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(71) Applicant: **AM3D A/S**
9200 Aalborg SV (DK)

(72) Inventors:
- **Larsen, Clemen Boje**
  9000 Aalborg (DK)
- **Beierholm, Thomas**
  9000 Aalborg (DK)
- **Hounum, Peter Theilgaard**
  9000 Aalborg (DK)

(74) Representative: **Plougmann & Vingtoft A/S**
Rued Langgaards Vej 8
2300 Copenhagen S (DK)

(54) Distortion reduction for small loudspeakers by band limiting

(57) The invention provides a method and a device for reducing distortion from an associated loudspeaker acoustically mounted such that it exhibits a lower resonance frequency Fc. A limited frequency band, including Fc, of an audio input signal is attenuated. Hereby distortion due to large diaphragm excursions in the frequency range around Fc can be eliminated. Especially, the amount of attenuation to be applied to this limited signal frequency range is determined in response to the peak signal level in this limited signal frequency range so as to only apply an attenuation when the signal level in this frequency range exceeds a predetermined level. Hereby, it is possible to take into account the properties of a miniature loudspeaker and ensure that sufficient attenuation is applied so as to avoid maximum diaphragm excursions which result in severe audible distortion. Thus, by controlling this attenuation in a narrow frequency band, e.g. 1 octave or even down to such as 1/3 octave, severe audible distortion can be eliminated, and the negative audible effect of such "band limitation" is hardly audible since the frequency range is so narrow. Most of the time the attenuation effect is completely inactive, since its effect is only required when large peak levels occur in the range near Fc.

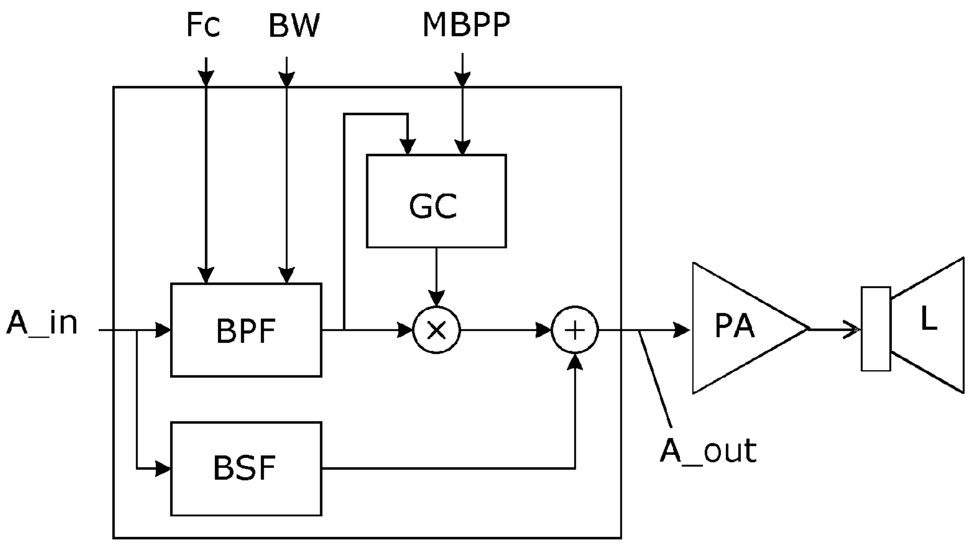


Fig. 1

EP 2 600 636 A1

Description

FIELD OF THE INVENTION

[0001] The present invention relates to the field of signal processing, especially audio signal processing, and more specifically processing of audio signals for playback by small loudspeakers. More specifically, the invention provides a processor and a method for reducing distortion produced by small loudspeakers, and/or increasing the possible acoustic output for such loudspeakers, and/or possibly reducing the risk of damaging the loudspeakers.

