METHOD AND A DEVICE FOR PRODUCING A 4-CHANNEL STEREOPHONIC SOUND FIELD

Inventors: Kazuo Kamata; Shogo Shigeyama, both of Tokyo, Japan

Assignee: Trio Kabushiki Kaisha, Tokyo, Japan

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Primary Examiner—Kathleen H. Claffy
Assistant Examiner—Thomas D’Amico
Attorney, Agent, or Firm—Holman & Stern

ABSTRACT

A method of producing a 4-channel stereophonic sound reproduction, in which 4-channel stereophonic signals are converted into 2-channel stereophonic signals by means of an encoder, provided with matrices; the thus obtained 2-channel stereophonic signals are transmitted, recorded and reproduced by means of a conventional 2-channel stereophonic signal medium; further, the processed 2-channel stereophonic signals are converted into 4-channel stereophonic signals by means of a decoder provided with matrices and phase-dividers again. An apparatus to carry out the method is described.
METHOD AND A DEVICE FOR PRODUCING A 4-CHANNEL STEREOPHONIC SOUND FIELD

This is a continuation, of application Ser. No. 187,313, filed Oct. 7, 1971.

BACKGROUND OF THE INVENTION

The present invention relates to a method and a device for producing a 4-channel stereophonic sound reproduction, in which 4-channel stereophonic signals are converted into 2-channel stereophonic signals which are well known, the thus obtained 2-channel stereophonic signals are transmitted, recorded and reproduced by means of a conventional 2-channel stereophonic signal device; and then the processed 2-channel stereophonic signals are converted into 4-channel stereophonic signals again; and the invention also relates to a device for producing multi-channel stereophonic sound from a two-channel stereophonic signal.

A number of methods and devices for recording and reproducing 4-channel stereophonic signals have been invented or devised. However, it has hitherto been impossible for these methods and devices to use a conventional 2-channel stereophonic signal medium such as a conventional FM stereophonic system, a stereophonic record and a stereophonic tape as a medium transmitting the signals. In other words, the conventional methods and devices for recording and reproducing the 4-channel stereophonic signals suffer from a disadvantage in that said method and devices are not compatible with the conventional 2-channel stereophonic system, being not capable of using conventional recording and reproducing methods and devices.

SUMMARY OF THE INVENTION

It is accordingly a main object of the present invention to provide a method and a device for producing 4-channel stereophonic sound, having compatibility such that 4-channel stereophonic signals can be transmitted and recorded by means of a conventional 2-channel stereophonic signal medium, and conventional 2-channel stereophonic signals can be reproduced as pseudo-4-channel stereophonic signals.

It is a further object of the invention to provide a method and a device for encoding four channel stereophonic signals into two channel type signals.

It is another object of the invention to provide a device for producing a multi-channel stereophonic signal, which is provided with connecting terminals adapted to connect the terminals of loudspeakers and resistors, in which a two-channel stereophonic signal is readily converted into a multi-channel stereophonic signal by merely connecting loudspeakers only or a matrix resistor thereto.

The nature, utility and principle of the present invention will be more clearly understood from the following description with reference to the accompanying drawings, in which like components are indicated by like numerals or symbols.

BRIEF DESCRIPTION OF THE DRAWING

In the accompanying drawings:

FIG. 1 is a block diagram of a device for producing a 4-channel stereophonic sound field according to the present invention;

FIGS. 2 to 4, 5(1)-5(4), 6(1)-6(4) are auxiliary diagrams illustrating the present invention;

FIG. 7 shows curves illustrating the phase-shifting characteristics of phase-shifters employed in a decoder shown in FIG. 1;

FIG. 8 is a circuit diagram showing one embodiment of the encoder according to the present invention;

FIG. 9 is a circuit diagram illustrating one embodiment of the decoder according to the present invention;

FIG. 10 is a block diagram showing another embodiment of the encoder according to the present invention;

FIG. 11 is a block diagram illustrating another embodiment of the decoder, in which 2-channel stereophonic signals are decoded according to the present invention as 4-channel stereophonic signals;

FIG. 12 shows curves exhibiting the characteristics of phaseshifters employed in the encoder shown in FIG. 10;

FIG. 13 is a circuit diagram illustrating another embodiment of the encoder according to the present invention;

FIGS. 14 through 20 are diagrams serving to help explain the present invention;

FIG. 21 is a connecting circuit diagram of an example of the multi-channel stereophonic sound field production device according to the present invention; and

FIG. 22 is a connecting circuit of another example according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

With reference now to FIG. 1, there is shown a block diagram of a four-channel stereophonic sound field production device which comprises a 4-channel encoder 1 having input terminals a, b, c and d of 4-channel stereophonic signals (a front-left signal F1, a front-right signal F2, a rear-left signal R1, and a rear-right signal R2) to matrices M4 and M4, and output terminals e and f for 2-channel stereophonic signals, a conventional two-channel stereophonic signal medium 2 which is used on an FM stereophonic system, for instance a stereophonic record of a stereophonic type known in the art; and a four-channel decoder 8 which comprises a connecting circuit 3 having input terminals g and h for the 2-channel stereophonic signals and output terminals i and j for the front-left signal F1 and front-right signal F2 of the 4-channel stereophonic signal, phase-dividers 4 and 5, matrices M5 and M5, phase-shifter 6 and 7, and output terminals k and l for a rear-left signal R1 and a rear-right signal R2 of the 4-channel stereophonic signals.

In general, when there is a sound field created by signals A, B, C and D originated from four-sound sources as shown in FIG. 2, in a four-channel stereophonic signal reproduction loudspeaker system corresponding to the sound field as shown in FIG. 3 a front-left loudspeaker SP1, a front-right loudspeaker SP2, a rear-left loudspeaker SP3 and a rear-right loudspeaker SP4 will sound in accordance with the front-left signal FL1, the front-right signal FR1, the rear-left signal RL1 and the rear-right signal RR1, respectively.

Under this condition, it is required that for instance the front-left signal FL1 does not contain as its component the signal D originated from the sound source faced and located on its diagonal line and that the signal A included therein is greater in level, than the signals B and C. Considering this requirement, it is assumed that the front-left signal FL1 and the front-right...
signal $F_3$ are represented by the following equations (1) and (2), respectively; and then the rear-left signal $R_k$ and the rear-right signal $R_n$ equivalent to the equations (1) and (2) in construction are represented by the equations (3) and (4) shown below:

\begin{align*}
F_3 &= nA + B + C \\
F_4 &= nB + A + D \\
R_k &= nC + A + D \\
R_n &= nD + nB + nC
\end{align*}

where : $n > 1$

$nC$ in the equation (3) and $nD$ in the equation (4) may be obtained by arranging the equations (1) and (2) as follows:

\begin{align*}
nF_3 - F_4 &= (n^2 - 1)A + nC - D \\
nF_4 - F_3 &= (n^2 - 1)B + nD - C
\end{align*}

In order to make the equations (5) and (6) equivalent to the equations (3) and (4) $(n^2 - 1)$ should be equal to one.

$(n^2 - 1) = 1$ and $n > 1$, then: $n = \sqrt{2}$

Therefore, the equations (1) through (4) can be converted as follows:

\begin{align*}
F_3' &= \sqrt{2} A + B + C \\
F_4' &= \sqrt{2} B + A + D \\
R_k' &= \sqrt{2} C + A - D \\
R_n' &= \sqrt{2} D + B - C
\end{align*}

Consequently, it is required for the 4-channel encoder 1 shown in FIG. 1 to mix the signals A, B, C and D which come from the four sound sources, according to the equations (7) and (8), thereby to obtain the two-channel stereophonic signals.

Now, if the signals A, B, C and D are applied, as the signal of the 4-channel stereophonic signal, to the input terminals a, b, c and d of the 4-channel encoder 1, respectively, the signals A, B and C are mixed at a ratio of $\sqrt{2} : 1 : 1$ in the matrix $M_1$. In order to obtain the left signal of the two-channel stereophonic signal represented by the equation (1), and in the same way the signals B, A, and D are mixed at a level ratio of $\sqrt{2} : 1 : 1$ in the matrix $M_2$ in order to obtain the right signal of the two-channel stereophonic signal represented by the equation (2). When the two-channel stereophonic signals are fed into the two-channel stereophonic medium, or a recording and reproducing medium as a stereophonic record or a stereophonic tape, through the terminals e and f for recording and reproducing them, the signals A, B, C and D are radiated from a left loudspeaker $SP_1$ and a right loudspeaker $SP_2$ of FIG. 4 and are heard such as positioned with respect to a listening position M shown in FIG. 4.

Therefore, in order to obtain the signals represented by the equations (9) and (10) from the signals represented by the equations (7) and (8), the two-channel stereophonic signals are applied to the four-channel decoder 8 shown in FIG. 1. The two-channel stereophonic signals applied to the input terminals g and h of the 4-channel decoder 8 are, as they are, obtained as a front-left signal $F_3$ and a front-right signal $F_4$ in the 4-channel stereophonic signals as represented by the equations (1) and (2) through the connecting circuit 3 at the output terminals i and j. The left signal and right signals of the two-channel stereophonic signals represented by the equations (7) and (8) are divided to be in the same and opposite phase by the phase-dividers 4 and 5, respectively. The thus divided left signal and right signal are mixed at a ratio of $\sqrt{2} : 1$ in the matrix $M_3$ thereby converting them into the signal represented by the equation (9), and the thus converted signal is obtained as the rear-left signal $R_k$ of the 4-channel stereophonic signals at the output terminal k. In the same way the divided right signal and left signal are mixed at a level ratio of $\sqrt{2} : 1$ in the matrix $M_4$ thereby converting them into the signal represented by the equation (10), and the thus converted signal is obtained as the rear-right signal $R_n$ of the 4-channel stereophonic signals at the output terminal l.

With reference now to FIG. 5, there is described how the four signals A, B, C and D originated from the four sound source are radiated from the loudspeakers, respectively. In other words, there is explained with reference to a level ratio of levels in said four signals contained in the respective channel of the four-channel stereophonic signals when said four signals are radiated from the respective loudspeakers.

As for the signal A, it can be understood from FIG. 5(1) that the level of sound radiated from a loudspeaker $SP_1$ is $\sqrt{2}$, that of sound radiated from loudspeakers $SP_2$ and $SP_3$ adjacent to the loudspeaker $SP_1$ is 1, respectively, and no radiation is obtained from a loudspeaker $SP_4$ located on a diagonal line starting from the loudspeaker $SP_1$.

As for the signal B, C and D also, as apparent from FIGS. 5(2), (3) and (4), each level of sounds radiated from loudspeakers is completely at the same ratio as mentioned above on the basis of the loudspeakers $SP_2$, $SP_3$ and $SP_4$, respectively. Therefore, in producing a sound field by the four-channel stereophonic signals obtained at the output terminals i, j, k and l, the fixed position of the sound image of each channel signal is as shown in FIGS. 6 (1) through 6 (4), and is located at a position where the sound image should be produced.

With regard to the 4-channel stereophonic signals derived through a 4-channel decoder 8 in FIG. 1, as apparent from the equations (9) and (10), the signal components $-D$ and $-C$ are included in the rear-left signal $R_k$ and the rear-right signal $R_n$, respectively. The signal components $-D$ and $-C$ are obtained by reversing the phases of the signal components D and C by 180°, respectively.

When the same signals C (or D) are radiated in opposite phase opposing loudspeakers $SP_3$ and $SP_4$, both signals thus radiated are subjected to a spatial combination, as a result of which the fixed positions thereof in audible feeling are located extremely outside a line connecting the loudspeakers $SP_3$ and $SP_4$, thereby giving an unpleasant feeling to a listener. In order to eliminate this disadvantage, the rear-left signal $R_k$ and the rear-right signal $R_n$ which are respectively the output signals of the matrices $M_3$ and $M_4$ in FIG. 1, are fed into the phase-shifters 6 and 7, respectively, whereby a phase difference of 180° between both signals is decreased by substantially 90° as shown in FIG. 7. Consequently, a rear-left signal $R_k$ and a rear-right signal $R_n$ which have been corrected, are obtained at the output terminals ko and lo. If the phase-shifting of said both signals is conducted within a low frequency range on the order of from 100 Hz to 1 kHz, a more effective sound reproduction can be expected.

With reference now to FIG. 8, there is an example of the 4-channel encoder 1 (in FIG. 8, like parts in FIG. 1 are indicated with like numerals or symbols).

The front-left signal $F_{k1}$, front-right signal $F_{k2}$ and rear-left signal $R_k$ in the 4-channel stereophonic signals applied to the input terminals a, b, c and d are mixed at a level ratio of $\sqrt{2} : 1 : 1$ by selecting the resistance
5 values of the resistors \( R_1, R_2, \) and \( R_a \) of a matrix \( M_1 \) to be, for instance, 33 k ohm, 47 k ohm and 47 k ohm, respectively, whereby a left signal represented by the equation (7) of the 2-channel stereophonic signal is obtained at a terminal \( f \).

In the same way, the front-right signal \( R_{bL} \), front-left signal \( F_L \) and rear-right signal \( R_{br} \) in the 4-channel stereophonic signals applied to the input terminals \( a, b, c \) and \( d \) are mixed at a level ratio of \( \sqrt{2} : 1 : 1 \) by selecting the resistance values of resistors \( R_{aL}, R_{bL} \) and \( R_{br} \) of a matrix \( M_2 \) to be, for instance, 33 k ohm and 47 k ohm, respectively, whereby a right signal represented by the equation (8) of the two-channel stereophonic signals, is obtained at a terminal \( f \).

Referring to FIG. 9, there is shown an embodiment of the 4-channel decoder \( 8 \) (in FIG. 9, like components in FIG. 1 are shown with like symbols or numerals).

When the left signal and right signal (represented by the equations 7 and 8 of the two-channel signals are applied through a two-channel stereophonic signal medium to the input terminal, \( g \) and \( h \), whereby the front-left signal \( F_L \) and front-right signal \( F_R \) of the 4-channel stereophonic signals are obtained through the connecting circuit \( 3 \) at the output terminals \( i \) and \( j \) as they are. Each of the left signals and the right signal of the two-channel stereophonic signals are divided into the same phase signal and the opposite phase signal by means of phase-dividers \( 4 \) and \( 5 \), respectively and the left signal and the right signal divided as mentioned above and being in opposite phase relation, are mixed at a level ratio of \( \sqrt{2} : 1 \) by selecting the resistance values of the resistors \( R_{fl}, R_{fr}, R_{bl} \) and \( R_{br} \) of matrices \( M_3 \) and \( M_4 \) to be \( R_{fl} = 33 \) k ohm, \( R_{fr} = 47 \) k ohm, \( R_{bl} = 33 \) k ohm, and \( R_{br} = 47 \) k ohm, respectively, as a result of which the signals represented by the equations (9) and (10) can be obtained as the rear-left signal \( R_L \) and rear-right signal \( R_R \) of the 4-channel stereophonic signals at terminals \( k \) and \( l \). When the signals from the terminals \( k \) and \( l \) are fed into phase-shifter \( 6 \) and \( 7 \), respectively, the rear-left signal \( R_L \) and the rear-right signal \( R_R \) having the phase-shifting characteristic as shown in FIG. 7 can be obtained at output terminal \( k_0 \) and \( l_0 \).

With reference now to FIG. 10, there is shown another embodiment of an encoder according to the present invention, which comprises: input terminals \( a, b, c, \) and \( d \) respectively for fourchannel signals \( A, B, C \) and \( D \) (corresponding to a front-left signal \( F_L \), a front-right signal \( F_R \), a rear-left signal \( R_L \) and a rear-right signal \( R_R \) in a 4-channel stereophonic sound field production, respectively); phase-shifter \( 9 \) and \( 10 \) which operate so that the signal \( C \) (rear-left signal \( R_L \)) from the input terminal \( c \) and the signal \( D \) (rear-right signal \( R_R \)) from the input terminal \( d \) are shifted by substantially 90° from each other in phase; matrices \( M_5 \) and \( M_6 \) adapted to mix 3-channel signals for obtaining a left signal and a right signal of the 2-channel stereophonic signals, respectively; and output terminals \( e \) and \( f \) respectively for the left signal and right signal of the 2-channel stereophonic signals.

When the signals \( A, B, C \) and \( D \) of the 4-channel signals are applied to the input terminal \( a, b, c \) and \( d \), respectively, the phases of the signals \( C \) and \( D \) are shifted by substantially 90° from each other by means of the phase-shitzers \( 9 \) and \( 10 \). When the signals \( A \) and \( B \) and the signal \( C \) passed through phase-shifter \( 9 \) are mixed at a level ratio of \( 1 : 0.7 : 0.7 \), respectively, by means of the matrix \( M_4 \), a signal corresponding to the left signal \( L \) of the 2-channel stereophonic signals can be obtained at the output terminal \( e \). The thus obtained signal can be represented by the following equation (11):

$$ L = A + 0.7B + 0.7C + 45° $$

In the same way, when the signals \( B \) and \( A \) and the signal \( D \) passed through the phase-shifter \( 10 \) are mixed at a level ratio of \( 1 : 0.7 : 0.7 \), respectively, by means of the matrix \( M_5 \), a signal corresponding to a right signal \( R \) of the 2-channel stereophonic signals can be obtained at the output terminal \( f \). The thus obtained signal can be represented by the following equation (12):

$$ R = B + 0.7A + 0.7D - 45° $$

Referring now to FIG. 2, if the signal \( L \) and \( R \) represented by the formulas (11) and (12), respectively obtained by means of the encoder are applied to input terminals \( g \) and \( h \) of a decoder, respectively, the signals \( L \) and \( R \) are obtained as signals corresponding to a front-left signal \( F_L \) and a front-right signal \( F_R \) of the 4-channel stereophonic signals as they are, at output terminals \( i \) and \( j \), respectively. Moreover, a left signal \( L \) and a right signal \( R \) from the input terminals \( g \) and \( h \) are respectively, divided by phase dividers \( 4 \) and \( 5 \) into signals which are in opposite phase relationship with each other, and then mixed at a level ratio of approximately 1 : 0.7 by means of matrices \( M_3 \) and \( M_4 \) as a result of which a rear-left signal \( R_L \) and a rear-right signal \( R_R \) in the 4-channel stereophonic sound field production can be obtained. The signals \( R_L \) and \( R_R \) are represented by the following equations:

$$ R_L = L - 0.7R = 0.7C + 45° + 0.5A - 0.5D - 45° $$

$$ R_R = C + 45° - 0.7A - 0.7D - 45° $$

$$ R_L = 0.7L - 0.7C + 45° $$

$$ R_R = 0.7C - 0.7L - 45° $$

Now, by assuming \( A = B = 0 \) and \( C = D \), the equations (13) and (14) may be written as follows:

$$ R_L = C - 0.7C - 45° $$

$$ R_R = C - 0.7C - 45° $$

If the magnitudes of vectors composed respectively in the above equations (15) and (16) are taken into consideration, the equations (17) and (18) are written as follows:

$$ R_L = 1.23C $$

$$ R_R = 1.23C $$

In the same way, by assuming the case where \( A = B = 0 \) and \( C = D \) with respect to a front-left signal \( F_L \) and a front-right signal \( F_R \) in the 4-channel stereophonic sound field production, the following equations (19) and (20) can be obtained from the equations (11) and (12), respectively.

$$ F_L = 0.7C + 45° $$

$$ F_R = 0.7C - 45° $$

Also, the equations (19) and (20) can be expressed in consideration with the magnitudes of the vectors as the following equations (21) and (22).

$$ F_L = 0.7C $$

$$ F_R = 0.7C $$

Accordingly, it can be understood on comparison of the equations (17), (18), (21) and (22) that the fixed positions of sound images with respect to the 4-channel stereophonic sound field are positioned at rear-center, that is, at the center of the line connecting two rear speakers.
A left signal $L$ and a right signal $R$ of the 2-channel stereophonic signals, both of which are encoded without the phase-shifters (9) and (10), can be represented by the following equations (23), and (24):

\[ L = A + 0.7B + 0.7C \quad (23) \]
\[ R = B + 0.7A + 0.7D \quad (24) \]

In the same way as in the above cases, by assuming the case where $A = B = O$ and $C = D$, the equations (23) and (24) will be as follows:

\[ L = 0.7C \quad (25) \]
\[ R = 0.7D = 0.7C \quad (26) \]

By feeding the 2-channel stereophonic signals represented by the equations (25) and (26) into the decoder, a rear-left signal $R_L$ and a rear-right signal $R_R$ in the 4-channel stereo phonie sound field can be obtained at the output terminals $k$ and $l$, respectively, and the signals $R_L$ and $R_R$ are represented by the following equations (27) and (28):

\[ R_L = L - 0.7R = C - 0.7C = 0.3C \quad (27) \]
\[ R_R = R - 0.7L = C - 0.7C = 0.3C \quad (28) \]

In the case where $A = B = 0$ and $C = D$ have been assumed with respect to the front-left signal $F_L$ and front-right signal $F_R$ which are represented by the equations (23) and (24), the signals $F_L$ and $F_R$ can be shown as follows:

\[ F_L = 0.7C \quad (29) \]
\[ F_R = 0.7C \quad (30) \]

Accordingly, it can be understood on comparison of the equations (27), (28), (29) and (30) that the fixed positions of sound images with respect to the 2-channel stereophonic sound field are located in a front position because front side signals are greater in level than rear side signals, though the fixed positions should be located in a rear position.

Accordingly, by causing a phase difference between the signals C and D corresponding respectively to the rear-left signal $R_L$ and the rear-right signal $R_R$ with respect to the 4-channel stereophonic sound field to be substantially 90°, the sound image of rear-channels in the 4-channel stereophonic sound field is fixedly positioned aside the center of space surrounded by the four speakers.

In the case also where the 2-channel signals (left signal $L$ and right signal $R$) obtained from the encoder are decoded by a conventional two-channel stereophonic reproduction device, rear-channel components are never cancelled by each other because they are encoded in substantially 90° phase difference and not in opposite phase relation with each other.

There is shown in FIG. 12 a graph illustrating the phase-characteristics of the phase-shifters 9 and 10 employed for the encoder shown in FIG. 10, in which a phase difference between the signals C and D is maintained at 90° or less, within an appropriate frequency range, for instance, between $f_s = 100$ Hz and $F_n = 1$ kHz.

With reference now to FIG. 13, there is shown a circuit diagram for another embodiment of the encoder according to the present invention (in which like components are indicated with like numerals or symbols).

If 4-channel signals $A$, $B$, $C$ and $D$ are applied to input terminals $a$, $b$, $c$ and $d$, respectively, then the signals $A$ and $D$ are shifted by means of phase-shifters 9 and 10 so that a phase difference between the signals $C$ and $D$ become substantially 90°. Each of the phase-shifters 9 and 10 comprises transistors, resistors and capacitors, and are well known in the art. 3-channel signals consisting of the signals $A$ and $B$ and the signal $C$ from the phase-shifter 9, are applied to a matrix $M_4$, and the thus applied signals are mixed at a level ratio of $1 : 0.7 : 0.7$ by means of resistors $R_{14}$, $R_{34}$ and $R_{54}$, respectively, as a result of which a left signal represented by the equation (11) of the 2-channel stereophonic signals, can be obtained at an output terminal $e$. In the same way, 3-channel signals consisting of the signals $B$ and $A$ and the signal $D$ from the phase-shifter 10 are fed into a matrix $M_5$, and the thus fed signals are mixed at a level ratio of $1 : 0.7 : 0.7$ by means of resistors $R_{15}$, $R_{35}$ and $R_{55}$, respectively, as a result of which a right signal, represented by the equation (12), of the 2-channel stereophonic signals can be obtained at an output terminal $f$.

Now, described hereinafter is the operation with reference to FIGS. 14 - 22 wherein a two-channel stereophonic signal consisting of a left signal $L$ and a right signal $R$, which are represented by the following equations (31) and (32), respectively, are converted into a multi-channel stereophonic signal.

\[ L = A + 0.7B + 0.7C + 0.85E + 0.35F + 0.85G + 0.35H \quad (31) \]
\[ R = 0.7A + B + 0.7D + 0.85E = 0.35F + 0.35G + 0.85H \quad (32) \]

Where: $A$ through $H$ are signals obtained from eight sound sources.

When the equations (31) and (32) are mixed at rates shown by the following equations, signals of 8 channels (a front-left signal $F_{L1}$, a front-right signal $F_{R1}$, a rear-left signal $F_{L2}$, a rear-right signal $F_{R2}$, a rear-center signal $F_{C}$, a left-center signal $L_{C}$, and a right-center $R_{C}$) can be obtained.

\[ F_{L1} = L = A + 0.7B + 0.7C + 0.85E + 0.35F + 0.85G + 0.35H \quad (33) \]
\[ F_{R1} = R = 0.7A + B + 0.7D + 0.85E - 0.35F + 0.35G + 0.85H \quad (34) \]
\[ F_{L2} = \sqrt{2}L - R = 0.7A + C - 0.7D + 0.35E + 0.85F + 0.35G - 0.85H \quad (35) \]
\[ F_{R2} = \sqrt{2} R - L = 0.7B - 0.7C + D + 0.35E - 0.85F - 0.35G + 0.85H \quad (36) \]
\[ F_{L} = 0.6 \times (L + R) = A + B + 0.4C + 0.4D + E + 0.7G + 0.7H \quad (37) \]
\[ F_{R} = 0.6 \times (L - R) = 0.4A + 0.4B + C - D + F + 0.7G - 0.7H \quad (38) \]
\[ F_{L_{C}} = 0.6 \times (2.4L - R) = A + 0.4B + C - 0.4D + 0.7E + 0.7G \quad (39) \]
\[ F_{R_{C}} = 0.6 \times 2.4B - L = 0.4A + B + 0.4C + D + 0.7E - 0.7F + H \quad (40) \]

When the signals of eight channels represented by the above equations (33) through (40) are sounded through 8 loudspeakers arranged as shown in FIG. 14, each of the signals is fixedly positioned as a sound image in a direction where the sound image should be naturally positioned, whereby an eight-channel stereophonic sound field is created. In this case, eight sound sources for obtaining the signals $A$ through $H$ are assumed to be positioned in the same directions as those in the arrangement of eight loudspeakers in FIG. 14.

Signals $C$ and $D$ from two sound sources are included, in opposite phase and at a similar level, in the rear-left signal $R_{L2}$ and the rear-right signal $R_{R2}$ which are represented by equations (35) and (36), respectively, which may give an unpleasant feeling to a listener. This disadvantage can be however eliminated effectively by producing both signals through loudspeakers $SP_3$ and
SP via a phase-shifter adapted to shift the signals by approximately 90° in phase.

There is shown in FIG. 15 a connecting circuit which comprises signal sources L and R for a left signal and a right signal in a two-channel signal, and loudspeakers SP₁ and SP₂ which are respectively connected to the signal sources L and R. These loudspeakers are adapted to reproduce the two-channel stereophonic signal.

FIG. 16 shows another connecting circuit which comprises loudspeakers SP₃ and SP₄, the positive terminals of which are respectively connected to the positive sides of the above-mentioned signal sources L and R, and the negative terminals of which are connected to a common connecting point “a” and the ground. Reference symbols Zₐ, Zₐ, and Zₐ represent impedances of loudspeakers SP₃, SP₄, and SP₅, respectively.

In this case, if voltages applied to the loudspeakers SP₃, SP₄, and SP₅ are Vₚ, Vₚ and Vₚ, respectively, Vₚ, Vₚ, and Vₚ can be represented by the following equations:

\[ Vₚ = \frac{\sqrt{n^2 + 1}}{nL - R} \]  
\[ Vₚ = \frac{\sqrt{n^2 + 1}}{nR - L} \]  
\[ Vₚ = \frac{\sqrt{n^2 + 1}}{(R + L)} \]

where: Zₐ = Zₐ, and n = (Zₐ + Zₐ)/Zₐ.

In the above equations, if n = 1.4, equations (41) through (43) are relatively equivalent to formulas (35) through (37); and if n = 2.5, equations (41) through (43) are relatively equivalent to formulas (39), (40) and (37). In other words, the circuit of FIG. 16 having the loudspeakers and the signal sources thereof provides the rear-left signal Rₐ, rear-right signal Rₐ, and front-center signal Fₕ; or the left-center signal Lₑ, right-center signal Rₑ, and front-center signal Fₕ in an eight-channel stereophonic signal.

Accordingly, combination of the connecting circuits shown in FIGS. 15 and 16 creates a five-channel stereophonic sound field having the front-left signal Fₕ, front-right signal Fₕ, rear-left signal Rₑ, rear-right signal Rₑ, and front-center signal Fₕ. Furthermore, combination of the connecting circuit of FIG. 15 and two pairs of the connecting circuits shown in FIG. 16, produces a seven-channel stereophonic sound filed having the front-left signal Fₕ, front-right signal Fₕ, rear-left signal Rₑ, rear-right signal Rₑ, front-center signal Fₕ, left-center signal Lₑ, and right-center signal Rₑ. In addition, when a matrix resistor Rₐ is employed in place of the loudspeaker SP₅ of FIG. 16, as shown in FIG. 17, the rear-left signal Rₐ and rear-right signal Rₐ can be obtained from the speakers SP₃ and SP₅, respectively; however, a value of the matrix resistor Rₐ corresponding to the loudspeaker SP₅ of FIG. 18 will be 20 ohm from the above-mentioned equation n = (Zₐ + Zₐ)/Zₐ where n = 1.4, Zₐ = 8 (ohm) and Zₐ = R. Therefore, a device producing a four-channel stereophonic sound field can be obtained by setting a value of the resistor Rₐ to be substantially 20 ohm in the connecting circuit shown in FIG. 18. Assuming both loudspeakers SP₃ and SP₅ to be 8 ohm in impedance after selecting a value of the resistance R to be 20 ohm in FIG. 18 as mentioned above, the following equation is obtained.

\[ n = \frac{8}{8 + 20} = 0.7 \]

Thus, a signal radiated from the loudspeaker SP₅ may be found:

\[ L - 0.7R = L - \frac{R}{\sqrt{2}} \]

which is substantially equivalent of the equation (35). The signal will be the rear-left signal Rₑ in the same way, a signal represented by a formula Rₑ = 1.4L - R, which is substantially equivalent to equation (36), is radiated as the rear-right signal Rₑ from the speaker SP₅. In other words, the above operation is that the left signal L and the right signal R in opposite phase therewith in the two-channel stereophonic signal are mixed at a level rate of approximately \( \sqrt{2} \) : 1 thereby to obtain rear-left signal Rₑ in the four-channel stereophonic signals, and the right signal R and the left signal L in opposite phase therewith are mixed at a rate of approximately \( \sqrt{2} \) : 1 thereby to obtain the rear-right signal Rₑ in the four-channel stereophonic signal.

In a combining circuit of FIG. 19, a signal corresponding to a (L - R) component, or the rear-center signal Rₑ is radiated from a loudspeaker SP₆. Therefore, when the connecting circuits of FIGS. 16, 18, and 19 are properly combined thereby to obtain a connecting circuit as shown in FIG. 20, and for instance eight loudspeakers are arranged as illustrated in FIG. 14, a device adapted to create an ideal eight-channel stereophonic sound field can be obtained. In FIG. 20, reference symbols R₁, R₂ and R₃ are signal-level-correcting resistors, R₄ is an impedance-correcting resistor, connected across the speaker SP₁ for correcting impedance Zₐ, R₅ is a matrix resistor, and Zₐ through Zₐ are impedances of loudspeakers SP₁ through SP₅, respectively.

Now, relationships among the impedances of the loudspeakers are required to meet the following requirement, however the requirement will be explained by assuming all of the loudspeakers to have an 8 ohm impedance.

First of all, obtained from the following calculation is a resistance value of the impedance-correcting resistor R₄ in order to obtain rear-left signal Rₑ, rear-right signal Rₑ, and front-center signal Fₕ, respectively from the loudspeakers SP₃, SP₄, and SP₅:

\[ n = 2.4 = \frac{Zₐ + R'}{R'} \quad R' = \frac{Zₐ + R}{Zₐ + R₁} \]

Thus

\[ R' = 5.7, \quad (\because Zₐ = 8 \text{ ohm}) \]

Furthermore, a resistance value of the matrix resistor R₅ in order to obtain the left-center signal Lₑ and the right-center signal Rₑ, respectively from the loudspeakers SP₁, SP₂, and SP₅, is obtained by solving the following equations:

\[ n = 1.4 = \frac{Zₐ + R'}{R'} \quad Zₐ = Zₐ \]

Then

\[ R₅ = 20 \text{ (ohm)} \quad (\because Zₐ = 8 \text{ ohm}) \]

In addition, the levels of signals from signal sources applied to all the loudspeakers should be at the level ratios of theoretical values shown by Table 1, however actual values Vₕ through Vₕ corresponding thereto respectively will be actual values shown in Table 1. A correction factor for correcting difference therebe-
tween and a correction value as a multiplying factor are shown in Table 2. For instance, the signal level should be attenuated by as much as the correction factor with the aid of a proper level attenuator, as a result of which the theoretical value and the correction value are made relatively equal to each other. The correction value is 0.4 time as much as the theoretical value, respectively, in tables 1 and 2.

The level attenuator is substituted by level-correcting resistors R1, R2 and R3 in FIG. 20. As the correction factors of the rear-left signal R4 and the rear-right signal R8 are 0.4, the resistance values of the resistors R1 and R2 obtained from a potential-dividing ratio of the resistance to the impedance of a loudspeaker, will be found:

\[ R_1 = R_2 = 12 \text{ ohm}. \]

In the same way, the resistance value of the resistor R3 determined from the correction factor 0.56 of the rear-center signal Rx will be:

\[ R_3 = 6 \text{ ohm}. \]

### Table 1

<table>
<thead>
<tr>
<th>X-channel</th>
<th>Theoretical value</th>
<th>Actual value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fv (Vv)</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Fv (Vv)</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Fv (Vv)</td>
<td>1.0</td>
<td>0.4</td>
</tr>
<tr>
<td>Fv (Vv)</td>
<td>1.0</td>
<td>0.4</td>
</tr>
<tr>
<td>Fv (Vv)</td>
<td>0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>Fv (Vv)</td>
<td>1.4</td>
<td>1.0</td>
</tr>
<tr>
<td>Lc (Vl)</td>
<td>0.57</td>
<td>0.29</td>
</tr>
<tr>
<td>Rl (Vl)</td>
<td>0.57</td>
<td>0.29</td>
</tr>
</tbody>
</table>

### Table 2

<table>
<thead>
<tr>
<th>X-channel</th>
<th>Correction factor</th>
<th>Correction value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fv</td>
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<td>0.4</td>
</tr>
<tr>
<td>Fv</td>
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<tr>
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</tr>
<tr>
<td>Fv</td>
<td>0.56</td>
<td>0.23</td>
</tr>
<tr>
<td>Lc</td>
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<td>0.23</td>
</tr>
<tr>
<td>Rl</td>
<td>0.8</td>
<td>0.23</td>
</tr>
</tbody>
</table>

Now, a device according to the present invention will be disclosed by explaining a connecting circuit diagram shown in FIG. 21 which illustrates a device producing a multi-channel stereophonic sound field and including an amplifier.

The connecting circuit diagram comprises a conventional two-channel stereophonic amplifier 11, multi-channel stereophonic amplifier 12 and loudspeakers SP1 to SP4. The amplifier 11 is provided with input terminals 3 and 4 respectively provided for the left signal L and the right signal R, of the two-channel stereophonic signal; a positive output terminal C and a negative output terminal D for the left signal L; a positive output terminal E and a negative output terminal F for the right signal R; and record terminals or preamplifier output terminals g and h for the left signal L and the right signal R.

The amplifier 12 is provided with "tape-play" terminals j and k or input terminals of the two-channel stereophonic signal, to which the left signal L and the right signal R are respectively applied; a positive output terminal K and a negative output terminal L for the left signal L; a positive output terminal M and a negative output terminal N for the right signal R; and a connecting terminal A corresponding to the common connecting point "a" of FIG. 16.

With respect to the terminal A, there are two cases considered: one is that a matrix resistor R is connected between the terminal A and the ground such as the negative output terminals l and n in advance so that the resistor R be of a built-in type, and the other is that the matrix resistor R is connected therebetween later on.

The two-channel stereophonic signal is applied to the input terminals i and j; the loudspeakers SP1, SP2, SP3 and SP4 are connected to the output terminals c and d, the output terminals e and f, the output terminal k and the connecting terminal A, and the output terminal m and the connecting terminal A, respectively, as shown in FIG. 21, and the matrix resistor R is connected so as to be at a predetermined position, so that the loudspeakers SP1 through SP4, are arranged, for instance, as shown in FIG. 14 in the same way as described with respect to FIG. 18, whereby a four-channel stereophonic sound field production device is composed. The feature of this case resides in that two amplifiers are employed, and the amplifier 11 is assigned only for the front-left signal Fv and front-right signal Fv of the four-channel stereophonic signal. In this invention, the multi-channel stereophonic amplifier 12 is responsible for the other signals, namely the rear-left signal Rl and the rear-right signal Rl; therefore the tone quality, the frequency response characteristic and the like of the rear signal component of the four-channel stereophonic signal can be controlled independent of the front signal component. In addition, by adjusting a ratio of the output level of the amplifier 10 to that of the amplifier 11 to be 0.4 : 1, correction of the actual value shown in Table 1 can be effected at the correction factor shown in Table 2 without a level-correcting resistor, whereby the four-channel stereophonic sound field which is relatively equivalent to the theoretical value, is produced.

In the embodiment of FIG. 21, two amplifiers are employed; however one multi-channel stereophonic amplifier provided with the input terminals, output terminals, connecting point A and resistor R of both amplifiers 11 and 12 may be employed so as to simply produce the four-channel stereophonic sound field, of course.

Shown in FIG. 22 is another embodiment of the multi-channel stereophonic sound field production device employing the multi-channel stereophonic amplifier according to the present invention. In this embodiment, reference symbol A1 is a connecting terminal corresponding to the connecting terminal a of FIG. 20. There are two cases with respect to the terminal A: one is that an impedance-correcting resistor Ra is connected between the terminal A1 and the ground such as output terminals l1 and n1 in advance, and the other is that the resistor Ra is individually connected therebetween later on. A connecting terminal B1 is adapted to connect a matrix resistor Rb and is corresponding to the connecting point b of FIG. 20. Connecting terminals O1 and k2 are adapted to connect a level-correcting resistor Rb therebetween. Reference symbols k1, l1, m1 and
$n_i$ in FIG. 22 are output terminals corresponding to reference symbols $k$, $l$, $m$, and $n$ in FIG. 21.

Now, consider the case where, in the device shown in FIG. 22 the left signal $L$ and right signal $R$ of the two-channel stereophonic signal are applied to "tape-play" or input terminals $i$ and $j$, a conventional two-channel stereophonic signal amplifier is assigned for amplification of both front-left signal $F_L$ and front-right signal $F_R$ in the same way as in FIG. 21 and loudspeakers $SP$, through $SP_R$ are arranged as shown in FIG. 14. In this case also, by adjusting a ratio of the output level of the amplifier $10$ to that of an amplifier $13$ to be $0.4 : 1$ as described with reference to FIG. 21, it is possible to obtain a device producing the eight-channel stereophonic sound field which significantly meets the theoretical values shown in Table 1.

We claim:

1. An encoding method for producing 2-channel stereophonic signals from a 4-channel stereophonic sound field production, constituted by front-left, front-right, rear-left and rear-right channel signals, comprising:
   a. obtaining a phase difference of 90° between said rear-right signal and said rear-left signal;
   b. mixing said front-left signal, said front-right signal and said rear-left signal having passed through the above step at a sound level ratio of substantially $1 : 0.7 : 0.7$ respectively thereby obtaining a left signal of said 2-channel stereophonic signals; and
c. mixing said front-right signal, said front-left signal and said rear-right signal at a sound level ratio of substantially $1 : 0.7 : 0.7$ respectively thereby obtaining a right signal of said 2-channel stereophonic signals.

2. A decoding method for producing a 4-channel stereophonic sound field, comprising:
   a. utilizing a left signal and a right signal of 2-channel stereophonic signals as a front-left signal and a front-right signal of said 4-channel stereophonic sound field;
   b. mixing said left signal with said right signal oppositely phased at a level ratio of $\sqrt{2} : 1$, respectively thereby obtaining a rear-left signal of said 4-channel stereophonic sound field;
   c. mixing said right signal with said left signal oppositely phased at a level ratio of $\sqrt{2} : 1$, respectively thereby obtaining a rear-right signal of said 4-channel stereophonic sound field; and
   d. obtaining a phase difference between said rear-left signal and said rear-right signal to be substantially 90° with a low frequency range.

3. An encoder for producing a 4-channel stereophonic sound field which comprises:
   a. phase-shifters adapted to obtain a phase difference within 90° mutually between 2-channel signals corresponding to a rear-right signal and a rear-left signal in the 4-channel stereophonic sound field production with respect to 4-channel signals;
   b. a resistance matrix adapted to mix at a level ratio of $1 : 0.7 : 0.7$ respective-channel signals corresponding to a front-left signal and a front-right signal and a rear-left signal having passed through one of said phase shifters in the 4-channel stereophonic sound field production with respect to said 4-channel signals, thereby obtaining a left signal of the 2-channel stereophonic signals; and
   c. means for mixing at a level ratio of substantially $1 : 0.7 : 0.7$ respective-channel signals corresponding to a front-right signal, a front-left signal and a rear-right signal having passed through the other phase shifter in the 4-channel stereophonic sound field production with respect to said 4-channel signals, thereby obtaining a right signal of said 2-channel stereophonic signals.

4. A decoder in a 4-channel stereophonic sound field production, which comprises:
   a. a connecting circuit adapted to obtain a left signal and a right signal of the 2-channel stereophonic signals as a front left signal and a front-right signal of the 4-channel stereophonic signals, respectively;
   b. two phase dividers adapted to divide a left signal and a right signal of said 2-channel stereophonic signals into an in-phase signal and oppositely phased signal, respectively;
   c. a first matrix in which a left signal and an oppositely phased right signal having passed through said phase dividers are mixed at a level ratio of $\sqrt{2} : 1$, respectively thereby obtaining a left signal of said 4-channel stereophonic signals.
   d. a second matrix in which a right signal and an oppositely phased left signal having passed through said phase dividers are mixed at a level ratio of $\sqrt{2} : 1$, respectively thereby obtaining a rear-right signal of said 4-channel stereophonic signals; and
   e. two phase-shifters adapted to obtain a phase difference between the rear-left signal from said first matrix and the rear-right signal from said second matrix to be substantially 90° within a low frequency range.

5. A device for reproducing a multi-channel stereophonic signal composed of front-left, front-right, rear-left, rear-right, front-center, rear-center, left-center and right-center signals obtained by mixing in a predetermined ratio left and right signals in a 2-channel stereophonic sound system, said device comprising:
   a left signal source, a right signal source;
   a first loudspeaker used for said front-left signal being connected to said left signal source; and
   a second loudspeaker used for said front-right signal being connected to said right signal source;
   third and fourth loudspeakers used for said rear-right and rear-left signals being connected in series between said left and right signal sources;
   a fifth loudspeaker used for said front-center signal being connected between ground and a first connecting point defining the connection between said third and fourth loudspeakers;
   a sixth loudspeaker used for said rear-center signal being connected between said left and right signal sources;
   seventh and eighth loudspeakers used for said left-center and right-center signals being connected in series between said left and right signal sources; an impedance-correcting resistor connected across said fifth loudspeaker; and
   a matrix resistor connected between ground and second connecting point defining the connection between said seventh and eighth speakers.

* * * *