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(54) **SOUND SIGNAL PLAYBACK MACHINE AND METHOD THEREOF**

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(73) Assignee: **Pioneer Corporation**, Tokyo (JP)

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Issued: **Oct. 12, 2004**
Appl. No.: **10/164,411**
Filed: **Jun. 10, 2002**

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(51) **Int. Cl.**
H03G 3/00 (2006.01)
H03G 5/00 (2006.01)
H04R 5/02 (2006.01)

(52) **U.S. Cl.** **381/99**; 381/97; 381/61; 381/307

(58) **Field of Classification Search** 381/1, 300, 381/307, 310, 61, 80, 97–99, 103
See application file for complete search history.

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Primary Examiner — Xu Mei
(74) *Attorney, Agent, or Firm* — Sughrue Mion, PLLC

(57) **ABSTRACT**

In a sound signal playback machine and method thereof, predetermined high frequency components are extracted from sound signals S_L to S_C of a main channel by high frequency pass filters **21** to **25**, and these high frequency components are respectively played back by speakers. At the same time, predetermined low frequency components are extracted from sound signals S_L to S_C of the main channel by low frequency pass filters. These low frequency components and sound signal S_{LFE} exclusively used for the low frequency band are added to each other, and the thus obtained addition signal is played back by the speaker **66**. In this case, the degree of the low frequency pass filters is set higher than the degree of the high frequency pass filters, and the high frequency component is delayed.

38 Claims, 10 Drawing Sheets

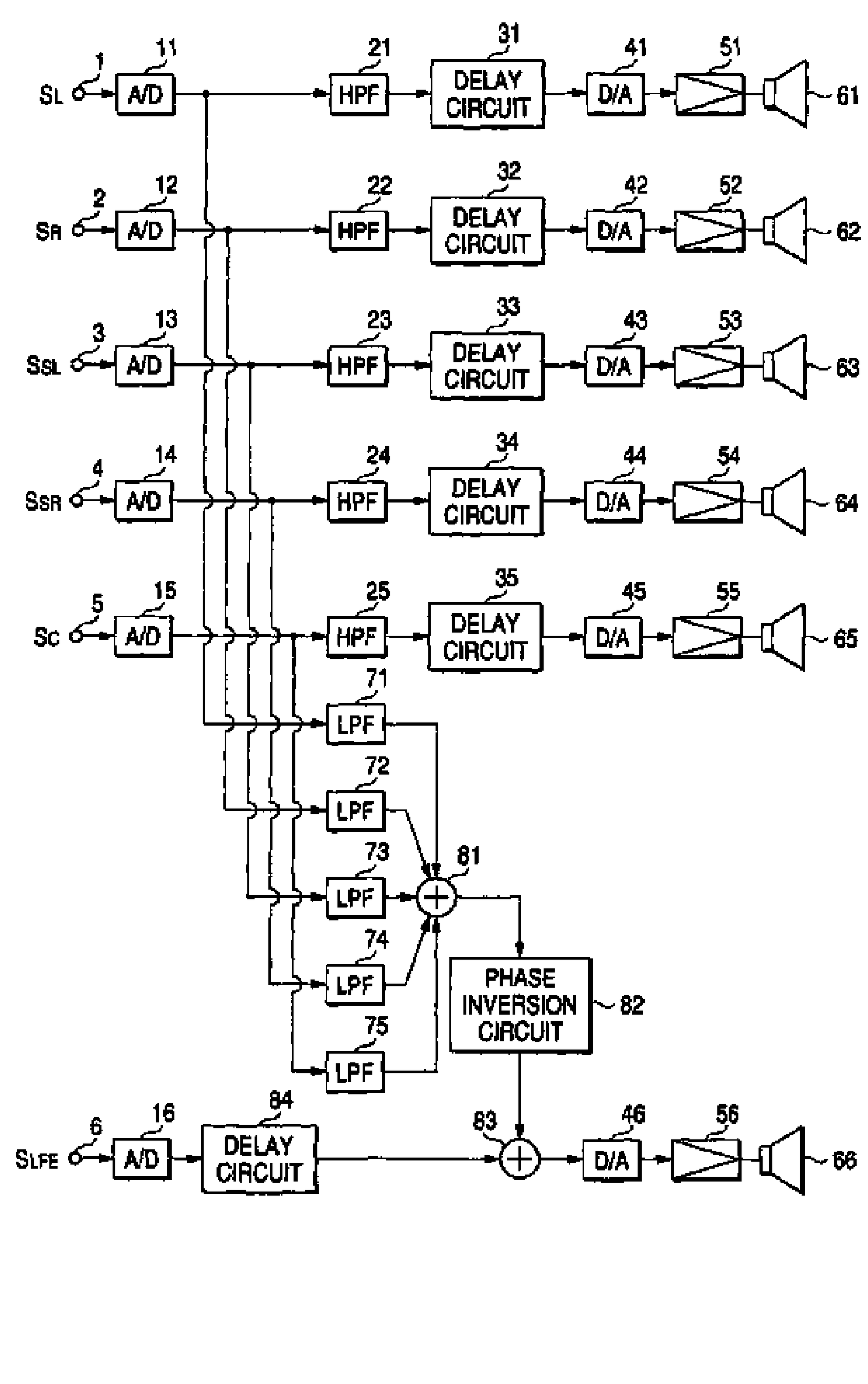
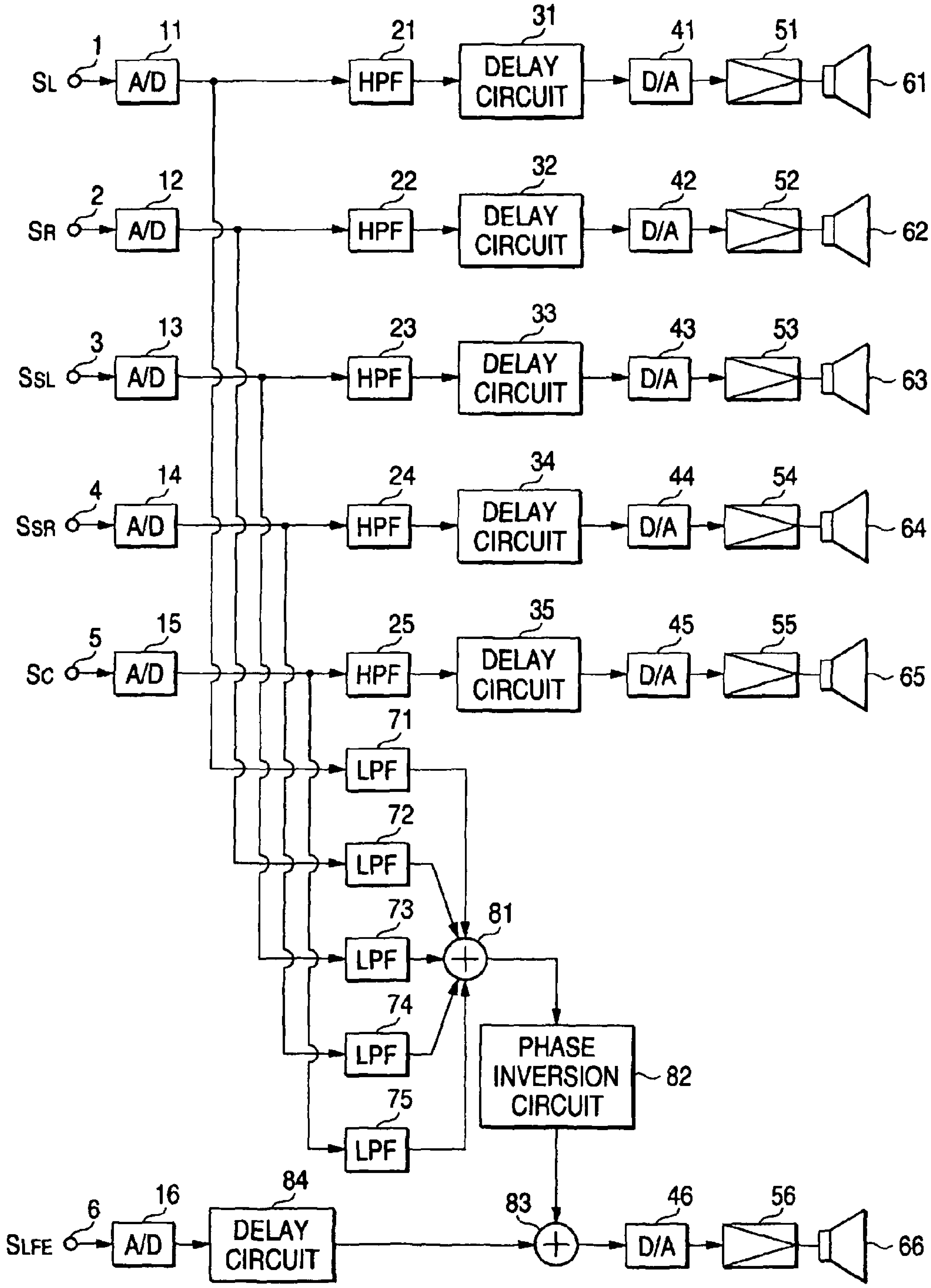


FIG. 1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1
11
A/D
21
HPF
31
DELAY CIRCUIT
41
D/A
51
61
SR
2
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A/D
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HPF
32
DELAY CIRCUIT
42
D/A
52
62
SSL
3
13
A/D
23
HPF
33
DELAY CIRCUIT
43
D/A
53
63
SSR
4
14
A/D
24
HPF
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DELAY CIRCUIT
44
D/A
54
64
SC
5
15
A/D
25
HPF
35
DELAY CIRCUIT
45
D/A
55
65
71
LPF
72
LPF
73
LPF
74
LPF
75
LPF
81
PHASE INVERSION CIRCUIT
82
SLFE
6
16
A/D
84
DELAY CIRCUIT
83
46
D/A
56
66

