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Takahashi et al.

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[45] **July 1, 1975**

[54] **SOUND SIGNAL CONVERTING APPARATUS FOR USE IN A FOUR CHANNEL STEREOPHONIC REPRODUCTION SYSTEM**

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[30] **Foreign Application Priority Data**

May 2, 1972 Japan 47-42991

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

[51] **Int. Cl.**[2] **H04R 5/00**

[58] **Field of Search** ....179/1 GQ, 1 G, 1 GP, 179/100.4 ST, 100.1 TD

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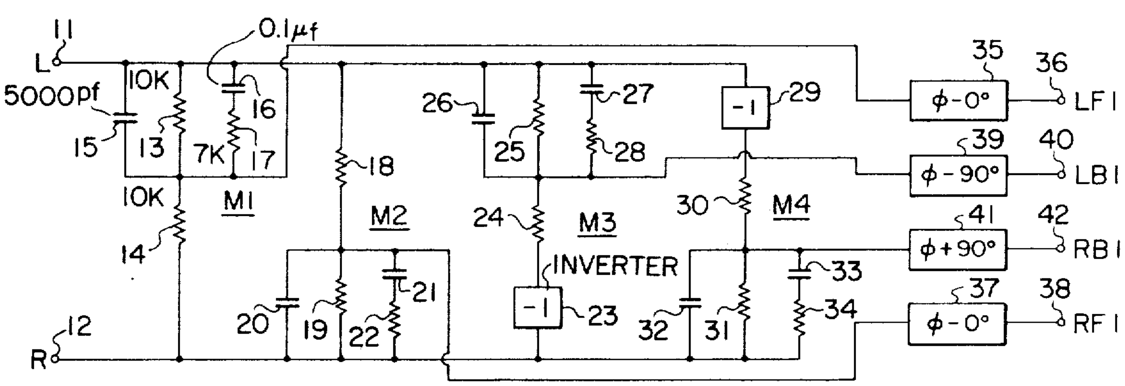
Assistant Examiner—Thomas D'Amico
Attorney, Agent, or Firm—Harris, Kern, Wallen & Tinsley

[57] **ABSTRACT**

A sound signal-converting apparatus for reproducing four sound signals by additively combining signals of two channels in two ways and also by subtractively combining the two channel signals similarly in two ways, which comprises matrix circuits capable of changing the mixing ratio of the two channel signals according to their frequencies, thereby furnishing a listener with a full sense of presence by varying separation between the reproduced four-channel signals according to their frequencies.

