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Enomoto et al.

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(45) Date of Patent: Aug. 19, 2025

(54) **SOUND PICKUP DEVICE**

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(73) Assignee: **PANASONIC INTELLECTUAL PROPERTY CORPORATION OF AMERICA**, Torrance, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 249 days.

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(22) Filed: **Apr. 21, 2023**

(65) **Prior Publication Data**

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Related U.S. Application Data

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(30) **Foreign Application Priority Data**

Nov. 10, 2020 (JP) 2020-187537

(51) **Int. Cl.**
H04R 1/08 (2006.01)

(52) **U.S. Cl.**
CPC ***H04R 1/08*** (2013.01); *H04R 2430/00* (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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WO	2020/166634	8/2020	

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Lloyd J. Griffiths, et al., "An Alternative Approach to Linearly Constrained Adaptive Beamforming", IEEE Transactions on Antennas and Propagation, vol. AP-30, No. 1, Jan. 1982, pp. 27-34.

* cited by examiner

Primary Examiner — Kenny H Truong
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(57) **ABSTRACT**

A sound pickup device includes microphone elements arranged three-dimensionally in a distributed manner. A total number of effective microphone pairs is greater than a total number of the microphone elements, the effective microphone pairs each being a combination of two microphone elements having a distance less than a distance D between each other. The distance D is represented by D=c/2f, where f represents a frequency of a target sound obtained from each of the microphone elements and c represents a velocity of the target sound. Any one of straight lines each of which connects the two microphone elements of a different one of the effective microphone pairs is not parallel to any other of the straight lines.

5 Claims, 23 Drawing Sheets

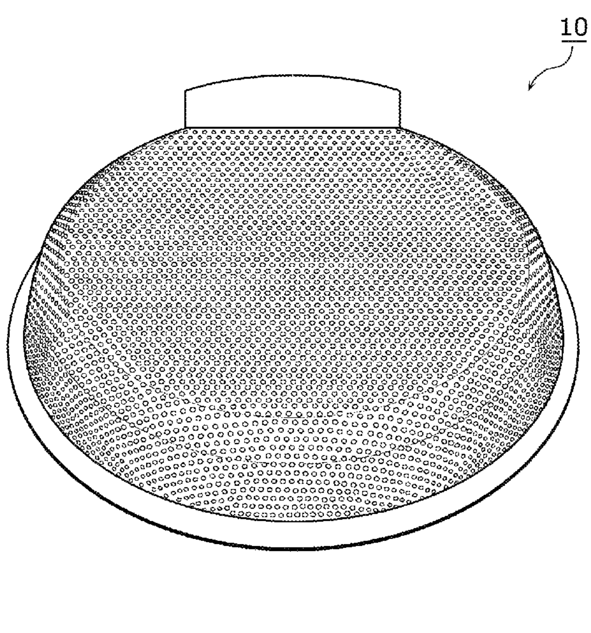


FIG. 1

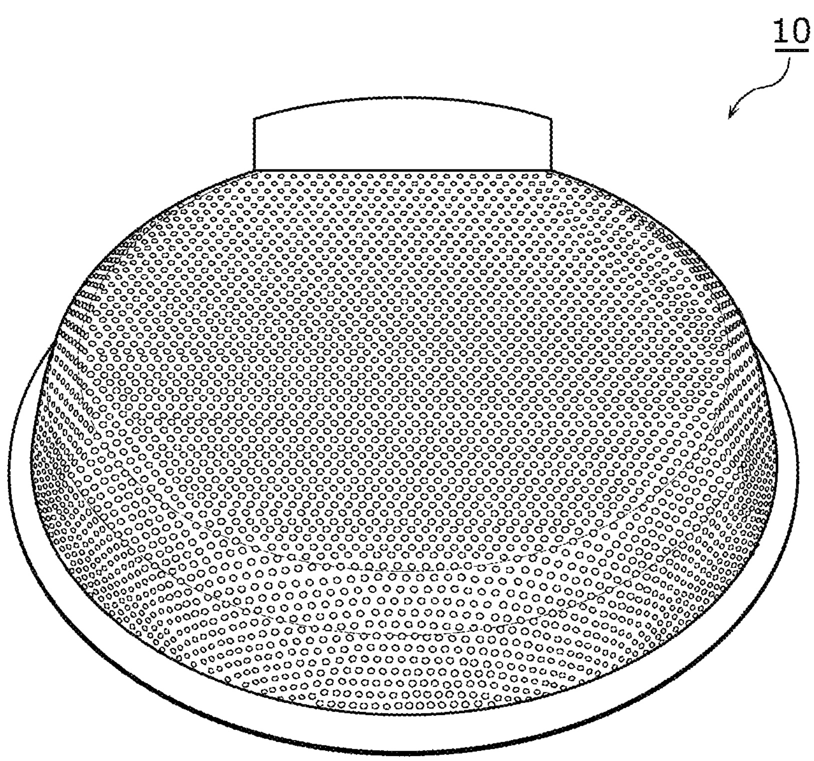


FIG. 2

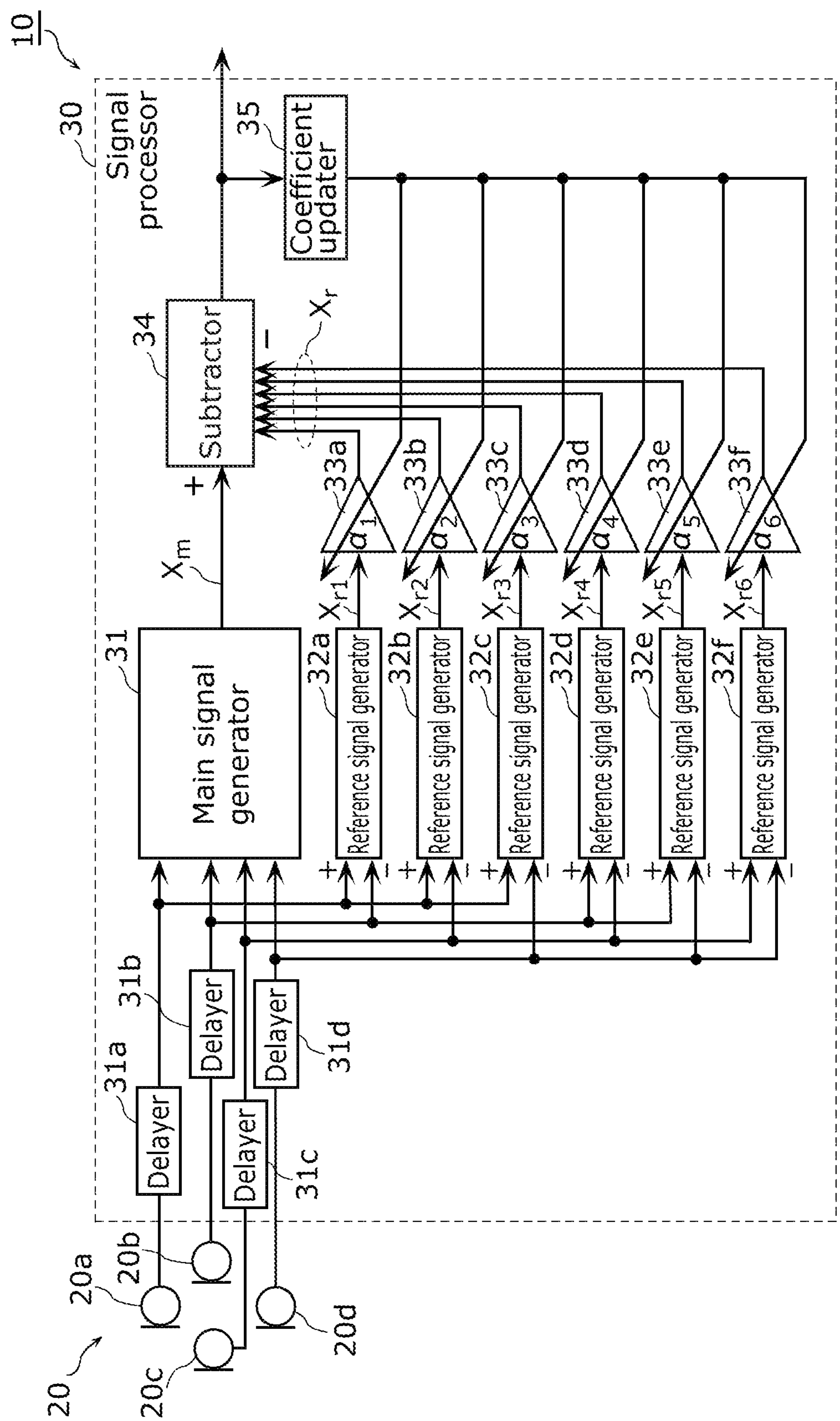

10
30
Signal processor
35
Coefficient updater
34
Subtractor
+
−
X_r
X_m
31
Main signal generator
32a
32b
32c
32d
32e
32f
Reference signal generator
Reference signal generator
Reference signal generator
Reference signal generator
Reference signal generator
Reference signal generator
33a
33b
33c
33d
33e
33f
α_1
α_2
α_3
α_4
α_5
α_6
X_{r1}
X_{r2}
X_{r3}
X_{r4}
X_{r5}
X_{r6}
31a
31b
31c
31d
Delayer
Delayer
Delayer
Delayer
20a
20b
20c
20d
20

FIG. 3

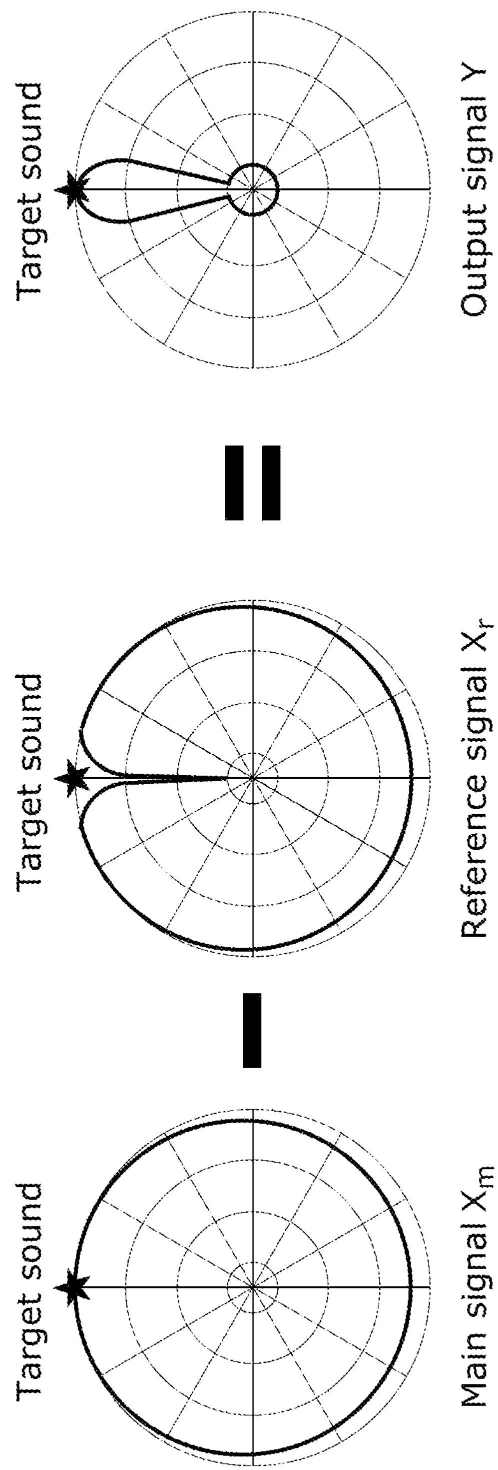

Target sound
Output signal Y
=
Target sound
Reference signal X_r
−
Target sound
Main signal X_m

