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ACTIVE DRIVING SOUND EFFECT GENERATOR

Abstract

An active driving sound effect generator includes a waveform generator to generate a signal depending on vehicle information, multiple speakers to output the signal generated by the waveform generator, and a sound image control processor to change a volume of an output of the signal from each of the multiple speakers. The waveform generator generates a low frequency waveform signal containing relatively many low frequency components and a high frequency waveform signal containing more high frequency components than the low frequency waveform signal does.

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Background/Summary

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates to an active driving sound effect generator.

2. Description of the Related Art

[0002] Heretofore, regarding vehicle driving operations, an active sound effect generator has been studied which generates sound effects according to changes in the vehicle speed in response to driver's accelerator pedal operations (for example, Patent Literature 1 and Patent Literature 2).

[0003] Regarding the technique related to an active sound effect generator, Abstract of Patent Literature 1 describes an active sound effect generator that can realize at least one of generation of more natural sound effects and applicability of the generator even to an electric vehicle (see Patent Literature 1).

[0004] ABSTRACT of Patent Literature 2 describes an active sound effect generator which generates a sound effect along with an increase in the vehicle speed such that the sound effect is highly realistic as an automobile driving sound even in a high-speed region (see Patent Literature 2).

[0005] As a technique related to an audio output control apparatus in a vehicle, Abstract of Patent Literature 3 describes an audio output control apparatus that plays back sound data from a digital versatile disc (DVD) as a Dolby Digital 5.1ch surround sound (see Patent Literature 3). Using a surround speaker system, the audio output control apparatus described in Patent Literature 3 outputs 5.1ch surround sound signals from front right and left speakers, rear right and left speakers, center and subwoofer speakers of a vehicle.

PRIOR ART DOCUMENT(S)

Patent Literature(s)

[0006] Patent Literature 1: JP2015-229403A [0007] Patent Literature 2: JP2019-128378A [0008] Patent Literature 3: JP2000-209699A

[0009] In order to provide passengers with a more realistic driving sound effect, it is desirable to control a sound image of the sound effect generated according to a driving condition such that the sound image is generated in an appropriate place. For example, it is desirable to control a sound image of a component imitating an intake sound such that it is generated from the engine room direction on the front side of the vehicle, and control a sound image of a component imitating an exhaust sound such that it is generated from a direction where the muffler is installed on the rear side of the vehicle.

[0010] However, the active sound effect generators described in Patent Literature 1 and Patent Literature 2 are incapable of controlling a sound image because they output a driving sound effect uniformly from the speakers. Meanwhile, the audio output control apparatus described in Patent Literature 3 merely outputs the 5.1ch surround sound signals as they are from the respective speakers and is configured with no consideration given to control of a sound effect generated depending on a driving condition such that the sound effect can give a passenger a more realistic sensation.

SUMMARY OF THE INVENTION

[0011] The present invention was made in view of the above circumstances, and has an object to provide an active driving sound effect generator capable of causing a passenger to associate a low frequency component signal generated on a vehicle front side with an intake sound and to associate a high frequency component signal generated on a vehicle rear side with an exhaust sound, thereby providing the passenger with a realistic sensation as if they were in an engine-equipped vehicle.

[0012] To achieve the above object of the present invention, an active driving sound effect generator is an active driving sound effect generator mounted on a vehicle, comprising a waveform generator configured to generate a signal depending on vehicle information; a plurality of speakers configured to output a signal generated by the waveform generator; and a sound image controller

configured to change a volume of an output of the signal from each of the plurality of speakers, wherein the waveform generator generates a low frequency waveform signal containing relatively many low frequency components and a high frequency waveform signal containing more high frequency components than the low frequency waveform signal does, and the sound image controller outputs the low frequency waveform signal at a relatively low volume and the high frequency waveform signal at a relatively high volume from the speaker arranged on a front side of the vehicle, and outputs the low frequency waveform signal at a higher volume and the high frequency waveform signal at a lower volume from the speaker arranged on a rear side of the vehicle than from the speaker arranged on the front side.
[0013] According to the present invention, it is possible to cause a passenger to associate a high frequency component signal generated on the front side of the vehicle with an intake sound and to associate a low frequency component signal generated on the rear side of the vehicle with an exhaust sound, thereby providing the passenger with a realistic sensation as if they were in an engine-equipped vehicle.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0014] FIG. **1** is a block diagram showing an outline of a configuration of an active driving sound effect generator according to a present embodiment, mounted on a vehicle.
[0015] FIG. **2** is a block diagram showing an outline of a configuration of a waveform generator.
[0016] FIG. **3**A is an explanatory diagram showing a concept in which a generation processor reads a signal (waveform data) at a position specified by a sum of a previous read position and an obtained skip number (No. 1).
[0017] FIG. **3**B is an explanatory diagram showing the concept in which the generation processor reads the signal (waveform data) at the position specified by the sum of the previous read position and the obtained skip number (No. 2).
[0018] FIG. **4** is an explanatory diagram showing an example of processing of synthesizing a waveform table.
[0019] FIG. **5** is an explanatory diagram showing characteristics of each gain adjuster of a gain controller to add a gain to a signal obtained from the waveform generator.
[0020] FIG. **6** is a block diagram showing a configuration of a sound image control processor.
[0021] FIG. **7**A shows a display audio provided in a vehicle.
[0022] FIG. **7**B shows a low frequency waveform table that is an example of a powerful EV sports tone.
[0023] FIG. **7**C shows a high frequency waveform table that is an example of a futuristic EV tone.
[0024] FIG. **8**A is an explanatory diagram showing a configuration in which a tone screen of the display audio is provided with a button for adding a tone (waveform table).
[0025] FIG. **8**B is an explanatory diagram showing a waveform table added to the waveform generator by a user.
[0026] FIG. **9**A is an explanatory diagram showing a first skip table.
[0027] FIG. **9**B is an explanatory diagram showing a second skip table.
DETAILED DESCRIPTION OF THE EMBODIMENTS
[0028] Hereinafter, embodiments for carrying out the present invention will be described in detail. The embodiments described below are examples for carrying out the present invention, and should be modified or altered as needed depending on the structure of an apparatus and various conditions to which the present invention is applied. The present invention should not be limited to the embodiments described below. Moreover, in the drawings, the same constituent elements will be denoted with the same reference signs and description thereof will be omitted if unnecessary.