BACKGROUND OF THE INVENTION

[0002] Small loudspeaker units are used in many devices today for reproducing audio signals in compact portable audio devices, e.g. mobile phones, media players, car audio systems and the like. Due to the small size, such loudspeakers have a limited maximum acoustic output, a limited dynamic range, and especially a limited low frequency output. When the dynamic capability of a small loudspeaker is exceeded, the result is a severely distorted audio signal. Especially, the distortion is clearly audible on audio signal including a few pure tones, e.g. as popular ring tones used by many Japanese in their mobile phones.

[0003] A number of known solutions exist for processing the electric signal applied to a small loudspeaker in order to remedy the limited capacity of the loudspeaker, if a low distortion signal is required: reduce the overall level and accept a low acoustic output, sharply filter out low frequency content, or limit the level by means of a compressor.

SUMMARY OF THE INVENTION

[0004] Thus, according to the above description, it is an object of the present invention to provide a simple and effective processor and processing method for preprocessing an audio signal before applying it to a small loudspeaker, so as to increase the acoustic output of the loudspeaker without severely affecting sound quality due to distortion. Alternatively, the goal is to maintain an acoustic output while lower the distortion.

[0005] In a first aspect, the invention provides a device arranged for application to an associated loudspeaker acoustically mounted such that it exhibits a lower resonance frequency. The device comprises

- an input arranged to receive an audio input signal,
- a filter section arranged to receive the audio input signal and to attenuate a limited frequency band thereof and generate a modified audio signal accordingly, wherein the limited frequency band includes said lower resonance frequency of the associated loudspeaker, and
- an output arranged to output the modified audio signal as an audio output signal.

[0006] Such device is advantageous, since it allows reproduction of sound with a miniature or micro-speaker with reduced distortion. Typical loudspeakers where the invention is advantageous are loudspeaker with a small diaphragm area and which are mounted such that its lower resonance frequency Fc is rather high, e.g. 1 kHz, as in many mobile phones and the like. The free air resonance frequency of the loudspeaker is typically lower, but due to a small back volume the resulting lower resonance frequency Fc often becomes rather high. The invention is based on the insight that by attenuating a limited frequency band including the Fc, e.g. centred around Fc (on a logarithmic frequency scale), it is possible to limit large diaphragm excursions of the loudspeaker which occurs when applying sound around Fc. Such large excursions of the diaphragm will at higher signal levels lead to severe audible non-linear distortion, and potentially they may damage the loudspeaker. Such severe distortion can be reduced or even eliminated by proper attenuation of the limited frequency band around Fc. Since the attenuated frequency band is limited, e.g. only 1 octave wide or even narrower such as 1/3-2/3 octaves wide, the negative audible effect of such attenuation is very limited, and in many cases not even audible. Such as 3-6 dB of attenuation at high signal levels in said frequency band can dramatically reduce distortion from a small loudspeaker, thus leading to either improved sound quality and/or increased effective acoustic output from the small loudspeaker at audio frequencies above Fc, but in many cases also below Fc.

[0007] In a digital signal processing chain, the invention should preferably be present just prior to digital to analog conversion resulting in the analog signal to drive the loudspeaker.

[0008] In preferred embodiments, the limited frequency band has a bandwidth of less than 2 octaves, such as less than 1 octave, such as less than 2/3 octaves, such as less than 1/3 octave. The limited frequency band may be centred around said lower resonance frequency of the associated loudspeaker. The bandwidth optimal in each case will depend on the loudspeaker and the acoustical environment where it is mounted. A more effective distortion protection can be achieved with a rather wide bandwidth, whereas the most inaudible processing is obtained with a narrow bandwidth.

[0009] Preferred embodiments comprise a gain control unit arranged to control said attenuation in the limited frequency band. The gain control unit may be arranged to detect a level of the audio input signal within the limited frequency band and to provide said attenuation according to a predetermined attenuation scheme. Said scheme may include detecting whether a peak level of the audio input signal within the limited frequency band exceeds a predetermined maximum level, and determining said attenuation accordingly to ensure that the modified audio signal does not exceed the predetermined maximum level. Said predetermined maximum level is preferably selected such in relation to the associated loudspeaker that the audio output signal will not cause the loudspeaker to perform a diaphragm excursion exceeding its limit.

