United States Patent [19]

Ito et al.

[11] **3,889,061**

[45] **June 10, 1975**

[54] **FOUR-CHANNEL REPRODUCING SYSTEM**

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[73] Assignee: **Sansui Electric Co., Ltd.,** Tokyo, Japan

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[21] Appl. No.: **428,423**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 315,928, Dec. 18, 1972.

[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, 100.4 ST, 179/100.1 TD, 15 BT

[56] **References Cited**

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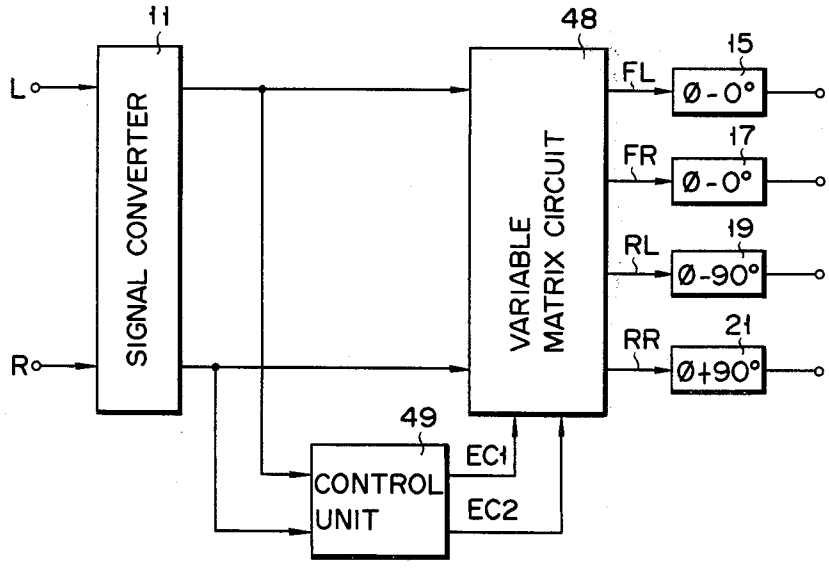
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Primary Examiner—Kathleen H. Claffy
Assistant Examiner—Thomas D'Amico
Attorney, Agent, or Firm—Harris, Kern, Wallen & Tinsley

[57] **ABSTRACT**

A signal converter is provided for mixing first and second channel signals from a conventional two-channel source to produce first and second composite signals. Phase differences between the first and second composite signals with respect to the first and second channel signals respectively vary as a function of frequency of the first and second channel signals. The first and second channel signals or the first and second composite signals are applied to a second signal converter for producing four-channel output signals by mixing input signals. The second signal converter is operative to vary mixing ratios of input signals in accordance with the phase relationship between the first and second composite signals.

13 Claims, 17 Drawing Figures



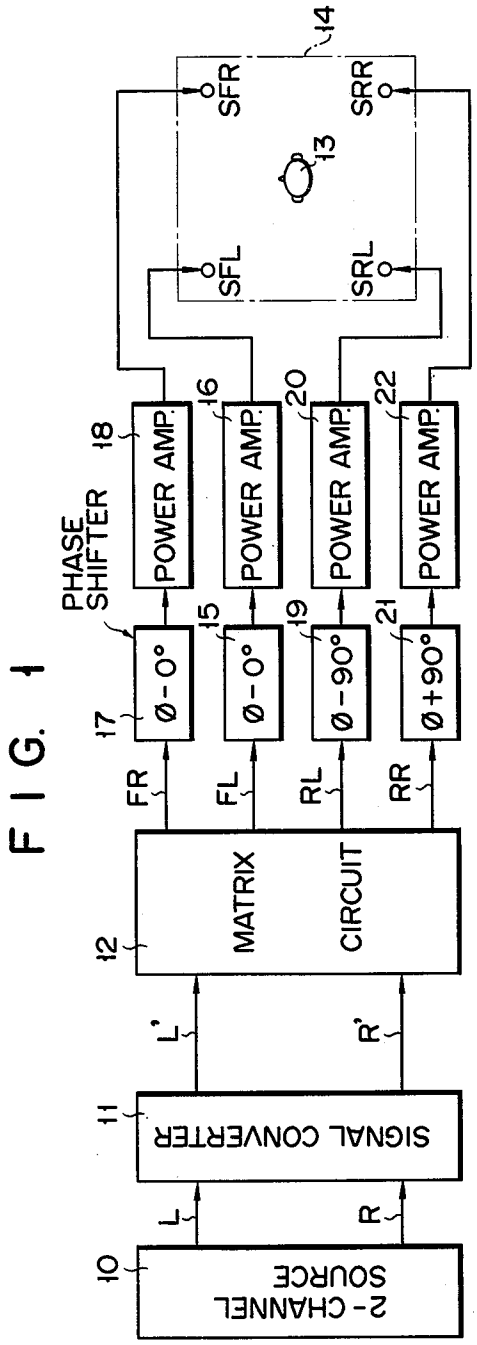

2-CHANNEL SOURCE
10
L
R
SIGNAL CONVERTER
11
L'
R'
MATRIX CIRCUIT
12
FR
FL
RL
RR
PHASE SHIFTER
17
Ø-0°
15
Ø-0°
19
Ø-90°
21
Ø+90°
POWER AMP.
18
16
20
22
13
SFR
SRR
SFL
SRL
14