Present Embodiment

[Outline of Configuration of Active Driving Sound Effect Generator]

[0029] FIG. **1** is a block diagram showing an outline of a configuration of an active driving sound effect generator according to a present embodiment, mounted on a vehicle (see FIG. **6**).

[0030] As shown in FIG. **1**, an active driving sound effect generator **100** according to the present embodiment includes a waveform generator **10**, a gain coefficient calculator **20**, a gain controller **30**, a sound controller **40**, and speakers **50**.

[0031] In the present embodiment, the waveform generator **10**, the gain coefficient calculator **20**, the gain controller **30**, and the sound controller **40** constitute an active sound control (ASC) apparatus. The active sound control is a system for improving the sound quality of an acceleration sound heard inside a vehicle depending on an accelerator position. In other words, the active sound control provides a user with an acceleration sound according to a vehicle speed or a rotation speed of a power unit by outputting the sound synchronized with the vehicle speed or the rotation speed from the speakers **50** to the inside of the vehicle.

[0032] As shown in a vehicle **300** in FIG. **6** to be described later, the speakers **50** shown in FIG. **1** include a speaker **51** arranged on a front side of the vehicle **300** (for example, in front of a driver's seat and a front passenger seat), a speaker **52** arranged at approximately the center of the vehicle **300** (for example, beside the driver's seat or the front passenger seat), and a speaker **5**S arranged on a rear side of the vehicle **300** (for example, behind rear passenger seats).

[0033] The vehicle **300** is any of electric automobiles including, for example, a fuel cell vehicle and a hybrid vehicle, and the like, and includes a motor (not shown). This motor is controlled by a motor electronic controller (ECU) (not shown).

[0034] The waveform generator **10** of the active driving sound effect generator **100** generates a signal from a waveform table according to vehicle information. The waveform generator **10** includes multiple waveform tables and generates signals respectively from the multiple waveform tables. The vehicle information herein indicates a vehicle speed or a rotation speed of a power unit. The power unit is not limited to the motor, but may be, for example, an engine.

[0035] The waveform generator **10** includes a vehicle speed/rotation speed obtainer **11** and frequency component group generation processors **12-1**, . . . , **12-**N. The frequency component group generation processors **12-1**, . . . , **12-**N will be also simply referred to as the frequency component group generation processors **12** when any one of them does not have to be specified.

[0036] The vehicle speed/rotation speed obtainer **11** obtains, as the vehicle information, the vehicle speed or the rotation speed of the power unit from the vehicle **300** (see FIG. **6**). The vehicle speed/rotation speed obtainer **11** includes, for example, a vehicle speed sensor. The vehicle speed/rotation speed obtainer **11** obtains the vehicle speed or the rotation speed of the power unit based on a rotation speed of the motor or a vehicle shaft (not shown) by means of the vehicle speed sensor, and supplies the obtained information to the gain coefficient calculator **20**.

[0037] Each of the frequency component group generation processors **12-1**, . . . , **12-**N has a corresponding waveform table (tone). For example, the frequency component group generation processor **12-1** has a low frequency waveform table containing relatively many low frequency components, while a frequency component group generation processor **12-2** (where N is 2) has a high frequency waveform table containing more high frequency components than the low frequency waveform table does. The low frequency waveform table only has to contain more low frequency components than high frequency components and may be composed of only low frequency components. The high frequency waveform table only has to contain more high frequency components than low frequency components, and may be composed of only high frequency components. The low frequency waveform table and the high frequency waveform table are not limited to waveform tables but may be data containing low frequency waveform signals and high frequency waveform signals.

[0038] The waveform generator **10** includes multiple waveform tables because the frequency component group generation processors **12-1**, . . . , **12**-N include respectively different waveform tables.

[0039] FIG. **2** is a block diagram showing an outline of a configuration of the waveform generator. As shown in FIG. **2**, the waveform generator **10** includes a skip table **123** and a generation processor **124**. The generation processor **124** has a waveform table **125** that forms a tone. The waveform table **125** contains waveform data to be read by the generation processor **124** and is composed of table values. The waveform table **125** is an example of waveform data which has one cycle of 1 [s] and which contains multiple frequency components (1 [Hz], 2 [Hz], and 4 [Hz]).

[0040] The skip table **123** obtains a skip number for read positions based on the vehicle information. The skip table **123** is provided to, for example, the vehicle speed/rotation speed obtainer **11**.

[0041] The skip table **123** includes at least one of a vehicle speed step table **121** and a rotation speed step table **122**. In the vehicle speed step table **121**, a skip number (read pitch) ΔP is defined based on the vehicle speed [km/h] of the vehicle **300**. In the rotation speed step table **122**, a skip number ΔP is defined based on the rotation speed [rpm] of the power unit. The skip number specifies, for example, a read pitch at which waveform data is to be read from the waveform table **125**. In other words, the skip number specifies a rate for thinning out the waveform table **125**, and is set to an n-times speed value for playback of the waveform table **125** at n-times speed.