9 Claims, 5 Drawing Figures



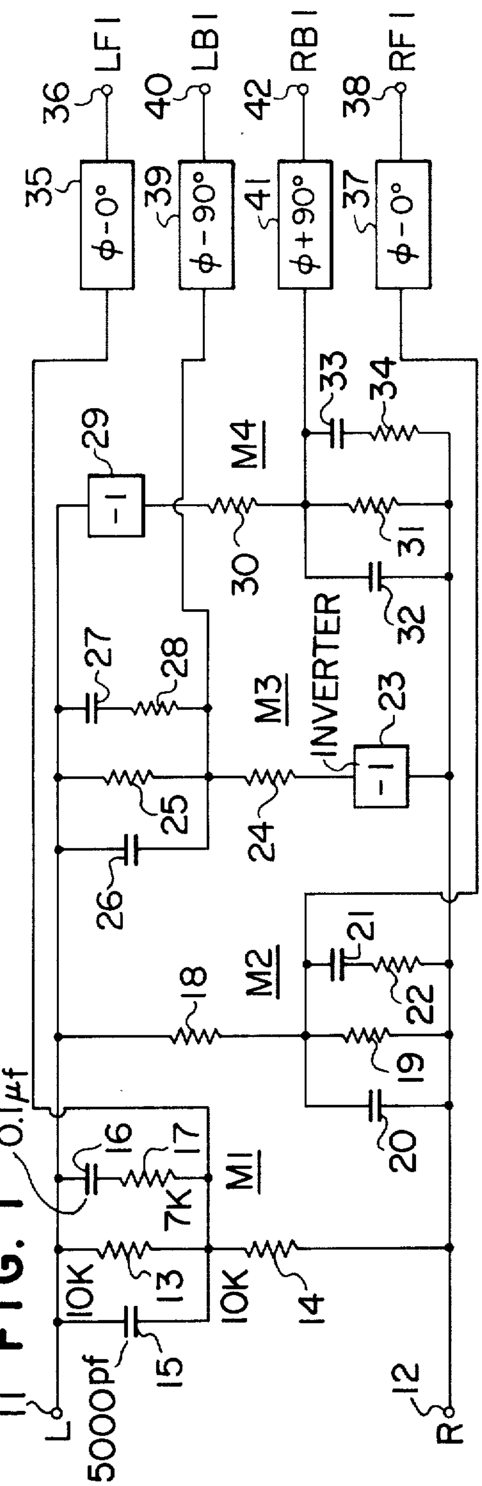


FIG. 1

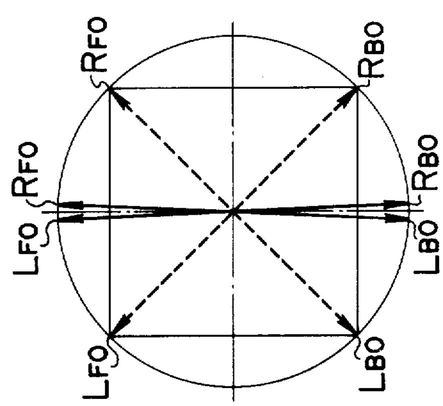


FIG. 2

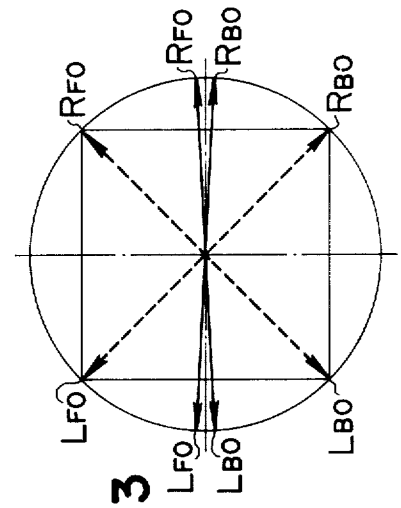
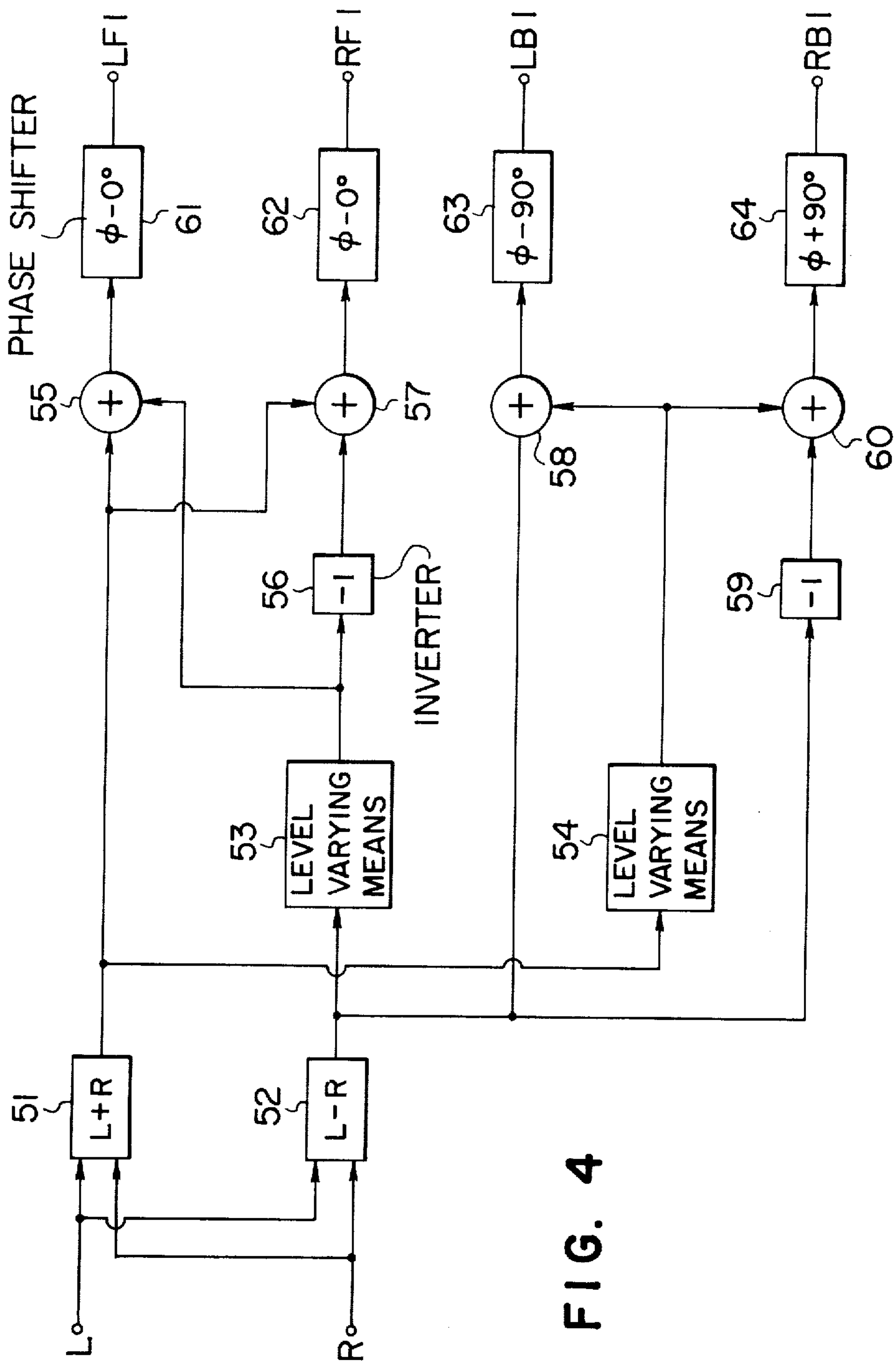