FIG. 4

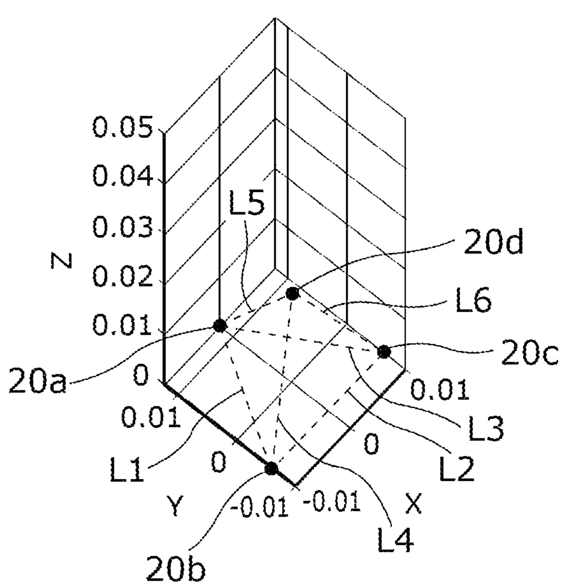
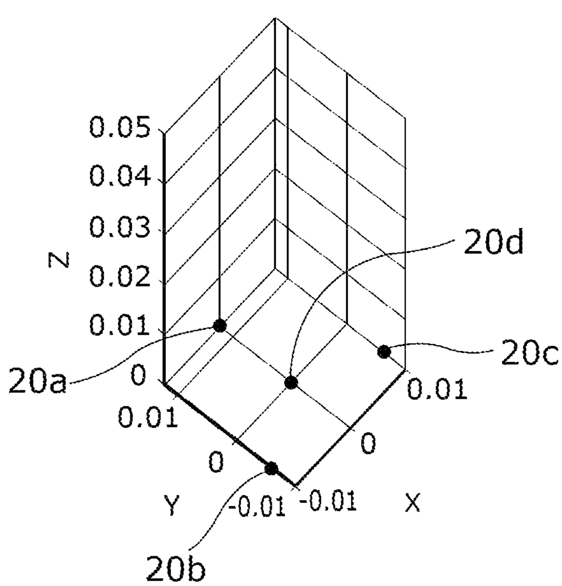
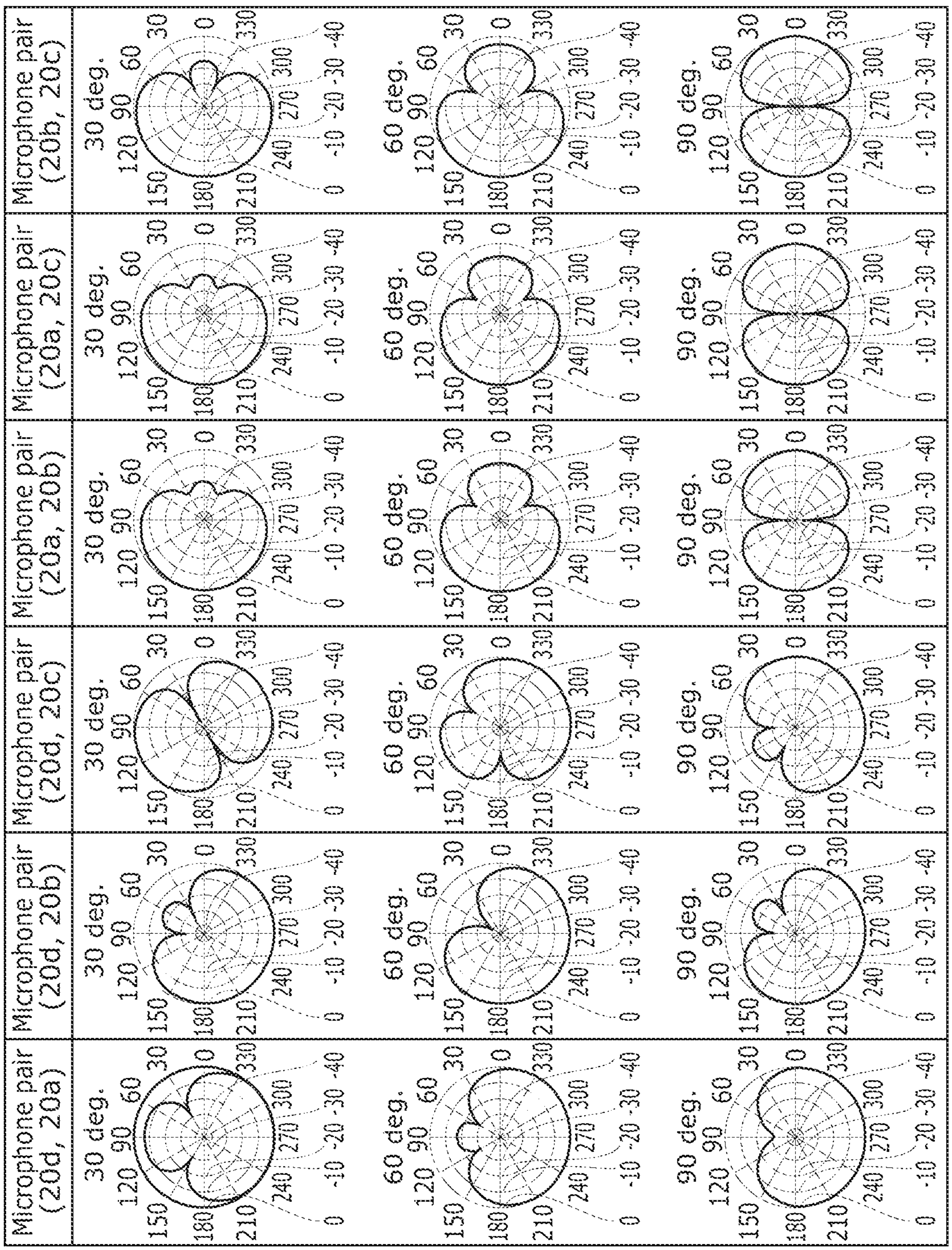

0.05
0.04
0.03
0.02
0.01
0
Z
L5
20d
L6
20c
20a
0.01
0.01
0
0
L1
L3
L2
Y
-0.01
-0.01
X
L4
20b

FIG. 5

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Microphone pair (20d, 20b)
Microphone pair (20d, 20c)
Microphone pair (20a, 20b)
Microphone pair (20a, 20c)
Microphone pair (20b, 20c)
30 deg.
60 deg.
90 deg.

FIG. 6

FIG. 7

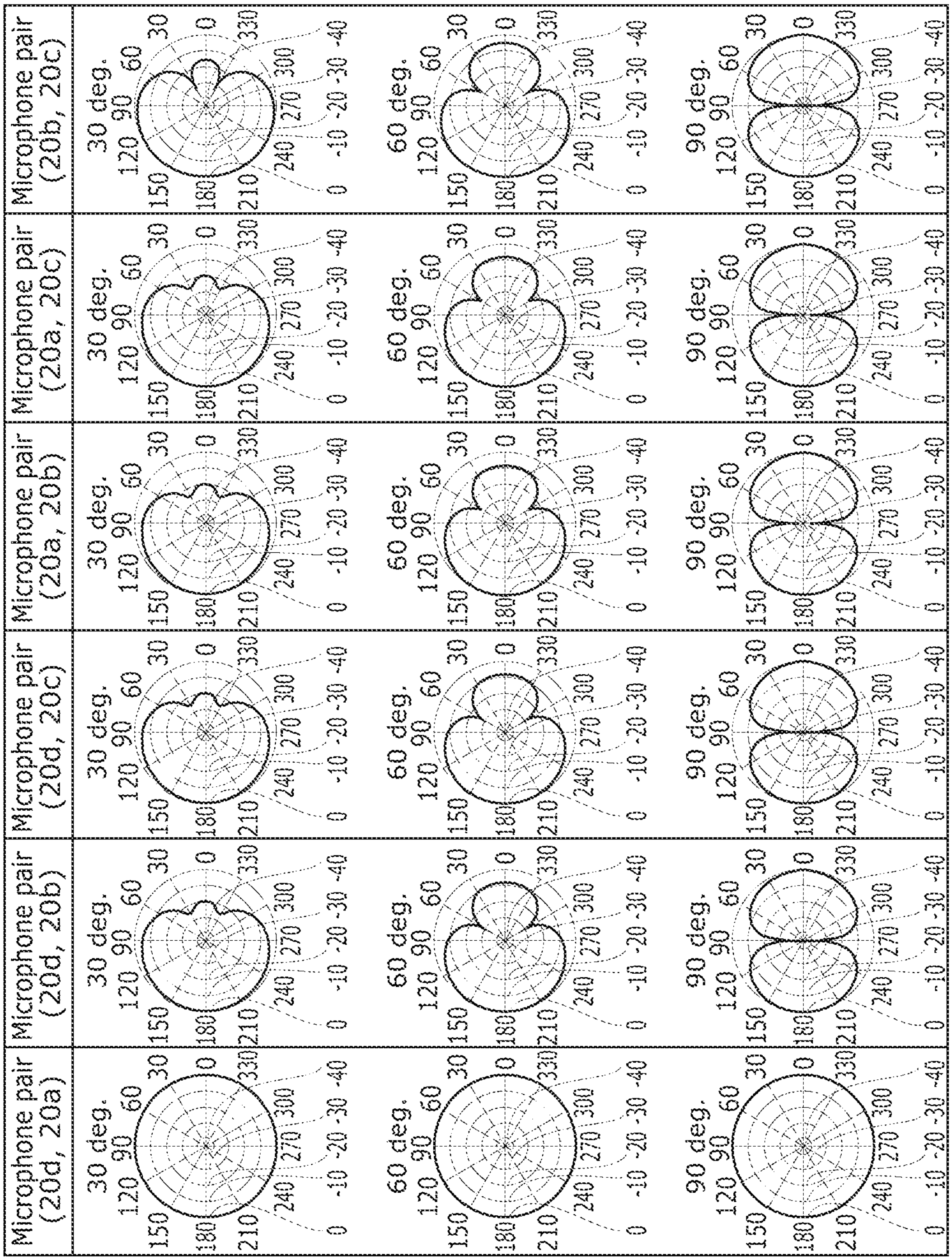

Microphone pair (20d, 20a)
Microphone pair (20d, 20b)
Microphone pair (20d, 20c)
Microphone pair (20a, 20b)
Microphone pair (20a, 20c)
Microphone pair (20b, 20c)
30 deg.
60 deg.
90 deg.
0
30
60
90
120
150
180
210
240
270
300
330
0 -10 -20 -30 -40

FIG. 8

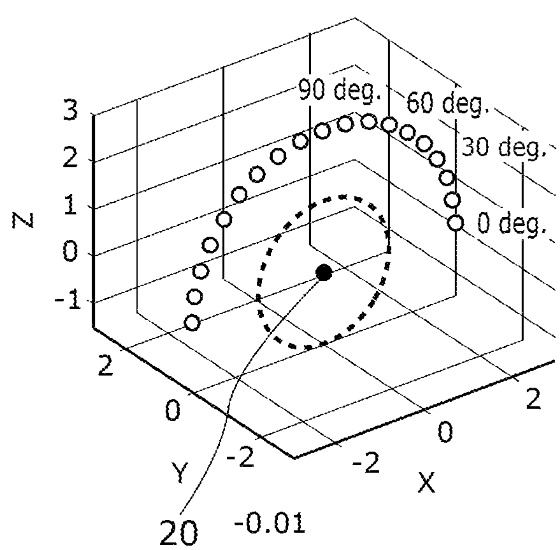


FIG. 9

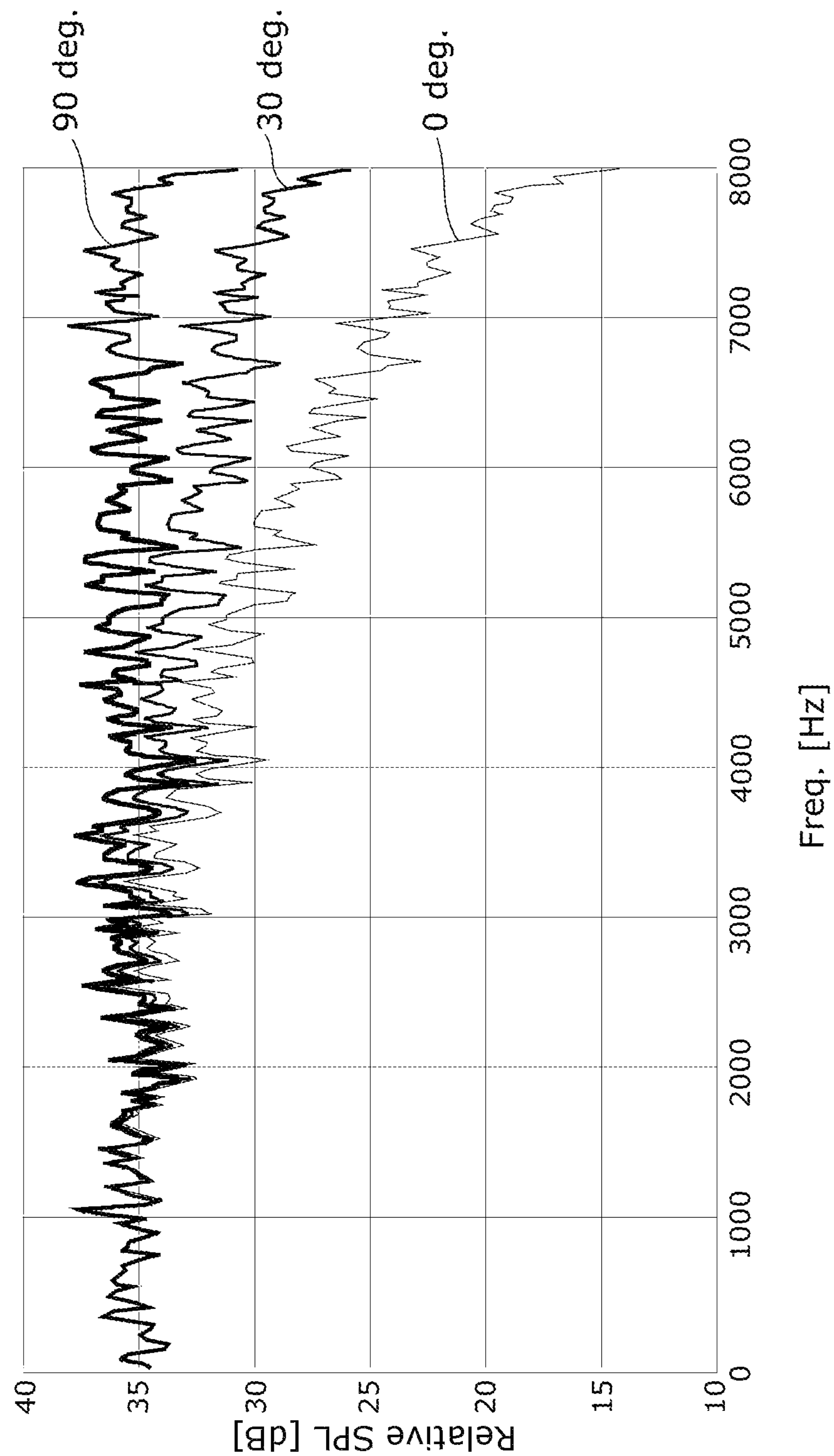

90 deg.
30 deg.
0 deg.
Relative SPL [dB]
40
35
30
25
20
15
10
Freq. [Hz]
0
1000
2000
3000
4000
5000
6000
7000
8000

