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ACTIVE DRIVING SOUND EFFECT GENERATOR

Abstract

An active driving sound effect generator is an active driving sound effect generator mounted on a vehicle and includes a waveform generator configured to generate a signal from a waveform table depending on vehicle information, and a speaker configured to output the signal generated by the waveform generator. The waveform table is a cyclic waveform table in which an end point and a start point of the waveform table are continuous and contains multiple frequency components.

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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 JA2015-229403A 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).

PRIOR ART DOCUMENT(S)

Patent Literature(s)

[0005] Patent Literature 1: JP2015-229403A [0006] Patent Literature 2: JP2019-128378A

[0007] The active sound effect generators described in Patent Literature 1 and Patent Literature 2 involve a large amount of calculation. Accordingly, a load on the processing is high and makes it difficult to provide a driving sound effect in real time.

[0008] For example, the active sound effect generator described in Patent Literature 1 includes a reference signal generator and a control signal generator. The reference signal generator generates a reference signal by sequentially reading waveform data from a waveform data table. The control signal generator generates a control signal for use to generate a sound effect based on the generated reference signal. The control signal generator adjusts the amplitude of the control signal by changing the amplitude of the reference signal according to a change in the frequency and the load of a driving source.

[0009] The active sound effect generator described in Patent Literature 1 also requires a rotational frequency change calculator that calculates a rotational frequency change, which is a time differential value of the rotational frequency, and an engine load detector that detects the engine load, and accordingly involves a large amount of calculation required to adjust the amplitude of the control signal.

[0010] Meanwhile, the active sound effect generator described in Patent Literature 2 includes a waveform data table and an amplitude data table. The waveform data table generates ordered acoustic signals having ordered acoustic frequencies from a sine wave of 1 [Hz]. For example, the number of ordered acoustic frequencies is three. In this case, the waveform data table generates three ordered acoustic signals. Meanwhile, the amplitude data table adjusts the amplitude of each of the three ordered acoustic signals. An adder generates an acoustic signal by combining (adding) the three ordered acoustic signals whose amplitudes are adjusted.

[0011] In this way, the active sound effect generator described in Patent Literature 2 also places a load on the processing due to the large amount of calculation required for the ordered acoustic signals. In addition, the amount of calculation required for the ordered acoustic signals is further increased in the case of outputting multiple tones (sets of ordered acoustic signals) simultaneously or controlling the volume and other parameters.

[0012] In the case where a user desires to individually adjust the waveform (tone) of a sound effect, it is difficult for an ordinary user to adjust the tone because the settings for the ordered sounds are difficult to understand.

SUMMARY OF THE INVENTION

[0013] The present invention was made in view of the above circumstances, and has an object to provide an active driving sound effect generator that generates highly realistic driving sound effects while achieving a reduction in the amount of calculation in the process of generating sound signals and enabling easy adjustment of a tone.

[0014] In order 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 from a waveform table depending on vehicle information; and a speaker configured to output the signal generated by the waveform generator, wherein the waveform table is a cyclic waveform table in which an end point and a start point of the waveform table are continuous and contains a plurality of frequency components.

[0015] According to the present invention, it is possible to generate highly realistic driving sound effects while achieving a reduction in the amount of calculation in the process of generating sound signals and enabling easy adjustment of a tone.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] FIG. **1** is a block diagram showing an outline of a configuration of an active driving sound effect generator according to a first embodiment, mounted on a vehicle.

[0017] FIG. **2** is a block diagram showing an outline of a configuration of a waveform generator.

[0018] 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).

[0019] 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).

[0020] FIG. **4** is an explanatory diagram showing an example of processing of synthesizing a waveform table.

[0021] 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.

[0022] FIG. **6** is a block diagram showing a configuration of a sound image control processor.

[0023] FIG. **7**A shows a display audio provided in a vehicle.

[0024] FIG. **7**B shows a low frequency waveform table that is an example of a powerful EV sports tone.

[0025] FIG. **7**C shows a high frequency waveform table that is an example of a futuristic EV tone.

[0026] 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).