FIG. 3


L
R
51
L+R
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L-R
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LEVEL VARYING MEANS
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LEVEL VARYING MEANS
56
-1
INVERTER
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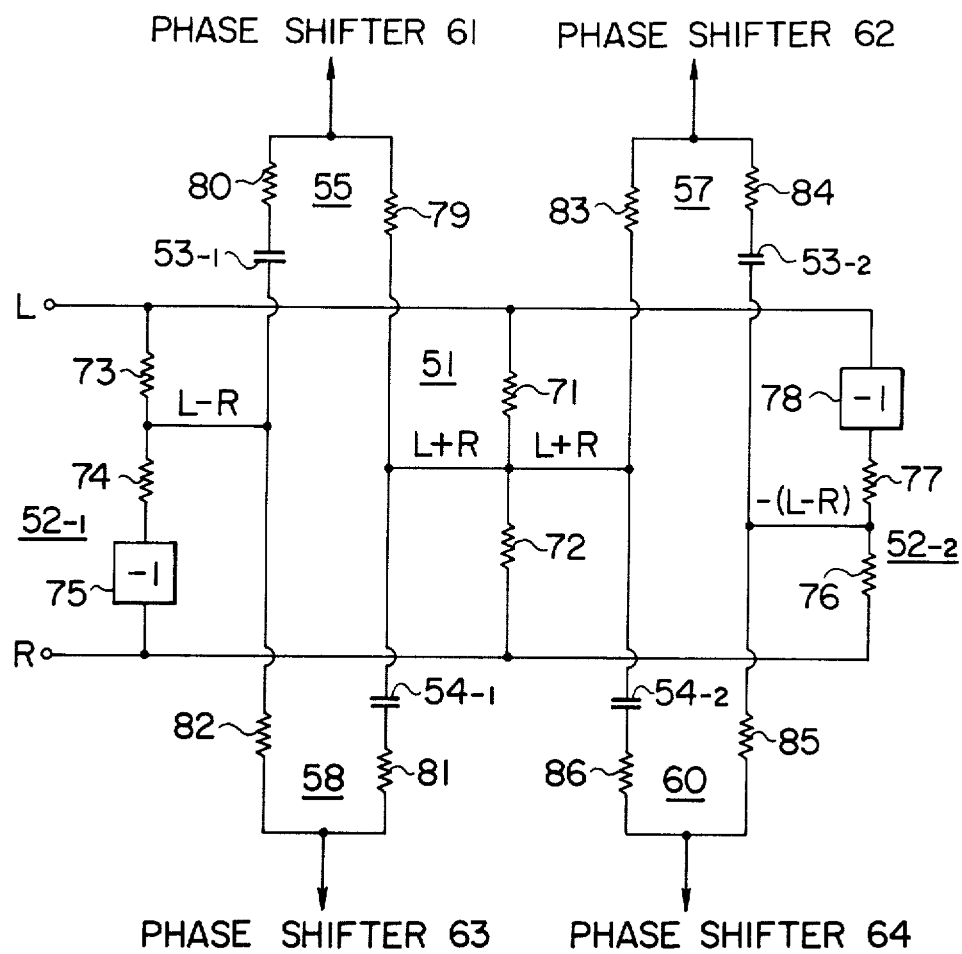
-1
55
57
58
60
PHASE SHIFTER
61
φ-0°
62
φ-0°
63
φ-90°
64
φ+90°
LFI
RFI
LBI
RBI

