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Low frequency audio conversion circuit
Umwandlungsschaltung für Niedrigfrequenz-Tonsignale
Montage de circuit de conversion audio en basse fréquence

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BACKGROUND OF THE INVENTION

[0001] The present invention relates to a low frequency audio conversion circuit for enhancing the presence of low frequency audio by compensating the low frequency component which is deficiently reproduced by a speaker having a poor response for low frequency audio.

[0002] The size and shape of a speaker built in an ordinary television receiving set, etc. is restricted by the structure of receiver set, etc. Due to such restrictions, the reproduction of the low frequency sound is limited. Although satellite broadcasting programs and the Hi-vision programs are presented in digital sound, listeners are not able to enjoy the quality music source. In order to improve sound quality, some receiving sets available in the market are equipped with low-frequency dedicated speakers and amplifiers. However, the size of such sets inevitably increases because additional space for incorporating the dedicated speakers and amplifiers is needed. Moreover, such sets often have the problem of sound resonating within the cabinet of the television set.

[0003] To overcome these disadvantages, there have been circuits proposed for compensating the low frequency component of an audio signal one of which is shown in FIG. 6.

[0004] An exemplary circuit for low frequency compensation is described below with reference to FIG. 6.

[0005] In FIG. 6, numeral 10 denotes a low pass filter for extracting the low frequency audio component by passing only the low frequency signals. A normalizer 11 coordinates the amplitude of the low frequency component with that of other frequency components. A second harmonics generator 12 generates secondary harmonics. A third harmonics generator 13 generates tertiary harmonics. A n-th harmonics generator 14 generates n-th harmonics. An adder 15 adds signals from the harmonics generators.

[0006] Another exemplary circuit for low frequency compensation is described in the patent application EP 0 546 619 A.

[0007] The operation of the low frequency audio component compensation circuit is now described. When an audio signal comes to the circuit, only the low frequency component is extracted by low pass filter 10 and sent to normalizer 11. The normalizer 11 applies a normalization process to the low frequency signal component by coordinating the amplitude of the low frequency component with that of other frequency components. A second harmonics generator 12 generates secondary harmonics. A third harmonics generator 13 generates tertiary harmonics. A n-th harmonics generator 14 generates n-th harmonics. An adder 15 adds signals from the harmonics generators.

[0008] Secondary harmonics are obtained according to

\[ \cos 2\theta = 2\cos^2\theta - 1 \]

where the original sound: \( \cos \theta \), tertiary harmonics are obtained according to

\[ \cos 3\theta = 4\cos^3\theta - 3\cos \theta, \]

and fourth harmonics are obtained according to

\[ \cos 4\theta = 8\cos^4\theta - 8\cos^2\theta + 1. \]

Likewise, n-th order harmonics can be determined with similar mathematical formulas. The harmonics of each order are multiplied by a coefficient and then mixed at adder 15 with the original audio input signal to produce a final output signal.

[0009] By using the low frequency audio component compensation circuit described above, even a speaker having poor low frequency reproduction characteristics as shown in FIG. 3(a) can reproduce the harmonics. As shown in FIG. 3(a), an audio component at frequency \( f_0 \) is hardly reproducible because the frequency curve 7 of the speaker does not cover, for example, the low range component 8 at frequency \( f_0 \). The speaker can reproduce, as compound sound, the secondary harmonics 9, tertiary harmonics 16 and the n-th order harmonics 17 of the low frequency audio component at frequency \( f_0 \), as shown in FIG. 7. The compound sound containing secondary harmonics 9, tertiary harmonics 16 and the n-th harmonics of the low frequency audio component at frequency \( f_0 \) creates, by taking advantage of the
psychological effects of sound on the human auditory sense, an effect as if the low range sound is actually reproduced.

The conventional circuitry described above is difficult to implement with an analog circuit because of the need for mathematical processing. Another problem is that the scale of the circuitry becomes very large. As a matter of course, the conventional circuit is easily implemented by using digital signal processors. However, in this case a large processing program is required, which substantially increases cost.

Moreover, the conventional circuit described above has a drawback in that it eventually produces a malaise in the musical sense. For example, when a 55 Hz sound “la” is inputted, its secondary harmonic is a 110Hz sound “la”, but the tertiary harmonic is a 165Hz sound which is almost “mi”. The synthetic chord of these harmonics and the original sound creates a dissonance. Therefore, the conventional circuitry can only reproduce a sound in which the fidelity to the pitch of original sound is low.