FIG. 1

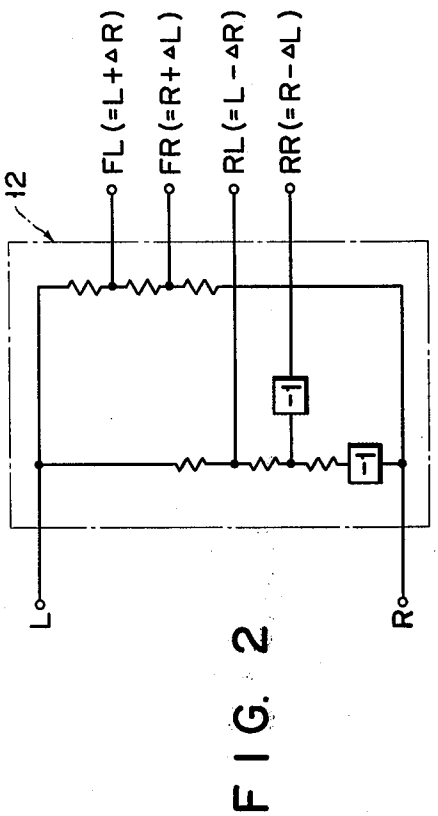

12
FL (=L+ΔR)
FR (=R+ΔL)
RL (=L-ΔR)
RR (=R-ΔL)
-1
-1
L
R

FIG. 2

FIG. 3

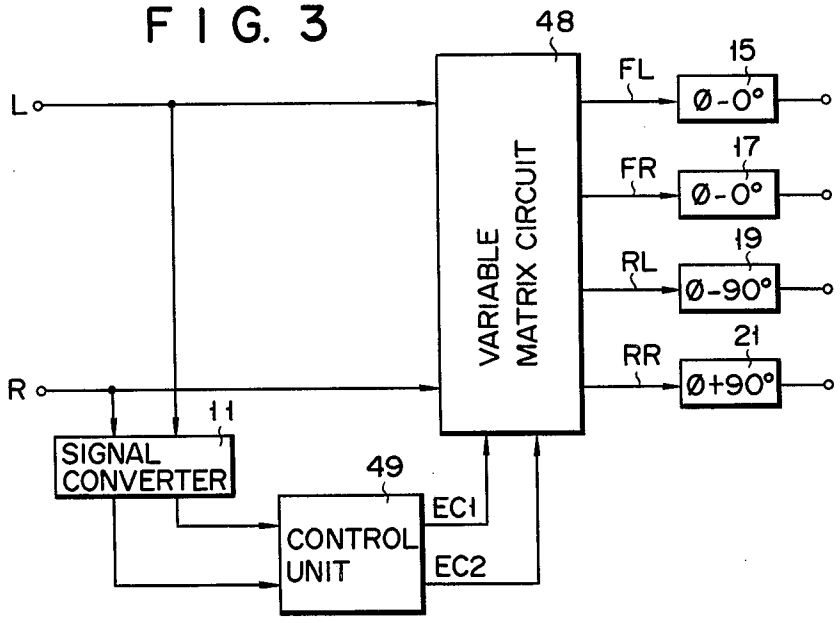

48
15
FL
Ø-0°
17
FR
Ø-0°
19
RL
Ø-90°
21
RR
Ø+90°
L
R
VARIABLE MATRIX CIRCUIT
11
SIGNAL CONVERTER
49
CONTROL UNIT
EC1
EC2

FIG. 4

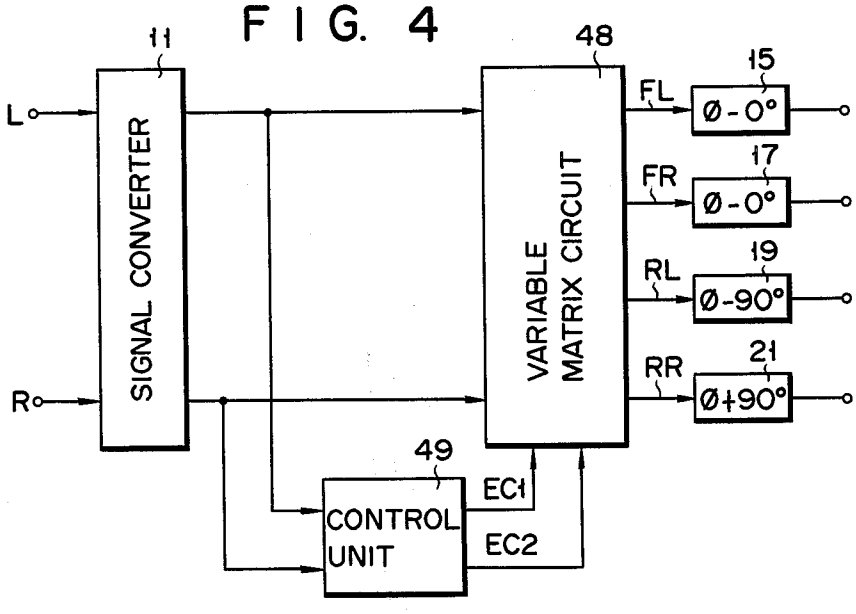

11
48
15
FL
Ø-0°
17
FR
Ø-0°
19
RL
Ø-90°
21
RR
Ø+90°
L
R
SIGNAL CONVERTER
VARIABLE MATRIX CIRCUIT
49
CONTROL UNIT
EC1
EC2

FIG. 5

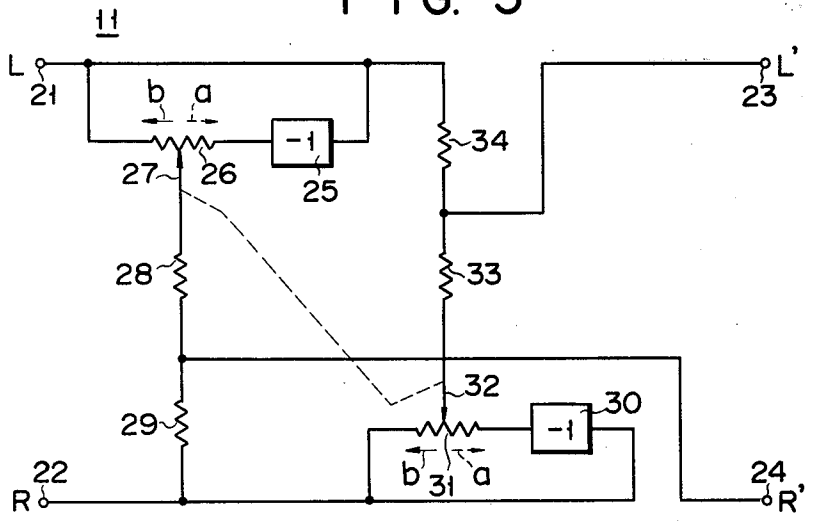


FIG. 6

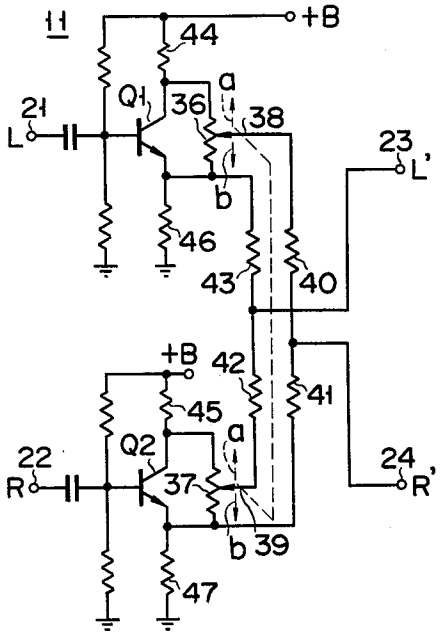


FIG. 7

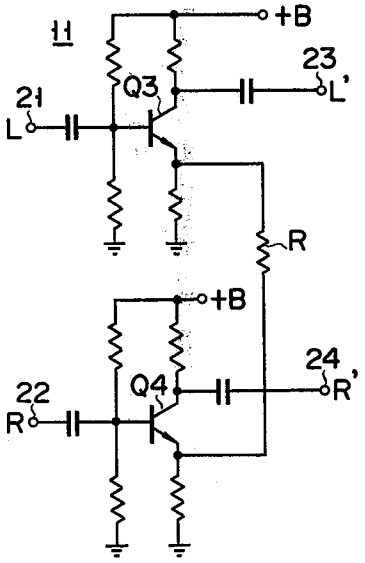
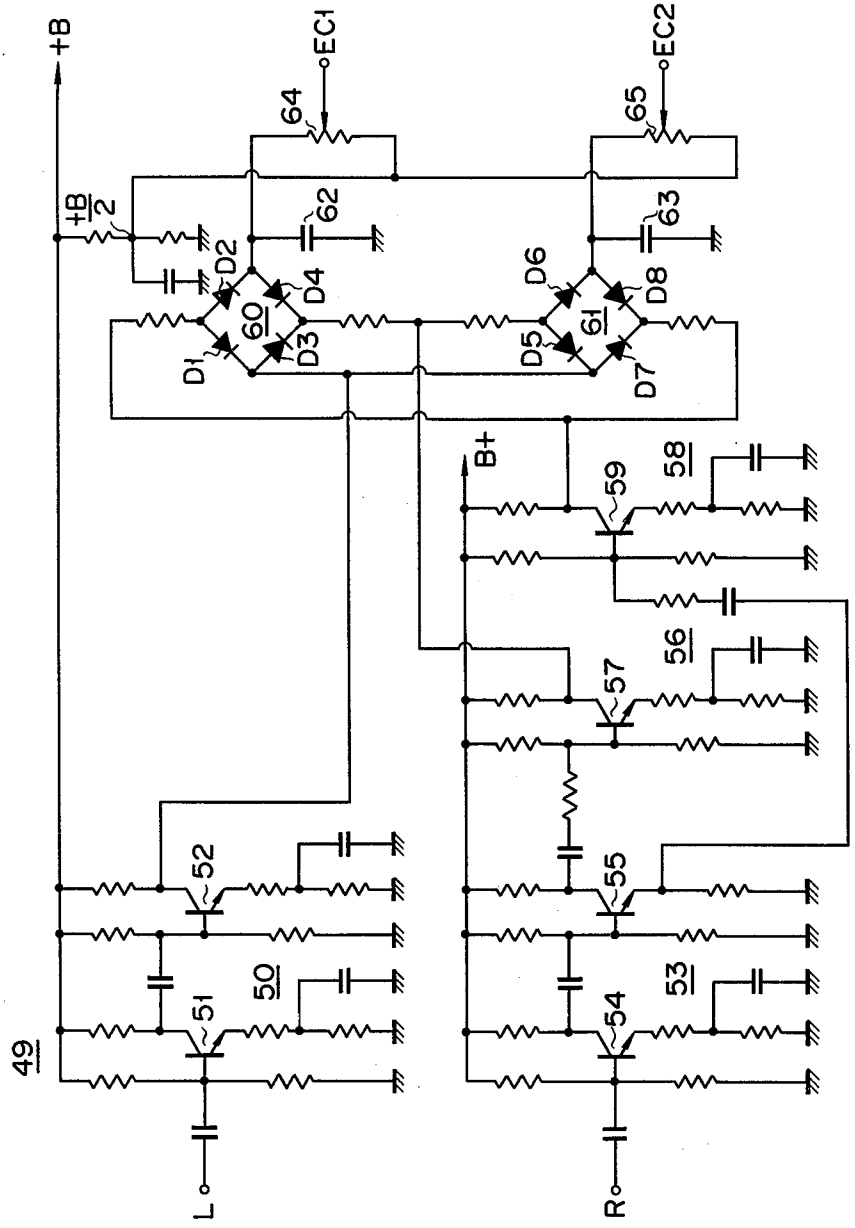