FIG. 10

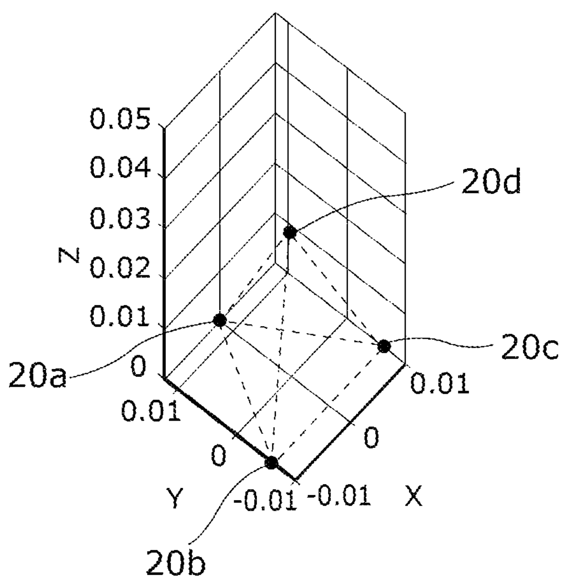


FIG. 11

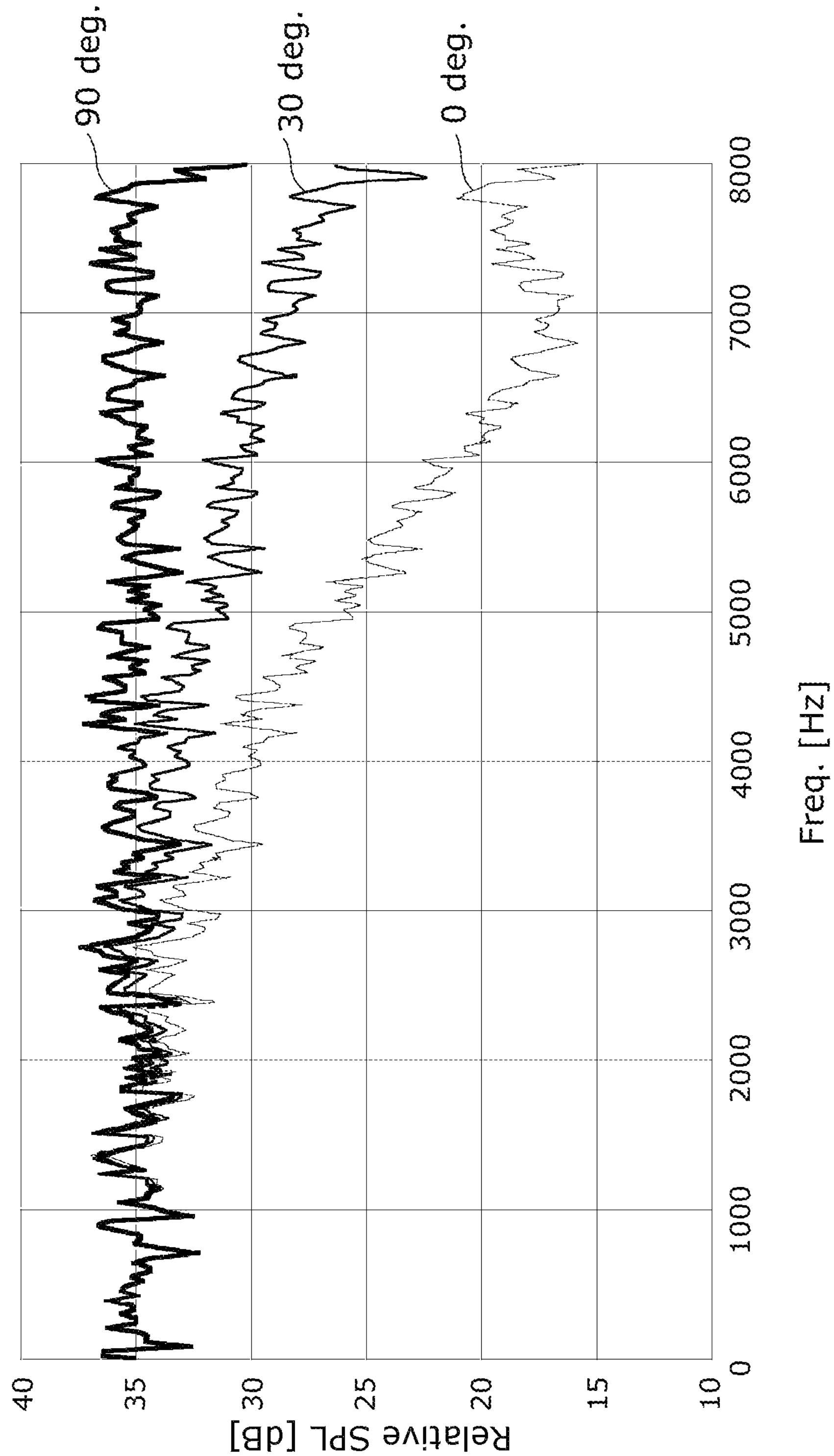

90 deg.
30 deg.
0 deg.
Relative SPL [dB]
40
35
30
25
20
15
10
Freq. [Hz]
0
1000
2000
3000
4000
5000
6000
7000
8000

FIG. 12

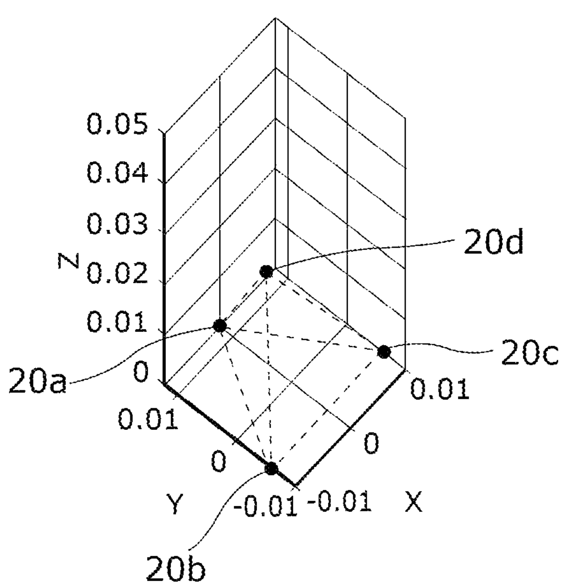


FIG. 13

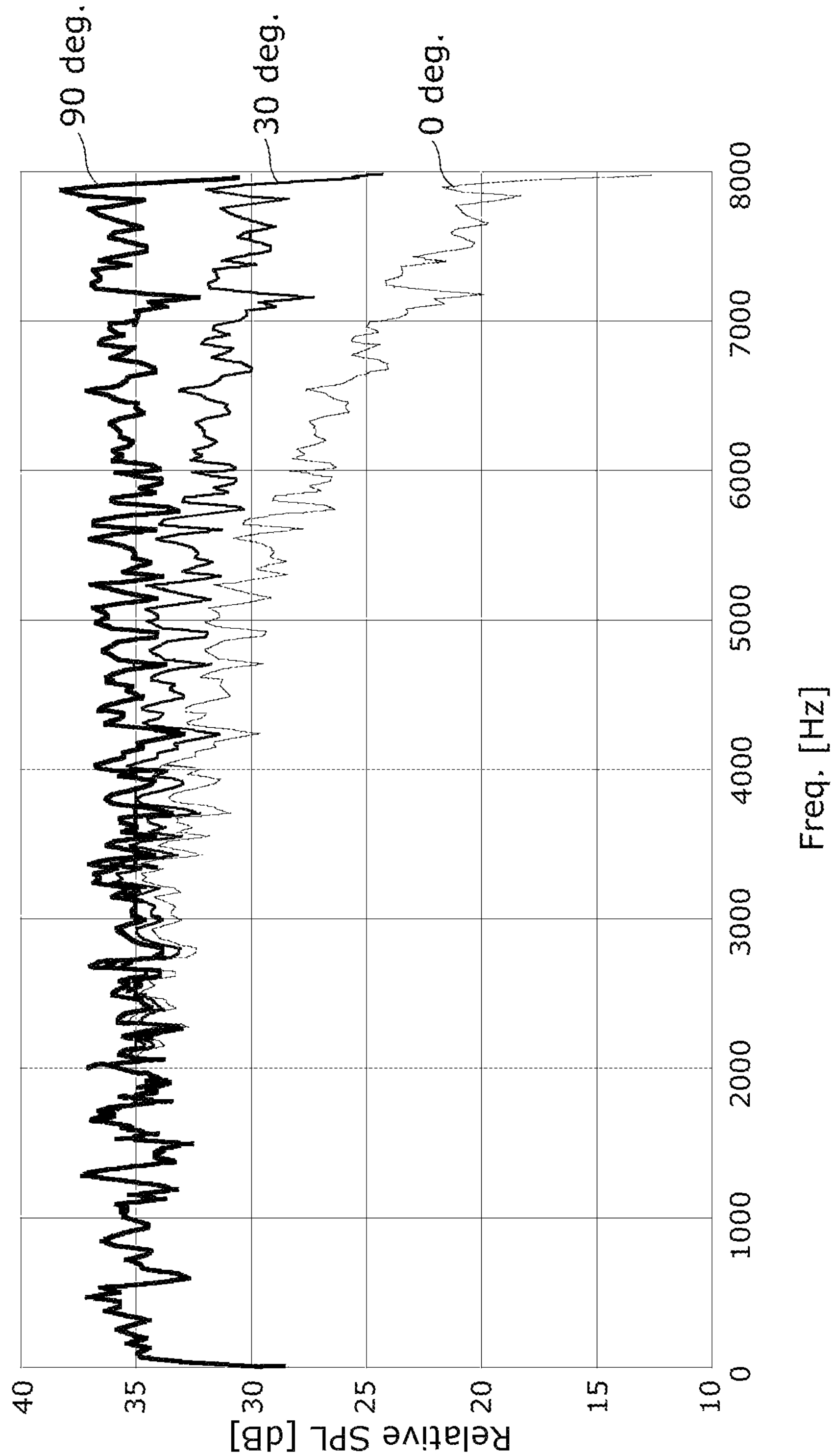

90 deg.
30 deg.
0 deg.
Relative SPL [dB]
40
35
30
25
20
15
10
0
1000
2000
3000
4000
5000
6000
7000
8000
Freq. [Hz]

FIG. 14

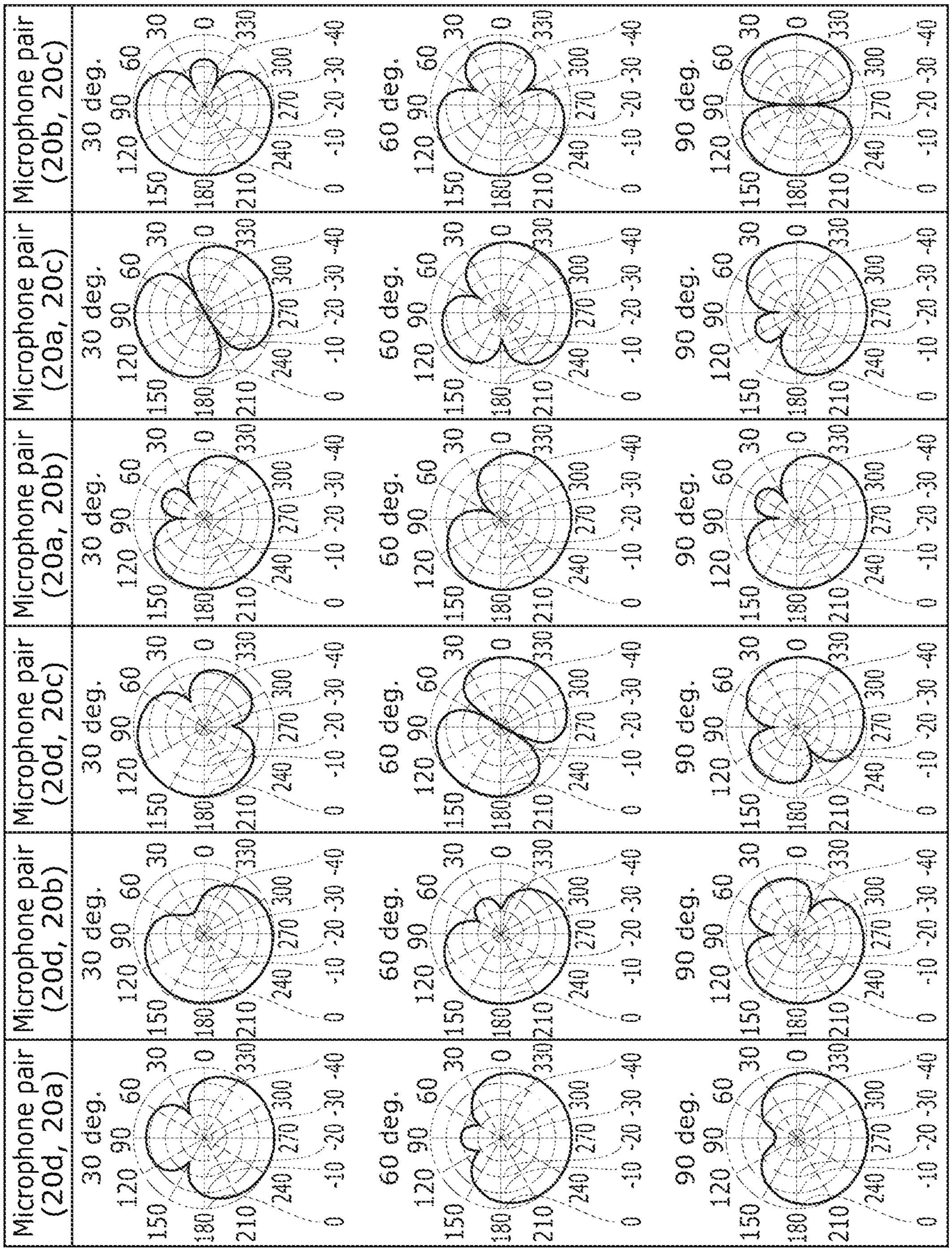
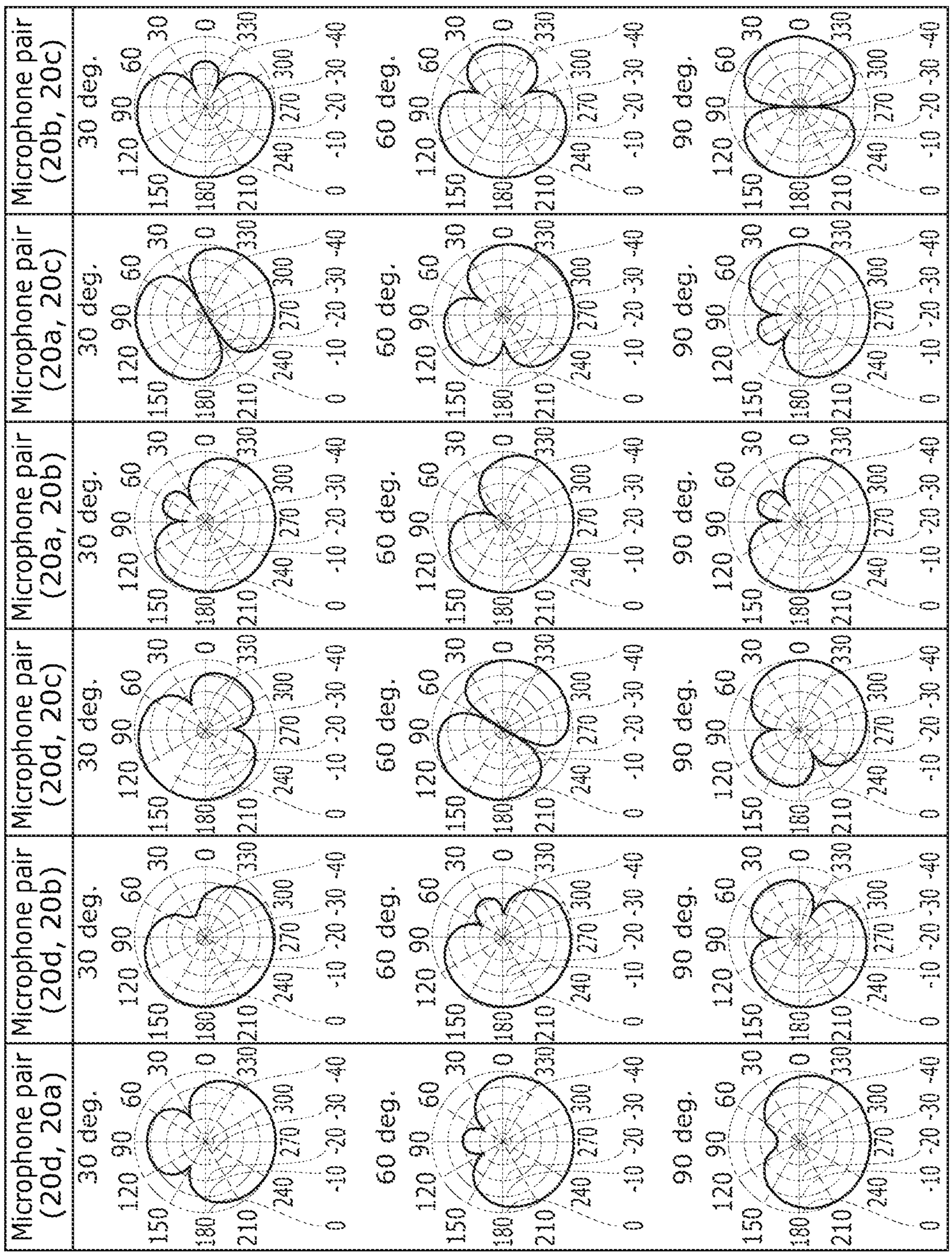