[0042] The skip table **123** stores skip numbers ΔP in a table format. For example, based on the vehicle speed step table **121**, the vehicle speed/rotation speed obtainer **11** reads a skip number ΔP of 1 when the vehicle speed is 10 [km/h] and reads a skip number ΔP of 4 when the vehicle speed is 20 [km/h]. In addition, the vehicle speed/rotation speed obtainer **11** reads a skip number ΔP of 9 when the vehicle speed is 30 [km/h] and reads a skip number ΔP of 400 when the vehicle speed is 200 [km/h].

[0043] Meanwhile, for example, based on the rotation speed step table **122**, the vehicle speed/rotation speed obtainer **11** reads a skip number ΔP of 1 when the rotation speed of the power unit is 600 [rpm] and reads a skip number ΔP of 2 when the rotation speed of the power unit is 700 [rpm]. The vehicle speed/rotation speed obtainer **11** reads a skip number ΔP of 4 when the rotation speed of the power unit is 800 [rpm] and reads a skip number ΔP of 100 when the rotation speed of the power unit is 3000 [rpm].

[0044] In this way, when the vehicle speed/rotation speed obtainer **11** obtains the vehicle speed or the rotation speed of the power unit, the waveform generator **10** obtains the skip number ΔP for the read positions based on the obtained vehicle speed or rotation speed. In the vehicle speed step table **121** or the rotation speed step table **122**, skip numbers desired by a user are defined as the skip numbers ΔP.

[0045] Meanwhile, the generation processor **124** is provided to each of the frequency component group generation processors **12-1**, . . . , **12**-N. In other words, the generation processors **124** correspond to the respective frequency component group generation processors **12-1**, . . . , **12**-N. Based on the skip number ΔP obtained by the vehicle speed/rotation speed obtainer **11**, each of the generation processors **124** reads the signal in the waveform table **125** at every position specified by the sum of every previous read position and the obtained skip number ΔP, thereby generating a signal (that is, a waveform table read at intervals of the skip number ΔP) to be input to the speakers **50**.

[0046] Here, the signal generated by the generation processor **124** is defined by following Formula (1):

[Formula1]

[00001]
$$P(t+1) = P(t) + \quad P(t), \qquad (1)$$

where P(t) denotes a pointer, P(0) denotes an initial value 0, and ΔP(t) denotes a skip number.

[0047] As shown in Formula (1), the signal to be input to the speakers **50** is generated, based on the skip number ΔP read from the skip table **123** by the vehicle speed/rotation speed obtainer **11** and the previous value of the pointer P(t), by reading out the waveform table **125** at the position advanced by the skip number ΔP from the previous value of the pointer (t). In this case, the waveform data pieces in the waveform table **125** read at the intervals of the skip number ΔP constitute the signal (tone).

[0048] FIGS. **3**A and **3**B are explanatory diagrams showing a concept in which the generation processor reads a signal (waveform data) at every position specified by the sum of every previous read position and the obtained skip number ΔP.

[0049] FIG. **3**A shows a concept in which the generation processor **124** reads a signal (waveform data) from a waveform table **126**, for example, when the skip number ΔP is 2. As shown in FIG. **3**A, from waveform data (the waveform table **126**) with one cycle per second, the generation processor **124** reads waveform data (waveform table **127**) in double cycles (double rounds) from the previous read position.

[0050] FIG. **3**B shows a concept in which the generation processor **124** reads a signal (waveform data) from a waveform table **128**, for example, when the skip number ΔP is 3. As shown in FIG. **3**B, from waveform data (waveform table **128**) with one cycle per second, the generation processor **124** reads waveform data (waveform table **129**) in triple cycles (triple rounds) from the previous read position.

[0051] Here, each of the waveform tables **126** and **128** holds one cycle of values of the signal (waveform data) in a table data format. The present embodiment has a feature in the waveform tables **126** and **128** from which the waveform generator **10** reads the waveform data.

[0052] FIG. **4** is an explanatory diagram showing an example of processing for synthesizing a waveform table. FIG. **4** shows the processing for synthesizing a waveform table **134** of waveform data having three frequency components from a waveform table **131** with a frequency of 1 [Hz], a waveform table **132** with a frequency of 1.25 [Hz], and a waveform table **133** with a frequency of 1.5 [Hz].

[0053] The three waveform tables **131**, **132**, and **133** have different cycles, and therefore cannot be synchronized in the unit of one second. For this reason, in the present embodiment, in order to generate the waveform table **134** having the three frequency components, the frequencies of the waveform tables **131**, **132**, and **133** are multiplied by every integer value while their frequency ratio is maintained, and a minimum time [s] (multiplier) at which the three waveform tables **131**, **132**, and **133** can be synchronized is determined among the integer values with each of which all the integer multiples of the frequencies are converted to integers. As a result of transforming the waveform data in the waveform tables **131**, **132**, and **133** to waveform data whose frequency ratio is expressed by the integers, the waveform data in the waveform tables **131**, **132**, and **133** take the same values at the start point and the end point of the minimum time [s] and can be synchronized at every timing therein. Thus, in the present embodiment, one cycle is set to the minimum time [s] at which the waveform tables **131**, **132**, and **133** can be synchronized, and the waveform table **134** having the three frequency components is synthesized by combining the waveform data in all the waveform tables **131**, **132**, and **133**.

