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(54) **Title:** PHASE CONTROL DEVICE, ACOUSTIC DEVICE AND PHASE CONTROL METHOD

(57) **Abstract:**

Description

Title of Invention: PHASE CONTROL DEVICE, ACOUSTIC DEVICE AND PHASE CONTROL METHOD

Technical Field

[0001] The present invention relates to a phase control device, an acoustic device and a phase control method.

Background Art

[0002] Generally, in a vehicle interior, speakers are provided at a plurality of positions. For example, a front right speaker on the right door and a front left speaker on the left door are provided at positions symmetrical to each other with respect to a central line of an in-vehicle space. However, if a listening position (e.g., a driver seat, a front passenger seat or a rear seat) is considered as a reference position, these speakers are not positioned symmetrically.

[0003] For example, in case the listener is sitting on the driver seat, a distance between the front right speaker and the listener and a distance between the front left speaker and the listener are not the same. In case of a right-hand drive car, the former distance is shorter than the latter distance. Therefore, if sounds are output from both speakers at the same time, in general, the sound output from the front right speaker reaches the ears of the listener sitting on the driver seat first and then the sound output from the front left speaker reaches the ears of the listener. Due to such difference in times required for playback sounds output from respective speakers to reach the ears of the listener caused by the differences in distances between the listening position and respective speakers, sound image localization bias by Haas effect occurs.

[0004] As a technique for suppressing the sound image localization bias, a time alignment is known. The time alignment is a technique for setting time delays to respective channels corresponding to respective speakers such that sounds output from respective speakers reach the listener (listening position) at the same time. Specific configuration of a device for performing the time alignment is disclosed for example in Japanese Patent Provisional Publication No. 2005-341534 (hereinafter referred to as “Patent Document 1”).

[0005] The device disclosed in Patent Document 1 sequentially collects sounds which are sequentially output from respective speakers at a predetermined position set as a target for the time alignment, measures impulse responses between respective speakers and the predetermined position from the collected sounds, measures rise times of the impulse responses corresponding to respective speakers, and sets time delays to respective channels corresponding to respective speakers based on difference in the rise times. The device disclosed in Patent Document 1 is configured to improve calculation accuracy of the delay times to be set to respective channels corresponding to respective speakers by applying a low pass filter to the impulse responses to remove high-frequency noise to thereby detect the rises of the impulse responses with high accuracy.

Summary of Invention

[0006] In special listening environments such as a vehicle interior, interferences between sounds output from respective speakers are likely to occur. Since such interferences causes dips in the frequency spectrum, it is difficult to suppress degradation in sound quality and decrease in sound pressure due to the dip only by the conventional technique (i.e., the time alignment) for localizing sound image.

[0007] The present invention is made in view of the above mentioned circumstances and thus the object of the present invention is to provide a phase control device, an acoustic device and a phase control method that are capable of suppressing the sound image localization bias at the listening position and further suppressing degradation in sound quality and decrease in sound pressure due to the interferences between sounds output from respective speakers at the listening position.

[0008] A phase control device according to an embodiment of the present invention includes a measuring part configured to measure impulse responses between a predetermined position and respective one of two speakers from signals of sounds collected at the predetermined position, the sounds being output from respective one of the two speakers at timings such that the sounds output from respective one of the two speakers do not interfere with each other at the predetermined position, a Fourier transform part configured to obtain frequency spectrums corresponding to respective one of the two speakers by performing Fourier transform on the impulse responses corresponding to respective one of the two speakers, a computing part configured to obtain a first frequency characteristic of amplitude by performing a predetermined phase control on one of the frequency spectrums obtained by the Fourier transform part and being set as a phase control target frequency spectrum and synthesizing the phase control target frequency spectrum with the other frequency spectrum on which the predetermined phase control is not performed, and to obtain a second frequency characteristic of amplitude by synthesizing, without performing the predetermined phase control, the phase control target frequency spectrum with the other frequency spectrum, a detecting part configured to detect a speaker that satisfies a predetermined condition, from among the two speakers, based on the first frequency characteristic of amplitude and the second frequency characteristic of amplitude obtained by making each of the frequency spectrums the phase control target frequency spectrum, and a generating part configured to generate, based on a first phase adjustment data for adjusting phases at respective frequencies of a sound to be input to the detected speaker, second phase adjustment data for adjusting phases at respective frequencies of sound signals to be input to respective one of the two speakers such that, at respective frequencies, destructive interference between sounds output by respective one of the two speakers is reduced at a plurality of positions, including the predetermined position, satisfying predetermined environmental relationships with respect to the two speakers. The plurality of positions satisfying the predetermined environmental relationships with respect to the two speakers are positions whose positions and listening environments are substantially symmetrical to each other with respect to the two speakers.

[0009] The detecting part may calculate a sound pressure level difference between the first frequency characteristic of amplitude and the second frequency characteristic of amplitude for each of the cases where respective one of the frequency spectrums is made the phase control target frequency spectrum, compare values being based on the calculated sound pressure level differences corresponding to respective cases where respective one of the frequency spectrums is made the phase control target frequency spectrum, and detect the speaker that satisfies the predetermined condition based on the result of the comparison. More specifically, the detecting part may calculate the sound pressure level differences at respective frequencies, calculate an accumulated value of the calculated sound pressure level differences, compare the accumulated values corresponding to respective cases where respective one of the frequency spectrums is made the phase control target frequency spectrum, and detect a speaker corresponding to the greater accumulated value as the speaker that satisfies the predetermined condition.

[0010] The computing part may be configured to perform the following processes (1) to (5) for each of the frequency spectrums obtained by the Fourier transform part:

(1) sequentially shift phases of the phase control target frequency spectrum and synthesizes the phase control target frequency spectrum with the other frequency spectrum each time the phases of the phase control target frequency spectrum are shifted;

(2) obtain, based on results of the synthesis, phase adjustment amounts at respective frequencies of the phase control target frequency spectrum when the phases of sounds from respective one of the two speakers become substantially the same at the predetermined position at respective frequencies;

(3) perform complex multiplication of the obtained phase adjustment amounts at respective frequencies by the phase control target frequency spectrum to shift phases of the phase control target frequency spectrum;

(4) obtain the first frequency characteristic of amplitude by synthesizing the phase control target frequency spectrum whose phases are shifted with the other frequency

spectrum; and
(5) obtain the second frequency characteristic of amplitude by synthesizing the phase control target frequency spectrum whose phases are not shifted with the other frequency spectrum.

[0011] The first phase adjustment data is, for example, data for adjusting phases at respective frequencies of a sound signal to be input to the detected speaker such that, at respective frequencies, phases of a sound from the detected speaker and phases of a sound from the other speaker become substantially the same or opposite at the predetermined position.

[0012] The generating part may calculate phase adjustment amounts at respective frequencies to be applied to respective sound signals to be input to the respective one of the two speakers based on the first phase adjustment data and obtain the calculated phase adjustment amounts at respective frequencies as the second phase adjustment data. In this case, the generating part may calculate the phase adjustment amounts such that, at respective frequencies, differences in the phase adjustment amounts to be applied to sound signals to be input to respective one of the two speakers become equal to or less than 180 degrees.

[0013] According to the phase control device configured as described above, it becomes possible to suppress the sound image localization bias and further suppress degradation in sound quality and decrease in sound pressure due to the interferences between sounds output from respective speakers at the plurality of positions, including the predetermined position (e.g., a listening position), satisfying predetermined environmental relationships with respect to the two speakers.

[0014] An acoustic device according to an embodiment of the present invention includes the above-described phase control device and is configured to input sound signals input from a sound source to respective one of the two speakers. The acoustic device includes an adjusting part configured to adjust, by using the second phase adjustment data, phases at respective frequencies of the sound signals input from the sound source and to be input to respective one of the two speakers.

[0015] According to the acoustic device configured as described above, it becomes possible to input, to the two speakers, respective sound signals that can suppress the sound image localization bias and further suppress degradation in sound quality and decrease in sound pressure due to the interferences between sounds output from respective speakers at the plurality of positions, including the predetermined position (e.g., a listening position), satisfying predetermined environmental relationships with respect to the two speakers.

[0016] A phase control method according to an embodiment of the present invention to be executed by a computer includes a measuring step of measuring impulse responses between a predetermined position and respective one of two speakers from signals of sounds collected at the predetermined position, the sounds being output from respective one of the two speakers at timings such that the sounds output from respective one of the two speakers do not interfere with each other at the predetermined position, a Fourier transform step of obtaining frequency spectrums corresponding to respective one of the two speakers by performing Fourier transform on the impulse responses corresponding to respective one of the two speakers, a computing step of obtaining a first frequency characteristic of amplitude by performing a predetermined phase control on one of the frequency spectrums obtained by the Fourier transform part and being set as a phase control target frequency spectrum and synthesizing the phase control target frequency spectrum with the other frequency spectrum on which the predetermined phase control is not performed, and of obtaining a second frequency characteristic of amplitude by synthesizing, without performing the predetermined phase control, the phase control target frequency spectrum with the other frequency spectrum, a detecting step of detecting a speaker that satisfies a predetermined condition, from among the two speakers, based on the first frequency characteristic of amplitude and the second frequency characteristic of amplitude obtained by making each of the frequency spectrums the phase control target frequency spectrum, and a generating step of generating, based on a first phase adjustment data for adjusting phases at respective frequencies of a sound to be input to the detected speaker, second phase adjustment data for adjusting phases at respective frequencies of sound signals to be input to respective one of the two speakers such that, at respective frequencies, destructive interference between sounds output by respective one of the two speakers is reduced at a plurality of positions, including the predetermined position, satisfying predetermined environmental relationships with respect to the two speakers. The plurality of positions satisfying the predetermined environmental relationships with respect to the two speakers are positions whose positions and listening environments are substantially symmetrical to each other with respect to the two speakers.

[0017] In the detecting step, a sound pressure level difference between the first frequency characteristic of amplitude and the second frequency characteristic of amplitude may be calculated for each of the cases where respective one of the frequency spectrums is made the phase control target frequency spectrum, values being based on the calculated sound pressure level differences corresponding to respective cases where respective one of the frequency spectrums is made the phase control target frequency spectrum may be compared, and the speaker that satisfies the predetermined condition may be detected based on the result of the comparison. Specifically, in the detecting step, the sound pressure level differences at respective frequencies may be calculated, an accumulated value of the calculated sound pressure level differences may be calculated, the accumulated values corresponding to respective cases where respective one of the frequency spectrums is made the phase control target frequency spectrum may be compared, and a speaker corresponding to the greater accumulated value may be detected as the speaker that satisfies the predetermined condition.

[0018] In the computing step, the following processes (1) to (5) may be performed for each of the frequency spectrums obtained by the Fourier transform part:

(1) sequentially shift phases of the phase control target frequency spectrum and synthesizes the phase control target frequency spectrum with the other frequency spectrum each time the phases of the phase control target frequency spectrum are shifted;

(2) obtain, based on results of the synthesis, phase adjustment amounts at respective frequencies of the phase control target frequency spectrum when the phases of sounds from respective one of the two speakers become substantially the same at the predetermined position at respective frequencies;

(3) perform complex multiplication of the obtained phase adjustment amounts at respective frequencies by the phase control target frequency spectrum to shift phases of the phase control target frequency spectrum;

(4) obtain the first frequency characteristic of amplitude by synthesizing the phase control target frequency spectrum whose phases are shifted with the other frequency spectrum; and

(5) obtain the second frequency characteristic of amplitude by synthesizing the phase control target frequency spectrum whose phases are not shifted with the other frequency spectrum.

[0019] The first phase adjustment data may be data for adjusting phases at respective frequencies of a sound signal to be input to the detected speaker such that, at respective frequencies, phases of a sound from the detected speaker and phases of a sound from the other speaker become substantially the same or opposite at the predetermined position.

[0020] In the generating step, phase adjustment amounts at respective frequencies to be applied to sound signals to be input to respective one of the two speakers are calculated based on the first phase adjustment data, and the calculated phase adjustment amounts at respective frequencies are obtained as the second phase adjustment data.

[0021] In the generating step, the phase adjustment amounts may be calculated such that, at respective frequencies, differences in the phase adjustment amounts to be applied to sound signals to be input to respective one of the two speakers become equal to or less than 180 degrees.

[0022] According to the phase control method described above, it becomes possible to suppress the sound image localization bias and further suppress degradation in sound quality and decrease in sound pressure due to the interferences between sounds output from respective speakers at the plurality of positions, including the predetermined position (e.g., a listening position), satisfying predetermined environmental relationships with respect to the two speakers.

[0023] The phase control method may further include, when inputting sound signals input from a sound source to respective one of the two speakers, an adjusting step of adjusting, by using the second phase adjustment data, phases at respective frequencies of the sound signals input from the sound source and to be input to respective one of the two speakers.

[0024] According to the phase control method described above, it becomes possible to input, to the two speakers, respective sound signals that can suppress the sound image localization bias and further suppress degradation in sound quality and decrease in sound pressure due to the interferences between sounds output from respective speakers at the plurality of positions, including the predetermined position, satisfying predetermined environmental relationships with respect to the two speakers.

Brief Description of Drawings

[0025] [fig.1]Fig. 1 is a diagram illustrating a vehicle in which an acoustic system according to an embodiment of the present invention is installed.

[fig.2]Fig. 2 is a block chart showing a configuration of the acoustic system according to the embodiment of the present invention.

[fig.3A]Fig. 3A is a flowchart showing a phase adjustment data setting process to be executed by the acoustic system according to the embodiment of the present invention.

[fig.3B]Fig. 3B is a continuation of the flowchart shown in Fig. 3B.

[fig.4]Fig. 4 is a block chart showing a configuration of a calculating part in an acoustic device included in the acoustic system according to the embodiment of the present invention.

[fig.5A]Fig. 5A is a diagram showing an impulse response between a front left speaker and a listening position (i.e., a driver seat).

[fig.5B]Fig. 5B is a diagram showing an impulse response between a front right speaker and the listening position.

[fig.6A]Fig. 6A is a diagram showing a frequency characteristic of amplitude obtained by performing Fourier transform on the impulse response between the front left speaker and the listening position.

[fig.6B]Fig. 6B is a diagram showing a frequency characteristic of amplitude obtained by performing Fourier transform on the impulse response between the front right speaker and the listening position.

[fig.7A]Fig. 7A is a diagram showing a frequency characteristic of phase obtained by performing Fourier transform on the impulse response between the front left speaker

and the listening position.
[fig.7B]Fig. 7B is a diagram showing a frequency characteristic of phase obtained by performing Fourier transform on the impulse response between the front right speaker and the listening position.
[fig.8A]Fig. 8A is a diagram showing relationships between a phase adjustment amount of a phase control target frequency spectrum and amplitudes of a synthesized frequency spectrum at 100Hz and 400Hz, respectively, obtained as a result of a predetermined synthesizing process when the frequency spectrum of the impulse response between the front left speaker and the listening position is made the phase control target frequency spectrum.
[fig.8B]Fig. 8B is a diagram showing the relationships between the phase adjustment amount of the phase control target frequency spectrum and the amplitudes of a synthesized frequency spectrum at 100Hz and 400Hz, respectively, obtained as a result of the predetermined synthesizing process when the frequency spectrum of the impulse response between the front right speaker and the listening position is made the phase control target frequency spectrum.
[fig.9A]Fig.9A is a diagram showing phase adjustment amounts at respective frequency points of the frequency spectrum of the impulse response between the front left speaker and the listening position when, at respective frequency points, phases of a sound from the front right speaker and phases of a sound from the front left speaker become the same (or substantially the same) at the listening position.
[fig.9B]Fig. 9B is a diagram showing phase adjustment amounts at respective frequency points of the frequency spectrum of the impulse response between the front right speaker and the listening position when, at respective frequency points, phases of a sound from the front right speaker and phases of a sound from the front left speaker become the same (or substantially the same) at the listening position.
[fig.10A]Fig. 10A is a diagram showing a first frequency characteristic of amplitude and a second frequency characteristic of amplitude obtained when the frequency spectrum of the impulse response between the front left speaker and the listening position is made the phase control target frequency spectrum.
[fig.10B]Fig. 10B is a diagram showing the first frequency characteristic of amplitude and the second frequency characteristic of amplitude obtained when the frequency spectrum of the impulse response between the front right speaker and the listening position is made the phase control target frequency spectrum.
[fig.11A]Fig. 11A is a diagram showing sound pressure level differences at respective frequency points between the first frequency characteristic of amplitude and the second frequency characteristic of amplitude shown in Fig. 10A.
[fig.11B]Fig. 11B is a diagram showing sound pressure level differences at respective

frequency points between the first frequency characteristic of amplitude and the second frequency characteristic of amplitude shown in Fig. 10B.

[fig.12]Fig. 12 is a diagram showing phase adjustment amounts at respective frequency points of the frequency spectrum of the impulse response between the front right speaker and the listening position when, at respective frequency points, phases of a sound from the front right speaker and phases of a sound from the front left speaker become the opposite (or substantially the opposite) at the listening position (i.e., a first phase adjustment data).

[fig.13]Fig. 13 is a diagram showing phase adjustment amounts at respective frequency points determined by a process at step S23 shown in Fig. 3.

[fig.14]Fig. 14 is a diagram showing phase adjustment amounts (second phase adjustment data for a standard speaker) obtained through smoothing by a smoothing part included in a calculating part according to the embodiment of the present invention.

[fig.15]Fig. 15 is a diagram showing phase adjustment amounts (second phase adjustment data for the other speaker) obtained through inversion by a phase inverting part included in the acoustic device according to the embodiment of the present invention.

[fig.16]Fig. 16 is a block chart showing a configuration of a phase adjusting part included in the acoustic device according to the embodiment of the present invention.

[fig.17A]Fig. 17A is a diagram showing a time characteristic of an audio signal collected by a microphone positioned at the driver seat in an example without phase adjustment.

[fig.17B]Fig. 17B is a diagram showing a time characteristic of an audio signal collected by the microphone positioned at the driver seat in an example with phase adjustment.

[fig.18A]Fig. 18A is a diagram showing a time characteristic of an audio signal collected by a microphone positioned at a front passenger seat in an example without phase adjustment.

[fig.18B]Fig. 18B is a diagram showing a time characteristic of an audio signal collected by the microphone positioned at the front passenger seat in an example with phase adjustment.

[fig.19]Fig. 19 is a diagram showing a frequency characteristic of amplitude of an audio signal collected by the microphone positioned at the driver seat in the example without phase adjustment and a frequency characteristic of amplitude of an audio signal collected by the microphone positioned at the driver seat in the example with phase adjustment.

[fig.20]Fig. 20 is a diagram showing a frequency characteristic of amplitude of an audio signal collected by the microphone positioned at the front passenger seat in the example without phase adjustment and a frequency characteristic of amplitude of an audio signal collected by the microphone positioned at the front passenger seat in the example with phase adjustment.

[fig.21]Fig. 21 is a diagram showing a frequency characteristic of amplitude of an audio signal collected by the microphone positioned at the driver seat in the example without phase adjustment and a frequency characteristic of amplitude of an audio signal collected by the microphone positioned at the driver seat in the example with phase adjustment obtained using another embodiment of the present invention.

[fig.22]Fig. 22 is a diagram showing a frequency characteristic of amplitude of an audio signal collected by the microphone positioned at the front passenger seat in the example without phase adjustment and a frequency characteristic of amplitude of an audio signal collected by the microphone positioned at the front passenger seat in the example with phase adjustment obtained using another embodiment of the present invention.

Description of Embodiments

[0026] Hereinafter, an embodiment of the present invention will be described with reference to the accompanying drawings. In the following, an acoustic system is cited as an embodiment of the present invention.

[0027] Fig. 1 is a diagram illustrating a vehicle A in which an acoustic system 1 according to the embodiment of the present invention is installed. Fig. 2 is a block diagram showing a configuration of the acoustic system 1.

[0028] As shown in Figs. 1 and 2, the acoustic system 1 includes an acoustic device 10, speakers SP_{FR} and SP_{FL} and a microphone MIC.

[0029] The acoustic device 10 has a phase adjustment data generating function (in other words, a phase control device) for generating phase adjustment data for suppressing sound image localization which is likely to occur in vehicle interiors and for suppressing sound quality degradation and sound pressure decrease due to interferences between sounds output from respective speakers installed in the vehicle A.

[0030] It is noted that various processes in the acoustic device 10 are executed under cooperation between hardware (e.g., a CPU, an ASIC or a combination thereof being examples of a computer) and software provided in the acoustic device 10. At least an OS (Operating System) of the software provided in the acoustic device 10 is provided as an embedded system, and the other part of the software, such as a software module for executing the phase adjustment data generating process, may be provided as an application which can be distributed through a network or an application storable in a recording medium such as a memory card. That is, the phase adjustment data generating function according to the present embodiment may be the function embedded in the acoustic device 10 in advance (e.g., before the shipment) or may be the function which can be added to the acoustic device 10 through a network or a recording medium.

[0031] As shown in Fig. 1, the speaker SP_{FR} is a front right speaker embedded in a right door (a door on the driver seat side) and the speaker SP_{FL} is a front left speaker embedded in a left door (a door on the front passenger seat side). Further speakers (e.g., rear speakers) may be provided to the vehicle A (i.e., three or more speakers may be provided to the vehicle A).

[0032] The acoustic device 10 has a controller 100, a display part 102, an operating part 104, a measurement signal generating part 106, a recording medium reproducing part 108, a phase adjusting part 110, an amplifier 112, a signal recording part 114 and a calculating part 116.

[0033] Fig. 3 is a flowchart showing a phase adjustment data setting process to be executed by the acoustic system 1. It is noted that various processes by the acoustic system 1 such as the phase adjustment data setting process shown in this flowchart are executed under control of the controller 100. Upon receiving a predetermined touching operation on the display part 102 or a predetermined operation on the operating part 104, the controller 100 starts executing the phase adjustment data setting process shown in this flowchart.

[0034] Once the execution of the phase adjustment data setting process shown in Fig. 3 is started, the measurement signal generating part 106 generates a predetermined measurement signal (step S11). The generated measurement signal is, for example, of M-sequence (Maximal length sequence) symbol. A length of the measurement signal is more than twice a length of the symbol. It is noted that the measurement signal may be signals of other types such as, for example, a TSP (Time Stretched Pulse) signal.

[0035] The measurement signal passes through the controller 100 and the phase adjusting part 110 by through-output and is sequentially output to respective speakers SP_{FR} and SP_{FL} via the amplifier 112 (step S12). A predetermined measurement sound is thereby sequentially output from respective speakers SP_{FR} and SP_{FL} with a predetermined time interval.

[0036] The microphone MIC is installed at a position where the sound image localization bias, sound quality degradation and sound pressure decrease are to be suppressed. In the present embodiment, the microphone MIC is installed at the driver seat in order to suppress the sound image localization bias, sound quality degradation and sound pressure decrease at a listening position of the listener (i.e., a listening position) sitting on the driver seat.

[0037] As will be described later, in the present embodiment, the sound image localization bias, the sound quality degradation and the sound pressure decrease are suppressed not only at the driver seat at which the microphone MIC is installed but also at the front passenger seat. In other words, the present invention is for suppressing the sound image localization bias, sound quality degradation and sound pressure decrease at a plurality of positions, including a predetermined position where the microphone MIC is installed, satisfying predetermined environmental relationships with respect to the two speakers. The plurality of positions satisfying the predetermined environmental relationships with respect to the two speakers are positions whose positions and listening environments are substantially symmetrical to each other with respect to the two speakers such as “positions whose positions and listening environments are symmetrical to each other with respect to a plane passing through the middle point of a line segment connecting the two speakers and being perpendicular to the line segment” (e.g., “the driver seat and the front passenger seat” and “the rear left passenger seat and rear right passenger seat”), “positions whose positions and listening environments are substantially line-symmetrical to each other with respect to a perpendicular bisector of the line segment connecting the two speakers”, and “positions whose positions and listening environments are substantially point-symmetrical to each other with respect to the middle point of the line segment connecting the two speakers”.