[0010] The gain control unit is preferably designed such, that zero attenuation is provided most of the time when signal levels are low enough to ensure that the loudspeaker diaphragm will not reach excursions causing severe distortion. Especially, an attenuation Att (in dB) should preferably be determined in response to a detected peak signal level P (in dB) such that a predetermined maximum allowable level ML (in dB), determined in accordance with the capability of the loudspeaker, e.g. according to:

$$Att = P - ML \text{ (all in dB)},$$

[0011] Thus, with ML = 100 dB, and a detected peak level P exceeding this, e.g. P = 110 dB, an attenuation of A = 10 dB will be determined, thus leading to a resulting signal level in the frequency band which has a peak level equal to the maximum allowed, i.e. ML. ML can be selected according to the application to include a safety margin to ensure that the loudspeaker is never overloaded, or it can be set to a more aggressive value allowing slightly overloading the loudspeaker. As mentioned, for many signals, the attenuation will preferably be zero, thus leaving the processing inactive. However, in case of signals with high levels within the frequency band including Fc, especially tone complexes with large onsets, the attenuation can effectively ensure that severe audible distortion is avoided.

[0012] It is to be understood, that the filter section may be implemented in various ways, using various types of filters with various cut off slope steepness etc. In one implementation, the filter section may comprise a band pass filter arranged to band pass filter the audio input signal to said limited frequency band, and a band stop filter arranged to band stop filter the audio input signal with the stop band being said limited frequency band. Outputs from the band pass filter and the band stop filter may then be summed to generate the audio output signal.

[0013] The device may be designed to accept an audio input signal with a plurality of audio channels, such as a stereo signal, and wherein the audio channels are processed to form an audio output signal with a corresponding plurality of audio channels. The audio input signal may be analog or digital, and also the audio output signal may be analog or digital. Preferably, the filter section and the attenuation is implemented by means of a digital processor programmed to perform the required signal processing.

[0014] The device may comprise a loudspeaker acoustically mounted such that it exhibits said lower resonance frequency, and a power amplifier connected to drive the loudspeaker according to the audio output signal. Especially, the device may be a mobile device, such as portable audio device, portable video devices, and portable players. More specifically, the device may be one of: a mobile phone, a tablet, a laptop, and a personal navigation device. However, it is to be understood that the invention may be useful in combination to any application where an acoustic output from a small loudspeaker is required with a minimum of audible distortion. Especially, the loudspeaker is small, i.e. has a diaphragm area of less than 10 cm^2, such as less than 5 cm^2, such as less than 2 cm^2, such as less than 1 cm^2. The loudspeaker may be further acoustically mounted, e.g. a closed or vented cabinet, such that the lower resonance frequency is above 100 Hz, such as above 300 Hz, such as above 500 Hz, such as above 800 Hz, such as above 1 kHz. Especially, the lower resonance frequency may be between 500 Hz and 2 kHz, such as between 700 Hz and 1.5 kHz.

[0015] In a second aspect, the invention provides a method for reducing distortion from an associated loudspeaker acoustically mounted such that it exhibits a lower resonance frequency, the method comprising attenuating a limited frequency band of an audio input signal, wherein the limited frequency band includes said lower resonance frequency.

[0016] In a third aspect, the invention provides a computer executable program code arranged to perform the method according to the second aspect, such as a computer executable program code stored on a data carrier. The program code may be implemented on any type of audio processing platform, e.g. a sound card in a computer, a general processor in a mobile device e.g.

[0017] It is appreciated that the same advantages and embodiments described for the first aspect apply as well for the second and third aspects. Further, it is appreciated that the described embodiments can be intermixed in any way between all the mentioned aspects.