[0027] FIG. **8**B is an explanatory diagram showing a waveform table added to the waveform generator by a user.

[0028] FIG. **9**A is an explanatory diagram showing a first skip table.

[0029] FIG. **9**B is an explanatory diagram showing a second skip table.

[0030] FIG. **10** is a block diagram showing an outline of a configuration of an active driving sound effect generator according to a second embodiment, mounted on a vehicle.

[0031] FIG. **11**A shows a coefficient of a band-pass filter included in a frequency characteristic adjustment processor.

[0032] FIG. **11**B is an explanatory diagram showing frequency characteristics based on the filter

coefficient.
[0033] FIG. **12**A is an explanatory diagram showing signals input to frequency characteristic adjustment processors.
[0034] FIG. **12**B is an explanatory diagram showing signals output from the frequency characteristic adjustment processors.
[0035] FIG. **13** is an explanatory diagram showing a configuration to switch a filter coefficient of the active driving sound effect generator according to the second embodiment.
[0036] FIG. **14** is an explanatory diagram showing a comparative example of generating a waveform table containing multiple frequency components.
DETAILED DESCRIPTION OF THE EMBODIMENTS
[0037] 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.
First Embodiment
[Outline of Configuration of Active Driving Sound Effect Generator]
[0038] FIG. **1** is a block diagram showing an outline of a configuration of an active driving sound effect generator according to a first embodiment, mounted on a vehicle (see FIG. **6**).
[0039] 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**.
[0040] 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.
[0041] 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).
[0042] 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).
[0043] 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.
[0044] 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.
[0045] 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**.

[0046] 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.

[0047] The waveform generator **10** includes multiple waveform tables because the frequency component group generation processors **12-1**, . . . , **12**-N include respectively different waveform tables.

[0048] 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]).

[0049] 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**.

[0050] 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.

[0051] 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].

[0052] 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].

[0053] 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.
[0054] 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 intervales of the skip number ΔP) to be input to the speakers **50**.
[0055] 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.
[0056] 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).
[0057] 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.
[0058] 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.
[0059] 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.
[0060] 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.
[0061] 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].
[0062] 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**.

[0063] 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.

[0064] 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.

[0065] 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.

[0066] 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.

[0067] 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.

[0068] 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**.

[0069] 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**.

[0070] 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.

[0071] 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.

[0072] 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.

[0073] 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.

[0074] 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**.

[0075] 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**.

[0076] 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.

[0077] 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.

[0078] 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).

[0079] 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.

[0080] 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**.

[0081] 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).

[0082] 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.

[0083] 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.

[0084] 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.

[0085] 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.

[0086] 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.

[0087] 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.

[0088] 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.

[0089] 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.

[0090] 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.

[0091] 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.

[0092] 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>

[0093] Next, operations of the active driving sound effect generator **100** according to the first embodiment will be described in reference to FIG. **1** and FIGS. **7**A to **9**B.

[0094] 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.

[0095] 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**.

[0096] 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**.

[0097] 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**.

[0098] 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>

[0099] 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.

[0100] 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.

[0101] 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**.

[0102] 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.

[0103] 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**.

[0104] 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.
[0105] 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.
[0106] 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>
[0107] 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.
[0108] 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).
[0109] 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**.
[0110] 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>
[0111] 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**.
[0112] 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**.
[0113] 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.
[0114] 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.

[0115] 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.

[0116] 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**.

[0117] 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.

[0118] As described above, the active driving sound effect generator **100** according to the first embodiment includes the waveform generator **10** and the speakers **50**. The waveform generator **10** generates the signals u**1** . . . uN from the waveform tables **125**, **134** . . . according to the vehicle information. The speakers **50** output the signals u**1**, . . . , uN generated by the waveform generator **10**. Each of the waveform tables **125**, **134** . . . is the cyclic waveform table in which the end point and the start point of the waveform table are continuous, and contains the multiple frequency components.

[0119] With this configuration, each of the waveform tables **125**, **134**, . . . included in the waveform generator **10** contains multiple frequency components. For this reason, the amount of calculation can be reduced as compared with a case of combining (superposing) ordered acoustic signals obtained by generating multiple frequency components from a waveform table containing a single frequency component (for example, a sinusoidal wave) as in the related art (for example, such as Patent Literature 1 and Patent Literature 2).

