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(54) **VIRTUAL HEIGHT FILTER FOR REFLECTED SOUND RENDERING USING UPWARD FIRING DRIVERS**

VIRTUELLES HÖHENFILTER FÜR REFLEKTIERTE TONDARSTELLUNG MIT AUFWÄRTS ABFEUERNDEN TREIBERN

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Description

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to United States Provisional Patent Application No. 61/749,789, filed on 7 January 2013, United States Provisional Patent Application No. 61/835,466, filed on 14 June 2013 and United States Provisional Patent Application No. 61/914,854, filed on 11 December 2013.

FIELD OF THE INVENTION

[0002] One or more implementations relate generally to audio signal processing, and more specifically to speakers and circuits for rendering adaptive audio content using reflected signals generated by upward firing speakers.

BACKGROUND

[0003] The advent of digital cinema has created new standards for cinema sound, such as the incorporation of multiple channels of audio to allow for greater creativity for content creators and a more enveloping and realistic auditory experience for audiences. Model-based audio descriptions have been developed to extend beyond traditional speaker feeds and channel-based audio as a means for distributing spatial audio content and rendering in different playback configurations. The playback of sound in true three-dimensional (3D) or virtual 3D environments has become an area of increased research and development. The spatial presentation of sound utilizes audio objects, which are audio signals with associated parametric source descriptions of apparent source position (e.g., 3D coordinates), apparent source width, and other parameters. Object-based audio may be used for many multimedia applications, such as digital movies, video games, simulators, and is of particular importance in a home environment where the number of speakers and their placement is generally limited or constrained by the confines of a relatively small listening environment.

[0004] Various technologies have been developed to more accurately capture and reproduce the creator's artistic intent for a sound track in both full cinema environments and smaller scale home environments. A next generation spatial audio (also referred to as "adaptive audio") format has been developed that comprises a mix of audio objects and traditional channel-based speaker feeds along with positional metadata for the audio objects. In a spatial audio decoder, the channels are sent directly to their associated speakers or down-mixed to an existing speaker set, and audio objects are rendered by the decoder in a flexible manner. The parametric source description associated with each object, such as a positional trajectory in 3D space, is taken as an input along with the number and position of speakers connected to the decoder. The renderer utilizes certain algorithms to distribute the audio associated with each object across the attached set of speakers. The authored spatial intent of each object is thus optimally presented over the specific speaker configuration that is present in the listening environment.

[0005] Current spatial audio systems have generally been developed for cinema use, and thus involve deployment in large rooms and the use of relatively expensive equipment, including arrays of multiple speakers distributed around a theater. An increasing amount of advanced audio content, however, is being made available for playback in the home environment through streaming technology and advanced media technology, such as Blu-ray disks, and so on. In addition, emerging technologies such as 3D television and advanced computer games and simulators are encouraging the use of relatively sophisticated equipment, such as large-screen monitors, surround-sound receivers and speaker arrays in home and other listening environments. In spite of the availability of such content, equipment cost, installation complexity, and room size remain realistic constraints that prevent the full exploitation of spatial audio in most home environments. For example, advanced object-based audio systems typically employ overhead or height speakers to playback sound that is intended to originate above a listener's head. In many cases, and especially in the home environment, such height speakers may not be available. In this case, the height information is lost if such sound objects are played only through floor or wall-mounted speakers.

[0006] What is needed, therefore, is a system that allows full spatial information of an adaptive audio system to be reproduced in a listening environment that may include only a portion of the full speaker array intended for playback, such as limited or no overhead speakers, and that can utilize upward directed speakers to reflect sound to places where direct speakers may not exist.

[0007] What is further needed is a filtering method that applies a desired frequency transfer function to reduce or eliminate direct sound components from height sound components in audio signals intended to be reflected off of upper surfaces of a listening environment.

[0008] What is further needed is a speaker system that incorporates the desired frequency transfer function directly into the transducer design of the speakers configured to reflect sound off of the upper surfaces.

[0009] The subject matter discussed in the background section should not be assumed to be prior art merely as a result of its mention in the background section. Similarly, a problem mentioned in the background section or associated with the subject matter of the background section should not be assumed to have been previously recognized in the prior art. The subject matter in the background section merely represents different approaches, which in and of themselves may also be inventions.

BRIEF SUMMARY OF EMBODIMENTS

[0010] Embodiments are directed to speakers and circuits that reflect sound off a ceiling or upper surface to a listening location at a distance from a speaker. Document JP2010258653 shows a rendering system using upward firing speakers. The reflected sound provides height cues to reproduce audio objects that have overhead audio components. The speaker comprises one or more upward firing drivers to reflect sound off of the upper surface and represents a virtual height speaker. A virtual height filter based on a directional hearing model is applied to the upward-firing driver signal to improve the perception of height for audio signals transmitted by the virtual height speaker to provide optimum reproduction of the overhead reflected sound. Additionally, the virtual height filter may be incorporated as part of a crossover circuit that separates the full band and sends high frequency sound to the upward-firing driver. Room correction processes are also used to provide calibration and maintain virtual height filtering in systems that perform automatic room equalization and other anomaly negating processes.

[0011] Such speakers and circuits are configured to be used in conjunction with an adaptive audio system for rendering sound using reflected sound elements comprising an array of audio drivers for distribution around a listening environment, where some of the drivers are direct drivers and others are upward-firing drivers that project sound waves toward the ceiling of the listening environment for reflection to a specific listening area; a renderer for processing audio streams and one or more metadata sets that are associated with each audio stream and that specify a playback location in the listening environment of a respective audio stream, wherein the audio streams comprise one or more reflected audio streams and one or more direct audio streams; and a playback system for rendering the audio streams to the array of audio drivers in accordance with the one or more metadata sets, and wherein the one or more reflected audio streams are transmitted to the reflected audio drivers.

[0012] Embodiments are further directed to speakers or speaker systems that incorporate a desired frequency transfer function directly into the transducer design of the speakers configured to reflect sound off of the upper surfaces, wherein the desired frequency transfer function filters direct sound components from height sound components in an adaptive audio signal produced by a renderer.

[0013] Embodiments are yet further directed to methods of making and using or deploying the speakers, circuits, and transducer designs that optimize the rendering and playback of reflected sound content using a frequency transfer function that filters direct sound components from height sound components in an audio playback system.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] In the following drawings like reference numbers are used to refer to like elements. Although the following figures depict various examples, the one or more implementations are not limited to the examples depicted in the figures.

FIG. 1 illustrates the use of an upward-firing driver using reflected sound to simulate an overhead speaker in a listening environment.

FIG. 2 illustrates an integrated virtual height and front firing speaker, under an embodiment.

FIG. 3 is a graph that illustrates the magnitude response of a virtual height filter derived from a directional hearing model, under an embodiment.

FIG. 4A illustrates a virtual height filter incorporated as part of a speaker unit having an upward firing driver, under an embodiment.

FIG. 4B illustrates a virtual height filter incorporated as part of a rendering unit for driving an upward firing driver, under an embodiment.

FIG. 5 illustrates a height filter receiving positional information and a bypass signal, under an embodiment.

FIG. 6 illustrates an inclination angle of an upward-firing driver used in a virtual height speaker, under an embodiment.

FIG. 7 is a diagram illustrating a virtual height filter system including crossover circuit, under an embodiment.

FIG. 8A is a high-level circuit diagram of a two-band crossover filter used in conjunction with a virtual height filter, under an embodiment.

FIG. 8B illustrates a two-band crossover that implements virtual height filtering in the high-pass filtering path, under an embodiment.

FIG. 8C illustrates a crossover that combines upward-firing and front-firing speaker crossover filter networks for use with different high-frequency drivers, under an embodiment.

FIG. 9 shows the frequency response of the two-band crossover of FIG. 8, under an embodiment.

FIG. 10 illustrates various different upward-firing and direct or front-firing speakers configurations for use with a virtual height filter, under an embodiment.

FIG. 11 is a block diagram of a virtual height rendering system that includes room correction and virtual height speaker detection capabilities, under an embodiment.

FIG. 12 is a graph that displays the effect of pre-emphasis filtering for calibration, under an embodiment.

FIG. 13 is a flow diagram illustrating a method of performing virtual height filtering in an adaptive audio system, under an embodiment.

FIG. 14A is a circuit diagram illustrating an analog virtual height filter circuit, under an embodiment.

FIG. 14B illustrates an example frequency response curve of the circuit of FIG. 14A in conjunction with a desired response curve.

FIG. 15A illustrates example coefficient values for a digital implementation of a virtual height filter, under an embodiment.

Figure 15B illustrates an example frequency response curve of the filter of FIG. 15A along with a desired response curve.

FIG. 16 illustrates a speaker integrating direct and upward firing drivers in an integrated cabinet, under an embodiment.

FIG. 17 illustrates an example placement of speakers having upward-firing drivers and virtual height filter components within a listening environment.

FIG. 18 illustrates a height cue filter transfer function for use in height-specific transducer designs, under an embodiment.

DETAILED DESCRIPTION

[0015] Systems and methods are described for an adaptive audio system that renders reflected sound for adaptive audio systems through upward-firing speakers that incorporate virtual height filter circuits for rendering object based audio content using reflected sound to reproduce overhead sound objects and provide virtual height cues. Aspects of the one or more embodiments described herein may be implemented in an audio or audio-visual (AV) system that processes source audio information in a mixing, rendering and playback system that includes one or more computers or processing devices executing software instructions. Any of the described embodiments may be used alone or together with one another in any combination. Although various embodiments may have been motivated by various deficiencies with the prior art, which may be discussed or alluded to in one or more places in the specification, the embodiments do not necessarily address any of these deficiencies. In other words, different embodiments may address different deficiencies that may be discussed in the specification. Some embodiments may only partially address some deficiencies or just one deficiency that may be discussed in the specification, and some embodiments may not address any of these deficiencies.

[0016] For purposes of the present description, the following terms have the associated meanings: the term "channel" means an audio signal plus metadata in which the position is coded as a channel identifier, e.g., left-front or right-top surround; "channel-based audio" is audio formatted for playback through a pre-defined set of speaker zones with associated nominal locations, e.g., 5.1, 7.1, and so on; the term "object" or "object-based audio" means one or more audio channels with a parametric source description, such as apparent source position (e.g., 3D coordinates), apparent source width, etc.; and "adaptive audio" means channel-based and/or object-based audio signals plus metadata that renders the audio signals based on the playback environment using an audio stream plus metadata in which the position is coded as a 3D position in space; and "listening environment" means any open, partially enclosed, or fully enclosed area, such as a room that can be used for playback of audio content alone or with video or other content, and can be embodied in a home, cinema, theater, auditorium, studio, game console, and the like. Such an area may have one or more surfaces disposed therein, such as walls or baffles that can directly or diffusely reflect sound waves.

[0017] Embodiments are directed to a reflected sound rendering system that is configured to work with a sound format and processing system that may be referred to as a "spatial audio system" or "adaptive audio system" that is based on an audio format and rendering technology to allow enhanced audience immersion, greater artistic control, and system flexibility and scalability. An overall adaptive audio system generally comprises an audio encoding, distribution, and decoding system configured to generate one or more bitstreams containing both conventional channel-based audio elements and audio object coding elements. Such a combined approach provides greater coding efficiency and rendering flexibility compared to either channel-based or object-based approaches taken separately. An example of an adaptive audio system that may be used in conjunction with present embodiments is described in pending US Provisional Patent Application 61/636,429, filed on April 20, 2012 and entitled "System and Method for Adaptive Audio Signal Generation, Coding and Rendering."

[0018] In general, audio objects can be considered as groups of sound elements that may be perceived to emanate from a particular physical location or locations in the listening environment. Such objects can be static (stationary) or dynamic (moving). Audio objects are controlled by metadata that defines the position of the sound at a given point in time, along with other functions. When objects are played back, they are rendered according to the positional metadata using the speakers that are present, rather than necessarily being output to a predefined physical channel.

[0019] An example implementation of an adaptive audio system and associated audio format is the Dolby® Atmos™ platform. Such a system incorporates a height (up/down) dimension that may be implemented as a 9.1 surround system, or similar surround sound configuration (e.g., 11.1, 13.1, 19.4, etc.). A 9.1 surround system may comprise composed five speakers in the floor plane and four speakers in the height plane. In general, these speakers may be used to produce sound that is designed to emanate from any position more or less accurately within the listening environment. In a typical commercial or professional implementation speakers in the height plane are usually provided as ceiling mounted speakers or speakers mounted high on a wall above the audience, such as often seen in a cinema. These speakers provide height cues for signals that are intended to be heard

above the listener by directly transmitting sound waves down to the audience from overhead locations.

Virtual Height Speaker System

[0020] In many cases, such as typical home environments, ceiling mounted overhead speakers are not available or practical to install. In this case, the height dimension must be provided by floor or low wall mounted speakers. In an embodiment, the height dimension is provided by upward-firing speakers that simulate height speakers by reflecting sound off of the ceiling. In an adaptive audio system, certain virtualization techniques are implemented by the renderer to reproduce overhead audio content through these upward-firing speakers, and the speakers use the specific information regarding which audio objects should be rendered above the standard horizontal plane to direct the audio signals accordingly.

[0021] For purposes of description, the term "driver" means a single electroacoustic transducer that produces sound in response to an electrical audio input signal. A driver may be implemented in any appropriate type, geometry and size, and may include horns, cones, ribbon transducers, and the like. The term "speaker" means one or more drivers in a unitary enclosure, and the terms "cabinet" or "housing" mean the unitary enclosure that encloses one or more drivers.

[0022] FIG. 1 illustrates the use of an upward-firing driver using reflected sound to simulate one or more overhead speakers. Diagram 100 illustrates an example in which a listening position 106 is located at a particular place within a listening environment. The system does not include any height speakers for transmitting audio content containing height cues. Instead, the speaker cabinet or speaker array includes an upward-firing driver along with the front firing driver(s). The upward-firing driver is configured (with respect to location and inclination angle) to send its sound wave 108 up to a particular point 104 on the ceiling 102 where it reflected back down to the listening position 106. It is assumed that the ceiling is made of an appropriate material and composition to adequately reflect sound down into the listening environment. The relevant characteristics of the upward-firing driver (e.g., size, power, location, etc.) may be selected based on the ceiling composition, room size, and other relevant characteristics of the listening environment.

[0023] The embodiment of FIG. 1 illustrates a case in which the forward firing driver or drivers are enclosed within a first cabinet 112, and the upward firing driver is enclosed within a second separate cabinet 110. The upward firing speaker 110 for the virtual height speaker is generally placed on top of the forward firing speaker 112, but other orientations are also possible. It should be noted that any number of upward-firing drivers could be used in combination to create multiple simulated height speakers. Alternatively, a number of upward-firing drivers may be configured to transmit sound to substantially the same spot on the ceiling to achieve a certain sound intensity or effect.