FIG. 4

FIG. 5


PHASE SHIFTER 61
PHASE SHIFTER 62
80
55
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57
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53-1
53-2
L
73
L-R
51
71
78
-1
74
L+R
L+R
77
-(L-R)
52-1
72
52-2
75
-1
76
R
54-1
54-2
82
85
58
81
86
60
PHASE SHIFTER 63
PHASE SHIFTER 64

SOUND SIGNAL CONVERTING APPARATUS FOR USE IN A FOUR CHANNEL STEREOPHONIC REPRODUCTION SYSTEM

This invention relates to a sound signal-converting apparatus and more particularly to a sound signal-converting apparatus adapted for four-channel stereophonic reproduction.

Recently, there have been developed various matrix four-channel stereophonic systems which comprise converting four-channel signals to two-channel signals; storing the two-channel signals in a recording medium such as a phonographic record or magnetic tape; picking up the two-channel signals from the recording medium to demodulate them substantially to the original four-channel signals; and reproducing the demodulated signals by four loud-speakers arranged around a listener.

According to one of the matrix four-channel stereophonic systems, two-channel signals L and R being stored in a recording medium are each composed as follows:

$$\left.\begin{aligned} L &= LF + \Delta RF + JLB + J\Delta RB \\ R &= RF + \Delta LF - JRB - J\Delta LB \end{aligned}\right\} \qquad (1)$$

where:

LF = left-front sound signals

RF = right-front sound signals

LB = left-back sound signals

RB = right-back sound signals

Δ = a constant or matrix coefficient having a value of about 0.4

+JLB = signal LB having its phase shifted +90° relative to the signals LF and RF

−JRB = signal RB having its phase shifted −90° relative to the signals LF and RF

A sound signal-converting apparatus or decoder reproduces from the signals L and R shown in the above equation (1) the following four-channel signals LF1, RF1, LB1 and RB1 mainly consisting of signals corresponding to said L and R signals.

$$\left.\begin{aligned} LF1 &= L + \Delta R \\ RF1 &= R + \Delta L \\ LB1 &= -J(L-\Delta R) \\ RB1 &= +J(R-\Delta L) \end{aligned}\right\} \qquad (2)$$

In a matrix four-channel system where the four-channel input signals are encoded to two-channel signals as shown in the aforesaid equation (1) and the two-channel signals are decoded to four-channel output signals as shown in the above equation (2), let the level of a sound signal LF appearing on the left-front output channel be designated as 0 dB. Then there will appear the −3 dB crosstalk component of the LF sound signal regardless of its frequency on the adjacent left-back and right-front output channels. However, the crosstalk component of the sound signal LF does not appear at all on the right-back output channel diagonally opposite to the left-front output channel.

The aforementioned matrix four-channel system has the drawback that separation between signals of the adjacent channels is very poor. Where a stereophonic record is manufactured for the matrix four-channel system, most customary practice is to localize the sound image of low pitch musical instruments such as a bass or drum at the center between the left-front channel and the right-front channel, at the center between the left-back channel and the right-back channel or both centers. On the other hand, the sound image of high pitch musical instruments such as a trumpet is localized at the center between the left-front channel and left-back channel, at the center between the right-front channel and right-back channel or both centers. However, the prior art matrix four-channel system fails to enable a listener distinctly to feel the location of the sound image of low or high pitch musical instruments due to poor separation between signals of the adjacent channels.

It is accordingly the object of this invention to provide a sound signal-converting apparatus for converting two-channel signals to four-channel signals which enables a listener to have a full sense of presence by effecting the separation between signals of the respective channels in different degrees according to the frequencies of the sound signals.