[0038] The microphone MIC collects the measurement sounds which are sequentially output from respective speakers SP_{FR} and SP_{FL} at timings such that the measurement sounds output from respective speakers SP_{FR} and SP_{FL} do not interfere with each other at the microphone MIC. Signals of the measurement sounds collected by the microphone MIC (i.e., measured signals) are stored in the signal recording part 114 and are input from the signal recording part 114 to the calculating part 116 (step S13). It is noted that, if the calculating part 116 has the function to store the measured signals, the recording part 114 may be omitted and the measured signals output from the microphone MIC may be directly input to the calculating part 116.

[0039] Fig. 4 is a block chart showing a configuration of the calculating part 116. As shown in Fig. 4, the calculating part 116 includes measuring parts 116A and 116B.

[0040] The measuring parts 116A and 116B measure impulse responses (step S14).

[0041] Specifically, the measuring part 116A obtains a cross-correlation function between the measured signal of the measurement sound output by the speaker SP_{FL} (hereinafter referred to as a “measured signal L”) and a reference measurement signal input from the controller 100 by calculation to calculate an impulse response of the measured signal L (in other words, an impulse response between the speaker SP_{FL} and the listening position; hereinafter referred to as an “impulse response L”).

[0042] Similarly, the measuring part 116B obtains a cross-correlation function between the measured signal of the measurement sound output by the speaker SP_{FR} (hereinafter referred to as a “measured signal R”) and a reference measurement signal input from the controller 100 by calculation to calculate an impulse response of the measured signal R (in other words, an impulse response between the speaker SP_{FR} and the listening position; hereinafter referred to as an "impulse response R'").

[0043] It is noted that the reference measurement signal is a signal that is identical to the measurement signal generated by the measurement signal generating part 106 and that is time-synchronized with the measurement signal.

[0044] As described above, the measuring parts 116A and 116B operate as a measuring part for measuring impulse responses between a predetermined position and respective one of two speakers from signals of sounds collected at the predetermined position, the sounds being output from respective one of the two speakers at timings such that the sounds output from respective one of the two speakers do not interfere with each other at the predetermined position.

[0045] Fig. 5A shows an example of the impulse response L', and Fig. 5B shows an example of the impulse response R'. In Figs. 5A and 5B, the vertical axis represents amplitude and the horizontal axis represents time (unit: sec). In the examples shown in Figs. 5A and 5B, the sampling frequency is 44.1 kHz, the symbol length of the M-sequence symbol is 32,767, and the frequency range is 3 kHz. It is noted that the frequency range (i.e., a frequency range for a phase adjustment according to the present invention) can be arbitrarily set within the range of up to Nyquist frequency. In the present embodiment, a range from the lower frequency limit of sound reproducible by the speakers SP_{FR} and SP_{FL} (60 Hz) up to twice an upper frequency of a frequency range that has great influence on the image localization (in other words, a frequency range within which shift in phase greatly influences the image localization) (i.e., 3 kHz) is set as the frequency range for the phase adjustment. However, the frequency range for the phase adjustment may be arbitrarily set in accordance with, for example, desired degree of effect and processing capacity of the system.

[0046] As shown in Figs. 5A and 5B, due to the special listening environment in the vehicle interior (i.e., an environment influenced by reflections with short propagation delay time differences due to structures in the vehicle interior, masking of sounds due to structures in the vehicle interior, interferences between sounds output from respective speakers and the like), a sound of low sound pressure level is observed at the listening position first (in other words, a sound pressure level of a rising part of the impulse response is low) and then a sound of high sound pressure level is observed at the listening position.

[0047] As shown in Fig. 4, the calculating part 116 includes Fourier transform parts 116C and 116D.

[0048] The Fourier transform part 116C performs Fourier transform on the impulse response L' input from the measuring part 116A and obtains a frequency spectrum of the impulse response L' (i.e., a frequency characteristic of amplitude and a frequency characteristic of phase of the impulse response L'; hereinafter referred to as "frequency spectrum L''") (step S15). The Fourier transform part 116D performs Fourier transform on the impulse response R' input from the measuring part 116B and obtains a frequency spectrum of the impulse response R' (i.e., a frequency characteristic of amplitude and a frequency characteristic of phase of the impulse response R'; hereinafter referred to as "frequency spectrum R''") (step S15). The Fourier transform parts 116C and 116D operate as a Fourier transform part for obtaining frequency spectrums corresponding to respective one of the two speakers by performing Fourier transform on the impulse responses corresponding to respective one of the two speakers.

[0049] Fig. 6A is a diagram showing the frequency characteristic of amplitude of the impulse response L' obtained by performing Fourier transform on the impulse response L', and Fig. 6B is a diagram showing the frequency characteristic of amplitude of the impulse response R' obtained by performing Fourier transform on the impulse response R'. In Figs. 6A and 6B, the vertical axis represents sound pressure level (unit: dB) and the horizontal axis represents frequency (unit: Hz).

[0050] Fig. 7A is a diagram showing the frequency characteristic of phase of the impulse response L' obtained by performing Fourier transform on the impulse response L', and Fig. 7B is a diagram showing the frequency characteristic of phase of the impulse response R' obtained by performing Fourier transform on the impulse response R'. In Figs. 7A and 7B, the vertical axis represents angle (unit: degree) and the horizontal axis represents frequency (unit: Hz).

[0051] In the examples shown in Figs. 6A, 6B, 7A and 7B, the Fourier transform length is 8,192 samples. The number of frequency points is set to 4,097 points obtained by dividing a frequency range of 0 Hz to Nyquist frequency of 22.05 kHz with intervals of 5.38 Hz. The number of frequency points within a frequency range of 0 Hz to 3 kHz is 557 points. Since the reflections, masking and interferences occur in the vehicle interior, in the examples shown in Figs. 6A and 6B, amplitude varies widely depending on frequency and, in the examples shown in Figs. 7A and 7B, phase varies widely depending on frequency.

[0052] As shown in Fig. 4, the calculating part 116 includes a phase control part 116E.

[0053] The phase control part 116E executes processes (1) to (5) described below to obtain a first frequency characteristic of amplitude and a second frequency characteristic of amplitude, which will be described in details later, for each of the frequency spectrum signals L'' and R''.

[0054] <Process (1)>

The phase control part 116E sequentially shifts phases of one of the frequency spectrum L" and the frequency spectrum R" (hereinafter referred to as a phase control target frequency spectrum) within a range of -180 degrees to +180 degrees at predetermined angle intervals and synthesizes the phase control target frequency spectrum with the other frequency spectrum (i.e., the other of the frequency spectrum L" and the frequency spectrum R") each time the phases of the phase control target frequency spectrum are shifted (step S16). This synthesizing process is executed not for every frequency points but for, for example, a total of 557 frequency points within a range of 0 Hz to 3 kHz in order to reduce processing load.

[0055] Fig. 8A is a diagram showing the result of the synthesizing process when the frequency spectrum L" is set as the phase control target frequency spectrum, and Fig. 8B is a diagram showing the result of the synthesizing process when the frequency spectrum R" is set as the phase control target frequency spectrum. Figs. 8A and 8B show results of the synthesizing processes at, among the 557 frequency points, 100Hz (thick solid line) and 400Hz (fine solid line) as representatives. In Figs. 8A and 8B, the vertical axis represents sound pressure level (unit: dB) after the synthesizing process and the horizontal axis represents phase (unit: degree). The sound pressure level at the phase of 0 degree (in other words, the sound pressure level when the phase adjustment amount is zero) indicates sound pressure level when the phase control target frequency spectrum is synthesized with the other frequency spectrum without changing the phases of the phase control target frequency spectrum.

[0056] <Process (2)>

When phases of a sound signal to be input to the speaker SP_{FL} is shifted by an angle at which the sound pressure level indicated in Fig. 8A is the greatest, at respective frequency points, phases of a sound from the speaker SP_{FR} and phases of a sound from the speaker SP_{FL} become the same (or substantially the same) at the listening position (i.e., the strongest constructive interference between the sound from the speaker SP_{FR} and the sound from the speaker SP_{FL} occurs at the listening position), and when the phases of the sound signal to be input to the speaker SP_{FL} is shifted by an angle at which the sound pressure level indicated in Fig. 8A is the smallest, at respective frequency points, the phases of the sound from the speaker SP_{FR} and the phases of the sound from the speaker SP_{FL} become the opposite (or substantially the opposite) at the listening position (i.e., the strongest destructive interference between the sound from the speaker SP_{FR} and the sound from the speaker SP_{FL} occurs at the listening position). Similarly, When phases of a sound signal to be input to the speaker SP_{FR} is shifted by an angle at which the sound pressure level indicated in Fig. 8B is the greatest, at respective frequency points, phases of a sound from the speaker SP_{FR} and phases of a sound from the speaker SP_{FL} become the same (or substantially the same) at the listening position (i.e., the strongest constructive interference between the sound from the speaker SP_{FR} and the sound from the speaker SP_{FL} occurs at the listening position), and when the phases of the sound signal to be input to the speaker SP_{FR} is shifted by an angle at which the sound pressure level indicated in Fig. 8B is the smallest, at respective frequency points, the phases of the sound from the speaker SP_{FR} and the phases of the sound from the speaker SP_{FL} become the opposite (or substantially the opposite) at the listening position (i.e., the strongest destructive interference between the sound from the speaker SP_{FR} and the sound from the speaker SP_{FL} occurs at the listening position).

[0057] In the example shown in Fig. 8A, at 100 Hz, the phases of the sound from the speaker SP_{FR} and the phases of the sound from the speaker SP_{FL} become the same (or substantially the same) at the listening position when the phases of the sound signal to be input to the speaker SP_{FL} is shifted by about -110 degrees and become the opposite (or substantially the opposite) at the listening position when the phases of the sound signal to be input to the speaker SP_{FL} is shifted by about +70 degrees. At 400 Hz, the phases of the sound from the speaker SP_{FR} and the phases of the sound from the speaker SP_{FL} become the same (or substantially the same) at the listening position when the phases of the sound signal to be input to the speaker SP_{FL} is shifted by about +180 degrees and become the opposite (or substantially the opposite) at the listening position when the phases of the sound signal to be input to the speaker SP_{FL} is shifted by about -10 degrees.

[0058] In the example shown in Fig. 8B, at 100 Hz, the phases of the sound from the speaker SP_{FR} and the phases of the sound from the speaker SP_{FL} become the same (or substantially the same) at the listening position when the phases of the sound signal to be input to the speaker SP_{FR} is shifted by about +110 degrees and become the opposite (or substantially the opposite) at the listening position when the phases of the sound signal to be input to the speaker SP_{FR} is shifted by about -70 degrees. At 400 Hz, the phases of the sound from the speaker SP_{FR} and the phases of the sound from the speaker SP_{FL} become the same (or substantially the same) at the listening position when the phases of the sound signal to be input to the speaker SP_{FR} is shifted by about -180 degrees and become the opposite (or substantially the opposite) at the listening position when the phases of the sound signal to be input to the speaker SP_{FR} is shifted by about +10 degrees.

[0059] The phase control part 116E obtains, from the result of the synthesizing process for each of the frequency points, the phase adjustment amount for each of the frequency points of the phase control target frequency spectrum for making the phases of the sound from the speaker SP_{FR} and the phases of the sound from the speaker SP_{FL} the same (or substantially the same) at the listening position (step S17).

[0060] Fig. 9A is a diagram showing the phase adjustment amounts at respective frequency points of the frequency spectrum L” when, at respective frequency points within the range of 60 Hz to 3 kHz, the phases of the sound from the speaker SP_{FR} and the phases of the sound from the speaker SP_{FL} become the same (or substantially the same) at the listening position. Fig. 9B is a diagram showing the phase adjustment amounts at respective frequency points of the frequency spectrum R” when, at respective frequency points within the range of 60 Hz to 3 kHz, the phases of the sound from the speaker SP_{FR} and the phases of the sound from the speaker SP_{FL} become the same (or substantially the same) at the listening position. In Figs. 9A and 9B, the vertical axis represents the phase adjustment amount (unit: degree) and the horizontal axis represents frequency (unit: Hz).

[0061] As shown in Figs. 9A and 9B, in the present embodiment, the phase adjustment amount varies widely depending on frequency due to variations in propagation delay times at respective frequencies in the vehicle interior.

[0062] <Process (3)>

The phase control part 116E converts the phase control target frequency spectrum (i.e., the frequency spectrum L” or the frequency spectrum R”) and the phase adjustment amounts at respective frequency points of the phase control target frequency spectrum obtained at step S17 (see Fig. 9A or 9B) into complex numbers and performs complex multiplication of these complex numbers (step S18).

[0063] <Process (4)>

The phase control part 116E obtains the first frequency characteristic of amplitude by synthesizing the phase control target frequency spectrum obtained by the complex multiplication at step S18 (in other words, the phase control target frequency spectrum whose phases have been adjusted) with the other frequency spectrum signal (i.e., the frequency spectrum signal L” or the frequency spectrum signal R”) (step S19).

[0064] <Process (5)>

The phase control part 116E obtains the second frequency characteristic of amplitude by synthesizing the phase control target frequency spectrum whose phases have not been adjusted (i.e., the frequency spectrum signal L” or the frequency spectrum signal R”) with the other frequency spectrum (i.e., the frequency spectrum signal L” or the frequency spectrum signal R”) (step S20).

[0065] By the processes (1) to (5) described above, the first frequency characteristic of amplitude and the second frequency characteristic of amplitude are obtained for each of the case where the frequency spectrum signals L” is set as the phase control target frequency spectrum and the case where the frequency spectrum signals R” is set as the phase control target frequency spectrum. As described above, the phase control part 116E operates as a computing part for obtaining the first frequency characteristic of amplitude by performing a predetermined phase control on one of the frequency spectrums obtained by the Fourier transform part and being set as the phase control target frequency spectrum and synthesizing the phase control target frequency spectrums with the other frequency spectrum on which the predetermined phase control is not performed, and to obtain the second frequency characteristic of amplitude by synthesizing, without performing the predetermined phase control, the phase control target frequency spectrum with the other frequency spectrum.

[0066] Fig. 10A is a diagram showing the first frequency characteristic of amplitude (solid line) and the second frequency characteristic of amplitude (broken line) obtained when the frequency spectrum L” is made the phase control target frequency spectrum, and Fig. 10B is a diagram showing the first frequency characteristic of amplitude (solid line) and the second frequency characteristic of amplitude (broken line) obtained when the frequency spectrum R” is made the phase control target frequency spectrum. In Figs. 10A and 10B, the vertical axis represents sound pressure level (unit: dB) and the horizontal axis represents frequency (unit: Hz).

[0067] The phase control part 116E calculates, for respective frequency points, level differences between the first frequency characteristic of amplitude and the second frequency characteristic of amplitude obtained when the frequency spectrum signal L” is made the phase control target frequency spectrum and calculates an accumulated value of the calculated sound pressure level differences. Similarly, the phase control part 116E calculates, for respective frequency points, sound pressure level differences between the first frequency characteristic of amplitude and the second frequency characteristic of amplitude of the frequency spectrum signal R” and calculates an accumulated value of the calculated sound pressure level differences. The phase control part 116E compares these accumulated values and detects a speaker corresponding to the greater accumulated value as a speaker that satisfies a predetermined condition (step S21). As described above, the phase control part 116E operates as a detecting part for detecting a speaker that satisfies a predetermined condition, from among the two speakers, based on the first frequency characteristic of amplitude and the second frequency characteristic of amplitude obtained by making each of the frequency spectrums the phase control target frequency spectrum.

[0068] Fig. 11A is a diagram showing the sound pressure level differences at respective frequency points between the first frequency characteristic of amplitude and the second frequency characteristic of amplitude obtained when the frequency spectrum L” is made the phase control target frequency spectrum, and Fig. 11B is a diagram showing the sound pressure level differences at respective frequency points between the first frequency characteristic of amplitude and the second frequency characteristic of amplitude obtained when the frequency spectrum R” is made the phase control target frequency spectrum. In Figs. 11A and 11B, the vertical axis represents sound pressure level (unit: dB) and the horizontal axis represents frequency (unit: Hz).

[0069] As described above, the first frequency characteristic of amplitude is obtained by performing the predetermined phase control on the phase control target frequency spectrum and synthesizing the phase control target frequency spectrum whose phases have been controlled with the other frequency spectrum, and the second frequency characteristic of amplitude is obtained by synthesizing, without performing the predetermined phase control, the phase control target frequency spectrum with the other frequency spectrum. Therefore, the accumulated value of the sound pressure level differences indicates a degree of an effect (a suppression of destructive interference between sounds from respective speakers at the listening position) obtained by controlling phases of the phase control target frequency spectrum. The higher the accumulated value, the higher the effect.

[0070] The accumulated value of the sound pressure level differences shown in Fig. 11A is 782, and the accumulated value of the sound pressure level differences shown in Fig. 11B is 2,404. Since the accumulated value obtained when the frequency spectrum signal R'' is made the phase control target frequency spectrum is greater, by setting the speaker SP_{FR} corresponding to the frequency spectrum signal R'' as a standard for calculating phase adjustment amounts to be used in a phase adjustment process according to the present embodiment which will be describe below (hereinafter referred to as a "standard speaker"), a higher degree of the effect (the suppression of destructive interference between sounds from respective speakers at the listening position) can be obtained and thus it becomes possible to suppress the sound image localization bias and further suppress degradation in sound quality and decrease in sound pressure due to the interferences between sounds output from respective speakers in a higher degree.

[0071] Even if a distance from a speaker to a listening position is the same, if a position of the speaker and/or listening environment changes, a time between an output of a sound from the speaker and a timing at which a sound of practical sound pressure level is observed at the listening position (hereinafter referred to as a "practical sound pressure level reaching time") may change due to changes in influences of, for example, the reflection, masking and interference of sound. In the present embodiment, as shown in Figs. 5A and 5B, the practical sound pressure level reaching time of the impulse response R' corresponding to the speaker SP_{FR} being nearer to the listening position is shorter than the practical sound pressure level reaching time of the impulse response L' corresponding to the speaker SP_{FL} being farther from the listening position. However, if the positions of the speakers SP_{FL} and SP_{FR} and/or the listening environment are changed without changing the distances from the speakers SP_{FL} and SP_{FR} to the listening position, the practical sound pressure level reaching time of the impulse response R' may become longer than that the practical sound pressure level reaching time of the impulse response L'. For example, the practical sound pressure level reaching time of the impulse response R' may change to 5.0 msec but the practical sound pressure level reaching time of the impulse response L' may remain 4.1 msec (as shown in Fig. 5A). Even in this case, since the distance between the speaker SP_{FR} and the listening position is shorter than the distance between the speaker SP_{FL} and the listening position, the sound from the speaker SP_{FR} reaches the listening position faster than the sound from the speaker SP_{FL} (i.e., rise time of the impulse response R' is shorter than that of the impulse response L'). Therefore, in the conventional time alignment, the sound from the speaker SP_{FR} is delayed to suppress the image localization bias.

[0072] However, the sound pressure level of the rising part of the impulse response R' remains low for 5 msec. This low-level sound cannot be said to be a sound of practical sound pressure level that has substantial influence on the sound image localization. The impulse response R' reaches the practical sound pressure level at about 5.0 msec. On the other hand, as described above, the impulse response L' reaches the practical sound pressure level at about 4.1 msec.

[0073] That is, with the conventional time alignment, there are cases where a speaker whose time between an output of a sound from the speaker and a timing at which a sound of practical sound pressure level is observed at the listening position is longer is set as a speaker to which delay is to beg given. Therefore, there are cases where, with the conventional time alignment, image localization bias is not sufficiently suppressed.

[0074] In contrast, as described above, in the present embodiment, the standard speaker is detected in accordance with whether a higher degree of the effect (the suppression of destructive interference between sounds from respective speakers at the listening position) can be obtained or not. Therefore, even in special listening environments such as in the vehicle interior, the image localization bias at the listening position and degradation in sound quality and decrease in sound pressure due to the interferences between sounds output from respective speakers at the listening position can be sufficiently suppressed.

[0075] The phase control part 116E obtains, from the result of the synthesizing process for each of the frequency points when the frequency spectrum corresponding to the standard speaker detected at step S21 is made the phase control target frequency spectrum (In the present embodiment, the result of the synthesizing process for each of the frequency points obtained when the frequency spectrum R" is made the phase control target frequency spectrum. See Fig. 8B.), phase adjustment amounts at respective frequency points (first phase adjustment data) of a frequency spectrum corresponding to the standard speaker when phases of a sound from the speaker SP_{FR} and phases of a sound from the speaker SP_{FL} become the opposite (or substantially the opposite) at the listening position (step S22).

[0076] Fig. 12 is a diagram showing phase adjustment amounts at respective frequency points (first phase adjustment data) of the frequency spectrum R" when phases of a sound from the speaker SP_{FR} and phases of a sound from the speaker SP_{FL} become the opposite (or substantially the opposite) at the listening position. In Fig. 12, the vertical axis represents the phase adjustment amount (unit: degree) and the horizontal axis represents frequency (unit: Hz).

[0077] As shown in Fig. 4, the calculating part 116 includes a phase adjustment amount determining part 116F.

[0078] The phase adjustment amount determining part 116F determines phase adjustment amounts at respective frequency points for adjusting phases of a sound signal to be input to the standard speaker in accordance with the first phase adjustment data (see Fig. 12) (step S23). Specifically, the phase adjustment amount determining part 116F determines the phase adjustment amount at respective frequency points in accordance with the following formula.

[0079] When | Phc | is equal to or smaller than 90 degrees, Phs = + 90 degrees; and
when | Phc | is greater than 90 degrees, Phs = 0 degrees,
where:
Phc is a phase adjustment amount determined at step S22; and
Phs is a phase adjustment amount to be determined at step S23.

[0080] Fig. 13 is a diagram showing the phase adjustment amounts at respective frequency points determined at step S23. In Fig. 13, the vertical axis represent the phase adjustment amount (unit: degree) and the horizontal axis represent frequency (unit: Hz).

[0081] As shown in Fig. 4, the calculating part 116 includes a smoothing part 116G.

[0082] The smoothing part 116G performs smoothing on the phase adjustment amounts at respective frequency points input from the phase adjustment amount determining part 116F on the frequency axis (step S24). By this process, phase adjustment data for adjusting phases at respective frequency points of a sound signal to be input to the standard speaker (second phase adjustment data for the standard speaker) is obtained.

[0083] Fig. 14 is a diagram showing the phase adjustment amounts after the smoothing process by the smoothing part 116G (i.e., the second phase adjustment data for the standard speaker). In Fig. 14, the vertical axis represents the phase adjustment amount (unit: degree) and the horizontal axis represents frequency (unit: Hz). The smoothing part 116G performs smoothing on the phase adjustment amounts at respective frequency points input from the phase adjustment amount determining part 116F by using an FIR (Finite Impulse Response) filter of eight taps.

[0084] due to the smoothing process by the smoothing part 116G, sudden change in phase in the frequency domain can be suppressed. Therefore, by outputting a sound signal whose phases are adjusted using the phase adjustment data, harmonics due to the sudden phase change can be suppressed and thus auditory allophones due to such harmonics can be suppressed.

[0085] As shown in Fig. 4, the calculating part 116 includes a phase inverting part 116H.

[0086] The phase inverting part 116H inverts the phases of the phase adjustment amounts after the smoothing process at step S24 (i.e., the second phase adjustment data for the standard speaker) to obtain phase adjustment amounts at respective frequency points for adjusting phases of a sound signal to be input to the other speaker (in the present embodiment, the speaker SP_{FL}) (i.e., second phase adjustment data for the other speaker) (step S25).

[0087] Fig. 15 is a diagram showing the second phase adjustment data for the other speaker obtained by the phase inverting part 116H. In Fig. 15, the vertical axis represents the phase adjustment amount (unit: degree) and the horizontal axis represents frequency (unit: Hz).