[0024] FIG. 2 illustrates an embodiment in which the upward firing driver(s) and forward firing driver(s) are provided in the same cabinet. As shown in FIG. 2, speaker cabinet 202 includes both the forward firing driver 206 and the upward firing driver 204. Although only one upward-firing driver is shown in each of FIG. 1 and FIG. 2, multiple upward-firing drivers may be incorporated into a reproduction system in some embodiments. For the embodiment of FIGS. 1 and 2, it should be noted that the drivers may be of any appropriate, shape, size and type depending on the frequency response characteristics required, as well as any other relevant constraints, such as size, power rating, component cost, and so on.

[0025] As shown in FIGS. 1 and 2, the upward firing drivers are positioned such that they project sound at an angle up to the ceiling where it can then bounce back down to a listener. The angle of tilt may be set depending on listening environment characteristics and system requirements. For example, the upward driver 204 may be tilted up between 20 and 60 degrees and may be positioned above the front-firing driver 206 in the speaker enclosure 202 so as to minimize interference with the sound waves produced from the front-firing driver 206. The upward-firing driver 204 may be installed at a fixed angle, or it may be installed such that the tilt angle may be adjusted manually. Alternatively, a servo mechanism may be used to allow automatic or electrical control of the tilt angle and projection direction of the upward-firing driver. For certain sounds, such as ambient sound, the upward-firing driver may be pointed straight up out of an upper surface of the speaker enclosure 202 to create what might be referred to as a "top-firing" driver. In this case, a large component of the sound may reflect back down onto the speaker, depending on the acoustic characteristics of the ceiling. In most cases, however, some tilt angle is usually used to help project the sound through reflection off the ceiling to a different or more central location within the listening environment.

[0026] In an embodiment, the adaptive audio system utilizes upward-firing drivers to provide the height element for overhead audio objects. This is achieved partly through the perception of reflected sound from above as shown in FIGS. 1 and 2. In practice, however, sound does not radiate in a perfectly directional manner along the reflected path from the upward-firing driver. Some sound from the upward firing driver will travel along a path directly from the driver to the listener, diminishing the perception of sound from the reflected position. The amount of this undesired direct sound in comparison to the desired reflected sound is generally a function of the directivity pattern of the upward firing driver or drivers. To compensate for this undesired direct sound, it has been shown that incorporating signal processing to introduce perceptual height cues into the audio signal being fed to the upward-firing drivers improves the positioning and perceived quality of the virtual height signal. For example, a directional hearing model has been devel-

oped to create a virtual height filter, which when used to process audio being reproduced by an upward-firing driver, improves that perceived quality of the reproduction. In an embodiment, the virtual height filter is derived from both the physical speaker location (approximately level with the listener) and the reflected speaker location (above the listener) with respect to the listening position. For the physical speaker location, a first directional filter is determined based on a model of sound travelling directly from the speaker location to the ears of a listener at the listening position. Such a filter may be derived from a model of directional hearing such as a database of HRTF (head related transfer function) measurements or a parametric binaural hearing model, pinna model, or other similar transfer function model that utilizes cues that help perceive height. Although a model that takes into account pinna models is generally useful as it helps define how height is perceived, the filter function is not intended to isolate pinna effects, but rather to process a ratio of sound levels from one direction to another direction, and the pinna model is an example of one such model of a binaural hearing model that may be used, though others may be used as well.

[0027] An inverse of this filter is next determined and used to remove the directional cues for audio travelling along a path directly from the physical speaker location to the listener. Next, for the reflected speaker location, a second directional filter is determined based on a model of sound travelling directly from the reflected speaker location to the ears of a listener at the same listening position using the same model of directional hearing. This filter is applied directly, essentially imparting the directional cues the ear would receive if the sound were emanating from the reflected speaker location above the listener. In practice, these filters may be combined in a way that allows for a single filter that both at least partially removes the directional cues from the physical speaker location, and at least partially inserts the directional cues from the reflected speaker location. Such a single filter provides a frequency response curve that is referred to herein as a "height filter transfer function," "virtual height filter response curve," "desired frequency transfer function," "height cue response curve," or similar words to describe a filter or filter response curve that filters direct sound components from height sound components in an audio playback system.

[0028] With regard to the filter model, if P_1 represents the frequency response in dB of the first filter modeling sound transmission from the physical speaker location and P_2 represents the frequency response in dB of the second filter modeling sound transmission from the reflected speaker position, then the total response of the virtual height filter P_T in dB can be expressed as: $P_T = \alpha(P_2-P_1)$, where α is a scaling factor that controls the strength of the filter. With α=1, the filter is applied maximally, and with α=0, the filter does nothing (0 dB response). In practice, α is set somewhere between 0 and 1 (e.g. α=0.5) based on the relative balance of reflected to direct sound. As the level of the direct sound increases in comparison to the reflected sound, so should α in order to more fully impart the directional cues of the reflected speaker position to this undesired direct sound path. However, α should not be made so large as to damage the perceived timbre of audio travelling along the reflected path, which already contains the proper directional cues. In practice a value of α=0.5 has been found to work well with the directivity patterns of standard speaker drivers in an upward firing configuration. In general, the exact values of the filters P_1 and P_2 will be a function of the azimuth of the physical speaker location with respect to the listener and the elevation of the reflected speaker location. This elevation is in turn a function of the distance of the physical speaker location from the listener and the difference between the height of the ceiling and the height of the speaker (assuming the listener's head is at the same height of the speaker).

[0029] FIG. 3 depicts virtual height filter responses P_T with α=1 derived from a directional hearing model based on a database of HRTF responses averaged across a large set of subjects. The black lines 303 represent the filter P_T computed over a range of azimuth angles and a range of elevation angles corresponding to reasonable speaker distances and ceiling heights. Looking at these various instances of P_T, one first notes that the majority of each filter's variation occurs at higher frequencies, above 4Hz. In addition, each filter exhibits a peak located at roughly 7kHz and a notch at roughly 12kHz. The exact level of the peak and notch vary a few dB between the various responses curves. Given this close agreement in location of peak and notch between the set of responses, it has been found that a single average filter response 302, given by the thick gray line, may serve as a universal height cue filter for most reasonable physical speaker locations and room dimensions. Given this finding, a single filter P_T may be designed for a virtual height speaker, and no knowledge of the exact speaker location and room dimensions is required for reasonable performance. For increased performance, however, such knowledge may be utilized to dynamically set the filter P_T to one of the particular black curves in FIG. 3, corresponding to the specific speaker location and room dimensions.

[0030] The typical use of such a virtual height filter for virtual height rendering is for audio to be pre-processed by a filter exhibiting one of the magnitude responses depicted in FIG. 3 (e.g. average curve 302), before it is played through the upward-firing virtual height speaker. The filter may be provided as part of the speaker unit, or it may be a separate component that is provided as part of the renderer, amplifier, or other intermediate audio processing component. FIG. 4A illustrates a virtual height filter incorporated as part of a speaker unit having an upward firing driver, under an embodiment. As shown in system 400 of FIG. 4A, an adaptive audio processor 402 outputs audio signals that contain separate height signal components and direct signal components. The height signal components are meant to be played through an

upward firing speaker 408, and the direct audio signal component is meant to be played through a direct or forward firing speaker 407. The signal components are not necessarily different in terms of frequency content or audio content, but are instead differentiated on the basis of height cues present in the audio objects or signals. For the embodiment of FIG. 4A, a height filter 406 contained within or otherwise associated with the height speaker 408. The height filter 406 compensates for any undesired direct sound direct sound components that may be present in the height signal by providing perceptual height cues into the height signal to improve the positioning and perceived quality of the virtual signal. Such a height filter may incorporate the reference curve shown in FIG. 3.

[0031] In an alternative embodiment, the virtual height filter pre-processing can take place in the rendering equipment prior to input to a speaker amplifier (i.e., an AV receiver or preamp). FIG. 4B illustrates a virtual height filter incorporated as part of a rendering unit for driving an upward firing driver, under an embodiment. As shown in system 410 of FIG. 4B, renderer 412 outputs separate height and direct signals through amp 414 to drive upward firing speakers 418 and direct speakers 417, respectively. A height filter 416 within the renderer 412 provides the direct sound compensation through a notch filter (e.g., reference curve 302) for the upward firing speaker 418, as described above with respect to FIG. 4A. This allows the height filter function to be provided for speakers that do not have any built-in virtual height filtering.

[0032] In an embodiment, certain positional information is provided to the height filter, along with a bypass signal to enable or disable the virtual height filter within the speaker system. FIG. 5 illustrates a height filter receiving positional information and a bypass signal, under an embodiment. As shown in FIG. 5, positional information is provided to the virtual height filter 502, which is connected to the upward firing speaker 504. The positional information may include speaker position and room size utilized for the selection of the proper virtual height filter response from the set depicted in FIG 3. In addition, this positional data may be utilized to vary the inclination angle of the virtual height speaker 504 if such angle is made adjustable through either automatic or manual means. A typical and effective angle for most cases is approximately 20 degrees. FIG. 6 illustrates an inclination angle of an upward-firing driver used in a virtual height speaker, under an embodiment. As shown in diagram 600, speaker cabinet 602 includes forward-firing driver(s) 606 and upward-firing driver 604. The upward-firing driver is positioned at an angle 608 relative to the ground or horizontal plane defining the axis of transmission 610 of the forward-firing driver 606. FIG. 6 illustrates an example case in which angle = 20 degrees. As discussed earlier, however, the angle should ideally be set to maximize the ratio of reflected to direct sound at the listening position. If the directivity pattern of the upward firing speaker is known, then the optimal angle may be computed given the exact speaker distance and ceiling height, and the angle 608 may then be adjusted if the upward-firing driver 604 is movable with respect to the forward firing driver 606, such as through a hinged cabinet or servo-controlled arrangement. Depending on implementation of the control circuitry (e.g., either analog, digital, or electromechanical), such positional information can be provided through electrical signaling methods, electromechanical means, or other similar mechanisms

[0033] In certain scenarios, additional information about the listening environment may necessitate further adjustment of the inclination angle through either manual or automatic means. This may include cases where the ceiling is very absorptive or unusually high. In such cases, the amount of sound travelling along the reflected path may be diminished, and it may therefore be desirable to tilt the driver further forward to increase the amount of direct path signal from the driver to increase reproduction efficiency. As this direct path component increases, it is then desirable to increase the filter scaling parameter α, as explained earlier. As such this filter scaling parameter α may be set automatically as a function of the variable inclination angle as well as the other variables relevant to the reflected to direct sound ratio. For the embodiment of FIG. 6, the virtual height filter 502 also receives a bypass signal, which allows that filter to be cut out of the circuit if virtual height filtering is not desired.

[0034] As shown in FIGS. 4A and 4B, the renderer outputs separate height and direct signals to directly the respective upward firing and direct speakers. Alternatively, the renderer could output a single audio signal that is separated into height and direct components by a discrete separation or crossover circuit. In this case, the audio output from the renderer would be separated into its constituent height and direct components by a separate circuit. In certain cases the height and direct components are not frequency dependent and an external separation circuit is used to separate the audio into height and direct sound components and route these signals to the appropriate respective drivers, where virtual height filtering would be applied to the upward firing speaker signal.

[0035] In most common cases, however, the height and direct components may be frequency dependent, and the separation circuit comprises crossover circuit that separates the full-bandwidth signal into low and high (or bandpass) components for transmission to the appropriate drivers. This is often the most useful case since height cues are typically more prevalent in high frequency signals rather than low frequency signals, and for this application, a crossover circuit may be used in conjunction with or integrated in the virtual height filter component to route high frequency signals to the upward firing driver(s) and lower frequency signals to the direct firing driver(s). FIG. 7 is a diagram illustrating a virtual height filter system including crossover circuit, under an embodiment. As shown in system 700, output from the renderer 702 through an amp (not shown) is a full bandwidth signal

and a virtual height speaker filter 708 is used to impart the desired height filter transfer function for signals sent to the upward firing speaker 712. A crossover circuit 706 separates the full bandwidth signal from renderer 702 into high (upper) and low (direct) frequency components for transmission to the appropriate speakers 712 (upward firing) and 714 (direct). The crossover 706 may be integrated with or separate from the height filter 708, and these separate or combined circuits may be provided anywhere within the signal processing chain, such as between the renderer and speaker system (as shown), as part of an amp or pre-amp in the chain, within the speaker system itself, or as components closely coupled or integrated within the renderer 702. The crossover function may be implemented prior to or after the virtual height filtering function.

[0036] A crossover circuit typically separates the audio into two or three frequency bands with filtered audio from the different bands being sent to the appropriate drivers within the speaker. For example in a two-band crossover, the lower frequencies are sent to a larger driver capable of faithfully reproducing low frequencies (e.g., woofer/midranges) and the higher frequencies are typically sent to smaller transducers (e.g., tweeters) that are more capable of faithfully reproducing higher frequencies. FIG. 8A is a high-level circuit diagram of a two-band crossover filter used in conjunction with a virtual height filter, such as shown in FIG. 7, under an embodiment. With reference to diagram 800, an audio signal input to crossover circuit 802 is sent to a high-pass filter 804 and a low-pass filter 806. The crossover 802 is set or programmed with a particular cut-off frequency that defines the crossover point. This frequency may be static or it may be variable (i.e., through a variable resistor circuit in an analog implementation or a variable crossover parameter in a digital implementation). The high-pass filter 804 cuts the low frequency signals (those below the cut-off frequency) and sends the high frequency component to the high frequency driver 807. Similarly, the low-pass filter 806 cuts the high frequencies (those above the cut-off frequency) and sends the low frequency component to the low frequency driver 808. A three-way crossover functions similarly except that there are two crossover points and three band-pass filters to separate the input audio signal into three bands for transmission to three separate drivers, such as tweeters, mid-ranges, and woofers.

[0037] The crossover circuit 802 may be implemented as an analog circuit using known analog components (e.g., capacitors, inductors, resistors, etc.) and known circuit designs. Alternatively, it may be implemented as a digital circuit using digital signal processor (DSP) components, logic gates, programmable arrays, or other digital circuits.