FIG. 8


+B
EC1
EC2
64
65
+B/2
62
63
D2
D4
D6
D8
60
61
D1
D3
D5
D7
B+
59
58
56
57
52
55
50
53
51
54
49
L
R

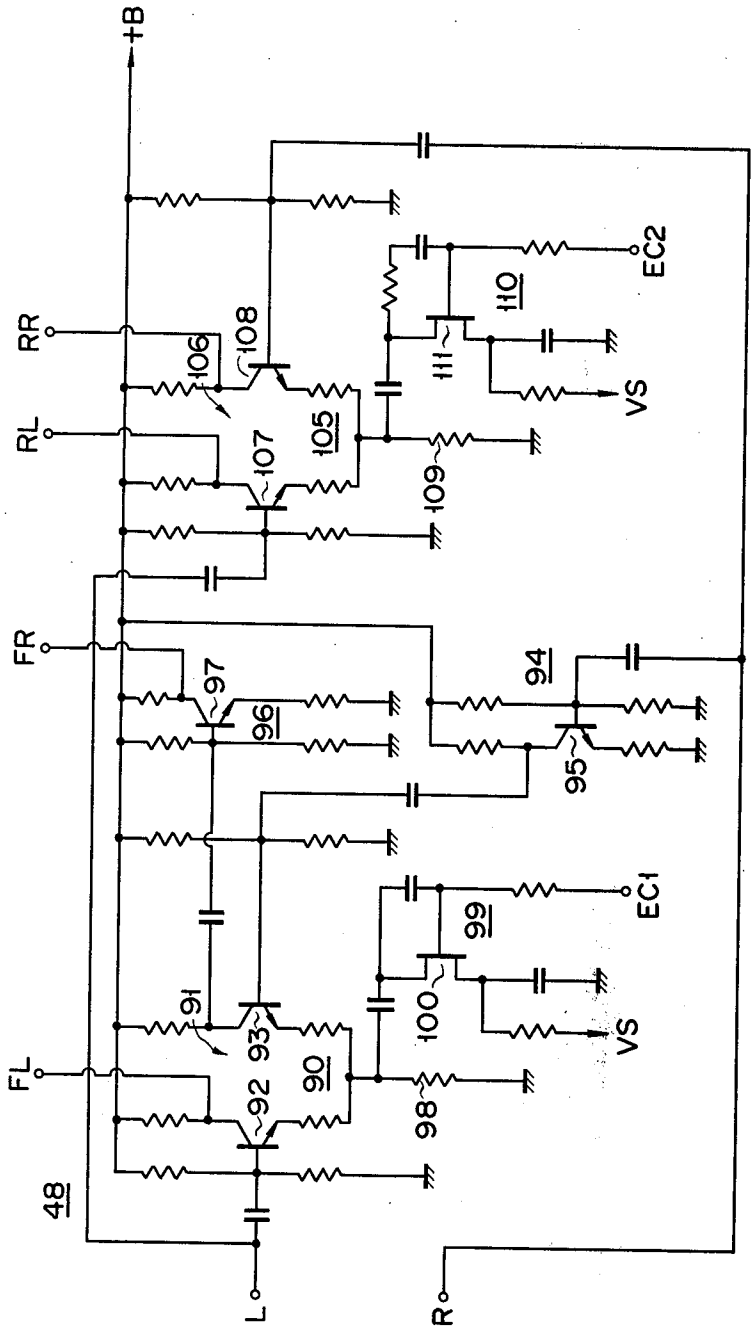

+B
RR
RL
FR
FL
L
R
EC2
EC1
VS
VS
48
90
91
92
93
94
95
96
97
98
99
100
105
106
107
108
109
110
111

FIG. 9

FIG. 10

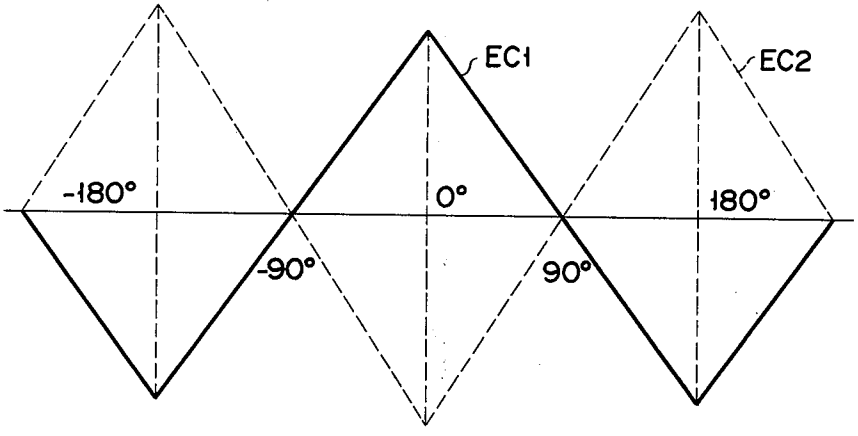
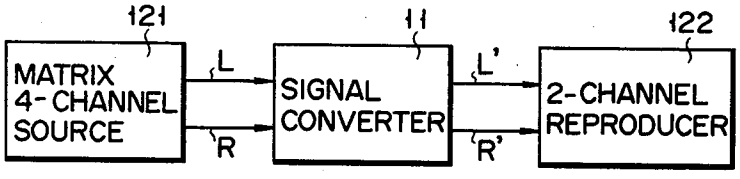

EC1
EC2
-180°
0°
180°
-90°
90°

FIG. 11


121
MATRIX
4-CHANNEL
SOURCE
L
R
11
SIGNAL
CONVERTER
L'
R'
122
2-CHANNEL
REPRODUCER

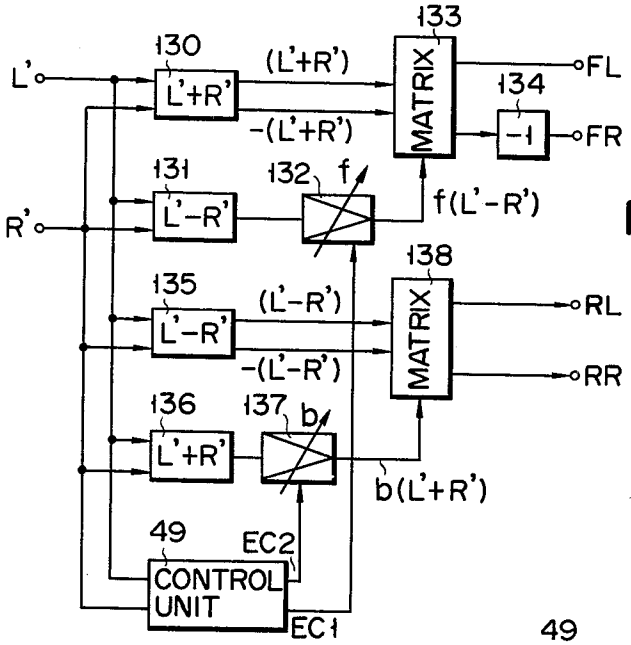

L'
R'
130
L'+R'
131
L'-R'
132
f
f(L'-R')
133
MATRIX
134
-1
FL
FR
(L'+R')
-(L'+R')
135
L'-R'
(L'-R')
-(L'-R')
138
MATRIX
RL
RR
136
L'+R'
137
b
b(L'+R')
49
CONTROL UNIT
EC2
EC1

FIG. 12

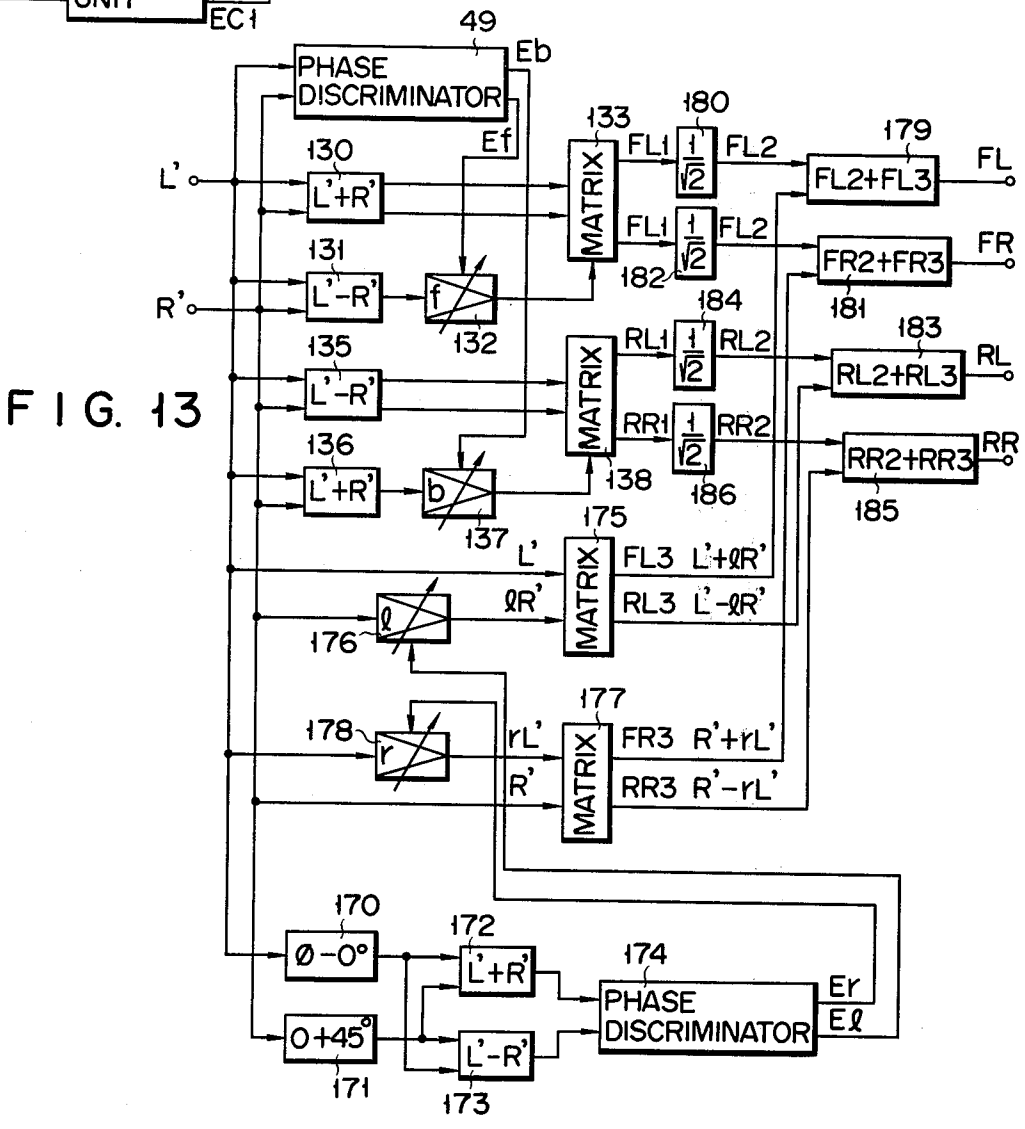

49
PHASE DISCRIMINATOR
Eb
Ef
L'
R'
130
L'+R'
131
L'-R'
132
f
135
L'-R'
136
L'+R'
137
b
133
MATRIX
138
MATRIX
FL1
FL2
RL1
RL2
RR1
RR2
180
182
184
186
179
FL2+FL3
FL
FR2+FR3
FR
181
183
RL2+RL3
RL
RR2+RR3
RR
185
175
MATRIX
L'
ℓR'
FL3 L'+ℓR'
RL3 L'-ℓR'
176
ℓ
177
MATRIX
178
r
rL'
R'
FR3 R'+rL'
RR3 R'-rL'
170
Ø-0°
0+45°
171
172
L'+R'
L'-R'
173
174
PHASE DISCRIMINATOR
Er
Eℓ