Microphone pair (20d, 20a)
Microphone pair (20d, 20b)
Microphone pair (20d, 20c)
Microphone pair (20a, 20b)
Microphone pair (20a, 20c)
Microphone pair (20b, 20c)
30 deg.
60 deg.
90 deg.
0 30 60 90 120 150 180 210 240 270 300 330
0 -10 -20 -30 -40

FIG. 15



Microphone pair (20d, 20a)
Microphone pair (20d, 20b)
Microphone pair (20d, 20c)
Microphone pair (20a, 20b)
Microphone pair (20a, 20c)
Microphone pair (20b, 20c)
30 deg.
60 deg.
90 deg.

FIG. 16

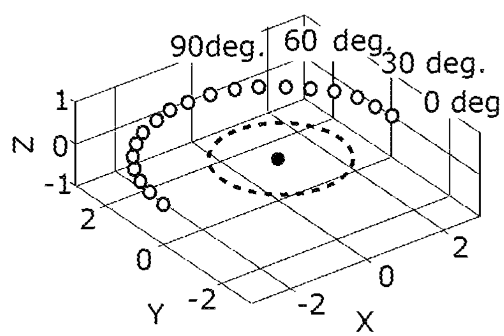


FIG. 17

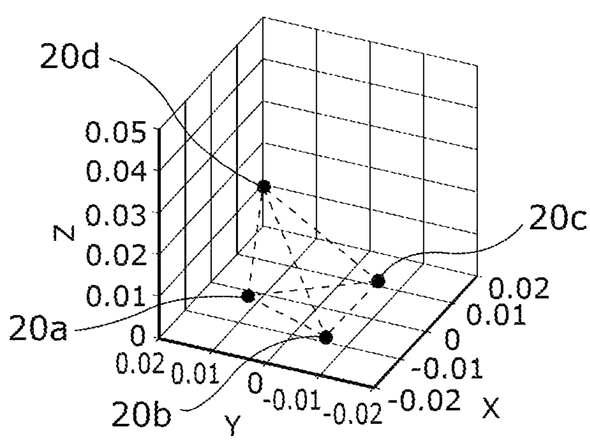

20d
0.05
0.04
0.03
Z
0.02
0.01
0
20c
20a
0.02
0.01
0
-0.01
-0.02
X
0.02
0.01
0
-0.01
-0.02
20b
Y

FIG. 18

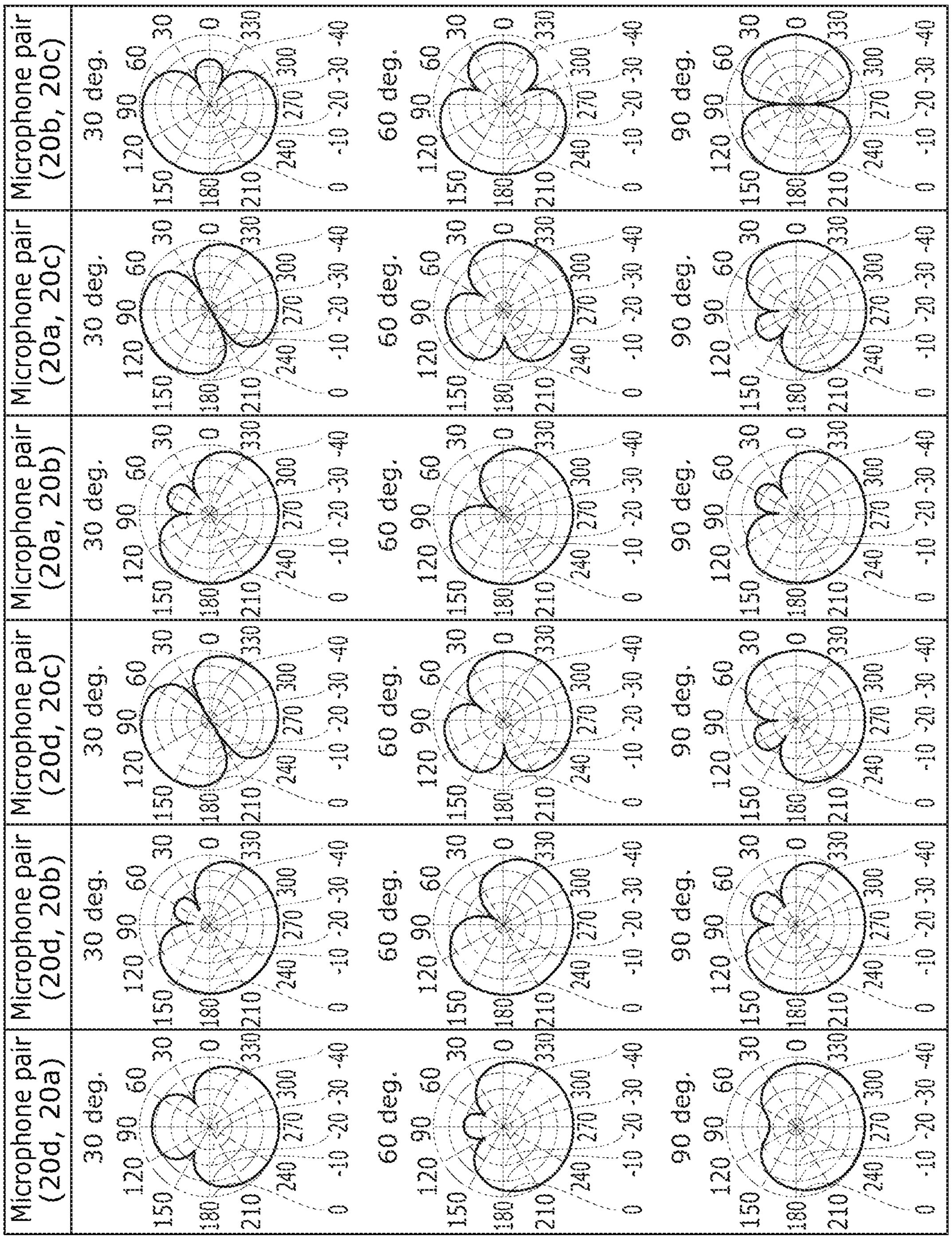

Microphone pair (20d, 20a)
Microphone pair (20d, 20b)
Microphone pair (20d, 20c)
Microphone pair (20a, 20b)
Microphone pair (20a, 20c)
Microphone pair (20b, 20c)
30 deg.
60 deg.
90 deg.

FIG. 19

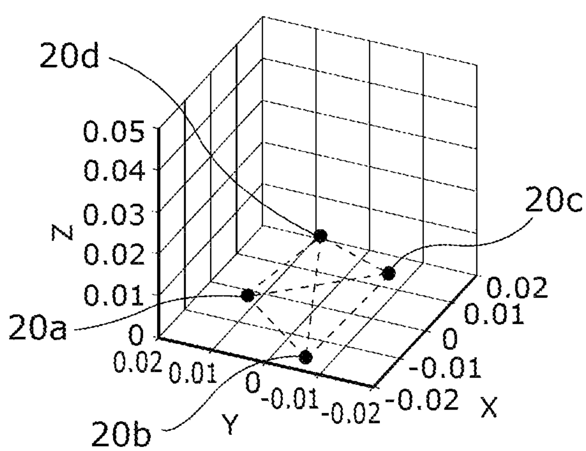

20d
0.05
0.04
0.03
Z
0.02
0.01
0
20a
20c
0.02
0.01
0
-0.01
-0.02
X
0.02
0.01
0
-0.01
-0.02
Y
20b

FIG. 20

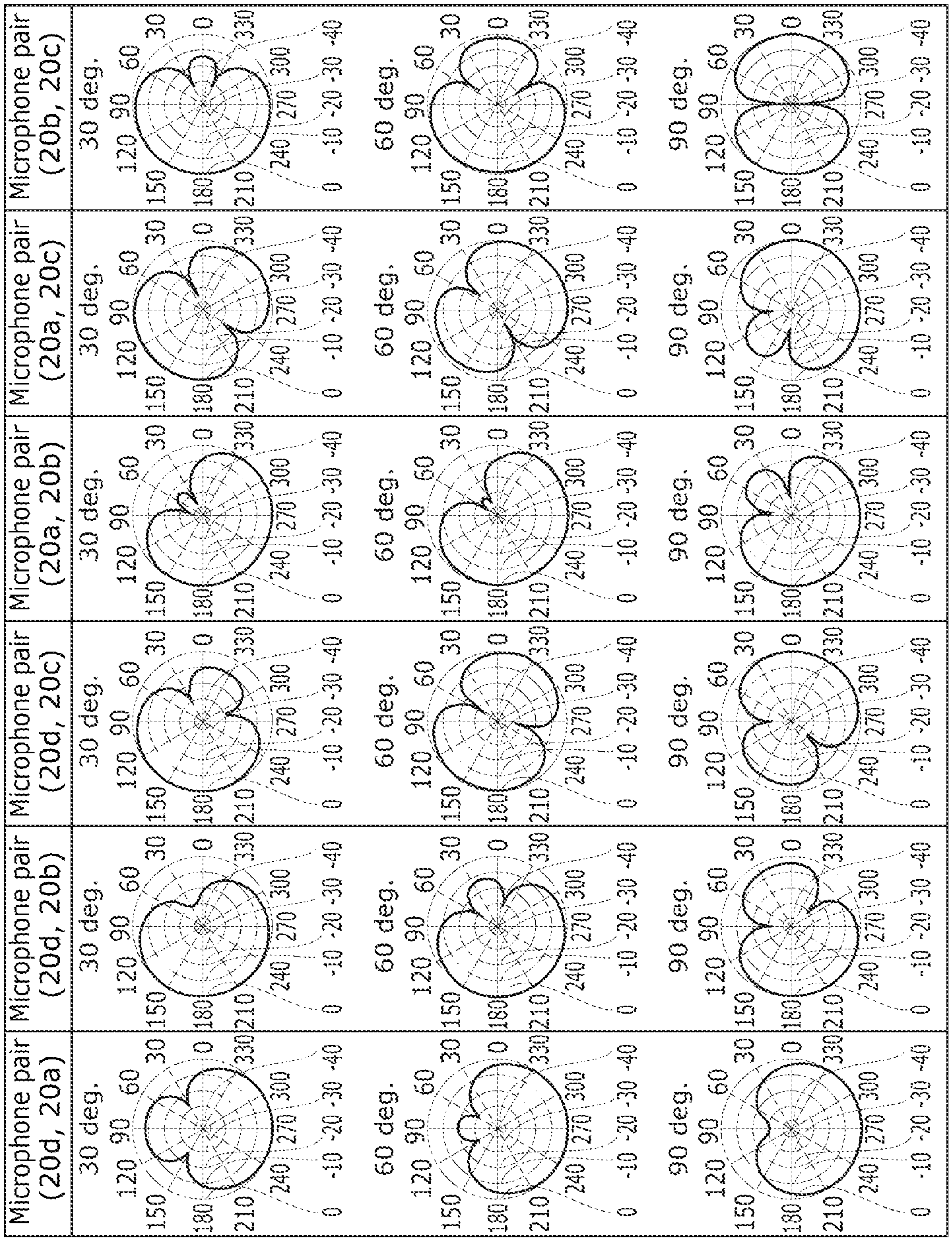

Microphone pair (20d, 20a)
Microphone pair (20d, 20b)
Microphone pair (20d, 20c)
Microphone pair (20a, 20b)
Microphone pair (20a, 20c)
Microphone pair (20b, 20c)
30 deg.
60 deg.
90 deg.

FIG. 21

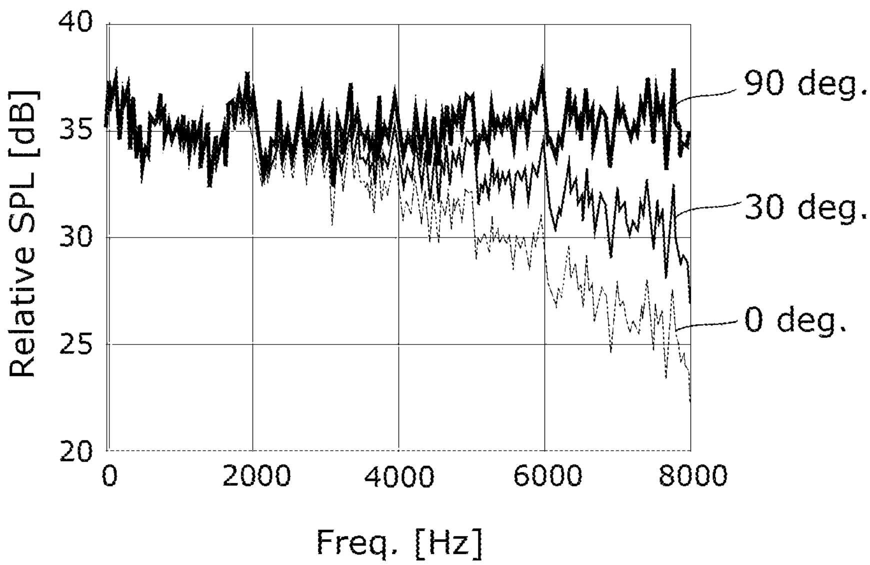

40
35
30
25
20
Relative SPL [dB]
0
2000
4000
6000
8000
Freq. [Hz]
90 deg.
30 deg.
0 deg.