[0038] The crossover circuit of FIG. 8A can used to implement at least a portion of the virtual height filter, such as virtual height filter 702 of FIG. 7. As seen in FIG. 3, most of the virtual height filtering takes place at frequencies above 4kHz, which is higher than the cut-off frequency for many two-way crossovers. FIG. 8B illustrates a two-band crossover that implements virtual height filtering in the high-pass filtering path, under an embodiment. As shown in diagram 820, crossover 821 includes low-pass filter 825 and high-pass-filter 824. The high-pass filter is part of a circuit 820 that includes a virtual height filter component 828. This virtual height filter applies the desired height filter response, such as curve 302, to the high-pass filtered signal prior to transmission to the high-frequency driver 830.

[0039] A bypass switch 826 may be provided to allow the system or user to bypass the virtual height filter circuit during calibration or setup operations so that other audio signal processes can operate without interfering with the virtual height filter. The switch 826 can either be a manual user operated toggle switch that is provided on the speaker or rendering component where the filter circuit resides, or it may be an electronic switch controlled by software, or any other appropriate type of switch. Positional information 822 may also be provided to the virtual height filter 828.

[0040] The embodiment of FIG. 8B illustrates a virtual height filter used with the high-pass filter stage of a crossover. It should be noted in an alternative embodiment, a virtual height filter may be used with the low-pass filter so that that the lower frequency band could also be modified so as to mimic the lower frequencies of the response as shown in FIG 3. However, in most practical applications, the crossover may be unduly complicated in light of the minimal height cues present in the low-frequency range.

[0041] FIG. 9 illustrates the frequency response of the two-band crossover of FIG. 8B, under an embodiment. As shown in diagram 900, the crossover has a cut-off frequency of 902 to create a frequency response curve 904 of the low-pass filter that cuts frequencies above the cut-off frequency 902, and a frequency response curve 906 for the high-pass filter that cuts frequencies below the cut-off frequency 902. The virtual height filter curve 908 is superimposed over the high-pass filter curve 906 when the virtual height filter is applied to the audio signal after the high-pass filter stage.

[0042] The crossover implementation shown in FIG. 8B assumes that the upward-firing virtual height speaker is implemented using two drivers, one for low frequencies and one for high frequencies. However, this configuration may not be ideal under most conditions. Specific and controlled directionality of an upward-firing speaker is often critical for effective virtualization. For example, a single transducer speaker is usually more effective when implementing the virtual height speaker. Additionally, a smaller, single transducer (e.g., 3" in diameter) is preferred as it is more directional at higher frequencies and more affordable than a larger transducer.

[0043] In an embodiment, the upward firing speaker may comprise a pair or array of two or more speakers of different sizes and/or characteristics. FIG. 10 illustrates various different upward-firing and direct or front-firing

speakers configurations for use with a virtual height filter, under an embodiment. As shown in FIG. 10, an upward firing speaker may include two drivers 1002 and 1004 both mounted within the same cabinet 1001 to fire upwards at the same angle. The drivers may be of the same configuration or they may be of different configurations (size, power, frequency response, etc.), depending on application needs. The upward firing (UF) audio signal is transmitted to this speaker 1001 and internal processing may be used to send appropriate audio to either or both of the drivers 1002 and 1004. In an alternative embodiment, one of the upward firing drivers, e.g., 1004 may be angled differently to the other driver, as shown in speaker 1010. In this case upward firing driver 1004 is directed to fire substantially frontward out of the cabinet 1010. It should be noted that any appropriate angle may be selected for either or both of drivers 1002 and 1004, and that the speaker configuration may include any appropriate number of drivers or driver arrays of various types (cone, ribbon, horn, etc.). In an embodiment, the upward firing speakers 1001 and 1002 may be mounted on a forward or direct firing speaker 1020 that includes one or more drivers 1020 that transmits sound directly out from the main cabinet. This speaker receives the main audio input signal, as separate from the UF audio signal.

[0044] FIG. 8C illustrates a crossover that combines upward-firing and front-firing speaker crossover filter networks for use with different high-frequency drivers, such as shown in FIG. 10, under an embodiment. Diagram 8000 illustrates an embodiment in which separate crossovers are provided for the front-firing speaker and the virtual height speaker. The front firing speaker crossover 8012 comprises a low-pass filter 8016 that feeds low-frequency driver 8020 and a high-pass filter 8014 that feeds high-frequency driver 8018. The virtual height speaker crossover 8002 includes a low-pass filter 8004 that also feeds low-frequency driver 8020 through combination with the output of low-pass filter 8016 in crossover 8012. The virtual height crossover 8002 includes a high-pass filter 8006 that incorporates virtual height filter function 8008. The output of this component 8007 feeds high frequency driver 8010. Driver 8010 is an upward-firing driver and is typically a smaller and possibly different composition driver than the front-firing low-frequency driver 8020. As an example, the effective frequency range for front-facing driver low frequency driver 8020 may be set from 40Hz to 2Khz, for front-facing high frequency driver 8018 from 2Khz to 20kHz, and for upward-firing high frequency driver 8010 from 400Hz to 20kHz.

[0045] There are several benefits from combining the crossover networks for the top and forward firing speakers as shown in FIG. 10. First, the preferred smaller driver will not be able to effectively reproduce lower frequencies and may actually distort at loud levels. Therefore filtering and redirecting the low frequencies to the front firing speaker's low frequency drivers will allow the smaller single speaker to be used for the virtual height speaker and result in greater fidelity. Additionally, research has shown that there is little virtual height effect for audio signals below 400 Hz, so sending only higher frequencies to the virtual height speaker 1010 represents an optimum use of that driver.

Room Correction with Virtual Height Speakers

[0046] As discussed above, adding virtual height filtering to a virtual height speaker adds perceptual cues to the audio signal that add or improve the perception of height to upward-firing speakers. Incorporating virtual height filtering techniques into speakers and/or renderers may need to account for other audio signal processes performed by playback equipment. One such process is room correction, which is a process that is common in commercially available AVRs. Room correction techniques utilize a microphone placed in the listening environment to measure the time and frequency response of audio test signals played back through an AVR with connected speakers. The purpose of the test signals and microphone measurement is to measure and compensate for several key factors, such as the acoustical effects of the room and environment on the audio, including room nodes (nulls and peaks), non-ideal frequency response of the playback speakers, time delays between multiple speakers and the listening position, and other similar factors. Automatic frequency equalization and/or volume compensation may be applied to the signal to overcome any effects detected by the room correction system. For example, for the first two factors, equalization is typically used to modify the audio played back through the AVR/speaker system, in order to adjust the frequency response magnitude of the audio so that room nodes (peaks and notches) and speaker response inaccuracies are corrected.

[0047] If virtual height speakers are used in the system and virtual filtering is enabled, a room correction system may detect the virtual height filter as a room node or speaker anomaly and attempt to equalize the virtual height magnitude response to be flat. This attempted correction is especially noticeable if the virtual height filter exhibits a pronounced high frequency notch, such as when the inclination angle is relatively high.

[0048] Embodiments of a virtual height speaker system include techniques and components to prevent a room correction system from undoing the virtual height filtering. FIG. 11 is a block diagram of a virtual height rendering system that includes room correction and virtual height speaker detection capabilities, under an embodiment. As shown in diagram 1100, an AVR or other rendering component 1102 is connected to one or more virtual height speakers 1106 that incorporates a virtual height filter process 1108. This filter produces a frequency response, such as illustrated in FIG. 7, which may be susceptible to room correction 1104 or other anomaly compensation techniques performed by renderer 1102.

[0049] In an embodiment, the room correction compensation component includes a component 1105 that

allows the AVR or other rendering component to detect that a virtual height speaker is connected to it. One such detection technique is the use of a room calibration user interface and a speaker definition that specifies a type of speaker as a virtual or non-virtual height speaker. Present audio systems often include an interface that ask the user to specify the size of the speaker in each speaker location, such as small, medium, large. In an embodiment, a virtual height speaker type is added to this definition set. Thus, the system can anticipate the presence of virtual height speakers through an additional data element, such as small, medium, large, virtual height, etc. In an alternative embodiment, a virtual height speaker may include signaling hardware that states that it is a virtual height speaker as opposed to a non-virtual height speaker. In this case, a rendering device (such as an AVR) could probe the speakers and look for information regarding whether any particular speaker incorporates virtual height technology. This data could be provided via a defined communication protocol, which could be wireless, direct digital connection or via a dedicated analog path using existing speaker wire or separate connection. In a further alternative embodiment, detection can be performed through the use of test signals and measurement procedures that are configured or modified to identify the unique frequency characteristics of a virtual height filter in a speaker and determine that a virtual height speaker is connected via analysis of the measured test signal.

[0050] Once a rendering device with room correction capabilities has detected the presence of a virtual height speaker (or speakers) connected to the system, a calibration process 1105 is performed to correctly calibrate the system without adversely affecting the virtual height filtering function 1108. In one embodiment, calibration can be performed using a communication protocol that allows the rendering device to have the virtual height speaker 1106 bypass the virtual height filtering process 1108. This could be done if the speaker is active and can bypass the filtering. The bypass function may be implemented as a user selectable switch, or it may be implemented as a software instruction (e.g., if the filter 1108 is implemented in a DSP), or as an analog signal (e.g., if the filter is implemented as an analog circuit).

[0051] In an alternative embodiment, system calibration can be performed using pre-emphasis filtering. In this embodiment, the room correction algorithm 1104 performs pre-emphasis filtering on the test signal it generates and outputs to the speakers for use in the calibration process. FIG. 12 is a graph that displays the effect of pre-emphasis filtering for calibration, under an embodiment. Plot 1200 illustrates a typical frequency response for a virtual height filter 1204, and a complimentary pre-emphasis filter frequency response 1202. The pre-emphasis filter is applied to the audio test signal used in the room calibration process, so that when played back through the virtual height speaker, the effect of the filter is cancelled, as shown by the complementary plots of the two curves 1202 and 1204 in the upper frequency range of plot 1200. In this way, calibration would be applied as if using a normal, non-virtual height speaker.

[0052] In yet a further alternative embodiment, calibration can be performed by adding the virtual height filter response to the target response of the calibration system.

[0053] In either of these two cases (pre-emphasis filter or modification of target response), the virtual height filter used to modify the calibration procedure may be chosen to match exactly the filter utilized in the speaker. If, however, the virtual height filter utilized inside the speaker is a universal filter, such as curve 302, which is not modified as a function of the speaker location and room dimensions, then the calibration system may instead select a virtual height filter response corresponding to the actual location and dimensions if such information is available to the system. In this way, the calibration system applies a correction equivalent to the difference between the more precise, location dependent virtual height filter response and the universal response utilized in the speaker. In this hybrid system, the fixed filter in the speaker provides a good virtual height effect, and the calibration system in the AVR further refines this effect with more knowledge of the listening environment.

[0054] FIG. 13 is a flow diagram illustrating a method of performing virtual height filtering in an adaptive audio system, under an embodiment. The process of FIG. 13 illustrates the functions performed by the components shown in FIG. 11. Process 1300 starts by sending a test signal or signals to the virtual height speakers with built-in virtual height filtering, act 1302. The built-in virtual height filtering produces a frequency response curve, such as that shown in FIG. 7, which may be seen as an anomaly that would be corrected by any room correction processes. In act 1304, the system detects the presence of the virtual height speakers, so that any modification due to application of room correction methods may be corrected or compensated to allow the operation of the virtual height filtering of the virtual height speakers, act 1306.

[0055] As described above and illustrated in FIGS. 4A-B and 7, the virtual height filter may be implemented in a speaker either on its own or with or as part of a crossover circuit that separates input audio frequencies into high and low bands, or more depending on the crossover design. Either of these circuits may be implemented as a digital DSP circuit or other circuit that implements an FIR (finite impulse response) or IIR (infinite impulse response) filter to approximate the virtual height filter curve, such as shown in FIG. 3. Either of the crossover, separation circuit, and/or virtual height filter may be implemented as passive or active circuits, wherein an active circuit requires a separate power supply to function, and a passive circuit uses power provided by other system components or signals.

[0056] For an embodiment in which the height filter or crossover is provided as part of a speaker system (cabinet plus drivers), this component may be implemented in an analog circuit. FIG. 14A is a circuit diagram illus-

trating an analog virtual height filter circuit, under an embodiment. Circuit 1400 includes a virtual height filter comprising a connection of analog components with values chosen to approximate the equivalent of curve 302 with scaling parameter α=0.5 for a 3-inch 6-ohm speaker with a nominally flat response to 18kHz. The frequency response of this circuit is depicted in FIG. 14B as a black curve 1422 along with the desired curve 1424 in gray. The example circuit 1400 of FIG. 14 is meant to represent just one example of a possible circuit design or layout for a virtual height filter circuit, and other designs are possible.

[0057] Figure 15A depicts a digital implementation of the height cue filter for use in a powered speaker employing a DSP or active circuitry. The filter is implemented as a fourth order IIR filter with coefficients chosen for a sampling rate of 48kHz. This filter may alternatively be converted into an equivalent active analog circuit through means well known to one skilled in the art. Figure 15B depicts an example frequency response curve 1524 of this filter along with a desired response curve 1522.

Speaker Specifications

[0058] The speakers used in an adaptive audio system that implements virtual height filtering for a home theater or similar listening environment may use a configuration that is based on existing surround-sound configurations (e.g., 5.1, 7.1, 9.1, etc.). In this case, a number of drivers are provided and defined as per the known surround sound convention, with additional drivers and definitions provided for the upward-firing sound components.

[0059] As shown in FIG. 10, upward firing and direct drivers may be packaged in various different configurations with different stand-alone driver units and combinations of drivers in unitary cabinets. FIG. 16 illustrates the configuration of upward and direct firing speakers for a reflected sound application that utilizes virtual height filtering, under an embodiment. In speaker system 1600 a cabinet contains direct firing drivers comprising woofer 1604 and tweeter 1602. An upward firing driver 1606 is disposed to transmit signals out of the top of the cabinet for reflection off of the ceiling of the listening room. As described earlier, the inclination angle may be set to any appropriate angle, such as 20 degrees, and the driver 1606 may be manually or automatically movable with respect to this inclination angle. Sound absorbing foam 1610, or any similar baffling material may be included in the upward firing driver port to acoustically isolate this driver from the rest of the speaker system. The configuration of FIG. 16 is intended to provide an example illustration only, and many other configurations are possible. The cabinet size, driver size, driver type, driver placement, and other speaker design characteristics may all be configured differently based on the requirements and limitations of the audio content, rendering system and listening environment.