FIG. 13

FIG. 14

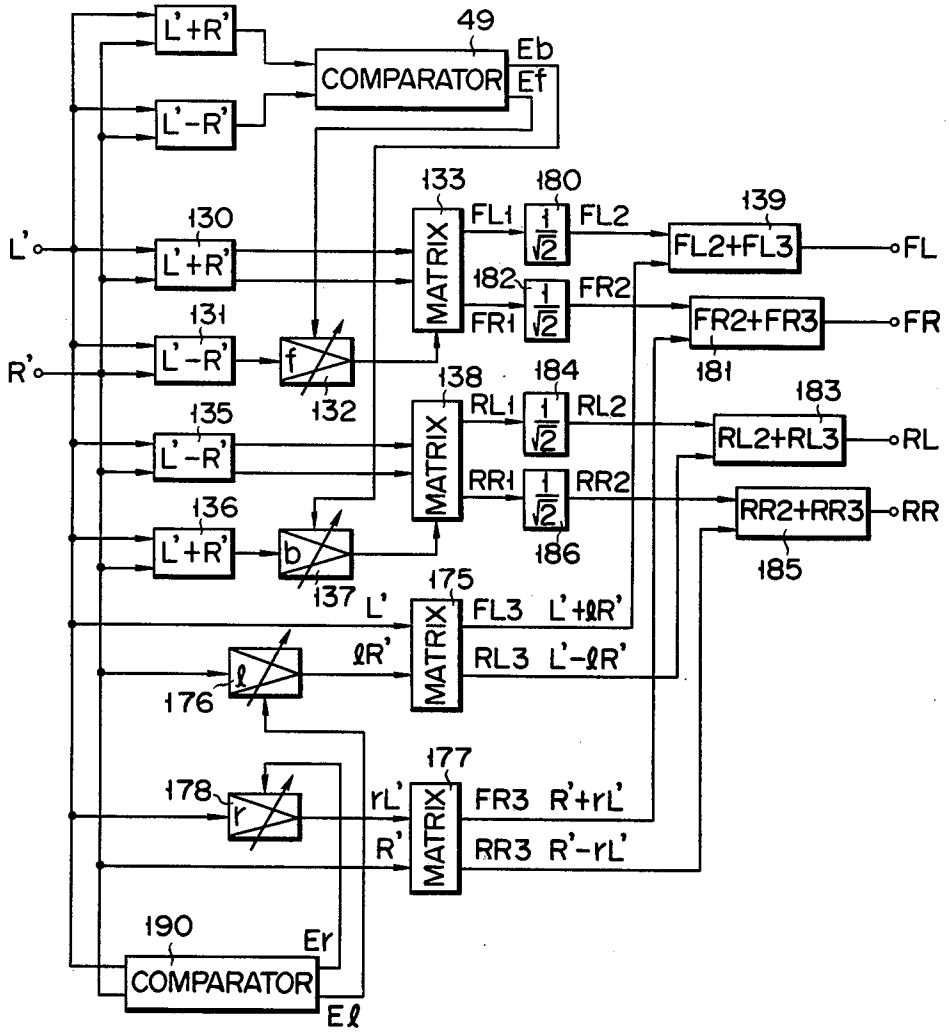

L'+R'
L'-R'
49
COMPARATOR
Eb
Ef
133
180
139
130
MATRIX
FL1
FL2
FL2+FL3
FL
L'
L'+R'
182
FR2
FR1
FR2+FR3
FR
131
R'
L'-R'
f
132
181
138
184
183
135
RL1
RL2
RL2+RL3
RL
L'-R'
MATRIX
RR1
RR2
136
RR2+RR3
RR
L'+R'
b
186
137
185
175
L'
FL3 L'+ℓR'
ℓR'
RL3 L'-ℓR'
ℓ
176
177
178
r
rL'
FR3 R'+rL'
R'
RR3 R'-rL'
190
Er
COMPARATOR
Eℓ

FIG. 15

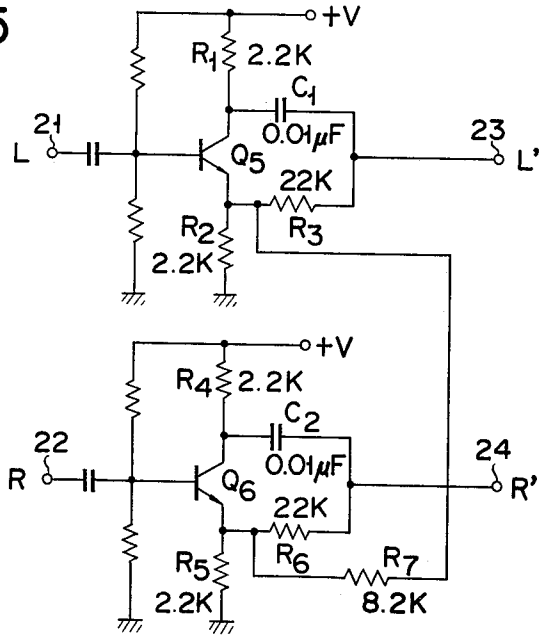


FIG. 16

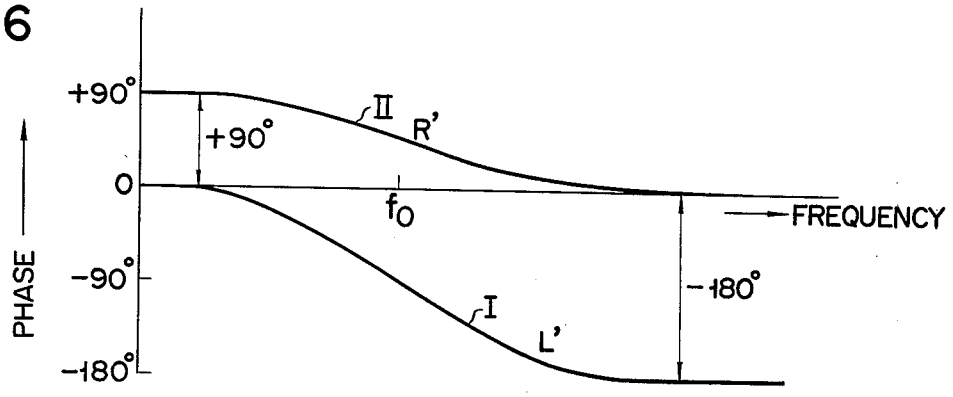
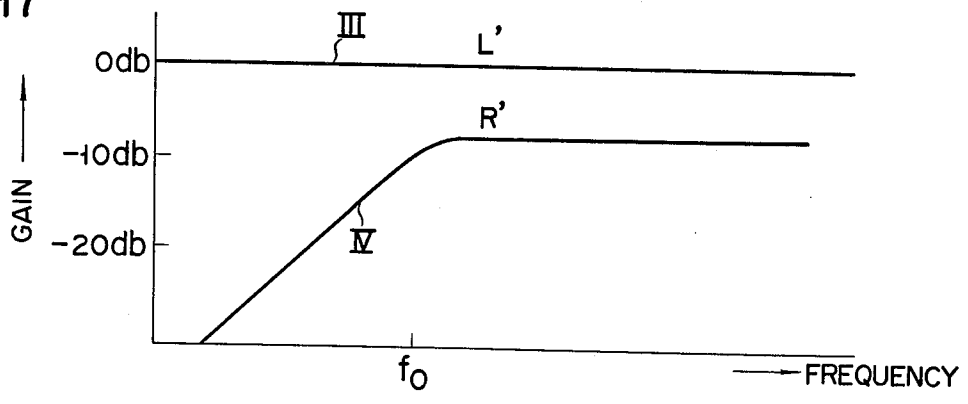


FIG. 17



FOUR-CHANNEL REPRODUCING SYSTEM

CROSS-REFERENCE TO RELATED APPLICATION

This is a Continuation-in-part of U.S. Patent application Ser. No. 315,928, filed Dec. 18, 1972.

This invention relates to a signal converting system which is utilized to reproduce two-channel signals from a conventional two-channel source by a four-channel reproduction system and capable of enhancing the separation between signals in a reproduced sound field.

Recently, a matrix four-channel sound reproduction system has been used wherein four-channel original signals are converted into two-channel signals, the two-channel signals are recorded on such recording medium as a phonograph record or a magnetic tape, the two-channel signals reproduced from the recording medium are converted into four-channel signals corresponding to the original signals and the four-channel signals are reproduced by four loudspeakers arranged around a listener.

The matrix four-channel reproducing system, however, involves a serious problem that the crosstalk between reproducing channels is extremely large. Specifically, in one type of the matrix four-channel reproducing systems the separation between channels disposed in a diagonal direction is infinity whereas that between adjacent channels equals −3 db.

Although the matrix four-channel reproducing system has been successfully developed as above pointed out, the number of matrix four-channel stereo records now on the market is far smaller than that of two-channel stereo records. The matrix four-channel reproducing system is compatible with conventional two-channel stereo records so that it is possible to enjoy a four-channel playback of a conventional two-channel stereo record.