FIG. 2

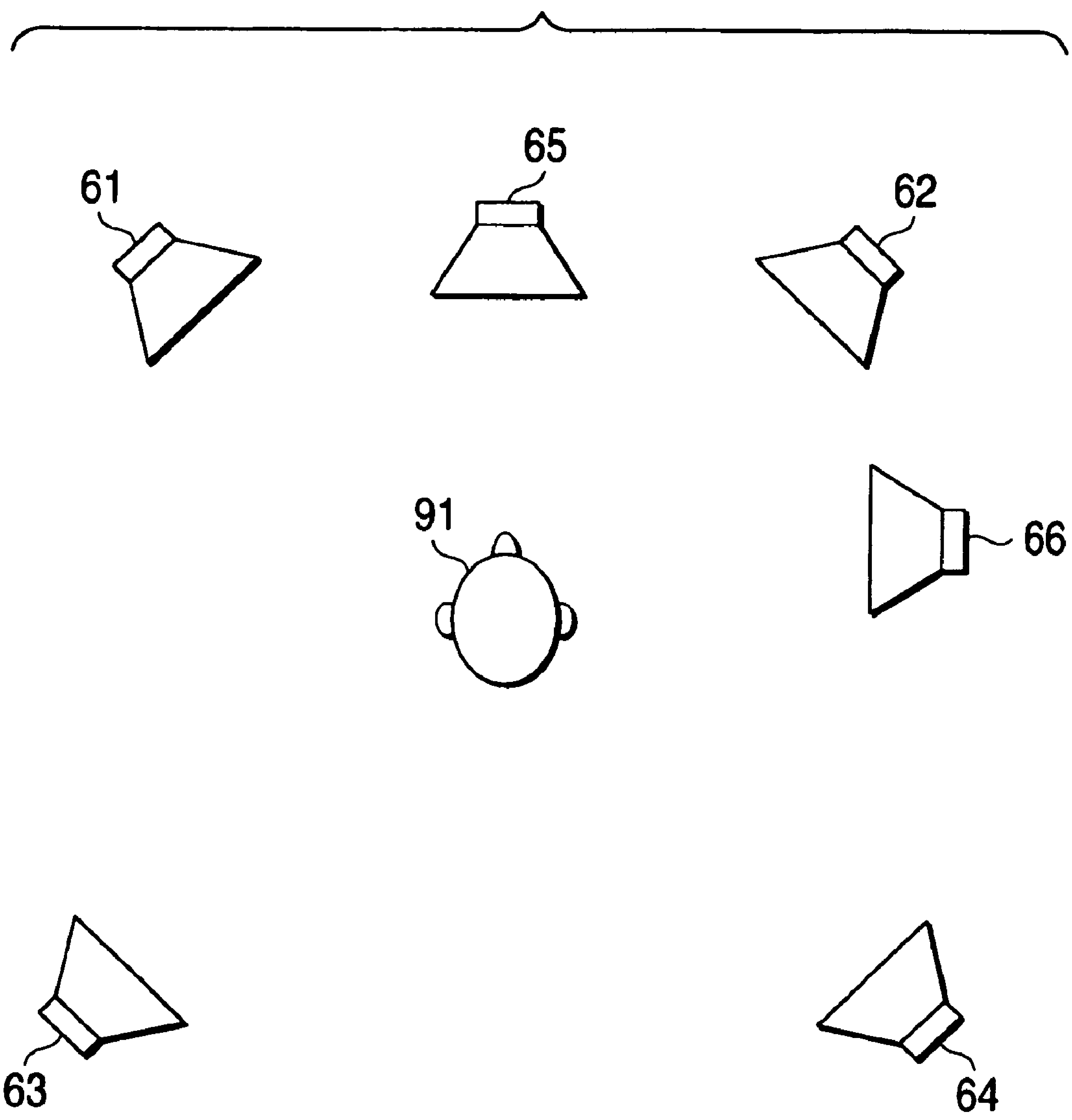


FIG. 3

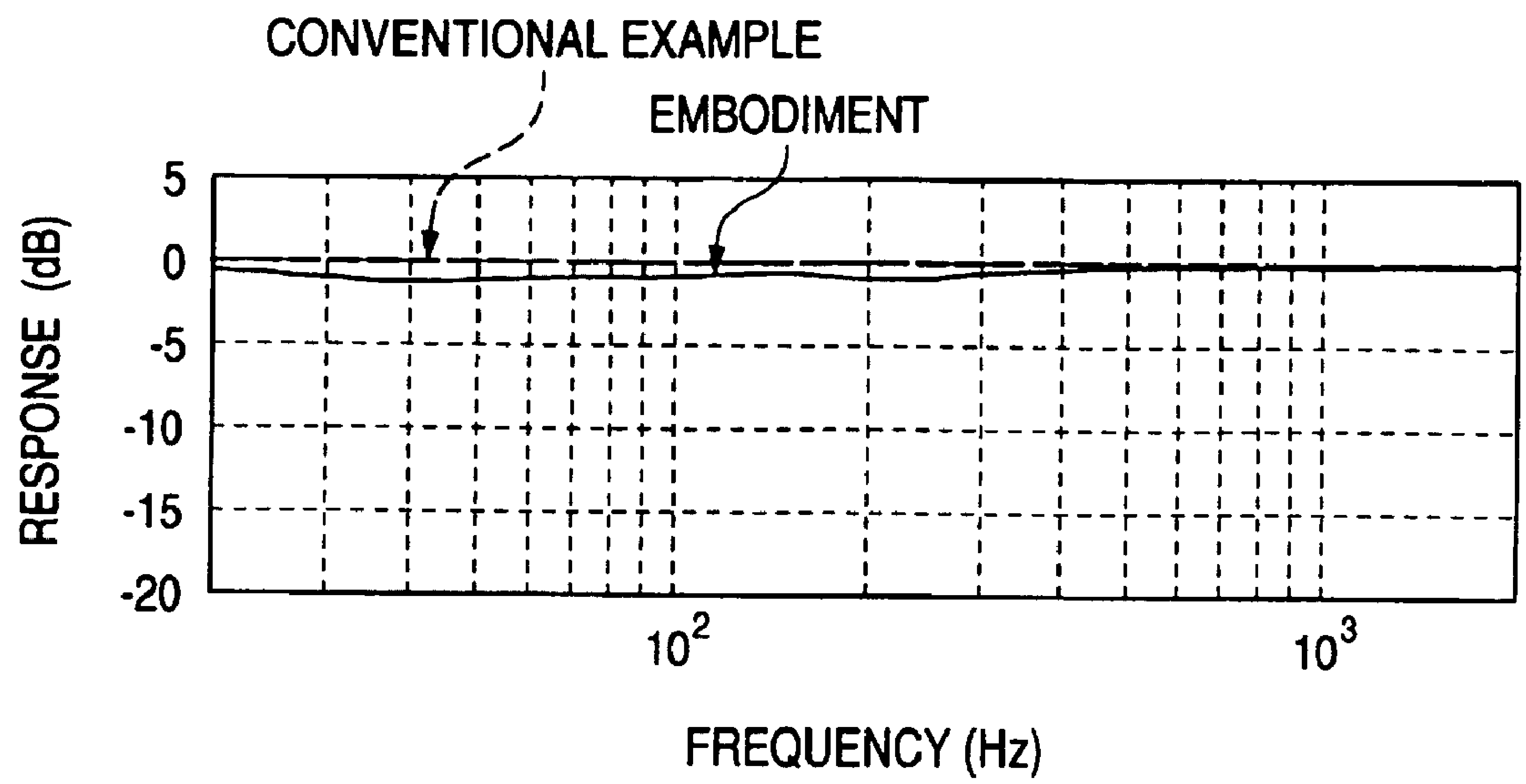

CONVENTIONAL EXAMPLE
EMBODIMENT
5
0
-5
-10
-15
-20
RESPONSE (dB)
10^2
10^3
FREQUENCY (Hz)

FIG. 4

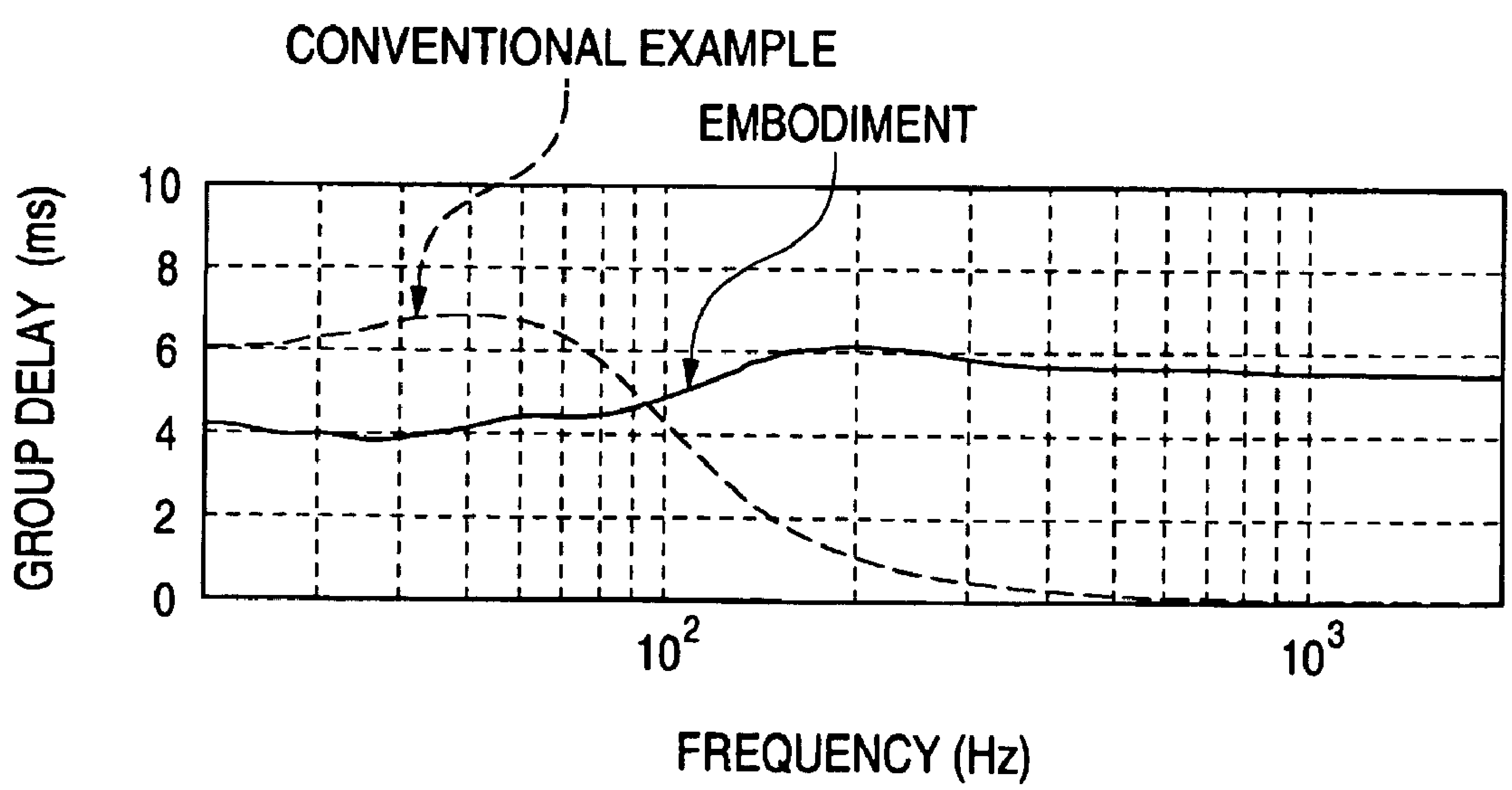

CONVENTIONAL EXAMPLE
EMBODIMENT
10
8
6
4
2
0
GROUP DELAY (ms)
10^2
10^3
FREQUENCY (Hz)

FIG. 5

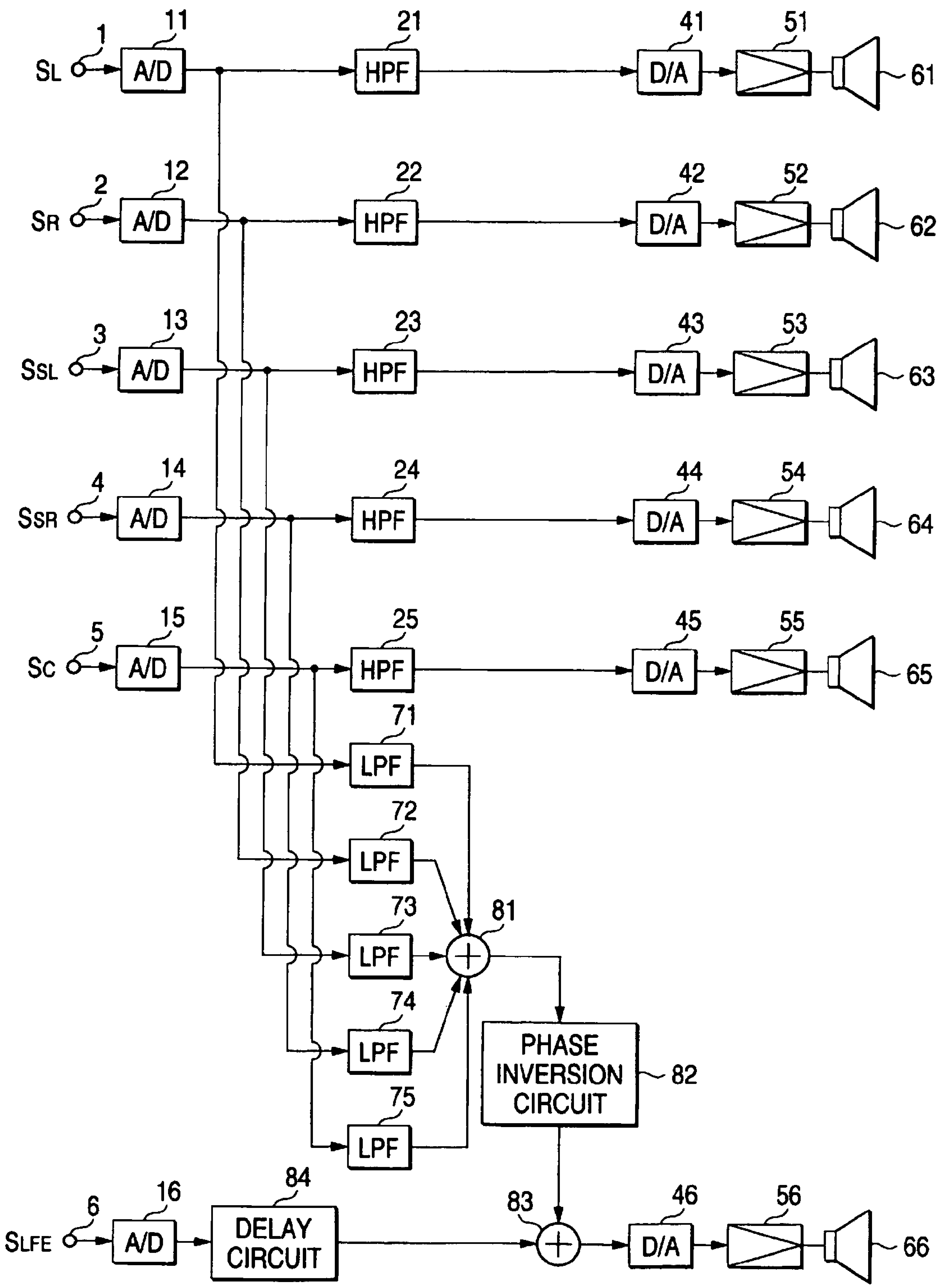

SL
SR
SSL
SSR
SC
SLFE
1
2
3
4
5
6
11
12
13
14
15
16
A/D
21
22
23
24
25
HPF
71
72
73
74
75
LPF
81
82
PHASE INVERSION CIRCUIT
83
84
DELAY CIRCUIT
41
42
43
44
45
46
D/A
51
52
53
54
55
56
61
62
63
64
65
66