FIG. 22

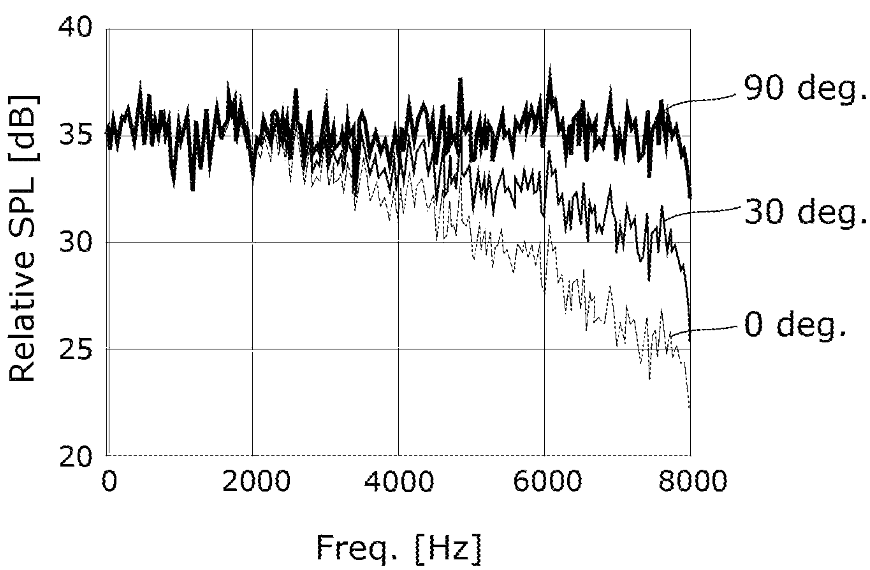

40
35
30
25
20
Relative SPL [dB]
0
2000
4000
6000
8000
Freq. [Hz]
90 deg.
30 deg.
0 deg.

FIG. 23

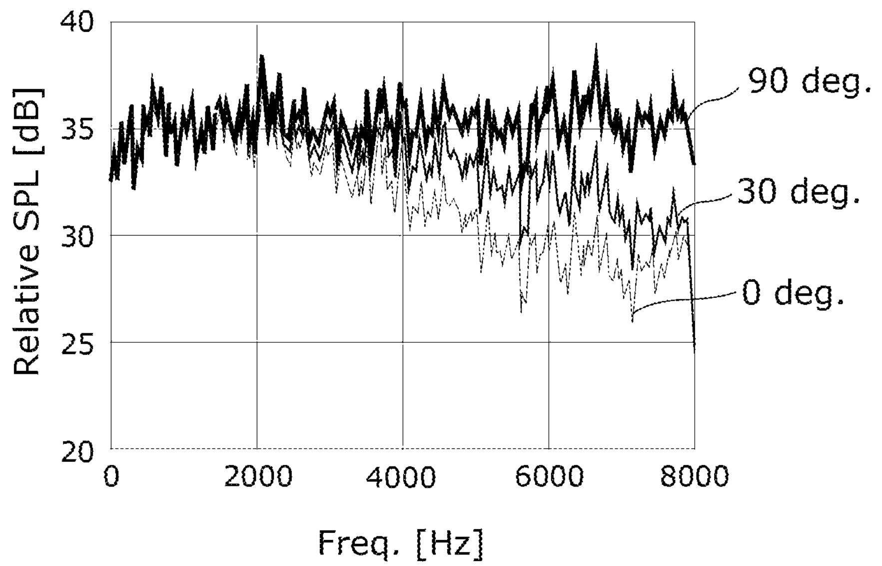

40
35
30
25
20
Relative SPL [dB]
0
2000
4000
6000
8000
Freq. [Hz]
90 deg.
30 deg.
0 deg.

FIG. 24

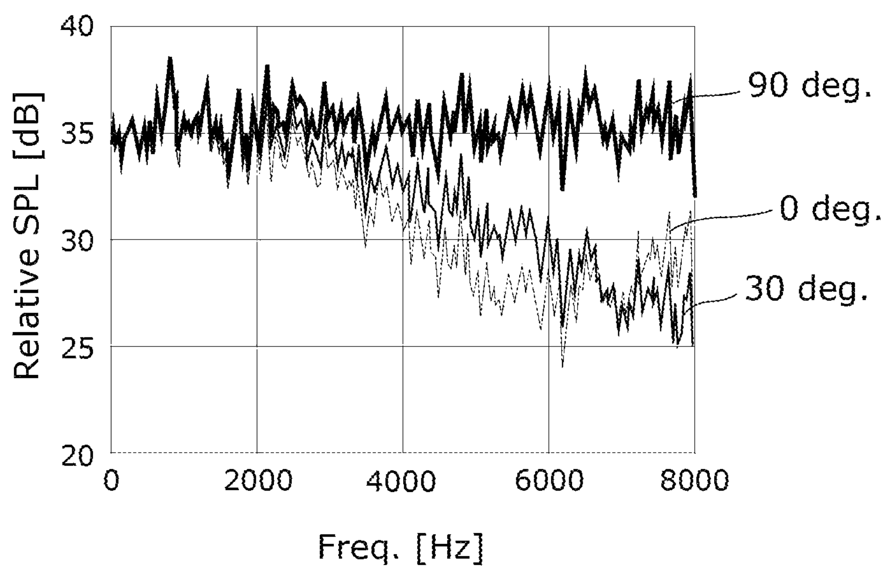

40
35
30
25
20
Relative SPL [dB]
0
2000
4000
6000
8000
Freq. [Hz]
90 deg.
0 deg.
30 deg.

FIG. 25

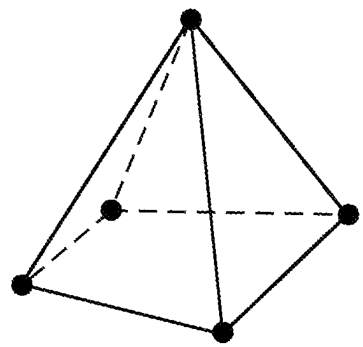
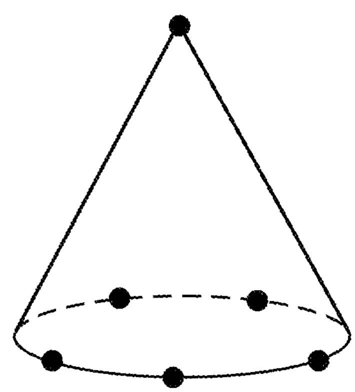


FIG. 26



SOUND PICKUP DEVICE

CROSS REFERENCE TO RELATED APPLICATIONS

This is a continuation application of PCT International Application No. PCT/JP2021/037473 filed on Oct. 8, 2021, designating the United States of America, which is based on and claims priority of Japanese Patent Application No. 2020-187537 filed on Nov. 10, 2020. The entire disclosures of the above-identified applications, including the specifications, drawings and claims are incorporated herein by reference in their entirety.

FIELD

The present disclosure relates to a sound pickup device for beamforming.

BACKGROUND

Beamforming is a technique of generating a signal emphasizing a sound from a target sound direction by using sound signals obtained from microphone elements. Non-Patent Literature (NPL) 1 discloses a generalized sidelobe canceller (GSC) as an example of a beamformer using adaptive filters.

CITATION LIST

Non-Patent Literature

NPL1: L. Griffiths and C. W. Jim, “An alternative approach to linearly constrained adaptive beamforming”, IEEE Trans. Antennas Propagation, vol. AP-30, pp 27-34, January 1982.

SUMMARY

Technical Problem

The present disclosure provides a sound pickup device that effectively reduces sound other than a target sound.

Solution to Problem

A sound pickup device according to an aspect of the present disclosure includes a plurality of microphone elements that are arranged three-dimensionally in a distributed manner, wherein among microphone pairs each of which is a different combination of two microphone elements of the plurality of microphone elements, a total number of effective microphone pairs is greater than a total number of the plurality of microphone elements, the effective microphone pairs each being a combination of two microphone elements having a distance less than a distance D between each other, the distance D is represented by D=c/2f, where f represents a frequency of a target sound obtained from the plurality of microphone elements and c represents a velocity of the target sound, and any one of straight lines each of which connects the two microphone elements of a different one of the effective microphone pairs is not parallel to any other of the straight lines.

Advantageous Effects

A sound pickup device according to an aspect of the present disclosure can effectively reduce sound other than a target sound.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is an external perspective view of a sound pickup device according to an embodiment.

FIG. **2** is a block diagram illustrating a functional configuration of the sound pickup device according to the embodiment.

FIG. **3** is a diagram schematically illustrating a calculation formula of an output signal based on sensitivity characteristics of a main signal, a reference signal, and the output signal.

FIG. **4** is a diagram illustrating three-dimensional arrangement example **1** of microphone elements.

FIG. **5** is a diagram illustrating a planar arrangement example of microphone elements.

FIG. **6** is a diagram illustrating sensitivity characteristics, in a direction along an XZ plane, of reference signals that are generated by a sound pickup device employing three-dimensional arrangement example **1**.

FIG. **7** is a diagram illustrating sensitivity characteristics, in the direction along the XZ plane, of reference signals that are generated by a sound pickup device employing the planar arrangement example.

FIG. **8** is a diagram for describing a method for calculating sensitivity characteristics shown in FIG. **6** and FIG. **7**.

FIG. **9** is a diagram illustrating frequency responses of a main signal that is generated by the sound pickup device employing three-dimensional arrangement example **1** and of which the target sound direction is a 90° direction along the XZ plane.

FIG. **10** is a diagram illustrating three-dimensional arrangement example **2** of microphone elements.

FIG. **11** is a diagram illustrating frequency responses of a main signal that is generated by a sound pickup device employing three-dimensional arrangement example **2** and of which the target sound direction is the 90° direction along the XZ plane.

FIG. **12** is a diagram illustrating three-dimensional arrangement example **3** of microphone elements.

FIG. **13** is a diagram illustrating frequency responses of a main signal that is generated by a sound pickup device employing three-dimensional arrangement example **3** and of which the target sound direction is the 90° direction along the XZ plane.

FIG. **14** is a diagram illustrating sensitivity characteristics, in a direction along an XY plane, of reference signals that are generated by the sound pickup device employing three-dimensional arrangement example **1**.

FIG. **15** is a diagram illustrating sensitivity characteristics, in the direction along the XY plane, of reference signals that are generated by the sound pickup device employing the planar arrangement example.

FIG. **16** is a diagram for describing a method for calculating sensitivity characteristics shown in FIG. **14** and FIG. **15**.

FIG. **17** is a diagram illustrating three-dimensional arrangement example **4** of microphone elements.

FIG. **18** is a diagram illustrating sensitivity characteristics, in the direction along the XY plane, of reference signals that are generated by a sound pickup device employing three-dimensional arrangement example **4**.

FIG. **19** is a diagram illustrating three-dimensional arrangement example **5** of microphone elements.

FIG. **20** is a diagram illustrating sensitivity characteristics, in the direction along the XY plane, of reference signals that are generated by a sound pickup device employing three-dimensional arrangement example **5**.

FIG. **21** is a diagram illustrating frequency responses of a main signal that is generated by the sound pickup device employing the planar arrangement example and of which the target sound direction is a 90° direction along the XY plane.

FIG. **22** is a diagram illustrating frequency responses of a main signal that is generated by the sound pickup device employing three-dimensional arrangement example **1** and of which the target sound direction is the 90° direction along the XY plane.

FIG. **23** is a diagram illustrating frequency responses of a main signal that is generated by the sound pickup device employing three-dimensional arrangement example **4** and of which the target sound direction is the 90° direction along the XY plane.

FIG. **24** is a diagram illustrating frequency responses of a main signal that is generated by the sound pickup device employing three-dimensional arrangement example **5** and of which the target sound direction is the 90° direction along the XY plane.

FIG. **25** is a diagram illustrating an example where microphone elements are arranged at the vertices of a quadrangular pyramid.

FIG. **26** is a diagram illustrating an example where microphone elements are arranged at the apex and the circumference of the bottom of a cone.

DESCRIPTION OF EMBODIMENT

Hereinafter, an embodiment will be described with reference to the Drawings. The embodiment described below shows a general or specific example. The numerical values, shapes, materials, constituent elements, the arrangement and connection of the constituent elements, etc. shown in the embodiment below are mere examples, and therefore do not limit the scope of the present disclosure. Moreover, among the constituent elements in the embodiment below, constituent elements not recited in any one of the independent claims defining the broadest concept are described as arbitrary constituent elements.

Furthermore, the Drawings are schematic drawings and are not necessarily precise depictions. Furthermore, elements that are essentially the same share the same reference signs in the respective Drawings, and overlapping explanations thereof may be omitted or simplified.

Furthermore, in the embodiment below, when a sound from a certain direction is a main target to be output by a sound pickup device, the certain direction is referred to as a target sound direction and the sound is referred to as a target sound. Furthermore, sound other than the target sound may be referred to as noise.

Embodiment

(Configuration of Sound Pickup Device)

Hereinafter, a configuration of a sound pickup device according to an embodiment will be described with reference to FIG. **1** and FIG. **2**. FIG. **1** is an external perspective view of the sound pickup device according to the embodiment. FIG. **2** is a block diagram illustrating a functional configuration of the sound pickup device according to the embodiment.