[0120] In sum, the active driving sound effect generator **100** according to the first embodiment is able to generate the signals u**1** . . . uN to be output from the speakers **50** only by reading the waveform data of the waveform tables **125**, **134**, . . . , which are the cyclic waveform tables. As a result, the active driving sound effect generator **100** is able to generate a sound signal without needing to perform calculation, which otherwise would impose a load on the processing.

[0121] In particular, as described in reference to FIG. **4**, the waveform generator **10** includes the waveform table **134** of the waveform data having three (multiple) frequency components. This waveform table **134** is the cyclic waveform table in which the end point and the start point of the waveform data are continuous, and is the table containing the three (multiple) frequency components.

[0122] The waveform table **134** contains waveform data formed by adding up the integer multiples of the cyclic data of the waveform tables **131**, **132**, and **133** for the minimum time (4 [s]) for which the waveform tables **131**, **132**, and **133** can be synchronized, so that the waveform data has no discontinuity.

Comparative Example

[0123] Here, a comparative example will be described.

[0124] FIG. **14** is an explanatory diagram showing a comparative example of synthesizing a waveform table containing multiple frequency components. FIG. **14** shows processing for synthesizing a waveform table **164** of waveform data having three frequency components from a waveform table **161** with a frequency of 1 [Hz], a waveform table **162** with a frequency of 1.25 [Hz], and a waveform table **163** with a frequency of 1.5 [Hz].

[0125] Since the three waveform tables **161**, **162**, and **163** have different cycles, the non-cyclic waveform table **164** is generated when waveform data pieces for 1 [s] in these waveform tables **161**, **162**, and **163**, as they are, are added up by an adder **135**.

[0126] In particular, the waveform table **164** is formed of the sum of the waveform data pieces for 1 [s] in the respective waveform tables **161**, **162**, and **163**. In this case, regarding the waveform tables **162** and **163**, only some of the waveform data pieces per cycle are added, so that the waveform table **164** lacks the full waveform data pieces per cycle in the waveform tables **161**, **162**, and **163**. Specifically, in the waveform table **164**, the start point of the waveform data for 1 [s] takes 0 but the end point thereof takes 1, so that the start point and the end point are discontinuous. In this case, when the waveform data of the waveform table **164** is repeatedly read, discontinuity occurs due to the discontinuous start point and end point. As a result, if the waveform table **164** is applied to a cyclic waveform table to be continuously repeated, the active driving sound effect generator **100** will make a sound gap between the start point and the end point.
[0127] In the related art, to avoid a sound gap due to discontinuity in a waveform table, multiple waveform tables each containing a single frequency component are prepared, specific kinds of operations are performed by using these waveform tables, and then the resultant waveform tables are combined by an adder.
[0128] In contrast to this, in the waveform table **134** in the first embodiment, the numeric values in the frequency ratio of the waveform tables **131**, **132**, and **133** are first converted to integers, and then the time (minimum time) for minimum required data strings of the waveform data is determined as one cycle. In other words, in the waveform table **134**, desired waveform data is generated by adding up the integer multiples of the cyclic data (waveform data) of the waveform tables **131**, **132**, and **133** under the setting in which the minimum time [s] for which the waveform tables **131**, **132**, and **133** can be synchronized is set as one cycle. Even when the waveform data is read repeatedly, this ensures a sound continuity without causing a sound gap at a middle point in any of the cycles. Since the waveform table **134** can be generated by combining waveform tables containing desired frequency components, the tone can be easily adjusted to a tone desired by the user.
[0129] Thus, the active driving sound effect generator **100** according to the first embodiment enables easy adjustment of a tone, and accordingly enables generation of a highly-realistic driving sound effect.
[0130] The waveform generator **10** includes the multiple waveform tables and generates the signals u**1**, . . . , uN respectively from the multiple waveform tables. The active driving sound effect generator **100** includes the multiple gain adjusters **31**, . . . , **3**N respectively corresponding to the signals u**1**, . . . , uN generated from the multiple waveform tables by the waveform generator **10**.
[0131] With this configuration, the frequency component group generation processors **12-1**, . . . , **12**-N include their respective waveform tables, and the active driving sound effect generator **100** includes the gain adjusters **31**, . . . , **3**N respectively corresponding to the frequency component group generation processors **12-1**, . . . , **12**-N.
[0132] Thus, the active driving sound effect generator **100** is able to adjust the gains for the generated signals u**1**, . . . , uN and superimpose the gain-adjusted signals u**1**, . . . , uN, thereby composing a chord and generating a desired complex tone.
[0133] Moreover, the waveform generator **10** includes the waveform table **1201** (low frequency waveform table) containing relatively many low frequency components and the waveform table **1202** (high frequency waveform table) containing more high frequency components than the waveform table **1201** does. The vehicle information indicates the vehicle speed or the rotation speed of the power unit. When the vehicle speed or the rotation speed is relatively low, the gain for the waveform table **1201** is increased. On the other hand, when the vehicle speed or the rotation speed is relatively high, the gain for the waveform table **1202** is increased.
[0134] With this configuration, as shown in FIG. **5**, in a low vehicle speed range, the waveform generator **10** can generate strongly powerful signals like an engine sound by setting a high gain for the low frequency components in the waveform table **1201** according to the gain G**1** and setting a low gain for the high frequency components in the waveform table **1202** according to the gain G**2**.