According to this invention there is provided a sound signal-converting apparatus including matrix circuit means for reproducing four-channel signals on four output channels by combining two channel signals is characterized in that the matrix circuit means includes means for varying the mixing ratio of two channel signals according to their frequencies.

Separation characteristics of the reproduced four-channel signals by the sound signal-converting apparatus of the invention are characterized in that with respect to a medium frequency, separation between the front and back channels and separation between the left and right channels are substantially equal to each other; with respect to a low frequency, separation between the left and right channels is lowered, whereas separation between the front and back channels is enhanced; and with respect to a high frequency, separation between the front and back channels is lowered, whereas separation between the left and right channels is enhanced.

According to an embodiment of this invention, an impedance circuit including resistors and capacitors are connected in series with a separate resistor between the input terminals receiving two channel signals to deliver desired additively combined signals from the junction of the impedance circuit with the separate resistor. The capacitors whose impedance varies with the frequencies of signals supplied thereto change the mixing ratio of two channel signals according to their frequencies. To form subtractively combined output signals, there are connected a similar impedance circuit and a separate resistor between the input terminals of two channel signals having opposite polarities.

According to another embodiment of this invention, there are also produced signals representing the sum and difference of two channel signals. To obtain additively combined signals, the difference signals are mixed with the sum signals through a filter or capacitor which increasingly attenuates the level of signals as they fall in frequency. To produce subtractively combined signals, the sum signals are mixed with the difference signals through a filter or capacitor which attenuates the level of signals more prominently as they decrease in frequency.

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

FIG. 1 is a circuit diagram of a sound signal-converting apparatus according to an embodiment of this invention;

FIG. 2 shows a pattern of reproduced low frequency signals obtained by the sound signal-converting apparatus of FIG. 1;

FIG. 3 indicates a pattern of reproduced high frequency signals produced by the apparatus;

FIG. 4 is a block diagram of a sound signal-converting apparatus according to another embodiment of the invention; and

FIG. 5 is a concrete circuit diagram of the apparatus of FIG. 4.

Referring to FIG. 1 illustrating an embodiment of this invention, there are connected between input terminals 11 and 12 supplied with signals L and R of a first and a second channel a plurality of matrix circuits which reproduce four signals LF1, RF1, LB1, and RB1 by additive and subtractive combinations of the signals L and R of the first and second channels. A first matrix circuit M1 for reproducing the signal LF1 by additive combination of the signals L and R includes serially connected resistors 13 and 14 having an equal value, for example, 10 kohms; a reactive impedance element 15 such as a capacitor of, for example, 5,000 picofarads connected parallel with the resistor 13 and exhibiting a relatively low impedance at a higher frequency than a predetermined frequency, for example, 5 kHz; a series circuit connected parallel with the resistor 13 and including a capacitor 16 of 0.1 microfarad and a resistor 17 of 7 kohms. The junction of the resistors 13 and 14 is connected to an output terminal 36 for deriving the reproduced signal LF1 through a phase shifter 35.

A second matrix circuit M2 for reproducing the signal RF1 by additive combination of the signals L and R includes serially connected resistors 18 and 19; a capacitor 20 connected parallel with the resistor 19, a series circuit connected parallel with the resistor 19 and including a capacitor 21 and a resistor 22. The junction of the resistors 18 and 19 is connected to an output terminal 38 for deriving the signal RF1 through a phase shifter 37.

A third matrix circuit M3 for reproducing the signal LB1 by subtractive combination of the signals L and R includes an inverter 23 and resistors 24 and 25 all connected in series, a capacitor 26 connected parallel with the resistor 25, a series circuit connected parallel with the resistor 25 and including a capacitor 27 and a resistor 28. The junction of the resistors 24 and 25 is connected to an output terminal 40 for deriving the signal LB1 through a phase shifter 39.

A fourth matrix circuit M4 for reproducing the signal RB1 by subtractive combination of the signals L and R includes an inverter 29 and resistors 30 and 31 all connected in series, a capacitor 32 connected parallel with the resistor 31, and a series circuit connected parallel with the resistor 31 and including a capacitor 33 and a resistor 34. The junction of the resistors 30 and 31 is connected to an output terminal 42 for deriving the signal RB1 through a phase shifter 41.