SUMMARY OF THE INVENTION

The present invention solves the above described drawbacks and provides a low frequency audio conversion circuit which compensates for the deficient low frequency sound component that inevitably occurs when a sound is reproduced with a speaker having poor low frequency response. The present invention reproduces a low frequency sound at low cost, without an accompanying malaise in a musical sense.

A low frequency audio conversion circuit according to a first example which is useful for understanding the invention comprises:

- a first low pass filter for passing only a low frequency audio component of an input audio signal lower than the lowest frequency that can be reproduced by a speaker,
- a full wave rectifier coupled to the first low pass filter, for producing even numbered harmonics of the low frequency audio component passed by the first low pass filter,
- a second low pass filter coupled to the full wave rectifier, for passing only the secondary among an output generated by the full wave rectifier,
- an amplifier coupled to the second low pass filter, for amplifying the secondary harmonics passed by the second low pass filter, and
- an adder for adding an output signal from the amplifier for amplifying the secondary harmonics and the input audio signal, to produce an output audio signal.

A low frequency audio conversion circuit according to a second example which is useful for understanding the invention comprises:

- a left first low pass filter for passing only a low frequency audio component of an input audio signal of a left channel lower than the lowest frequency that can be reproduced by a speaker,
- a left full wave rectifier coupled to the left first low pass filter, for producing even-numbered harmonics of the low frequency audio component passed by the left first low pass filter,
- a left second low pass filter coupled to the left full wave rectifier, for passing only the secondary among an output generated by the left full wave rectifier,
- a left amplifier, coupled to the left second low pass filter, for amplifying the secondary harmonics extracted by the left second low pass filter, and
- a left second adder for adding an output signal from the left amplifier for amplifying the secondary harmonics and the left channel audio input signal, to produce a left channel audio output signal,

- a right first low pass filter for passing only a low frequency audio component of the input audio signal of a right channel lower than the lowest frequency that can be reproduced by a speaker,
- a right full wave rectifier coupled to the right first low pass filter, for producing even-numbered harmonics of the low frequency audio component passed by the right first low pass filter,
a right second low pass filter coupled to the right full wave rectifier, for passing only the secondary harmonics among the even-numbered harmonics generated by the right full wave rectifier,

a right amplifier coupled to the right second low pass filter, for amplifying the secondary harmonics passed by the right second low pass filter, and

a right adder for adding an output signal from the right amplifier for amplifying the secondary harmonics and the right channel audio input signal, to produce a right channel audio output signal.

A low frequency audio conversion circuit according to an embodiment of the present invention comprises:

a first adder for adding a left channel audio input signal and a right channel audio input signal,

a first low pass filter coupled to the first adder, for passing only a low frequency audio component, produced by said first adder, lower than the lowest frequency that can be reproduced by a speaker,

a full wave rectifier coupled to the first low pass filter, for producing even-numbered harmonics of the low frequency audio component passed by the first low pass filter,

a second low pass filter coupled to the full wave rectifier, for passing only secondary harmonics among the even-numbered harmonics generated by the full wave rectifier,

an amplifier coupled to the second low pass filter, for amplifying the secondary harmonics passed by the second low pass filter,

a left second adder for adding an output signal from the amplifier and the left channel audio input signal, to produce a left channel audio output signal, and

a right second adder for adding an output signal from the amplifier for amplifying the secondary harmonics and the right channel audio input signal, to produce a right channel audio output signal.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of a low frequency audio conversion circuit according to the first example;

FIG. 2 is a wave form chart showing the function of each part of a low frequency audio conversion circuit according to the first example;

FIG. 3(a) shows the relationship between the reproduction frequency curve of a speaker and the input low frequency audio signal.

FIG. 3(b) shows the reproduction frequency curve of a speaker, the input low frequency audio signal and the secondary harmonic.

FIG. 4 is a block diagram of a low frequency audio conversion circuit according to the second example;

FIG. 5 is a block diagram of a low frequency audio conversion circuit according to an embodiment of the present invention.

FIG. 6 is a block diagram of a conventional low frequency audio conversion circuit.

FIG. 7 shows the relationship among the reproduction frequency curve of a speaker, input low frequency audio signal and the harmonic signals, in a conventional low frequency audio conversion circuit.
DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0016] A low frequency audio conversion circuit according to a first example is described in detail below with reference to FIG. 1, FIG. 2, and FIG. 3.