BRIEF DESCRIPTION OF THE FIGURES

[0018] The invention will now be described in more detail with regard to the accompanying figures of which

Fig. 1 illustrates a block diagram of a possible implementation of the invention,

Fig. 2 illustrates another block diagram of a stereo device embodiment,

Fig. 3 illustrates examples of frequency band attenuations for an example of a loudspeaker with Fc = 1 kHz, and

Fig. 4 illustrates calculated total harmonic distortion versus frequency for a loudspeaker with Fc = 1.3 kHz.

[0019] The figures illustrate specific ways of implementing the present invention and are not to be construed as being limiting to other possible embodiments falling within the scope of the attached claim set.

DETAILED DESCRIPTION OF EMBODIMENTS

[0020] Fig. 1 illustrates a device embodiment in block diagram form taking an audio signal A_in as input. A miniature loudspeaker L with lower resonance frequency Fc = 1 kHz, e.g. resulting from the loudspeaker L being mounted in a mobile device cabinet which causes the lower resonance frequency Fc to be higher than the free air resonance frequency of the loudspeaker L. The large box illustrates the signal processing which is preferably implemented as program code of a processor system, e.g. the main processor of a mobile device. This processing is preferably the last part of a digital audio processing chain, since it is important that the correct signal level is detected to ensure that the resulting output signal A_out is the actual signal reaching the loudspeaker L, e.g. taking into account a possible gain in an intermediate power amplifier PA driving the loudspeaker L.

[0021] The signal processing according to the invention can be interpreted as a "band limiter", since it basically detects and attenuates, i.e. limits signal level, in a narrow frequency band around the lower resonance frequency Fc of the loudspeaker L. Thus, it is possible, within this narrow frequency range, e.g. 1/3-2/3 octave wide, to control the signal level in this range to ensure that the large diaphragm excursions which occur around Fc will be limited such that the diaphragm will not reach its maximum amplitude - not even during onsets of demanding sound signals with high energy level in the range around Fc. This reduces distortion of the loudspeaker L. Thus, better sound quality can be obtained, and/or more acoustic output can be obtained from a small loudspeaker. Interfering only with a narrow frequency band, normally only within short periods during demanding signal onsets, the audible degrading due to the attenuation is minimal if audible at all. Even if slightly audible, this effect is preferred to the severe non-linear distortion otherwise resulting.

[0022] In the example shown in Fig. 1, the band limiter is implemented as a band pass filter BPF and a band stop filter BSF, both operating on the same frequency range, namely a frequency range with a bandwidth BW of less than 1 octave, e.g. 2/3 octaves, and centred around Fc. The input signal A_in is applied to both filters BPF, BSF, and a gain control unit GC detects a peak level of an output of the band pass filter BPF, i.e. the peak level of the signal present within the frequency range around Fc. With a predetermined maximum allowed band pass peak level MBPP (e.g. -10 dB re. full scale), the gain control unit GC determines the gain factor to be applied to the output of the band pass filter BPF so as to obtain a resulting attenuation of the signal level within this band according to a predetermined attenuation scheme. The rest of the input signal A_in, i.e. the output of the band stop filter BSF, is finally added to the attenuated version of the output of the band pass filter BPF to form the output signal A_out. This output signal A_out is then digital to analog converted and applied to the power amplifier PA driving the loudspeaker L.

[0023] The attenuation scheme applied by the gain control unit GC can be selected differently, however it may be preferred that the attenuation can be graduated and adjusted based on the detected peak level. Preferably, such that a minimum possible attenuation is selected to ensure that MBPP is not exceeded, e.g. by determining the attenuation Att continuously along with the detected peak level P e.g. according to: Att = P - MBPP (all in dB), when P exceeds MBPP, otherwise Att = 0 dB is selected. Alternatively, a simple scheme is to apply zero attenuation at low signal levels and then apply a fixed attenuation, e.g. 10 dB attenuation, when the detected peak level exceeds MBPP. During most normal operation, the attenuation will thus be zero dB, i.e. the resulting processing is inactive and thus does not influence sound quality. However, during onsets with high signal levels at frequencies around Fc, the processing will effectively protect the loudspeaker L from large diaphragm excursions, and thus severe audible distortion can be eliminated.