[0060] In a typical adaptive audio environment, a number of speaker enclosures will be contained within the listening environment. FIG. 17 illustrates an example placement of speakers having upward-firing drivers and virtual height filter components within a listening environment. As shown in FIG. 17, listening environment 1700 includes four individual speakers 1702, each having at least one front-firing, side-firing, and upward-firing driver. The listening environment may also contain fixed drivers used for surround-sound applications, such as center speaker and subwoofer or LFE (low-frequency element). As can be seen in FIG. 17, depending on the size of the listening environment and the respective speaker units, the proper placement of speakers 1702 within the listening environment can provide a rich audio environment resulting from the reflection of sounds off the ceiling from the number of upward-firing drivers. The speakers can be aimed to provide reflection off of one or more points on the ceiling plane depending on content, listening environment size, listener position, acoustic characteristics, and other relevant parameters.

[0061] As stated previously, the optimal angle for an upward firing speaker is the inclination angle of the virtual height driver that results in maximal reflected energy on the listener. In an embodiment, this angle is a function of distance from the speaker and ceiling height. While generally the ceiling height will be the same for all virtual height drivers in a particular room, the virtual height drivers may not be equidistant from the listener or listening position 106. The virtual height speakers may be used for different functions, such as direct projection and surround sound functions. In this case, different inclination angles for the upward firing drivers may be used. For example, the surround virtual height speakers may be set at a shallower or steeper angle as compared to the front virtual height drivers depending on the content and room conditions. Furthermore, different α scaling factors may be used for the different speakers, e.g., for the surround virtual height drivers versus the front height drivers. Likewise, a different shape magnitude response curve may be used for the virtual height model 302 that is applied to the different speakers. Thus, in a deployed system with multiple different virtual height speakers, the speakers may be oriented at different angles and/or the virtual height filters for these speakers may exhibit different filter curves.

Native Transducer Design

[0062] Embodiments have been described wherein the virtual height frequency curve for use with upward firing drivers is provided by a specific circuit or digital processing component. Such a circuit may add a certain amount of cost and complexity to an audio playback system, which may be undesirable. In an embodiment, the desired virtual height transfer function may be designed into the upward firing driver's native frequency response. Many speakers have inherent high frequency errors by parts that do not remain linear in the speakers operating

range, and that may be similar to the desired height filter transfer function. In current driver designs, these errors are typically minimized to produce a more linear speaker. However, a specific non-linear response to improve height cue information may be designed directly into drivers intended to reflect sound off of ceiling surfaces. Certain characteristics and components of the drivers or transducers of the upward firing speaker may be modified to incorporate a specific height cue transfer curve, such as that shown in diagram 1800 of FIG. 18. FIG. 18 illustrates a desired height cue transfer curve 1804 compared to a linear curve 1802 of an optimum linearized driver. The curve 1804 may correspond to the virtual height filter curve 302, or it may be a modified curve optimized for the design of the upward firing driver or drivers.

[0063] Certain elements of the upward firing driver are modified to create the desired height transfer function 1804 natively in the driver itself, and may include the driver cone, dust cap, spider, or other elements.

[0064] In an embodiment, the driver cone and/or cone edge may be modified. A cone edge assembly with a thin band on the perimeter of the cone or multiple varying thickness bands may be used. The cone may alternatively include a hinged section or multiple hinged sections using 'u' or 'v' shaped areas on the cone. The driver may also utilize bands of the cone area that are not tangent to the main cone profile, i.e., zig-zag profiles; or a section of the outside cone perimeter that is at a very small angle to the front plane of the speaker producing a substantially flat area. Alternatively, a section of the inside edge perimeter that is at a very small angle to the front plane of the speaker may be used to create a substantially flat area that can radiate independent of the cone body. This may also be accomplished by a section of the inside edge perimeter that is at a very acute angle to the front plane of the speaker with a large increase in the moment arm mass at the junction of the cone/edge assembly. The cone may also incorporate a hinged section or multiple hinged sections using 'u' or 'v' shaped areas on the edge; or an edge with a substantially asymmetrical compliance between the forward and rear excursion that creates harmonics in the required band. These design variations are all meant to introduce harmonics that help create the desired response curve 1804 for the driver.

[0065] The driver cone is often capped with a dust cap positioned in the center of the cone circle. The dust cap may also be configured to help produce the desired frequency curve. For example, a cone dust cap assembly with a hinged cone section or thin cone sections that allow the dust cap to vibrate at high frequencies in a substantially decoupled mode may be used. Alternatively, the dust cap may be shaped to become an efficient secondary radiator at the desired height frequency range. Similarly, a dust cap with a cone shaped whizzer or other spinning or vibrating element that is shaped to become an efficient secondary radiator at the height frequency range may be used. Such a dust cap may be modified and used by itself, or in combination with modified cone assembly.

[0066] The cone is typically supported by a plastic or metal frame called a spider. In an embodiment, the spider may be modified instead of, or in conjunction with the cone and/or dust cap. For example, a spider with a substantially asymmetrical compliance between the forward and rear excursion that creates harmonics in the required band may be used.

[0067] Certain specifications may be defined to optimize the upward firing driver. For example, the specification may define a transducer incorporating a cone with a varying cross-section shape that creates a high frequency response with a rise at 7 kHz of 5 dB followed by a drop of 7 dB at 12 kHz, and such a varying cross-section shape may include an annular section creating a hinge that allows this section cone to vibrate anti-phase to the rest of the cone body. It should be noted that all of the cited modifications to the driver elements may be used alone or in combination with each other to produce the desired frequency response curve.

[0068] Instead of the cone portion of the driver, the desired frequency curve may be built into the speaker using other or additional speaker components. In an embodiment, a wave guide (e.g., horn, lens, etc.) is used independently or in conjunction with the upward firing driver to produce the target desired target function 1804. This embodiment uses a waveguide to create the desired transfer function by controlling directivity. For this embodiment, the desired transfer function itself is created by the waveguide shape, and/or the use of the waveguide in conjunction with the optimized driver creates the desired transfer function.

[0069] In general, the upward-firing speakers incorporating virtual height filtering techniques as described herein can be used to reflect sound off of a hard ceiling surface to simulate the presence of overhead/height speakers positioned in the ceiling. A compelling attribute of the adaptive audio content is that the spatially diverse audio is reproduced using an array of overhead speakers. As stated above, however, in many cases, installing overhead speakers is too expensive or impractical in a home environment. By simulating height speakers using normally positioned speakers in the horizontal plane, a compelling 3D experience can be created with easy to position speakers. In this case, the adaptive audio system is using the upward-firing/height simulating drivers in a new way in that audio objects and their spatial reproduction information are being used to create the audio being reproduced by the upward-firing drivers. The virtual height filtering components help reconcile or minimize the height cues that may be transmitted directly to the listener as compared to the reflected sound so that the perception of height is properly provided by the overhead reflected signals.

[0070] Aspects of the systems described herein may be implemented in an appropriate computer-based sound processing network environment for processing digital or digitized audio files. Portions of the adaptive

audio system may include one or more networks that comprise any desired number of individual machines, including one or more routers (not shown) that serve to buffer and route the data transmitted among the computers. Such a network may be built on various different network protocols, and may be the Internet, a Wide Area Network (WAN), a Local Area Network (LAN), or any combination thereof.

[0071] One or more of the components, blocks, processes or other functional components may be implemented through a computer program that controls execution of a processor-based computing device of the system. It should also be noted that the various functions disclosed herein may be described using any number of combinations of hardware, firmware, and/or as data and/or instructions embodied in various machine-readable or computer-readable media, in terms of their behavioral, register transfer, logic component, and/or other characteristics. Computer-readable media in which such formatted data and/or instructions may be embodied include, but are not limited to, physical (non-transitory), non-volatile storage media in various forms, such as optical, magnetic or semiconductor storage media.

[0072] Unless the context clearly requires otherwise, throughout the description and the claims, the words "comprise," "comprising," and the like are to be construed in an inclusive sense as opposed to an exclusive or exhaustive sense; that is to say, in a sense of "including, but not limited to." Words using the singular or plural number also include the plural or singular number respectively. Additionally, the words "herein," "hereunder," "above," "below," and words of similar import refer to this application as a whole and not to any particular portions of this application. When the word "or" is used in reference to a list of two or more items, that word covers all of the following interpretations of the word: any of the items in the list, all of the items in the list and any combination of the items in the list.

[0073] While one or more implementations have been described by way of example and in terms of the specific embodiments, it is to be understood that one or more implementations are not limited to the disclosed embodiments. To the contrary, it is intended to cover various modifications and similar arrangements as would be apparent to those skilled in the art. Therefore, the scope of the appended claims should be accorded the broadest interpretation so as to encompass all such modifications and similar arrangements.

Claims

1. A speaker driver for rendering sound for reflection off of an upper surface of a listening environment, comprising:

   a driver cone;
   a cone dust cap affixed to a central portion of the driver cone; and
   a frame securing the cone for mounting within a speaker cabinet, wherein at least one of the driver cone, dust cap, and frame are configured to apply a height filter having a frequency response curve that is configured to at least partially remove directional cues from a speaker location, and at least partially insert the directional cues from a reflected speaker location, the frequency response curve based on

   a first frequency response of a filter modeling sound travelling directly from the reflected speaker location to the ears of a listener at a listening position, for said inserting of directional cues from the reflected speaker location, and
   a second filter frequency response of a filter modeling sound travelling directly from the speaker location to the ears of the listener at the listening position, for removing of directional cues for audio travelling along a path directly from the speaker location to the listener.

2. The speaker driver of claim 1, wherein the frequency response curve is a universal height filter frequency response curve that represents an average of a plurality of individual height filter frequency responses, where each of the individual height filter frequency responses corresponds to a different combination of reflected speaker location, listening position, and physical speaker location.

3. The speaker driver of claim 2, wherein the height filter response exhibits a peak located at about 7 kHz and a notch at about 12 kHz.

4. A system for rendering sound using reflected sound elements, comprising:

   a speaker placed at a speaker location and comprising a housing enclosing an upward-firing driver oriented at an inclination angle relative to the ground plane and configured to reflect sound off an upper surface of a listening environment to produce a reflected speaker location; and

   a virtual height filter applying a frequency response curve to an audio signal transmitted to the upward-firing driver, wherein the virtual height filter at least partially removes directional cues from the speaker location and at least partially inserts the directional cues from the reflected speaker location, the frequency response curve based on
   a first frequency response of a filter modeling sound travelling directly from the reflect-

ed speaker location to the ears of a listener at a listening position, for said inserting of directional cues from the reflected speaker location, and

a second filter frequency response of a filter modeling sound travelling directly from the speaker location to the ears of the listener at the listening position, for removing of directional cues for audio travelling along a path directly from the speaker location to the listener.

5. The system of claim 4, wherein the frequency response curve is a universal height filter frequency response curve that represents an average of a plurality of individual height filter frequency responses, where each of the individual height filter frequency responses corresponds to a different combination of reflected speaker location, listening position, and physical speaker location.

6. The system of claim 5, wherein the height filter response exhibits a peak located at about 7kHz and a notch at about 12 kHz.

7. The system of claim 4, wherein the inclination angle is variable, the system further comprising:

a location component configured to determine an optimum listening position within the listening environment;

a communication component configured to communicate the optimum listening position to the speaker; and

a control component configured to alter the inclination angle to reflect the sound waves off of the upper surface to the optimum listening position.

8. The system of claim 4, further comprising:

a detection component configured to detect the presence of the virtual height filter in the listening environment

or

a bypass switch to bypass the virtual height filter during a calibration process that prepares audio playback equipment to transmit the sound waves to the listening environment.

9. The system of claim 4, further comprising a room correction component either:

performing a pre-emphasis filtering operation on the sound waves transmitted to the listening environment to compensate for the virtual height filtering applied to the signal transmitted to the upward-firing driver

or generating a target response of the listening environment by use of a probe signal and adding a default virtual height filter response to a target response of the listening environment.

10. The system of claim 4, wherein the virtual height filter implements an algorithm using a scaling factor to compensate for height cues present in sound waves transmitted directly through the listening environment in favor of the height cues present in the sound reflected off the upper surface of the listening environment, and, optionally,

wherein the virtual height filter represents a unique frequency response curve, and wherein one or more characteristics of the frequency response curve are changed based on the value of the inclination angle.

11. The system of claim 4, wherein the housing further encloses a front-firing driver configured to transmit sound waves along an axis proximately corresponding to the ground plane.

12. The system of claim 11, wherein the speaker comprises two input terminals, wherein the first input terminal is configured to receive signals corresponding to the sound to be reflected off the upper surface of the listening environment, and the second input terminal is configured to receive signals corresponding to the sound waves to be transmitted along the axis proximately corresponding to the ground plane.

13. The system of claim 11, wherein the system further comprises a crossover filter, the crossover filter having a low-pass section configured to transmit low frequency signals below a threshold frequency to the front-firing driver, and a high-pass section configured to transmit high frequency signals above the threshold frequency to the upward-firing driver.

14. A speaker for transmitting sound waves to be reflected off an upper surface of a listening environment, comprising:

a housing;

an upward-firing driver within the housing and oriented at an inclination angle relative to a ground plane and configured to reflect sound off a reflection point on the upper surface of the listening environment; and

a virtual height filter applying a frequency response curve to a signal transmitted to the upward-firing driver, the frequency response curve based on

a first frequency response of a filter modeling sound travelling directly from

a reflected speaker location to the ears of a listener at a listening position, for inserting of directional cues from the reflected speaker location, and
a second filter frequency response of a filter modeling sound travelling directly from a speaker location to the ears of the listener at the listening position, for removing of directional cues for audio travelling along a path directly from a speaker location to the listener.

15. The speaker of claim 14, wherein the frequency response curve is a universal height filter frequency response curve that represents an average of a plurality of individual height filter frequency responses, where each of the individual height filter frequency responses corresponds to a different combination of reflected speaker location, listening position, and physical speaker location.

16. The speaker of claim 15, wherein the height filter response exhibits a peak located at about 7 kHz and a notch at about 12 kHz.

Patentansprüche

1. Lautsprechertreiber für die Tondarstellung für eine Reflexion von einer oberen Oberfläche einer Hörumgebung, umfassend:

einen Treiberkonus;
eine Konusstaubkappe, die an einem mittigen Teil des Treiberkonus angebracht ist; und
einen Rahmen, der den Konus für die Montage in einem Lautsprechergehäuse sichert, wobei wenigstens eines von dem Treiberkonus, der Staubkappe und dem Rahmen dafür ausgelegt ist, ein Höhenfilter anzuwenden, das eine Frequenzantwortkurve aufweist, welche dafür ausgelegt ist, wenigstens teilweise Richtungsinformationen von einem Lautsprecherstandort zu entfernen, und wenigstens teilweise die Richtungsinformationen von einem reflektierten Lautsprecherstandort einzufügen, wobei die Frequenzantwortkurve basiert auf

einer ersten Frequenzantwort eines Filters, die Schall modelliert, welcher sich direkt von dem reflektierten Lautsprecherstandort zu den Ohren eines Hörers an einer Hörposition ausbreitet, um Richtungsinformationen vom reflektierten Lautsprecherstandort einzufügen, und
einer zweiten Filterfrequenzantwort eines Filters, die Schall modelliert, welcher sich direkt vom Lautsprecherstandort zu den Ohren eines Hörers an der Hörposition ausbreitet, um Richtungsinformationen für Audiosignale zu entfernen, welche auf einem Pfad direkt vom Lautsprecherstandort zum Hörer laufen.