In the above-mentioned arrangement, the capacitors and resistors included in the second, third and fourth matrix circuits M2, M3 and M4 have the same values as those included in the first matrix M1. The phase shifters 35 and 37 have the same phase-shifting characteristics over the entire audible frequency range. The phase shifter 39 has a phase-shifting characteristic which is displaced −90° relative to those of the phase shifters 35 and 37, while the phase shifter 41 has a

phase-shifting characteristic which is displaced +90° relative to those of the phase shifters 35 and 37.

There will now be described the first matrix circuit M1 in particular. For signals of medium frequency, the capacitor 15 has a large impedance while the capacitor 16 serially connected to the resistor 17 has a small impedance. Therefore, the resultant impedance of the impedance circuit including the resistors 13 and 17 and capacitors 15 and 16 is determined substantially by the parallel resistance (about 4 kohms) of the resistors 13 and 17. For signals of low frequency, both capacitors 15 and 16 exhibit a large impedance, so that the above-mentioned resultant impedance is substantially defined by the resistor 13. For signals of high frequency, the capacitor 15 has a far smaller impedance than the resistors 13 and 17, so that the resultant impedance is substantially determined by the impedance of the capacitor 15. This resultant impedance is negligibly small as compared with the value of the resistor 14 (10 kohms) serially connected to the impedance circuit. The impedance circuits of the second, third and fourth matrices M2, M3 and M4 have the same property as that of the first matrix M1.

Obviously, therefore, four-channel reproduced signals obtained by the decoder of FIG. 1 from the two channel signals L and R having a medium frequency may be expressed as follows:

$$\left.\begin{aligned} LF1 &= L + \Delta R \\ RF1 &= R + \Delta L \\ LB1 &= -J(L - \Delta R) \\ RB1 &= +J(R - \Delta L) \end{aligned}\right\} \tag{3}$$

These reproduced signals are the same as those obtained by the prior art decoder. In this case, there is obtained a square reproduction pattern indicating substantially the same degree of separation of signals between the front and back channels as between the left and right channels as shown by dotted lines in FIG. 2.

When reproduced, the two channel signals L and R having a low frequency of less than 200 Hz provide four-channel signals substantially as shown below:

$$\left.\begin{aligned} LF1 &= L + R \\ RF1 &= R + L \\ LB1 &= -J(L - R) \\ RB1 &= +J(R - L) \end{aligned}\right\} \tag{4}$$

A reproduction pattern obtained in the above case is shown by solid lines in FIG. 2. As apparent from this figure, separation between the left and right channels is decreased, whereas separation between the front and back channels is increased. In the case of low frequency signals, there takes place front-back stereophonic reproduction wherein the stereophonic reproduction of low frequency signals is carried out between the centers between the front and back channels, with the image of sounds from a low pitched musical instrument localized at the front and/or back center.

When reproduced, the two channel signals L and R having a high frequency of more than 5 kHz provide four-channel signals substantially as indicated below:

$$\left.\begin{aligned} LF1 &= L \\ RF1 &= R \\ LB1 &= -JL \\ RB1 &= +JR \end{aligned}\right\} \tag{5}$$

In the case of high frequency, separation between the front and back channels is decreased, while separation between the left and right channels is increased, as clearly seen from the reproduction pattern of FIG. 3.

In the case of high frequency signals, there takes place left-right stereophonic reproduction wherein the stereophonic reproduction of high frequency signals is carried out between the left and right centers, with the image of sounds from a high pitched musical instrument localized at the left and/or right centers.

As mentioned above, a decoder according to this invention causes matrix circuits additively or subtractively to combine signals of the two channels in different degrees according to their frequencies, namely, enabling low frequency two channel signals to be combined in a larger ratio than medium frequency signals, and high frequency two channel signals to be combined in a smaller ratio than the medium frequency signals.