[0024] Fig. 2 shows an example with a band limiter BL as explained in connection with Fig. 2 with Fc, BW, and MBPP as input parameters. The band limiter BL is here implemented on a processor P which also handles a pre-equalizing Eq, e.g. to compensate unequal frequency response of the loudspeakers used, of the audio input signal, here shown as a stereo PCM signal. In such case, the band limiter BL has separate path ways for the two stereo signals, here illustrated as a stereo PCM output signal to be applied to a stereo power amplifier PA which drives a set of stereo loudspeakers.

[0025] Fig. 3 shows an example of different curves of attenuation of an embodiment of a band limiter. In the illustrated example, a loudspeaker with Fc = 1 kHz is used, and thus attenuation of the input signal can be applied in a rather narrow band around this frequency, so as to obtain a resulting output signal without severe signal peaks around Fc which can lead to distortion. The upper curve show zero attenuation (0 dB), whereas the lowest curve illustrates 10 dB attenuation (-10 dB).

[0026] Fig. 4 shows a result of a calculation of total harmonic distortion THD for a miniature loudspeaker mounted in a cabinet resulting in a lower resonance frequency of Fc = 1.3 kHz (dashed vertical line). The loudspeaker plays a single tone with a duration of 200 ms, i.e. a tone burst. As seen, the maximum distortion about 7.5 %, occurs for tones with a frequency near Fc, i.e. a clearly audible distortion. Thus, attenuation of the input signal to the loudspeaker in this frequency range helps to reduce the resulting distortion. However, what is not illustrated, and potentially more audible, is the non-linear distortion resulting from even a temporally short overload of the loudspeaker diaphragm, e.g. during onset of a tone or complex of tones in the frequency range near Fc, which will lead to a severe audible distortion clearly exceeding 10 %. Such severe distortion can be eliminated with application of the invention.

[0027] To sum up: the invention provides a method and a device for reducing distortion from an associated loudspeaker acoustically mounted such that it exhibits a lower resonance frequency Fc. A limited frequency band, including Fc, of an audio input signal is attenuated. Hereby distortion due to large diaphragm excursions in the frequency range around Fc can be eliminated. Especially, the amount of attenuation to be applied to this limited signal frequency range is determined in response to the peak signal level in this limited signal frequency range so as to only apply an attenuation when the signal level in this frequency range exceeds a predetermined level. Hereby, it is possible to take into account the properties of a miniature loudspeaker and ensure that sufficient attenuation is applied so as to avoid maximum diaphragm excursions which result in severe audible distortion. Thus, by controlling this attenuation in a narrow frequency band, e.g. 1 octave or even down to such as 1/3 octave, severe audible distortion can be eliminated, and the negative audible effect of such "band limitation" is hardly audible since the frequency range is so narrow. Most of the time the attenuation effect is completely inactive, since its effect is only required when large peak levels occur in the range near Fc.

[0028] Although the present invention has been described in connection with the specified embodiments, it should not be construed as being in any way limited to the presented examples. The scope of the present invention is to be interpreted in the light of the accompanying claim set. In the context of the claims, the terms "including" or "includes" do not exclude other possible elements or steps. Also, the mentioning of references such as "a" or "an" etc. should not be construed as excluding a plurality. The use of reference signs in the claims with respect to elements indicated in the figures shall also not be construed as limiting the scope of the invention. Furthermore, individual features mentioned in different claims, may possibly be advantageously combined, and the mentioning of these features in different claims does not exclude that a combination of features is not possible and advantageous.