[0017] FIG. 1 is a block diagram of a low frequency audio conversion circuit according to a first example.

[0018] In FIG. 1, numeral 1 denotes a first low pass filter which receives input audio signals and passes only low frequency audio signals having a frequency lower than the lowest reproduction limit of a speaker. Full wave rectifier 2 generates even-numbered harmonics. A second low pass filter 3 passes only the secondary harmonics among the even-numbered harmonics generated by the full wave rectifier 2. Amplifier 4 amplifies the secondary harmonics supplied from the second low pass filter 3. An adder 5 adds the input audio signal and the amplified secondary harmonics signal.

[0019] Next, the operation of a low frequency audio conversion circuit according to the first example is described. FIG. 3(a) shows the relationship between the reproduction frequency curve 7 of a speaker and the low frequency audio component of a signal at frequency f0. Speakers used in TV receivers, etc. are usually small-sized and the lowest frequency of reproduction by such speakers is around 100Hz, as shown in FIG. 3(a). In the normal music signal, there is an audio component having a frequency f0 below 100Hz which provides a powerful low frequency sound. Because of the poor reproduction characteristics in the low frequency range, such speakers are unable to reproduce the signal having the frequency f0 and hence, cannot offer an appealing low frequency sound.

[0020] FIG. 3(b) illustrates the relationship among the frequency f0 lower than the lowest limit of sound reproduction curve 7 of a speaker, the secondary harmonic signal of the f0 signal, and the reproduction frequency curve 7 of a speaker. In the first embodiment of the invention, the f0 signal is converted to its second harmonic (a sound signal having a frequency one octave higher than frequency f0), which falls within the frequency range of a speaker to provide a sound rich in a low frequency sound.

[0021] In FIG. 1, a frequency component which is lower than the lowest frequency a speaker in use can reproduce is extracted from the input audio signal by the No. 1 low pass filter 1, and the low frequency component thus extracted is rectified by full wave rectifier 2 to generate even-numbered harmonics.

[0022] Defining the input signal B = sin(wt), the output signal C produced by the full wave rectifier 2 is expressed through Fourier expansion by the formula

\[ C = \frac{2}{\pi} + \frac{4}{\pi} \cdot \{\sin(2wt)/3 - \sin(4wt)/15 + \sin(6wt)/35 : \ldots\}. \]

The formula represents that the full wave rectified output includes even-numbered harmonics, and that, as the coefficients indicate, more than 80% are the secondary harmonics.

[0023] By letting only the secondary harmonics pass through the No. 2 low pass filter 3, the secondary harmonics can be extracted efficiently. Then, the secondary harmonics which passed through the No. 2 low pass filter 3 are amplified by amplifier 4 to produce a signal of an appropriate level. The amplified secondary harmonics are added by adder 5 to the input audio signal to produce an output audio signal.

[0024] FIG. 2 shows the waveforms at each of the components shown in FIG. 1, where A is the input audio signal, B is the output of the No. 1 low pass filter 1, C is the output of the full wave rectifier 2, D is the output of the No. 2 low pass filter 3. In this way, secondary harmonics of an audio signal below the lowest frequency a speaker can reproduce contained in an input audio signal are generated, to be converted into a signal within the frequency range the speaker can reproduce, which is to be added to the input audio signal. The audio signal added to the input audio signal includes only secondary harmonics having a frequency higher than the original audio signal frequency by one octave. Therefore, no dissonance is created. The original low frequency audio signal is never reproduced because what is added to the input audio signal is a signal one octave higher than the original sound. However, according to experiments, the reproduced sound is recognized by listeners as a sound that has been reinforced with the low frequency signal, unless the listeners have a full knowledge and memory of the corresponding musical score. A better effect is produced by reproducing a sound with a low frequency component below the lowest limit a speaker can reproduce as secondary harmonics, rather than eliminating the low frequency component. The present invention is more effective than conventional methods where the level of low sound range is raised with a tone control technique.

[0025] In the first example above, the low frequency audio conversion circuit is used for reproduction of a monaural signal. A circuit for stereo reproduction is described below as a second example.