FIG. 6

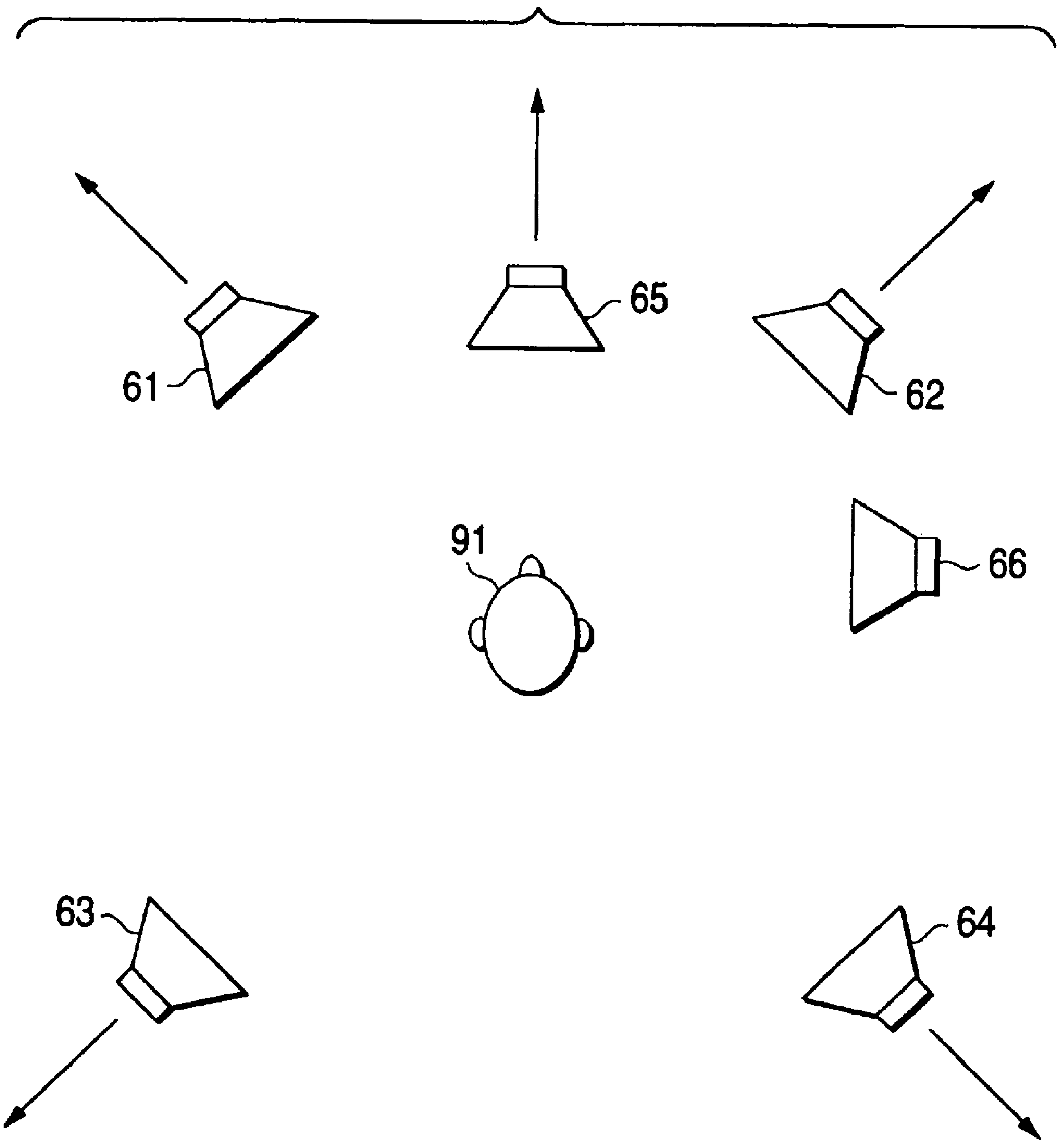
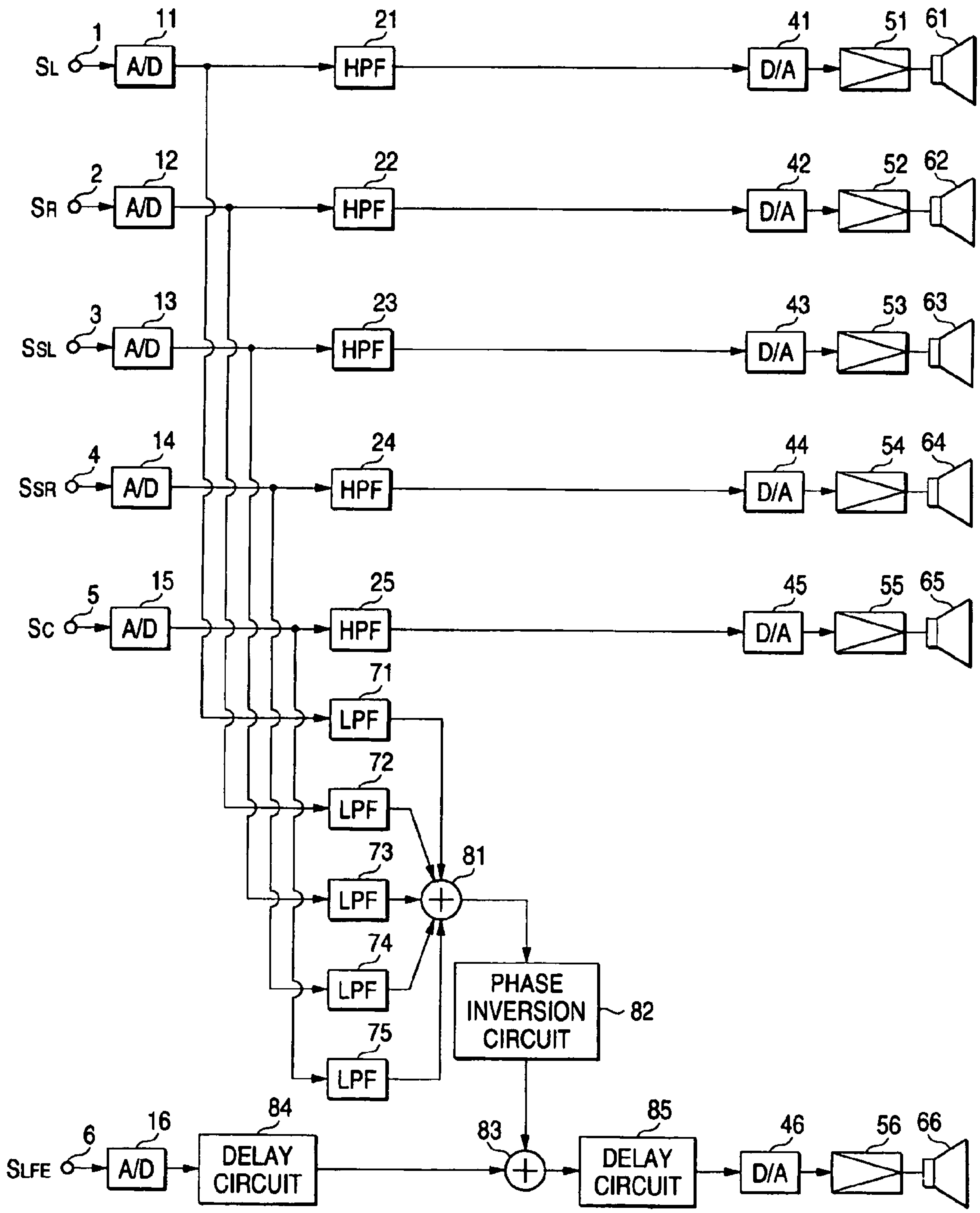


FIG. 7


SL
SR
SSL
SSR
SC
SLFE
A/D
HPF
LPF
D/A
PHASE INVERSION CIRCUIT
DELAY CIRCUIT
DELAY CIRCUIT
1
2
3
4
5
6
11
12
13
14
15
16
21
22
23
24
25
41
42
43
44
45
46
51
52
53
54
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56
61
62
63
64
65
66
71
72
73
74
75
81
82
83
84
85