[0088] As shown in Figs. 14 and 15, in the second phase adjustment data for the standard speaker, the phase adjustment amounts at respective frequency points are set within the range of 0 to 90 degrees in accordance with the phase adjustment amounts at respective frequency points (i.e., the first phase adjustment data) of the sound signal to be input to the standard speaker when, at respective frequency points, phases of a sound from the standard speaker and phases of a sound from the other speaker become the opposite (or substantially the opposite) at the listening position, and in the second phase adjustment data for the other speaker, the phase adjustment amounts are set within the range of 0 to -90 degrees in accordance with the first phase adjustment data when, at respective frequency points, phases of a sound from the standard speaker and phases of a sound from the other speaker become the opposite (or substantially the opposite) at the listening position.

[0089] In the present embodiment, pieces of the second phase adjustment data for respective speakers are calculated based on the phase adjustment amounts at respective frequency points (i.e., the first phase adjustment data) of the sound signal to be input to one speaker when, at respective frequency points, phases of sounds from respective speakers become the opposite (or substantially the opposite) at the listening position and, furthermore, the pieces of the second phase adjustment data for respective speakers are calculated such that, at respective frequency points, differences in the phase adjustment amounts between the pieces of the second phase adjustment data become equal to or less than 180 degrees (in other words, the pieces of the second phase adjustment data for respective speakers are calculated such that, at respective frequency points, differences in the phase adjustment amounts to be applied to sound signals to be input to respective one of the two speakers become equal to or less than

180 degrees). Therefore, destructive interference between sounds from respective speakers can be suppressed at both the driver seat and the front passenger seat whose positions and listening environments are substantially symmetrical with respect to a plane passing through the middle point of a line segment connecting the speaker SP_{FR} and the speaker SP_{FL} and being perpendicular to the line segment and thus the image localization bias and the degradation in sound quality and decrease in sound pressure due to occurrence of dips can be suppressed.

[0090] As described above, the phase control part 116E, the phase adjustment amount determining part 116F, the smoothing part 116G and the phase inverting part 116H operate as a generating part for generating the second phase adjustment data for adjusting phases at respective frequencies of sound signals to be input to respective one the two speakers such that, at respective frequencies, destructive interference between sounds output by respective one of the two speakers is reduced at a plurality of positions including the predetermined position.

[0091] The controller 100 sets the pieces of the second phase adjustment data for respective speakers to the phase adjusting part 110 (step S26). The phase adjusting part 110 operates as a phase adjusting part for adjusting phases at respective frequencies of the sound signals input from a sound source and to be input to respective speakers by using the second phase adjustment data.

[0092] Next, operations for reproducing the sound signals input from the sound source by using the second phase adjustment data which has been set to the phase adjusting part 110 will be described.

[0093] The recording medium reproducing part 108 reproduces sound signals S_R and S_L (hereinafter referred to as "audio signals S_R and S_L") input from a sound source such as a CD (Compact Disc) or a DVD (Digital Versatile Disc). The controller 100 outputs the audio signals S_R and S_L reproduced by the recording medium reproducing part 108 to the phase adjusting part 110.

[0094] The phase adjusting part 110 adjusts phases at respective frequency points of audio signals to be input to respective speakers and outputs the audio signals whose phases have been adjusted. The audio signals S_R and S_L output from the phase adjusting part 110 are output from respective speakers SP_{FR} and SP_{FL} via the amplifier 112 into the vehicle interior.

[0095] Fig. 16 is a block chart showing a configuration of the phase adjusting part 110. As shown in Fig. 16, the phase adjusting part 110 includes an FFT (Fast Fourier Transform) part 110A, a complex multiplication part 110B and an IFFT (Inverse Fast Fourier Transform) part 110C.

[0096] The FFT part 110A performs an overlapping process and a weighting by use of a window function on the audio signals S_R and S_L, converts the audio signal from the time domain to the frequency domain by the STFT (Short-Term Fourier Transform), and outputs a signal of a frequency spectrum consisting of a frequency characteristic of amplitude and a frequency characteristic of phase to the complex multiplication part 110B. The overlapping process and the window function are for reducing noise when the localization position is changed by a user operation (e.g., when the localization position is changed from the driver seat to the front passenger seat) by gradually changing the phase adjustment amount.

[0097] In the present embodiment, the FFT part 110A has a sampling frequency of 44.1 kHz, a Fourier transform length of 8,192 samples, an overlap length of 6,144 samples, and a window function being Hanning. The FFT part 110A obtains a frequency spectrum consisting of 4,097 points, the 4,097 points being obtained by dividing a frequency range from 0 Hz up to 22.05 kHz being Nyquist frequency at 5.38 Hz intervals, by performing STFT while shifting the time by 2,048 samples.

[0098] The second phase adjustment data input from the controller 100 is set to the complex multiplication part 110B. The complex multiplication part 110B adjusts phases at respective frequency points of audio signals to be input to channels corresponding to respective speakers by performing complex multiplication of signals of the frequency spectrums input from the FFT part 110A based on the second phase adjustment data.

[0099] The IFFT part 110C converts a signal of the frequency spectrum, input from the complex multiplication part 110B and whose phases have been adjusted, from the frequency domain to the time domain by ISTFT (Inverse Short-Term Fourier Transform), performs weighting by a window function and an overlapping addition on the converted signal, and output the processed signal to the amplifier 112.

[0100] A specific example of the phase adjustment of audio signals to be input to the channels corresponding to respective speakers will be described with reference to Figs. 17 to 20. In the example, the audio signal is a monaural impulse signal with a frequency range of 0 Hz to 1 kHz. It is known that the interaural phase difference affects the sound image localization in a frequency range below 750 Hz (low frequency range), the interaural phase difference and the interaural sound pressure level difference affect the sound image localization in a frequency range between 750 Hz to 1.5 kHz (low to middle frequency range), and the interaural sound pressure level difference affects the sound image localization in a frequency range above 1.5 kHz (middle to high frequency range) (for example, see Japanese Patent Provisional publication No. 2004-325284). Therefore, in the present embodiment, a target frequency range of the phase adjustment is set to 0 Hz to 1 kHz. In the frequency range of 0 Hz to 1 kHz, since a wavelength of a sound is relatively long, the interaural phase difference is relatively small. Therefore, in the present embodiment, a sound reaching the left ear of the listener and a sound reaching the right ear of the listener are assumed to be the same and thus the number of measuring points (the number of microphones MIC) for each listening position is set to one.

[0101] Figs. 17A and 17B are diagrams showing time characteristics of audio signals collected by the microphone MIC positioned at the driver seat. Specifically, Fig. 17A is a diagram showing a time characteristic of an audio signal collected by the microphone MIC positioned at the driver seat when audio signals on which the phase adjustment process according to the present embodiment is not performed are output from respective speakers SP_{FR} and SP_{FL} at the same time (hereinafter referred to as an “example without phase adjustment”), and Fig. 17B is a diagram showing a time characteristic of an audio signal collected by the microphone MIC positioned at the driver seat when audio signals on which the phase adjustment process according to the present embodiment is performed are output from respective speakers SP_{FR} and SP_{FL} at the same time (hereinafter referred to as an “example with phase adjustment”). In Figs. 17A and 17B, the vertical axis represents amplitude and the horizontal axis represents time (unit: sec).

[0102] Figs. 18A and 18B are diagrams showing time characteristics of audio signals collected by the microphone MIC positioned at the front passenger seat. Specifically, Fig. 18A is a diagram showing a time characteristic of an audio signal collected by the microphone MIC positioned at the front passenger seat in the example without phase adjustment, and Fig. 18B is a diagram showing a time characteristic of an audio signal collected by the microphone MIC positioned at the front passenger seat in the example with phase adjustment. In Figs. 18A and 18B, the vertical axis represents amplitude and the horizontal axis represents time (unit: sec).

[0103] As can be seen from Figs. 17A and 17B, the amplitude of the audio signal collected by the microphone MIC positioned at the driver seat gets greater when the phase adjustment process according to the present embodiment is performed on the audio signals. Furthermore, as can be seen from Figs. 18A and 18B, the amplitude of the audio signal collected by the microphone MIC positioned at the front passenger seat gets greater when the phase adjustment process according to the present embodiment is performed on the audio signals. These are because the destructive interference between the sound from the speaker SP_{FR} and the sound from the speaker SP_{FL} at respective listening positions (i.e., at the driver seat and at the front passenger seat) are suppressed due the phase adjustment process according to the present embodiment on the audio signal.

[0104] Fig. 19 is a diagram showing a frequency characteristic of amplitude of the audio signal collected by the microphone MIC positioned at the driver seat in the example without phase adjustment (fine solid line) and a frequency characteristic of amplitude of the audio signal collected by the microphone MIC positioned at the driver seat in the example with phase adjustment (thick solid line). Fig. 20 is a diagram showing a frequency characteristic of amplitude of the audio signal collected by the microphone MIC positioned at the front passenger seat in the example without phase adjustment (fine solid line) and a frequency characteristic of amplitude of the audio signal collected by the microphone MIC positioned at the front passenger seat in the example with phase adjustment (thick solid line). In Figs. 19 and 20, the vertical axis represents sound pressure level (unit: dB) and the horizontal axis represents frequency (unit: Hz).

[0105] As shown in Figs. 19 and 20, in the example with phase adjustment according to the present embodiment, the sound pressure level is greater than that in the example without phase adjustment across almost the entire frequency range. This means that, in the example with phase adjustment, the destructive interference between the sound from the speaker SP_{FR} and the sound from the speaker SP_{FL} are suppressed at both listening positions at the driver seat and the front passenger seat as compared to the example without phase adjustment. Furthermore, in the example with phase adjustment, occurrence of dips in the frequency domain is suppressed as compared to the example without phase adjustment. These indicate that, in the example with phase adjustment according to the present embodiment, at both listening positions at the driver seat and the front passenger seat, the sound image localization bias can be suppressed and degradation in sound quality and decrease in sound pressure due to the interferences between sounds output from the speakers SP_{FR} and SP_{FL} can be suppressed as compared to the example without phase adjustment.

[0106] Frequency components of voice and music concentrate in low to middle frequency range. Therefore, if an audio signal of voice or music (i.e., an audio signal including frequency components that are similar to those in the monaural signal with a frequency range of 0 Hz to 1 kHz illustrated in the present embodiment) is the subject of the phase adjustment, the sound image localization bias can be sufficiently suppressed and degradation in sound quality and decrease in sound pressure due to the interferences between sounds output from the speakers SP_{FR} and SP_{FL} can be sufficiently suppressed only by adjusting phases of low to middle frequency components.

[0107] The foregoing is explanation of an exemplary embodiment of the present invention. The present invention is not limited to the above described embodiment, but can be varied in various ways within the scope of the invention. For example, embodiments of the present invention include appropriate combinations of embodiments explicitly described in this specification and/or embodiments that are obvious from the above described embodiment.

[0108] The formula that the phase adjustment amount determining part 116F uses to determine the phase adjustment amounts at respective frequency points at step S23 is not limited to the above-described formula. For example, the phase adjustment amount determining part 116F may determine the phase adjustment amounts at respective frequency points by using the following formula.

[0109] When | Phc | is equal to or smaller than 90 degrees, Phs = Phc + 90 degrees; and when | Phc | is greater than 90 degrees, Phs = Phc - 90 degrees,
where:
Phc is a phase adjustment amount determined at step S22; and
Phs is a phase adjustment amount to be determined at step S23.

[0110] Fig. 21 is a diagram showing a frequency characteristic of amplitude of the audio signal collected by the microphone MIC positioned at the driver seat in the example without phase adjustment (fine solid line) and a frequency characteristic of amplitude of the audio signal collected by the microphone MIC positioned at the driver seat in the example with phase adjustment (thick solid line) in the case where the phase adjustment amount determining part 116F determined the phase adjustment amounts at respective frequency points by using the above formula. Fig. 22 is a diagram showing a frequency characteristic of amplitude of the audio signal collected by the microphone MIC positioned at the front passenger seat in the example without phase adjustment (fine solid line) and a frequency characteristic of amplitude of the audio signal collected by the microphone MIC positioned at the front passenger seat in the example with phase adjustment (thick solid line) in the case where the phase adjustment amount determining part 116F determined the phase adjustment amounts at respective frequency points by using the above formula. In Figs. 21 and 22, the vertical axis represents sound pressure level (unit: dB) and the horizontal axis represents frequency (unit: Hz).

[0111] Even in the case where the phase adjustment amount determining part 116F determines the phase adjustment amounts at respective frequency points by using the above formula, as shown in Figs. 21 and 22, in the example with phase adjustment, the sound pressure level is greater than that in the example without phase adjustment across almost the entire frequency range. This means that, in the example with phase adjustment, the destructive interference between the sound from the speaker SP_{FR} and the sound from the speaker SP_{FL} are suppressed at both listening positions at the driver seat and the front passenger seat as compared to the example without phase adjustment. Furthermore, in the example with phase adjustment, occurrence of dips in the frequency domain is suppressed as compared to the example without phase adjustment. These indicate that, even in the case where the phase adjustment amount determining part 116F determines the phase adjustment amounts at respective frequency points by using the above formula, in the example with phase adjustment, at both listening positions at the driver seat and the front passenger seat, the sound image localization bias can be suppressed and degradation in sound quality and decrease in sound pressure due to the interferences between sounds output from the speakers SP_{FR} and SP_{FL} can be suppressed as compared to the example without phase adjustment.

[0112] In the above-described embodiment, at step S22, the phase control part 116E obtains the phase adjustment amounts at respective frequency points of the frequency spectrum corresponding to the standard speaker when phases of a sound from the speaker SP_{FR} and phases of a sound from the speaker SP_{FL} become the opposite (or substantially the opposite) at the listening position as the first phase adjustment data. However, the phase control part 116E may obtain the phase adjustment amounts at respective frequency points of the frequency spectrum corresponding to the standard speaker when phases of a sound from the speaker SP_{FR} and phases of a sound from the speaker SP_{FL} become the same (or substantially the same) at the listening position as the first phase adjustment data.

[0113] In this case, the phase adjustment amount determining part 116F may determine the phase adjustment amounts at respective frequency points by using the following formula.

[0114] When | Phc | is equal to or smaller than 90 degrees, Phs = 0 degrees; and
when | Phc | is greater than 90 degrees, Phs = + 90 degrees,
where:
Phc is a phase adjustment amount determined at step S22; and
Phs is a phase adjustment amount to be determined at step S23.

[0115] Alternatively, the phase adjustment amount determining part 116F may determine the phase adjustment amounts at respective frequency points by using the following formula.

[0116] When | Phc | is equal to or smaller than 90 degrees, Phs = Phc - 90 degrees; and
When | Phc | is greater than 90 degrees, Phs = Phc + 90 degrees,
where:
Phc is a phase adjustment amount determined at step S22; and
Phs is a phase adjustment amount to be determined at step S23.

[0117] In the above-described embodiment, the acoustic device 10 has the phase adjustment data generating function (phase control device) for generating phase adjustment data. However, an acoustic device without the phase adjustment data generating function is also within the scope of the present invention. For example, such acoustic device has the pieces of the second phase adjustment data for respective speakers generated in a manufacturing facility or the like and stored in the acoustic device in advance (e.g., before the shipment). This acoustic device is configured to suppress the destructive interference between sounds from two speakers at a plurality of listening positions at respective frequency bands by adjusting phases at respective frequency bands of sound signals input from a sound source and to be input to respective speakers with use of the stored pieces of the second phase adjustment data.

[0118] In another embodiment, the phase adjusting part 110 may perform Fourier transform on the phase adjustment amounts at respective frequency bands to generate FIR filter coefficients and may perform the phase adjustment for respective frequency bands on the audio signal to be input to the target speaker by a process in the time domain with use of the FIR filter. The phase adjusting part 110 may also perform a dividing process on each frequency band in accordance with the phase adjustment amount for each frequency band and may perform the phase adjustment on the audio signal to be input to the target speaker by using an all-pass filter which uses a second-order IIR (Infinite Impulse Response) filter or the like.

[0119] In the above-described embodiment, a process for the case where the impulse responses are measured at the driver seat has been described. However, similar process may be performed for each seat. In this case, the controller 100 may have pieces of the second phase adjustment data obtained by performing the process for respective seats as pieces of preset data. A listener can switch the target seats where the image localization bias and the like are to be suppressed by selecting one of the pieces of preset data through operation of the operating part 104.

[0120] In the above embodiment, a case where two front speakers are provided to a vehicle has been described. However, if, for example, there are two rear speakers in addition to the two front speakers, similar process as that of the above-described embodiment may be performed for the rear speakers.

Claims

[Claim 1] A phase control device comprising:
a measuring part configured to measure impulse responses between a predetermined position and respective one of two speakers from signals of sounds collected at the predetermined position, the sounds being output from respective one of the two speakers at timings such that the sounds output from respective one of the two speakers do not interfere with each other at the predetermined position;
a Fourier transform part configured to obtain frequency spectrums corresponding to respective one of the two speakers by performing Fourier transform on the impulse responses corresponding to respective one of the two speakers;
a computing part configured to obtain a first frequency characteristic of amplitude by performing a predetermined phase control on one of the frequency spectrums obtained by the Fourier transform part and being set as a phase control target frequency spectrum and synthesizing the phase control target frequency spectrum with the other frequency spectrum on which the predetermined phase control is not performed, and to obtain a second frequency characteristic of amplitude by synthesizing, without performing the predetermined phase control, the phase control target frequency spectrum with the other frequency spectrum;
a detecting part configured to detect a speaker that satisfies a predetermined condition, from among the two speakers, based on the first frequency characteristic of amplitude and the second frequency characteristic of amplitude obtained by making each of the frequency spectrums the phase control target frequency spectrum; and
a generating part configured to generate, based on a first phase adjustment data for adjusting phases at respective frequencies of a sound to be input to the detected speaker, second phase adjustment data for adjusting phases at respective frequencies of sound signals to be input to respective one of the two speakers such that, at respective frequencies, destructive interference between sounds output by respective one of the two speakers is reduced at a plurality of positions, including the predetermined position, satisfying predetermined environmental relationships with respect to the two speakers.

[Claim 2] The phase control device of claim 1, wherein the plurality of positions satisfying the predetermined environmental relationships with respect to the two speakers are positions whose positions and listening environments are substantially symmetrical to each other with respect to the two speakers.

[Claim 3] The phase control device of claim 1 or 2,
wherein the detecting part:
calculates a sound pressure level difference between the first frequency characteristic of amplitude and the second frequency characteristic of amplitude for each of the cases where respective one of the frequency spectrums is made the phase control target frequency spectrum;
compares values being based on the calculated sound pressure level differences corresponding to respective cases where respective one of the frequency spectrums is made the phase control target frequency spectrum; and
detects the speaker that satisfies the predetermined condition based on the result of the comparison.

[Claim 4] The phase control device of claim 3,
wherein the detecting part:
calculates the sound pressure level differences at respective frequencies;
calculates an accumulated value of the calculated sound pressure level differences;
compares the accumulated values corresponding to respective cases where respective one of the frequency spectrums is made the phase control target frequency spectrum; and
detects a speaker corresponding to the greater accumulated value as the speaker that satisfies the predetermined condition.

[Claim 5] The phase control device of any one of claims 1 to 4,
wherein the computing part is configured to perform the following processes (1) to (5) for each of the frequency spectrums obtained by the Fourier transform part:
(1) sequentially shift phases of the phase control target frequency spectrum and synthesizes the phase control target frequency spectrum with the other frequency spectrum each time the phases of the phase control target frequency spectrum are shifted;
(2) obtain, based on results of the synthesis, phase adjustment amounts at respective frequencies of the phase control target frequency spectrum when the phases of sounds from respective one of the two speakers

become substantially the same at the predetermined position at respective frequencies;
(3) perform complex multiplication of the obtained phase adjustment amounts at respective frequencies by the phase control target frequency spectrum to shift phases of the phase control target frequency spectrum;
(4) obtain the first frequency characteristic of amplitude by synthesizing the phase control target frequency spectrum whose phases are shifted with the other frequency spectrum; and
(5) obtain the second frequency characteristic of amplitude by synthesizing the phase control target frequency spectrum whose phases are not shifted with the other frequency spectrum.

[Claim 6] The phase control device of any one of claims 1 to 5,
wherein the first phase adjustment data is data for adjusting phases at respective frequencies of a sound signal to be input to the detected speaker such that, at respective frequencies, phases of a sound from the detected speaker and phases of a sound from the other speaker become substantially the same or opposite at the predetermined position.

[Claim 7] The phase control device of claim 6,
wherein the generating part:
calculates phase adjustment amounts at respective frequencies to be applied to sound signals to be input to respective one of the two speakers based on the first phase adjustment data; and
obtains the calculated phase adjustment amounts at respective frequencies as the second phase adjustment data.

[Claim 8] The phase control device of claim 7,
wherein the generating part calculates the phase adjustment amounts such that, at respective frequencies, differences in the phase adjustment amounts to be applied to sound signals to be input to respective one of the two speakers become equal to or less than 180 degrees.

[Claim 9] An acoustic device comprising the phase control device of any one of claims 1-8 and configured to input sound signals input from a sound source to respective one of the two speakers,
the acoustic device comprising an adjusting part configured to adjust, by using the second phase adjustment data, phases at respective frequencies of the sound signals input from the sound source and to be input to respective one of the two speakers.

[Claim 10] A phase control method to be executed by a computer, including:
a measuring step of measuring impulse responses between a prede-

termined position and respective one of two speakers from signals of sounds collected at the predetermined position, the sounds being output from respective one of the two speakers at timings such that the sounds output from respective one of the two speakers do not interfere with each other at the predetermined position;
a Fourier transform step of obtaining frequency spectrums corresponding to respective one of the two speakers by performing Fourier transform on the impulse responses corresponding to respective one of the two speakers;
a computing step of obtaining a first frequency characteristic of amplitude by performing a predetermined phase control on one of the frequency spectrums obtained by the Fourier transform part and being set as a phase control target frequency spectrum and synthesizing the phase control target frequency spectrum with the other frequency spectrum on which the predetermined phase control is not performed, and of obtaining a second frequency characteristic of amplitude by synthesizing, without performing the predetermined phase control, the phase control target frequency spectrum with the other frequency spectrum;
a detecting step of detecting a speaker that satisfies a predetermined condition, from among the two speakers, based on the first frequency characteristic of amplitude and the second frequency characteristic of amplitude obtained by making each of the frequency spectrums the phase control target frequency spectrum; and
a generating step of generating, based on a first phase adjustment data for adjusting phases at respective frequencies of a sound to be input to the detected speaker, second phase adjustment data for adjusting phases at respective frequencies of sound signals to be input to respective one of the two speakers such that, at respective frequencies, destructive interference between sounds output by respective one of the two speakers is reduced at a plurality of positions, including the predetermined position, satisfying predetermined environmental relationships with respect to the two speakers.

[Claim 11] The phase control method of claim 10,
wherein the plurality of positions satisfying the predetermined environmental relationships with respect to the two speakers are positions whose positions and listening environments are substantially symmetrical to each other with respect to the two speakers.

[Claim 12] The phase control method of claim 10 or 11,
wherein, in the detecting step:
a sound pressure level difference between the first frequency characteristic of amplitude and the second frequency characteristic of amplitude is calculated for each of the cases where respective one of the frequency spectrums is made the phase control target frequency spectrum;
values being based on the calculated sound pressure level differences corresponding to respective cases where respective one of the frequency spectrums is made the phase control target frequency spectrum are compared; and
the speaker that satisfies the predetermined condition is detected based on the result of the comparison.

[Claim 13] The phase control method of claim 12,
wherein, in the detecting step:
the sound pressure level differences at respective frequencies are calculated;
an accumulated value of the calculated sound pressure level differences are calculated;
the accumulated values corresponding to respective cases where respective one of the frequency spectrums is made the phase control target frequency spectrum are compared; and
a speaker corresponding to the greater accumulated value is detected as the speaker that satisfies the predetermined condition.