There will now be described by reference to FIG. 4 a sound signal-converting apparatus according to another embodiment of this invention. Matrix circuits **51** and **52** provide sum signals L + R and different signals L − R from the two channel signals L and R respectively. The difference signals L − R and sum signal L + R are supplied to a first and a second level-varying means **53** and **54** which increasingly attenuate the levels of signals as they fall in frequency. The sum signal L + R and an output signal from the first level-varying means **53** are mixed by a first mixer **55** to form the reproduced signal **LF1**, and then conducted to a phase shifter **61** of the same type as the phase shifter **35** of FIG. **1**. The output signal from the first level-varying means **53** is also supplied to a second mixer **57** through a phase inverter **56** to be mixed with the sum signal L + R for formation of the reproduced signal **RF1**. An output signal from the second mixer **57** is transmitted to a phase shifter **62** of the same type as the phase shifter **37** of FIG. **1**. The difference signal L − R and an output signal from the second level-varying device **54** are conducted to a third mixer **58** and then to a phase shifter **63** of the same type as the phase shifter **39** of FIG. **1**. The difference signal is also transmitted to a fourth mixer **60** through a phase inverter **59** to be mixed with an output signal from the second level-varying means **54** for formation of the reproduced signal **RB1**. An output signal from the fourth mixer **60** is supplied to a phase shifter **64** of the same type as the phase shifter **41** of FIG. **1**. The embodiment of FIG. **4** enables signals of two channels to be mixed in different ratios according to their frequencies as in the embodiment of FIG. **1**.

The first and second level-varying means **53** and **54** may each consist of a filter or capacitor which increasingly attenuates the level of input signals as they decrease in frequency. The sound signal-converting apparatus whose arrangement is schematically illustrated in the block diagram of FIG. **4** may be devised in a variety of forms, one concrete form being presented in FIG. **5**.

The parts of FIG. **5** the same as those of FIG. **4** are denoted by the same numerals. The matrix circuit **51** for producing the sum signal L + R includes resistors **71** and **72** of the same value connected in series between the input terminals receiving the two channel signals L and R, the sum signal L + R being delivered from the junction of the resistors **71** and **72**. A matrix circuit **52-1** for providing a first difference signal L − R includes a serial circuit consisting of resistors **73** and **74** of the same value and a phase inverter **75** for inverting the polarity of the signal R, the first difference signal L − R being obtained from the junction of the resistors **73** and **74**. A matrix circuit **52-2** for producing a

second difference signal R − L includes a serial circuit consisting of resistors **76** and **77** of the same value and a phase inverter **78** for inverting the polarity of the signal L, the second difference signal R − L being delivered from the junction of the resistors **76** and **77**.

To the first mixer **55** including mixing resistors **79** and **80** are supplied the sum signal L + R directly and the first difference signal L − R through a capacitor **53-1**. To the third mixer **58** including mixing resistors **81** and **82** are conducted the first difference signal L − R directly and the sum signal L + R through a capacitor **54-1**. To the second mixer **57** including mixing resistors **83** and **84** are supplied the sum signal L + R directly and the second difference signal R − L through a capacitor **53-2**. To the fourth mixer **60** including mixing resistors **85** and **86** are transmitted the second difference signal R − L directly the sum signal L + R through a capacitor **54-2**. The embodiment of FIG. **5** eliminates the necessity of providing the phase inverters **56** and **59** of FIG. **4** because two different signals L − R and R − L which are opposite in polarity are produced.

The foregoing description refers to the case where the sound signal-converting apparatus of this invention was applied in converting two channel signals including a plurality of channel signals to the plural channel signals. However, the present sound signal-converting apparatus can be used intact with the stereophonic signals obtained from the conventional two-channel stereophonic phonographic records, magnetic tape or FM stereophonic broadcasting. Further, the sound signal-converting apparatus of the invention is not limited to the aforesaid embodiments, but may be applied with any other modifications or changes, provided they fall within the scope of the claims of the invention.

What we claim is:

1. In a sound signal-converting apparatus including matrix circuit means for reproducing first, second, third and fourth four-channel output signals by additively combining two channel input signals in first and second ratios to produce said first and second output signals, respectively, and subtractively combining said two channel input signals in third and fourth ratios to produce said third and fourth output signals, respectively, the improvement wherein said matrix circuit means includes means for varying each of said first, second, third, and fourth mixing ratios from a first ratio when both two channel input signals are at one frequency to a second higher ratio when both two channel input signals are at a second higher frequency.

2. A sound signal converting apparatus for reproducing four output signals from first and second channel signals comprising:

- means connected to receive the first and second channel signals for producing sum and difference signals;
- first level varying means connected to receive the difference signals for varying the level thereof according to the frequency thereof;
- second level varying means connected to receive the sum signal for varying the level thereof according to the frequency thereof;
- means for additively combining the sum signal of first and second channel signals and the output signal of said first level varying means to produce a first output signal;
- means for subtractively combining the sum signal of first and second channel signals and the output sig-

nal of said first level varying means to produce a second output signal;

means for additively combining the difference signal of first and second channel signals and the output signal of said second level varying means to produce a third output signal; and

means for subtractively combining the difference signal of first and second channel signals and the output signal of said second level varying means to produce a fourth output signal.

