of a signal applied to its first input terminal to 0.707 of a signal applied to its second input terminal.

24. A method for transforming a multi-channel program including at least first, second, third and fourth audio information signals, to the extent they are present, into two composite signals suitable for recording or transmitting on only first and second channels, comprising the steps of:

transferring substantially equal predetermined-amplitude proportions of said first and fourth signals to said first and second channels, respectively, and

transferring substantially equal predetermined smaller amplitude proportions of both said second and third signals to both said first and second channels with a substantially constant differential phase-shift angle between said second signal in said first channel and said second signal in said second channel, and between said third signal in said first channel and said third signal in said second channel, over the audio frequency range of interest.

25. A method for transforming a multi-channel program including up to four audio information signals identified as L_f, L_b, R_b and R_f, if present, into first and second composite signals identified as L_T and R_T, respectively, suitable for recording or transmitting on first and second channels, respectively, comprising the steps of:

transferring substantially equal amplitude proportions of said L_f and R_f signals to said first and second channels, respectively, and

transferring substantially equal smaller amplitude proportions of both said L_b and R_b signals to both said first and second channels with a substantially constant differential phase-shift angle of substantially 90° between said L_b and R_b signals in said first channel and said L_b and R_b signals, respectively, in said second channel over the audio frequency range of interest.

26. A method according to claim **25** wherein the transferred proportion of said L_f and R_f signals is re-

lated to the transferred proportion of said L_b and R_b signals by substantially the ratio 1:0.707.

27. A method for transforming a multi-channel program including up to four audio information signals identified as L_f, L_b, R_b and R_f, to the extent they are present, into first and second composite signals identified as L_T and R_T, respectively, suitable for recording on first and second channels, respectively, comprising the steps of:

adding the L_f signal to a reduced amplitude proportion of the R_b signal to produce a first sum signal,

adding the R_f signal to a reduced amplitude proportion of the L_b signal to produce a second sum signal,

adding said first sum signal to a reduced amplitude proportion of the L_b signal shifted in phase relative to said first sum signal by substantially 90° to produce a first composite signal L_T containing the L_f signal and substantially equal reduced amplitude proportions of the L_b and R_b signals, and

adding said second sum signal to a reduced amplitude proportion of the R_b signal shifted in phase relative to said second sum signal by substantially 90° to produce a second composite signal R_T containing the R_f signal and substantially equal reduced amplitude proportions of the L_b and R_b signals.

28. The method according to claim **27** wherein said reduced amplitude L_b and R_b signals are relatively phase-shifted to cause the L_b signals in the two composite signals to be substantially in phase quadrature and the R_b signals in the two composite signals to also be substantially in phase quadrature and the L_b and R_b signals in one of the two composite signals to lead and lag, respectively, the L_b and R_b signals in the other composite signal, said L_f signal to be either in phase or in phase opposition with the R_b signal in said first composite signal and the R_f signal to be either in phase or in phase opposition with the L_b signal in said second composite signal, and at least one of the L_f and R_f signals in said composite signals to be in phase with the signal with which it is either in phase or phase opposition.

29. The method according to claim **28** wherein the L_f signal in said first composite signal is in phase with the R_b signal in said first composite signal.

30. The method according to claim **28** wherein the L_f signal in said first composite signal is in phase opposition with the R_b signal in said first composite signal.

31. The method according to claim **30** wherein the R_f signal in said second composite signal is in phase with the L_b signal in said second composite signal.

32. Apparatus for transforming a multi-channel program including up to four audio information signals identified as L_f, L_b, R_b and R_f into two composite signals suitable for recording or transmitting on respective separate channels, said apparatus comprising;

first, second, third and fourth input terminals to which the L_f, L_b, R_b and R_f signals to the extent they are present are respectively applied,

first and second output terminals,

signal-transfer means including a plurality of summing networks and a plurality of phase-shifting networks connected in circuit between said second and third input terminals and said output terminals, said signal-transfer means being operative to transfer substantially equal portions of the L_b and R_b signals to both of the output terminals with the L_b signals at the two output terminals substantially in phase quadrature and with the R_b signals at the two output terminals also substantially in phase quadrature and the L_b and R_b signals at one of the output terminals leading and lagging, respectively, the L_b and R_b signals at the other output terminal, and

means directing connecting said first and fourth input terminals to said first and second output terminals, respectively, for transferring the L_f and R_f signals to the first and second output terminals, respectively, with the same relative phase relationship that they exhibit at their respective input terminals,

said phase-shifting networks being operative to shift the L_b and R_b signals transferred therethrough by phase-shift angles which include a reference angle which varies as a function of frequency, thereby causing said L_f and R_f signals to be equally displaced relative to their associated quadrature-related L_b and R_b signals by said reference angle.

33. Apparatus for transforming a multi-channel program including up to four audio information signals indentified as L_f, L_b, R_b and R_f into two composite signals suitable for recording or transmission on respective separate channels, said apparatus comprising, in combination:

first, second third and fourth input terminals to which the L_f, L_b, R_b and R_f signals to the extent they are present are respectively applied,

first and second output terminals, and

signal-transfer means connected between said input terminals and said output terminals for combining the signals applied to the input terminals with predetermined amplitude and phase relationships and transferring them to the output terminals,

said signal-transfer means including first, second, third and fourth phase-shifting networks each of which is operative to shift the phase of signals applied thereto by a frequency-dependent reference angle, and said second and third phase-shifting networks each being operative to introduce an additional phase shift of substantially 90°,

means including first summing means for coupling the sum of said L_f signal and a portion of said L_b signal through said second phase-shifting network to said first output terminal,

means including second summing means for coupling the sum of said R_f signal and a portion of said R_b signal through said third phase-shifting network to said second output terminal,

means including said fourth phase-shifting network for coupling a portion of said L_b signal to said second output terminal, and

means including said first phase-shifting network for coupling a portion of said R_b signal to said first output terminal,

whereby said signal-transfer means is operative to transfer substantially equal portions of the L_b and R_b signals to both of the output terminals with the L_b signals at the two output terminals substantially in phase quadrature and with the R_b signals at the two output terminals also substantially in phase quadrature, and with the L_b and R_b signals at one of the output terminals leading and lagging, respectively, the L_b and R_b signals at the other output terminals, and to transfer the L_f signal to the first output terminal in phase with the L_b signal at said first terminal and to transfer the R_f signal to the second output terminal in phase with the R_b signal at said second output terminal and in anti-phase relationship with the L_f signal at said first output terminal.

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