[0026] FIG. 4 shows a low frequency audio conversion circuit for stereo reproduction according to a second example. Because stereo reproduction needs processing of two signal channels, this example employs two channels of the circuitry as described in the first example. In FIG. 4, with respect to the left channel, a low frequency component below the lowest frequency a speaker can reproduce is extracted from the left channel audio input signal by a left No. 1 low pass filter.
With respect to the right channel, a low frequency audio component below the lowest frequency a speaker can reproduce is extracted from the right channel audio input signal by a right No. 1 low pass filter 1R which passes only a low frequency audio signal below the lowest reproduction frequency range. A right full wave rectifier 2R rectifies the low frequency component extracted by the right No. 1 low pass filter 1R to generate even-numbered harmonics. The output signal from right full wave rectifier 2R containing even-numbered harmonics is supplied to right No. 2 low pass filter 3R which passes only the secondary harmonics. Thus, only the secondary harmonics are extracted. The secondary harmonics extracted by right No. 2 low pass filter 3R are amplified to produce a signal of an appropriate level by a right amplifier 4R. The amplified secondary harmonics are added by a right adder 5R to the right channel audio input signal, to make a right channel audio output signal.

As described above, in stereo sound reproduction, a low frequency component can be reinforced without any accompanying dissonance by using two channels of low frequency audio conversion circuitry for monaural sound reproduction. The secondary harmonics of a low frequency component below the lowest frequency a speaker can reproduce contained in an input sound signal are generated and added to the input audio signal. Another low frequency audio conversion circuit for stereo sound reproduction is described as an embodiment of the present invention. This embodiment is a reduced version of the second example shown in FIG. 4 for the purpose of cost reduction. FIG. 5 shows the circuit of the embodiment.

In FIG. 5, numeral 6 denotes a first adder for adding a left channel audio input signal and a right channel audio input signal. A first low pass filter passes only a low frequency audio signal lower than the frequency a speaker can reproduce A full wave rectifier 2 generates even-numbered harmonics and converts the frequency. A second low pass filter 3 passes only the secondary harmonics among the even-numbered harmonics generated by the full wave rectifier 2. An amplifier 4 amplifies the secondary harmonics signal supplied from the second low pass filter 3 to an appropriate level. A left second adder 5L adds the amplified secondary harmonics signal to the left input audio signal. A right second adder 5R adds the amplified secondary harmonics signal to the right input audio signal.

In this embodiment, the left and the right input audio signals are added in No. 1 adder 6 to have the left channel audio input signal and the right channel audio input signal combined instead of directly entering a low pass filter. The combined left/right input audio signal is provided to No. 1 low pass filter 1 to have low frequency audio signals lower than the frequency a speaker can reproduce extracted. The low frequency audio signal thus extracted is rectified by full wave rectifier 2 to generate even-numbered harmonics and convert the frequency. From the frequency-converted output of full wave rectifier 2, which contains even-numbered harmonics, only the secondary harmonics are extracted by No. 2 low pass filter 3, and then amplified by amplifier 4 to an appropriate level. The secondary harmonics amplified by amplifier 4 to an appropriate level are, in one side, added by a left second adder 5L to the left input audio signal, to be outputted as a left audio output signal. The secondary harmonics amplified by amplifier 4 to an appropriate level are, in the other side, added by a right second adder 5R to the right input audio signal, to be outputted as a right audio output signal.

Symbols A, B, C and D in FIG. 4 correspond respectively to waveforms A, B, C, and D of FIG. 2, which show the waveform produced by each component. FIG. 2 illustrates how the low frequency component below the lowest frequency a speaker can reproduce is converted to secondary harmonics.

As described above, in stereo sound reproduction, a low frequency component can be reinforced without any accompanying dissonance by using a first adder which adds the left and the right channel audio input signals. One series circuit consisting of a first low pass filter, a full wave rectifier, a second low pass filter and an amplifier, and two second adders create the secondary harmonics of a low frequency component below the lowest frequency a speaker can reproduce contained in an input audio signal, and adds the secondary harmonics of the low frequency component to the input audio signal. Even with a simplified circuit as described above, a low frequency audio conversion circuit is implemented which empirically provides a sufficient effect, although slightly inferior in the fidelity of the sound when compared to the second example.

As explained in the foregoing descriptions, a low frequency audio conversion circuit according to the present invention enables a low frequency component lower than the frequency a speaker can reproduce supplied to a speaker whose low frequency sound reproduction characteristics are poor because of restrictions in size and shape, to be reproduced as a powerful sound in which the low frequency component, which is deficient in the speaker output, is
compensated for, without degrading the sound reproduced, by converting the low frequency component into secondary harmonics to be added to an input audio signal. Another advantage of the present invention is that it may be implemented using a low cost analog circuit.