[0054] In this way, in the present embodiment, after the numeric values in the frequency ratio of the waveform tables **131**, **132**, and **133** are converted to integers, a time (minimum time) for minimum required data strings of waveform data is determined.

[0055] In the case in FIG. **4**, the frequency ratio of the waveform table **131** with 1 [Hz], the waveform table **132** with 1.25 [Hz], and the waveform table **133** with 1.5 [Hz] is 1:1.25:1.5. This frequency ratio will be 4:5:6 or 100:125:150 as a result of multiplication by an integer. In this case, the minimum time [s] at which the waveform tables **131**, **132**, and **133** can be synchronized is determined as 4 [s] because (1:1.25:1.5)×4 is equal to 4:5:6. With the determination of the minimum time (4 [s]), the waveform data in the waveform table **131** is transformed to waveform data for four cycles, the waveform data in the waveform table **132** is transformed to waveform data for five cycles, and the waveform data in the waveform table **133** is transformed to waveform data for six cycles.

[0056] Then, for the waveform table **134**, the waveform data for the minimum time [s] set as one cycle is generated by adding up the cyclic data of the integer multiples (four cycles, five cycles, and six cycles) of the waveform tables **131**, **132**, and **133** within the minimum time (4 [s]) at which the waveform tables **131**, **132**, and **133** can be synchronized. Thus, the generated waveform table **134** is a cyclic waveform table in which the end point and the start point of the waveform data are continuous, and is the table containing the multiple frequency components.

[0057] In other words, in the present embodiment, the waveform table **134** is formed of the waveform data with one cycle of the waveform table set to a minimum multiplier (that is, a minimum time) with which all the numeric values in the ratio of the multiple frequencies are converted to integers while their frequency ratio is maintained.

[0058] In this way, the waveform table **134** containing the multiple frequency components is generated from the waveform data in the waveform tables **131**, **132**, and **133** containing the frequency components desired by a user.

[0059] Returning to FIG. **1**, the gain coefficient calculator **20** in the active driving sound effect generator **100** includes an accelerator position sensor **21**, an acceleration calculator **22**, a rotation speed change calculator **23**, a vehicle speed/rotation speed gain table **24**, an accelerator gain table **25**, an acceleration gain table **26**, and a rotation speed change gain table **27**.

[0060] The accelerator position sensor **21** detects the position of an accelerator pedal (this will be referred to as the accelerator position θ) when the user depresses the accelerator pedal of the vehicle **300**.

[0061] The acceleration calculator **22** obtains the vehicle speed or the rotation speed of the power unit from the vehicle speed/rotation speed obtainer **11** and calculates an acceleration Δa.

[0062] The rotation speed change calculator **23** obtains the vehicle speed or the rotation speed of the power unit from the vehicle speed/rotation speed obtainer **11** and calculates a rotation speed change Δb.

[0063] The vehicle speed/rotation speed gain table **24** has a feature of adding a gain to the vehicle speed or the rotation speed of the power unit provided. The accelerator gain table **25** has a feature of adding a gain to the detected accelerator position θ. The acceleration gain table **26** has a feature of adding a gain to the calculated acceleration Δa. The rotation speed change gain table **27** has a feature of adding a gain to the calculated rotation speed change Δb.

[0064] In each of the vehicle speed/rotation speed gain table **24**, the accelerator gain table **25**, the acceleration gain table **26**, and the rotation speed change gain table **27**, certain characteristics desired by the user are set as needed in a table format.

[0065] The gain controller **30** of the active driving sound effect generator **100** includes multiple gain adjusters **31**, . . . , **3**N. The gain controller **30** obtains signals u**1**, . . . , uN generated in the respective frequency component group generation processors **12-1**, . . . , **12**-N and obtains a coefficient for adjusting the gain of each of the signals u**1**, . . . , uN from the gain coefficient calculator **20**.

[0066] The multiple gain adjusters **31**, . . . , **3**N are in charge of the respective signals u**1**, . . . , uN generated from the waveform tables in the frequency component group generation processors **12-1**, . . . , **12**-N. Thus, each of the gain adjusters **31**, . . . , **3**N adjusts the gain of the corresponding one of the signals u**1**, . . . , uN generated in the frequency component group generation processors **12-1**, . . . , **12**-N by using the coefficient of the gain obtained from the gain coefficient calculator **20**.

[0067] FIG. **5** is an explanatory diagram showing characteristics of each of the gain adjusters of the gain controller to add a gain to a signal obtained from the waveform generator.

[0068] As shown in FIG. **5**, when the vehicle speed or the rotation speed is relatively low, the gain controller **30** increases (raises) a gain for the low frequency waveform table according to a gain G**1** prescribed for low frequency components. On the other hand, when the vehicle speed or the rotation speed is relatively high, the gain controller **30** increases a gain for the high frequency waveform table according to a gain G**2** prescribe for high frequency components.

[0069] In FIG. **5**, the gain G**1** shows characteristics of the gain for the low frequency components (low frequency waveform signals) and the gain G**2** shows characteristics of the gain for the high frequency components (high frequency waveform signals).

[0070] For example, in the case where the frequency component group generation processor **12-1** includes a low frequency waveform table and the frequency component group generation processor **12-2** (where N is 2) includes a high frequency waveform table, the gain adjuster **31** emphasizes and outputs the low frequency components in the low frequency waveform table of the frequency component group generation processor **12-1** according to the gain G**1**, when the vehicle speed or the rotation speed is relatively low.

[0071] On the other hand, when the vehicle speed or the rotation speed is relatively high, the gain adjuster **32** (where N is 2) emphasizes and outputs the high frequency components in the high frequency waveform table of the frequency component group generation processor **12-2** according to the gain G**2**.