2. Lautsprechertreiber nach Anspruch 1, wobei die Frequenzantwortkurve eine universelle Höhenfilter-Frequenzantwortkurve ist, die einen Durchschnitt aus mehreren einzelnen Höhenfilter-Frequenzantworten darstellt, wobei jede der einzelnen Höhenfilter-Frequenzantworten einer anderen Kombination von reflektiertem Lautsprecherstandort, Hörposition und physischem Lautsprecherstandort entspricht.

3. Lautsprechertreiber nach Anspruch 2, wobei die Höhenfilterantwort eine Spitze bei ungefähr 7 kHz und ein Tief bei ungefähr 12 kHz zeigt.

4. System für die Tondarstellung mit reflektierten Tonelementen, umfassend:

einen Lautsprecher, der an einem Lautsprecherstandort platziert ist und ein Gehäuse umfasst, welches einen aufwärts abfeuernden Treiber umfasst, der entsprechend einem Neigungswinkel bezogen auf die Grundebene ausgerichtet und dafür ausgelegt ist, Ton von einer oberen Oberfläche einer Hörumgebung zu reflektieren, um einen reflektierten Lautsprecherstandort zu erzeugen; und
ein virtuelles Höhenfilter, das eine Frequenzantwortkurve auf ein an den aufwärts abfeuernden Treiber übertragenes Audiosignal anwendet, wobei das virtuelle Höhenfilter wenigstens teilweise Richtungsinformationen vom Lautsprecherstandort entfernt und wenigstens teilweise die Richtungsinformationen vom reflektierten Lautsprecherstandort einfügt, wobei die Frequenzantwortkurve basiert auf

einer ersten Frequenzantwort eines Filters, die Ton modelliert, welcher sich direkt vom reflektierten Lautsprecherstandort zu den Ohren eines Hörers an einer Hörposition ausbreitet, um Richtungsinformationen vom reflektierten Lautsprecherstandort einzufügen, und
einer zweiten Filterfrequenzantwort eines Filters, die Ton modelliert, welcher sich direkt vom Lautsprecherstandort zu den Ohren des Hörers an der Hörposition ausbreitet, um Richtungsinformationen für Audiosignale zu entfernen, welche auf einem Pfad direkt vom Lautsprecherstandort zum Hörer laufen.

5. System nach Anspruch 4, wobei die Frequenzantwortkurve eine universelle Höhenfilter-Frequenzantwortkurve ist, die einen Durchschnitt aus mehreren einzelnen Höhenfilter-Frequenzantworten darstellt, wobei jede der einzelnen Höhenfilter-Frequenzantworten einer anderen Kombination von reflektiertem Lautsprecherstandort, Hörposition und physischem

Lautsprecherstandort entspricht.

6. System nach Anspruch 5, wobei die Höhenfilterantwort eine Spitze bei ungefähr 7kHz und ein Tief bei ungefähr 12 kHz zeigt.

7. System nach Anspruch 4, wobei der Neigungswinkel variabel ist, wobei das System ferner Folgendes umfasst:

eine Standortkomponente, die dafür ausgelegt ist, eine optimale Hörposition innerhalb der Hörumgebung zu bestimmen;
eine Kommunikationskomponente, die dafür ausgelegt ist, die optimale Hörposition an den Lautsprecher zu übermitteln; und
eine Steuerkomponente, die dafür ausgelegt ist, den Neigungswinkel zu ändern, um die Schallwellen von der oberen Oberfläche zur optimalen Hörposition hin zu reflektieren.

8. System nach Anspruch 4, ferner umfassend:

eine Erkennungskomponente, die dafür ausgelegt ist, das Vorhandensein des virtuellen Höhenfilters in der Hörumgebung zu erkennen
oder
einen Umgehungsschalter, um das virtuelle Höhenfilter während eines Kalibrierprozesses zu umgehen, in dem ein Audiowiedergabegerät für das Übertragen der Schallwellen in die Hörumgebung vorbereitet wird.

9. System nach Anspruch 4, ferner eine Raumkorrekturkomponente umfassend, die entweder: eine Präemphase-Filteroperation an den in die Hörumgebung übertragenen Schallwellen ausführt, um die virtuelle Höhenfilterung auszugleichen, die auf das an den aufwärts abfeuernden Treiber übertragene Signal angewandt wurde, oder eine Sollantwort der Hörumgebung erzeugt, unter Verwendung eines Sondensignals, und eine standardmäßige virtuelle Höhenfilterantwort einer Sollantwort der Hörumgebung hinzufügt.

10. System nach Anspruch 4, wobei das virtuelle Höhenfilter
einen Algorithmus implementiert, um mithilfe eines Skalierfaktors Höheninformationen, die in den direkt durch die Hörumgebung übertragenen Schallwellen vorhanden sind, zugunsten der Höheninformationen zu kompensieren, die in dem von der oberen Oberfläche der Hörumgebung reflektierten Schall vorhanden sind, und, wahlweise,
wobei das virtuelle Höhenfilter eine eindeutige Frequenzantwortkurve darstellt, und wobei eines oder mehrere Merkmale der Frequenzantwortkurve basierend auf dem Wert des Neigungswinkels geändert werden.

11. System nach Anspruch 4, wobei das Gehäuse ferner einen vorwärts abfeuernden Treiber umschließt, der dafür ausgelegt ist, Schallwellen entlang einer Achse zu übertragen, die annähernd der Grundebene entspricht.

12. System nach Anspruch 11, wobei der Lautsprecher zwei Eingangsanschlüsse umfasst, wobei der erste Eingangsanschluss dafür ausgelegt ist, Signale zu empfangen, die dem von der oberen Oberfläche der Hörumgebung zu reflektierenden Ton entsprechen, und der zweite Eingangsanschluss dafür ausgelegt ist, Signale zu empfangen, die den entlang der annähernd der Grundebene entsprechenden Achse zu übertragenden Schallwellen entsprechen.

13. System nach Anspruch 11, wobei das System ferner ein Frequenzweichenfilter umfasst, wobei das Frequenzweichenfilter einen Tiefpassabschnitt, der dafür ausgelegt ist, niederfrequente Signale unterhalb eines Frequenzschwellwerts an den vorwärts abfeuernden Treiber zu übertragen, und einen Hochpassabschnitt, der dafür ausgelegt ist, hochfrequente Signale oberhalb des Frequenzschwellwerts an den aufwärts abfeuernden Treiber zu übertragen, aufweist.

14. Lautsprecher für die Übertragung von Schallwellen, die von einer oberen Oberfläche einer Hörumgebung reflektiert werden sollen, umfassend:

ein Gehäuse;
einen aufwärts abfeuernden Treiber innerhalb des Gehäuses und ausgerichtet in einem Neigungswinkel bezogen auf eine Grundebene und dafür ausgelegt, Schall von einem Reflexionspunkt an der oberen Oberfläche der Hörumgebung zu reflektieren; und
ein virtuelles Höhenfilter, das eine Frequenzantwortkurve auf ein an den aufwärts abfeuernden Treiber übertragenes Signal anwendet, wobei die Frequenzantwortkurve basiert auf

einer ersten Frequenzantwort eines Filters, die Schall modelliert, welcher sich direkt von einem reflektierten Lautsprecherstandort zu den Ohren eines Hörers an einer Hörposition ausbreitet, um Richtungsinformationen vom reflektierten Lautsprecherstandort einzufügen, und
einer zweiten Filterfrequenzantwort eines Filters, die Schall modelliert, welcher sich direkt von einem Lautsprecherstandort zu den Ohren des Hörers an der Hörposition ausbreitet, um Richtungsinformationen für Audiosignale zu entfernen, welche auf einem Pfad direkt von einem Lautsprecherstandort zum Hörer laufen.

15. Lautsprecher nach Anspruch 14, wobei die Frequenzantwortkurve eine universelle Höhenfilter-Frequenzantwortkurve ist, die einen Durchschnitt aus mehreren einzelnen Höhenfilter-Frequenzantworten darstellt, wobei jede der einzelnen Höhenfilter-Frequenzantworten einer anderen Kombination von reflektiertem Lautsprecherstandort, Hörposition und physischem Lautsprecherstandort entspricht.

16. Lautsprecher nach Anspruch 15, wobei die Höhenfilterantwort eine Spitze bei ungefähr 7 kHz und ein Tief bei ungefähr 12 kHz zeigt.

Revendications

1. Actionneur de haut-parleur pour rendre un son par réflexion depuis une surface supérieure d'un environnement d'écoute, comprenant :

   - un cône d'actionneur ;
   - un cache anti-poussière de cône fixé à une partie centrale du cône d'actionneur ; et
   - un cadre fixant le cône en vue du montage dans une enceinte de haut-parleur, l'un au moins du cône d'actionneur, du cache anti-poussière et du cadre étant conçu pour appliquer un filtre de hauteur ayant une courbe de réponse de fréquence qui est configurée pour éliminer au moins partiellement des repères directionnels d'un emplacement de haut-parleur, et insérer au moins partiellement les repères directionnels d'un emplacement de haut-parleur réfléchi, la courbe de réponse de fréquence état basée sur :

     o une première réponse de fréquence d'un son de modélisation de filtre se déplaçant directement de l'emplacement de haut-parleur réfléchi vers les oreilles d'un auditeur à une position d'écoute pour l'insertion des repères directionnels depuis l'emplacement de haut-parleur réfléchi ; et
     o une seconde réponse de fréquence de filtre d'un son de modélisation de filtre se déplaçant directement de l'emplacement de haut-parleur réfléchi vers les oreilles d'un auditeur à une position d'écoute pour l'élimination des repères directionnels pour un audio se déplaçant le long d'un trajet directement de l'emplacement de haut-parleur vers l'auditeur.

2. Actionneur de haut-parleur selon la revendication 1, dans lequel la courbe de réponse de fréquence est une courbe de réponse de fréquence de filtre de hauteur universelle qui représente une moyenne de plusieurs réponses de fréquence de filtre de hauteur individuelles, chacune des réponses de fréquence de filtre de hauteur individuelles correspondant à une combinaison différente d'emplacement de haut-parleur réfléchi, de la position d'écoute et de l'emplacement physique du haut-parleur.

3. Actionneur de haut-parleur selon la revendication 2, dans lequel la réponse de filtre de hauteur possède un pic d'environ 7 kHz et un creux d'environ 12 kHz.

4. Système pour rendre un son en utilisant des éléments sonores réfléchis, comprenant :

   - un haut-parleur placé en une position de haut-parleur et comprenant un boîtier contenant un actionneur agissant vers le haut orienté à un angle d' inclinaison par rapport au plan de base et configuré pour réfléchir le son depuis une surface supérieure d'environnement d'écoute afin de produire un emplacement de haut-parleur réfléchi ; et
   - un filtre de hauteur virtuel appliquant une courbe de réponse de fréquence à un signal audio transmis vers l'actionneur agissant vers le haut, lequel filtre de hauteur virtuel élimine au moins partiellement des repères directionnels depuis l'emplacement de haut-parleur et insère au moins partiellement les repères directionnels depuis l'emplacement de haut-parleur réfléchi, la courbe de réponse de fréquence étant basée sur :

     o une première réponse de fréquence d'un son de modélisation de filtre se déplaçant directement de l'emplacement de haut-parleur réfléchi vers les oreilles d'un auditeur à une position d'écoute pour l'insertion des repères directionnels depuis l'emplacement de haut-parleur réfléchi ; et
     o une seconde réponse de fréquence de filtre d'un son de modélisation de filtre se déplaçant directement de l'emplacement de haut-parleur réfléchi vers les oreilles d'un auditeur à une position d'écoute pour l'élimination de repères directionnels pour un audio se déplaçant le long d'un trajet directement de l'emplacement de haut-parleur vers l'auditeur.

5. Système selon la revendication 4, dans lequel la courbe de réponse de fréquence est une courbe de réponse de fréquence de filtre de hauteur universelle qui représente une moyenne de plusieurs réponses de fréquence de filtre de hauteur individuelles, chacune des réponses de fréquence de filtre de hauteur individuelles correspondant à une combinaison différente d'emplacement de haut-parleur réfléchi, de la position d'écoute et de l'emplacement physique

du haut-parleur.

6. Système selon la revendication 5, dans lequel la réponse de filtre de hauteur possède un pic d'environ 7 kHz et un creux d'environ 12 kHz.

7. Système selon la revendication 4, dans lequel l'angle d'inclinaison est variable, lequel système comprend en outre :

- un composant d'emplacement conçu pour déterminer une position d'écoute optimale dans l'environnement d'écoute ;
- un composant de communication conçu pour communiquer la position d'écoute optimale au haut-parleur ; et
- un composant de commande conçu pour modifier l'angle d'orientation pour réfléchir les ondes sonores depuis la surface supérieure vers la position d'écoute optimale.

8. Système selon la revendication 4, comprenant en outre :

- un composant de détection conçu pour détecter la présence du filtre de hauteur virtuel dans l'environnement d'écoute ; ou
- un commutateur de dérivation afin de contourner le filtre de hauteur virtuel pendant un processus d'étalonnage qui prépare un équipement de relecture audio à transmettre les ondes sonores vers l'environnement d'écoute.

9. Système selon la revendication 4, comprenant en outre un composant de correction de pièce pour :

- effectuer une opération de filtrage de préemphase sur les ondes sonores transmises vers l'environnement d'écoute afin de compenser le filtrage de hauteur virtuel appliqué au signal transmis vers l'actionneur agissant vers le haut ; ou
- générer une réponse cible de l'environnement d'écoute en utilisant un signal de sonde et en ajoutant une réponse de filtre de hauteur virtuel par défaut à la réponse cible de l'environnement d'écoute.

10. Système selon la revendication 4, dans lequel le filtre de hauteur virtuel met en oeuvre un algorithme en utilisant un facteur d'échelonnage pour compenser les repères de hauteur présents dans les ondes sonores transmises directement à travers l'environnement d'écoute en faveur des repères de hauteur présents dans le son réfléchi depuis la surface supérieure de l'environnement d'écoute ; et éventuellement dans lequel le filtre de hauteur virtuel représente une courbe de réponse de fréquence unique, et dans lequel une ou plusieurs caractéristiques de la courbe de réponse de fréquence sont changées en fonction de la valeur de l'angle d'inclinaison.