In this way, the waveform generator **10** can generate a tone that will give an acceleration sensation.
[0135] As the vehicle **300** accelerates, the waveform generator **10** can generate signals of a frisky exhaust sound by setting a high gain for the high frequency components in the waveform table **1202** according to the gain G**2** and setting a low gain for the low frequency components in the waveform table **1201** according to the gain G**1** in a high vehicle speed range. In this way, the waveform generator **10** can generate an invigorating tone.
[0136] Moreover, in the operation 2 as described in reference to FIGS. **7**A to **7**C, the waveform generator **10** includes the multiple waveform tables **1201** and **1202** and is able to switch between the multiple waveform tables **1201** and **1202** in response to a user's operation.
[0137] With this configuration, the waveform generator **10** can switch between the powerful EV sports tone and the futuristic EV tone in response to a user's selection made on the tone screen **202** of the display audio **200**, thereby providing a passenger in the vehicle **300** with a more preferred sound.
[0138] Furthermore, in the operation 3 as described in reference to FIGS. **8**A and **8**B, the waveform generator **10** can further include the waveform table **1203** added by a user's operation, and is able to switch the waveform table for generating the signals u**1**, . . . , uN to the added waveform table **1203** among the multiple waveform tables.
[0139] With this configuration, in the waveform generator **10**, extra waveform data of a tone desired by a user may be added later in addition to default waveform data equipped in the active driving sound effect generator **100**, so that the active driving sound effect generator **100** can provide a sound effect more suited for user's preference.
[0140] In addition, as described in reference to FIG. **2**, the waveform generator **10** may include the skip table **123** and the generation processors **124**. The skip table **123** obtains the skip number ΔP for the read positions based on the vehicle information. Each of the generation processors **124** reads the signal in the waveform table at every position specified by the sum of each previous read position and the obtained skip number ΔP, and generates the corresponding one of the signals u**1**, . . . , uN to be input to the speakers **50**.
[0141] With this configuration, the waveform generator **10** only has to read the skip number ΔP from the skip table **123** according to a driving condition of the vehicle **300**, and add the skip number ΔP to the previous read position, so that the amount of calculation can be further reduced.
[0142] As shown in FIGS. **9**A and **9**B, the skip table **123** may include multiple skip tables such as the first skip table **1231** and the second skip table **1232** and can be switched therebetween in response to a user's selection operation.
[0143] With this configuration, the waveform generator **10** can switch the frequency by using the skip number ΔP according to the driving condition of the vehicle **300** based on the vehicle speed or the rotation speed of the power unit, thereby making it possible to provide a sound effect even more suited for user's preference. In particular, since a desired tone can be provided simply by switching the waveform data (data values in the table formats) to the first skip table **1231**, the second skip table **1232**, or the like, there is no need to change a software's calculation formula, and the skip table **123** can be easily switched to the desired one.
[0144] Moreover, the vehicle information indicates the vehicle speed or the rotation speed of the power unit, and the first skip table **1231** in FIG. **9**A may be set such that, based on an increase in the vehicle speed or the rotation speed of the power unit, the skip number is exponentially increased from the lower limit value to the upper limit value and is returned to the lower limit value when reaching the upper limit value.
[0145] With this configuration, the first skip table **1231** in FIG. **9**A enables generation of Shepard tone signals. Thus, the waveform generator **10** is able to easily generate a Shepard tone by using the first skip table **1231** in FIG. **9**A.
Second Embodiment
[Outline of Configuration of Active Driving Sound Effect Generator]