FIG. 8

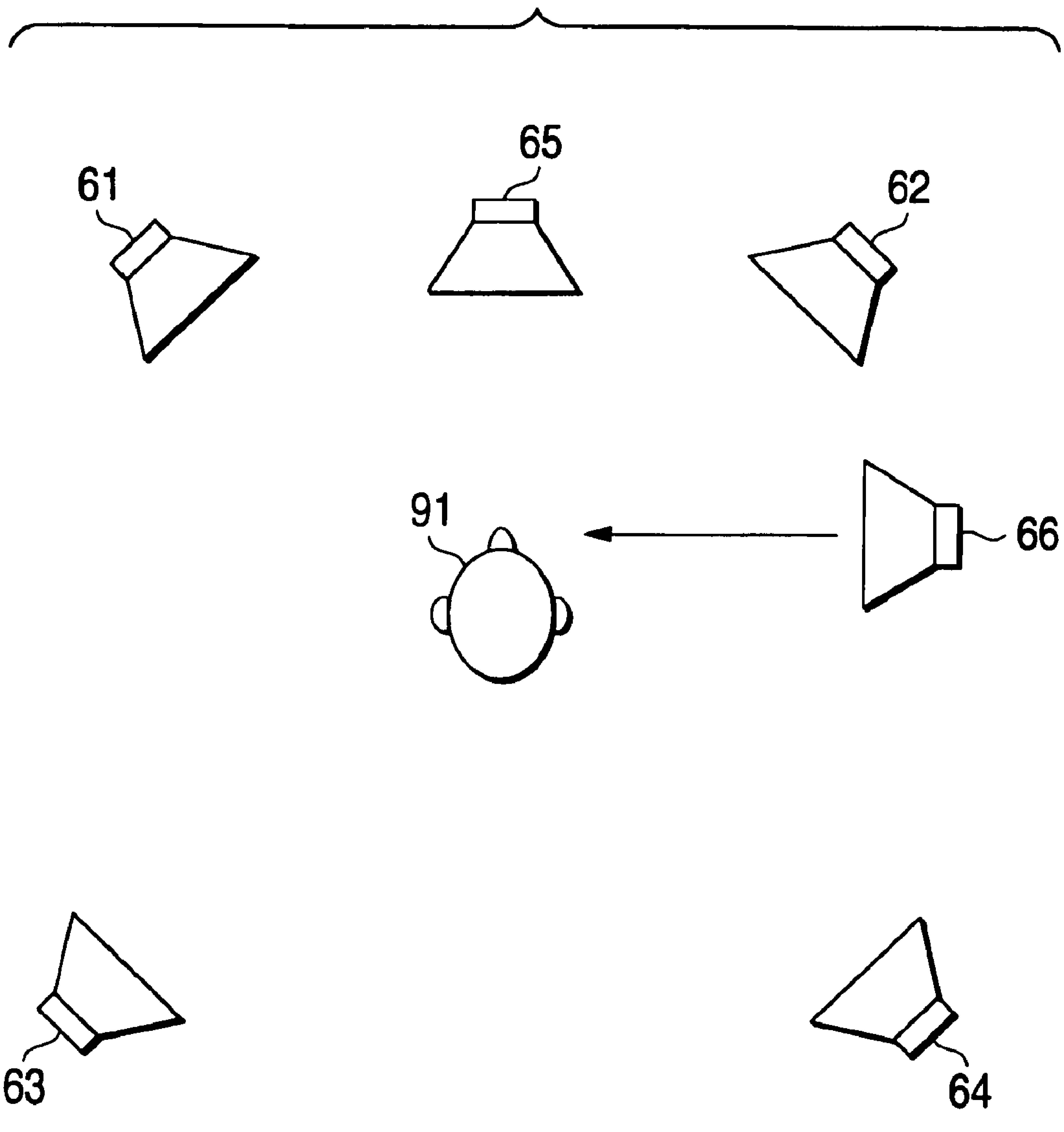
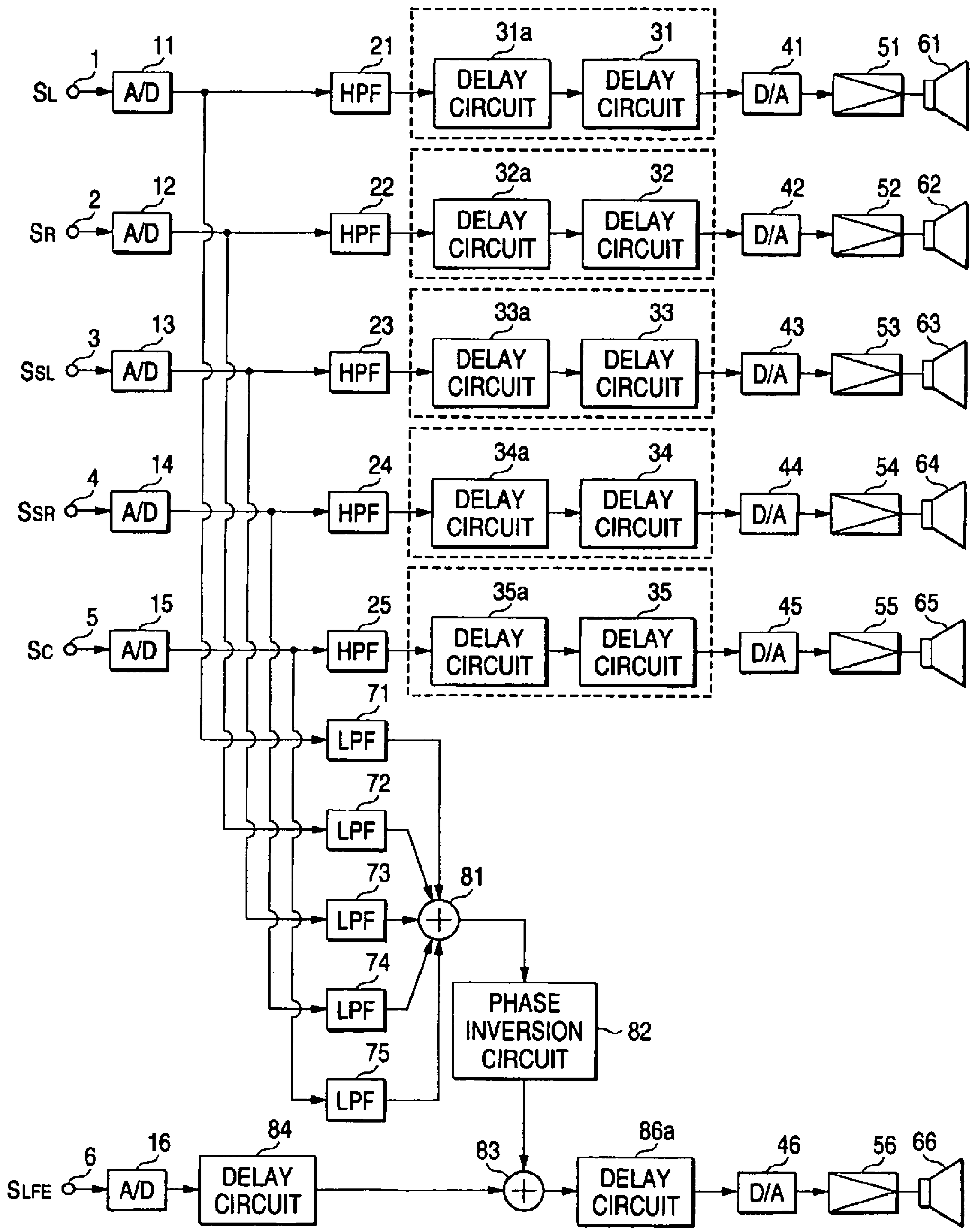


FIG. 9


SL
1
11
A/D
21
HPF
31a
DELAY CIRCUIT
31
DELAY CIRCUIT
41
D/A
51
61
SR
2
12
A/D
22
HPF
32a
DELAY CIRCUIT
32
DELAY CIRCUIT
42
D/A
52
62
SSL
3
13
A/D
23
HPF
33a
DELAY CIRCUIT
33
DELAY CIRCUIT
43
D/A
53
63
SSR
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A/D
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HPF
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DELAY CIRCUIT
34
DELAY CIRCUIT
44
D/A
54
64
SC
5
15
A/D
25
HPF
35a
DELAY CIRCUIT
35
DELAY CIRCUIT
45
D/A
55
65
71
LPF
72
LPF
73
LPF
74
LPF
75
LPF
81
PHASE INVERSION CIRCUIT
82
SLFE
6
16
A/D
84
DELAY CIRCUIT
83
86a
DELAY CIRCUIT
46
D/A
56
66

FIG. 10

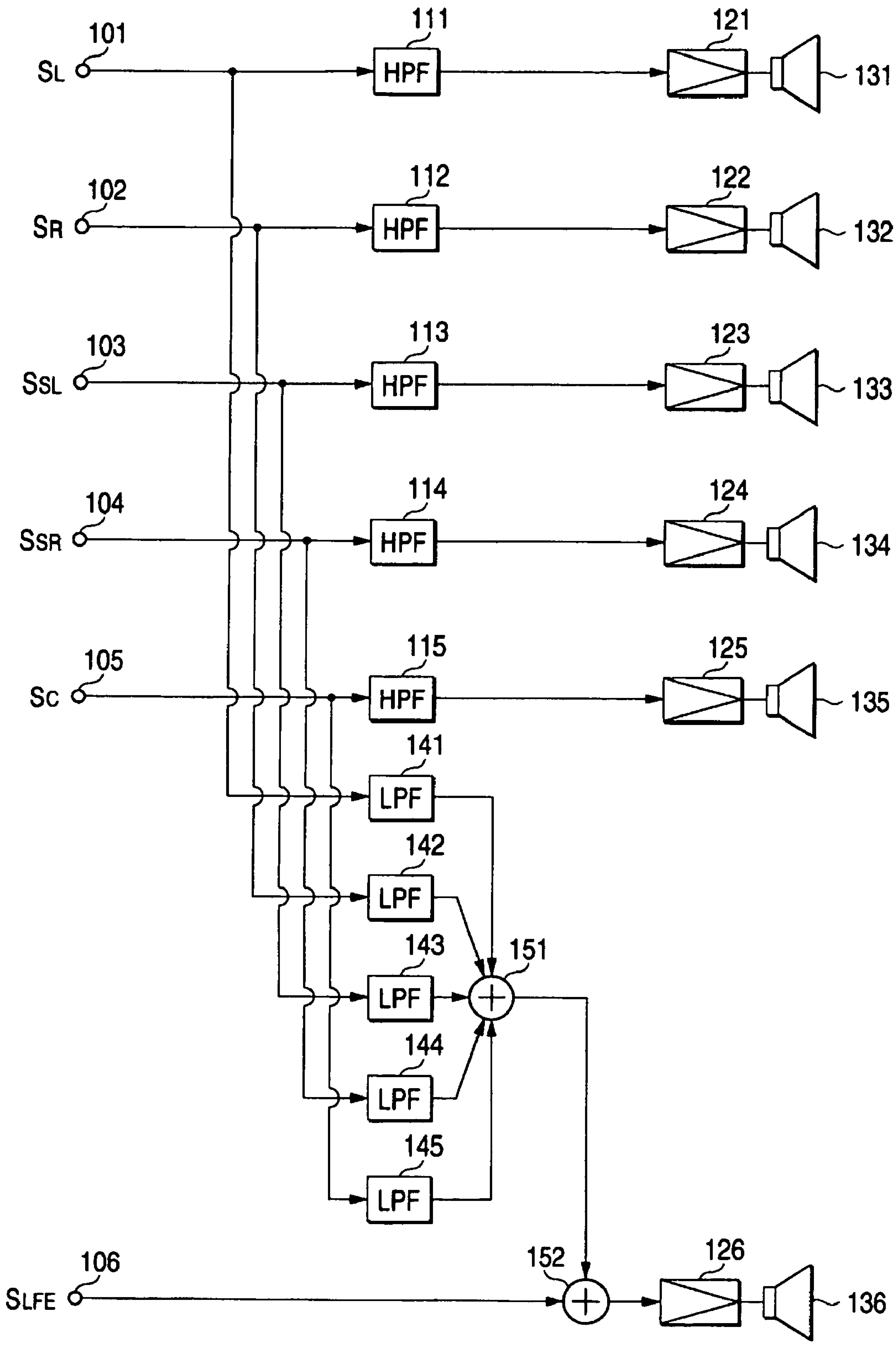

101
SL
102
SR
103
SSL
104
SSR
105
SC
106
SLFE
111
HPF
112
HPF
113
HPF
114
HPF
115
HPF
121
122
123
124
125
126
131
132
133
134
135
136
141
LPF
142
LPF
143
LPF
144
LPF
145
LPF
151
152