[0072] The sound controller **40** (see FIG. **1**) of the active driving sound effect generator **100** includes a sound image control processor **41**. The sound image control processor **41** changes (adjusts) the volume of an output of each of multiple signal components y**1**, . . . , yN from each of the multiple speakers **50** (**51**, **52**, . . . , **5**S).

[0073] The sound image control processor **41** inputs the signals to each of the speakers **50** and each of the speakers **50** outputs an output sound, which is expressed by following Formula (2):

[Formula2]

[00002]
$$s_S = \sum_{n=1}^{N} Z^{-D_{nS}} k_{nS} y_n, \quad (2)$$

where S.sub.s denotes an output sound of an S-th speaker, n denotes a frequency component number, N denotes a total number of frequency component groups, K.sub.nS denotes a gain coefficient for outputting an n-th frequency component group from the S-th speaker, and D.sub.nS denotes a time delay for outputting the n-th frequency component group from the S-th speaker.

[0074] As shown in Formula (2), for each of the signal components y**1**, . . . , yN obtained from the signals u**1**, . . . , uN generated in the frequency component group generation processors **12-1**, . . . , **12-**N, the sound image control processor **41** adjusts the volume by multiplying the signal component by each of gains set for the respective speakers **50**, and also adjusts the delay time. As a result, the output sound from each of the speakers **51**, **52**, . . . , **5**S is a sum total (result) of the frequency components with the adjusted volumes.

[0075] As a result, the sound image control processor **41** outputs the low frequency waveform signals (low frequency components) at relatively low volumes and outputs the high frequency waveform signals (high frequency components) at relatively high volumes from the speaker **51** arranged on the front side of the vehicle **300**, and outputs the low frequency waveform signals (low frequency components) at higher volumes and outputs the high frequency waveform signals (high frequency components) at lower volumes from the speaker **5**S arranged on the rear side than from the speakers **51** and **52** arranged on the front side.

[0076] In addition, the sound image control processor **41** is capable of adjusting a signal phase of each of the multiple signal components y**1**, . . . , yN for each of the speakers **50**. Thus, the speaker **51** arranged on the front side of the vehicle **300** is enabled to output the high frequency waveform signals earlier and the low frequency waveform signals later than the speaker **5**S arranged on the rear side of the vehicle **300** does.

[0077] FIG. **6** is a block diagram showing a configuration of the sound image control processor. As shown in FIG. **6**, the sound image control processor **41** includes amplifiers **421**, **422**, . . . , **42**S, **441**, **442**, . . . , **44**S each of which multiplies the corresponding one of the multiple signal components y**1**, . . . , yN by a constant for the corresponding one of the speakers **51**, **52**, . . . , **5**S.

[0078] FIG. **6** shows the case where the speakers **51**, **52**, . . . , **5**S are arranged. In this case, for the signal component y**1** of the frequency component group generation processor **12-1**, which assumes an intake sound, the sound image control processor **41** sets, for example, a coefficient of 1.0 for the amplifier **421**, a coefficient of 0.5 for the amplifier **422**, and a coefficient of 0.0 for the amplifier **42**S. As a result, the sound image control processor **41** localizes a sound image of the signal component y**1** on the front side of the vehicle.

[0079] On the other hand, for the signal component yN of the frequency component group generation processor **12-**N, which assumes an exhaust sound, the sound image control processor **41** sets, for example, a coefficient of 0.0 for the amplifier **441**, a coefficient of 0.5 for the amplifier **442**, and a coefficient of 1.0 for the amplifier **44**S. As a result, the sound image control processor **41** localizes a sound image of the signal component yN on the rear side of the vehicle.

[0080] As a result, the speaker **51** outputs the high frequency components at higher volumes than the speakers **52** and **5**S do, and the speaker **52** outputs the high frequency components at higher volumes than the speaker **5**S does. On the other hand, the speaker **5**S outputs the low frequency components at higher volumes than the speakers **51** and **52** do, and the speaker **52** outputs the low frequency components at higher volumes than the speaker **51** does. The sound image control processor **41** may divide the multiple speakers **50** (**51**, **52**, . . . , **5**S) into front and rear groups in a vehicle cabin, and collectively control the speakers in each of the groups.

[0081] The sound image control processor **41** also includes delay adjustment elements **431**, **432**, . . . , **43**S, **451**, **452**, . . . , **45**S each of which adjusts the signal phase of the corresponding one of the multiple signal components y**1**, . . . , yN for the corresponding one of the speakers **51**, **52**, . . . , **5**S.

[0082] In the delay adjustment elements **431**, **432**, . . . , **43**S, **451**, **452**, . . . , **45**S, a digital value is set as a delay time for each of the signal components y**1**, . . . , yN. This makes it possible for the speaker **51** arranged on the front side of the vehicle **300** to output the high frequency waveform signals (high frequency components) earlier and output the low frequency waveform signals (low frequency components) later than the speakers **52**, . . . , **5**S arranged on the rear side of the vehicle **300** do.

[0083] Thus, the speaker **51** outputs an added signal s**1** into the vehicle cabin, the added signal s**1** obtained by an adder **461** adding the signal amplified by the amplifier **421** and delayed by the delay adjustment element **431** and the signal amplified by the amplifier **441** and delayed by the delay adjustment element **451**. The speaker **52** outputs an added signal s**2** into the vehicle cabin, the added signal s**2** obtained by an adder **462** adding the signal amplified by the amplifier **422** and delayed by the delay adjustment element **432** and the signal amplified by the amplifier **442** and delayed by the delay adjustment element **452**. The speaker **5**S outputs an added signal sS into the vehicle cabin, the added signal sS obtained by an adder **46**S adding the signal amplified by the amplifier **42**S and delayed by the delay adjustment element **43**S and the signal amplified by the amplifier **44**S and delayed by the delay adjustment element **45**S.