Claims

1. A low frequency audio conversion circuit comprising:

- a first adder for adding a left channel audio input signal and a right channel audio input signal,
- a first low pass filter coupled to said first adder for passing a low frequency audio component produced by said first adder which is lower than the lowest frequency which can be reproduced by a speaker,
- a full wave rectifier coupled to said first low pass filter, for producing even-numbered harmonics of the low frequency audio component passed by said first low pass filter,
- a second low pass filter coupled to said full wave rectifier for passing a signal which includes secondary harmonics to the relative exclusion of other even-numbered harmonics supplied from said full wave rectifier,
- an amplifier coupled to said second low pass filter, for amplifying the signal passed by said second low pass filter to produce an output signal,
- a left second adder for adding the output signal from said amplifier and the left channel audio input signal, to produce a left channel audio output signal, and
- a right second adder for adding the output signal from said amplifier and the right channel audio input signal, to produce a right channel audio output signal.

Patentansprüche

1. Niederfrequenz-Tonsignal-Umwandlungsschaltung mit:

- einem ersten Adder zum Addieren eines Audio-Eingangssignals eines linken Kanals und eines Audio-Eingangs-
signals eines rechten Kanals;
- einem mit dem ersten Adder gekoppelten ersten Tiefpassfilter zum Durchlassen einer von dem ersten Adder
erzeugten Tonsignal-Niederfrequenzkomponente, die kleiner als die niedrigste Frequenz ist, die von einem
Lautsprecher wiedergegeben werden kann;
- einem mit dem ersten Tiefpassfilter gekoppelten Vollweggleichrichter zum Erzeugen von geradzahligen Ober-
wellen der von dem ersten Tiefpassfilter durchgelassenen Tonsignal-Niederfrequenzkomponente;
- einem mit dem Vollweggleichrichter gekoppelten zweiten Tiefpassfilter zum Durchlassen eines Signals, das
sekundäre Oberwellen enthält, bis zu dem relativen Ausschluss von anderen geradzahligen Oberwellen, die
dem Vollweggleichrichter zugeführt werden;
- einem mit dem zweiten Tiefpassfilter gekoppelten Verstärker zum Verstärken des von dem zweiten Tiefpassfilter
durchgelassenen Signals, um ein Ausgangssignal zu erzeugen;
- einem linken zweiten Adder zum Addieren des Ausgangssignals von dem Verstärker und des Audio-Eingangs-
signals des linken Kanals, um ein Audio-Ausgangssignal des linken Kanals zu erzeugen; und

Revendications

1. Circuit de conversion audio à basse fréquence comprenant:

- un premier additionneur destiné à additionner un signal d'entrée audio de canal gauche et un signal d'entrée
audio de canal droit,
- un premier filtre passe-bas couplé audit premier additionneur, destiné à transmettre une composante audio à
basse fréquence produite par ledit premier additionneur qui est inférieure à la fréquence la plus basse qui peut être reproduite par un haut-parleur,
- un redresseur à deux alternances couplé audit premier filtre passe-bas, destiné à produire des harmoniques
pairs de la composante audio à basse fréquence transmise par ledit premier filtre passe-bas,
- un second filtre passe-bas couplé audit redresseur à deux alternances, destiné à transmettre un signal qui
comprend des harmoniques secondaires à l’exclusion relative des autres harmoniques pairs fournis à partir
dudit redresseur à deux alternances,
un amplificateur couplé audit second filtre passe-bas, destiné à amplifier le signal transmis par ledit second
filtre passe-bas pour produire un signal de sortie,
un second additionneur gauche destiné à additionner le signal de sortie provenant dudit amplificateur et le
signal d’entrée audio du canal gauche, pour produire un signal de sortie audio de canal gauche, et
un second additionneur droit destiné à additionner le signal de sortie provenant dudit amplificateur et le signal
d’entrée audio du canal droit, pour produire un signal de sortie audio de canal droit.
FIG. 6

10 11 12 13 14 15

Input

Low Pass Filter
Normalizer
2nd Harmonics Generator
3rd Harmonics Generator
nth Harmonics Generator
Adder

Output
FIG. 7