As illustrated in FIG. **1**, sound pickup device **10** according to the embodiment is a substantially disk-shaped device. For example, sound pickup device **10** is placed on a desk and used for picking up voice during a teleconference or the like. It should be noted that the shape of sound pickup device **10** is not limited to a substantially disk shape. As illustrated in FIG. **2**, sound pickup device **10** includes microphone elements **20***a* to **20***d* and signal processor **30**, inside the body as illustrated in FIG. **1**. Microphone elements **20***a* to **20***d* constitute microphone array **20**. It should be noted that sound pickup device **10** does not necessarily include signal processor **30**, and signal processor **30** may be implemented as a separate device from sound pickup device **10**.

Microphone elements **20***a* to **20***d* constitute microphone array for generating main signal X_m and reference signals X_{r1} to X_{r6} that are used for beamforming. In other words, microphone elements **20***a* to **20***d* are used for enabling signal processor **30** that is a beamformer to obtain sound signals. Microphone elements **20***a* to **20***d* are arranged on the same plane. Although sound pickup device includes four microphone elements **20***a* to **20***d* in the embodiment, the total number of microphone elements is not particularly limited to this example. The total number of microphone elements may be an even number or an odd number. For example, sound pickup device **10** may include four or more microphone elements.

Signal processor **30** is a beamformer that performs beamforming using sound signals obtained from microphone elements **20***a* to **20***d*. Beamforming by signal processor **30** is signal processing for forming a directivity so that sensitivity to a target sound direction is ensured and noise is at a dead angle. In other words, according to beamforming by signal processor **30**, noise coming from any direction other than the target sound direction is reduced. Although each of microphone elements **20***a* to **20***d* is an omnidirectional microphone element, sound pickup device **10** achieves high sensitivity to the target sound direction through beamforming by signal processor **30**.

More specifically, signal processor **30** has a configuration similar to that of a generalized sidelobe canceller. For example, signal processor **30** is implemented as a processor such as a digital signal processor (DSP) but may also be implemented as a microcomputer or a circuit. Moreover, signal processor **30** may be implemented as a combination of two or more of a processor, a microcomputer, and a circuit. Signal processor **30** includes delayers **31***a* to **31***d*, main signal generator **31**, reference signal generators **32***a* to **32***f*, adaptive filters **33***a* to **33***f*, subtractor **34**, and coefficient updater **35**.

Delayers **31***a* to **31***d* correspond one-to-one to sound signals obtained from microphone elements **20***a* to **20***d*. Delayers **31***a* to **31***d* delay the sound signals obtained from microphone elements **20***a* to **20***d* according to the target sound direction, and output the delayed sound signals as output signals.

Main signal generator **31** is an example of a first signal generator, and generates main signal X_m by adding up sound signals that have been obtained from microphone elements **20***a* to **20***d* and delayed by delayers **31***a* to **31***d*, respectively, according to the target sound direction. Main signal X_m is an example of a first signal.

Each of reference signal generators **32***a* to **32***f* is an example of a second signal generator. Reference signal generators **32***a* to **32***f* correspond one-to-one to six microphone pairs each of which is a different combination of two microphone elements of microphone elements **20***a* to **20***d*. One reference signal generator generates a reference signal by performing subtraction between two sound signals that have been obtained from two microphone elements of a corresponding one of the microphone pairs and delayed by corresponding two of delayers **31**a to **31**d according to the target sound direction. Each of reference signals X_{r1} to X_{r6} is an example of a second signal.

Moreover, adaptive filters **33**a to **33**f correspond one-to-one to reference signal generators **32**a to **32**f. Adaptive filters **33**a to **33**f apply filter coefficients α_1 to α_6 to reference signals X_{r1} to X_{r6} generated by reference signal generators **32**a to **32**f, respectively.

For example, reference signal generator **32**a generates reference signal X_{r1} by performing subtraction between sound signals (output signals from delayers **31**a and **31**b) that have been obtained from microphone elements **20**a and **20**b and delayed by delayers **31**a and **31**b, respectively, according to the target sound direction. Adaptive filter **33**a applies filter coefficient α_1 to reference signal X_{r1}.

Similarly, reference signal generator **32**b generates reference signal X_{r2} by performing subtraction between sound signals (output signals from delayers **31**a and **31**c) that have been obtained from microphone elements **20**a and **20**c and delayed by delayers **31**a and **31**c, respectively, according to the target sound direction. Adaptive filter **33**b applies filter coefficient α_2 to reference signal X_{r2}.

Reference signal generator **32**c generates reference signal X_{r3} by performing subtraction between sound signals (output signals from delayers **31**a and **31**d) that have been obtained from microphone elements **20**a and **20**d and delayed by delayers **31**a and **31**d, respectively, according to the target sound direction. Adaptive filter **33**c applies filter coefficient α_3 to reference signal X_{r3}.

Reference signal generator **32**d generates reference signal X_{r4} by performing subtraction between sound signals (output signals from delayers **31**b and **31**c) that have been obtained from microphone elements **20**b and **20**c and delayed by delayers **31**b and **31**c, respectively, according to the target sound direction. Adaptive filter **33**d applies filter coefficient α_4 to reference signal X_{r4}.

Reference signal generator **32**e generates reference signal X_{r5} by performing subtraction between sound signals (output signals from delayers **31**b and **31**d) that have been obtained from microphone elements **20**b and **20**d and delayed by delayers **31**b and **31**d, respectively, according to the target sound direction. Adaptive filter **33**e applies filter coefficient α_5 to reference signal X_{r5}.

Reference signal generator **32**f generates reference signal X_{r6} by performing subtraction between sound signals (output signals from delayers **31**c and **31**d) that have been obtained from microphone elements **20**c and **20**d and delayed by delayers **31**c and **31**d, respectively, according to the target sound direction. Adaptive filter **33**f applies filter coefficient α_6 to reference signal X_{r6}.

Subtractor **34** subtracts, from main signal X_m generated, reference signals X_{r1} to X_{r6} to which filter coefficients α_1 to α_6 have been applied. Output signal Y obtained by the subtraction is represented by Formula 1 below. Output signal Y is an example of a third signal. In Formula 1, n represents the number of microphone pairs. Accordingly, n is a natural number, and n is six (n=6) in sound pickup device **10**.

(Math. 1)

$$Y=X_m-\sum_{k=1}^{n}\alpha_k X_{rk} \quad \text{(Formula 1)}$$

Coefficient updater **35** updates filter coefficients α_1 to α_6, based on output signal Y obtained through the subtraction by subtractor **34**.

FIG. **3** is a diagram schematically illustrating Formula 1 based on sensitivity characteristics of main signal X_m, reference signal X_r, and output signal Y. It should be noted that reference signal X_r represents the total of reference signals X_{r1} to X_{r6} to which filter coefficients α_1 to α_6 have been applied ($\alpha_1X_{r1}+\alpha_2X_{r2}+\alpha_3X_{r3}+\alpha_4X_{r4}+\alpha_5X_{r5}+\alpha_6X_{r6}$). The sensitivity characteristic is, in other words, directivity.

As illustrated in FIG. **3**, main signal X_m has high sensitivity to all directions. In contrast, reference signal X_r has low sensitivity to the target sound direction due to adaptive filters **33**a to **33**f and coefficient updater **35**. Accordingly, output signal Y that is obtained by subtracting reference signal X_r from main signal X_m has high sensitivity to the target sound direction. It should be noted that the target sound direction is, in other words, a beam direction.

(Arrangement of Microphone Elements)

In sound pickup device **10**, signal processor **30** can change a beam direction in output signal Y. For example, sound pickup device includes a user interface such as a touch screen or an operation button, and signal processor **30** changes the beam direction based on operation by a user through the user interface. Alternatively, signal processor **30** automatically changes the beam direction by detecting a sound volume or the like.

When signal processor **30** performs beamforming with a variable beam direction as above, sensitivity to directions other than the beam direction needs to be reduced as much as possible in output signal Y, whichever direction the beam direction is. Therefore, in sound pickup device **10**, the arrangement of microphone elements **20**a to **20**d is determined in order to ensure such performance.

First, in sound pickup device **10**, the total number of effective microphone pairs is greater than the total number of microphone elements **20**a to **20**d. Here, among microphone pairs each of which is a different combination of two microphone elements of microphone elements **20**a to **20**d, an effective microphone pair is a microphone pair in which a distance between the two microphone elements is less than distance D. Distance D is represented by D=c/2f, where f represents a frequency of a target sound obtained from microphone elements **20**a to **20**d and c represents a velocity of the target sound. In sound pickup device **10**, the total number of the effective microphone pairs is six and the total number of the microphone elements is four.

It should be noted that distance D varies depending on the frequency of the target sound. For example, when the frequency of the target sound is 8 kHz and the velocity of the target sound is c=34000 cm/s, distance D is 2.125 cm. Moreover, when the frequency of the target sound is 4 kHz and the velocity of the target sound is c=34000 cm/s, distance D is 4.25 cm.

In some cases, a reference signal that is calculated using a noneffective microphone pair in which the distance between the two microphone elements is greater than or equal to distance D does not have a sensitivity characteristic that is assumed from the arrangement of the noneffective microphone pair, due to occurrence of aliasing in signal processing or the like. In other words, a reference signal that is calculated using the noneffective microphone pair may have an unexpected sensitivity characteristic, and therefore generation of highly accurate output signal Y may be hindered. In sound pickup device **10**, generation of highly accurate output signal Y is achieved since the total number of the effective microphone pairs is greater than the total number of microphone elements **20**a to **20**d.

It should be noted that all of the microphone pairs obtainable from microphone elements **20**a to **20**d are the effective microphone pairs in sound pickup device **10**. Accordingly, the total number of the microphone pairs obtainable from microphone elements **20***a* to **20***d* is equal to the total number of the effective microphone pairs. However, there may be a case where some of the microphone pairs obtainable from microphone elements **20***a* to **20***d* are not the effective microphone pairs.

Moreover, microphone elements **20***a* to **20***d* are arranged three-dimensionally in a distributed manner. FIG. **4** is a diagram illustrating three-dimensional arrangement example **1** of microphone elements **20***a* to **20***d*. In FIG. **4**, the unit of the numerical values shown on the X-axis, the Y-axis, and the Z-axis is meter.

In three-dimensional arrangement example **1** in FIG. **4**, microphone elements **20***a* to **20***d* are arranged at the vertices of a regular tetrahedron with a side length of approximately 2.1 cm (0.021 in the coordinates in FIG. **4**). Specifically, microphone elements **20***a* to **20***c* are located on the XY plane where Z=0. The coordinates of microphone element **20***d* are (0, 0, Z1, where Z1=approximately 0.0171) and microphone element **20***d* is located on the positive side of the Z-axis direction with respect to the XY plane where Z=0. It should be noted that the side length of 2.1 cm of the regular tetrahedron is determined assuming a half wave length of a frequency of 8 kHz.

In three-dimensional arrangement example **1**, any one of straight lines each of which connects the two microphone elements of a different one of the effective microphone pairs is not parallel to any other of the straight lines. Specifically, in FIG. **4**, straight line (line segment) L**1** illustrated by a broken line is not parallel to any other straight lines L**2** to L**6**. The same applies to straight lines L**2** to L**6**. In other words, all of the straight lines each of which connects the two microphone elements of a different one of the effective microphone pairs are not parallel to one another.

(Sensitivity Characteristic of Reference Signal **1**)

As illustrated in FIG. **4**, when microphone elements **20***a* to **20***d* are arranged three-dimensionally in a distributed manner, variations of sensitivity characteristics of reference signals are increased as compared to when microphone elements **20***a* to **20***d* are arranged on the same plane. Hereinafter, sensitivity characteristics of reference signals achieved by three-dimensional arrangement example **1** will be described. First, a planar arrangement example, which is to be compared with three-dimensional arrangement example **1**, will be described. FIG. **5** is a diagram illustrating the planar arrangement example of microphone elements **20***a* to **20***d*. In FIG. **5**, the unit of the numerical values shown on the X-axis, the Y-axis, and the Z-axis is meter.

In the planar arrangement example in FIG. **5**, microphone elements **20***a* to **20***d* are located on the XY plane where Z=0. Specifically, the arrangement of microphone elements **20***a* to **20***c* is the same as that in three-dimensional arrangement example **1** but microphone element **20***d* has coordinates of (0, 0, 0). Accordingly, microphone elements **20***a* to **20***d* are arranged on the same plane in the planar arrangement example.

FIG. **6** is a diagram illustrating sensitivity characteristics, in a direction along the XZ plane, of reference signals that are generated by sound pickup device **10** employing three-dimensional arrangement example **1**. FIG. **7** is a diagram illustrating sensitivity characteristics, in the direction along the XZ plane, of reference signals that are generated by sound pickup device **10** employing the planar arrangement example. FIG. **8** is a diagram for describing a method for calculating sensitivity characteristics shown in FIG. **6** and FIG. **7**. In FIG. **8**, the unit of the numerical values shown on the X-axis, the Y-axis, and the Z-axis is meter.

In each of FIG. **6** and FIG. **7**, each of six columns shows sensitivity characteristics of a reference signal generated using a microphone pair. It should be noted that the sensitivity characteristic is, in other words, a directivity pattern.

For example, in each of FIG. **6** and FIG. **7**, the leftmost column among the six columns shows sensitivity characteristics of a reference signal (corresponding to reference signal X_{r3} in FIG. **2**) that is generated using a microphone pair of microphone element **20***d* and microphone element **20***a*. The second column from the left shows sensitivity characteristics of a reference signal (corresponding to reference signal X_{r5} in FIG. **2**) that is generated using a microphone pair of microphone element **20***d* and microphone element **20***b*. The third column from the left shows sensitivity characteristics of a reference signal (corresponding to reference signal X_{r6} in FIG. **2**) that is generated using a microphone pair of microphone element **20***d* and microphone element **20***c*.

The fourth column from the left shows sensitivity characteristics of a reference signal (corresponding to reference signal X_{r1} in FIG. **2**) that is generated using a microphone pair of microphone element **20***a* and microphone element **20***b*. The fifth column from the left shows sensitivity characteristics of a reference signal (corresponding to reference signal X_{r2} in FIG. **2**) that is generated using a microphone pair of microphone element **20***a* and microphone element **20***c*. The sixth column from the left shows sensitivity characteristics of a reference signal (corresponding to reference signal X_{r4} in FIG. **2**) that is generated using a microphone pair of microphone element **20***b* and microphone element **20***c*.