[Operations of Active Driving Sound Effect Generator]

<Operation 1>

[0084] Next, operations of the active driving sound effect generator **100** according to the present embodiment will be described in reference to FIG. **1** and FIGS. **7**A to **9**B.

[0085] In the active driving sound effect generator **100**, the vehicle speed/rotation speed obtainer **11** obtains the vehicle speed or the rotation speed of the power unit as the vehicle information of the vehicle **300**. The vehicle speed/rotation speed obtainer **11** obtains the skip number ΔP based on the obtained vehicle speed or rotation speed of the power unit.

[0086] Each of the frequency component group generation processors **12-1**, . . . , **12-**N (generation processors **124**) reads, from the corresponding one of the waveform tables, the signal at the position specified by the sum of the read position P(t) and the skip number ΔP and inputs the read signal to the gain controller **30**.

[0087] The gain coefficient calculator **20** calculates the gain coefficient for each of the signals u**1**, . . . , uN based on the accelerator position θ of the accelerator position sensor **21** and the vehicle speed or the rotation speed of the power unit obtained by the vehicle speed/rotation speed obtainer **11**, from the vehicle speed/rotation speed gain table **24**, the accelerator gain table **25**, the acceleration gain table **26**, and the acceleration gain table **26**.
[0088] The gain controller **30** controls (adjusts) the gains for the signals u**1**, . . . , uN generated from the respective multiple waveform tables in the frequency component group generation processors **12-1**, . . . , **12**-N, by using the respective gain coefficients calculated by the gain coefficient calculator **20**.
[0089] The sound controller **40** changes the output volumes for the signal components y**1**, . . . , yN for each of the multiple speakers **50** and inputs the resultant signal to each of the speakers **50**. As a result, each of the speakers **50** can output the signals u**1**, . . . , uN generated in the waveform generator **10**.
<Operation 2>
[0090] In the present embodiment, the active driving sound effect generator **100** includes the multiple waveform tables because the frequency component group generation processors **12-1**, . . . , **12**-N in the waveform generator **10** include their respective waveform tables. Therefore, the waveform generator **10** can receive a user's operation and switch the waveform table among from the multiple waveform tables according to the user's operation.
[0091] FIGS. **7**A to **7**C are explanatory diagrams showing that a desired waveform table is selectable from the multiple waveform tables included in the frequency component group generation processors of the waveform generator.
[0092] FIG. **7**A shows a display audio provided in the vehicle **300**. As shown in FIG. **7**A, a display audio **200** is provided with a volume screen **201** and a tone screen **202**.
[0093] The volume screen **201** is configured to receive ON/OFF for customizing a volume adjustment by a user, and allow the user to adjust the volume when ON is set.
[0094] The tone screen **202** is configured to enable tone switchover in response to a user's operation of selecting any of buttons. For example, the tone screen **202** allows a selection from a powerful electric vehicle (EV) sports tone and a futuristic EV tone. In this case, when the user selects the powerful EV sports tone, a waveform table **1201** shown in FIG. **7**B is selected from the frequency component group generation processors **12-1**, . . . , **12**-N of the waveform generator **10**. On the other hand, when the user selects the futuristic EV tone, a waveform table **1202** shown in FIG. **7**C is selected from the frequency component group generation processors **12-1**, . . . , **12**-N of the waveform generator **10**.
[0095] The waveform table **1201** in FIG. **7**B shows a low frequency waveform table that is an example of the powerful EV sports tone, for example, and the waveform table **1202** in FIG. **7**C shows a high frequency waveform table that is an example of the futuristic EV tone, for example.
[0096] The waveform table **1201** is provided for, for example, the frequency component group generation processor **12-1**, and the waveform table **1202** is provided for, for example, the frequency component group generation processor **12-2**, so that the user is allowed to select the waveform table for outputting their favorite tone.
[0097] In another possible mode, an extra waveform table for outputting a favorite tone may be added by the user. For example, the tone screen **202** may be configured to include a button **203** for receiving an addition of a tone by the user.
<Operation 3>
[0098] FIG. **8**A is an explanatory diagram showing a configuration in which the tone screen of the display audio is provided with a button for adding a tone (waveform table). FIG. **8**B is an explanatory diagram showing a waveform table added to the waveform generator by the user. A waveform table **1203** is waveform data downloaded from the Internet as tone data by the user. As similar to the waveform table **134**, the waveform table **1203** is a cyclic waveform table in which the

end point and the start point of the waveform table are continuous and contains multiple frequency components.

[0099] In FIG. **8**A, the user is allowed to add a desired waveform table to the waveform generator **10** by pressing down a button **203**. Thus, the waveform generator **10** can add the waveform table **1203** to the multiple waveform tables (the frequency component group generation processors **12-1**, . . . , **12**-N).

[0100] The waveform generator **10** is able to switch the waveform table for generating the signals to be input to the speakers **50** to the added waveform table **1203** among the multiple waveform tables. In this case, the user is allowed to add the waveform table **1203** from, for example, the Internet or an external memory, and select an output of the signals of the added waveform table **1203**.

[0101] In this way, the waveform generator **10** is able to receive addition of the waveform table **1203** and receive a selection of the waveform data (tone) of the waveform table **1203** to be output from the speakers **50**.