However, owing to the inherently poor separation characteristic of the matrix four-channel reproducing system, when reproducing a conventional two-channel stereo record by a four-channel system, the rear side location of the listening area of a sound image presents a problem. More particularly, where a two-channel stereo record is reproduced by a four-channel system, when only a left signal is reproduced from the record it is desirable to locate the sound image based on this signal at the rear-left side of the listening room for the purpose of providing a satisfactory four-channel reproduction. However, with the system described above, the sound image will be located at an intermediate point between the front-left side and the rear-left side. This means a poor separation between the front and rear channels.

It is an object of this invention to provide an improved signal converting system capable of enhancing the separation between the channels when reproducing sound signals from a conventional two-channel stereo recording medium by a four-channel reproduction system.

According to another aspect of this invention there is provided a signal converting system for reproducing two channel stereo signals from a two channel signal source by means of a four-channel stereo reproducing system, said system comprising a combination of: first signal converting means connected to receive the first and second channel signals from said two channel signal source for combining the first and second channel signals at a relative amplitude ratio and in a phase relationship to produce first and second composite signals; a control unit responsive to the phase relationship between the first and second composite signals for producing first and second control outputs; and second signal converting means connected to receive the two channel signals for producing four-channel output signals, said second signal converting means including means for combining the two channel signals at relative amplitude ratios and in phase relationships therebetween to produce the four-channel output signals and means responsive to the first and second control outputs from said control unit for controlling at least relative amplitude ratios between the two channel signals contained in the four-channel output signals.

According to still another aspect of this invention there is provided a signal converting system for reproducing two channel stereo signals from a two channel signal source by means of a four-channel stereo reproducing system comprising a combination of: first signal converting means connected to receive the first and second channel signals from said two channel signal source for combining the first and second channel signals at a relative amplitude ratio and in a phase relationship to produce first and second composite signals; a control unit responsive to the phase relationship between the first and second composite signals for producing first and second control outputs; and second signal converting means connected to receive the first and second composite signals for producing four-channel output signals, said second signal converting means including means for combining the first and second composite signals at relative amplitude ratios and in phase relationships therebetween to produce the four-channel output signals and means responsive to the first and second control outputs from said control unit for controlling at least relative amplitude ratios between the first and second composite signals contained in the four-channel output signals.

This invention can be more fully understood from the following detailed description when taken in conjunction with the accompanying drawings, in which:

FIG. **1** shows a block diagram of a signal converting system embodying the invention;

FIG. **2** shows a connection diagram of a matrix circuit shown in FIG. **1**;

FIG. **3** shows a block diagram of a portion of a modified embodiment of this invention;

FIG. **4** shows a modification of the embodiment shown in FIG. **3**;

FIGS. **5, 6** and **7** show connection diagrams of different signal converters utilized in this invention;

FIG. **8** shows a connection diagram of one example of a control unit utilized in the embodiments shown in FIGS. **3** and **4**;

FIG. **9** shows a connection diagram of one example of a variable matrix circuit utilized in the embodiments shown in FIGS. **3** and **4**;

FIG. **10** is a graph showing the output characteristic of the control unit shown in FIG. **8**;

FIG. **11** is a simplified block diagram of still another embodiment of the invention;

FIGS. **12, 13** and **14** show block diagrams of other variable matrix circuits;

FIG. **15** is a circuit diagram of a signal converter according to another embodiment of this invention; and

FIGS. **16** and **17** are characteristic diagrams of the signal converter shown in FIG. **15.**

With reference now to FIG. 1 of the accompanying drawing illustrating a preferred embodiment of this invention, reference numeral **10** designates a suitable two-channel source which may be a conventional stereo phonograph record, a stereo recorded magnetic tape or an FM stereo receiver. The first and second audio signals L and R produced by the two-channel source **10** are applied to a matrix circuit **12** via a signal converter **11** to be described later. The matrix circuit **12** may be constructed as shown in FIG. **2**, for example. The circuit shown in FIG. 2 is constructed to convert the first and second audio signals L and R into four-channel signals consisting of FL (front-left), FR (front-right), RL (rear-left) and RR (rear-right), which are expressed by the following equations:

$$FL = L + \Delta R$$
$$FR = R + \Delta L$$
$$RL = L - \Delta R$$
$$RR = R - \Delta L$$

where each Δ represents a matrix coefficient having a value of about 0.4. In the four-channel reproducing system, it is usual to install four loudspeakers SFL, SFR, SRL and SRR about a listener **13** in a listening room **14.**

The output FL from matrix circuit **12** is applied to the corresponding loudspeaker SFL through a phase shifter **15** and a power amplifier **16** while the output FR to loudspeaker SFR through a phase shifter **17** and a power amplifier **18.** Similarly, the outputs RL and RR are supplied to corresponding loudspeakers SRL and SRR respectively through phase shifters **19** and **21** and power amplifiers **20** and **22.** The purpose of the phase shifters **15, 17, 19** and **21** is to maintain front signals FL and FR at the in-phase relationship throughout the entire range of audio frequencies and to bring the rear signals RL and RR into in-phase relationship which have been 180° out-of-phase.

Where only a left signal is impressed upon the matrix circuit **12,** both signals FL and RL are designated by L. Accordingly, under these conditions, although it is desirable to locate the sound image of this left signal L at the position of the loudspeaker SRL, actually the sound image is located at a mid-point between the loudspeakers SFL and SRL. As will be described later, the signal converter **11** is constructed to form difference signals L′ (L-αR) and R′ (R-αL) in response to the left and right signals. Accordingly, responsive to the signals L-αR and R-αL, the matrix circuit **12** operates to form the following signals:

$$FL = L-\alpha R + \Delta(R-\alpha L) = L(1-\Delta\alpha) + R(\Delta-\alpha)$$
$$FR = R-\alpha L + \Delta(L-\alpha R) = R(1-\Delta\alpha) + L(\Delta-\alpha)$$
$$RL = L-\alpha R - \Delta(R-\alpha L) = R(1+\Delta\alpha) - R(\alpha+\Delta)$$
$$RR = R-\alpha L - \Delta(L-\alpha R) = R(1+\Delta\alpha) - L(\alpha+\Delta)$$

Accordingly, where only the left signal L is impressed upon signal converter **11,** the outputs FL and RL from the matrix circuit **12** are shown by $L(1-\Delta\alpha)$ and $L(1+\Delta\alpha)$, respectively. This means that the sound image corresponding to the left signal L is located at a position closer to the loudspeaker SRL.

One example of the signal converter **11** shown in FIG. **5** is provided with input terminals **21** and **22** connected to receive the left and right signals L and R, respectively, and a pair of output terminals **23** and **24.** The first input terminal **21** is connected to the input terminal of a first inverter **25,** and a first potentiometer resistor **26** is connected between the output terminal of the first inverter **25** and the first input terminal **21.** The sliding arm **27** of the first potentiometer resistor **26** is connected to the second input terminal **22** through serially connected resistors **28** and **29,** and the junction between these resistors **28** and **29** is connected to the second output terminal **24.** The second input terminal **22** is connected to the input terminal of a second inverter **30,** and a second potentiometer resistor **31** is connected between the output terminal of the second inverter **30** and the second input terminal **22.** The sliding arm **32** of the second potentiometer resistor **31** is connected to the first input terminal **21** through serially connected resistors **33** and **34,** the junction therebetween being connected to the first output terminal **23.** The sliding arms **27** and **32** of the first and second potentiometer resistors **26** and **31** are mechanically interlocked as shown by dotted lines.

When the sliding arms **27** and **32** are positioned at the centers of first and second potentiometers **26** and **31** the left and right signals L and R are produced at the first and second output terminals **23** and **24,** respectively.

When the sliding arms **27** and **32** are moved in the direction of arrows *a* along the potentiometer resistors **26** and **31,** respectively, there are respectively derived from the output terminals **23** and **24** two difference signals L-αR and R-αL each having varying relative amplitude ratio between the signals L and R, whereas when the sliding arms **27** and **32** are moved in the direction of arrows *b* there are obtained two sum signals L+βR and R+βL each having varying relative amplitude ratio. In the embodiment shown in FIG. **1** it is advantageous to use the potentiometer resistors **26** and **31** such that their sliding arms are positioned to the right of their mid-points to produce the two difference signals.

In a modified signal converter shown in FIG. **6,** each of the collector-emitter paths of first and second transistors Q_1 and Q_2 is connected across a source indicated by +B and the ground, and the base electrodes of these transistors are connected to input terminals **21** and **22** respectively through coupling capacitors. In parallel with the collector-emitter paths of the transistors Q_1 and Q_2 are connected first and second potentiometer resistors **36** and **37** provided with sliding arms **38** and **39,** respectively. The sliding arm **38** of the first potentiometer resistor **36** is connected to the emitter electrode of transistor Q_2 through serially connected resistors **40** and **41,** whereas the sliding arm **39** of the other potentiometer resistor **37** is connected to the emitter electrode of transistor Q_1 through serially connected resistors **42** and **43.** Junctions between resistors **42** and **43** and between **40** and **41** are connected to output terminals **23** and **24,** respectively. The sliding arms **38** and **39** of two potentiometer resistors **36** and **37** are mechanically interlocked each other as shown by dotted lines.