[Claim 14] The phase control method of any one of claims 10 to 13,
wherein, in the computing step, the following processes (1) to (5) are performed for each of the frequency spectrums obtained by the Fourier transform part:
(1) sequentially shift phases of the phase control target frequency spectrum and synthesizes the phase control target frequency spectrum with the other frequency spectrum each time the phases of the phase control target frequency spectrum are shifted;
(2) obtain, based on results of the synthesis, phase adjustment amounts at respective frequencies of the phase control target frequency spectrum when the phases of sounds from respective one of the two speakers become substantially the same at the predetermined position at respective frequencies;
(3) perform complex multiplication of the obtained phase adjustment

amounts at respective frequencies by the phase control target frequency spectrum to shift phases of the phase control target frequency spectrum;
(4) obtain the first frequency characteristic of amplitude by synthesizing the phase control target frequency spectrum whose phases are shifted with the other frequency spectrum; and
(5) obtain the second frequency characteristic of amplitude by synthesizing the phase control target frequency spectrum whose phases are not shifted with the other frequency spectrum.

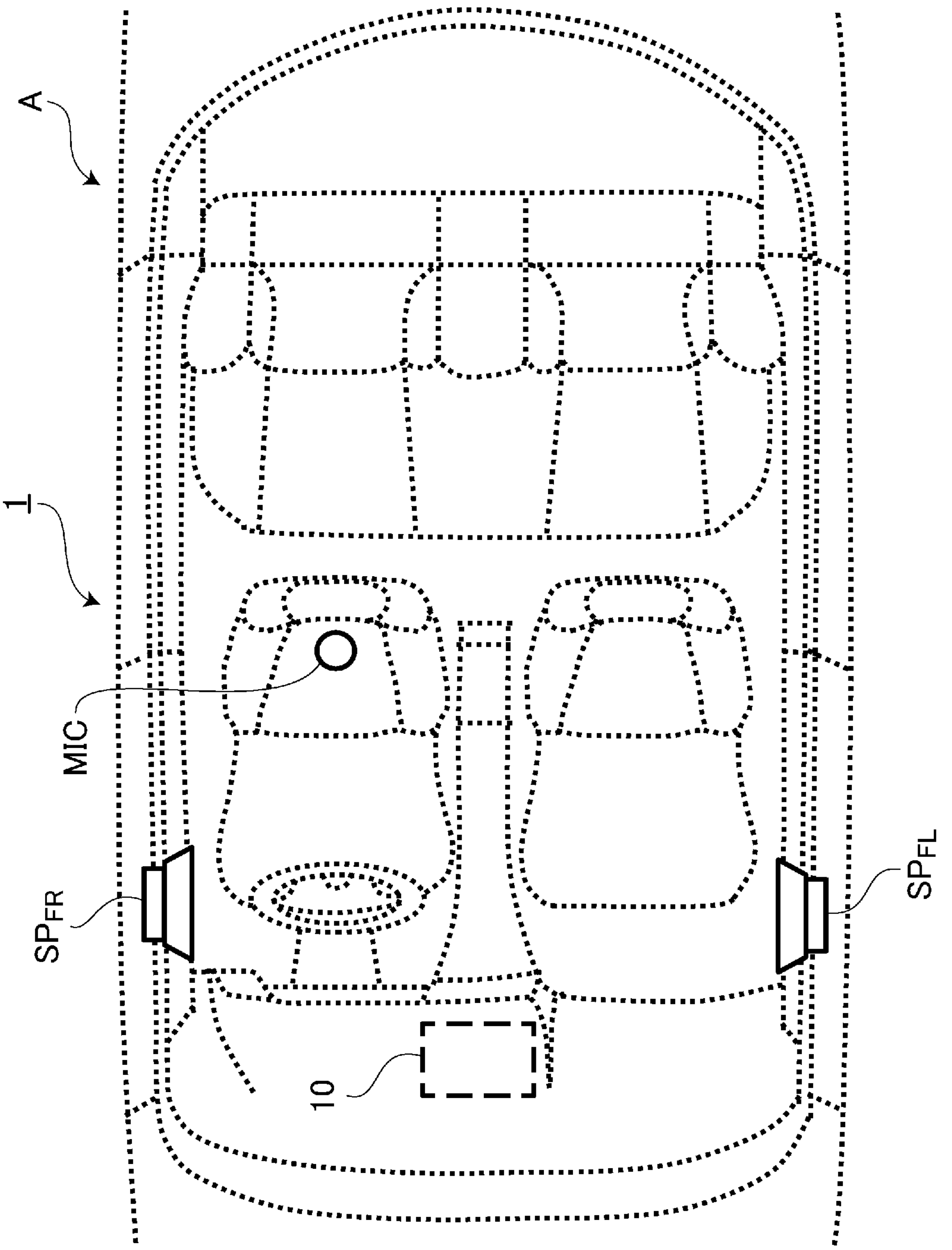
[Claim 15] The phase control method of any one of claims 10 to 14,
wherein the first phase adjustment data is data for adjusting phases at respective frequencies of a sound signal to be input to the detected speaker such that, at respective frequencies, phases of a sound from the detected speaker and phases of a sound from the other speaker become substantially the same or opposite at the predetermined position.

[Claim 16] The phase control method of claim 15,
wherein, in the generating step:
phase adjustment amounts at respective frequencies to be applied to sound signals to be input to respective one of the two speakers are calculated based on the first phase adjustment data; and
the calculated phase adjustment amounts at respective frequencies are obtained as the second phase adjustment data.

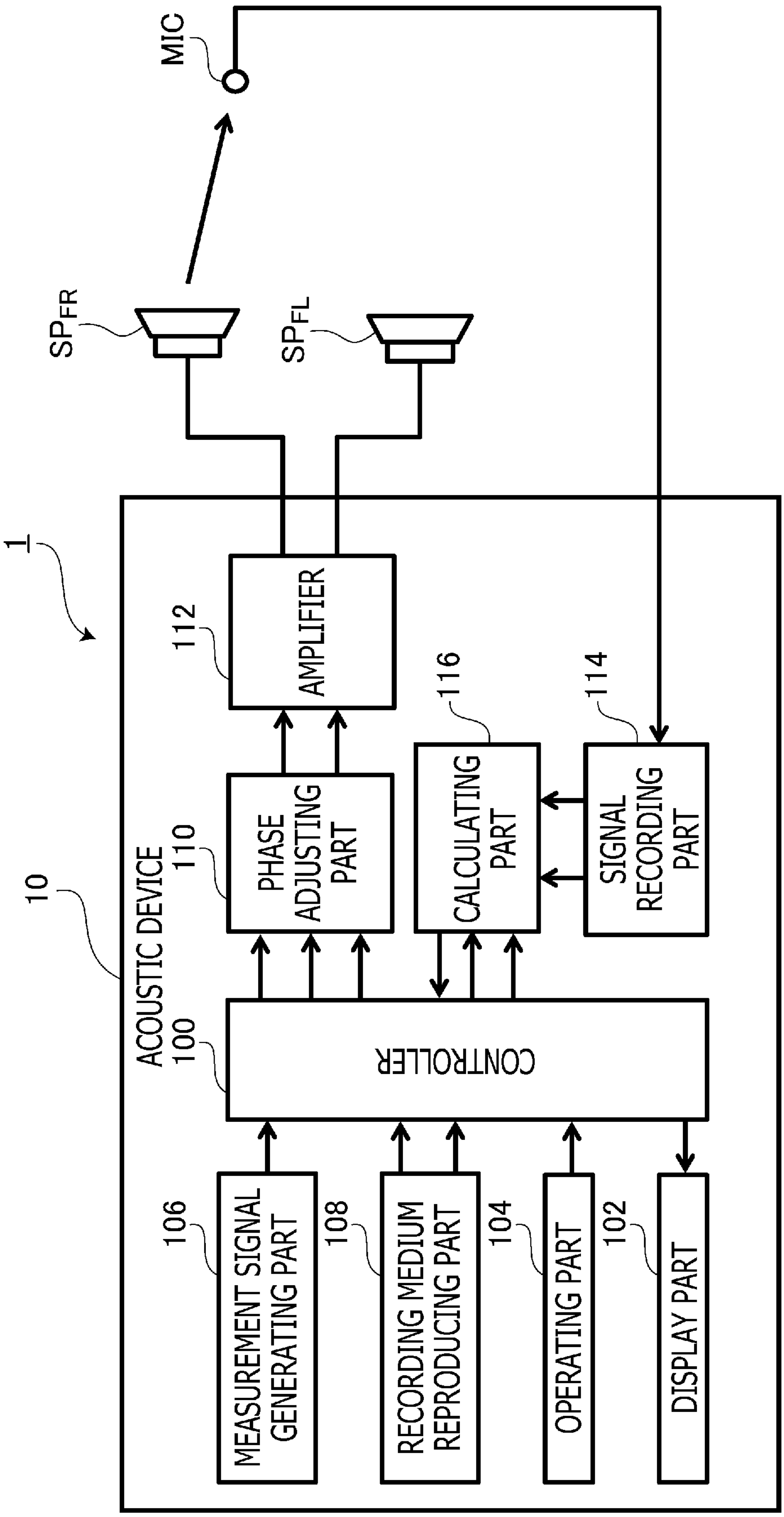
[Claim 17] The phase control method of claim 16,
wherein, in the generating step, the phase adjustment amounts are calculated such that, at respective frequencies, differences in the phase adjustment amounts to be applied to sound signals to be input to respective one of the two speakers become equal to or less than 180 degrees.

[Claim 18] The phase control method of any one of claims 10 to 17,
further including, when inputting sound signals input from a sound source to respective one of the two speakers, an adjusting step of adjusting, by using the second phase adjustment data, phases at respective frequencies of the sound signals input from the sound source and to be input to respective one of the two speakers.

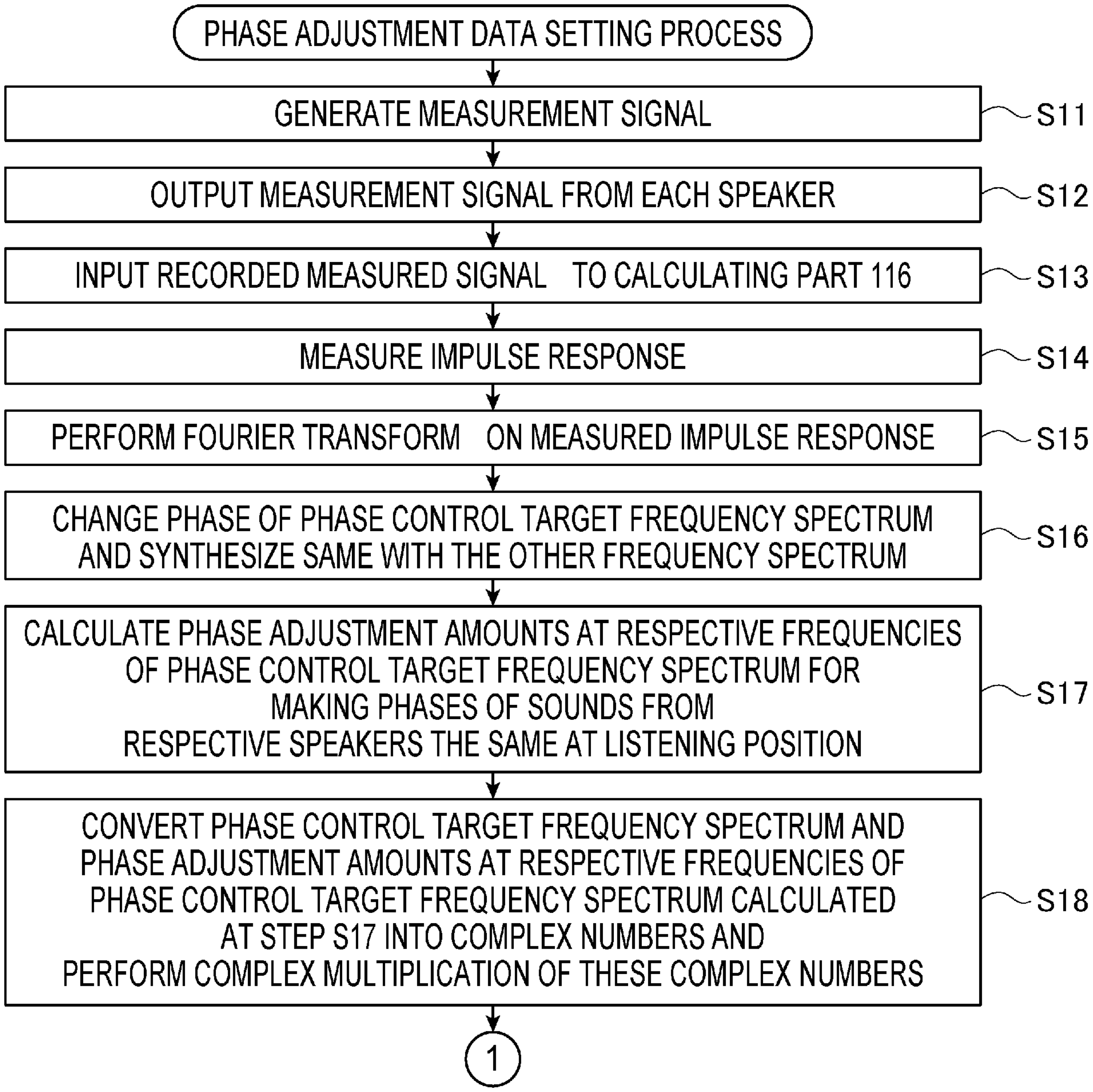
[Fig. 1]



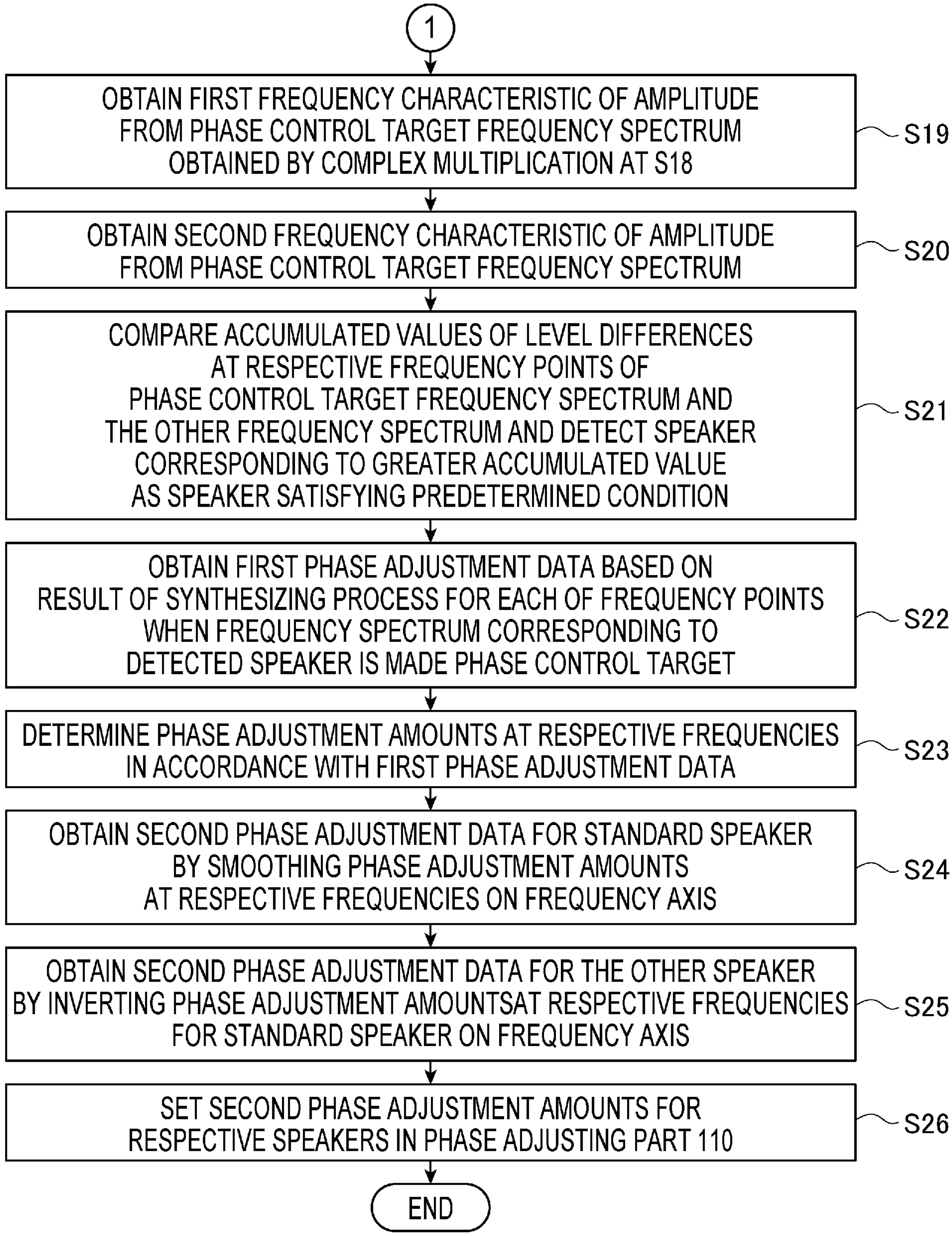
[Fig. 2]


MIC
SP_{FR}
SP_{FL}
1
10
ACOUSTIC DEVICE
112
AMPLIFIER
110
PHASE ADJUSTING PART
116
CALCULATING PART
114
SIGNAL RECORDING PART
100
CONTROLLER
106
MEASUREMENT SIGNAL GENERATING PART
108
RECORDING MEDIUM REPRODUCING PART
104
OPERATING PART
102
DISPLAY PART

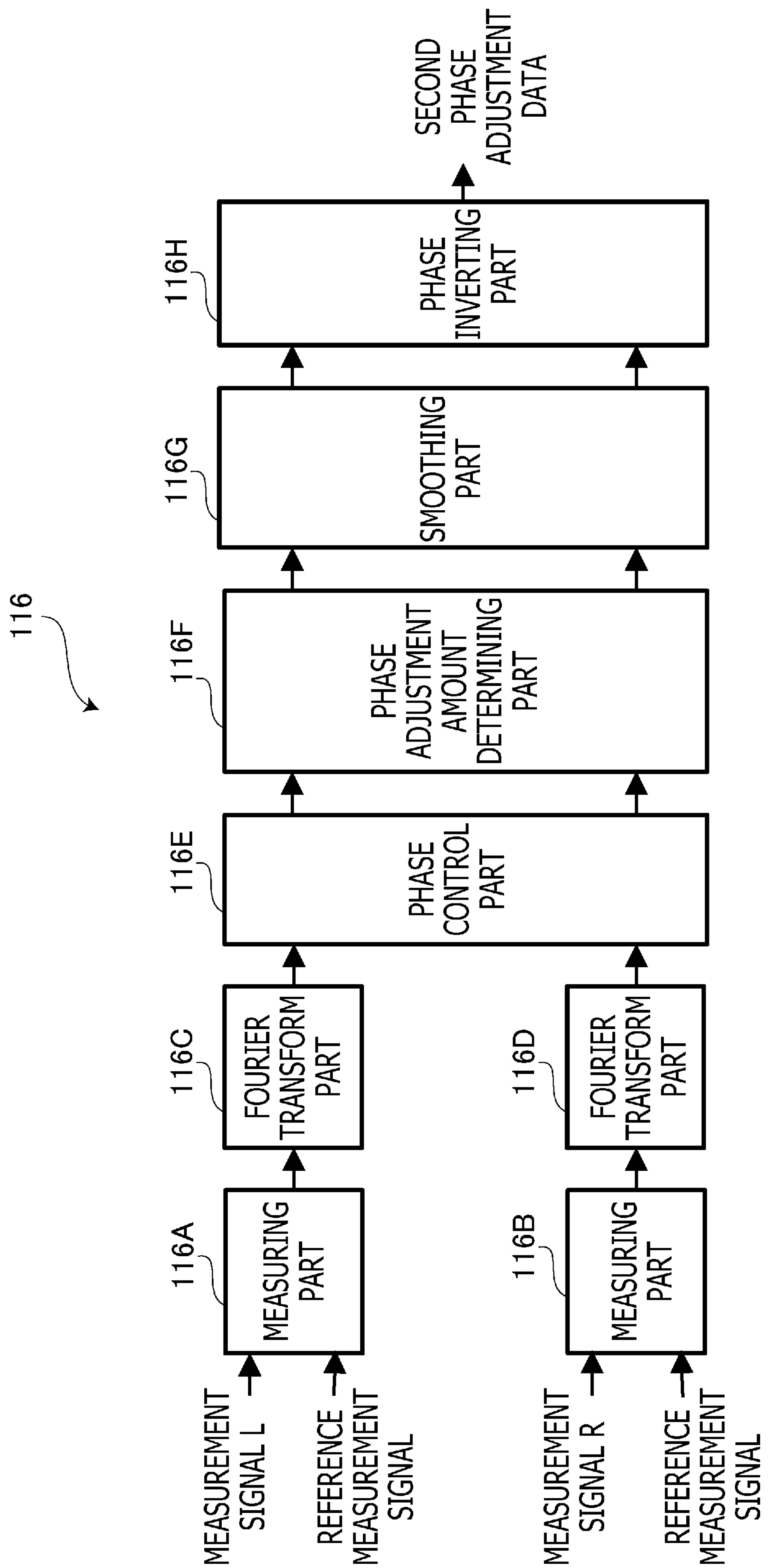
[Fig. 3A]


PHASE ADJUSTMENT DATA SETTING PROCESS
GENERATE MEASUREMENT SIGNAL
S11
OUTPUT MEASUREMENT SIGNAL FROM EACH SPEAKER
S12
INPUT RECORDED MEASURED SIGNAL TO CALCULATING PART 116
S13
MEASURE IMPULSE RESPONSE
S14
PERFORM FOURIER TRANSFORM ON MEASURED IMPULSE RESPONSE
S15
CHANGE PHASE OF PHASE CONTROL TARGET FREQUENCY SPECTRUM AND SYNTHESIZE SAME WITH THE OTHER FREQUENCY SPECTRUM
S16
CALCULATE PHASE ADJUSTMENT AMOUNTS AT RESPECTIVE FREQUENCIES OF PHASE CONTROL TARGET FREQUENCY SPECTRUM FOR MAKING PHASES OF SOUNDS FROM RESPECTIVE SPEAKERS THE SAME AT LISTENING POSITION
S17
CONVERT PHASE CONTROL TARGET FREQUENCY SPECTRUM AND PHASE ADJUSTMENT AMOUNTS AT RESPECTIVE FREQUENCIES OF PHASE CONTROL TARGET FREQUENCY SPECTRUM CALCULATED AT STEP S17 INTO COMPLEX NUMBERS AND PERFORM COMPLEX MULTIPLICATION OF THESE COMPLEX NUMBERS
S18
1

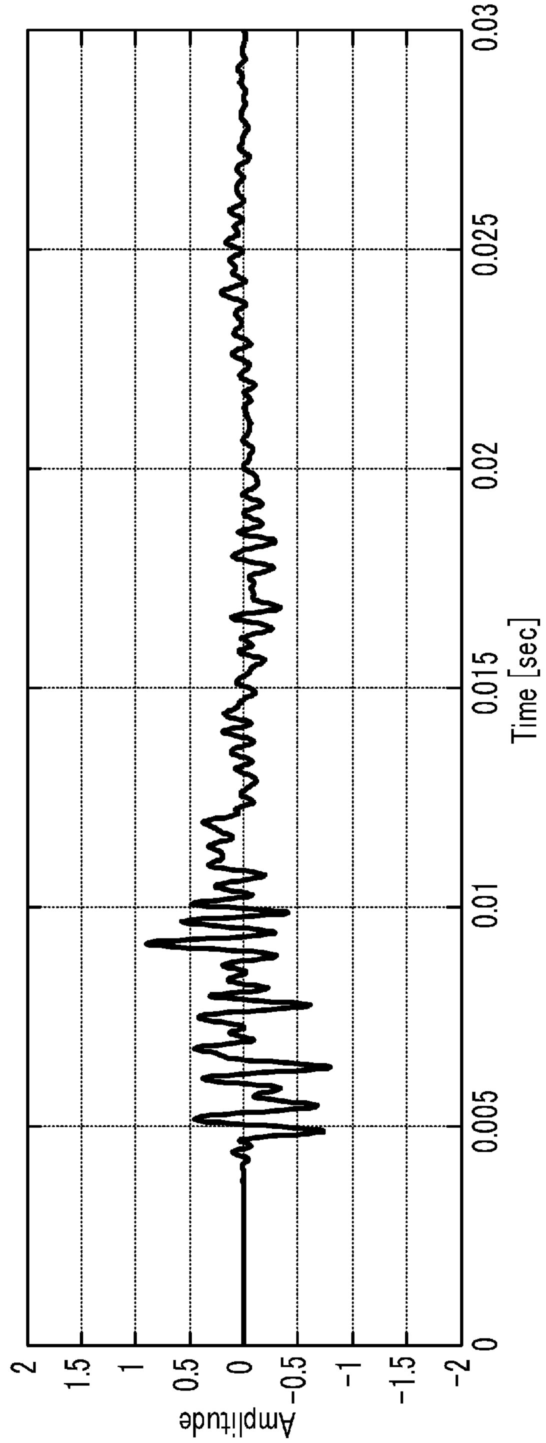
[Fig. 3B]