11. Système selon la revendication 4, dans lequel le boîtier comprend en outre un actionneur agissant vers l'avant conçu pour transmettre des ondes sonores le long d'un axe correspondant proximalement au plan de base.

12. Système selon la revendication 11, dans lequel le haut-parleur comprend deux bornes d'entrée, la première borne d'entrée étant conçue pour recevoir des signaux correspondant au son devant être réfléchi depuis la surface supérieure de l'environnement d'écoute tandis que la seconde borne d'entrée est conçue pour recevoir des signaux correspondant aux ondes sonores devant être transmises le long de l'axe correspondant proximalement au plan de base.

13. Système selon la revendication 11, dans lequel le système comprend en outre un filtre répartiteur, lequel filtre répartiteur comprend une section passe-bas conçue pour transmettre des signaux basse fréquence en dessous d'une fréquence seuil vers l'actionneur agissant vers l'avant, et une section passe-haut conçue pour transmettre des signaux haute fréquence au-dessus de la fréquence seuil vers l'actionneur agissant vers le haut.

14. Haut-parleur pour transmettre des ondes sonores devant être réfléchies depuis une surface supérieure d'un environnement d'écoute, comprenant :

- un boîtier ;
- un actionneur agissant vers le haut dans le boîtier qui est orienté à un angle d' inclinaison par rapport à un plan de base et qui est configuré pour réfléchir un son depuis un point de réflexion de la surface supérieure de l'environnement d'écoute ; et
- un filtre de hauteur virtuel appliquant une courbe de réponse de fréquence à un signal transmis vers l'actionneur agissant vers le haut, la courbe de réponse de fréquence étant basée sur :

o une première réponse de fréquence d'un son de modélisation de filtre se déplaçant directement d'un emplacement de haut-parleur réfléchi vers les oreilles d'un auditeur à une position d'écoute pour l'insertion de repères directionnels depuis l'emplacement de haut-parleur réfléchi ; et
o une seconde réponse de fréquence de filtre d'un son de modélisation de filtre se déplaçant directement de l'emplacement de haut-parleur réfléchi vers les oreilles de

l'auditeur à une position d'écoute pour l'élimination de repères directionnels pour un audio se déplaçant directement de l'emplacement de haut-parleur vers l'auditeur.

15. Haut-parleur selon la revendication 14, dans lequel la courbe de réponse de fréquence est une courbe de réponse de fréquence de filtre de hauteur universelle qui représente une moyenne de plusieurs réponses de fréquence de filtre de hauteur individuelles, chacune des réponses de fréquence de filtre de hauteur individuelles correspondant à une combinaison différente d'emplacement de haut-parleur réfléchi, de la position d'écoute et de l'emplacement physique du haut-parleur.

16. Haut-parleur selon la revendication 15, dans lequel la réponse de filtre de hauteur possède un pic d'environ 7 kHz et un creux d'environ 12 kHz.

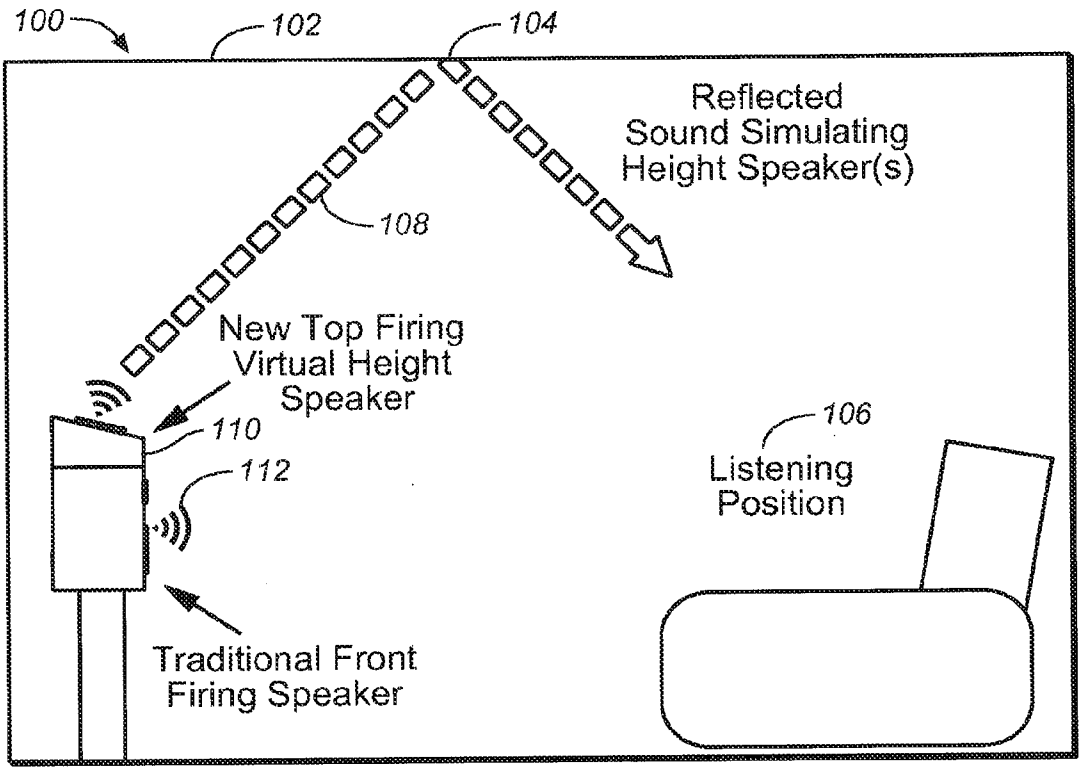

100
102
104
Reflected
Sound Simulating
Height Speaker(s)
108
New Top Firing
Virtual Height
Speaker
110
112
106
Listening
Position
Traditional Front
Firing Speaker

FIG. 1

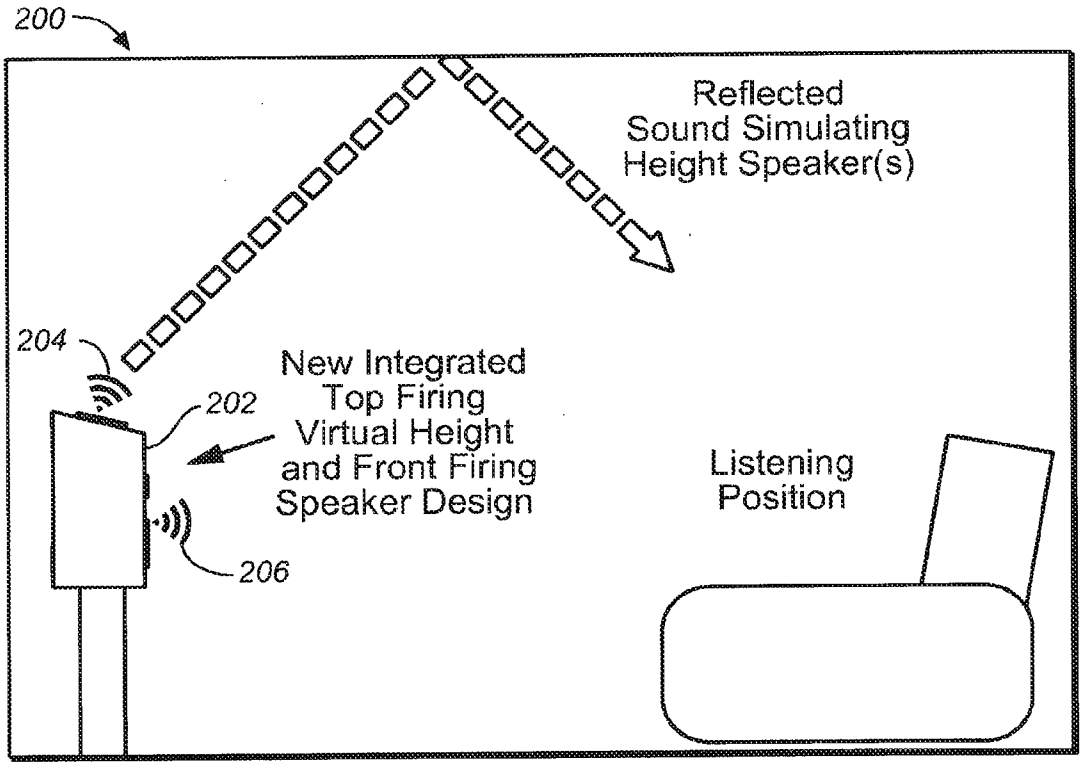

200
Reflected
Sound Simulating
Height Speaker(s)
204
New Integrated
Top Firing
Virtual Height
and Front Firing
Speaker Design
202
206
Listening
Position