In this embodiment, the collector resistors **44** and **45** and the emitter resistors **46** and **47** of transistors Q_1 and Q_2 are made to have an equal value. Again, when sliding arms **38** and **39** are moved in the direction of dotted arrows *a* two difference signals L−αR and R−αL are produced at the output terminals **23** and **24** respectively whereas when these sliding arms are moved in the direction of solid line arrows *b* two sum signals L+βR and R+βL are produced.

In another embodiment of the signal converter shown in FIG. 7, each of the collector-emitter paths of transistors Q_3 and Q_4 is connected across the source. The base electrodes of these transistors are connected to input terminals **21** and **22** respectively through coupling capacitors while the collector electrodes are connected to output terminals **23** and **24** respectively. The emitter electrodes of transistors Q_3 and Q_4 are inerconnected through a resistor R. In this signal converter two difference signals each having a predetermined fixed amplitude ratio between the signals L and R are derived out from output terminals **23** and **24.**

A modified embodiment of this invention shown in FIG. **3** comprises a variable matrix circuit **48** and a control unit **49.** This modification illustrates a decoder capable of reproducing with satisfactory channel separation sound signals recorded on a matrix four-channel recording medium by a four-channel system. In such a decoder the phase relationship between the two-channel signals, for example, $L = LF+\Delta FR+jRL+j\Delta RR$ and $R = FR+\Delta FL-jRR-j\Delta RL$ which are reproduced from the matrix four-channel recording medium is detected by the control unit **49** constituted by a phase discriminator or a level comparator, and the matrix coefficients of the matrix circuit **48** are controlled by the outputs EC1 and EC2 from the control unit **49.** When the two-channel signals reproduced from a conventional two-channel recording medium are applied to such a decoder system the control unit **49** can not control the matrix circuit **48** because the two-channel signals are generally in phase. For this reason, in such a case, it is desirable to provide signal converter **11** as shown in FIG. **5, 6** or **7** on the input side of the control unit **49** so that when only one signal is reproduced from the two-channel recording medium, the input signals to the control unit **49** will have opposite phases thereby enabling the control unit **49** to control the variable matrix circuit **48.** For example, where only L signal presents, it is possible to locate the sound image of the signal at the position of loudspeaker SRL by the operation of the variable matrix circuit **48,** thus improving the separation between the front channels and the rear channels.

To aid the understanding of the invention, the constructions and operations of variable matrix circuit **48** and control unit **49** will be described briefly hereunder.

FIG. **8** shows a circuit diagram of a phase discriminator which comprises a first limiter **50** including transistors **51** and **52** connected to receive the L signal and a second limiter **53** including transistors **54** and **55** connected to receive the R signal. The first and second limiters **50** and **53** have large amplification gains and operate to transform the signals L and R into rectangular wave signals. Two output signals of opposite polarities produced by the second limiter **53** are amplified by first and second amplifiers **56** and **58** including transistors **57** and **59** respectively. The outputs from the first and second amplifiers **56** and **58** are supplied to a first switching circuit **60** and a second switching circuit **61** respectively including bridge connected diodes D_1 to D_4 and diodes D_5 to D_8, thereby causing these switching circuits ON and OFF alternately. The output from the first limiter **50** is coupled to the common input of the first and second switching circuits **60** and **61,** while the output terminals of these switching circuits **60** and **61** are grounded through capacitors **62** and **63** respectively, and are connected to a point of reference voltage (in this case, +B/2 volts) through potentiometers **64** and **65,** respectively. The slidable arms of the potentiometers **64** and **65** supply the first and second control outputs EC1 and EC2.

The phase discriminator constructed as above described operates to switch the left signal L by alternately rendering ON and OFF the first and second switching circuits **60** and **61** in response to the right signal R thereby discriminating the phase difference between the right and left signals R and L. FIG. **10** shows the operating characteristic of the phase discriminator showing that the first and second control outputs EC1 and EC2 vary symmetrically but in opposite directions about the reference level, which is equal to about +B/2 volts in the phase discriminator shown in FIG. **8.**

FIG. **9** illustrates an example of the variable matrix circuit **48** wherein a first matrix circuit **90** associated with the front channels comprises a first differential amplifier **91** including transistors **92** and **93.** The left signal L is coupled to the base electrode of transistor **92** while the right signal R is coupled to the base electrode of transistor **93** through an inverter **94** including a transistor **95.** The collector electrode of transistor **92** is connected to the first output terminal of the matrix circuit while the collector electrode of transistor **93** is connected to the second output terminal of the matrix circuit through an inverter **96** comprising a transistor **97.** A first control circuit **99** including a field effect transistor **100** is capacitively connected in parallel with a common emitter resistor **98** of transistors **92** and **93** which constitute the differential amplifier **91.** The gate electrode of the field effect transistor **100** is connected to a control input terminal so that it acts as a variable resistor. The first control circuit **99** operates to vary the AC impedance of the emitter circuits of transistors **92** and **93** in accordance with the magnitude of the control input EC1 so as to control the common mode gain of the differential amplifier **91.**

The second matrix circuit **105** associated with the rear channels comprises a second differential amplifier **106** including transistors **107** and **108.** The left signal L is coupled to the base electrode of transistor **107,** whereas the right signal R is coupled to the base electrode of transistor **108.** The collector electrodes of transistors **107** and **108** are respectively connected to the third and fourth output terminals of the matrix circuit. A second control circuit **110** including a field effect transistor **111** is capacitively connected in parallel with a common emitter resistor **109** for transistors **107** and **108.** The gate electrode of field effect transistor **111** is connected to a control input terminal. The second control circuit **110** operates in the same manner as the first control circuit **99** so as to control the common mode gain of the second differential amplifier in accordance with the magnitude of the control input EC2. .

The operation of the variable matrix circuit shown in FIG. **9** will be briefly described as follows: Where the composite signals L′ and R′ are substantially in phase, the control input EC1 is large and the control input EC2 is small. Consequently, the AC impedance of the emitter circuits of transistors **92** and **93** is decreased whereby the gain of the first differential amplifier **91** is increased, whereas that of the second differential amplifier **106** is decreased. Increase in the gain of the first differential amplifier **91** results in the increase in the level of the left signal L which is derived out from the collector electrode of transistor **92** and in the decrease in the level of the right signal R contributing to increas-

ing the crosstalk. On the other hand, the level of the right signal R derived out from the collector electrode of transistor **93** is increased and the level of the left signal L contributing to increasing the cross-talk is decreased. Accordingly, the separation between the front channels is improved with the increase in the signal level. In the rear channels, as the gain of the second differential amplifier **106** decreases, the separation degrades with the decrease in the signal level.

In FIG. **3**, when the signal converter **11** produces two difference signals L-αR and R-αL in in-phase relationship, the outputs EC1 and EC2 of the control unit **49** have a large level and a small level, respectively. Then, the gains of the first and second differential amplifiers **91** and **106** are respectively increased and decreased, and the first output FL and second output FR of the first matrix circuit **90** are formed mostly of signal L and signal R, respectively. Thus, signal L is localized at the loudspeaker SFL, and signal R at the loudspeaker SFR.

If supplied with only signal L or signal R, the signal converter **11** produces two output signals L and -ΔL or two output signals R and —ΔR— both in reverse-phase relationship. As a result, the outputs EC1 and EC2 of the control unit **49** have a small level and a large level, respectively, thereby to decrease the gain of the first differential amplifier **91** and to increase the gain of the second differential amplifier **106.** Consequently, the outputs RL and RR of the second matrix circuit **105** come to be filled mostly with signal L and signal R, respectively. That is, if only signal L is supplied to the converter **11,** it is localized at the loudspeaker SRL. Similarly, if only signal R is supplied to the converter **11,** it is localized at the loudspeaker SRR.

To generalize the above, signals to be localized somewhere to the left and to the right of midway between left and right loudspeakers for 2-channel reproduction are localized at the loudspeaker SFL and at the loudspeaker SFR, respectively. Signals to be localized at the left and right loudspeakers are localized at the loudspeakers SRL and SRR, respectively.

When the signal converter **11** produces two sum signals L+βR and R+βL, the outputs EC1 and EC2 of the control unit **49** have a large level and a small level, respectively. As a result, the in-phase components in the input signals L and R are localized in front of the reproduction sound field, and the reverse-phase components, e.g. reverberation components, of these signals are localized at the back of the reproduction sound field.

The detail of the construction and operation of the variable matrix circuit **48** and the control unit **49** and their modifications are fully described in the copending U.S. Patent application Ser. No. 298,933, filed Oct. 19, 1972, of the title "Decoder for use in 4-2-4 matrix playback system" now U.S. Pat. No. 3,825,684.