FIG. 11

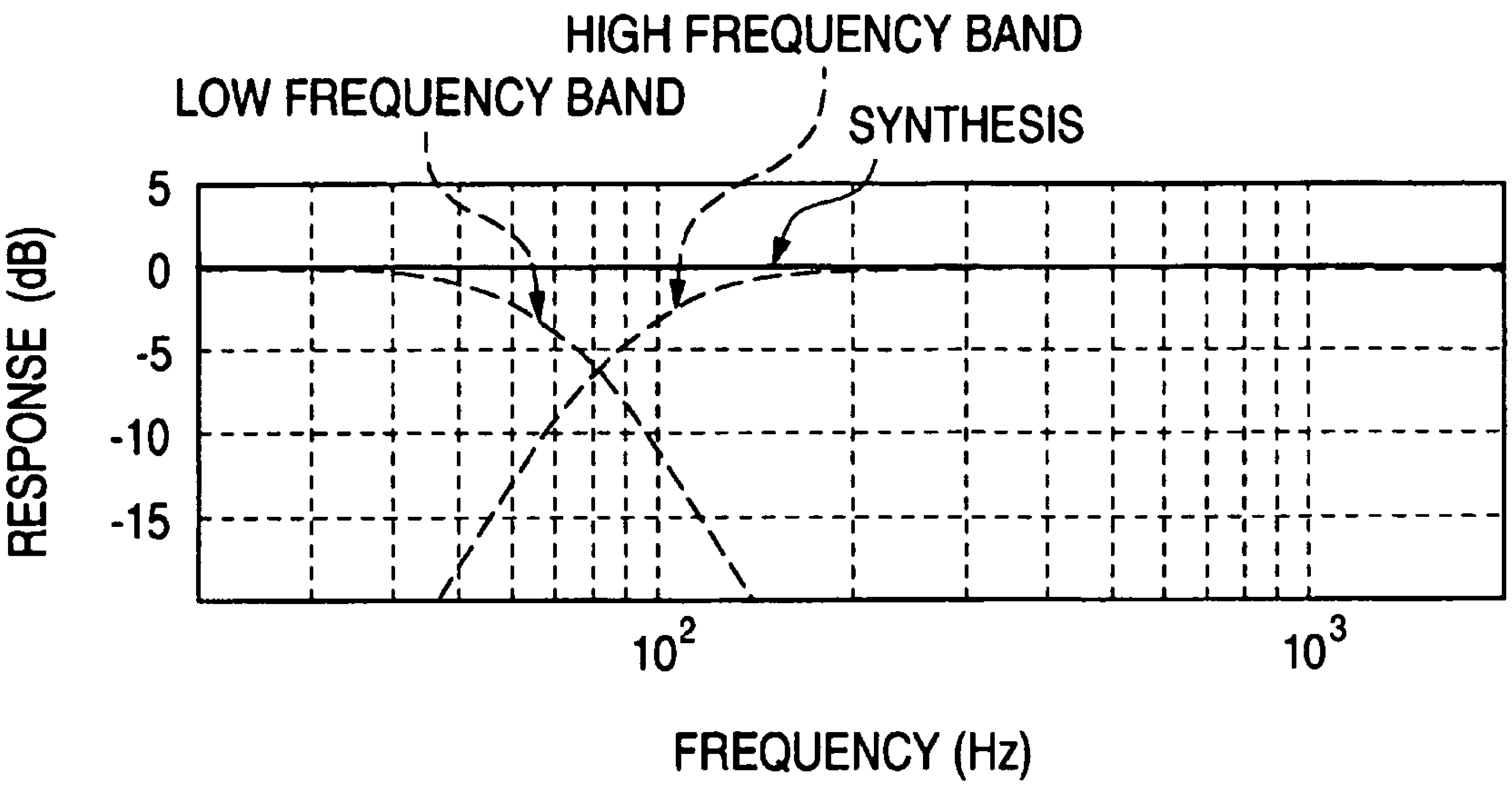
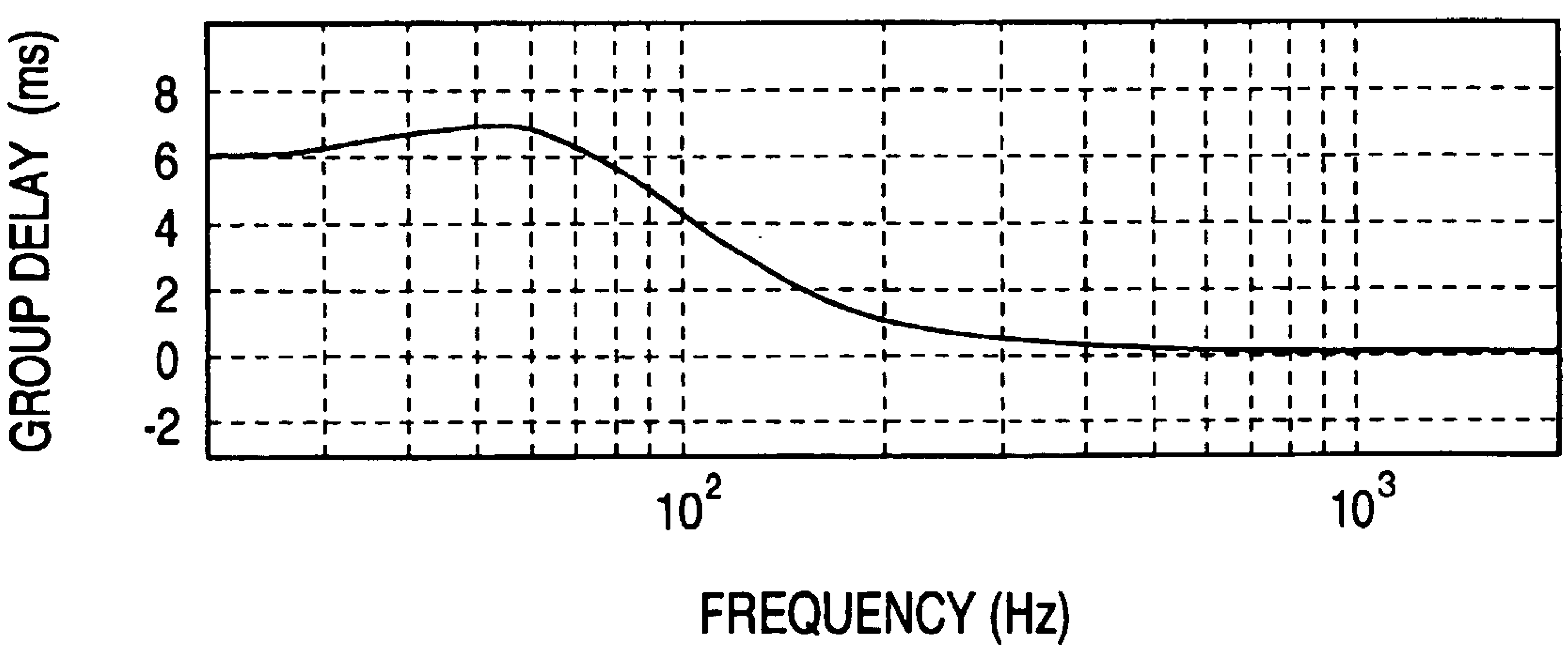

HIGH FREQUENCY BAND
LOW FREQUENCY BAND
SYNTHESIS
RESPONSE (dB)
5
0
-5
-10
-15
10^2
10^3
FREQUENCY (Hz)

FIG. 12


GROUP DELAY (ms)
8
6
4
2
0
-2
10^2
10^3
FREQUENCY (Hz)

SOUND SIGNAL PLAYBACK MACHINE AND METHOD THEREOF

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a sound signal playback machine and method thereof for playing back multichannel sounds.

2. Description of the Related Art

Concerning the sound signal playback machine for playing back multichannel sounds, for example, a sound signal playback machine to realize 5.1 surround playback is well known. FIG. **10** is a block diagram showing an example of such a sound signal playback machine. In FIG. **10**, the signal input terminal **101**, to which sound signal S_L of L-channel (left channel) is supplied, is connected to the speaker **131**, which is arranged at the front on the left, via HPF (high-pass filter) **111** and the amplifier **121**. At the same time, the signal input terminal **101** is connected to the signal adder **151** via LPF (low-pass filter) **141**. The signal input terminal **102**, to which sound signal S_R of R-channel (right channel) is supplied, is connected to the speaker **132**, which is arranged at the front on the right, via HPF **112** and the amplifier **122**. At the same time, the signal input terminal **102** is connected to the signal adder **151** via LPF **142**. The signal input terminal **103**, to which sound signal S_{SL} of SL-channel (surround left channel) is supplied, is connected to the speaker **133**, which is arranged at the rear on the left, via HPF **113** and the amplifier **123**. At the same time, the signal input terminal **103** is connected to the signal adder **151** via LPF **143**. The signal input terminal **104**, to which sound signal S_{SR} of SR-channel (surround right channel) is supplied, is connected to the speaker **134**, which is arranged at the rear on the right, via HPF **114** and the amplifier **124**. At the same time, the signal input terminal **104** is connected to the signal adder **151** via LPF **144**. Further, the signal input terminal **105**, to which sound signal S_C of C channel (central channel) is supplied, is connected to the speaker **135**, which is arranged at the front center, via HPF **115** and the amplifier **125**. At the same time, the signal input terminal **105** is connected to the signal adder **151** via LPF **145**. On the other hand, the signal input terminal **106**, to which sound signal S_{LFE} of LFE channel (channel exclusively used for the low frequency band) is supplied, is connected to the signal adder **152** to which the above signal adder **151** is connected. This signal adder **152** is connected to the speaker **136**, which is arranged on the side, via the amplifier **126**. In this case, the speakers **131** to **135** respectively compose a speaker system for playing back sounds of middle low frequency and higher frequency than that. In general, they are referred to as a satellite speaker system. The speaker **136** is a speaker system for playing back sounds of low frequency. In general, the speaker **136** is referred to as a sub-woofer.

In this connection, the above conventional sound signal playback machine is designed so that the frequency response can be flat when signals on the low frequency side and those on the high frequency side are electrically synthesized with each other. Further, in the above conventional sound signal playback machine, it is necessary to use a filter of the high order so that the band width, in which the frequency response on the low frequency side and that on the high frequency side cross each other, can be reduced. Accordingly, the following problems may be encountered. The frequency response of signals, which are obtained when signals on the low frequency side and signals on the high frequency side are electrically synthesized with each other, are flat as shown in FIG. **11**, however, as shown in FIG. **12**, a group delay in the low frequency band is increased, which causes such a problem that sounds of low frequency can not be faithfully played back and further a nuance of sounds of a musical instrument of low frequency is changed. In the case where sound signal S_{LFE} of channel LFE and sound signals S_L to S_C of the other channels (main channels) are correlated with each other, a group delay is increased in the low frequency band when sound signal S_{LFE} in channel LFE is added.

SUMMARY OF THE INVENTION

The present invention has been accomplished in view of the above circumstances. It is an object of the present invention to provide a sound signal playback machine and method thereof capable of making a group delay characteristic of signals, which are obtained when signals on the low frequency side and signals on the high frequency side are synthesized with each other, flat so that sounds of low frequency can be faithfully played back and a nuance of sounds of a musical instrument of low frequency can be improved.

In order to accomplish the above object, first, the present invention provides a sound signal playback machine comprising: a high frequency pass filter for extracting a predetermined high frequency component from a sound signal in a main channel; a first speaker for playing back the high frequency component extracted by the high frequency pass filter; a low frequency pass filter for extracting a predetermined low frequency component from the sound signal in the main channel; a signal adder for outputting an addition signal in which the low frequency component extracted by the low frequency pass filter is added to a sound signal in a channel exclusively used for a low frequency band; and a second speaker for playing back the addition signal outputted from the signal adder, wherein the degree of the low frequency pass filter is set higher than that of the high frequency pass filter, the sound signal playback machine further comprising a phase matching means for matching the phase of the high frequency component extracted by the high frequency pass filter with the phase of the low frequency component extracted by the low frequency pass filter. According to the sound signal playback machine composed as described above, it is possible to make a group delay characteristic of signals, which are obtained when signals on the low frequency side and signals on the high frequency side are electrically synthesized with each other, substantially flat.

Secondly, the present invention provides a sound signal playback machine according to the above item 1, wherein the phase matching means is a delay circuit for delaying the high frequency component extracted by the high frequency pass filter. According to the sound signal playback machine composed as described above, it is possible to make a group delay characteristic of signals, which are obtained when signals on the low frequency side and signals on the high frequency side are electrically synthesized with each other, substantially flat.

Thirdly, the present invention provides a sound signal playback machine according to the above item 2, wherein delay time T1 (sec) of the delay circuit is set at a value calculated by the equation of

$$T1=(\phi1-\phi2+\pi\cdot n)/(2\pi Fc)$$

$$(n=\ldots -2, -1, 0, 1, 2 \ldots)$$

where $\phi 1$ (rad) is a phase angle at a cut-off frequency Fc (Hz) of the high frequency pass filter, and $\phi 2$ (rad) is a phase angle of the low frequency pass filter. According to the sound signal playback machine composed as described above, it is possible to make a group delay characteristic of signals, which are obtained when signals on the low frequency side and signals on the high frequency side are electrically synthesized with each other, substantially flat.

Fourthly, the present invention provides a sound signal playback machine according to the above item 1, wherein the phase matching means is to set the first speaker by moving it in a direction so that the first speaker can be separated from a listener. According to the sound signal playback machine composed as described above, it is possible to make a group delay characteristic of signals, which are obtained when signals on the low frequency side and signals on the high frequency side are electrically synthesized with each other, substantially flat.

Fifthly, the present invention provides a sound signal playback machine according to the above item 1, wherein the phase matching means is to set the second speaker by moving it in a direction so that the second speaker can be approached to a listener, and the phase matching means is also a delay circuit for delaying the addition signal outputted from the signal adder. According to the sound signal playback machine composed as described above, it is possible to make a group delay characteristic of signals, which are obtained when signals on the low frequency side and signals on the high frequency side are electrically synthesized with each other, substantially flat.

Sixthly, the present invention provides a sound signal playback machine according to one of the above items 1 to 5, further comprising an auxiliary phase matching means for matching the phase of the low frequency component extracted by the low frequency pass filter with the phase of the sound signal in the channel exclusively used for the low frequency band. According to the sound signal playback machine composed as described above, it is possible to make a group delay characteristic of signals, which are obtained when signals on the low frequency side and signals on the high frequency side are electrically synthesized with each other, substantially flat. Even when sound signals in the channel exclusively used for the low frequency band and sound signals in the main channel are correlated with each other, there is no possibility that the group delay is increased in the low frequency band.