1
OBTAIN FIRST FREQUENCY CHARACTERISTIC OF AMPLITUDE FROM PHASE CONTROL TARGET FREQUENCY SPECTRUM OBTAINED BY COMPLEX MULTIPLICATION AT S18
S19
OBTAIN SECOND FREQUENCY CHARACTERISTIC OF AMPLITUDE FROM PHASE CONTROL TARGET FREQUENCY SPECTRUM
S20
COMPARE ACCUMULATED VALUES OF LEVEL DIFFERENCES AT RESPECTIVE FREQUENCY POINTS OF PHASE CONTROL TARGET FREQUENCY SPECTRUM AND THE OTHER FREQUENCY SPECTRUM AND DETECT SPEAKER CORRESPONDING TO GREATER ACCUMULATED VALUE AS SPEAKER SATISFYING PREDETERMINED CONDITION
S21
OBTAIN FIRST PHASE ADJUSTMENT DATA BASED ON RESULT OF SYNTHESIZING PROCESS FOR EACH OF FREQUENCY POINTS WHEN FREQUENCY SPECTRUM CORRESPONDING TO DETECTED SPEAKER IS MADE PHASE CONTROL TARGET
S22
DETERMINE PHASE ADJUSTMENT AMOUNTS AT RESPECTIVE FREQUENCIES IN ACCORDANCE WITH FIRST PHASE ADJUSTMENT DATA
S23
OBTAIN SECOND PHASE ADJUSTMENT DATA FOR STANDARD SPEAKER BY SMOOTHING PHASE ADJUSTMENT AMOUNTS AT RESPECTIVE FREQUENCIES ON FREQUENCY AXIS
S24
OBTAIN SECOND PHASE ADJUSTMENT DATA FOR THE OTHER SPEAKER BY INVERTING PHASE ADJUSTMENT AMOUNTSAT RESPECTIVE FREQUENCIES FOR STANDARD SPEAKER ON FREQUENCY AXIS
S25
SET SECOND PHASE ADJUSTMENT AMOUNTS FOR RESPECTIVE SPEAKERS IN PHASE ADJUSTING PART 110
S26
END

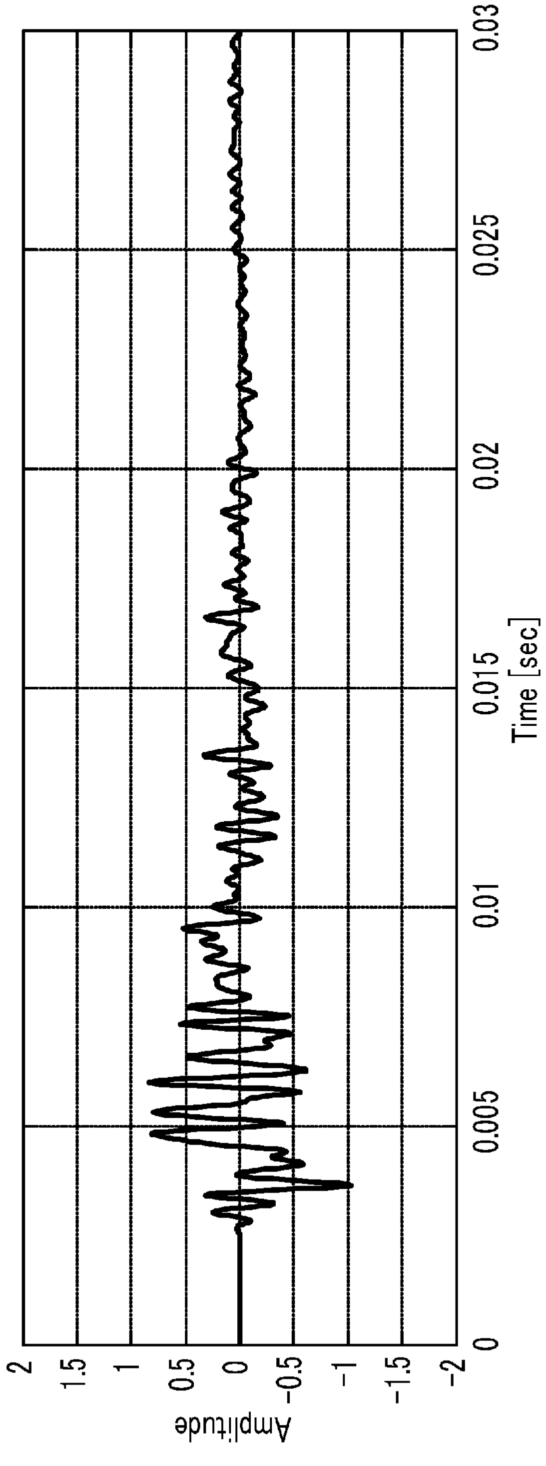
[Fig. 4]


116
MEASUREMENT SIGNAL L
REFERENCE MEASUREMENT SIGNAL
116A
MEASURING PART
116C
FOURIER TRANSFORM PART
MEASUREMENT SIGNAL R
REFERENCE MEASUREMENT SIGNAL
116B
MEASURING PART
116D
FOURIER TRANSFORM PART
116E
PHASE CONTROL PART
116F
PHASE ADJUSTMENT AMOUNT DETERMINING PART
116G
SMOOTHING PART
116H
PHASE INVERTING PART
SECOND PHASE ADJUSTMENT DATA

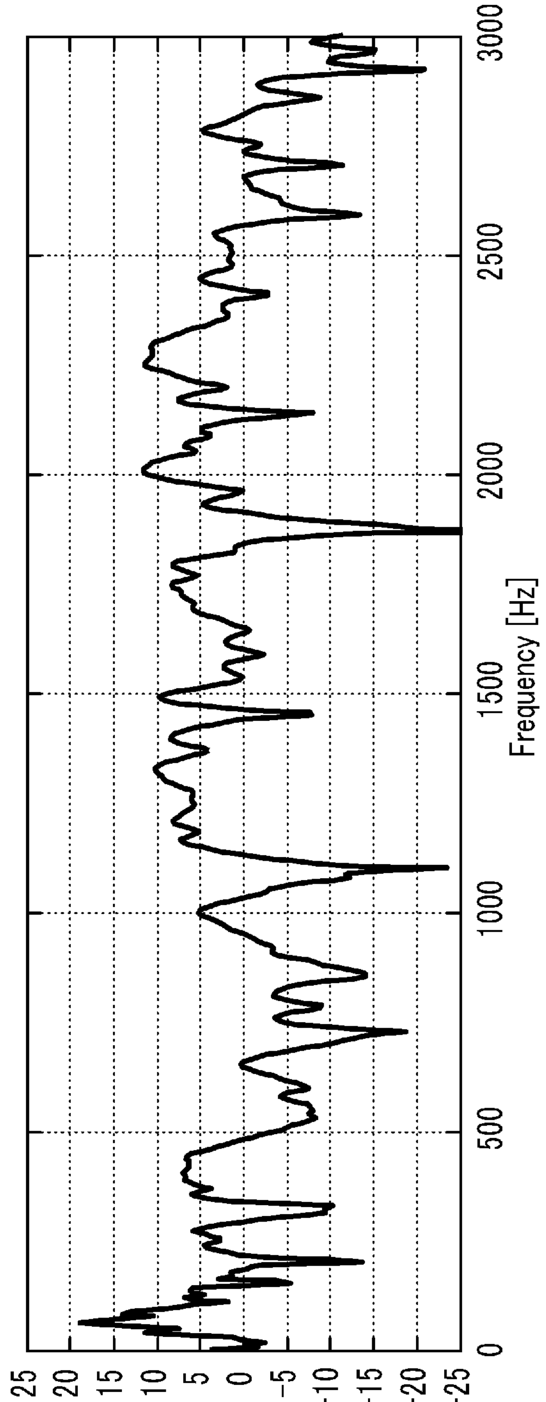
[Fig. 5A]


Amplitude
2
1.5
1
0.5
0
−0.5
−1
−1.5
−2
Time [sec]
0
0.005
0.01
0.015
0.02
0.025
0.03

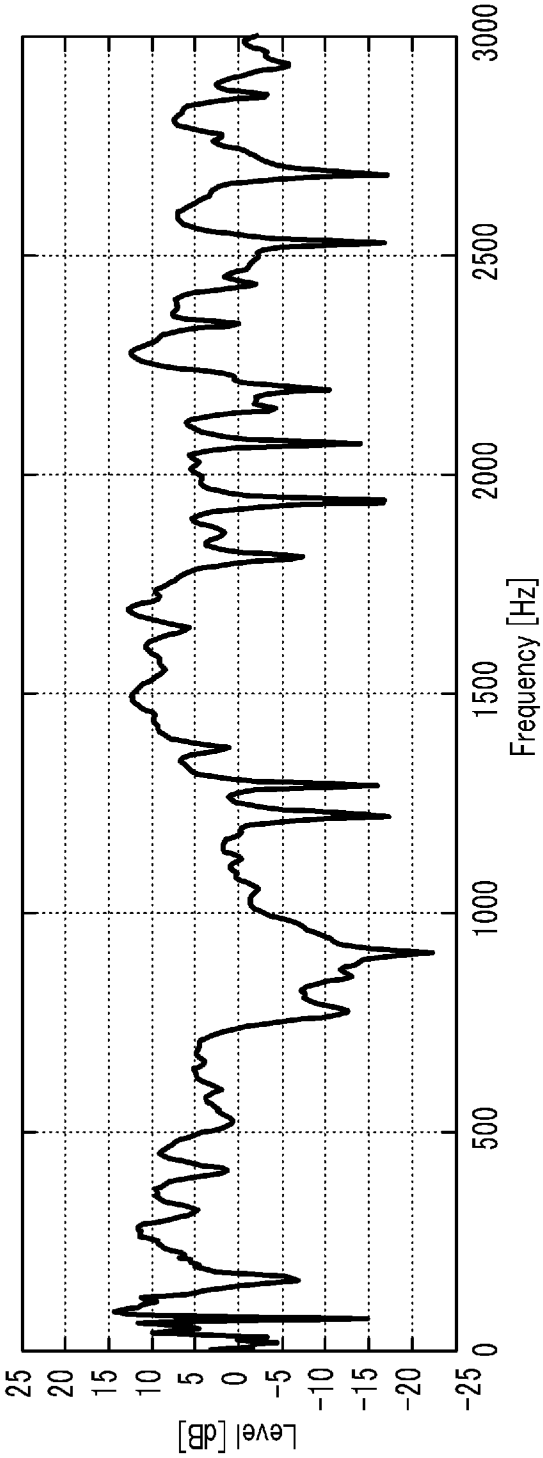
[Fig. 5B]


Amplitude
2
1.5
1
0.5
0
−0.5
−1
−1.5
−2
0
0.005
0.01
0.015
0.02
0.025
0.03
Time [sec]

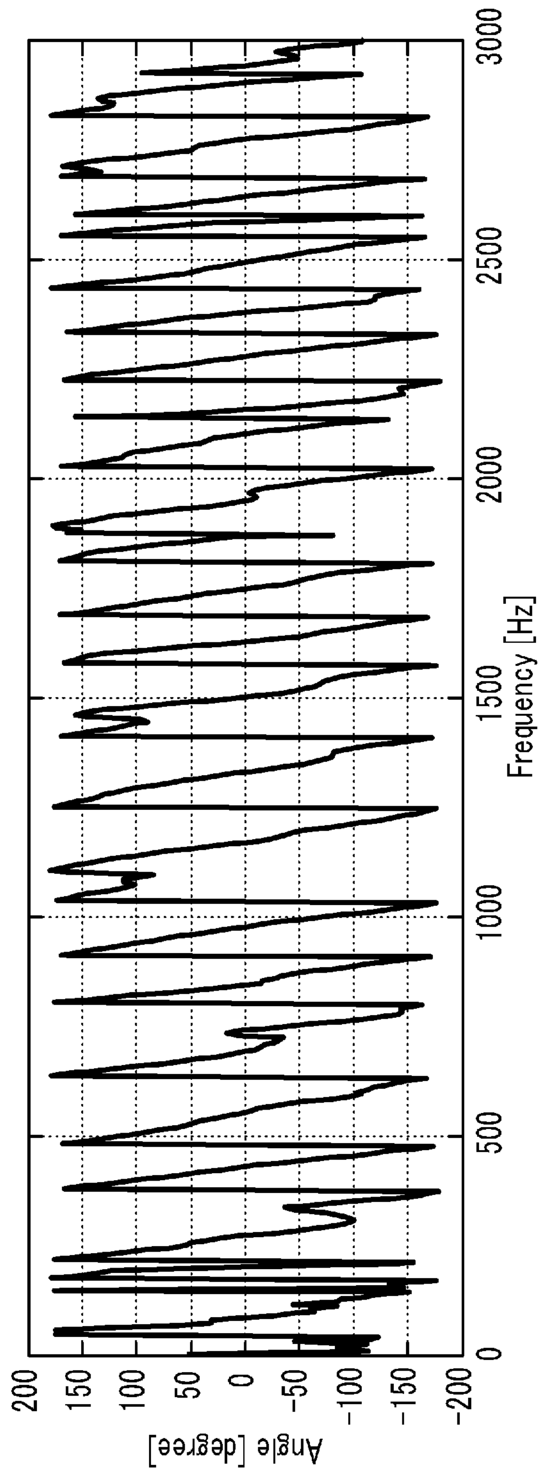
[Fig. 6A]


Level [dB]
25
20
15
10
5
0
-5
-10
-15
-20
-25
0
500
1000
1500
2000
2500
3000
Frequency [Hz]

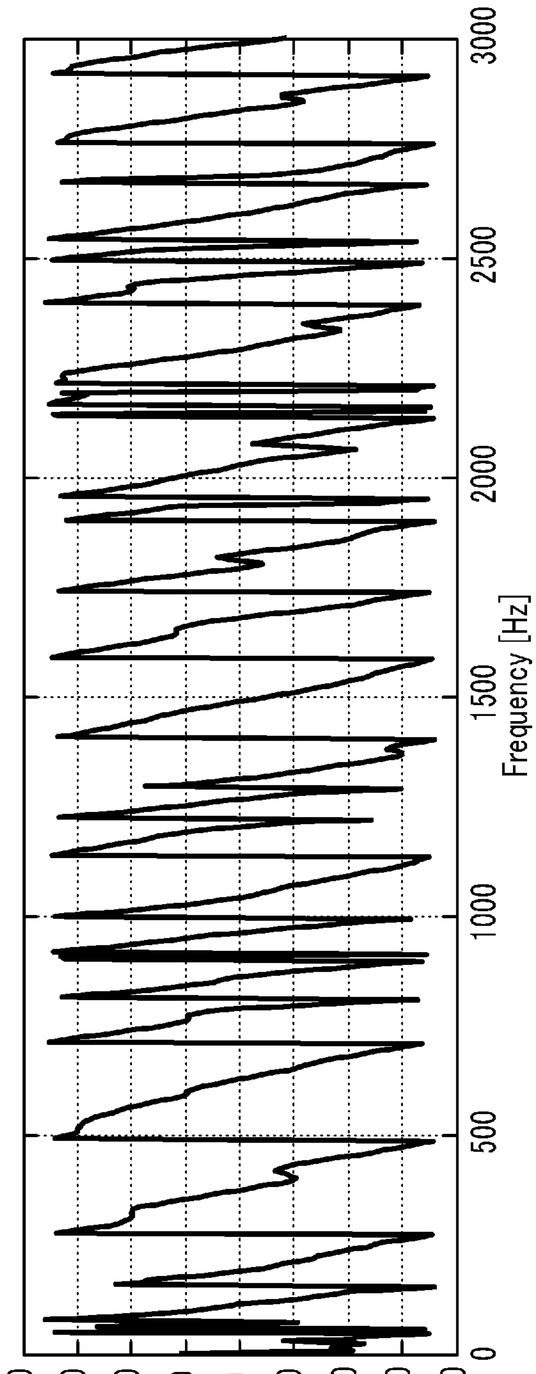
[Fig. 6B]


Level [dB]
25
20
15
10
5
0
-5
-10
-15
-20
-25
Frequency [Hz]
0
500
1000
1500
2000
2500
3000

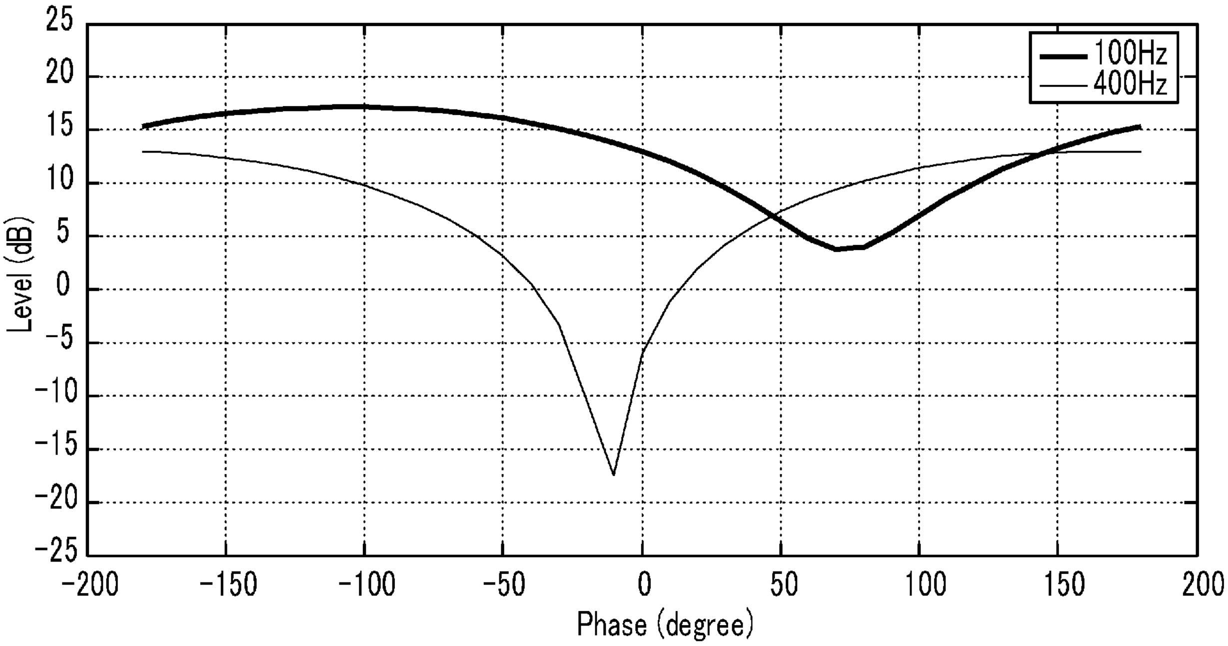
[Fig. 7A]


Angle [degree]
200
150
100
50
0
-50
-100
-150
-200
0
500
1000
1500
2000
2500
3000
Frequency [Hz]

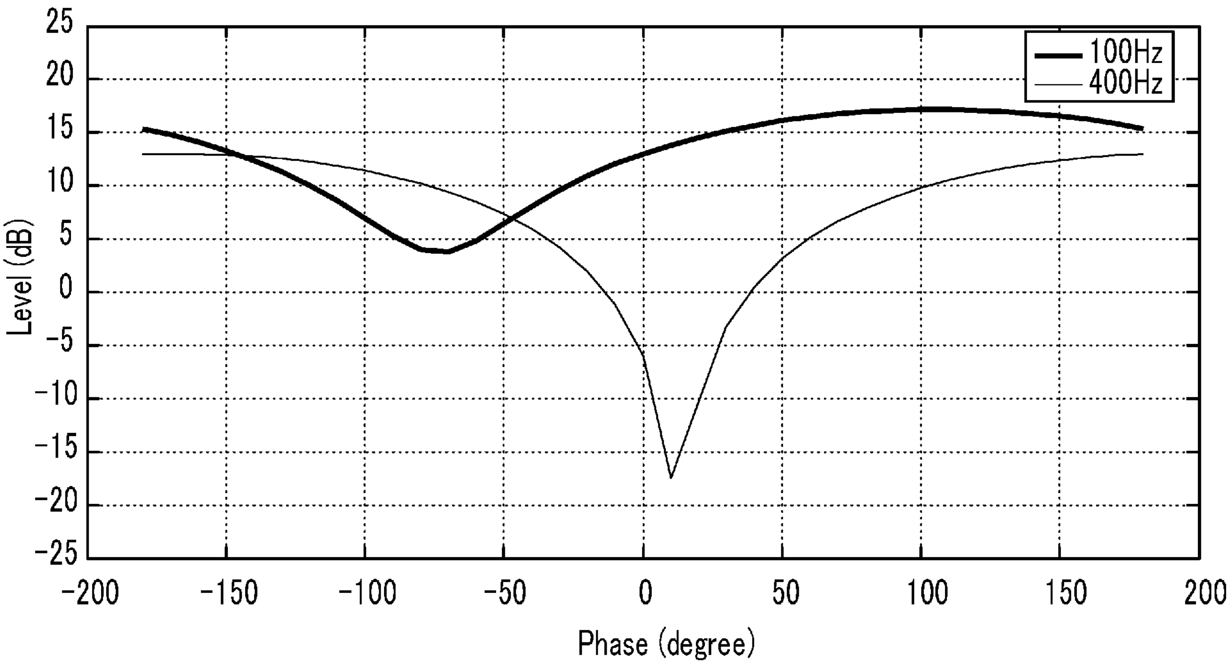
[Fig. 7B]


Angle [degree]
200
150
100
50
0
-50
-100
-150
-200
Frequency [Hz]
0
500
1000
1500
2000
2500
3000

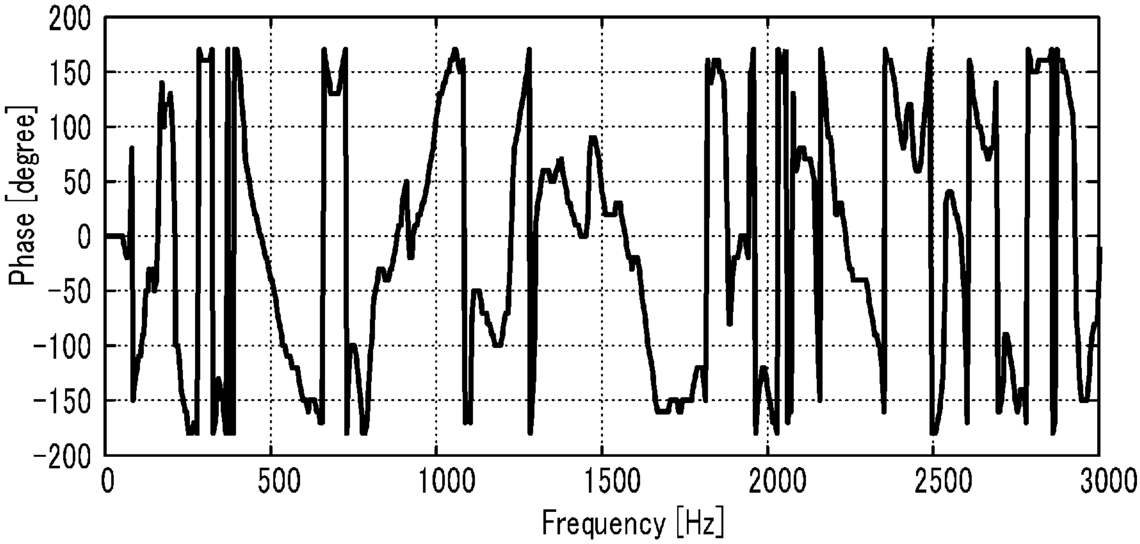
[Fig. 8A]