Claims

1. A device arranged for application to an associated loudspeaker (L) acoustically mounted such that it exhibits a lower resonance frequency (Fc),

- an input arranged to receive an audio input signal (A_in),
- a filter section (BPF, BSF) arranged to receive the audio input signal (A_in) and to provide an attenuation in a limited frequency band thereof and generate a modified audio signal accordingly, wherein the limited frequency band includes said lower resonance frequency (Fc) of the associated loudspeaker (L), and
- an output arranged to output the modified audio signal as an audio output signal (A_out).

2. Device according to claim 1, wherein the limited frequency band has a bandwidth (BW) of less than 2 octaves, such as less than 1 octave, such as less than 2/3 octaves, such as less than 1/3 octave.

3. Device according to claim 2, wherein the limited frequency band is centred around said lower resonance frequency (Fc) of the associated loudspeaker (L).

4. Device according to any of the preceding claims, comprising a gain control unit (GC) arranged to control said attenuation in the limited frequency band.

5. Device according to claim 4, wherein the gain control (GC) unit is arranged to detect a level of the audio input signal (A_in) within the limited frequency band and to provide said attenuation according to a predetermined attenuation scheme.

6. Device according to claim 5, wherein said scheme includes detecting whether a peak level of the audio input signal (A_in) within the limited frequency band exceeds a predetermined maximum level (MBPP), and determining said attenuation accordingly to ensure that the modified audio signal does not exceed the predetermined maximum level (MBPP).

7. Device according to claim 6, wherein said predetermined maximum level (MBPP) is selected such in relation to the associated loudspeaker (L) that the audio output signal (A_out) will not cause the loudspeaker (L) to perform a diaphragm excursion exceeding its limit.

8. Device according to any of the preceding claims, wherein the filter section (BPF, BSF) comprises a band pass filter (BPF) arranged to band pass filter the audio input signal (A_in) to said limited frequency band, and a band stop filter (BSF) arranged to band stop filter the audio input signal (A_in) with the stop band being said limited frequency band.

9. Device according to any of the preceding claims, wherein the audio input signal (A_in) includes a plurality of audio channels, such as a stereo signal, and wherein the audio channels are processed to form an audio output signal (A_out) with a corresponding plurality of audio channels.

10. Device according to any of the preceding claims, comprising a loudspeaker (L) acoustically mounted such that it exhibits said lower resonance frequency (Fc), and a power amplifier (PA) connected to drive the loudspeaker (L) according to the audio output signal (A_out).

11. Device according to claim 10, wherein the loudspeaker (L) has a diaphragm area of less than 10 cm^2, such as less than 5 cm^2, such as less than 2 cm^2, such as less than 1 cm^2.

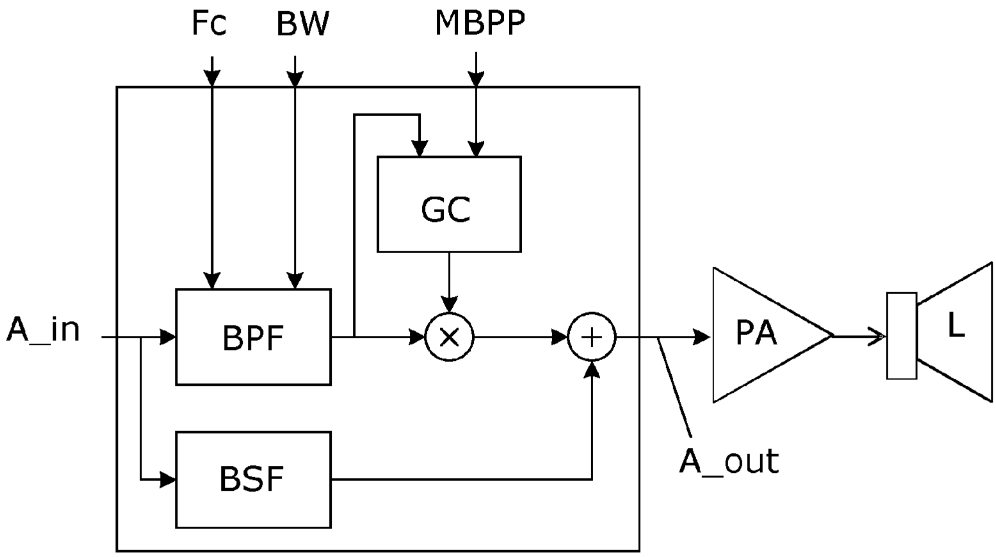
12. Device according to claim 11, wherein the loudspeaker is acoustically mounted such that the lower resonance frequency is above 100 Hz, such as above 300 Hz, such as above 500 Hz, such as above 800 Hz, such as above 1 kHz.