FIG. 2

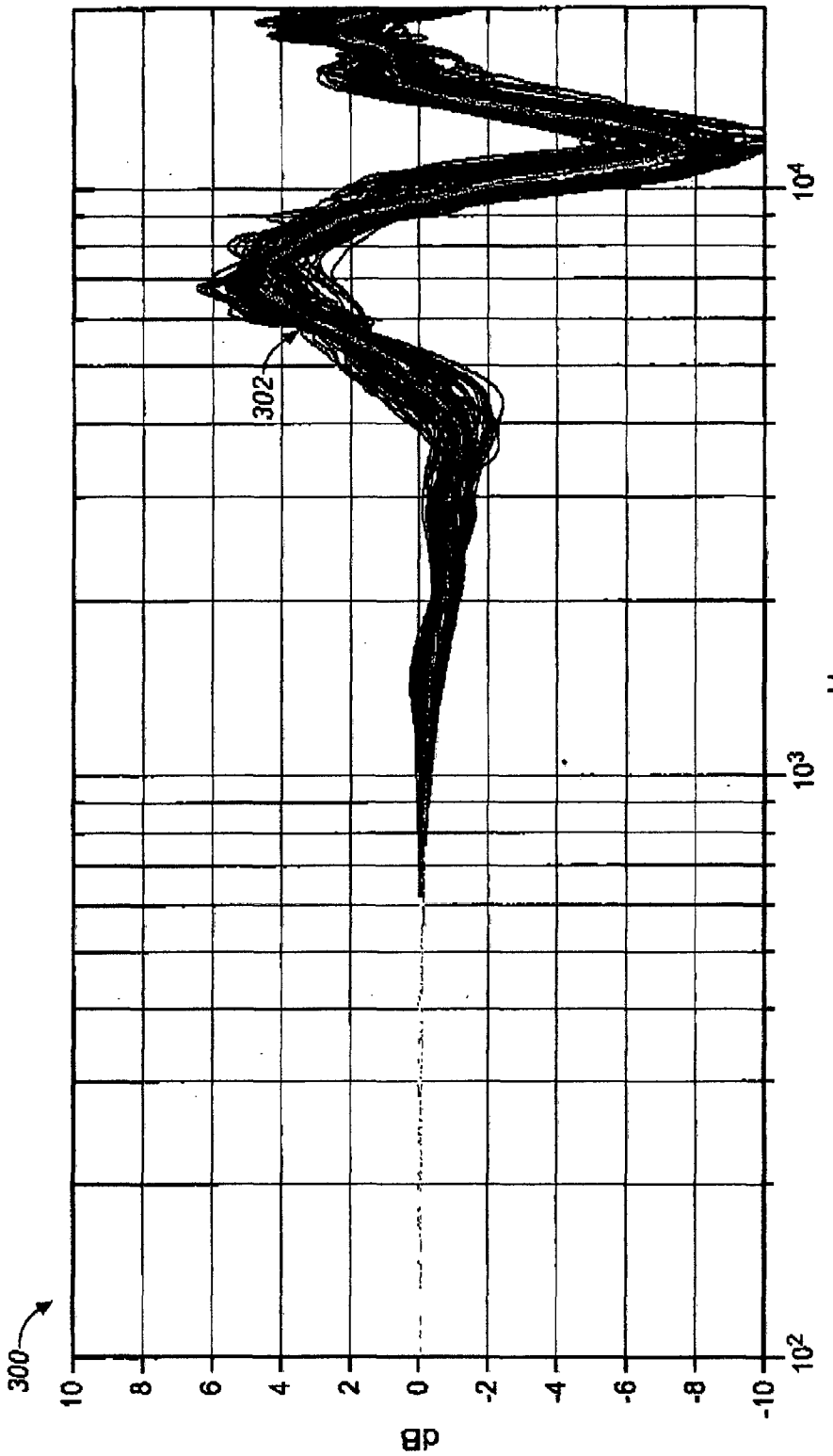


FIG. 3

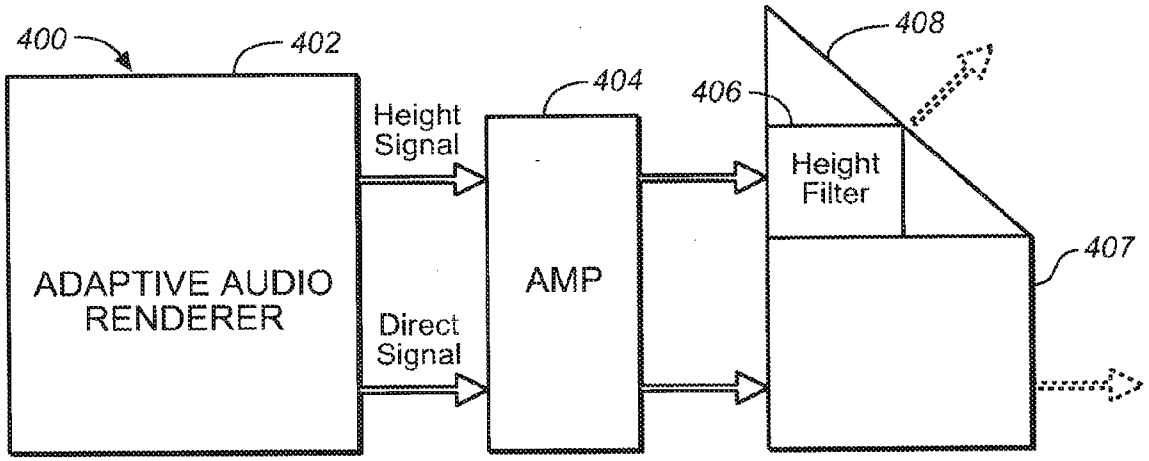


FIG. 4A

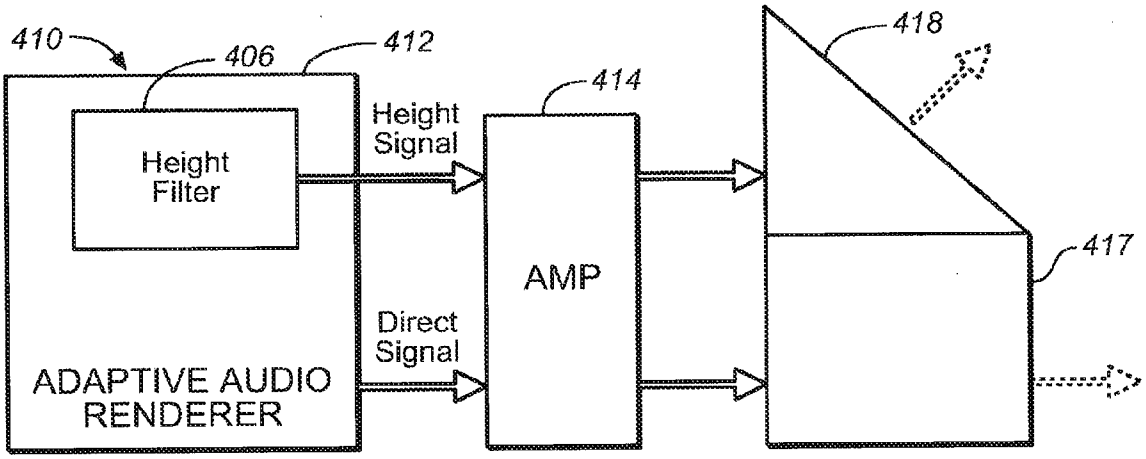


FIG. 4B

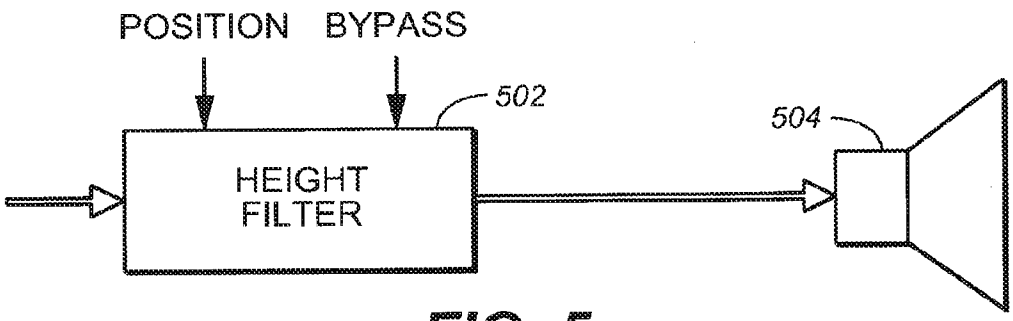


FIG. 5

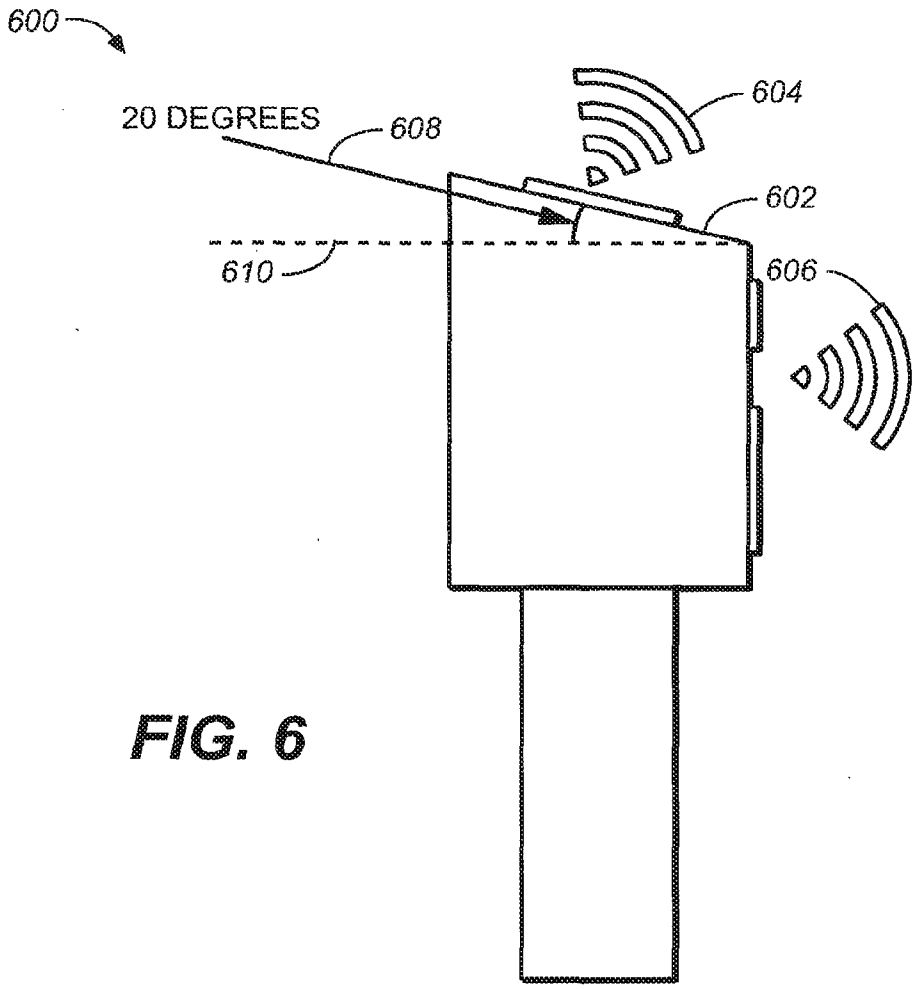

600
20 DEGREES
608
604
602
610
606

FIG. 6

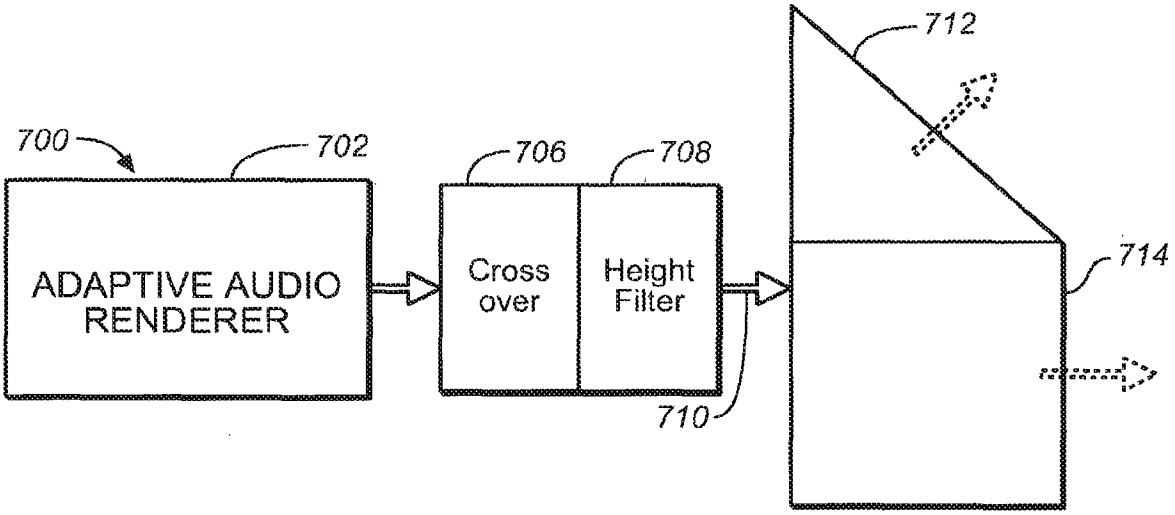

700
702
706
708
712
714
ADAPTIVE AUDIO RENDERER
Cross over
Height Filter
710

FIG. 7

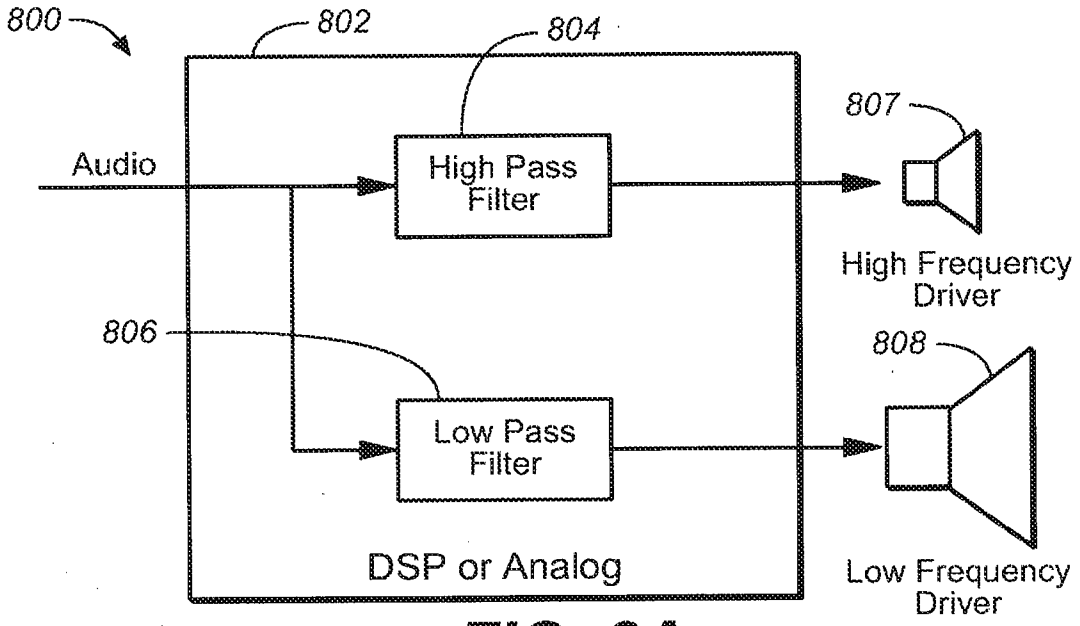

800
802
804
807
Audio
High Pass Filter
High Frequency Driver
806
808
Low Pass Filter
DSP or Analog
Low Frequency Driver

FIG. 8A

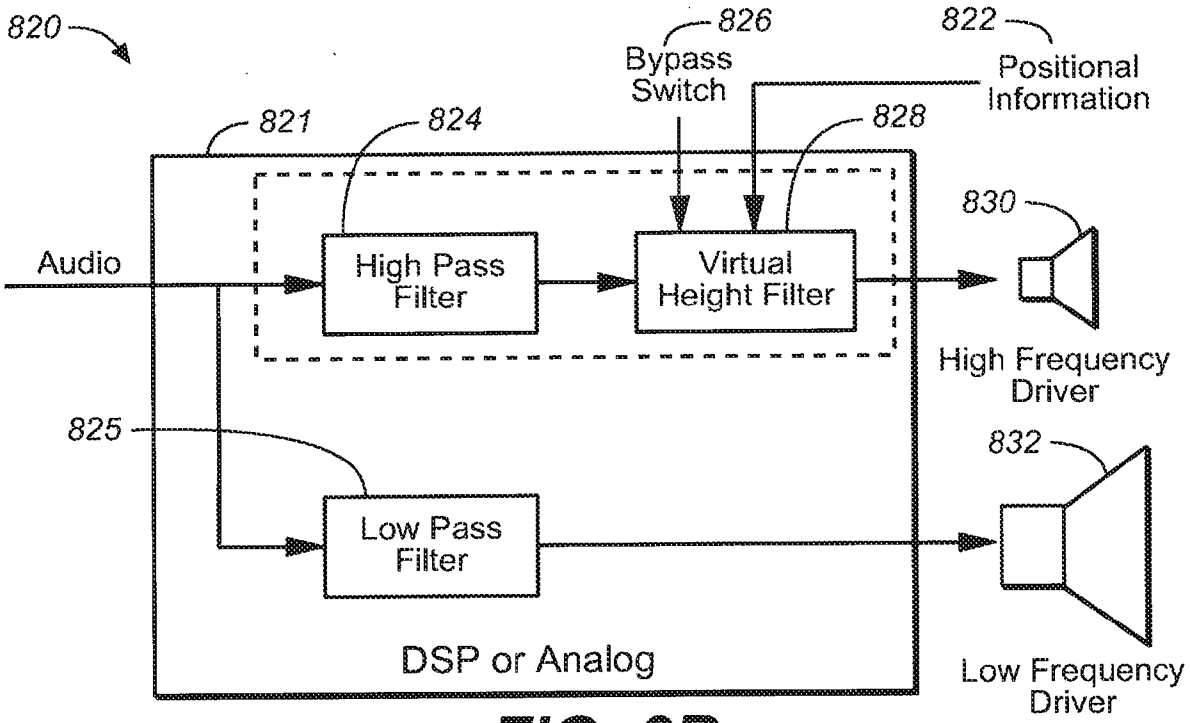

820
826
822
Bypass Switch
Positional Information
821
824
828
830
Audio
High Pass Filter
Virtual Height Filter
High Frequency Driver
825
832
Low Pass Filter
DSP or Analog
Low Frequency Driver