25
20
15
10
5
0
−5
−10
−15
−20
−25
Level (dB)
−200
−150
−100
−50
0
50
100
150
200
Phase (degree)
100Hz
400Hz

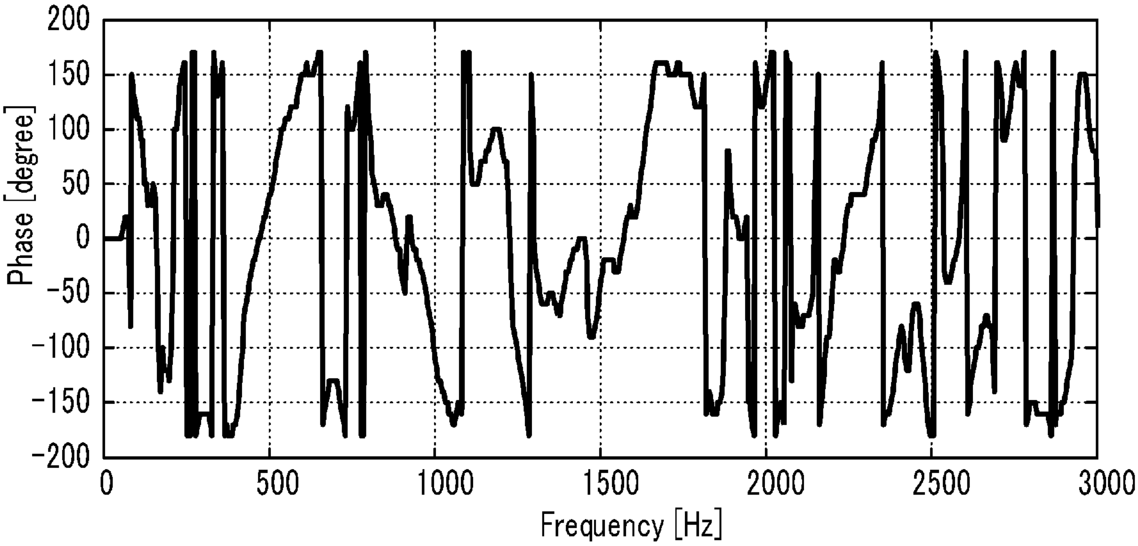
[Fig. 8B]


25
20
15
10
5
0
−5
−10
−15
−20
−25
Level (dB)
−200
−150
−100
−50
0
50
100
150
200
Phase (degree)
100Hz
400Hz

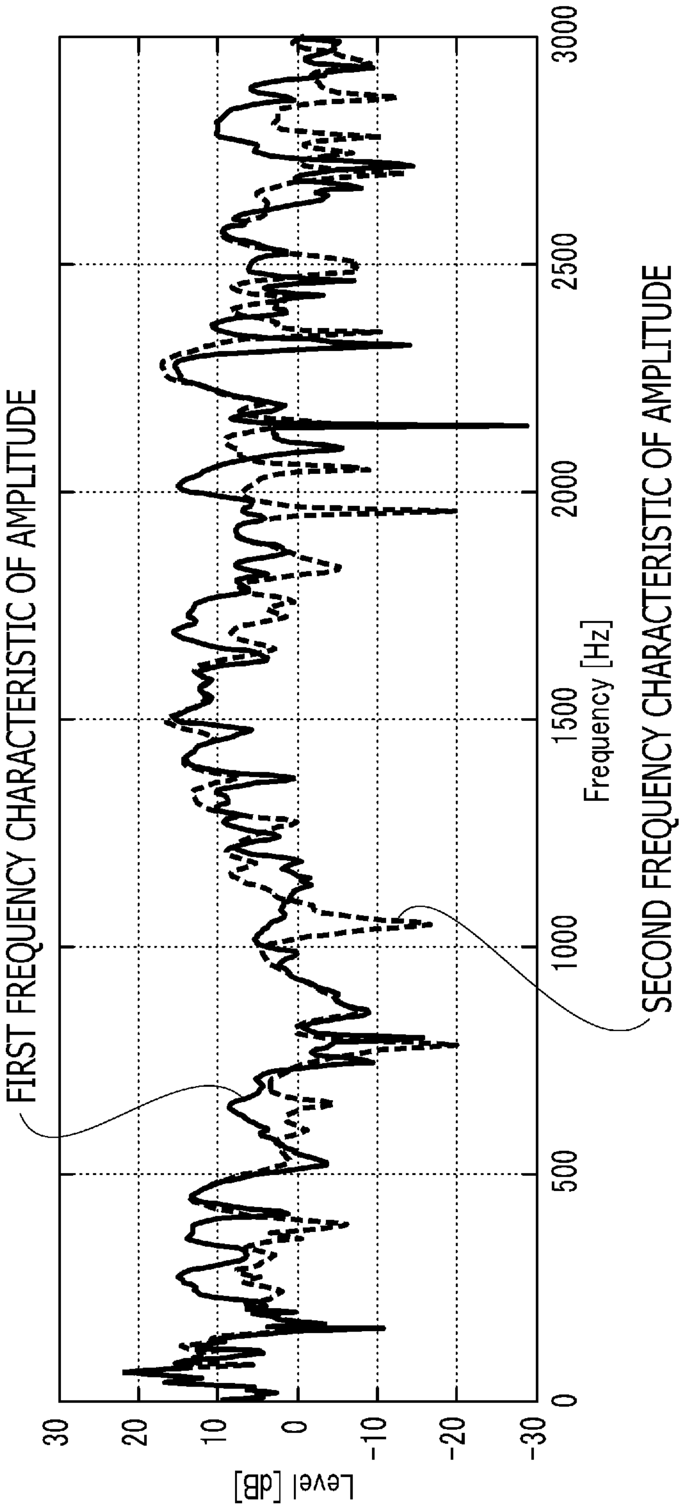
[Fig. 9A]


200
150
100
50
0
-50
-100
-150
-200
Phase [degree]
0
500
1000
1500
2000
2500
3000
Frequency [Hz]

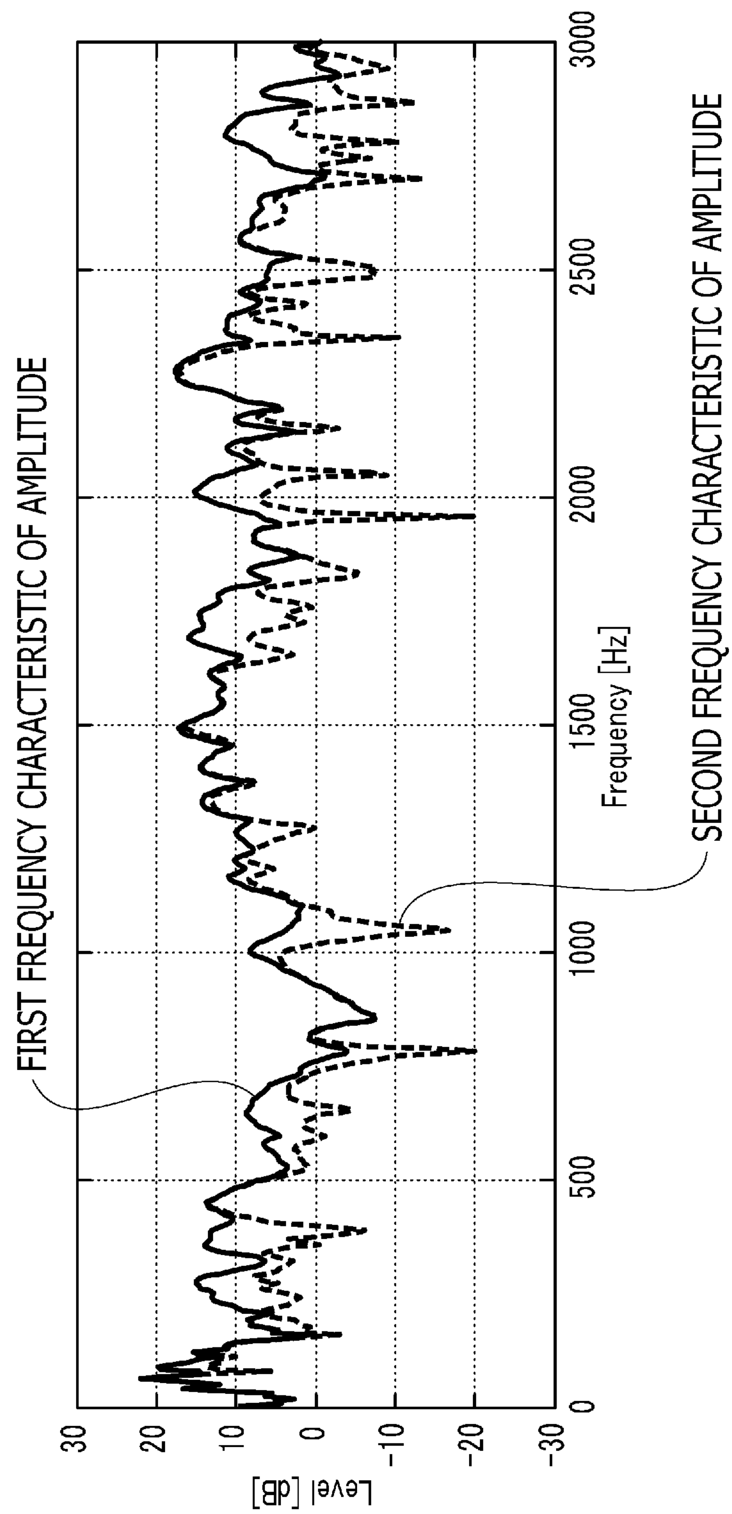
[Fig. 9B]


200
150
100
50
0
-50
-100
-150
-200
Phase [degree]
0
500
1000
1500
2000
2500
3000
Frequency [Hz]

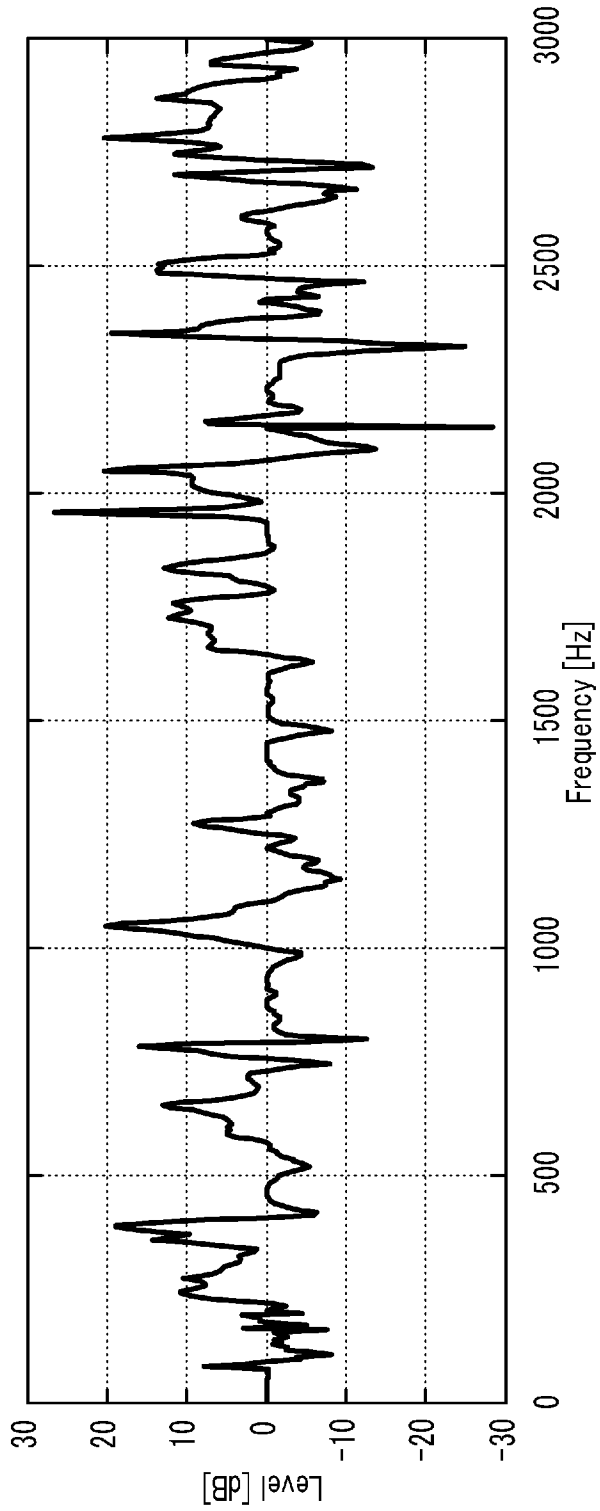
[Fig. 10A]


FIRST FREQUENCY CHARACTERISTIC OF AMPLITUDE
SECOND FREQUENCY CHARACTERISTIC OF AMPLITUDE
Level [dB]
30
20
10
0
-10
-20
-30
Frequency [Hz]
0
500
1000
1500
2000
2500
3000

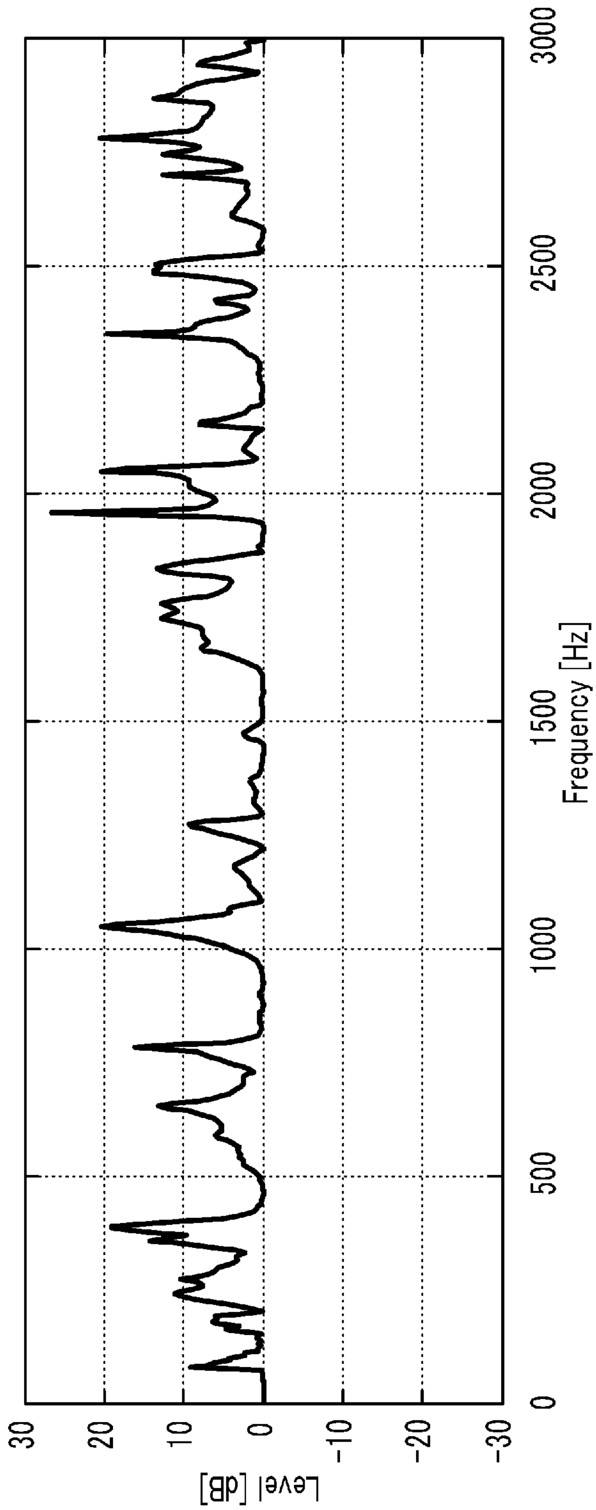
[Fig. 10B]


FIRST FREQUENCY CHARACTERISTIC OF AMPLITUDE
SECOND FREQUENCY CHARACTERISTIC OF AMPLITUDE
Frequency [Hz]
0
500
1000
1500
2000
2500
3000
Level [dB]
30
20
10
0
−10
−20
−30

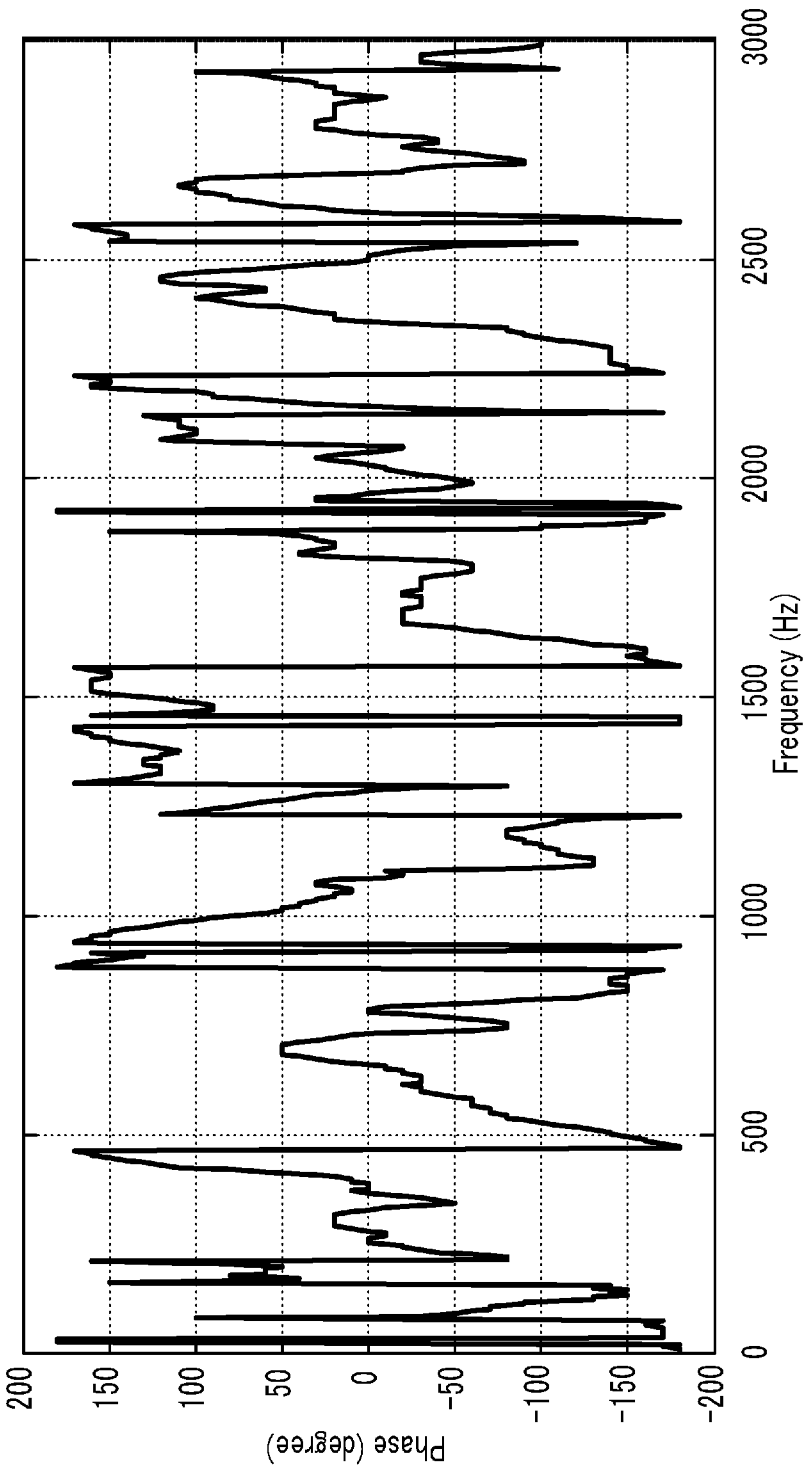
[Fig. 11A]


Level [dB]
30
20
10
0
-10
-20
-30
0
500
1000
1500
2000
2500
3000
Frequency [Hz]

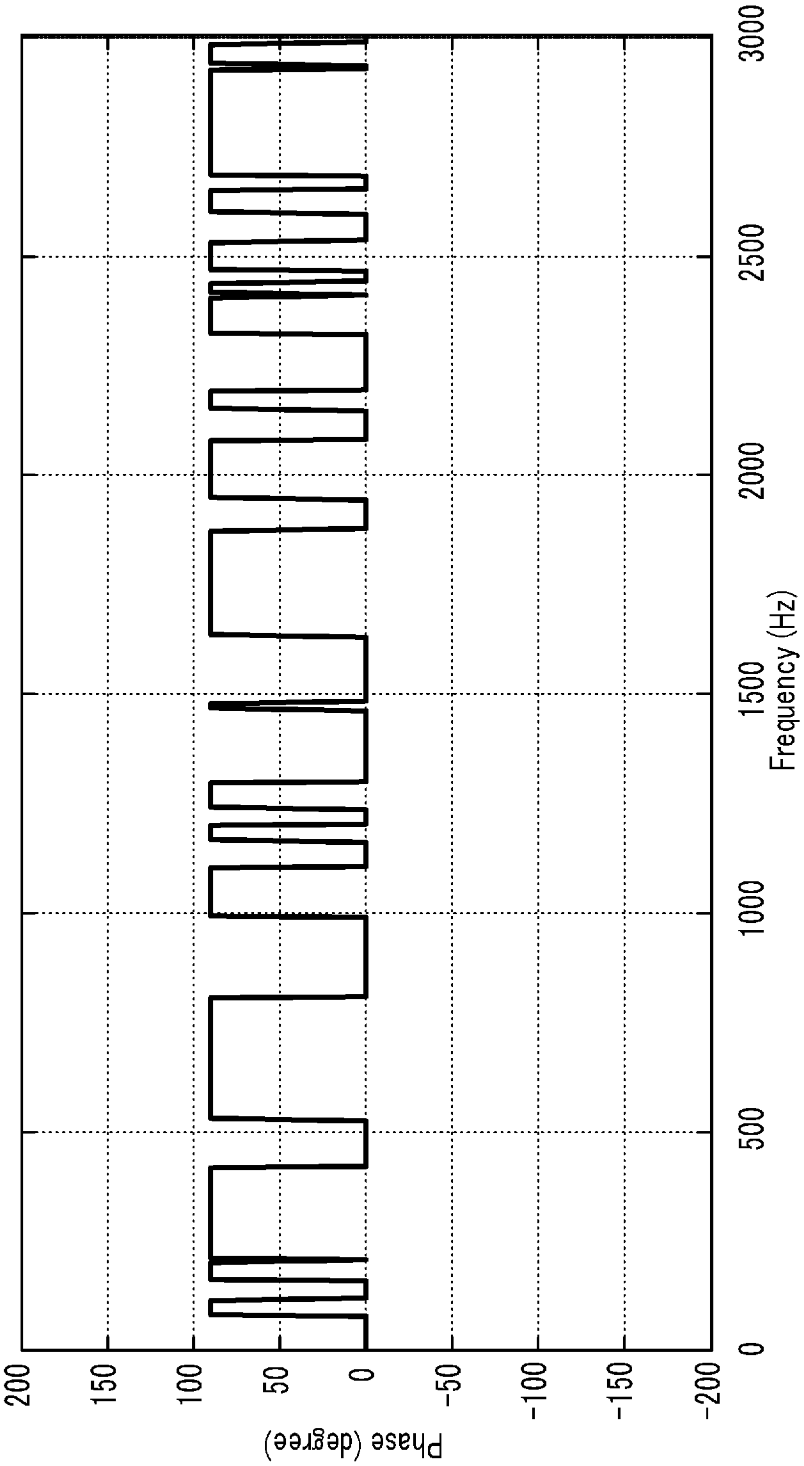
[Fig. 11B]