[0146] FIG. **10** is a block diagram showing an outline of a configuration of an active driving sound effect generator according to a second embodiment, mounted on a vehicle.

[0147] As shown in FIG. **10**, an active driving sound effect generator **101** according to the second embodiment further includes frequency characteristic adjustment processors **13-1**, . . . , **13**-N in the waveform generator **10** of the active driving sound effect generator **100** according to the first embodiment. The frequency characteristic adjustment processors **13-1**, . . . , **13**-N will be also simply referred to as the frequency characteristic adjustment processors **13** when any one of them does not have to be specified.

[0148] The frequency characteristic adjustment processors **13-1**, . . . , **13**-N include band-pass filters to be applied to the signals u**1**, . . . , uN generated respectively by the corresponding frequency component group generation processors **12**, . . . , **12**-N (generation processors **124**). Each of the band-pass filters is provided with a pass frequency band between the frequency of a signal generated at the upper limit value of the skip number ΔP in the skip table and the frequency of a signal generated at the lower limit value of the skip number ΔP.

[0149] FIG. **11**A is an explanatory diagram showing a coefficient of a band-pass filter included in the frequency characteristic adjustment processor. FIG. **11**B is an explanatory diagram showing frequency characteristics based on the filter coefficient.

[0150] Each of the frequency characteristic adjustment processors **13-1**, . . . , **13**-N includes a band-pass filter to pass a predetermined frequency band based on a predetermined filter coefficient. In addition, the frequency characteristics shown in FIG. **11**B are provided with a specific pass frequency band by combining a low-pass filter that attenuates frequency components higher than a predetermined cutoff frequency without attenuating low frequency components, and a high-pass filter that attenuates frequency components lower than a predetermined cutoff frequency without attenuating high frequency components.

[0151] FIG. **12**A is an explanatory diagram showing signals input to the frequency characteristic adjustment processors. As shown in FIG. **12**A, in the signals u**1**, . . . , uN input to the frequency characteristic adjustment processors **13-1**, . . . , **13**-N, a frequency switchover is clearly (distinctly) output as shown by an arrow **150** in switching from the high frequency to the low frequency along with a change in the vehicle speed.

[0152] In contrast, FIG. **12**B is an explanatory diagram showing signals output from the frequency characteristic adjustment processors. As shown in FIG. **12**B, in signals f**1**, . . . , fN output from the frequency characteristic adjustment processors **13-1**, . . . , **13**-N, high frequency components and low frequency components are attenuated with the band-pass filter having the frequency characteristics as shown in FIG. **11**B applied to the signals u**1**, . . . , uN input to the frequency characteristic adjustment processors **13-1**, . . . , **13**-N. Thus, in switchover from the high frequency component to the low frequency component, the signals f**1**, . . . , fN output from the frequency characteristic adjustment processors **13-1**, . . . , **13**-N can be faded out and faded in at these frequency components.

[Operation of Active Driving Sound Effect Generator]

[0153] An operation of the active driving sound effect generator according to the second embodiment will be described in reference to FIG. **13**.

[0154] FIG. **13** is an explanatory diagram showing a configuration to switch a filter coefficient of the active driving sound effect generator according to the second embodiment.