<Operation 4>

[0102] The waveform generator **10** includes the vehicle speed/rotation speed obtainer **11**, and the vehicle speed/rotation speed obtainer **11** includes the skip table **123**.

[0103] The skip table **123** may include, for example, the vehicle speed step table **121** and the rotation speed step table **122**, or may include multiple step tables in short. Thus, in response to a user's selection operation, the skip table **123** can be switched to the selected one of the vehicle speed step table **121** and the rotation speed step table **122**.

[0104] FIG. **9**A is an explanatory diagram showing a first skip table **1231**. As shown in FIG. **9**A, in the first skip table **1231**, based on an increase in the vehicle speed or the rotation speed of the power unit, the skip number is exponentially increased from a lower limit value to an upper limit value and is returned to the lower limit value when reaching the upper limit value. In the first skip table **1231**, the skip number again is exponentially increased after being returned to the lower limit value. Thus, the first skip table **1231** enables generation of Shepard tone signals.

[0105] FIG. **9**B is an explanatory diagram showing a second skip table **1232**. As shown in FIG. **9**B, in the second skip table **1232**, a frequency is increased in proportion to an increase in the vehicle speed or the rotational speed of the power unit, and is decreased by a predetermined level when the vehicle speed or the rotational speed reaches a predetermined value. In the second skip table **1232**, after the frequency is decreased, the frequency is increased again in proportion to an increase in the vehicle speed or the rotational speed of the power unit, so that the frequency is increased in a stepped manner. Thus, the second skip table **1232** enables generation of engine-like tone signals.

[0106] For example, when the futuristic EV tone is selected by a user's selection operation on the tone screen **202** in FIG. **7**A or **8**A, the first skip table **1231** in FIG. **9**A is selected. On the other hand, when an engine-like tone is selected by a user's selection operation on the tone screen **202**, the second skip table **1232** in FIG. **9**B is selected.

[0107] Thus, when the first skip table **1231** is selected, the waveform generator **10** can generate futuristic EV tone signals (Shepard tone signals) in the vehicle speed/rotation speed obtainer **11**. On the other hand, when the second skip table **1232** is selected, the waveform generator **10** can generate engine-like tone signals in the vehicle speed/rotation speed obtainer **11**.

[0108] Here, considered is the case where the first skip table **1231** (Shepard tone signal) is selected, in particular. In this case, even though an engine-like tone can be output, the waveform generator **10** purposely does not control the low frequency waveform signals and the high frequency waveform signals according to the positions of the speakers **50** but outputs them as they are from the speakers **51**, **52**, . . . , **5**S, so that the Shepard tone signals can be output.

[0109] As described above, the active driving sound effect generator **100** according to the present embodiment includes the waveform generator **10**, the speakers **50**, and the sound image control processor **41**.

[0110] According to the present embodiment, the waveform generator **10** generates the low frequency waveform signals containing relatively many low frequency components and the high frequency waveform signals containing more high frequency components than the low frequency waveform signals do. The sound image control processor **41** outputs the low frequency waveform signals (low frequency components) at relatively low volumes and outputs the high frequency waveform signals (high frequency components) at relatively high volumes from the speaker **51** arranged on the front side of the vehicle **300**, and outputs the low frequency waveform signals (low frequency components) at higher volumes and outputs the high frequency waveform signals (high frequency components) at lower volumes from the speaker **5**S arranged on the rear side than from the speaker **51** arranged on the front side.
[0111] With this configuration, the active driving sound effect generator **100** is capable of causing a passenger to associate the high frequency component signals generated from the front side of the vehicle with the intake sound by outputting the low frequency waveform signals (low frequency components) at relatively low volumes, and outputting the high frequency waveform signals (high frequency components) at relatively high volumes from the speaker **51** by using the sound image control processor **41**. Meanwhile, the active driving sound effect generator **100** is capable of causing a passenger to associate the low frequency component signals generated from the rear side of the vehicle with the exhaust sound by outputting the low frequency waveform signals (low frequency components) at higher volumes, and outputting the high frequency waveform signals (high frequency components) at lower volumes from the speaker **5**S than from the speaker **51** arranged on the front side.
[0112] Thus, the active driving sound effect generator **100** is able to provide a passenger in the vehicle **300** with a realistic sensation as if they were in an engine-equipped vehicle.
[0113] Moreover, the sound image control processor **41** is able to adjust the signal phase of each of the multiple signal components y**1**, . . . , yN for each of the speakers **50** as described in reference to FIG. **6**. As a result, the speaker **51** arranged on the front side of the vehicle **300** outputs the high frequency waveform signals earlier and outputs the low frequency waveform signals later than the speaker **5**S arranged on the rear side of the vehicle **300** does. Here, to adjust the signal phase means to set a digital value as a delay time for each signal.
[0114] With this configuration, the active driving sound effect generator **100** is able to cause the high frequency components (high frequency waveform signals) to arrive earlier and the low frequency components (low frequency waveform signals) to arrive later at the front side of the vehicle than at the rear side of the vehicle.
[0115] This makes it possible to give a passenger in the vehicle **300** a realistic sensation more similar to an actual sensation in an engine-equipped vehicle.
[0116] The sound image control processor **41**, in particular, is able to finely adjust the delay times of the signals using the digital values depending on the position of a passenger in the vehicle **300** by means of the delay adjustment elements **431**, **432**, . . . , **43**S, **451**, **452**, . . . , **45**S. As a result, the active driving sound effect generator **100** is able to provide a passenger in the vehicle **300** with a realistic sensation similar to an actual engine sound wherever the passenger is seated in the vehicle **300**.
[0117] Moreover, in the operation 2 as described in reference to FIGS. **7**A to **7**C, in the active driving sound effect generator **100**, the vehicle information indicates the vehicle speed or the rotation speed of the power unit, and the waveform generator **10** may be able to generate engine-like tone signals in which the frequency is increased in proportion to an increase in the vehicle speed or the rotation speed and is decreased by a predetermined level when the vehicle speed or the rotation speed reaches a predetermined value.
[0118] With this configuration, the active driving sound effect generator **100** is able to output engine-like tone signals from the speakers **50** by means of the waveform generator **10** increasing and decreasing the frequency and therefore give a passenger in the vehicle **300** a realistic sensation