Level [dB]
30
20
10
0
-10
-20
-30
Frequency [Hz]
0
500
1000
1500
2000
2500
3000

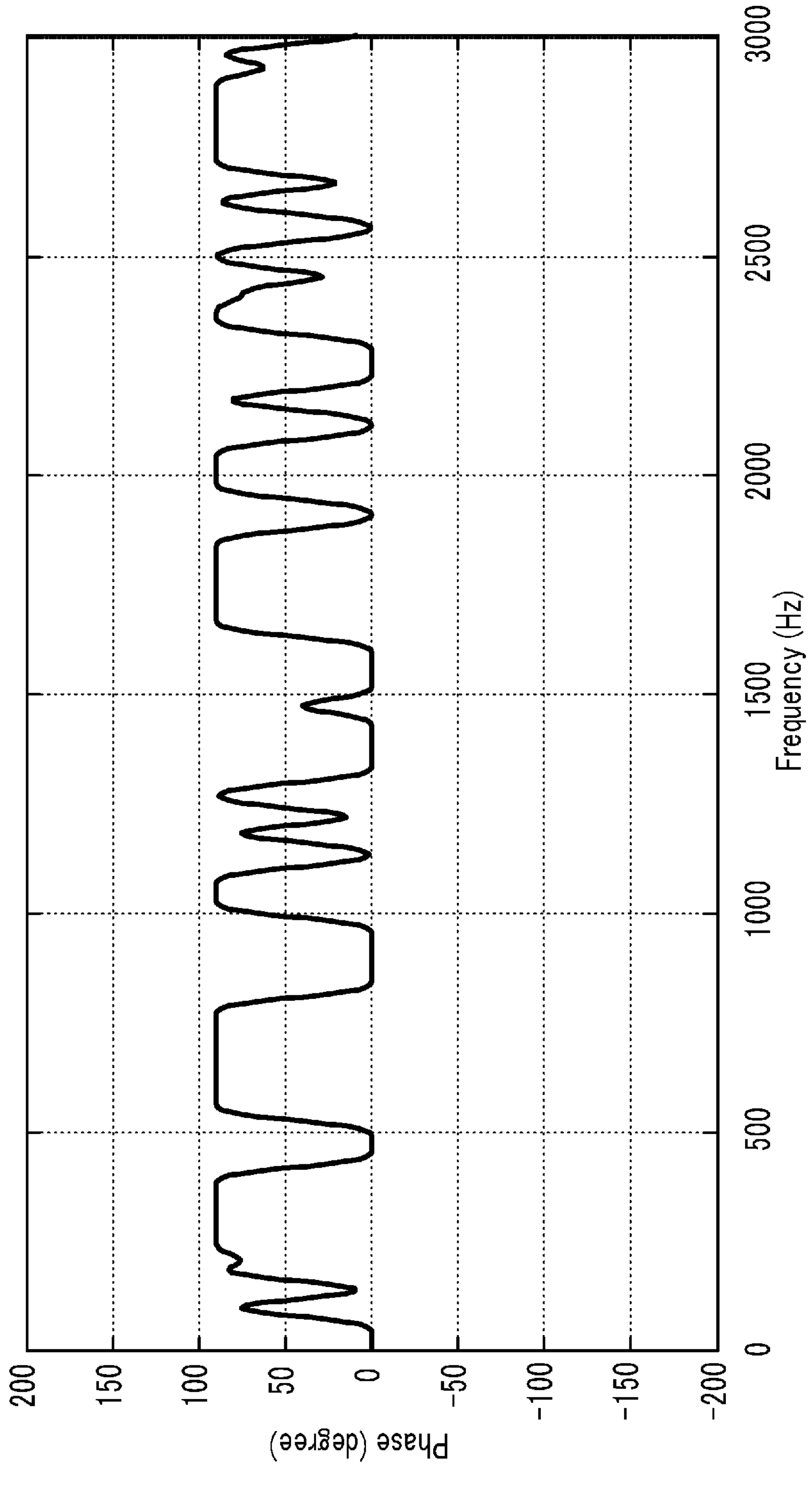
[Fig. 12]


Phase (degree)
200
150
100
50
0
−50
−100
−150
−200
0
500
1000
1500
2000
2500
3000
Frequency (Hz)

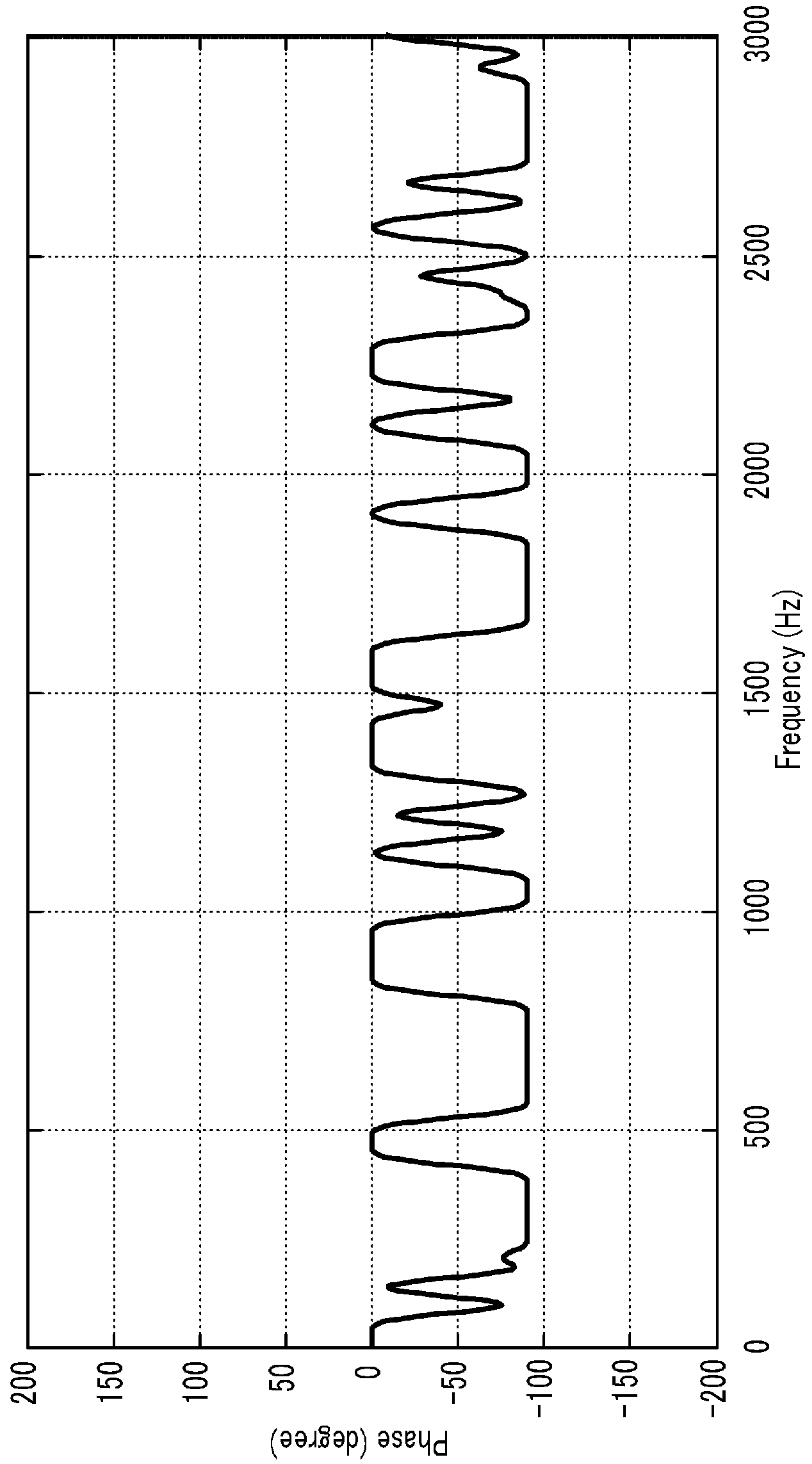
[Fig. 13]


Phase (degree)
200
150
100
50
0
-50
-100
-150
-200
Frequency (Hz)
0
500
1000
1500
2000
2500
3000

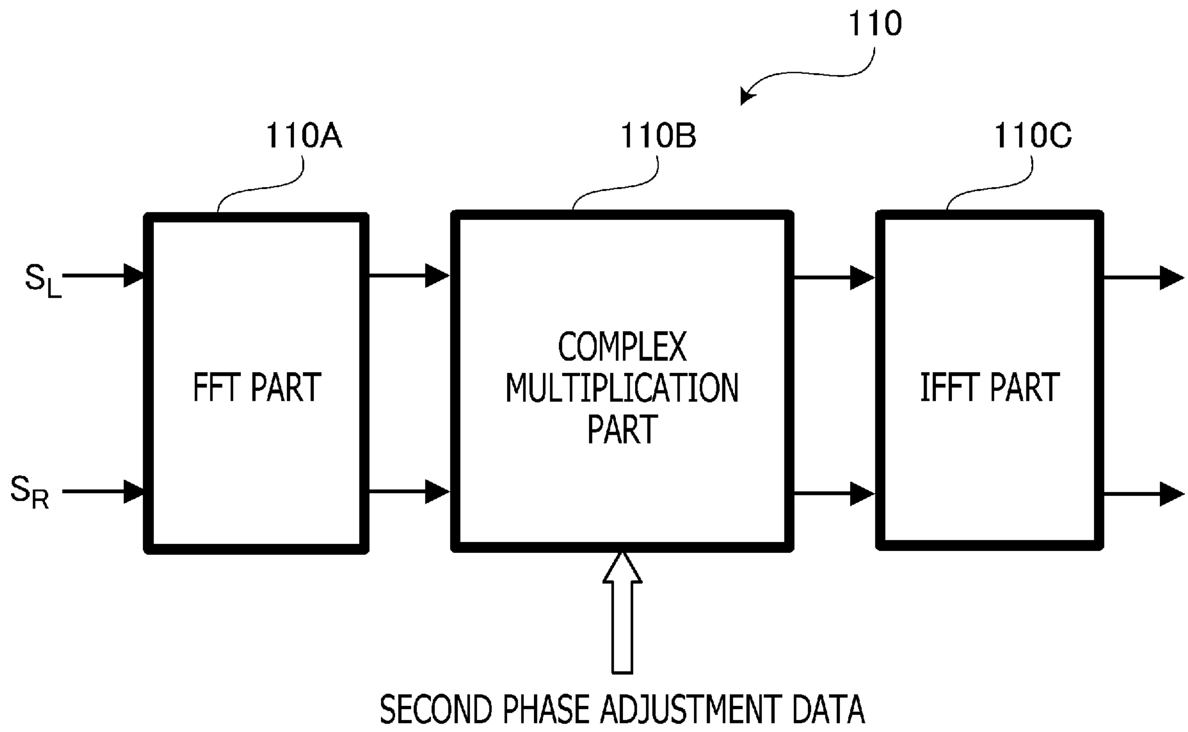
[Fig. 14]


Phase (degree)
200
150
100
50
0
−50
−100
−150
−200
Frequency (Hz)
0
500
1000
1500
2000
2500
3000

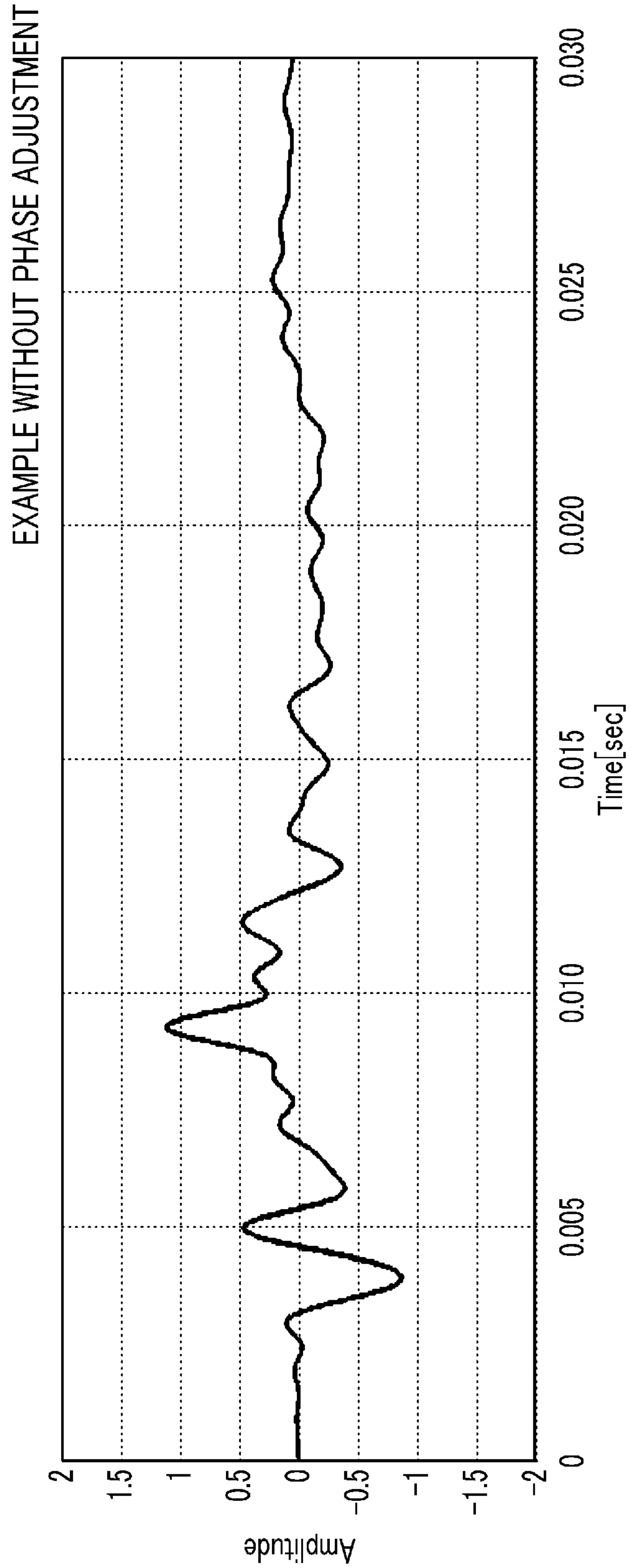
[Fig. 15]


Phase (degree)
200
150
100
50
0
-50
-100
-150
-200
Frequency (Hz)
0
500
1000
1500
2000
2500
3000

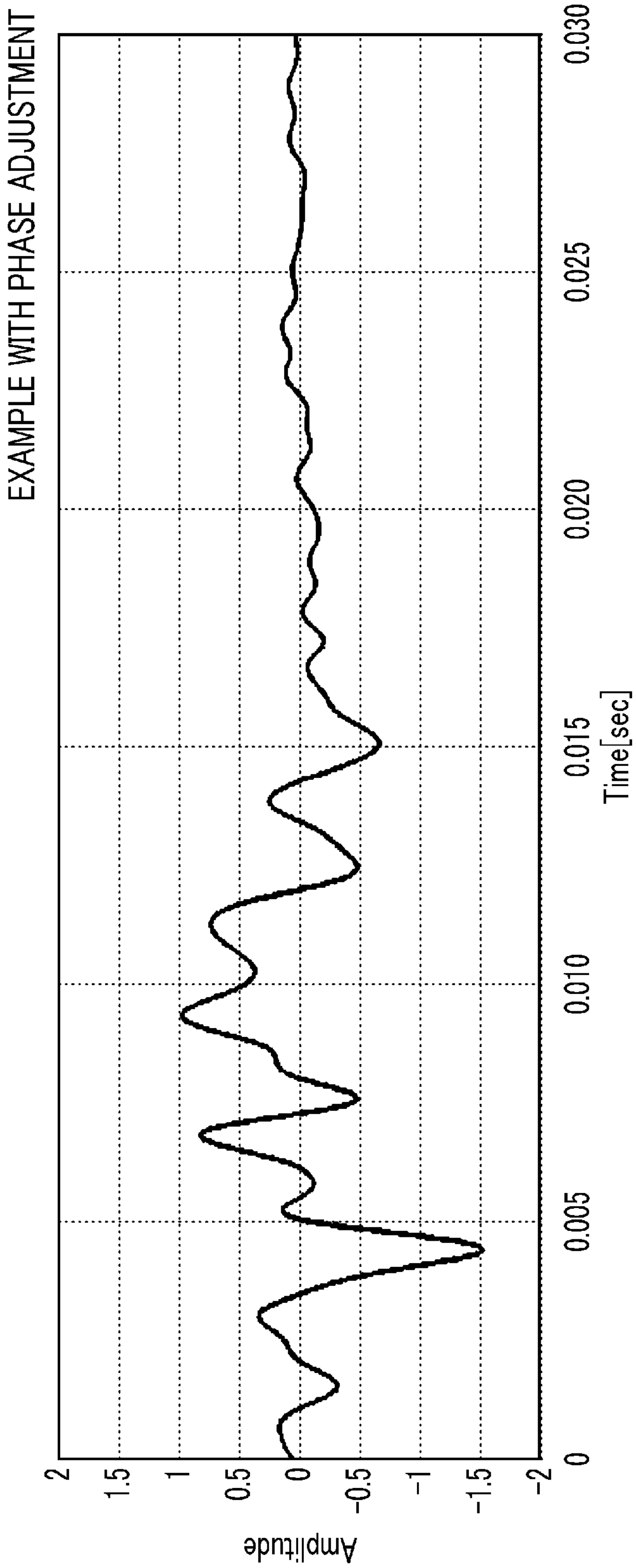
[Fig. 16]


110
110A
110B
110C
S_L
S_R
FFT PART
COMPLEX MULTIPLICATION PART
IFFT PART
SECOND PHASE ADJUSTMENT DATA

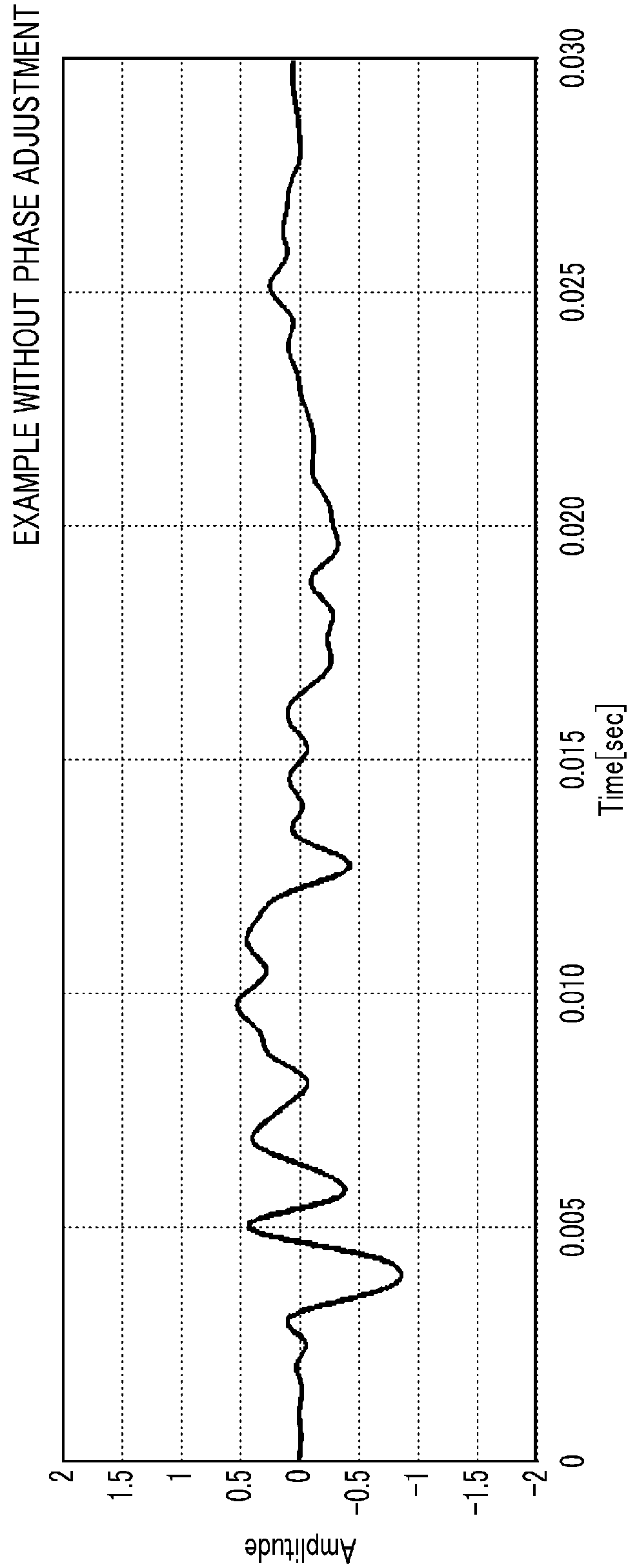
[Fig. 17A]


EXAMPLE WITHOUT PHASE ADJUSTMENT
Amplitude
2
1.5
1
0.5
0
−0.5
−1
−1.5
−2
0
0.005
0.010
0.015
0.020
0.025
0.030
Time[sec]

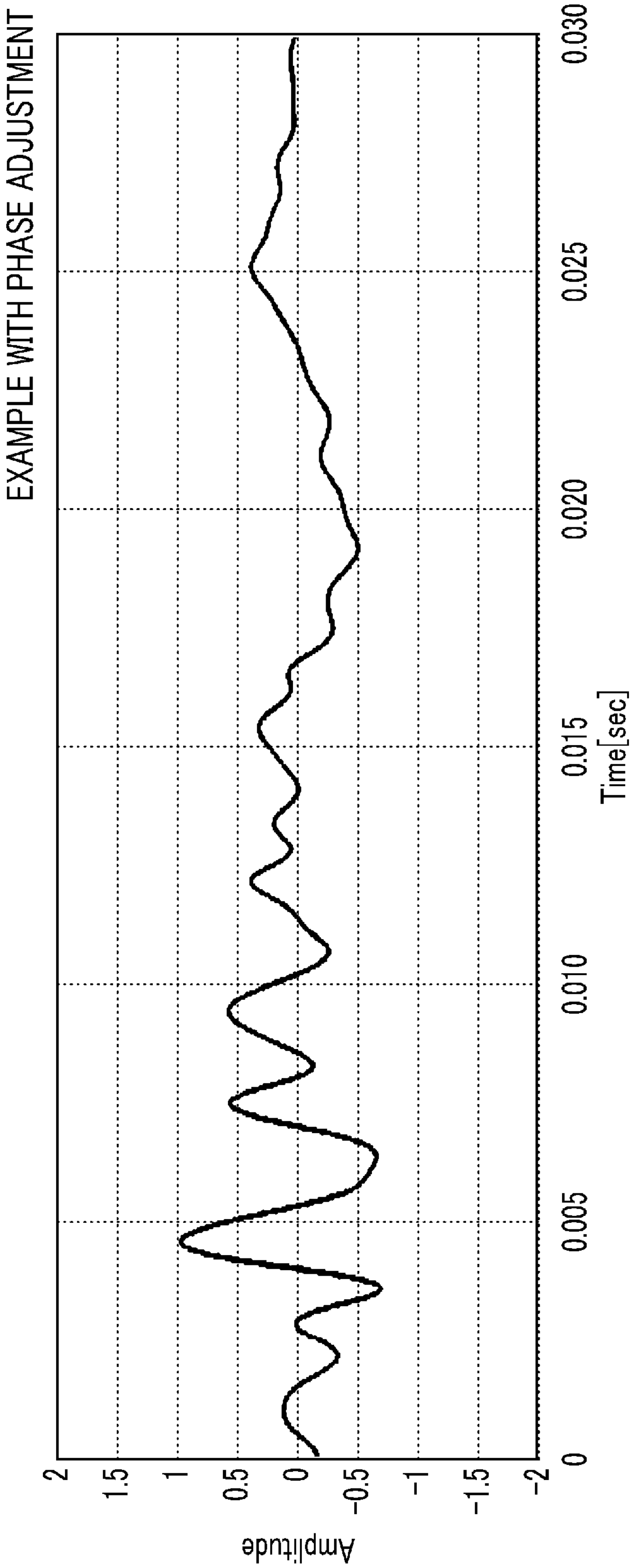
[Fig. 17B]