Seventhly, the present invention provides a sound signal playback machine according to the above item 6, wherein the auxiliary phase matching means is a delay circuit for delaying the sound signal in the channel exclusively used for the low frequency band. According to the sound signal playback machine composed as described above, it is possible to make a group delay characteristic of signals, which are obtained when signals on the low frequency side and signals on the high frequency side are electrically synthesized with each other, substantially flat. Even when sound signals in the channel exclusively used for the low frequency band and sound signals in the main channel are correlated with each other, there is no possibility that the group delay is increased in the low frequency band.

Eighthly, the present invention provides a sound signal playback machine according to the above item 7, wherein delay time T2 (sec) of the delay circuit is set at a value calculated by the equation of

$$T2=(\phi 1+\pi \cdot n)/(2\pi \cdot Fc)$$

$(n=\ldots -2, -1, 0, 1, 2 \ldots)$

where $\phi 1$ (rad) is a phase angle at a cut-off frequency Fc (Hz) of the high frequency pass filter. According to the sound signal playback machine composed as described above, it is possible to make a group delay characteristic of signals, which are obtained when signals on the low frequency side and signals on the high frequency side are electrically synthesized with each other, substantially flat. Even when sound signals in the channel exclusively used for the low frequency band and sound signals in the main channel are correlated with each other, there is no possibility that the group delay is increased in the low frequency band.

Ninthly, the present invention provides a sound signal playback machine according to one of the above items 1 to 5, further comprising a phase inversion circuit for inverting a phase of the low frequency component extracted by the low frequency pass filter when a difference between the phase of the low frequency component extracted by the low frequency pass filter and the phase of the sound signal in the channel exclusively used for the low frequency is π (rad). According to the sound signal playback machine composed as described above, it is possible to make a group delay characteristic of signals, which are obtained when signals on the low frequency side and signals on the high frequency side are electrically synthesized with each other, substantially flat.

Tenthly, the present invention provides a sound signal playback method comprising the steps of: extracting a predetermined high frequency component from a sound signal in a main channel by a high frequency pass filter; playing back the high frequency component, which has been extracted by the high frequency pass filter, by a first speaker; extracting a predetermined low frequency component from the sound signal in the main channel by a low frequency pass filter; adding the low frequency component extracted by the low frequency pass filter to a sound signal in the channel exclusively used for the low frequency by a signal adder and outputting an addition signal; and playing back the addition signal, which has been outputted from the signal adder, by a second speaker, wherein the degree of the low frequency pass filter is set higher than that of the high frequency pass filter, and the phase of the high frequency component extracted by the high frequency pass filter and the phase of the low frequency component extracted by the low frequency pass filter are matched with each other. According to the sound signal playback method described above, it is possible to make a group delay characteristic of signals, which are obtained when signals on the low frequency side and signals on the high frequency side are electrically synthesized with each other, substantially flat.

Eleventhly, the present invention provides a sound signal playback method according to the above item 10, wherein the phase of the high frequency component extracted by the high frequency pass filter and the phase of the low frequency component extracted by the low frequency pass filter are matched with each other when the high frequency component extracted by high frequency pass filter is delayed by the delay circuit. According to the sound signal playback method described above, it is possible to make a group delay characteristic of signals, which are obtained when signals on the low frequency side and signals on the high frequency side are electrically synthesized with each other, substantially flat.

Twelfthly, the present invention provides a sound signal playback method according to the above item 11, wherein delay time T1 (sec) of the delay circuit is set at a value calculated by the equation of

$$T1=(\phi 1-\phi 2+\pi \cdot n)/(2\pi \cdot Fc)$$

$(n=\ldots -2, -1, 0, 1, 2 \ldots)$

where $\phi 1$ (rad) is a phase angle at a cut-off frequency Fc (Hz) of the high frequency pass filter, and $\phi 2$ (rad) is a phase angle of the low frequency pass filter. According to the sound signal playback method described above, it is possible to make a group delay characteristic of signals, which are obtained when signals on the low frequency side and signals on the high frequency side are electrically synthesized with each other, substantially flat.

Thirteenthly, the present invention provides a sound signal playback method according to the above item 10, wherein the phase of the high frequency component extracted by the high frequency pass filter and the phase of the low frequency component extracted by the low frequency pass filter are matched with each other when the first speaker is arranged by moving so that it can be separated from a listener. According to the sound signal playback method described above, it is possible to make a group delay characteristic of signals, which are obtained when signals on the low frequency side and signals on the high frequency side are electrically synthesized with each other, substantially flat.

Fourteenthly, the present invention provides a sound signal playback method according to the above item 10, wherein the phase of the high frequency component extracted by the high frequency pass filter and the phase of the low frequency component extracted by the low frequency pass filter are matched with each other when the second speaker is arranged by moving so that it can be separated from a listener and the addition signal outputted from the signal adder is delayed by the delay circuit. According to the sound signal playback method described above, it is possible to make a group delay characteristic of signals, which are obtained when signals on the low frequency side and signals on the high frequency side are electrically synthesized with each other, substantially flat.

Fifteenthly, the present invention provides a sound signal playback method according to one of the above items 10 to 14, wherein the phase of the low frequency component extracted by the low frequency pass filter and the phase of the sound signal in the channel exclusively used for the low frequency band are matched with each other. According to the sound signal playback method described above, it is possible to make a group delay characteristic of signals, which are obtained when signals on the low frequency side and signals on the high frequency side are electrically synthesized with each other, substantially flat. Even when sound signals in the channel exclusively used for the low frequency band and sound signals in the main channel are correlated with each other, there is no possibility that the group delay is increased in the low frequency band.

Sixteenthly, the present invention provides a sound signal playback method according to the above item 15, wherein the phase of the low frequency component extracted by the low frequency pass filter and the phase of the sound signal in the channel exclusively used for the low frequency band are matched with each other by delaying the sound signal in the channel exclusively used for the low frequency band by the delay circuit. According to the sound signal playback method described above, it is possible to make a group delay characteristic of signals, which are obtained when signals on the low frequency side and signals on the high frequency side are electrically synthesized with each other, substantially flat. Even when sound signals in the channel exclusively used for the low frequency band and sound signals in the main channel are correlated with each other, there is no possibility that the group delay is increased in the low frequency band.

Seventeenthly, the present invention provides a sound signal playback method according to the above item 16, wherein delay time T2 (sec) of the delay circuit is set at a value calculated by the equation of

$$T2=(\phi 1+\pi\cdot n)/(2\pi\cdot Fc)$$

(n=. . . −2, −1, 0, 1, 2 . . .)

where $\phi 1$ (rad) is a phase angle at a cut-off frequency Fc (Hz) of the high frequency pass filter. According to the sound signal playback method described above, it is possible to make a group delay characteristic of signals, which are obtained when signals on the low frequency side and signals on the high frequency side are electrically synthesized with each other, substantially flat. Even when sound signals in the channel exclusively used for the low frequency band and sound signals in the main channel are correlated with each other, there is no possibility that the group delay is increased in the low frequency band.

Eighteenthly, the present invention provides a sound signal playback method according to one of the above items 10 to 14, wherein the phase of the low frequency component extracted by the low frequency pass filter is inverted by the phase inversion circuit when a difference between the phase of the low frequency component extracted by the low frequency pass filter and the phase of the sound signal in the channel exclusively used for the low frequency is π (rad). According to the sound signal playback method described above, it is possible to make a group delay characteristic of signals, which are obtained when signals on the low frequency side and signals on the high frequency side are electrically synthesized with each other, substantially flat.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram showing a sound signal playback machine of the first embodiment of the present invention;

FIG. **2** is a view showing a position at which a speaker is arranged with respect to a listener in a sound signal playback machine of the first embodiment of the present invention;

FIG. **3** is a characteristic diagram showing a frequency response of a sound signal playback machine of the first embodiment of the present invention;

FIG. **4** is a characteristic diagram showing a group delay characteristic of a sound signal playback machine of the first embodiment of the present invention;

FIG. **5** is a block diagram showing a sound signal playback machine of the second embodiment of the present invention;

FIG. **6** is a view showing a position at which a speaker is arranged with respect to a listener in a sound signal playback machine of the second embodiment of the present invention;

FIG. **7** is a block diagram showing a sound signal playback machine of the third embodiment of the present invention;

FIG. **8** is a view showing a position at which a speaker is arranged with respect to a listener in a sound signal playback machine of the third embodiment of the present invention;

FIG. **9** is a block diagram showing a sound signal playback machine of the fourth embodiment of the present invention;

FIG. **10** is a block diagram showing a conventional sound signal playback machine;

FIG. **11** is a characteristic diagram showing a frequency response of a conventional sound signal playback machine; and

FIG. **12** is a characteristic diagram showing a group delay characteristic of a conventional sound signal playback machine.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to the accompanying drawings, embodiments of the present invention will be explained in detail as follows.

First Embodiment

FIG. **1** is a block diagram showing a sound signal playback machine of the first embodiment of the present invention. In FIG. **1**, the signal input terminal **1**, to which sound signal S_L of channel L (left channel) is supplied, is connected to the speaker **61** via the A/D converter **11** for converting analog/digital, HPF (high-pass filter) **21**, delay circuit **31** for delaying a signal, D/A converter **41** for converting digital/analog and amplifier **51**. Further, the signal input terminal **1** is connected to the signal adder **81** for adding a signal via the A/D converter **11** and LPF (low-pass filter) **71**. The signal input terminal **2**, to which sound signal S_R of channel R (right channel) is supplied, is connected to the speaker **62** via the A/D converter **12**, HPF **22**, delay circuit **32**, D/A converter **42** and amplifier **52**. Further, the signal input terminal **2** is connected to the signal adder **81** for adding a signal via the A/D converter **12** and LPF **72**. The signal input terminal **3**, to which sound signal S_{SL} of channel SL (surround left channel) is supplied, is connected to the speaker **63** via the A/D converter **13**, HPF **23**, delay circuit **33**, D/A converter **43** and amplifier **53**. Further, the signal input terminal **3** is connected to the signal adder **81** for adding a signal via the A/D converter **13** and LPF **73**. Further, the signal input terminal **4**, to which sound signal S_{SR} of channel SR (surround right channel) is supplied, is connected to the speaker **64** via the A/D converter **14**, HPF **24**, delay circuit **34**, D/A converter **44** and amplifier **54**. Furthermore, the signal input terminal **4** is connected to the signal adder **81** for adding a signal via the A/D converter **14** and LPF **74**. The signal input terminal **5**, to which sound signal S_C of channel C (central channel) is supplied, is connected to the speaker **65** via the A/D converter **15**, HPF **25**, delay circuit **35**, D/A converter **45** and amplifier **55**. Further, the signal input terminal **5** is connected to the signal adder **81** for adding a signal via the A/D converter **15** and LPF **75**. This signal adder **81** is connected to the signal adder **83** via the phase inversion circuit **82** for inverting a phase of a signal under the condition described later. On the other hand, the signal input terminal **6**, to which sound signal S_{LFE} of channel LFE (channel exclusively used for the low frequency channel) is supplied, is connected to the signal adder **83** via A/D converter **16** and the delay circuit **84** for delaying a signal. This signal adder **83** is connected to the speaker **66** via D/A converter **46** and the amplifier **56**.

In this case, the speakers **61** to **65** compose a speaker system for playing back sounds of middle low frequency and higher frequency than that. In general, they are referred to as a satellite speaker system. The speaker **66** is a speaker system for playing back sounds of low frequency. In general, the speaker **66** is referred to as a sub-woofer. These speakers **61** to **66** are arranged, for example, as shown in FIG. **2**. That is, the speaker **61** for channel L is arranged at the front on the left with respect to the listener **91**, the speaker **62** for channel R is arranged at the front on the right, the speaker **63** for channel SL is arranged at the rear on the left, the speaker **64** for channel SR is arranged at the rear on the right, the speaker **65** for channel C is arranged at the front center, and the speaker **66** for channel LFE is arranged on the side.

HPF **21** to **25** respectively extract a predetermined high frequency component from the digitized sound signal of the channel (main channel) except for channel LFE. LPF **71** to **75** extract a predetermined low frequency component from the digitized sound signal in the same manner. When the degree of HPF **21** to **25** is N1 and the degree of LPF **71** to **75** is N2, it is set that N2>N1, that is, it is set that the degree of LPF **71** to **75** is higher than the degree of HPF **21** to **25**. In this connection, in the sound signal playback machine of the first embodiment, the degree of LPF **71** to **75** is set at "4" (N2=4), and the degree of HPF **21** to **25** is set at "2" (N1=2).