Three sensitivity characteristics are illustrated in each of the six columns. The three sensitivity characteristics include a sensitivity characteristic of the reference signal that has a dead angle in a 90° direction, a sensitivity characteristic of the reference signal that has a dead angle in a 60° direction, and a sensitivity characteristic of the reference signal that has a dead angle in a 30° direction. Here, as illustrated by white circles in FIG. **8**, the 90° direction is the positive Z-axis direction, and the 60° direction is a direction shifted by 30° from the positive Z-axis direction along the XZ plane. The 30° direction is a direction shifted by 60° from the positive Z-axis direction along the XZ plane. It should be noted that, as illustrated by a broken line in FIG. **8**, the sensitivity characteristics shown in FIG. **6** and FIG. **7** are sensitivity characteristics for a sound at a position (illustrated by the broken line in FIG. **8**) 1.5 m away from microphone array **20** (a collection of microphone elements **20***a* to **20***d*).

As described above with reference to FIG. **4** and FIG. **5**, only the position of microphone element **20***d* is different between three-dimensional arrangement example **1** and the planar arrangement example. Accordingly, as shown in the three columns in the right half of each of FIG. **6** and FIG. **7**, sensitivity characteristics achieved by microphone pairs each of which is a different combination of two of microphone elements **20***a* to **20***c* are not different between three-dimensional arrangement example **1** and the planar arrangement example.

In contrast, as shown in the three columns in the left half of each of FIG. **6** and FIG. **7**, sensitivity characteristics of microphone pairs each of which includes microphone element **20***d* are more varied in three-dimensional arrangement example **1** (FIG. **6**) than in the planar arrangement example (FIG. **7**). In other words, when microphone elements **20***a* to **20***d* are arranged three-dimensionally in a distributed manner, variations of sensitivity characteristics of reference signals can be increased as compared to when microphone elements **20**_a_ to **20**_d_ are arranged on the same plane. Wide variations of sensitivity characteristics are advantageous for a noise reduction algorithm based on a generalized sidelobe canceller, which is executed by signal processor **30**. When variations of sensitivity characteristics of reference signals are increased, sound pickup device **10** can reduce noise from various directions. Accordingly, sound pickup device **10** can effectively reduce sound other than a target sound.

(Frequency Response of Main Signal **1**)

Next, frequency responses, in a direction along the XZ plane, of a main signal that is generated by sound pickup device **10** employing three-dimensional arrangement example **1** will be described. FIG. **9** is a diagram illustrating frequency responses of a main signal of which the target sound direction is the 90° direction along the XZ plane. In FIG. **9**, a frequency response in the 90° direction, a frequency response in the 30° direction, and a frequency response in a 0° direction of the main signal are illustrated, and the target sound direction of the main signal is the 90° direction. In FIG. **9**, the vertical axis indicates sound pressure level (SPL) and the horizontal axis indicates frequency.

As illustrated in FIG. **9**, in the frequency response in the 90° direction of the main signal of which the target sound direction is the 90° direction, the sound pressure level is generally flat in a frequency band of from 0 to 8 kHz. In contrast, in the frequency response in the 30° direction of the main signal, the sound pressure level is attenuated in a high frequency band. Moreover, in the frequency response in the 0° direction of the main signal, the sound pressure level is further attenuated in the high frequency band than that in the frequency response in the 30° direction of the main signal.

As above, sound pickup device **10** employing three-dimensional arrangement example **1** can generate a main signal having a directivity in a target sound direction (90° direction).

Here, the inventors attempted to improve the directivity of the main signal by adjusting the position of microphone element **20**_d_ in three-dimensional arrangement example **1**. Specifically, the inventors have calculated frequency responses of a main signal in each of three-dimensional arrangement example **2** and three-dimensional arrangement example **3**.

First, three-dimensional arrangement example **2** will be described. FIG. **10** is a diagram illustrating three-dimensional arrangement example **2** of microphone elements **20**_a_ to **20**_d_. FIG. **11** is a diagram illustrating frequency responses of a main signal that is generated by sound pickup device **10** employing three-dimensional arrangement example **2** and of which the target sound direction is the 90° direction along the XZ plane. In FIG. **11**, a frequency response in the 90° direction, a frequency response in the 30° direction, and a frequency response in the 0° direction of the main signal are illustrated, and the target sound direction of the main signal is the 90° direction. In FIG. **11**, the vertical axis indicates sound pressure level and the horizontal axis indicates frequency.

In three-dimensional arrangement example **2** in FIG. **10**, the arrangement of microphone elements **20**_a_ to **20**_c_ is the same as that in three-dimensional arrangement example **1**. Microphone element **20**_d_ is located on the positive side of the Z-axis direction with respect to the position of microphone element **20**_d_ in three-dimensional arrangement example **1**, and the coordinates of microphone element **20**_d_ are (0, 0, 1.5×Z1). In other words, in three-dimensional arrangement example **2**, the position (height) of microphone element **20**_d_ with respect to the XY plane is 1.5 times higher than that in three-dimensional arrangement example **1**. It should be noted that, in three-dimensional arrangement example **2**, each of the distance between microphone element **20**_d_ and microphone element **20**_a_, the distance between microphone element **20**_d_ and **20**_b_, and the distance between microphone element **20**_d_ and **20**_c_ is approximately 2.9 cm (0.029 in the coordinates in FIG. **10**).

In FIG. **11**, the main signal is generated by sound pickup device **10** employing three-dimensional arrangement example **2**, and the target sound direction of the main signal is the 90° direction. As illustrated in FIG. **11**, in the frequency response in the 90° direction of the main signal, the sound pressure level is generally flat in a frequency band of from 0 to 8 kHz. In the frequency response in the 30° direction of the main signal when three-dimensional arrangement example **2** is employed, the sound pressure level is attenuated in a high frequency band; however, the frequency at which the sound pressure level starts to be attenuated is lower than the frequency at which the sound pressure level starts to be attenuated when three-dimensional arrangement example **1** is employed. Similarly, in the frequency response in the 0° direction of the main signal when three-dimensional arrangement example **2** is employed, the sound pressure level is attenuated in the high frequency band; however, the frequency at which the sound pressure level starts to be attenuated is lower than the frequency at which the sound pressure level starts to be attenuated when three-dimensional arrangement example **1** is employed. Accordingly, sound pickup device **10** employing three-dimensional arrangement example **2** can generate a main signal of which the sound pressure level in a direction other than the target sound direction starts to be attenuated at a frequency lower than the frequency at which the sound pressure level starts to be attenuated in three-dimensional arrangement example **1**. In other words, sound pickup device **10** employing three-dimensional arrangement example **2** can generate a main signal having a sharp directivity especially in a high frequency band.

Next, three-dimensional arrangement example **3** will be described. FIG. **12** is a diagram illustrating three-dimensional arrangement example **3** of microphone elements **20**_a_ to **20**_d_. FIG. **13** is a diagram illustrating frequency responses of a main signal that is generated by sound pickup device **10** employing three-dimensional arrangement example **3** and of which the target sound direction is the 90° direction along the XZ plane. In FIG. **13**, a frequency response in the 90° direction, a frequency response in the 30° direction, and a frequency response in the 0° direction of the main signal are illustrated, and the target sound direction of the main signal is the 90° direction. In FIG. **13**, the vertical axis indicates sound pressure level and the horizontal axis indicates frequency.

In three-dimensional arrangement example **3** in FIG. **12**, the arrangement of microphone elements **20**_a_ to **20**_c_ is the same as that in three-dimensional arrangement example **1**. Microphone element **20**_d_ is located on the positive side of the Y-axis direction with respect to the position of microphone element **20**_d_ in three-dimensional arrangement example **1**, and the coordinates of microphone element **20**_d_ are (0, Y1, Z1). In three-dimensional arrangement example **3**, the distance between microphone element **20**_d_ and microphone element **20**_a_ is approximately 1.9 cm (0.019 in the coordinates in FIG. **12**). In three-dimensional arrangement example **3**, each of the distance between microphone element **20**_d_ and microphone element **20**_b_ and the distance between microphone element **20***d* and microphone element **20***c* is approximately 2.3 cm (0.023 in the coordinates in FIG. **12**).

In FIG. **13**, the main signal is generated by sound pickup device **10** employing three-dimensional arrangement example **3**, and the target sound direction of the main signal is the 90° direction. As illustrated in FIG. **13**, the frequency response in the 90° direction, the frequency response in the 30° direction, and the frequency response in the 0° direction of the main signal are similar to those in three-dimensional arrangement example **1**. In other words, sound pickup device **10** employing three-dimensional arrangement example **3** can generate a main signal having a directivity in a target sound direction (90° direction).

(Sensitivity Characteristic of Reference Signal **2**)

In FIG. **6** and FIG. **7**, sensitivity characteristics in a direction along the XZ plane have been described, whereas sensitivity characteristics in a direction along the XY plane will be described below. FIG. **14** is a diagram illustrating sensitivity characteristics, in the direction along the XY plane, of reference signals that are generated by sound pickup device **10** employing three-dimensional arrangement example **1**. FIG. **15** is a diagram illustrating sensitivity characteristics, in the direction along the XY plane, of reference signals that are generated by sound pickup device **10** employing the planar arrangement example. FIG. **16** is a diagram for describing a method for calculating sensitivity characteristics shown in FIG. **14** and FIG. **15**. In FIG. **16**, the unit of the numerical values shown on the X-axis, the Y-axis, and the Z-axis is meter.

In FIG. **14** and FIG. **15**, the sensitivity characteristics of the reference signals are shown in the same format as those in FIG. **6** and FIG. **7**. Here, as illustrated by white circles in FIG. **16**, a 90° direction is the positive Y-axis direction, and a 60° direction is a direction shifted by 30° from the positive Y-axis direction along the XY plane. A 30° direction is a direction shifted by 60° from the positive Y-axis direction along the XY plane. It should be noted that, as illustrated by a broken line in FIG. **16**, the sensitivity characteristics shown in FIG. **14** and FIG. **15** are sensitivity characteristics for a sound at a position (illustrated by the broken line in FIG. **16**) 1.5 m away from microphone array **20** (a collection of microphone elements **20***a* to **20***d*).

As described above with reference to FIG. **4** and FIG. **5**, only the position of microphone element **20***d* is different between three-dimensional arrangement example **1** and the planar arrangement example. Accordingly, as shown in the three columns in the right half of each of FIG. **14** and FIG. **15**, sensitivity characteristics achieved by microphone pairs each of which is a different combination of two of microphone elements **20***a* to **20***c* are not different between three-dimensional arrangement example **1** and the planar arrangement example.

Moreover, as shown in the three columns in the left half of each of FIG. **14** and FIG. **15**, sensitivity characteristics of microphone pairs each of which includes microphone element **20***d* are similar between three-dimensional arrangement example **1** and the planar arrangement example. Accordingly, it can be said that even when microphone elements **20***a* to **20***d* are arranged three-dimensionally in a distributed manner, variations of sensitivity characteristics of reference signals are not decreased as compared to when microphone elements **20***a* to **20***d* are arranged on the same plane. In other words, it can be said that when microphone elements **20***a* to **20***d* are arranged three-dimensionally in a distributed manner, performance of microphone elements **20***a* to **20***d* is not deteriorated as compared to when microphone elements **20***a* to **20***d* are arranged on the same plane.

Here, the inventors have checked how sensitivity characteristics of reference signals are changed by adjusting the position of microphone element **20***d* in three-dimensional arrangement example **1**. Specifically, the inventors have calculated sensitivity characteristics of reference signals in three-dimensional arrangement example **4** and three-dimensional arrangement example **5** below.

First, three-dimensional arrangement example **4** will be described. FIG. **17** is a diagram illustrating three-dimensional arrangement example **4** of microphone elements **20***a* to **20***d*. FIG. **18** is a diagram illustrating sensitivity characteristics, in the direction along the XY plane, of reference signals that are generated by sound pickup device **10** employing three-dimensional arrangement example **4**.

In three-dimensional arrangement example **4** in FIG. **17**, the arrangement of microphone elements **20***a* to **20***c* is the same as that in three-dimensional arrangement example **1**. The position of microphone element **20***d* is shifted in both the Y-axis direction and the Z-axis direction from the position of microphone element **20***d* in three-dimensional arrangement example **1**. It should be noted that, the position of microphone element **20***d* does not overlap with any positions of microphone elements **20***a* to **20***c*, as viewed from the Z-axis direction. In other words, microphone element **20***d* is not located directly above any of microphone elements **20***a* to **20***c*.

Only the position of microphone element **20***d* is different between three-dimensional arrangement example **1** and three-dimensional arrangement example **4**. Accordingly, as shown in the three columns in the right half of each of FIG. **14** and FIG. **18**, sensitivity characteristics achieved by microphone pairs each of which is a different combination of two of microphone elements **20***a* to **20***c* are not different between three-dimensional arrangement example **1** and three-dimensional arrangement example **4**.

In contrast, as shown in the three columns in the left half of each of FIG. **14** and FIG. **18**, sensitivity characteristics of microphone pairs each of which includes microphone element **20***d* are significantly different between three-dimensional arrangement example **1** and three-dimensional arrangement example **4**. In other words, variations of sensitivity characteristics of reference signals can be differentiated by changing the position of microphone element **20***d*.

Next, three-dimensional arrangement example **5** will be described. FIG. **19** is a diagram illustrating three-dimensional arrangement example **5** of microphone elements **20***a* to **20***d*. FIG. is a diagram illustrating sensitivity characteristics, in the direction along the XY plane, of reference signals that are generated by sound pickup device **10** employing three-dimensional arrangement example **5**.

In three-dimensional arrangement example **5** in FIG. **19**, the arrangement of microphone elements **20***a* and **20***d* is the same as that in three-dimensional arrangement example **1**. In three-dimensional arrangement example **5**, a space between microphone element **20***b* and microphone element **20***c* is wider than that in three-dimensional arrangement example **1**. Specifically, microphone element **20***b* is located on the negative side of the X-axis direction with respect to the position of microphone element **20***b* in three-dimensional arrangement example **1**, and microphone element **20***c* is located on the positive side of the X-axis direction with respect to the position of microphone element **20***c* in three-dimensional arrangement example **1**.

The positions of microphone elements **20***b* and **20***c* are different between three-dimensional arrangement example **1** and three-dimensional arrangement example **5**. Accordingly, as shown in the leftmost column in each of FIG. **14** and FIG. **20**, sensitivity characteristics achieved by a microphone pair which is a combination of microphone element **20***a* and microphone element **20***d* are not different between three-dimensional arrangement example **1** and three-dimensional arrangement example **5**.