FIG. **4** shows a modification of the circuit shown in FIG. **3.**

In this modification, the variable matrix circuit **48** and control unit **49** are connected to receive the two channel signals L and R via the signal converter **11.** When the two channel signals L and R are in-phase and include crosstalk components therebetween, the difference signals produced by the signal converter **11** are caused to be decreased in level as well as enhanced in separation. Accordingly, the arrangement of FIG. **4** in which the separation previously enhanced two-channel signals are supplied to the variable matrix circuit **48** can provide somewhat better separation characteristics than the arrangement of FIG. **3.**

FIG. **12** is a block diagram of a variable matrix circuit according to another embodiment used in the arrangement of FIG. **4.** With reference first to the front channels, there are provided a first matrix circuit **130** adapted to produce sum signals (L'+R') and —(L'+R') of opposite polarities from the composite signals L' and R' produced by the signal converter **11,** and a second matrix circuit **131** adapted to produce a difference signal (L'—R'). The difference signal (L'—R') is applied to a third matrix circuit **133** via a variable gain amplifier **132** to be added therein to the outputs from the first matrix circuit **130.** The first variable gain amplifier **132** is controlled by the first control output EC1 from the control unit **49** and has an amplification gain f which varies from **0** to 2.41 with respect to the gain of the first matrix circuit **130.** The third matrix circuit **133** functions to produce a first output expressed by $(1+f)L' + (1-f)R'$ and a second output expressed by $-(1-f)L' - (1+f)R'$ which is phase inverted by an inverter **134.**

Associated with the rear channels there are provided a fourth matrix circuit **135** adapted to produce difference signals (L'—R') and —(L'—R') of the opposite polarities and a fifth matrix circuit **136** adapted to produce a sum signal (L'+R'). The sum signal (L'+R') is applied through a second variable gain amplifier **137** to a sixth matrix circuit **138** where it is added to the outputs (L'—R') and —(L'—R') from the fourth matrix circuit **135.**

The second variable gain amplifier **137** has an amplification gain *b* which varies from 0 to 2.41 with respect to the gain of the fourth matrix circuit **135.** Accordingly, the sixth matrix circuit **138** produces a third output expressed by $(1+b)L' - (1-b)R'$ and a fourth output expressed by $(1+b)R' - (1-b)L'$. The gains of the first and second variable gain amplifiers **132** and **137** are varied in the opposite directions by the control outputs EC1 and EC2 from the control unit **49.**

FIG. **13** shows a block diagram of another embodiment of the variable matrix circuit. FIG. **13** is different from FIG. **12** in that it is incorporated with the following circuit components. More particularly, there are provided a 0° phase shifter **170** and a 45° phase shifter **171** which introduce a phase difference of 45° between the composite signal L' and the composite signal R'. Responsive to the outputs from phase shifters **170** and **171** an adder **172** provides an output (L'+R'<+45°), whereas a subtractor **173** provides an output (L'—R'<+45°). A phase discriminator **174** for controlling the left and right channels operates to detect the phase difference between the output signals (L'+R'<+45°) and (L'—R'<+45°) to produce control outputs Er and E*l*. A matrix circuit **175** is connected to receive the signal L' and the signal R' through a variable gain amplifier **176** to produce outputs FL3 (=L'+*l*R') and RL3(=L'—*l*R'). Similarly, a matrix circuit **177** is connected to receive the signal L' through a variable gain amplifier **178,** and the signal R' to produce outputs FR3(=R'+rL') and RR3(=R'—RL') where *l* and *r* represent the gains of the variable gain amplifiers **176** and **178** respectively. These gains are controlled in the opposite directions in a range of from 0 to 3.414 by the outputs Er and E*l* from the phase discriminator **174.** The gains of the variable gain amplifiers **132** and **137** are controlled in the opposite directions in a range of from 0 to 3.414 by the outputs Ef

and Eb of phase discriminator as the control unit **49** for controlling rear and front channels by detecting the phase difference between the signals L′ and R′. The output FL1 from the matrix circuit **133** is coupled to one input of an adder **179** via a $1/\sqrt{2}$ attenuator **180** and the output FL3 from the matrix circuit **175** is applied to the other input of adder **179.** Similarly, the output FR1 from the matrix circuit **133** is applied to one input of an adder **181** through a $1/\sqrt{2}$ attenuator **182** whereas the output FR3 from the matrix circuit **177** is coupled to the other input of adder **181.** Likewise, the output RL1 of matrix circuit **138** is applied to one input of an adder **183** through a $1/\sqrt{2}$ attenuator **184** while the output RL3 of matrix circuit **175** is applied to the other input of adder **183.** The output RR1 of matrix circuit **138** is coupled to one input of adder **185** through a $1/\sqrt{2}$ attenuator **186** and the output RR3 of the matrix circuit **177** is applied to the other input of adder **185.**

It will be clear that the four channel signals FL, FR, RL and RR are expressed by the following equations.

$$FL = FL2+FL3 = 1/\sqrt{2}\{(1+f+\sqrt{2})L' + (1-f+\sqrt{2}l)R'\} = 1/\sqrt{2}\{(1+\sqrt{2})L' + R' + f(L'-R') + \sqrt{2}lR'\}$$

$$FR = FR2 + FR3 = 1/\sqrt{2}\{(1+f+\sqrt{2})R' + (1-f+\sqrt{2}r)L'\} = 1/\sqrt{2}\{(1+\sqrt{2})R' + L' - f(L'-R') + \sqrt{2}rL'\}$$

$$RL = RL2 + RL3 = 1/\sqrt{2}\{(1+b+\sqrt{2})L' - (1-b+\sqrt{2}l)R'\} = 1/\sqrt{2}\{(1+\sqrt{2})L' - R' + b(L'+R') - \sqrt{2}lR'\}$$

$$RR = RR2 + RR3 = 1/\sqrt{2}\{(1+b+\sqrt{2})R' - (1-b+\sqrt{2}r)L'\} = 1/\sqrt{2}\{(1+\sqrt{2})R' - L' + b(R'+L') - \sqrt{2}rL'\}$$

FIG. **14** shows a block diagram of a modification of the variable matrix circuit shown in FIG. **13.** In FIG. **14,** variable gain amplifiers **132** and **137** are controlled respectively by the outputs Ef and Eb from a comparator as the first control unit **49** for the front-rear control which detects the difference in the levels of the sum signal (L′+R′) and the difference signal (L′−R′), and variable gain amplifiers **176** and **178** are controlled respectively by the outputs El and Er from a comparator **190** as the second control unit for the left and right control which detects the difference in the levels of the left signal L′ and the right signal R′. In this manner, it is possible to obtain the same effect as the variable matrix circuit shown in FIG. **13** by detecting the difference in the signal levels.

A conventional **2**-channel stereophonic disc is so designed that the reproduced sound image of a low-tone instrument may be localized midway between the left and right loudspeakers. To use such a **2**-channel stereophonic disc for **4**-channel sound reproduction, the sound images of low-tone and high-tone instruments may better be localized respectively at the front and back of the reproduced sound field, thereby to effect a desirable **4**-channel sound reproduction. To this end, the characteristics of the converter **11** should be such that two composite signals L′ and R′ produced by the converter will possess a phase relationship which varies in accordance with the frequency of the input signals. In other words, the phase difference between the composite signals L′ and R′ should approach 180° as the frequencies of input signals L and R grow higher. Shown in FIG. **15** is an embodiment of a preferable signal converter having such phasefrequency characteristics and preferably combined with a variable matrix circuit.

In FIG. **15,** a transistor Q_5 has its base connected to an input terminal **21,** and a capacitor C_1 and a resistor R_3 are connected in series between the collector and emitter of the transistor Q_5 with their junction connected to an output terminal **23.** A collector resistor R_1 and an emitter resistor R_2 of the same value are provided for the transistor Q_5. The transistor Q_5, the resistors R_1, R_2 and R_3, and the capacitor C_1 constitute a phase shifter of well-known type. Similarly, a transistor Q_6 has its base connected to an input terminal **22,** and a capacitor C_2 and a resistor R_6 are connected in series between the collector and emitter of the transistor Q_6 with their junction connected to an output terminal **24.** A collector resistor R_4 and an emitter resistor R_5 of the same value are provided for the transistor Q_6. Another resistor R_7 is used to connect the emitters of the transistors Q_5 and Q_6.

The signal converter of the above-mentioned construction functions in the following manner. Between input signal L supplied to the input terminal **21** and output signal L′ appearing at the output terminal **23** there is observed a phase difference having such a frequency dependency as represented by curve I in FIG. **16.** If input signal L has a frequency f_o defined by the capacitor C_1 and the resistor R_3 (e.g. when $C_1 = 0.01$ microfarad and $R_3 = 22$ kiloohms, $f_o = \frac{1}{2}\pi C_1 R_3 = 723$ Hz), the resultant phase difference is −90°. Thus the phase difference goes near −180° as the frequency of the input signal L grows higher. As proved by curve II in FIG. **17,** however, the gain of the phase shifter including the transistor Q_5 is constant with respect to signal L regardless of the changes of frequency of signal L.

Signal L coming out of the emitter of the transistor Q_5 is attenuated by an attenuator constituted by the resistors R_4 and R_7, and appears at the output terminal **24** through a high-pass filter constituted by the capacitor C_2 and the resistor R_6. Signal L undergoes, at the high-pass filter, such a phase variation as indiated by curve II in FIG. **16** and, at the attenuator and high-pass filter, such a gain variation as depicted by curve IV in FIG. **17.** The phase of signal L is varied by 45° at the high-pass filter if the frequency of signal L is f_0. The above-mentioned operation of the signal converter is applicable also to the input signal R.

As mentioned above, the phase difference between the output signals L′ and R′ from the signal converter is about 90° when input signal L has a frequency of low frequency band. However, level amplitude lelvel of output signal R′ can be negligibly small compared with output signal L′. If input signal L has a frequency of high frequency band, output signals L′ and R′ are opposite in phase to each other. Accordingly, so long as input signals L and R are of frequencies of low frequency band, the phase relationship between output signals L′ and R′ can never be reversed even in only one of input signals is supplied to the input terminal, and signals having frequencies of low frequency band are never localized at the back of the reproduced sound field. If input signals L and R are of an equal frequency of low frequency band, that is, if they are to be localized midway between the left and right loudspeakers, they will be localized at the front of the reproduced sound field. If only input signal L is of a frequency of high frequency band, it will be localized at the rear-left

loudspeaker. And if only signal R is of a frequency of high frequency band, it will be localized at the rear-right loudspeaker.