more similar to a sensation in an engine-equipped vehicle. Specifically, the active driving sound effect generator **100** is able to generate a sound like a gear shift-up sound by means of the waveform generator **10**.

[0119] Further, in the operation 4 as described in reference to FIGS. **9**A and **9**B, the waveform generator **10** is able to generate Shepard tone signals in which, based on an increase in the vehicle speed or the rotation speed of the power unit, the frequency is exponentially increased from the lower limit value to the upper limit value, is returned to the lower limit value when reaching the upper limit value, and again is exponentially increased, and may be configured to select which will be generated, the engine-like tone signals or the Shepard tone signals. In the present embodiment, when generation of the Shepard tone signals is selected, the sound image control processor **41** does not control the low frequency waveform signals and the high frequency waveform signals depending on the positions of the speakers **50**, but outputs the signal components y**1**, . . . , yN, as they are, from the front and rear speakers **50**.

[0120] With this configuration, by means of the waveform generator **10**, the active driving sound effect generator **100** is able to further generate the Shepard tone signals and select which will be generated, the engine-like tone signals or the Shepard tone signals. When generation of the Shepard tone signals is selected, the active driving sound effect generator **100** outputs the low frequency signals and the high frequency signals as they are from the front and rear speakers **50** without dividing the sound image signals into the low frequency signals and the high frequency signals and without controlling the low frequency signals and the high frequency signals depending on the positions of the speakers **50**.

[0121] Thus, by means of the waveform generator **10**, the active driving sound effect generator **100** is able to output the Shepard tone signals easily and give a passenger in the vehicle **300** a realistic sensation (for example, an acceleration sensation) different from a sensation in an engine-equipped vehicle.

[0122] Moreover, as described in reference to FIG. **6**, the sound image control processor **41** includes the amplifiers **421**, **422**, . . . , **42**S, **441**, **442**, . . . , **44**S each of which multiplies the corresponding one of the multiple signal components y**1**, . . . , yN by a constant for the corresponding one of the speakers **51**, **52**, . . . , **5**S. The constants include 0.

[0123] With this configuration, by means of the multiple amplifiers **421**, **422**, . . . , **42**S, **441**, **442**, . . . , **44**S, the active driving sound effect generator **100** is able to easily multiply each of the signals u**1**, . . . , uN (or the signal components y**1**, . . . , yN) generated by the generation processors **124**. Thus, by means of the multiple amplifiers **421**, **422**, . . . , **42**S, **441**, **442**, . . . , **44**S, the active driving sound effect generator **100** is able to easily control an output of each of the speakers **51**, **52**, . . . , **5**S in the vehicle **300**.

Claims

1. An active driving sound effect generator mounted on a vehicle, comprising: a waveform generator configured to generate a signal depending on vehicle information; a plurality of speakers configured to output the signal generated by the waveform generator; and a sound image controller configured to change a volume of an output of the signal from each of the plurality of speakers, wherein the waveform generator generates a low frequency waveform signal containing relatively many low frequency components and a high frequency waveform signal containing more high frequency components than the low frequency waveform signal does, and the sound image controller outputs the low frequency waveform signal at a relatively low volume and the high frequency waveform signal at a relatively high volume from the speaker arranged on a front side of the vehicle, and outputs the low frequency waveform signal at a higher volume and the high frequency waveform signal at a lower volume from the speaker arranged on a rear side of the vehicle than from the speaker arranged on the front side.

2. The active driving sound effect generator according to claim 1, wherein the sound image controller is able to adjust a signal phase of each of a plurality of the signals for each of the speakers, and the speaker arranged on the front side of the vehicle outputs the high frequency waveform signal earlier and the low frequency waveform signal later than the speaker arranged on the rear side of the vehicle does.

3. The active driving sound effect generator according to claim 1, wherein the vehicle information indicates a vehicle speed or a rotation speed of a power unit, the waveform generator is able to generate an engine-like tone signal in which a frequency is increased in proportion to an increase in the vehicle speed or the rotation speed, and decreased by a predetermined level when the vehicle speed or the rotation speed reaches a predetermined value.

4. The active driving sound effect generator according to claim 3, wherein the waveform generator is able to generate a Shepard tone signal in which, based on an increase in the vehicle speed or the rotation speed, a frequency is exponentially increased from a lower limit value to an upper limit value, is returned to the lower limit value when reaching the upper limit value, and is again exponentially increased, and select which will be generated, the engine-like tone signal or the Shepard tone signal, when generation of the Shepard tone signal is selected, the sound image controller outputs the low frequency waveform signal and the high frequency waveform signal, as they are, from the speakers on the front and rear sides without controlling the low frequency waveform signal and the high frequency waveform signal depending on the positions of the speakers.

5. The active driving sound effect generator according to claim 1, wherein the sound image controller includes an amplifier configured to multiply each of the plurality of signals by a constant for each of the speakers.