The delay circuits **31** to **35** are provided as a phase matching means for matching a phase of the high frequency component extracted by HPF **21** to **25** with a phase of the low frequency component extracted by LPF **71** to **75**. Delay time T1 (sec) of each delay circuit **31** to **35** is set at a value calculated by the equation of

$$T1=(\phi1-\phi2+\pi\cdot n)/(2\pi\cdot Fc)$$

(n=. . . −2, −1, 0, 1, 2 . . .)

where $\phi1$ (rad) is a phase angle at a cut-off frequency Fc (Hz) of HPF **21** to **25**, and $\phi2$ (rad) is a phase angle of LPF **71** to **75**.

In this connection, in the sound signal playback machine of the first embodiment, the delay time of each delay circuit **31** to **35** is set at 5 msec (T1=5 msec).

The delay circuit **84** is provided as an auxiliary phase matching means for matching the phase of the low frequency component extracted by LPF **71** to **75** with the phase of the digitized sound signal in LFE channel in the case where sound signals S_L to S_C in the main channel and sound signal S_{LFE} in LFE channel are correlated with each other. Delay time T2 (sec) of this delay circuit **84** is set at a value calculated by the equation of

$$T2=(\phi1+\pi\cdot n)/(2\pi\cdot Fc)$$

(n=. . . −2, −1, 0, 1, 2 . . .)

where $\phi1$ (rad) is a phase angle at a cut-off frequency Fc (Hz) of the HPF **21** to **25**.

The phase inversion circuit **82** is controlled so that a phase of a signal outputted from the signal adder **81** can be inverted when a phase difference between the signal outputted from the signal adder **81** and the signal outputted from the delay circuit **84** is π (rad) (180°). That is, when n in the equation to calculate delay time T1 is represented by n=. . . 3, −1, 1, 3 . . . , the phase inversion circuit **82** conducts a phase inversion motion. When n in the equation to calculate delay time T1 is represented by n=. . . −4, 2, 0, 2, 4 . . . , the phase inversion circuit **82** does not conduct a phase inversion motion. In this connection, the value of n is determined by HPF and LPF to be used. Therefore, when n=. . . −4, −2, 0, 2, 4 . . . , the phase inversion circuit **82** may not be provided.

As described above, in the sound signal playback machine of the first embodiment, the degree of LPF **71** to **75** is set higher than the degree of HPF **21** to **25**, and the delay circuits **31** to **35** are provided as a phase matching means. Therefore, the phase characteristic of a signal, which is obtained when the signal on the low frequency side and the signal on the high frequency side are electrically synthesized with each other, becomes substantially flat as shown in FIG. **3** although it is a little inferior to that of the prior art, and as shown in FIG. **4**, the group delay characteristic becomes flat compared with that of the prior art in which the group delay is great in the low frequency band. Accordingly, sounds of low frequency can be faithfully played back, and a nuance of sounds of a musical instrument of low frequency can be improved. Therefore, multichannel sound playback can be excellently conducted. Since the delay circuit **84** is provided as an auxiliary phase matching means, even when sound signal S_{LFE} of LFE channel and sound signals S_L to S_C in the main channel are correlated with each other, there is no possibility that the group delay is increased in the low frequency band.

Second Embodiment

FIG. **5** is a block diagram showing a sound signal playback machine of the second embodiment of the present invention. In this sound signal playback machine of the second embodiment, the delay circuits **31** to **35**, which are arranged at the rear stage of HPF **21** to **25**, are deleted from the sound signal playback machine (shown in FIG. **1**) of the first embodiment described before, and the speakers **61** to **65** for the main channel are arranged being moved in a direction (direction shown by an arrow in the drawing) so that they can be separated from the listener **91** as shown in FIG. **6**. In this case, a distance by which the speakers **61** to **65** are respectively moved is set at a value corresponding to delay time T1 of the deleted delay circuits **31** to **35**. As a phase matching means, when the speakers **61** to **65** are respectively arranged being moved in a direction so that they can be separated from the listener **91**, it is possible to provide the same effect as that of a case in which the signal on the high frequency band side is delayed. In this case, the speaker **66** used for LFE channel is arranged at the same position. In this connection, in FIG. **5**, like reference characters are used to indicate like parts in the sound signal playback machine of the first embodiment described before and the sound signal playback machine of this second embodiment.

As described above, in the sound signal playback machine of the second embodiment, the degree of LPF **71** to **75** is set higher than the degree of HPF **21** to **25**, and the speakers **61** to **65** used for the main channel are provided as a phase matching means being respectively moved in a direction so that they can be separate from the listener **91**. Therefore, the sound signal playback machine of the second embodiment can provide the same effect as that of the sound signal playback machine of the first embodiment described before.

Third Embodiment

FIG. **7** is a block diagram showing a sound signal playback machine of the third embodiment of the present invention. In this sound signal playback machine of the third embodiment, the delay circuits **31** to **35**, which are arranged at the rear stage of HPF **21** to **25**, are deleted from the sound signal playback machine (shown in FIG. **1**) of the first embodiment described before, and the speaker **66** for the LFE channel is arranged being moved in a direction (direction shown by an arrow in the drawing) so that they can be approached to the listener **91** as shown in FIG. **8**, and the delay circuit **85** to delay a signal is arranged at the rear stage of the signal adder **83**. In this case, the distance by which the speaker **66** is moved and the delay time of the delay circuit **85** are set so that the time, which is obtained when the delay time of the delay circuit **85** is subtracted from the time corresponding to the distance by which the speaker **66** is moved, can coincide with delay time T1 of the deleted delay circuits **31** to **35**. As a phase matching means, the speaker **66** is arranged being moved to a direction so that it can be approached to the listener **91**, and the delay circuit **85** is arranged at the rear of the signal adder **83**. Due to the foregoing, it is possible to provide the same effect as that of a case in which the signal on the high frequency band side is delayed. In this case, the speakers **61** to **65** used for the main channel are arranged at the same positions. In this connection, in FIG. **7**, like reference characters are used to indicate like parts in the sound signal playback machine of the first embodiment described before and the sound signal playback machine of this third embodiment.

As described above, in the sound signal playback machine of the third embodiment, the degree of LPF **71** to **75** is set higher than the degree of HPF **21** to **25**, and the speaker **66** used for the main channel is provided as a phase matching means being respectively moved in a direction so that it can be approached to the listener **91**, and the delay circuit **85** is arranged at the rear of the signal adder **83**. Therefore, the sound signal playback machine of the third embodiment can provide the same effect as that of the sound signal playback machine of the first embodiment.

Fourth Embodiment

FIG. **9** is a block diagram showing a sound signal playback machine of the fourth embodiment of the present invention. In the fourth embodiment, the present invention is applied to a sound signal playback machine which is housed in a so-called AV amplifier and provided with a speaker distance adjusting function. In FIG. **9**, the signal input terminal **1**, to which sound signal S_L of channel L is supplied, is connected to the speaker **61** via the A/D converter **11** for converting analog/digital, HPF **21**, delay circuits **31**a, **31** for delaying a signal, D/A converter **41** for converting digital/analog and amplifier **51**. Further, the signal input terminal **1** is connected to the signal adder **81** for adding a signal via the A/D converter **11** and LPF **71**. The signal input terminal **2**, to which sound signal S_R of channel R is supplied, is connected to the speaker **62** via the A/D converter **12**, HPF **22**, delay circuits **32**a, **32**, D/A converter **42** and amplifier **52**. Further, the signal input terminal **2** is connected to the signal adder **81** via the A/D converter **12** and LPF **72**. Further, the signal input terminal **3**, to which sound signal S_{SL} of channel SL is supplied, is connected to the speaker **63** via the A/D converter **13**, HPF **23**, delay circuit **33**a, **33**, D/A converter **43** and amplifier **53**. Furthermore, the signal input terminal **3** is connected to the signal adder **81** for adding a signal via the A/D converter **13** and LPF **73**. Further, the signal input terminal **4**, to which sound signal S_{SR} of channel SR is supplied, is connected to the speaker **64** via the A/D converter **14**, HPF **24**, delay circuits **34**a, **34**, D/A converter **44** and amplifier **54**. Further, the signal input terminal **4** is connected to the signal adder **81** for adding a signal via the A/D converter **14** and LPF **74**. The signal input terminal **5**, to which sound signal S_C of channel C is supplied, is connected to the speaker **65** via the A/D converter **15**, HPF **25**, delay circuits **35**a, **35**, D/A converter **45** and amplifier **55**. Further, the signal input terminal **5** is connected to the signal adder **81** for adding a signal via the A/D converter **15** and LPF **75**. This signal adder **81** is connected to the signal adder **83** via the phase inversion circuit **82** for inverting a phase of a signal in the same manner as that of the first embodiment described before. On the other hand, the signal input terminal **6**, to which sound signal S_{LFE} of channel LFE is supplied, is connected to the signal adder **83** via A/D converter **16** and the delay circuit **84** for delaying a signal. This signal adder **83** is connected to the speaker **66** via the delay circuit **86**a for delaying a signal, D/A converter **46** and the amplifier **56**.

In this case, the speakers **61** to **66**, HPF **21** to **25**, LPF **71** to **75**, delay circuits **31** to **35**, phase inversion circuit **82** and delay circuit **84** are the same as those of the first embodiment described before. Therefore, the explanations are omitted here.

Each delay circuit **31**a to **35**a fulfills a function of adjusting a speaker distance. In order to adjust a distance from the listener **91** to each speaker **61** to **65** used for the main channel shown in FIG. **2**, the delay circuit **31**a to **35**a respectively delays a component of the high frequency band extracted by HPF **21** to **25**. The delay time of the delay circuit **31**a to **35**a is set at a value calculated from the distance to be adjusted and the sound velocity. Actually, as shown by broken lines in FIG. **9**, the delay circuit **31**a for adjusting the speaker distance and the delay circuit **31** for matching the phase may be arranged being integrated with each other, and the delay time in this case may be obtained by adding the delay time in the delay circuit **31**a to the delay time in the delay circuit **31**. Concerning the delay circuits **32**a to **35**a for adjusting the speaker distance and the delay circuits **32** to **35** for matching the phase, the delay time can be obtained in the same manner. In this connection, the delay circuit **86**a fulfills a function of adjusting the speaker distance. The delay circuit **86**a delays a signal sent from the signal adder **83** so as to adjust a distance from the listener **91** to the speaker **66** used for the LFE channel.

As described above, in the sound signal playback machine of the fourth embodiment, the degree of LPF **71** to **75** is set higher than the degree of HPF **21** to **25**, and the delay circuits **31** to **35** are provided as a phase matching means. Therefore, the same effect as that of the sound signal playback machine of the first embodiment can be provided.

In the first to the fourth embodiment, a phase converting circuit for conducting fine adjustment on the group delay may be arranged at the front stage of each of A/D converters **11** to **15**. Signal processing may be conducted not by digital processing but by analogue processing.

As can be seen from the above explanations, according to the present invention, the degree of the low frequency pass filter is set higher than the degree of the high-frequency-pass-filter, and the phase of the high frequency component extracted by the high frequency pass filter and the phase of the low frequency component extracted by the low frequency pass filter are matched to each other. Therefore, the group delay characteristic of the signal, which is obtained when the signal on the low frequency band side and the signal on the high frequency band side are electrically synthesized with each other, becomes substantially flat. Accordingly, sounds of low frequency can be faithfully played back and a nuance of sounds of a musical instrument of low frequency can be improved. Therefore, sounds can be excellently played back by means of multichannel playback.

What is claimed is:

1. A sound signal playback machine comprising:

a high frequency pass filter for extracting a predetermined high frequency component from a sound signal in a main channel;

a first speaker for playing back the high frequency component extracted by the high frequency pass filter;

a low frequency pass filter for extracting a predetermined low frequency component from the sound signal in the main channel;

a signal adder for outputting an addition signal in which the low frequency component extracted by the low frequency pass filter is added to a sound signal in a channel exclusively used for a low frequency band; and

a second speaker for playing back the addition signal outputted from the signal adder,

wherein the degree of the low frequency pass filter is set higher than that of the high frequency pass filter, and

wherein the sound signal playback machine further comprising a phase matching unit for matching the phase of the high frequency component extracted by the high frequency pass filter with the phase of the low frequency component extracted by the low frequency pass filter.