13. Device according to any of the preceding claims, wherein the device is one of:

a portable audio device, a portable video device, and a portable player, such as a mobile phone, a tablet, a laptop, or a personal navigation device.

14. A method for reducing distortion from an associated loudspeaker (L) acoustically mounted such that it exhibits a lower resonance frequency (Fc), the method comprising attenuating a limited frequency band of an audio input signal (A_in), wherein the limited frequency band includes said lower resonance frequency (Fc).

15. Computer executable program code arranged to perform the method according to claim 14, such as a computer executable program code stored on a data carrier.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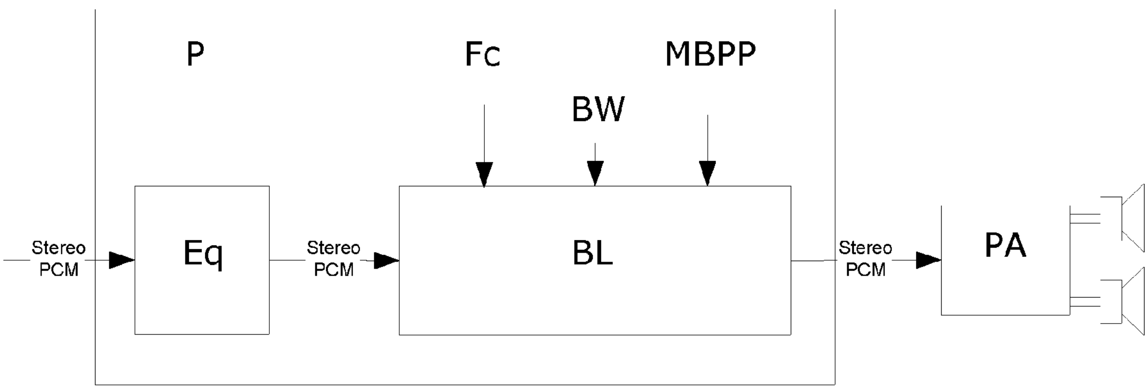
BW
MBPP
GC
A_in
BPF
BSF
PA
L
A_out

Fig. 1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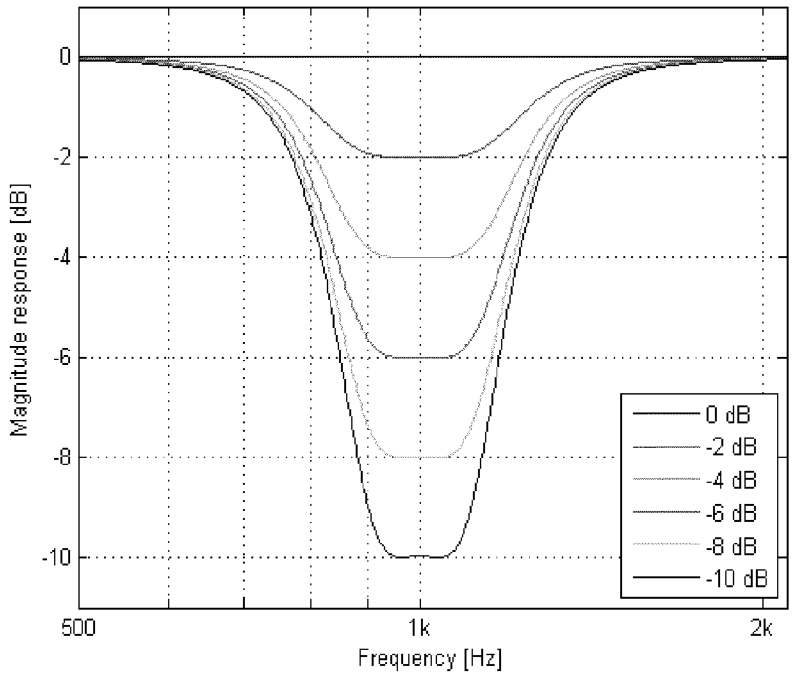
MBPP
BW
Stereo PCM
Eq
Stereo PCM
BL
Stereo PCM
PA