[0155] As shown in FIG. **13**, each of the frequency characteristic adjustment processors **13** includes a filter coefficient setting table **143**. The filter coefficient setting table **143** includes filter coefficients to be set to the band-pass filter depending on a vehicle speed range.

[0156] For example, when the vehicle speed of the vehicle **300** is up to 60 [kph], a data set **144** is applied and predetermined filter coefficients (0.0, 0.32, . . . , 0.01) are applied to the band-pass filter. When the vehicle speed of the vehicle **300** is in a range from 100 [kph] to 160 [kph], a data set **145** is applied and predetermined filter coefficients (0.0, 0.35, . . . , 0.00) are applied to the band-pass filter.

[0157] In this way, the frequency characteristic adjustment processors **13** switch the filter coefficients depending on the vehicle speed range and apply the band-pass filters to the signals u**1**, . . . , uN input to the frequency characteristic adjustment processors **13-1**, . . . , **13**-N.

[0158] As described above, the active driving sound effect generator **101** according to the second embodiment includes the band-pass filters in the waveform generator **10**. The band-pass filters are applied to the signals u**1**, . . . , uN generated by the waveform generator **10**. The band-pass filters are each provided with a pass frequency band between the frequency of a signal generated at the upper limit value in the skip table **123** and the frequency of the signal generated at the lower limit value in the skip table **123**.

[0159] With this configuration, the active driving sound effect generator **101** according to the second embodiment is able to apply the band-pass filters to the signals u**1**, . . . , uN input to the frequency characteristic adjustment processors **13-1**, . . . , **13**-N, thereby making it possible to generate a natural sound effect by eliminating the feeling of a frequency switchover along with a change in the vehicle speed.

Claims

1. An active driving sound effect generator mounted on a vehicle, comprising: a waveform generator configured to generate a signal from a waveform table depending on vehicle information; a speaker configured to output the signal generated by the waveform generator, wherein the waveform table is a cyclic waveform table in which an end point and a start point of the waveform table are continuous and contains a plurality of frequency components.

2. The active driving sound effect generator according to claim 1, wherein the waveform generator includes a plurality of the waveform tables, and generate a signal from each of the plurality of waveform tables, and the active driving sound effect generator further comprises a plurality of gain adjusters respectively corresponding to signals generated from the plurality of waveform tables.

3. The active driving sound effect generator according to claim 2, wherein the waveform generator includes a low frequency waveform table containing relatively many low frequency components and a high frequency waveform table containing more high frequency components than the low frequency waveform table does, the vehicle information indicates a vehicle speed or a rotation speed of a power unit, when the vehicle speed or the rotation speed is relatively low, a gain for the low frequency waveform table is increased, and when the vehicle speed or the rotation speed is relatively high, a gain for the high frequency waveform table is increased.

4. The active driving sound effect generator according to claim 1, wherein the waveform generator includes a plurality of the waveform tables, and the plurality of waveform tables are switchable in response to a user's operation.

5. The active driving sound effect generator according to claim 4, wherein the plurality of waveform tables include a waveform table added by a user's operation, and the waveform generator is capable of switching a waveform table from which to generate the signal to the added waveform table among the plurality of waveform tables.

6. The active driving sound effect generator according to claim 1, wherein the waveform generator includes a skip table from which a skip number for a read position is obtained based on the vehicle information, and a generation processor configured to generate a signal to be input to the speaker by reading a signal in the waveform table at a position specified by a sum of a previous read position in the waveform table and the obtained skip number.

7. The active driving sound effect generator according to claim 6, wherein a plurality of the skip tables are provided, and the skip tables are switched according to a user's selection operation.

8. The active driving sound effect generator according to claim 6, wherein the vehicle information indicates the vehicle speed or the rotation speed of the power unit, and in the skip table, based on an increase in the vehicle speed or the rotation speed, a value 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.

9. The active driving sound effect generator according to claim 8, wherein the waveform generator includes a band-pass filter to be applied to the signal generated by the generation processor, and the band-pass filter is provided with a pass frequency band between a frequency of a signal generated at the upper limit value in the skip table and a frequency of a signal generated at the lower limit value in the skip table.