2. The sound signal playback machine according to claim **1**, wherein the phase matching unit is a delay circuit for delaying the high frequency component extracted by the high frequency pass filter.

3. The sound signal playback machine according to claim **2**, wherein delay time T1 (sec) of the delay circuit is set at a value calculated by the equation of

$$T1=(\phi1-\phi2+\pi\cdot n)/(2\pi\cdot Fc)$$

(n=. . . −2, −1, 0, 1, 2 . . .)

where ϕ1 (rad) is a phase angle at a cut-off frequency Fc (Hz) of the high frequency pass filter, and ϕ2 (rad) is a phase angle of the low frequency pass filter.

4. The sound signal playback machine according to claim **1**, wherein the phase matching unit is to set the first speaker by moving it in a direction so that the first speaker can be separated from a listener.

5. The sound signal playback machine according to claim **1**, wherein the phase matching unit is to set the second speaker by moving it in a direction so that the second speaker can be approached to a listener, and the phase matching means is also a delay circuit for delaying the addition signal outputted from the signal adder.

6. The sound signal playback machine according to claim **1**, further comprising an auxiliary phase matching unit adapted to match the phase of the low frequency component extracted by the low frequency pass filter with the phase of the sound signal in the channel exclusively used for the low frequency band.

7. The sound signal playback machine according to claim **6**, wherein the auxiliary phase matching unit is a delay circuit for delaying the sound signal in the channel exclusively used for the low frequency band.

[8. The sound signal playback machine according to claim **7**, wherein delay time T2 (sec) of the delay circuit is set at a value calculated by the equation of

$$T2=(\phi1+\pi\cdot n)/(2\pi\cdot Fc)$$

(n=. . . −2, −1, 0, 1, 2 . . .)

where ϕ1 (rad) is a phase angle at a cut-off frequency Fc (Hz) of the high frequency pass filter.**]**

9. The sound signal playback machine according to claim **1**, further comprising a phase inversion circuit for inverting a phase of the low frequency component extracted by the low frequency pass filter when a difference between the phase of the low frequency component extracted by the low frequency pass filter and the phase of the sound signal in the channel exclusively used for the low frequency is n (rad).

10. A sound signal playback method comprising the steps of:

extracting a predetermined high frequency component from a sound signal in a main channel by a high frequency pass filter;

playing back the high frequency component, which has been extracted by the high frequency pass filter, by a first speaker;

extracting a predetermined low frequency component from the sound signal in the main channel by a low frequency pass filter;

adding the low frequency component extracted by the low frequency pass filter to a sound signal in the channel exclusively used for the low frequency by a signal adder and outputting an addition signal; and

playing back the addition signal, which has been outputted from the signal adder, by a second speaker,

wherein the degree of the low frequency pass filter is set higher than that of the high frequency pass filter, and

wherein the phase of the high frequency component extracted by the high frequency pass filter and the phase of the low frequency component extracted by the low frequency pass filter are matched with each other.

11. The sound signal playback method according to claim **10**, wherein the phase of the high frequency component extracted by the high frequency pass filter and the phase of the low frequency component extracted by the low frequency pass filter are matched with each other when the high frequency component extracted by high frequency pass filter is delayed by the delay circuit.

12. The sound signal playback method according to claim **11**, wherein delay time T1 (sec) of the delay circuit is set at a value calculated by the equation of

$$T1=(\phi1-\phi2+\pi\cdot n)/(2\pi\cdot Fc)$$

(n=. . . −2, −1, 0, 1, 2 . . .)

where $\phi1$ (rad) is a phase angle at a cut-off frequency Fc (Hz) of the high frequency pass filter, and $\phi2$ (rad) is a phase angle of the low frequency pass filter.

13. The sound signal playback method according to claim **10**, wherein the phase of the high frequency component extracted by the high frequency pass filter and the phase of the low frequency component extracted by the low frequency pass filter are matched with each other when the first speaker is arranged by moving so that it can be separated from a listener.

14. The sound signal playback method according to claim **10**, wherein the phase of the high frequency component extracted by the high frequency pass filter and the phase of the low frequency component extracted by the low frequency pass filter are matched with each other when the second speaker is arranged by moving so that it can be separated from a listener and the addition signal outputted from the signal adder is delayed by the delay circuit.

15. The sound signal playback method according to claim **10**, wherein the phase of the low frequency component extracted by the low frequency pass filter and the phase of the sound signal in the channel exclusively used for the low frequency band are matched with each other.

16. The sound signal playback method according to claim **15**, wherein the phase of the low frequency component extracted by the low frequency pass filter and the phase of the sound signal in the channel exclusively used for the low frequency band are matched with each other by delaying the sound signal in the channel exclusively used for the low frequency band by the delay circuit.

[17. The sound signal playback method according to claim **16**, wherein delay time T2 (sec) of the delay circuit is set at a value calculated by the equation of

$$T2=(\phi1+\pi\cdot n)/(2\pi\cdot Fc)$$

(n=. . . −2, −1, 0, 1, 2 . . .)

where $\phi1$ (rad) is a phase angle at a cut-off frequency Fc (Hz) of the high frequency pass filter.**]**

18. The sound signal playback method according to claim **10**, wherein the phase of the low frequency component extracted by the low frequency pass filter is inverted by the phase inversion circuit when a difference between the phase of the low frequency component extracted by the low frequency pass filter and the phase of the sound signal in the channel exclusively used for the low frequency is π (rad).

19. A sound signal playback machine comprising:

a high frequency pass filter for extracting a high frequency component from a sound signal in a main channel;

a first speaker for playing back the high frequency component extracted by the high frequency pass filter;

a low frequency pass filter for extracting a low frequency component from the sound signal in the main channel;

an adder that adds the low frequency component extracted by the low frequency pass filter to a sound signal in a channel exclusively used for a low frequency band to produce an addition signal; and

a second speaker for playing back the addition signal,

wherein a degree of the low frequency pass filter is set higher than a degree of the high frequency pass filter; and

wherein at least one of a phase of the high frequency component and a phase of the low frequency component is adjusted to match the phase of the high frequency component with the phase of the low frequency component.

20. The sound signal playback machine according to claim 19, wherein a group delay characteristic is obtained when a signal that includes the low frequency component is synthesized with a signal that includes the high frequency component, and

wherein the phase of the high frequency component is matched with the phase of the low frequency component such that the group delay characteristic is substantially flat.

21. The sound signal playback machine according to claim 19, further comprising a delay circuit that delays the high frequency component extracted by the high frequency pass filter to match the phase of the high frequency component with the phase of the low frequency component.

22. The sound signal playback machine according to claim 21, wherein a delay time T1 (sec) of the delay circuit is set at a value calculated by the equation of

$$T1=(\phi1-\phi2+\pi\cdot n)/(2\pi\cdot Fc)$$

(n=. . . −2, −1, 0, 1, 2 . . .)

where $\phi1$ (rad) is a phase angle at a cut-off frequency Fc (Hz) of the high frequency pass filter, and $\phi2$ (rad) is a phase angle of the low frequency pass filter.

23. The sound signal playback machine according to claim 19, further comprising an auxiliary phase matching circuit that matches the phase of the low frequency component extracted by the low frequency pass filter with a phase of the sound signal in the channel exclusively used for the low frequency band.

24. The sound signal playback machine according to claim 23, wherein the auxiliary phase matching circuit comprises a delay circuit that delays the sound signal in the channel exclusively used for the low frequency band so that the phase of the sound signal in the channel exclusively used for the low frequency band matches the phase of the low frequency component extracted by the low frequency pass filter.

25. The sound signal playback machine according to claim 19, further comprising a phase inversion circuit that inverts a phase of the low frequency component extracted by the low frequency pass filter when a difference between the phase of the low frequency component and the phase of the sound signal in the channel exclusively used for the low frequency is π (rad).

26. The sound signal playback machine according to claim 19, wherein the phase of the high frequency component is matched with the phase of the low frequency component by moving the first speaker away from a predetermined position of a listener by a particular distance.

27. The sound signal playback machine according to claim 26, wherein the particular distance corresponds to a delay time T1 (sec), which is set at a value calculated by the equation of

$$T1=(\phi1-\phi2+\pi\cdot m)/(2\pi\cdot Fc)$$

(n=. . . −2, −1, 0, 1, 2 . . .)

where $\phi1$ (rad) is a phase angle at a cut-off frequency Fc (Hz) of the high frequency pass filter, and $\phi2$ (rad) is a phase angle of the low frequency pass filter.

28. The sound signal playback machine according to claim 19, wherein the phase of the high frequency component is matched with the phase of the low frequency component by moving the second speaker towards a predetermined position of a listener by a particular distance.

29. The sound signal playback machine according to claim 28, further comprising a delay circuit,

wherein the phase of the high frequency component is matched with the phase of the low frequency component by (1) moving the second speaker towards the predetermined position by the particular distance and (2) delaying the addition signal played back by the second speaker.

30. The sound signal playback machine according to claim 29, wherein a difference between a delay time of the delay circuit and a delay time corresponding to the particular distance corresponds to a delay time T1 (sec), which is set at a value calculated by the equation of

$$T1=(\phi 1-\phi 2+\pi\cdot n)/(2\pi\cdot Fc)$$

(n=. . . −2, −1, 0, 1, 2 . . .)

where ϕ1 (rad) is a phase angle at a cut-off frequency Fc (Hz) of the high frequency pass filter, and ϕ2 (rad) is a phase angle of the low frequency pass filter.

31. The sound signal playback machine according to claim 19, further comprising:

a first delay circuit that delays the high frequency component based on a distance between the first speaker and a predetermined position of a listener; and

a second delay circuit that delays the high frequency component to match the phase of the high frequency component with the phase of the low frequency component.

32. The sound signal playback machine according to claim 31, further comprising:

a third delay circuit that delays the addition signal based on a distance between the second speaker and the predetermined position of the listener.

33. A sound signal processing machine comprising:

a high frequency pass filter for extracting a high frequency component from a sound signal in a main channel;

a low frequency pass filter for extracting a low frequency component from the sound signal in the main channel;

wherein a degree of the low frequency pass filter is set higher than a degree of the high frequency pass filter, and

wherein at least one of a phase of the high frequency component and a phase of the low frequency component is adjusted to match the phase of the high frequency component with the phase of the low frequency component.

34. The sound signal playback machine according to claim 33, wherein a group delay characteristic is obtained when a signal that includes the low frequency component is synthesized with a signal that includes the high frequency component, and

wherein the phase of the high frequency component is matched with the phase of the low frequency component such that the group delay characteristic is substantially flat.

35. The sound signal playback machine according to claim 33, further comprising a delay circuit that delays the high frequency component extracted by the high frequency pass filter to match the phase of the high frequency component with the phase of the low frequency component.

36. The sound signal processing machine according to claim 33, further comprising:

a signal adder that adds the low frequency component extracted by the low frequency pass filter to a sound signal in a channel exclusively used for a low frequency band.

37. The sound signal playback machine according to claim 35, wherein a delay time T1 (sec) of the delay circuit is set at a value calculated by the equation of

$$T1=(\phi 1-\phi 2+\pi\cdot n)/(2\pi\cdot Fc)$$

(n=. . . −2, −1, 0, 1, 2 . . .)

where ϕ1 (rad) is a phase angle at a cut-off frequency Fc (Hz) of the high frequency pass filter, and ϕ2 (rad) is a phase angle of the low frequency pass filter.

38. The sound signal playback machine according to claim 36, further comprising an auxiliary phase matching circuit that matches the phase of the low frequency component extracted by the low frequency pass filter with a phase of the sound signal in the channel exclusively used for the low frequency band.

39. The sound signal playback machine according to claim 38, wherein the auxiliary phase matching circuit comprises a delay circuit that delays the sound signal in the channel exclusively used for the low frequency band so that the phase of the sound signal in the channel exclusively used for the low frequency band matches the phase of the low frequency component extracted by the low frequency pass filter.

40. The sound signal playback machine according to claim 36, further comprising a phase inversion circuit that inverts a phase of the low frequency component extracted by the low frequency pass filter when a difference between the phase of the low frequency component and the phase of the sound signal in the channel exclusively used for the low frequency is π (rad).

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