EXAMPLE WITH PHASE ADJUSTMENT
Amplitude
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
0.005
0.010
0.015
0.020
0.025
0.030
Time[sec]

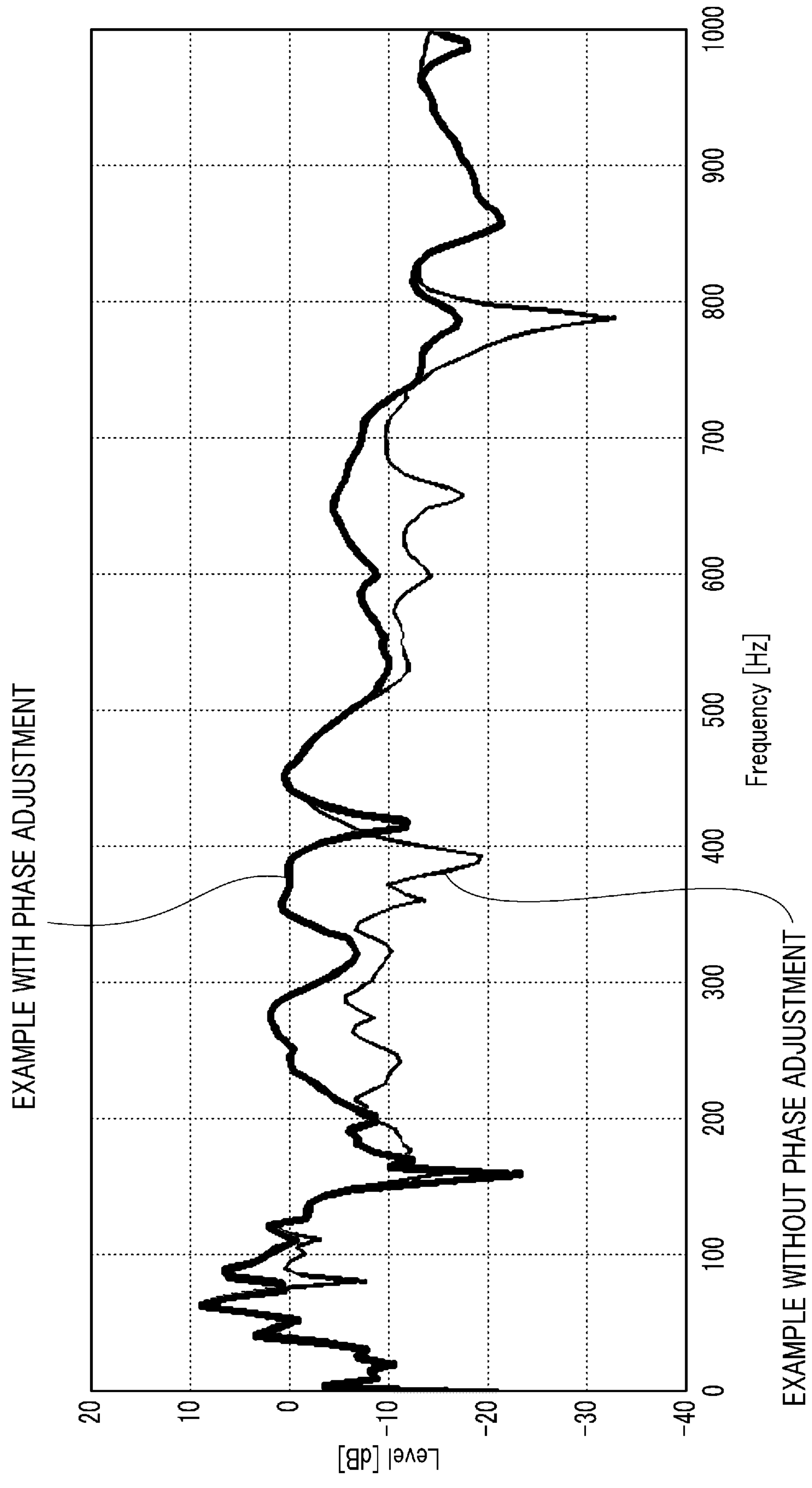
[Fig. 18A]


EXAMPLE WITHOUT PHASE ADJUSTMENT
Amplitude
2
1.5
1
0.5
0
−0.5
−1
−1.5
−2
0
0.005
0.010
0.015
0.020
0.025
0.030
Time[sec]

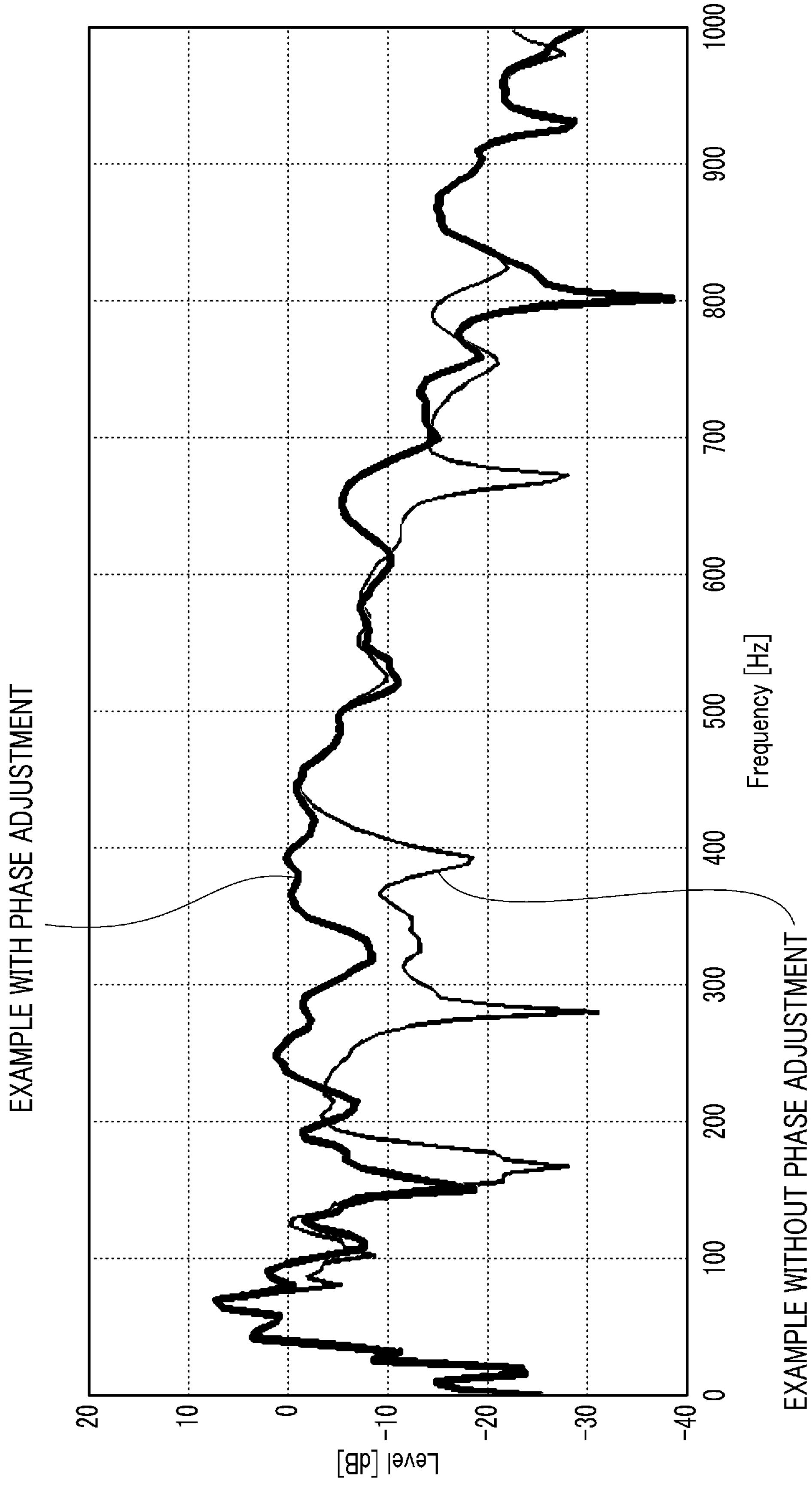
[Fig. 18B]


EXAMPLE WITH PHASE ADJUSTMENT
Amplitude
2
1.5
1
0.5
0
−0.5
−1
−1.5
−2
0
0.005
0.010
0.015
0.020
0.025
0.030
Time[sec]

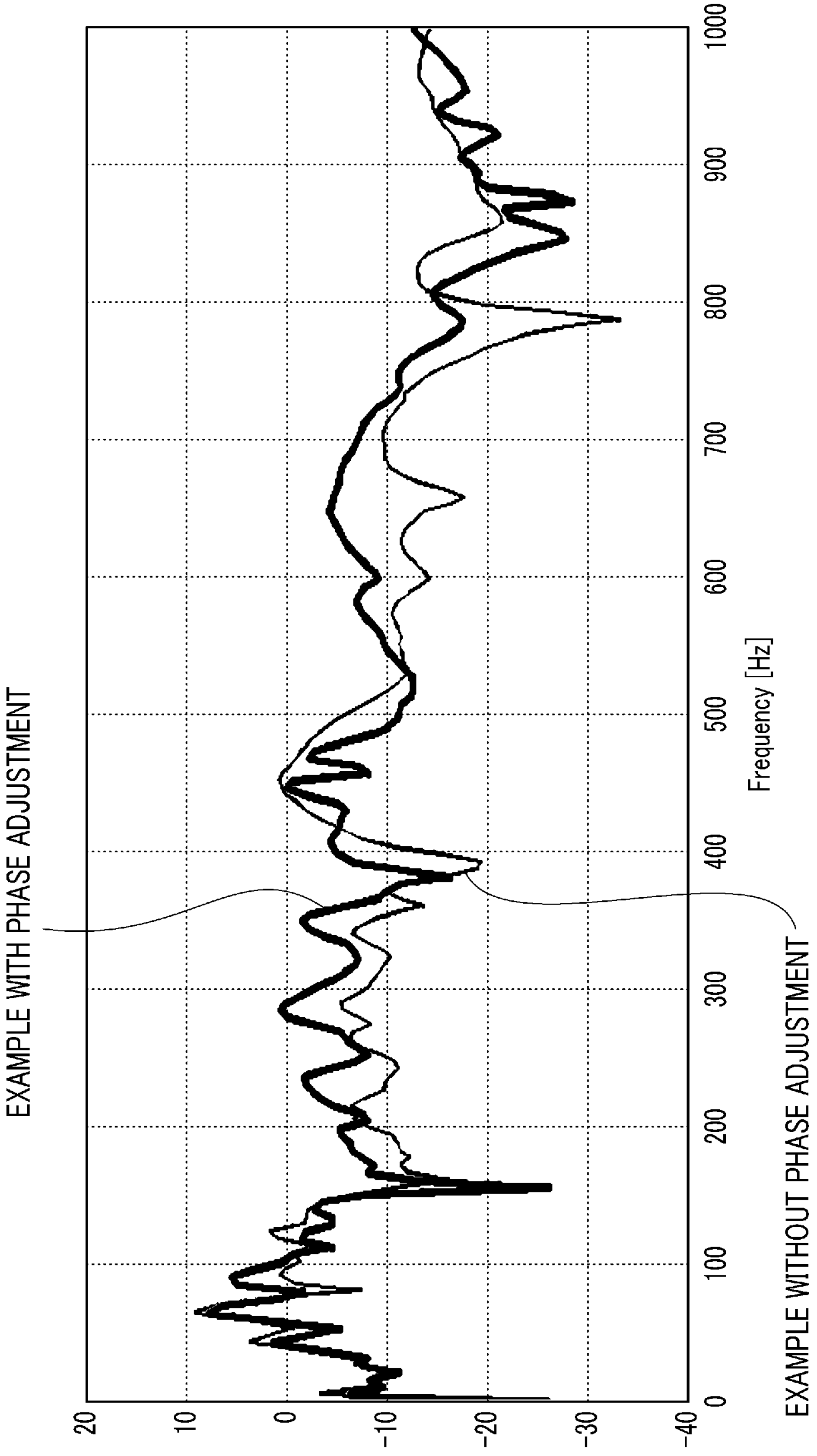
[Fig. 19]


EXAMPLE WITH PHASE ADJUSTMENT
EXAMPLE WITHOUT PHASE ADJUSTMENT
Level [dB]
20
10
0
-10
-20
-30
-40
Frequency [Hz]
0
100
200
300
400
500
600
700
800
900
1000

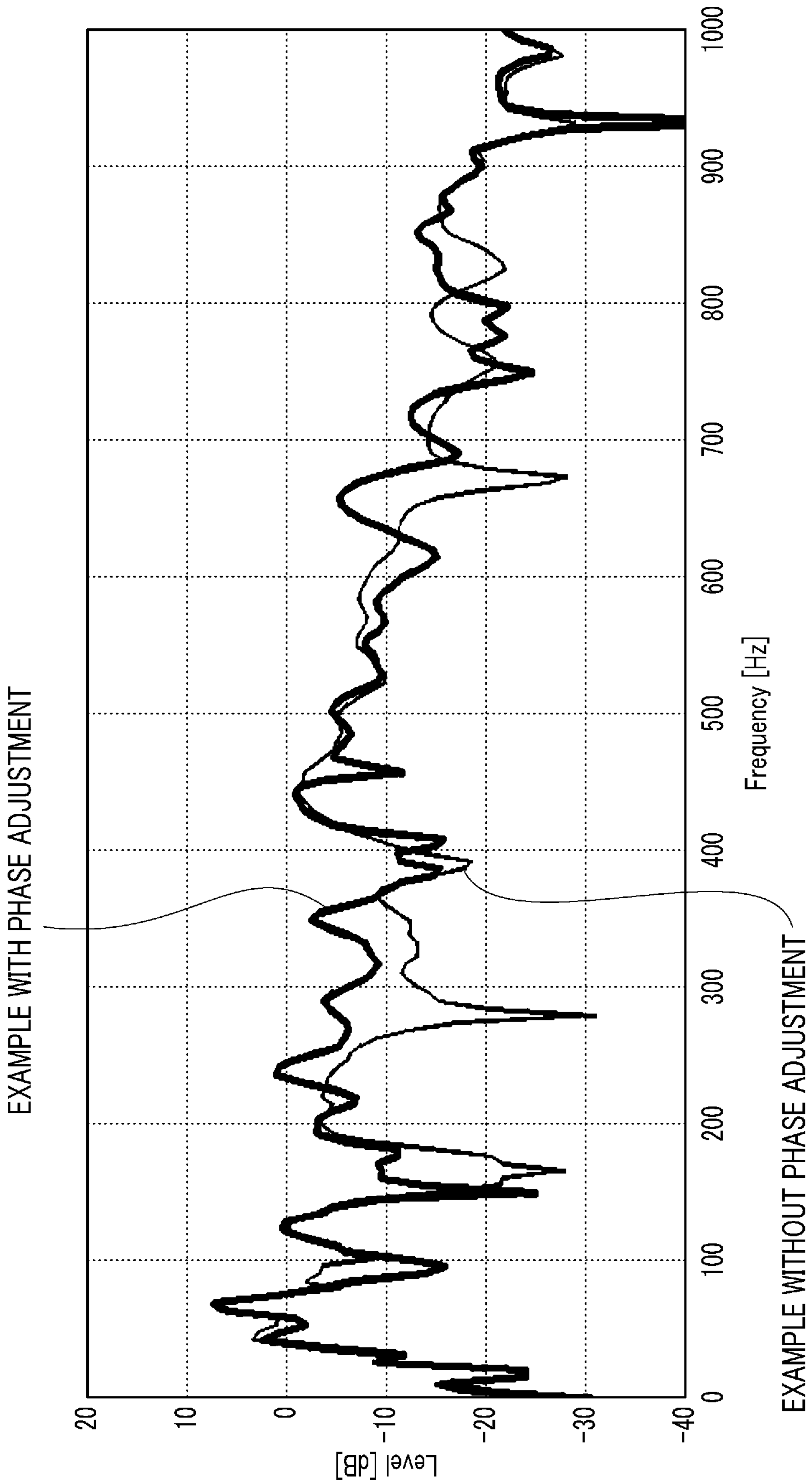
[Fig. 20]


EXAMPLE WITH PHASE ADJUSTMENT
EXAMPLE WITHOUT PHASE ADJUSTMENT
Level [dB]
20
10
0
-10
-20
-30
-40
Frequency [Hz]
0
100
200
300
400
500
600
700
800
900
1000

[Fig. 21]


EXAMPLE WITH PHASE ADJUSTMENT
EXAMPLE WITHOUT PHASE ADJUSTMENT
Level [dB]
Frequency [Hz]
20
10
0
-10
-20
-30
-40
0
100
200
300
400
500
600
700
800
900
1000

[Fig. 22]


EXAMPLE WITH PHASE ADJUSTMENT
EXAMPLE WITHOUT PHASE ADJUSTMENT
Level [dB]
20
10
0
-10
-20
-30
-40
Frequency [Hz]
0
100
200
300
400
500
600
700
800
900
1000

PATENT COOPERATION TREATY

PCT

DECLARATION OF NON-ESTABLISHMENT OF INTERNATIONAL SEARCH REPORT

(PCT Article 17(2)(a), Rules 13ter.1(c) and Rule 39)

Applicant's or agent's file reference 022867WO01	IMPORTANT DECLARATION	Date of mailing *(day/month/year)* 24 April 2020 (24-04-2020)
International application No. PCT/JP2020/005724	International filing date *(day/month/year)* 14 February 2020 (14-02-2020)	(Earliest) Priority date *(day/month/year)* 25 February 2019 (25-02-2019)
International Patent Classification (IPC) or both national classification and IPC H04S7/301, H04R5/04		
Applicant CLARION CO., LTD.		

This International Searching Authority hereby declares, according to Article 17(2)(a), that **no international search report will be established** on the international application for the reasons indicated below

1. ☐ The subject matter of the international application relates to:
   - a. ☐ scientific theories.
   - b. ☐ mathematical theories
   - c. ☐ plant varieties.
   - d. ☐ animal varieties.
   - e. ☐ essentially biological processes for the production of plants and animals, other than microbiological processes and the products of such processes.
   - f. ☐ schemes, rules or methods of doing business.
   - g. ☐ schemes, rules or methods of performing purely mental acts.
   - h. ☐ schemes, rules or methods of playing games.
   - i. ☐ methods for treatment of the human body by surgery or therapy.
   - j. ☐ methods for treatment of the animal body by surgery or therapy.
   - k. ☐ diagnostic methods practised on the human or animal body.
   - l. ☐ mere presentations of information.
   - m. ☐ computer programs for which this International Searching Authority is not equipped to search prior art.

2. ☒ The failure of the following parts of the international application to comply with prescribed requirements prevents a meaningful search from being carried out:

   ☒ the description ☒ the claims ☐ the drawings

3. ☐ The failure of the nucleotide and/or amino acid sequence listing to comply with the standard provided for in Annex C of the Administrative Instructions prevents a meaningful search from being carried out:

   ☐ the written form has not been furnished or does not comply with the standard.

   ☐ the computer readable form has not been furnished or does not comply with the standard.

4. Further comments:

Name and mailing address of the International Searching Authority	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL-2280 HV Rijswijk Tel. (+31-70) 340-2040 Fax: (+31-70) 340-3016	HAZELEGER, Jolanda Tel: +31 (0)70 340-3143

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 203

A) Features in lines 12-21 of each of claims 1 and 10 cannot be understood, since the signal processing implied by "synthesizing a spectrum with another spectrum" is not defined. The features of synthesizing a spectrum with another spectrum are neither explicitly defined nor is this type of signal processing standardly known as such in the art, nor is the signal processing disclosed in the description.
The description, in particular paragraphs [0052]-[0055], merely point to the same unclear and undefined spectrum synthesis processing, without giving any detail whatsoever about how to carry it out (Article 5 PCT). In particular, it is not clear how the graphs of Figs. 8A and 8B have been obtained.
To conclude, the application does not provide the reader with (sufficient) information/disclosure in order to allow the carrying out of the alleged invention, contrary to the requirements of Article 5 PCT.
The non-compliance with the substantive provisions is to such an extent that a meaningful search of the claimed subject-matter could not be carried out (Article 17(2) PCT and PCT Guidelines 9.30). There being no reasonable basis in the application that clearly indicates the subject-matter which might be expected to form the subject of the claims later in the procedure, no search at all was deemed possible, in particular since the objected features appear to be crucial for the claimed device and method.
B) Independently of the above, the application is deficient in fulfilling the requirements of Article 6 PCT for the following reasons:
1) The inconsistent use of the word "respective" renders claims 1 and 10 ambiguous, since it cannot be known when the word refers to only one of the speakers or when it refers to both speakers. The ambiguity results from the lack of the definite/indefinite article before the the word "respective" considered in combination with the word "one". In particular, it is not clear if the occurrence in line 6 of the claims should read "respective one", "the respective one" or "the respective ones".
2) The feature "the sounds being output from respective one of the two speakers at timings such that the sounds output from respective one of the two speakers do not interfere with each other at the predetermined position" (lines 4-7 of claims 1 and 10) renders claims 1 and 10 ambiguous, since it attempts to define the phase control device and method by non-claimed entities.
3) Related to the previously raised objection, it is noted that the features of generating and outputting the measurement signals (see S11 and S12 in Fig. 3 and corresponding description parts) are not defined in claims 1 and 10. Moreover, the claims do not define that the measurement signals are sequentially output from each of the speakers, such as to allow the non-interfering condition (see paragraph [0038]). Without specifying these aspects, the claims amount to define parts of the claim subject-matter in terms of results to be achieved.
4) Claims 1 and 10 are not supported by the description over their entire claimed scope, since they do not mention that measuring the impulse responses (see the first 7 lines of the claims) includes the processing of a cross-correlation between the measured signal of the measurement sound output by a respective speaker and a reference measurement signal output by the computing part. The essentiality of this feature can be inferred from paragraphs [0041]-[0043] of the description, which define only one measuring methodology for the impulse response.
5) Claims 1 and 10 are vague and therefore unclear, since they do not

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 203

define the "predetermined environmental relationship" (see the last 2 lines of the claims). The non-defined aspect appears to be disclosed in paragraph [0037] of the description, which provides support and disclosure only for specific "predetermined environmental relationships", whereas the scope of the claims covers any possible environmental relationship (including speaker orientation, constructional details, air composition and pressure around the speaker, etc.). The above-mentioned support and disclosure do not support the claims over their entire claimed scope, and the claims are therefore non-compliant with the requirements of Article 6 PCT.

6) Independent claims 1 and 10 are vague and therefore unclear, since they do not define the "predetermined condition" (see lines 22-23 of the claims).

7) The features introduced by the expression "based on" introduce a lack of clarity by non-determination in claims 1, 3, 5, 7, 10, 12, 14, 16, since the claims do not specify the necessary combination/constellation of values/features/parameters that are considered in the decision or action which is triggered "based on" them. This type of formulation generates an arbitrary definition of a dependency, which includes an infinite number of non-working examples, and therefore does not contain any useful information about the invention.

The applicant's attention is drawn to the fact that claims relating to inventions in respect of which no international search report has been established need not be the subject of an international preliminary examination (Rule 66.1(e) PCT). The applicant is advised that the EPO policy when acting as an International Preliminary Examining Authority is normally not to carry out a preliminary examination on matter which has not been searched. This is the case irrespective of whether or not the claims are amended following receipt of the search report or during any Chapter II procedure. If the application proceeds into the regional phase before the EPO, the applicant is reminded that a search may be carried out during examination before the EPO (see EPO Guidelines C-IV, 7.2), should the problems which led to the Article 17(2) declaration be overcome.