3. A sound signal converting apparatus according to claim **2** wherein said first and second level varying means are operative to attenuate the levels of the difference and sum signals, respectively, as the frequencies thereof fall.

4. A sound signal converting apparatus according to claim **3** wherein each of said first and second level varying means includes a capacitor.

5. A sound signal-converting apparatus for reproducing on four output channels four-channel signals from first and second channel signals, comprising:

first means for additively combining said second channel signal with said first channel signal in a predetermined ratio of said second channel signal to said first channel signal for channel signals of a medium frequency, in a larger ratio than said predetermined ratio for channel signals of a lower frequency and in a smaller ratio than said predetermined ratio for channel signals of a higher frequency to produce a first output signal;

second means for additively combining said first channel signal with sadi second channel signal said a predetermined ratio of said first channel signal to said second channel signal for channel signals of the medium frequency, in a larger ratio than said predetermined ratio for channel signals of the lower frequency and in a smaller ratio than said predetermined ratio for channel signals of the higher frequency to produce a second output signal;

third means for subtractively combining said second channel signal with said first channel signal in a predetermined ratio of said second channel signal to said first channel signal for channel signals of a medium frequency, in a larger ratio than said predetermined ratio for channel signals of the lower frequency and in a smaller ratio than said predetermined ratio for channel signals of the higher frequency to produce a third output signal; and

fourth means for subtractively combining said first channel signal with said second channel signal in a predetermined ratio of said first channel signal to said second channel signal for channel signals of the medium frequency, in a larger ratio than said predetermined ratio for channel signals of the lower frequency and in a smaller ratio than said predetermined ratio for channel signals of the higher frequency to produce a fourth output signal.

6. A sound signal-converting apparatus according to claim **1** wherein said first means includes an impedance circuit including reactive impedance elements for coupling said first channel signal to the first output channel, and a resistor for coupling said second channel signal to the first output channel; said second means includes an impedance circuit including reactive impedance elements for coupling said second channel signal to the second output channel, and a resistor for coupling said first channel signal to the second output channel; said third means includes an impedance circuit including reactive impedance elements for coupling said first channel signal to the third output channel, and a resistor for coupling said second channel signal of opposite polarity to the third output channel; and said fourth means includes an impedance circuit including reactive impedance elements for coupling said second channel signal to the fourth output channel, and a resistor for coupling said first channel signal of opposite polarity to the fourth output channel.

7. A sound signal-converting apparatus according to claim **6** wherein said impedance circuits include a parallel arrangement including a first resistor, a first capacitor and a serial circuit of a second resistor and a second capacitor, respectively.

8. A sound signal-converting apparatus according to claim **5** further including means for producing a sum signal by additively combining said first and second channel signals and for producing first and second difference signals having the opposite polarities by subtractively combining said first and second channel signals; wherein said first means includes means for coupling said sum signal to the first output channel and means for coupling said first difference signal to the first output channel, the latter means including level-varying means for increasingly attenuating the level of said first difference signal as its frequency falls; said second means includes means for coupling said sum signal to the second output channel and means for coupling said second difference signal to the second output channel, said latter means including level-varying means for increasingly attenuating the level of said second difference signal as its frequency falls; said third means comprises means for coupling said first difference signal to the third output signal and means for coupling said sum signal to the third output channel, said latter means including level-varying means for increasingly attenuating the level of said sum signal as its frequency falls; and said fourth means has means for coupling said second difference signal to the fourth output channel and means for coupling said sum signal to the fourth output channel, said latter means including level-varying means for increasingly attenuating the level of said sum signal as its frequency falls.

9. A sound signal-converting apparatus according to claim **8** wherein said level-varying means include a capacitor, respectively.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,892,918 Dated July 1, 1975

Inventor(s) Susumu Takahashi; Ryosuke Ito

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

[30] Foreign Application Priority Data, "May 2, 1972 Japan ....47-42991" should be --May 2, 1972 Japan.. ....43991/72--.

Signed and Sealed this

fourteenth Day of *October 1975*

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks