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(54) Sound field reproducing device

(57) Right and left sound signals (R, L) output from a sound signal source (20) are supplied to any one of a plurality of crosstalk cancelling circuits (6 - 10) depending on actual user-selected arrangement of right and left speakers (30R, 30L) relative to a listener, where the supplied sound signals are subjected to processing to cancel unwanted crosstalk at a listening position of the listener. The thus-processed sound signals are then passed to power amplifiers (31R, 31L) to be audibly reproduced via the right and left speakers (30R, 30L). In this manner, a sound field reproducing device is provided which is capable of effectively cancelling crosstalk in a variety of possible speaker arrangements.

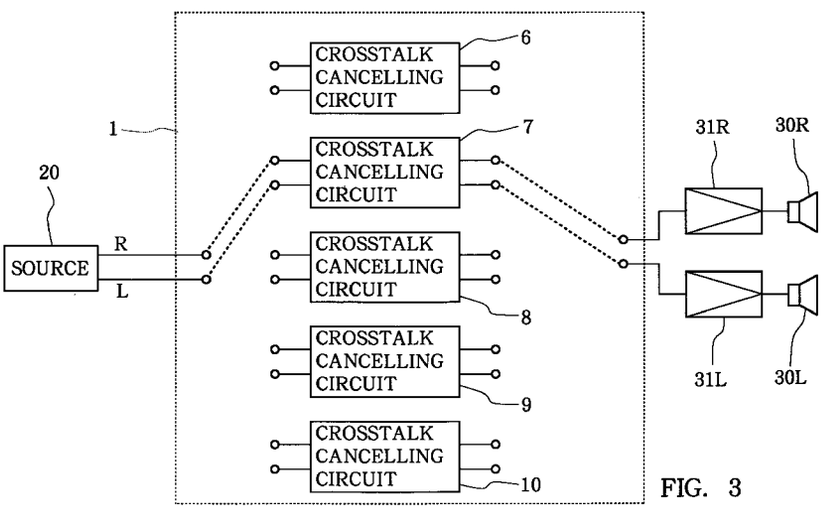

FIG. 3

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Description

The present invention relates to a sound field reproducing device capable of faithfully reproducing an original sound field that existed during recording of sound.

Transaural systems are among conventionally-known means which, using speakers, faithfully reproduce, close to listener's ears, sound pressure in a sound field that existed during recording of sound (hereinafter referred to as an "original sound field"). As one typical example of such transaural systems, there has been known a sound field reproducing device that employs crosstalk cancelling circuitry. Generally, when sounds recorded in two channels by use of a dummy head are to be reproduced via right and left speakers in a given sound field (hereinafter referred to as a "reproducing sound filed"), it is desirable that the sound output from, for example, the right speaker should reach only the listener's right ear. In effect, however, the sound also reaches the left ear due to a spatial sound propagation factor, and this is rather an unwanted phenomenon commonly known as "crosstalk". The crosstalk could be a significant obstacle in faithfully reproducing recorded sounds in the reproducing sound field. The sound output from the left speaker is also affected by similar spatial sound propagation characteristics in the reproducing sound field. It is desirable that the sounds output from the speakers be not affected by such characteristics.

Known crosstalk cancelling circuitry includes a filter having a filter characteristic to eliminate the influences of the spatial sound propagation characteristics in the reproducing sound field, where signals of each sound recorded by use of a dummy head are reproduced after having been processed by the filter. As the above-noted filter characteristic, there has been employed one calculated primarily for a standard stereo-reproducing speaker arrangement where the right and left speakers are placed in a horizontal plane at $\pm 30°$ with respect to a listener.

In recent years, the so-called stereo dipole (SD) method has been employed where crosstalk is cancelled by setting the right and left speakers in front of and close to a listener. Condition to efficiently eliminate crosstalk differs between the case where the right and left speakers are in the standard stereo-reproducing speaker arrangement and the case where the two speakers are set in front of and close to a listener as in the stereo dipole method. Thus, crosstalk cancelling circuitry with a fixed filter characteristic could not properly deal with these two cases.

Normally, various speakers, such as speakers for TV, mini component stereo unit, personal computer, etc., tend to be set in accordance with a compromise between the above-noted standard stereo-reproducing speaker arrangement and the speaker arrangement of the stereo dipole method. In this case as well, crosstalk cancelling circuitry with a fixed filter characteristic could not properly cancel crosstalk.

It is therefore an object of the present invention to provide a sound field reproducing device which is capable of effectively cancelling crosstalk in a variety of possible speaker arrangements.

In order to achieve the above-mentioned object, the present invention provides a sound field reproducing device for reproducing an original sound field in a reproducing sound field, which comprises a plurality of crosstalk cancelling sections to cancel crosstalk that occurs at a listening position of a listener when two-channel input sound signals are to be reproduced via a pair of right and left speakers placed in front of the listener. The crosstalk cancelling sections are provided in corresponding relations to a plurality of possible arrangements of the speakers relative to the listener, and each of the crosstalk cancelling sections is set to be able to most efficiently cancel the crosstalk when the speakers are in one of the arrangements corresponding to the crosstalk cancelling section. The device further comprises a selector section which selects any one of the crosstalk cancelling sections and allows the two-channel input sound signals to be processed by the selected crosstalk cancelling section.

According to another aspect of the present invention, there is provided a sound field reproducing device for reproducing an original sound field in a reproducing sound field, which comprises a crosstalk cancelling section including a plurality of filters having respective filter characteristics determined by coefficient data supplied from outside the sound field reproducing device. The crosstalk cancelling section allows two-channel input sound signals to be processed by the filters to thereby cancel crosstalk that occurs at a listening position of a listener when the input sound signals are to be reproduced via a pair of right and left speakers placed in front of the listener. The device also comprises a storage section having prestored therein, in corresponding relations to a plurality of possible arrangements of the speakers relative to the listener, plural sets of coefficient data to be supplied to the filters. Each of the sets of coefficient data sets the filters to respective filter characteristics that allow the filters to most efficiently cancel the crosstalk when the speakers are in one of the arrangements corresponding to the set. The device further comprises a data selector section which selects one of the sets of coefficient data and supplies the coefficient data of the selected set to the respective filters.

Now, the preferred embodiments of the present invention will be described in detail below with reference to the the accompanying drawings, in which:

Fig. 1 is a view showing exemplary arrangements of left and right speakers relative to a listener to which is suitably applied a sound field reproducing device according to an embodiment of the present invention;

Fig. 2 is a diagram showing an outer appearance of the sound field reproducing device of the present invention and peripheral circuits of the device;

Fig. 3 is a block diagram showing an exemplary circuit structure of the sound field reproducing device;

Fig. 4 is a block diagram showing a structure of a crosstalk cancelling circuit employed in the sound field reproducing device; and

Fig. 5 is a block diagram showing a structure of a FIR (Finite Impulse Response) filter employed in the crosstalk cancelling circuit.

Referring first to Fig. 1, there is shown exemplary arrangements of right and left speakers relative to a listener to which is applied a sound field reproducing device according to an embodiment of the present invention. Here, let's assume that the right and left speakers R and L can be variably placed, symmetrically about a "0° position" right in front of the listener LM, at a plurality of different positions; more specifically, the right speaker 30R can be variably set at any one of position A (+5° position), position B (+15° position), position C (+30° position), position D (+45° position) and position E (+60° position), while the left speaker 30L can be variably set at any of position A' (-5° position), position B' (-15° position), position C' (-30° position), position D' (-45° position) and position E' (-60° position). As shown, the plus sign (+) is attached to the placement angles of the right speaker R, while the minus sign (-) is attached to the placement angles of the left speaker L.

Of course, the optimum filter characteristic of crosstalk cancelling circuitry that can most efficiently cancel undesirable crosstalk substantially differ among the above-noted five possible speaker arrangements. In the sound field reproducing device of the present embodiment, a plurality of crosstalk cancelling circuits are provided in corresponding relations to the possible speaker arrangements A, A' - E, E' and each of these crosstalk cancelling circuits is provided with filters each having an optimum filter characteristic depending on the corresponding speaker arrangement. Thus, the crosstalk cancelling circuit to be used is switched from one to another, depending on the arrangement of the speakers 30R and 30L selected by a user for desired reproduction.

Now, with reference to Fig. 2, a description will be made about an outer appearance of the sound field reproducing device and peripheral circuits of the device. Reference numeral 1 denotes the body of the sound field reproducing device according to the present embodiment, to which a sound signal source 20 supplies a right signal R and a left sound signal L (hereinafter, referred to simply as "signal R and signal L"). The body 1 of the sound field reproducing device processes the supplied signals R and L so that crosstalk is cancelled most effectively depending on current positions or actual user-selected arrangement of the speakers 30R and 30L, and then it outputs the processed sound signals to power amplifiers 31R and 31L, respectively. The signals amplified by the power amplifiers 31R and 31L are audibly reproduced via the right and left speakers 30R and 30L. Here, let's assume that the signals R and L are signals of a sound recorded in two channels using a dummy head (not shown).

Further, in Fig. 2, reference numeral 2 denotes a plug connector for coupling electric power from a power supply to the device body 1, and 4 is a power supply switch of the sound field reproducing device. Reference numeral 3 denotes a neon tube that is illuminated by turning on the power supply switch 4. Reference numeral 5 is a rotary switch having five operating positions: "± 5° "; "± 15° "; "± 30° "; "± 45° "; and " ± 60° ". The user can set a pointer mark ("△") 5a of the rotary switch 5 to any one of the five operating positions depending on a detected user-selected arrangement of the right and left speakers 30R and 30L.

When the user sets the pointer mark 5a to the operating position "± 30° " as shown in Fig. 2 with the right and left speakers 30R and 30L set at positions C and C', respectively, processing is performed, within the body 1 of the device, on signals R and L supplied from the source 20 such that crosstalk is cancelled most efficiently when the speakers R and L are at positions C and C'.

Next, an exemplary circuit structure of the sound field reproducing device will be described hereinbelow with reference to a block diagram of Fig. 3, in which the above-mentioned body 1 of the device is shown within a dotted-line block. In the figure, reference numerals 6 to 10 denote crosstalk cancelling circuits. The crosstalk cancelling circuit 6 has a filter characteristic such that crosstalk is cancelled most efficiently when the speakers R and L are at positions A and A'. Similarly, the other crosstalk cancelling circuits 7 to 10 have respective filter characteristics such that crosstalk is cancelled most efficiently when the speakers R and L are at positions B and B', C and C', D and D', and E and E', respectively.

Depending on the current operating position of the rotary switch 5, signals R and L output output from the sound signal source 20 are supplied to a specific one of the above-mentioned crosstalk cancelling circuits 6 to 10, and resultant output signals from the specific crosstalk cancelling circuit are then passed to the power amplifiers 31R and 31L, respectively. Namely, in response to a speaker arrangement selected via the pointer mark 5a of the rotary switch 5, such a signal route is selected which allows the signals R and L to be processed by any one of the crosstalk cancelling circuits 6 to 10 that has a filter characteristic capable of cancelling unwanted crosstalk with maximum efficiency.

Fig. 3 shows an example where the pointer mark 5a of the rotary switch 5 is set to point to the "± 15° " operating position. In this case, signals R and L output output from the sound signal source 20 are supplied to the crosstalk cancelling circuit 7, where the signals R and L are subjected to processing such that crosstalk is cancelled most efficiently while the right and left speakers R and L are at positions "B" and "B' ", respectively. The thus-processed signals R and

L are then passed to the power amplifiers 31R and 31L to be reproduced as audible sounds via the right and left speakers 30R and 30L, respectively.

The following paragraphs describe a detailed construction of the above-mentioned crosstalk cancelling circuits 6 to 10, with reference to Fig. 4. In the figure, a dotted-line block represents the construction of one of the crosstalk cancelling circuits 6 to 10. The illustrated construction is the same for all the circuits 6 to 10.

In Fig. 4, reference numerals 11 to 14 denote FIR (Finite Impulse Response) filters. The signal R from the sound signal source 20 is supplied to the FIR filters 11 and 12, while the signal L from the source is supplied to the FIR filters 13 and 14. Each of the FIR filters 11 to 14 has such a filter characteristic that cancels out sound propagation characteristics in a reproducing sound field for the corresponding placement positions of the right and left speakers 30R and 30L. Reference numerals 15 to 16 denote adders. The adder 15 adds together output signals from the FIR filters 11 and 13 and supplies the addition result to the right speaker 30R via the power amplifier 31R (not shown in Fig. 4), while the adder 16 adds together output signals from the FIR filters 12 and 14 and supplies the addition result to the left speaker 30L via the power amplifier 31L (not shown in Fig. 4).

The following paragraphs describe the respective filter characteristics of the FIR filters 11 to 14. First, let's consider a case where the signals R and L output from the sound signal source 20 are simply reproduced through the right and left speakers 30R and 30L. Further, for convenience of the description, assume that the reproducing sound field in this case is an anechoic room or a sound field with little echoic effect. Here, if signals reproduced close to listener's right and left ears are denoted by Sr and Sl, respectively, the relationship between these signals Sr, Sl and signals R and L from the source 20 may be represented by the following expression:

$$\begin{bmatrix} Sr \\ Sl \end{bmatrix} = \begin{bmatrix} HRr & HLr \\ HRl & HLl \end{bmatrix} \begin{bmatrix} R \\ L \end{bmatrix} \quad \text{(Expression 1),}$$

where HRr represents a speaker-to-head propagation function of sound travelling from the right speaker 30R to the right ear r of the listener LM, HRl represents a speaker-to-head propagation function of sound travelling from the right speaker 30R to the left ear l of the listener LM, HLr represents a speaker-to-head propagation function of sound travelling from the left speaker 30L to the right ear r of the listener LM, and HLl represents a speaker-to-head propagation function of sound travelling from the left speaker 30L to the left ear l of the listener LM.

Thus, in order to eliminate the influences of the individual speaker-to-head propagation functions in Expression 1, it is only necessary to set the FIR filters 11 to 14 to filter characteristics that are the inverse of the following matrix:

$$\begin{bmatrix} HRr & HLr \\ HRl & HLl \end{bmatrix} \quad \text{(Expression 2)}$$

Namely, the inverse of the matrix represented by Expression 2 is:

$$\begin{bmatrix} HLl/H & -HLr/H \\ -HRl/H & HRr/H \end{bmatrix} \quad \text{(Expression 3),}$$

where $H = HLl \cdot HRr - HLl \cdot HRl$. Then, respective filter characteristics HA to HD of the FIR filters 11 to 14 may be obtained as follows:

1) filter characteristic HA of the FIR filter 11

$$HA = HRr / (HLl \cdot HRr - HLr \cdot HRl) \quad (3)$$

2) filter characteristic HB of the FIR filter 12

$$HB = -HLr / (HLl \cdot HRr - HLr \cdot HRl) \quad (4)$$

3) filter characteristic HC of the FIR filter 13

$$HC = -HRl / (HLl \cdot HRr - HLr \cdot HRl) \quad (5)$$

4) filter characteristic HD of the FIR filter 14

$$HD = HLI / (HLI \cdot HRr - HLr \cdot HRI) \quad (6)$$

Now, a description will be made below about a general structure of each of the FIR filters 11 to 14 having the above-mentioned filter characteristics, with reference to Fig. 5.

In Fig. 5, reference numerals 17-1 to 17-N-1 denote unit time delay elements connected in series, each of which delays, by one sampling period, signal x(n) (signal R or signal L) that is output from the sound signal source 20 every sampling period; here, "n" denotes a time in sampling periods. Reference numerals 18-1 to 18-N denote multipliers, which multiply input signal x(n) and output signals from the unit time delay elements 17-1 to 17-N-1 by predetermined multiplication coefficients h(0) and h(1) to h(N-1), respectively. Further, reference numerals 19-1 to 19-N-1 denote adders, which sequentially add together respective output signals from the multipliers 18-1 to 18-N.

The following relationship is present, in each of the FIR filters, between input signal x(n) and output signal y(n):

$$y(n) = \sum_{i=0}^{N-1} h(i) \cdot x(n-i) \quad \text{(Expression 4)}$$

Further, the relationships among time-domain input signal x(n), output signal y(n) and multiplication coefficient h(n) and among frequency-domain input signal X(n), output signal Y(n) and multiplication coefficient H(n) may be represented by the following expressions based on 1) the discrete Fourier transform (DFT) and 2) the inverse discrete Fourier transform (IDFT):

1) DFT

$$X(f) = \sum_{n=0}^{N-1} x(n) e^{-j2\pi fn/N} \quad \text{(Expression 5)}$$

$$Y(f) = \sum_{n=0}^{N-1} y(n) e^{-j2\pi fn/N}$$

$$H(f) = \sum_{i=0}^{N-1} h(i) e^{-j2\pi fi/N}$$

2) IDFT

$$x(n) = \frac{1}{N} \sum_{k=0}^{N-1} X(k) e^{2\pi kn/N} \quad \text{(Expression 6)}$$

$$y(n) = \frac{1}{N} \sum_{k=0}^{N-1} Y(k) e^{2\pi kn/N}$$

$$h(i) = \frac{1}{N} \sum_{k=0}^{N-1} H(k) e^{2\pi ki/N}$$

For each of the above-described FIR filters, the number of the unit time delay elements and the multiplication coefficients of the multipliers are determined on the basis of actual measurements of individual impulse responses of sound travelling from the right and left speakers 30R and 30L to the listener's right and left years.

In the above-described sound field reproducing device of Fig. 3, a plurality of crosstalk cancelling circuits are provided which have filter characteristics corresponding to a plurality of possible arrangements of the right and left speakers 30R and 30L of Fig. 1 relative to the listener, and any one of the crosstalk cancelling circuits is selected depending

on an actual user-selected arrangement of the speakers so that signals R and L are processed by the selected circuit. As an alternative, only one crosstalk cancelling circuit may be provided. In this alternative, plural sets of coefficient data to be used in the individual FIR filters may be stored in a memory, in corresponding relations to the possible arrangements of the speakers, so that one of the sets of coefficient data is selected depending on an actual user-selected arrangement of the speakers and the individual coefficient data of the selected set are supplied to the respective FIR filters.

In summary, the sound field reproducing device arranged in accordance with one aspect of the present invention can select one of the crosstalk cancelling circuits that is set to most efficiently cancel unwanted crosstalk in an actual user-selected arrangement of the speakers. As a result, a single sound field reproducing device thus arranged always permits optimum crosstalk cancellation in a variety of possible speaker arrangements.

Further, the sound field reproducing device arranged in accordance with another aspect of the present invention always permits optimum crosstalk cancellation in a variety of possible speaker arrangements with only a single crosstalk cancelling circuit by just supplying the filters with a different set of coefficient data depending on an actual user-selected arrangement of the speakers, without a need to provide a plurality of crosstalk cancelling circuits in corresponding relations to a plurality of possible arrangements of the speakers.

According to its broadest aspect the invention relates to a sound field reproducing device for reproducing an original sound field in a reproducing sound field, which comprises:

a plurality of crosstalk cancelling sections; and
a selector section that selects any one of said crosstalk cancelling sections.

Claims

1. A sound field reproducing device for reproducing an original sound field in a reproducing sound field, which comprises:

   a plurality of crosstalk cancelling sections that cancel crosstalk occurring at a listening position of a listener when two-channel input sound signals are to be reproduced via a pair of right and left speakers placed in front of the listener, said crosstalk cancelling sections being provided in corresponding relations to a plurality of possible arrangements of said speakers relative to the listener, each of said crosstalk cancelling sections being set to be able to most efficiently cancel the crosstalk when said speakers are in one of the arrangements corresponding to said crosstalk cancelling section; and
   a selector section that selects any one of said crosstalk cancelling sections and allows the two-channel input sound signals to be processed by the selected crosstalk cancelling section.

2. A sound field reproducing device for reproducing an original sound field in a reproducing sound field, which comprises:

   a crosstalk cancelling section including a plurality of filters having respective filter characteristics determined by coefficient data supplied from outside said sound field reproducing device, said crosstalk cancelling section allowing two-channel input sound signals to be processed by said filters to thereby cancel crosstalk that occurs at a listening position of a listener when the input sound signals are to be reproduced via a pair of right and left speakers placed in front of the listener; and
   a storage section having prestored therein, in corresponding relations to a plurality of possible arrangements of said speakers relative to the listener, plural sets of coefficient data to be supplied to said filters, each of the sets of coefficient data setting said filters to respective filter characteristics that allow said filters to most efficiently cancel the crosstalk when said speakers are in one of the arrangements corresponding to the set; and
   a data selector section that selects one of the sets of coefficient data and supplies the coefficient data of the selected set to respective ones of said filters.

3. A sound field reproducing method for reproducing an original sound field in a reproducing sound field, which comprises steps of:

   selecting any one a plurality of crosstalk cancelling sections that cancel corsstalk occurring at a listening position of a listener when two-channel input sound singals are to be reproduced via a pair of right and left speakers placed in front of the listener, said crosstalk cancelling sections being provided in corresponding relations to a plurality of possible arrangments of said crosstalk cancelling sections being set to be able to most efficiently cancel the crosstalk when said speakers are in one of the arrangements corresponding to said crosstalk

cancelling section: and

allowing the two-channel input sound signals to be processed by the selected crosstalk cancelling section.

4. A sound field reproducing device for reproducing an original sound field in a reproducing sound field, which comprises:

a plurality of crosstalk cancelling sections; and

a selector section that selects any one of said crosstalk cancelling sections.

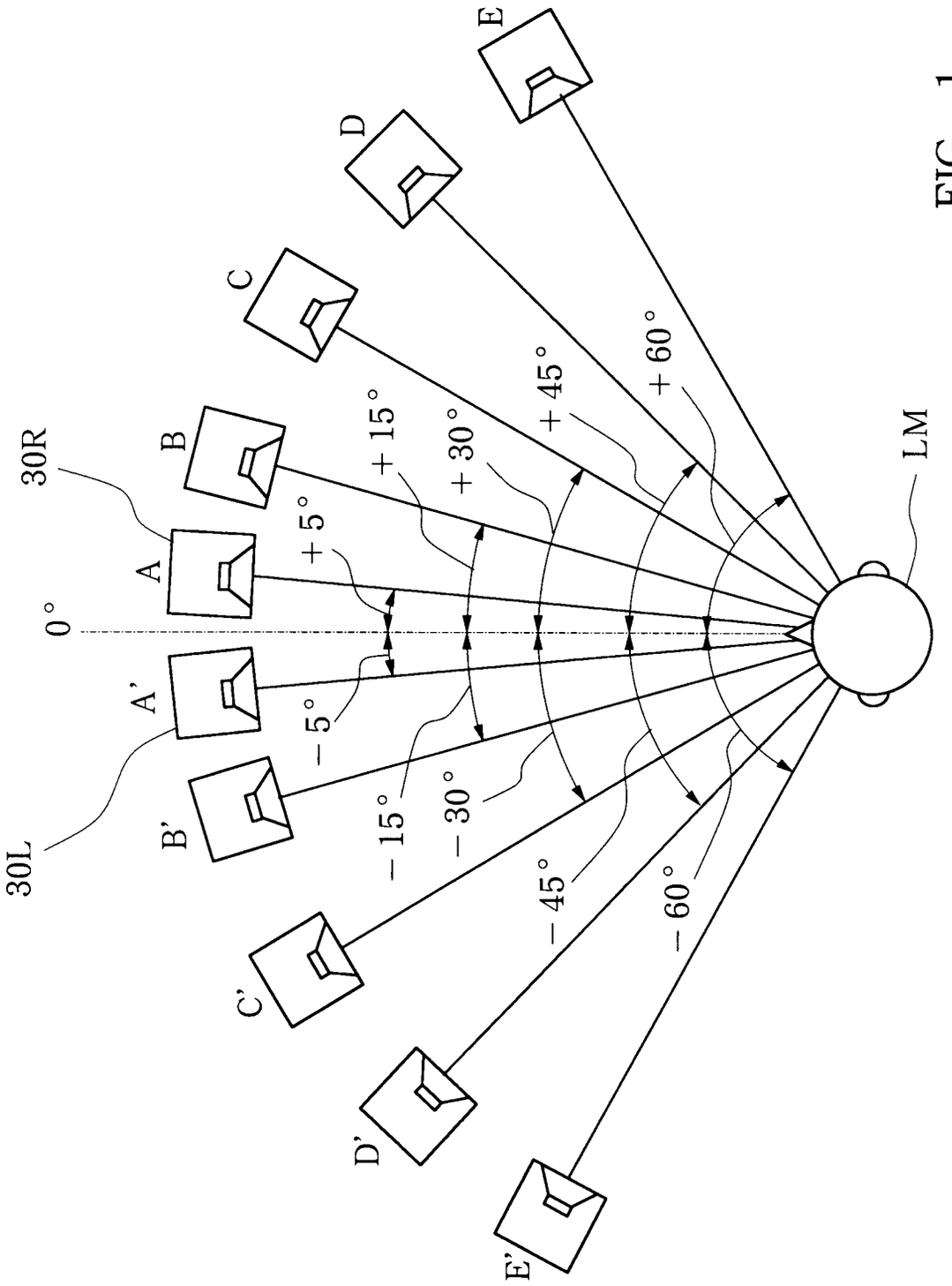

FIG. 1

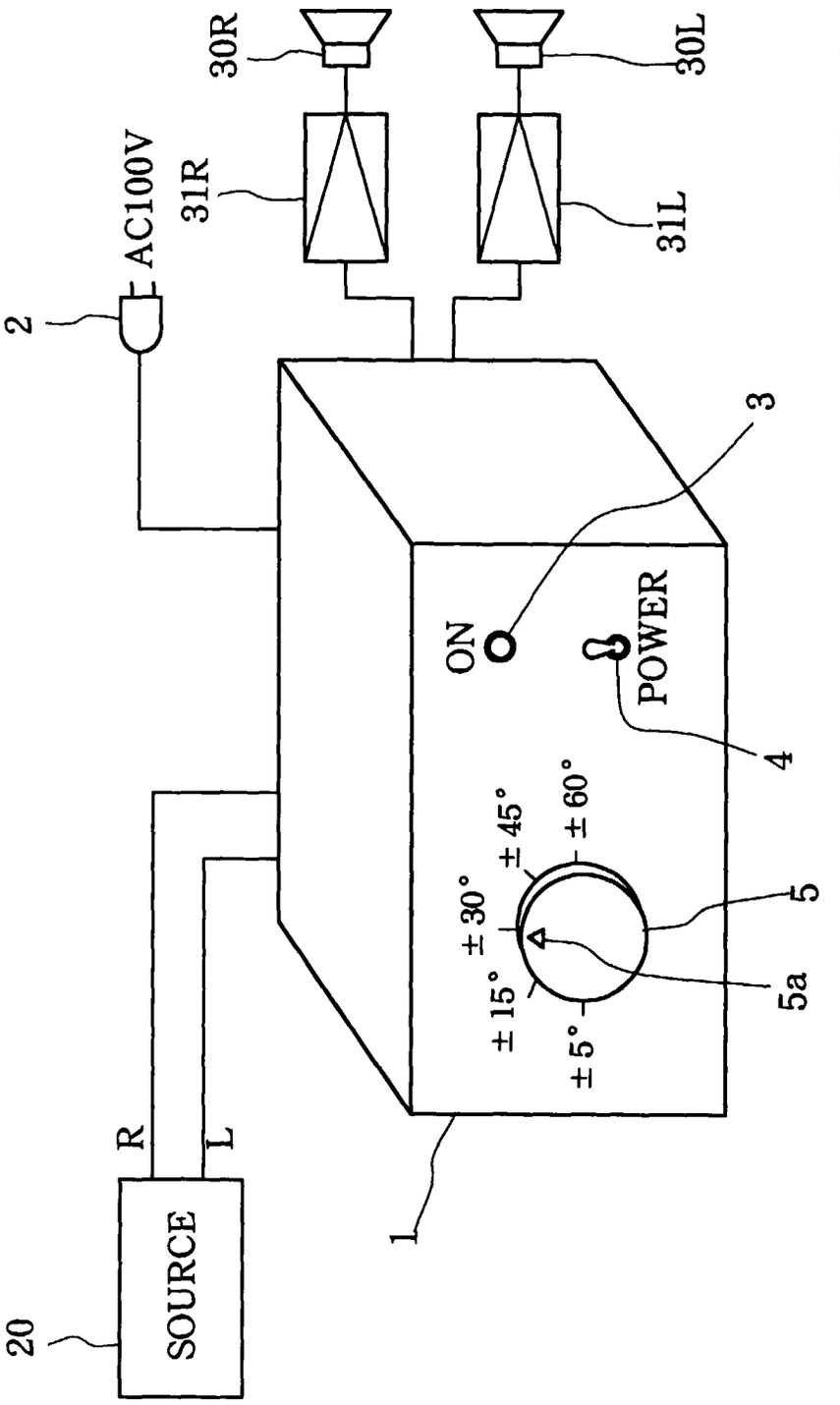
30R
30L
AC100V
31R
31L
2
3
ON
POWER
4
± 60°
± 45°
± 30°
± 15°
± 5°
5
5a
R
L
SOURCE
20
1

FIG. 2

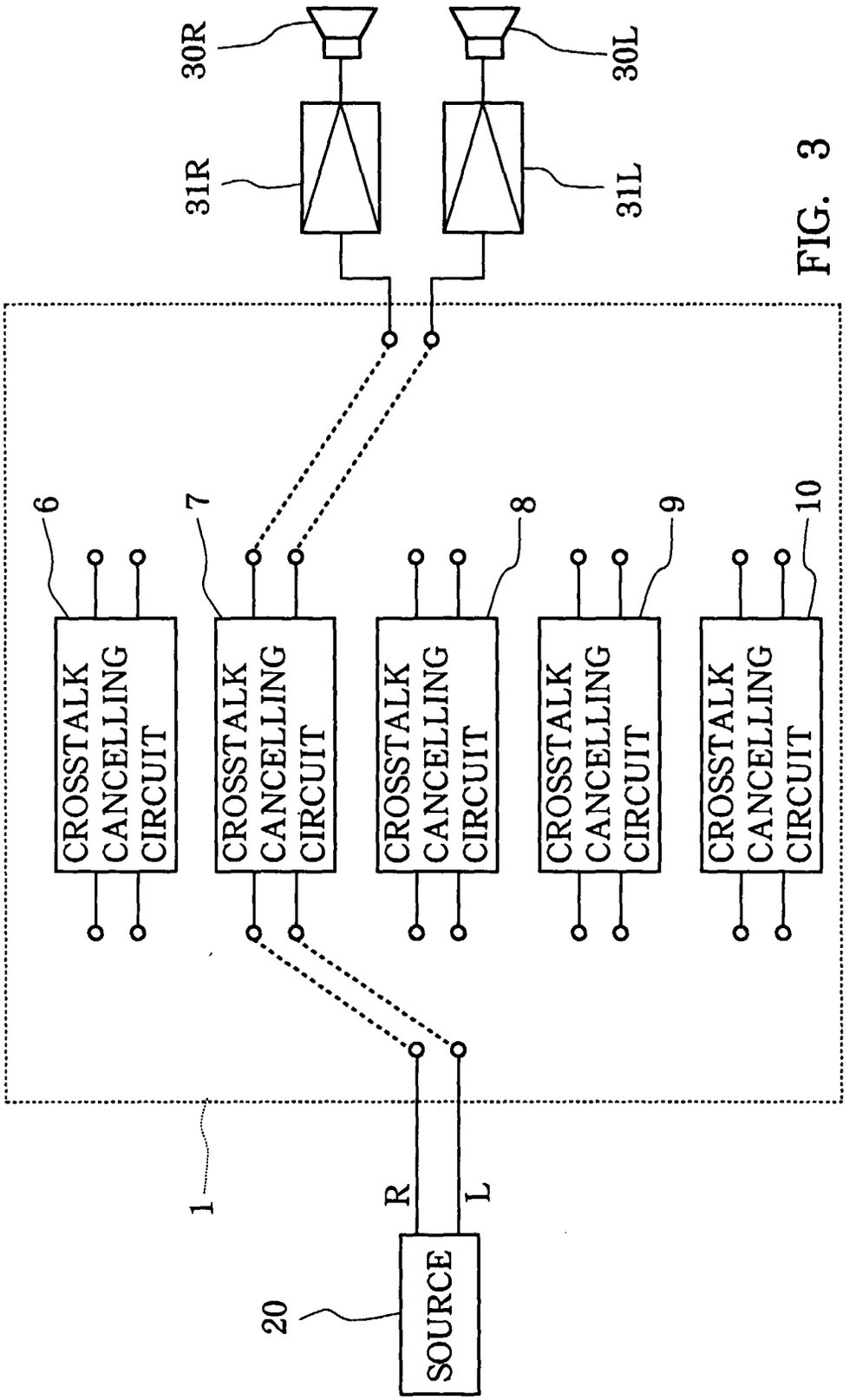
30R
30L
31R
31L
6
7
8
9
10
CROSSTALK CANCELLING CIRCUIT
CROSSTALK CANCELLING CIRCUIT
CROSSTALK CANCELLING CIRCUIT
CROSSTALK CANCELLING CIRCUIT
CROSSTALK CANCELLING CIRCUIT
1
R
L
20
SOURCE

FIG. 3

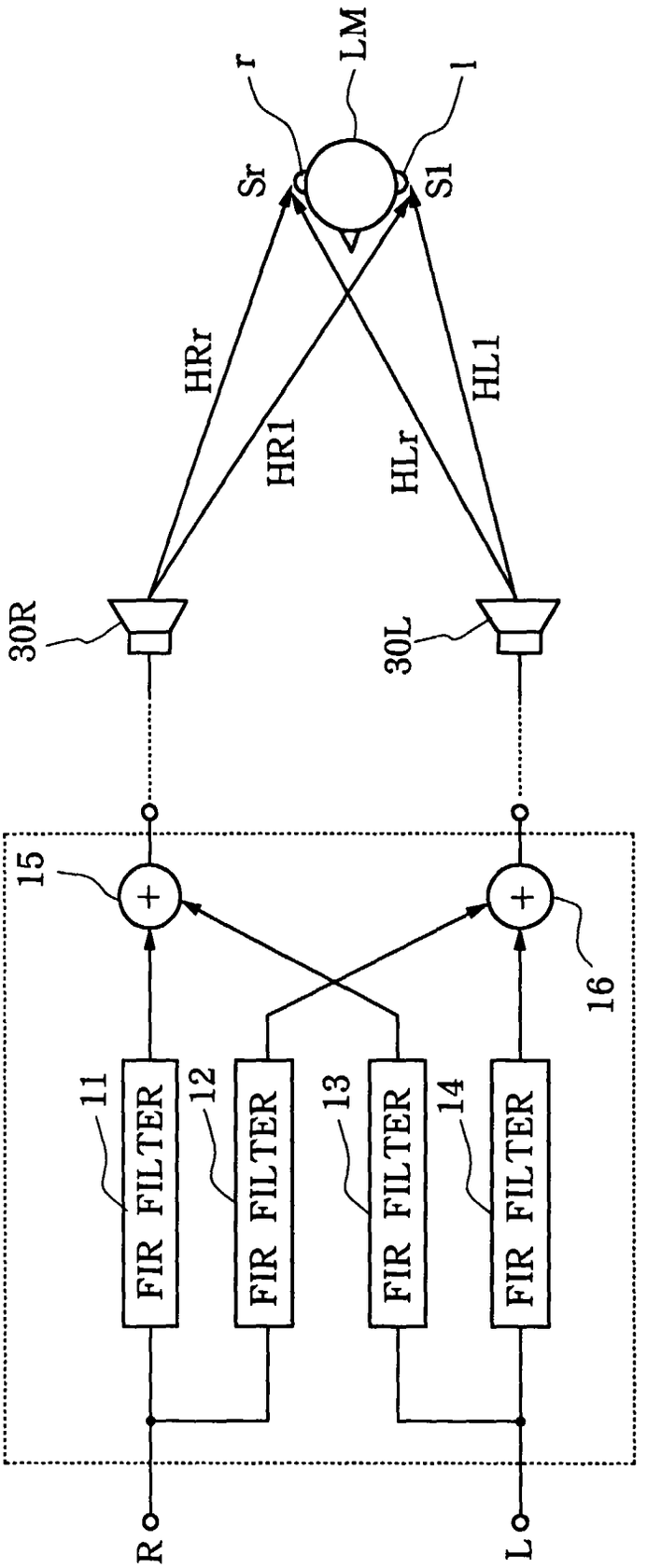
r
LM
l
Sr
Sl
HRr
HR1
HLr
HL1
30R
30L
15
16
11
12
13
14
FIR FILTER
FIR FILTER
FIR FILTER
FIR FILTER
R
L

FIG. 4

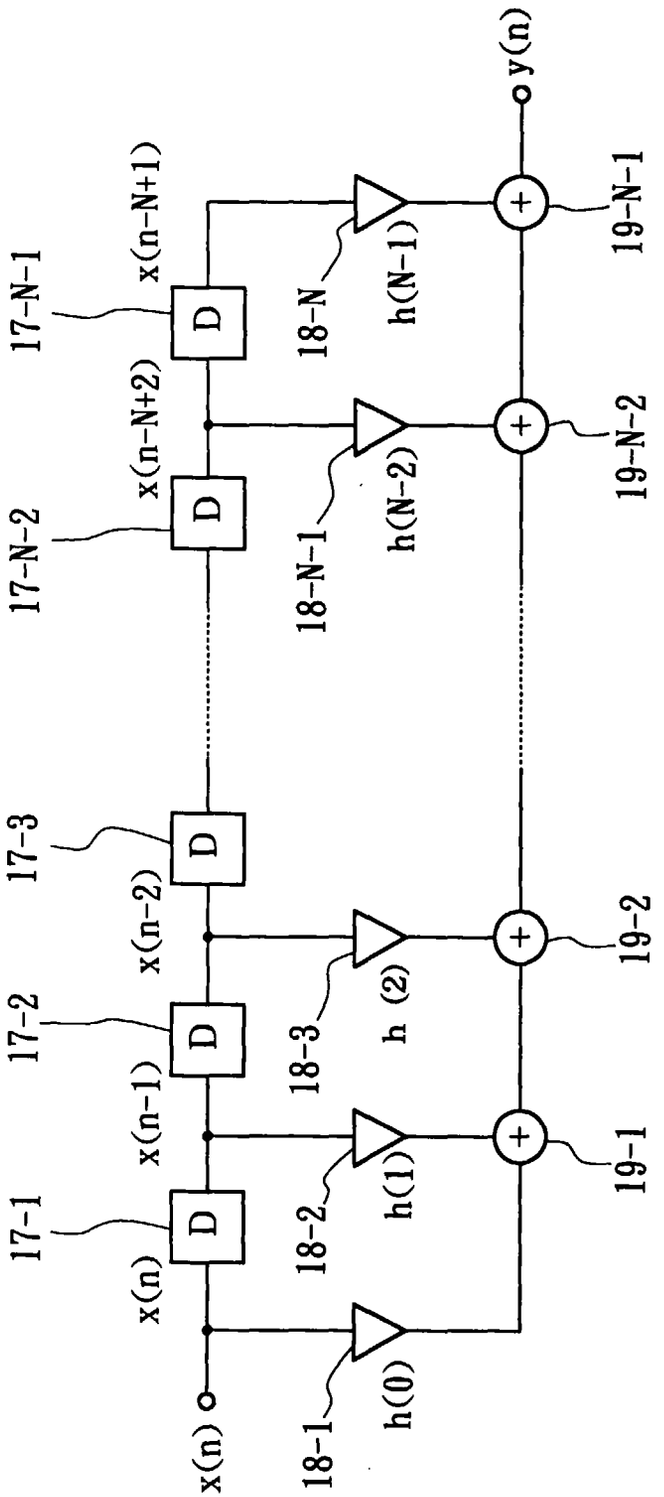
x(n)
x(n-1)
x(n-2)
x(n-N+2)
x(n-N+1)
D
17-1
17-2
17-3
17-N-2
17-N-1
18-1
18-2
18-3
18-N-1
18-N
h(0)
h(1)
h (2)
h(N-2)
h(N-1)
19-1
19-2
19-N-2
19-N-1
y(n)

FIG. 5