FIG. **11** shows another embodiment of this invention in which a signal converter is used for the two-channel playback of a matrix four-channel source. The first and second audio signals L and R reproduced from the matrix four-channel source which may be a matrix four-channel stereo record, a matrix four-channel magnetic tape or a matrix four-channel FM stereo signal source are expressed by the following equation;

$$L = FL + \Delta FR + jRL + j\Delta RR$$

$$R = FR + \Delta FL - jRR - j\Delta RL$$

Where only the rear-left signal RL presents, $L = RL$ and $R = -\Delta RL$. Where signal converter **11** shown in FIG. **5** or **6** is adjusted to provide two sum signals $L' = L + \beta r$ and $R' = R + \beta L$ which are applied to a conventional 2-channel reproducer **122**, the signal converter described above will produce outputs $L' = RL - \Delta\beta RL$ and $R' = -RL + \beta RL$. Accordingly, outputs $L' = (1-\Delta^2)RL$ and $R' = 0$ can be produced by a proper adjustment of β. This means that it is possible to make infinity the separation between rear signals. Thus, it will be seen that incorporation of a signal converter which produces sum signals into a combination of a matrix four-channel source containing rear signals of an especially large level and a two-channel reproducing system is advantageous in the reproduction of a matrix four-channel sound source by a two-channel system.

Where only a front left signal FL presents, $L = FL$ and $R = \Delta FL$. When the potentiometer resistors of the signal converter shown in FIGS. **5** and **6** are adjusted to provide difference signals $L' = L - \alpha R$ and $R' = R - \alpha L$ respectively, the outputs will become $L' = FL - \Delta\alpha FL$ and $R' = \Delta FL - \alpha FL$. Thus, it is possible to obtain outputs $L' = (1-\Delta^2)FL$ and $R' = 0$ by a proper adjustment of α. This shows that it is possible to make infinity the separation between front signals. Accordingly, when a signal converter **11** as shown in FIG. **5** or **6** is used in the circuit shown in FIG. **11** it is possible to control the separation between rear signals or front signals in accordance with the content recorded on a matrix four-channel recording medium. In the case of a jazz, the level of the rear signal is relatively high whereas in the case of a classical music the level of the rear signal is low.

What we claim is:

1. A sound reproducing system for reproducing stereophonically related first and second channel signals from a two-channel signal source by means of a four-channel reproducing system, said system comprising a combination of:

first means connected to receive the first and second channel signals for producing first and second composite signals by combining the first and second channel signals with such amplitude and phase relationships that the first composite signal contains a greater proportion of the first channel signal and a smaller proportion of the second channel signal, the second composite signal contains a greater proportion of the second channel signal and a smaller proportion of the first channel signal, and for producing phase differences between the first and second composite signals with respect to the first and second channel signals respectively which vary as a function of frequency of the first and second channel signals;

control means connected to receive the first and second composite signals for producing control outputs the levels of which vary depending on the phase relationship between the first and second composite signals; and

second means connected to receive, as first and second input signals, the first and second composite signals or the first and second channel signals for producing four-channel output signals by combining the first and second input signals, said second means being operative to produce the four-channel output siganls varying at least mixing ratios of the first and second input signals depending on the levels of the control outputs of said control means.

2. A sound reproducing system according to claim **1** wherein the phase differences between the first and second composite signals with respect to the first and second channel signals represent substantially 90° at a low frequency and substantially 180° at a high frequency, respectively.

3. A sound reproducing system according to claim **1** wherein the amplitude levels of the second and first channel signals contained in the first and second composite signals vary as a function of frequency, respectively.

4. A sound reproducing system according to claim **1** wherein said first means comprises first and second phase shifter means each including a transistor having a collector, and emitter and a base, and a resistor and a capacitor connected in series across the collector and emitter of the transistor; and a resistor means connecting the emitter of transistor in said first phase shifter means with the emitter of transistor in said second phase shifter means, the bases of transistors in said first and second phase shifter means being connected to receive the first and second channel signals, respectively, the resistor-capacitor junctions in said first and second phase shifter means being adapted to derive the first and second composite signals, respectively.

5. A sound reproducing system according to claim **1** wherein said second means comprises a first differential amplifier having first and second output terminals deriving a pair of output signals and first and second input terminals, the first input terminal being connected to receive the first input signal; phase reversing means for reversing the phase of the second input signal; means for coupling the output of said phase reversing means to the second input terminal of said first differential amplifier; a second differential amplifier having first and second output terminals deriving another pair of output signals and first and second input terminals connected to receive the first and second input signals, respectively; and means for controlling the gains of said first and second differential amplifiers in opposite relationship in accordance with the levels of control outputs from said control means.

6. A second reproducing system according to claim **1** wherein said second means comprises means connected to receive the first and second input signals A and B for producing a first output signal substantially proportional to $(1+f)A + (1-f)B$ where f represents a first variable matrix coefficient; means connected to receive the first and second input signals A and B for producing second output signal substantially proportional to $(1+f)B + (1-f)A$; means connected to receive

the first and second input signals A and B for producing a third output signal substantially proportional to $(1+b)A-(1-b)B$ where b represents a second variable matrix coefficient; means connected to receive the first and second input signals A and B for producing a fourth output signal substantially proportional to $(1+b)B-(1-b)A$; and means for varying the matrix coefficients f and b in opposite relationship depending on the levels of control outputs from said control means.

7. A sound reproducing system according to claim **1** wherein said control means includes a phase discriminator for detecting the phase difference between the first and second composite signals.

8. A sound reproducing system according to claim **1** wherein said control means includes a level comparator for comparing the levels of sum and difference of the first and second composite signals.

9. A sound reproducing system according to claim **1** further comprising further control means for producing control outputs in response to the first and second composite signals; and wherein said second means comprises means connected to receive the first and second input signals A and B for producing a first output signal substantially proportional to $(1+f+\sqrt{2})A+(1-f+\sqrt{2}l)B$, where f and l represent variable matrix coefficients; means connected to receive the first and second input signals A and B for producing a second output signal substantially proportional to $(1+f+\sqrt{2})B+(1-f+\sqrt{2}r)A$, where r represent a variable matrix coefficient; means connected to receive the first and second input signals A and B for producing a third output signal substantially proportional to $(1+b+\sqrt{2})A-(1-b+\sqrt{2}l)B$, where b represent a variable matrix coefficient; means connected to receive the first and second input signals A and B for producing a fourth output signal substantially proportional to $(1+b+\sqrt{2})B-(1-b+\sqrt{2}r)A$; and means for varying the matrix coefficients f and b in opposite relationship depending on the levels of control outputs from said control means; and means for varying the matrix coefficients l and r in opposite relationship depending on the levels of control outputs from said further control means.

10. A sound reproducing system according to claim **9** wherein said further control means includes a phase discriminator for detecting phase difference between sum and difference of the first and second composite signals.

11. A sound reproducing system according to claim **9** wherein said further control means includes a level comparator for comparing the levels of the first and second composite signals.

12. A sound reproducing system for reproducing stereophonically related first and second channel signals from a two-channel signal source by means of a four-channel reproducing system, said system comprising a combination of:

first means connected to receive the first and second channel signals for producing first and second composite signals by combining the first and second channel signals with such amplitude and phase relationships that the first composite signal contains a greater proportion of the first channel signal and a smaller proportion of the second channel signal, the second composite signal contains a greater proportion of the second channel signal and a smaller proportion of the first channel signal, and for producing phase differences between the first and second composite signals with respect to the first and second channel signals respectively vary as a function of frequency of the first and second channel signals;

first control means connected to receive the first and second composite signals for producing control outputs the levels of which vary depending on the phase relationship between the first and second composite signals;

second control means connected to receive the first and second composite signals for producing control outputs the levels of which vary depending on the phase relationship between sum and difference of the first and second composite signals;

second means connected to receive, as first and second input signals, the first and second composite signals or the first and second channel signals for producing four-channel output signals by combining the first and second input signals, said second means including means for varying the mixing ratios of and polarity relationship between the first and second input signals in producing the output signals depending on the levels of control outputs from said first control means; and means for varying the mixing ratios of the first and second input signals in producing the output signals depending on the levels of control outputs from said second control means.

13. A sound reproducing system for reproducing stereophonically related first and second channel signals from a two-channel signal source by means of a four-channel reproducing system, said system comprising a combination of:

first means connected to receive the first and second channel signals for producing first and second composite signals by combining the first and second channel signals with such amplitude and phase relationships that the first composite signal contains a greater proportion of the first channel signal and a smaller proportion of the second channel signal, the second composite signal contains a greater proportion of the second channel signal and a smaller proportion of the first channel signal, and for producing phase differences between the first and second composite signals with respect to the first and second channel signals respectively vary as a function of frequency of the first and second channel signals;

control means connected to receive the first and second composite signals for producing control outputs the levels of which vary depending on the phase relationship between the first and second composite signals; and

second means connected to receive, as first and second input signals, the first and second composite signals or the first and second channel signals for producing four-channel output signals by combining the first and second input signals, said second means including means for varying the mixing ratios of and polarity relationship between the first and second input signals in producing the output signals depending on the levels of control outputs from said control means.

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. 3,889,061

DATED June 10, 1975

INVENTOR(S) : Ryosuke Ito and Susumu Takahashi

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Add on first page of patent:

[30] Foreign Application Priority Data
December 21, 1971 Japan 103970/71

Signed and Sealed this

thirtieth Day of *September 1975*

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

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