In contrast, as shown in the five columns except for the leftmost column in each of FIG. **14** and FIG. **20**, sensitivity characteristics of microphone pairs each of which includes at least microphone element **20***b* or microphone element **20***c* are different between three-dimensional arrangement example **1** and three-dimensional arrangement example **5**. Accordingly, variations of sensitivity characteristics of reference signals can be differentiated by changing the positions of microphone elements **20***b* and **20***c*.

(Frequency Response of Main Signal **2**)

Next, frequency responses, in the direction along the XY plane, of main signals that are each generated by sound pickup device **10** employing one of the planar arrangement example, three-dimensional arrangement example **1**, three-dimensional arrangement example **4**, and three-dimensional arrangement example **5** will be described. FIG. **21** is a diagram illustrating frequency responses of a main signal that is generated by sound pickup device **10** employing the planar arrangement example and of which the target sound direction is the 90° direction along the XY plane. FIG. **22** is a diagram illustrating frequency responses of a main signal that is generated by sound pickup device **10** employing three-dimensional arrangement example **1** and of which the target sound direction is the 90° direction along the XY plane. FIG. **23** is a diagram illustrating frequency responses of a main signal that is generated by sound pickup device **10** employing three-dimensional arrangement example **4** and of which the target sound direction is the 90° direction along the XY plane. FIG. **24** is a diagram illustrating frequency responses of a main signal that is generated by sound pickup device **10** employing three-dimensional arrangement example **5** and of which the target sound direction is the 90° direction along the XY plane.

In each of FIG. **21** to FIG. **24**, a frequency response in the 90° direction, a frequency response in the 30° direction, and a frequency response in the 0° direction of the main signal are illustrated, and the target sound direction of the main signal is the 90° direction. In each of FIG. **21** to FIG. **24**, the vertical axis indicates sound pressure level and the horizontal axis indicates frequency.

In comparison between FIG. **21** (planar arrangement example) and FIG. **22** (three-dimensional arrangement example **1**), it can be said that the frequency response in the 90° direction, the frequency response in the 30° direction, and the frequency response in the 0° direction of the main signal when three-dimensional arrangement example **1** is employed are similar to those when the planar arrangement example is employed.

In comparison between FIG. **22** (three-dimensional arrangement example **1**) and FIG. **23** (three-dimensional arrangement example **4**), it can be said that the frequency response in the 90° direction and the frequency response in the 30° direction of the main signal when three-dimensional arrangement example **4** is employed are similar to those when three-dimensional arrangement example **1** is employed. In contrast, a reduction amount of the sound pressure level in the 0° direction at a frequency band of 7 kHz or more when three-dimensional arrangement example **4** is employed is decreased as compared to when three-dimensional arrangement example **1** is employed.

In comparison between FIG. **22** (three-dimensional arrangement example **1**) and FIG. **24** (three-dimensional arrangement example **5**), it can be said that the frequency response in the 90° direction of the main signal when three-dimensional arrangement example **5** is employed is similar to that when three-dimensional arrangement example **1** is employed.

In contrast, a reduction amount of the sound pressure level in the 30° direction at a frequency band of 4 kHz or more when three-dimensional arrangement example **5** is employed is increased as compared to when three-dimensional arrangement example **1** is employed. However, although a reduction amount of the sound pressure level in the 0° direction at a frequency band of from 4 kHz to 5 kHz when three-dimensional arrangement example **5** is employed is increased as compared to when three-dimensional arrangement example **1** is employed, a reduction amount of the sound pressure level in the 0° direction at a frequency band of 7 kHz or more when three-dimensional arrangement example **5** is employed is decreased as compared to when three-dimensional arrangement example **1** is employed.

Thus, sound pickup device **10** employing any of three-dimensional arrangement example **1**, three-dimensional arrangement example **4**, and three-dimensional arrangement example **5** can generate a main signal having a directivity in a target sound direction (90° direction).

(Summary of Three-Dimensional Arrangement)

In each of three-dimensional arrangement examples **1** to **5**, any one of straight lines each of which connects two microphone elements of a different one of effective microphone pairs is not parallel to any other of the straight lines. When explained with vectors, vi=t·vj (t is a real number) is not established, where vi and vj (i and j each being a natural number) represent any two of vectors of straight lines each of which connects two microphone elements of a different one of the effective microphone pairs.

Specifically, in each of three-dimensional arrangement examples **1** to **5**, the positions of microphone elements **20***a* to **20***d* correspond to the positions of the vertices of a tetrahedron (triangular pyramid), and six sides of the tetrahedron corresponding to straight lines (line segments) each of which connects two microphone elements of a different one of the effective microphone pairs (straight lines L**1** to L**6** in three-dimensional arrangement example **1**) are not parallel to one another. In such sound pickup device **10** employing any of three-dimensional arrangement examples **1** to **5**, variations of sensitivity characteristics of reference signals are increased.

It should be noted that, in each of three-dimensional arrangement examples **1** to **5**, microphone elements **20***a* to **20***d* include three microphone elements **20***a* to **20***c* that are located on the same plane and one microphone element **20***d* that is not located on the same plane, and three microphone elements **20***a* to **20***c* are arranged to form a triangle on the same plane.

Moreover, in each of three-dimensional arrangement examples **2** to **5**, one of distances each of which is the distance between two microphone elements of a different one of the effective microphone pairs is different from at least another one of the distances. In other words, in each of three-dimensional arrangement examples **2** to **5**, distances between microphone elements are partially irregular. Thus, the directivity of a main signal can be made sharp. According to the consideration by the inventors, the directivity of a main signal can be made sharp in both a low frequency band and a high frequency band by making a distance between any two microphone elements longer.

(Variations of Three-Dimensional Arrangement)

Here, a three-dimensional arrangement employed in sound pickup device **10** is not limited to three-dimensional arrangement examples **1** to **5**. For example, four or more microphone elements included in sound pickup device **10** may include n (n being a natural number greater than or equal to 3) microphone elements that are located on the same plane and one or more microphone elements that are not located on the same plane. For example, microphone elements may be arranged at the vertices of a pyramid whose base is an n-sided polygon.

In this case, the base may be a regular n-sided polygon (n being an odd number) or may be a polygon whose n sides are not parallel to one another. FIG. **25** is a diagram illustrating an example where microphone elements are arranged at the vertices of a quadrangular pyramid whose base is a quadrangle having four sides that are not parallel to one another. In FIG. **25**, the positions of microphone elements are indicated by black circles.

Moreover, microphone elements may be arranged at the apex and the circumference of the bottom of a cone. FIG. **26** is a diagram illustrating an example where microphone elements are arranged at the apex and the circumference of the bottom of a cone. In FIG. **26**, the positions of microphone elements are indicated by black circles. It should be noted that the bottom of the cone may be either a perfect circle or an ellipse.

Moreover, microphone elements may be arranged spirally. Microphone elements may be arranged in any way in a range satisfying the condition that any one of straight lines each of which connects two microphone elements of a different one of effective microphone pairs is not parallel to any other of the straight lines.

(Advantageous Effects, Etc.)

As described above, sound pickup device **10** includes microphone elements **20***a* to **20***d* arranged three-dimensionally in a distributed manner. Among microphone pairs each of which is a different combination of two microphone elements of microphone elements **20***a* to **20***d*, a total number of effective microphone pairs is greater than a total number of microphone elements **20***a* to **20***d*, the effective microphone pairs each being a combination of two microphone elements having a distance less than a distance D between each other.

Distance D is represented by D=c/2f, where f represents a frequency of a target sound obtained from microphone elements **20***a* to **20***d* and *c* represents a velocity of the target sound. Any one of straight lines each of which connects two microphone elements of a different one of the effective microphone pairs is not parallel to any other of the straight lines.

Accordingly, variations of sensitivity characteristics of reference signals are increased, and thus sound pickup device **10** can reduce noise from various directions. In other words, sound pickup device **10** can effectively reduce sound other than a target sound.

Moreover, for example, microphone elements **20***a* to **20***d* include n (n being a natural number greater than or equal to 3) microphone elements that are arranged on a same plane and one or more microphone elements that are not arranged on the same plane.

Accordingly, variations of sensitivity characteristics of reference signals can be increased by employing an arrangement in which microphone elements **20***a* to **20***d* are arranged to form an n-sided pyramid (pyramid whose bottom is an n-sided polygon).

Moreover, for example, the n microphone elements are arranged to form a regular n-sided polygon on the same plane.

Accordingly, variations of sensitivity characteristics of reference signals can be increased by employing an arrangement in which microphone elements **20***a* to **20***d* are arranged to form a pyramid whose bottom is a regular n-sided polygon.

Moreover, for example, one of distances each of which is the distance between the two microphone elements of a different one of the effective microphone pairs is different from at least another one of the distances.

Accordingly, the directivity of a main signal can be made sharp.

Moreover, for example, the total number of the microphone pairs obtainable from microphone elements **20***a* to **20***d* is equal to the total number of the effective microphone pairs.

Accordingly, sound pickup device **10** can effectively reduce sound other than a target sound since all microphone pairs function as effective microphone pairs.

Moreover, for example, sound pickup device **10** further includes: delayers **31***a* to **31***d* that delay sound signals obtained from microphone elements **20***a* to **20***d*, respectively; main signal generator **31** that generates main signal X_m by adding up output signals from delayers **31***a* to **31***d*; reference signal generators **32***a* to **32***f* that generate reference signals X_{r1} to X_{r6}, respectively, by performing subtraction between each pair of output signals corresponding to combinations of two microphone elements of the effective microphone pairs, among the output signals from delayers **31***a* to **31***d*; adaptive filters **33***a* to **33***f* that apply filter coefficients to reference signals X_{r1} to X_{r6}, respectively; subtractor **34** that subtracts, from main signal X_m generated, reference signals X_{r1} to X_{r6} to which the filter coefficients have been applied; and coefficient updater **35** that updates the filter coefficients, based on output signal Y obtained by the subtraction by subtractor **34**.

Delayers **31***a* to **31***d* are an example of a delayer. Main signal X_m is an example of a first signal, and is a signal that is generated by adding up sound signals (output signals from delayers **31***a* to **31***d*) that have been obtained from microphone elements **20***a* to **20***d* and delayed by delayers **31***a* to **31***d*, respectively, according to a target sound direction. Each of reference signals X_{r1} to X_{r6} is an example of a second signal, and a signal that is generated by performing subtraction between two sound signals (among output signals from delayers **31***a* to **31***d*) that have been obtained from two microphone elements of a corresponding one of the effective microphone pairs and delayed by corresponding two of delayers **31***a* to **31***d* according to the target sound direction. Main signal generator **31** is an example of a first signal generator, each of reference signal generators **32***a* to **32***f* is an example of a second signal generator, and output signal Y is an example of a third signal.

Accordingly, sound pickup device **10** can perform beamforming based on sound signals obtained from microphone elements **20***a* to **20***d*.

OTHER EMBODIMENTS

Although the embodiment has been described thus far, the present disclosure is not limited to the embodiment.

For example, the shape or the like of the sound pickup device described in the embodiment is an example, and the sound pickup device may be in the shape of cuboid or other shape.

Moreover, the configuration of the signal processor according to the embodiment is an example. For example, the signal processor may include a D/A converter, a low pass filter (LPF), a high pass filter (HPF), a power amplifier, or an A/D converter, as a constituent element. Moreover, although signal processing performed by the signal processor is digital signal processing for example, part of the signal processing may be analog signal processing.

Furthermore, in the embodiment, the signal processor may be configured of dedicated hardware, or may be implemented by executing a software program suitable for the signal processor. The signal processor may be implemented by a program executor, such as a CPU or a processor, retrieving and executing a software program stored in a storage medium, such as a hard disk drive or a semiconductor memory device.

Moreover, the signal processor may be circuits (or an integrated circuit). These circuits may be configured as a single circuit or may be individual circuits. Moreover, these circuits may be ordinary circuits or specialized circuits.

Furthermore, although the signal processor is implemented as hardware (circuit) in the embodiment, part or all of the signal processor may be implemented by executing a software program suitable for the signal processor. The signal processor may be implemented by a program executor, such as a CPU or a processor, retrieving and executing a software program stored in a storage medium, such as a hard disk drive or a semiconductor memory device.

Additionally, forms obtained by making various modifications to the embodiment that can be conceived by a person skilled in the art, as well as other forms realized by arbitrarily combining some constituent elements and functions in the embodiment, without departing from the essence of the present disclosure, are included in the scope of the present disclosure. For example, the present disclosure may be implemented as a system including a sound pickup device according to the embodiment.

INDUSTRIAL APPLICABILITY

A sound pickup device according to the present disclosure is applicable as a sound pickup device used in a teleconference system or the like.

The invention claimed is:

1. A sound pickup device comprising:

a plurality of microphone elements that are arranged three-dimensionally in a distributed manner, wherein

among microphone pairs each of which is a different combination of two microphone elements of the plurality of microphone elements, a total number of effective microphone pairs is greater than a total number of the plurality of microphone elements, the effective microphone pairs each being a combination of two microphone elements having a distance less than a distance D between each other,

the distance D is represented by D=c/2f, where f represents a frequency of a target sound obtained from the plurality of microphone elements and c represents a velocity of the target sound,

any one of straight lines each of which connects the two microphone elements of a different one of the effective microphone pairs is not parallel to any other of the straight lines, and

the plurality of microphone elements include n microphone elements that are located on a same plane and one or more microphone elements that are not located on the same plane, n being a natural number greater than or equal to 3.

2. The sound pickup device according to claim **1**, wherein the n microphone elements are arranged to form a regular n-sided polygon on the same plane.

3. The sound pickup device according to claim **1**, wherein one of distances each of which is the distance between the two microphone elements of a different one of the effective microphone pairs is different from at least another one of the distances.

4. The sound pickup device according to claim **1**, wherein a total number of the microphone pairs obtainable from the plurality of microphone elements is equal to the total number of the effective microphone pairs.

5. The sound pickup device according to claim **1**, further comprising:

a delayer that individually delays sound signals obtained from the plurality of microphone elements;

a first signal generator that generates a first signal by adding up output signals from the delayer;

a second signal generator that generates a second signal by performing subtraction between two output signals corresponding to the two microphone elements of one of the effective microphone pairs, among the output signals from the delayer;

an adaptive filter that applies a filter coefficient to the second signal;

a subtractor that subtracts, from the first signal generated, the second signal to which the filter coefficient has been applied; and

a coefficient updater that updates the filter coefficient, based on a third signal obtained by the subtraction performed by the subtractor.

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