Fig. 2


Magnitude response [dB]
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-2
-4
-6
-8
-10
500
1k
2k
Frequency [Hz]
0 dB
-2 dB
-4 dB
-6 dB
-8 dB
-10 dB

Fig. 3

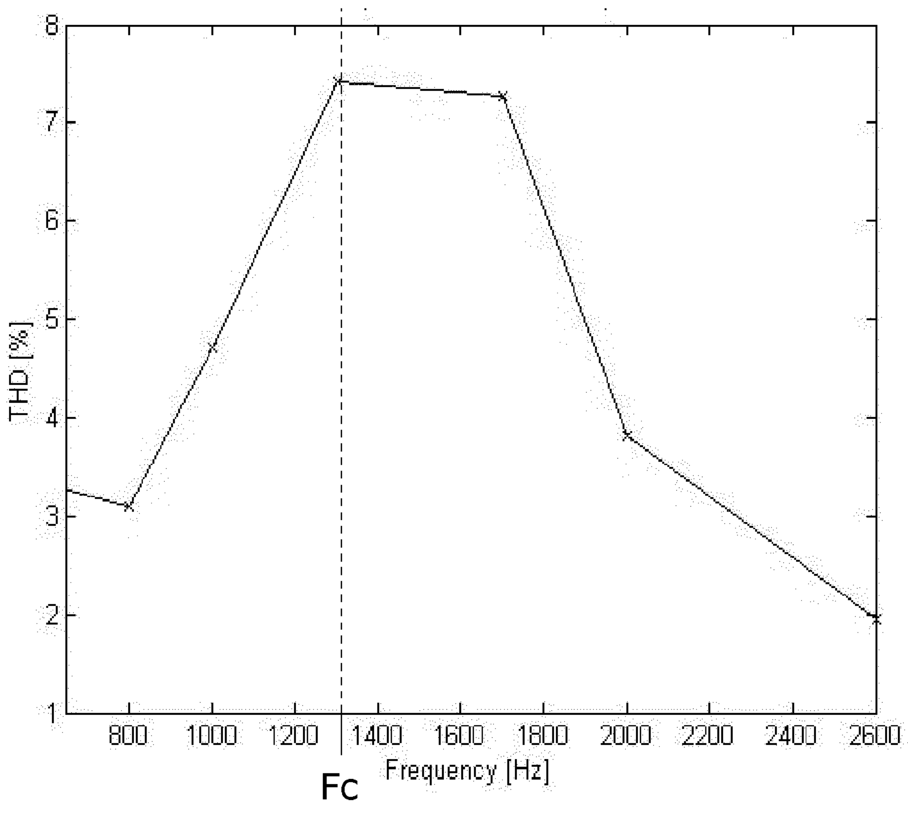
THD [%]
8
7
6
5
4
3
2
1
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
Frequency [Hz]
Fc

Fig. 4

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EUROPEAN SEARCH REPORT

Application Number
EP 11 19 1329

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TECHNICAL FIELDS SEARCHED (IPC)

H04R

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	16 May 2012	Meiser, Jürgen

CATEGORY OF CITED DOCUMENTS

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