FIG. 8B

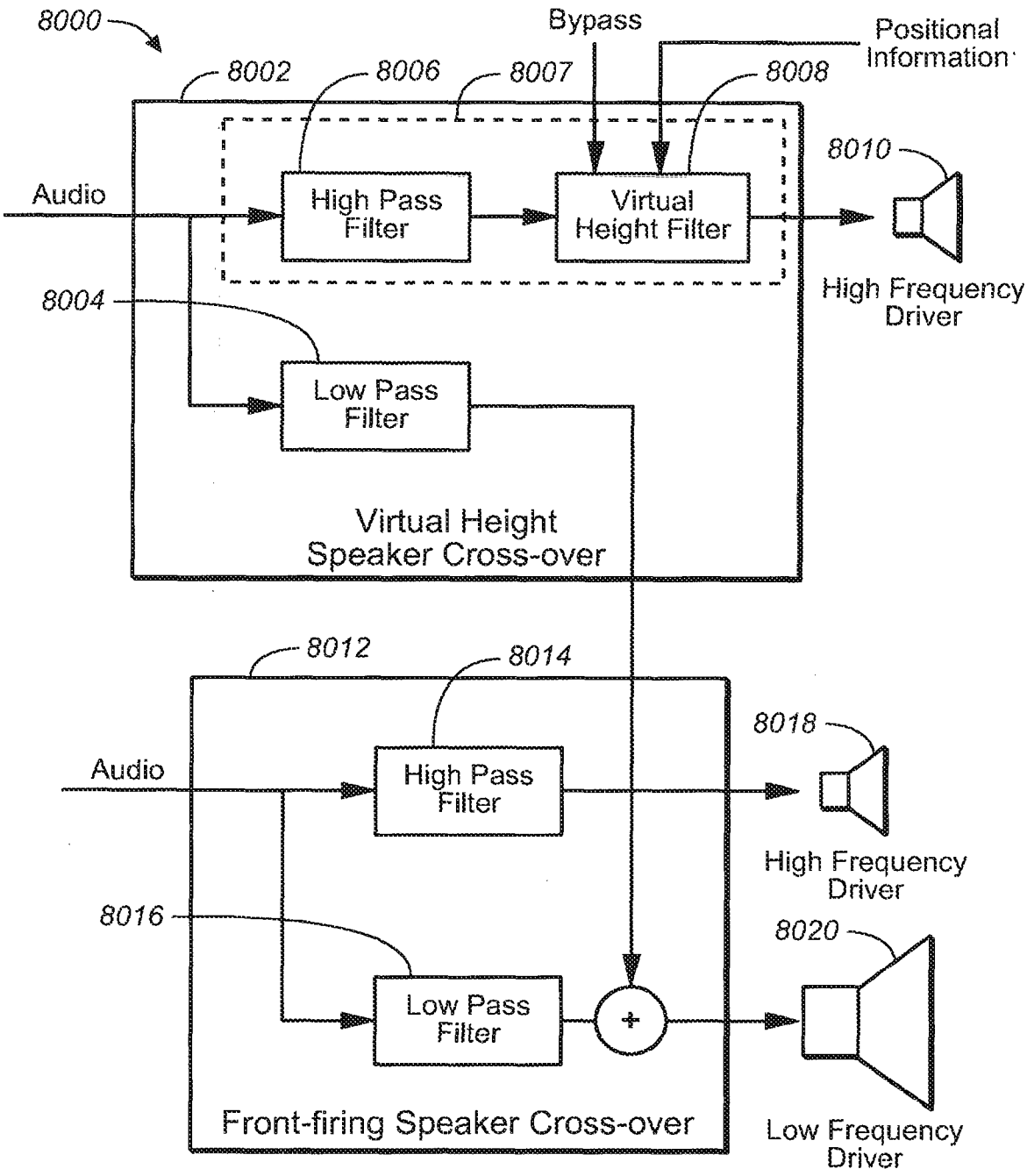

8000
Bypass
Positional Information
8002
8006
8007
8008
8010
Audio
High Pass Filter
Virtual Height Filter
High Frequency Driver
8004
Low Pass Filter
Virtual Height Speaker Cross-over
8012
8014
8018
Audio
High Pass Filter
High Frequency Driver
8016
8020
Low Pass Filter
+
Front-firing Speaker Cross-over
Low Frequency Driver

FIG. 8C

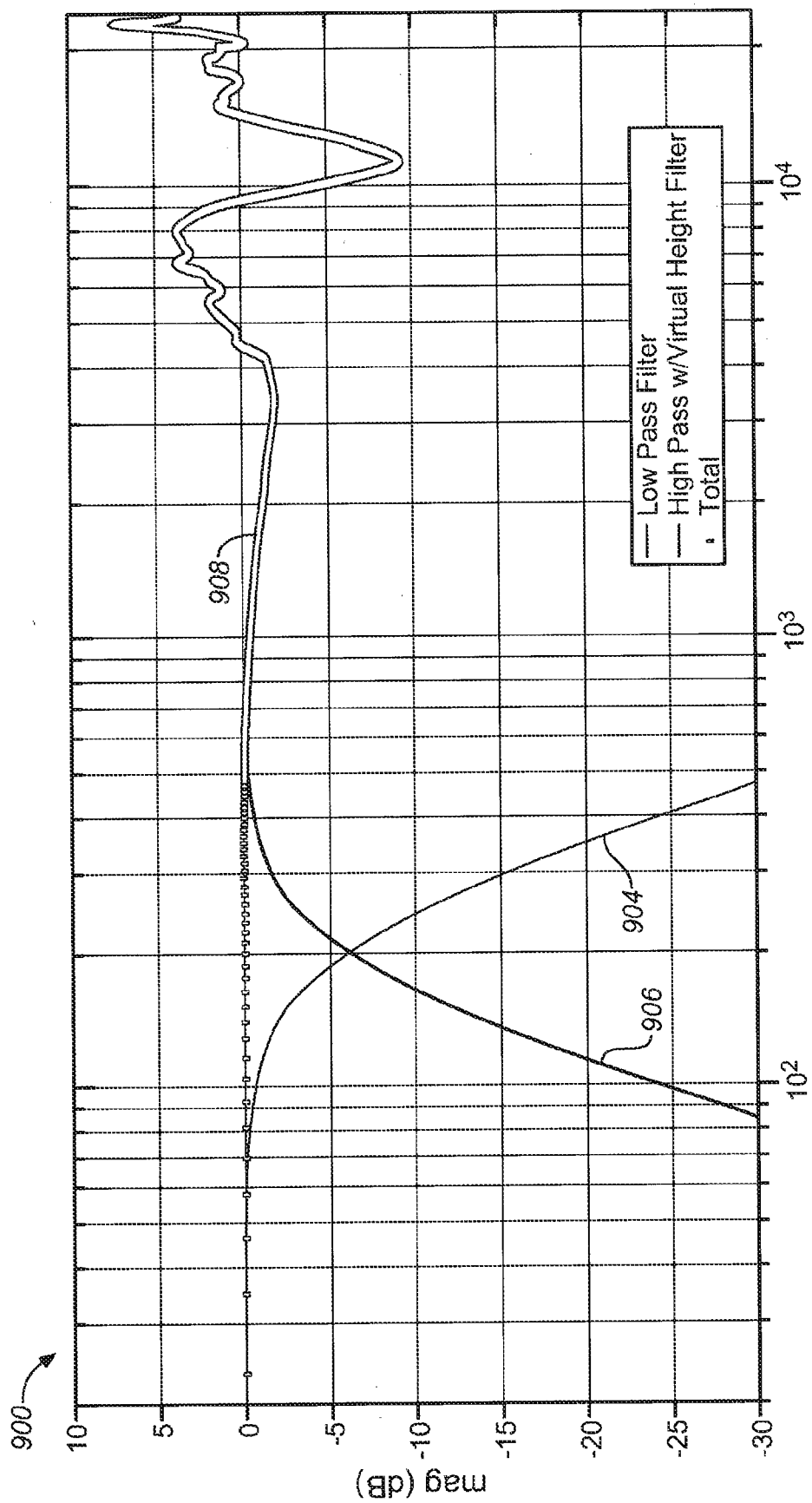
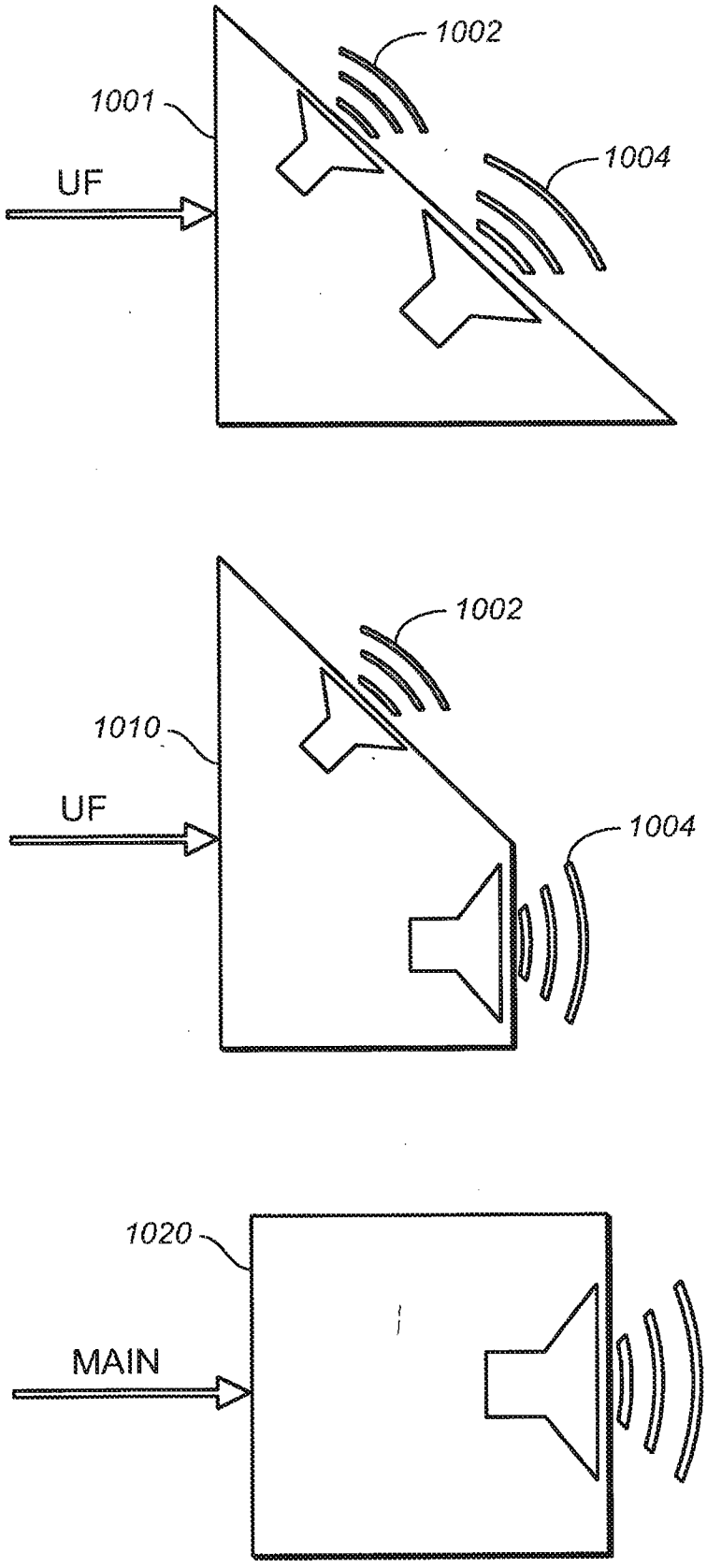

900
mag (dB)
10
5
0
-5
-10
-15
-20
-25
-30
10^2
10^3
10^4
Freq (Hz)
Low Pass Filter
High Pass w/Virtual Height Filter
Total
908
904
906

FIG. 9

FIG. 10



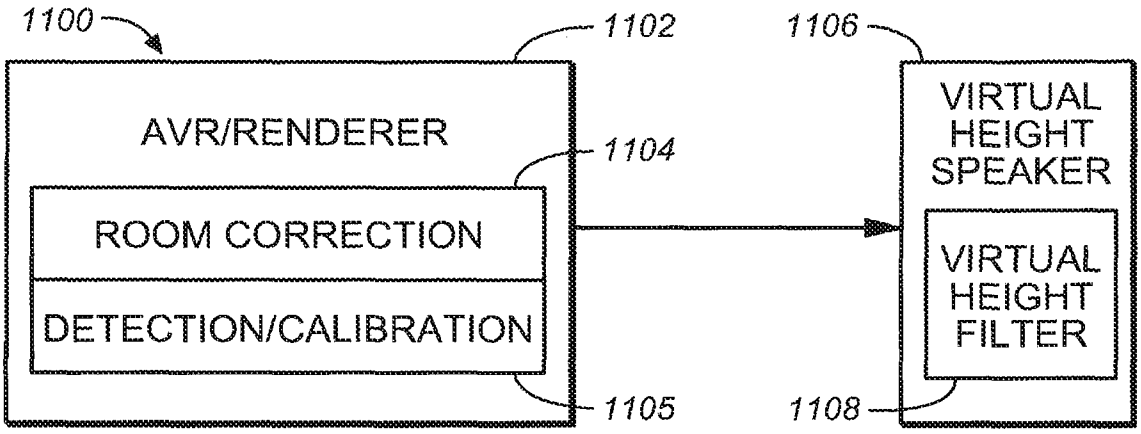

1100
1102
1106
AVR/RENDERER
1104
ROOM CORRECTION
DETECTION/CALIBRATION
1105
VIRTUAL HEIGHT SPEAKER
VIRTUAL HEIGHT FILTER
1108

FIG. 11

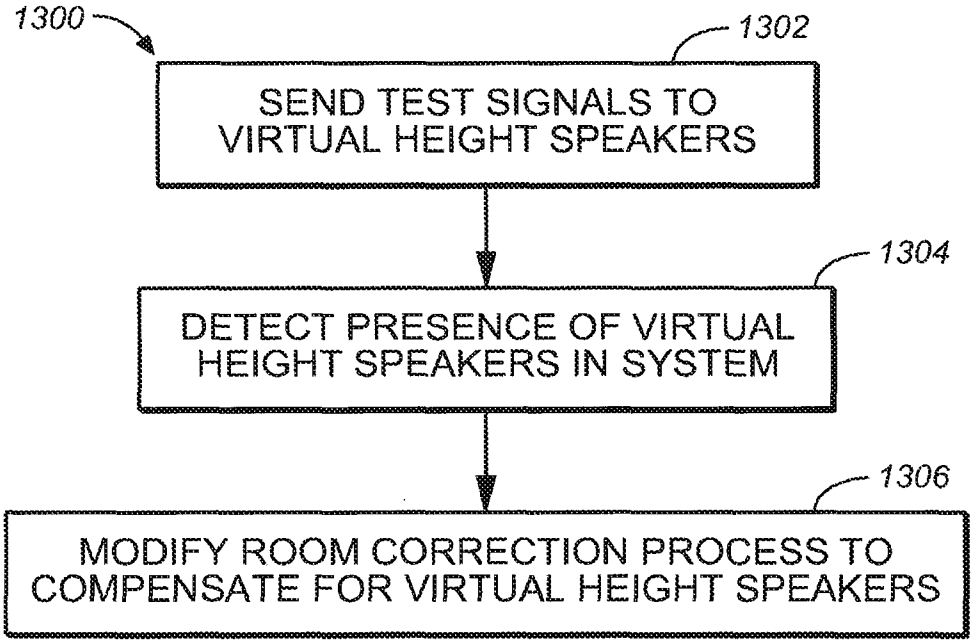

1300
1302
SEND TEST SIGNALS TO VIRTUAL HEIGHT SPEAKERS
1304
DETECT PRESENCE OF VIRTUAL HEIGHT SPEAKERS IN SYSTEM
1306
MODIFY ROOM CORRECTION PROCESS TO COMPENSATE FOR VIRTUAL HEIGHT SPEAKERS

FIG. 13

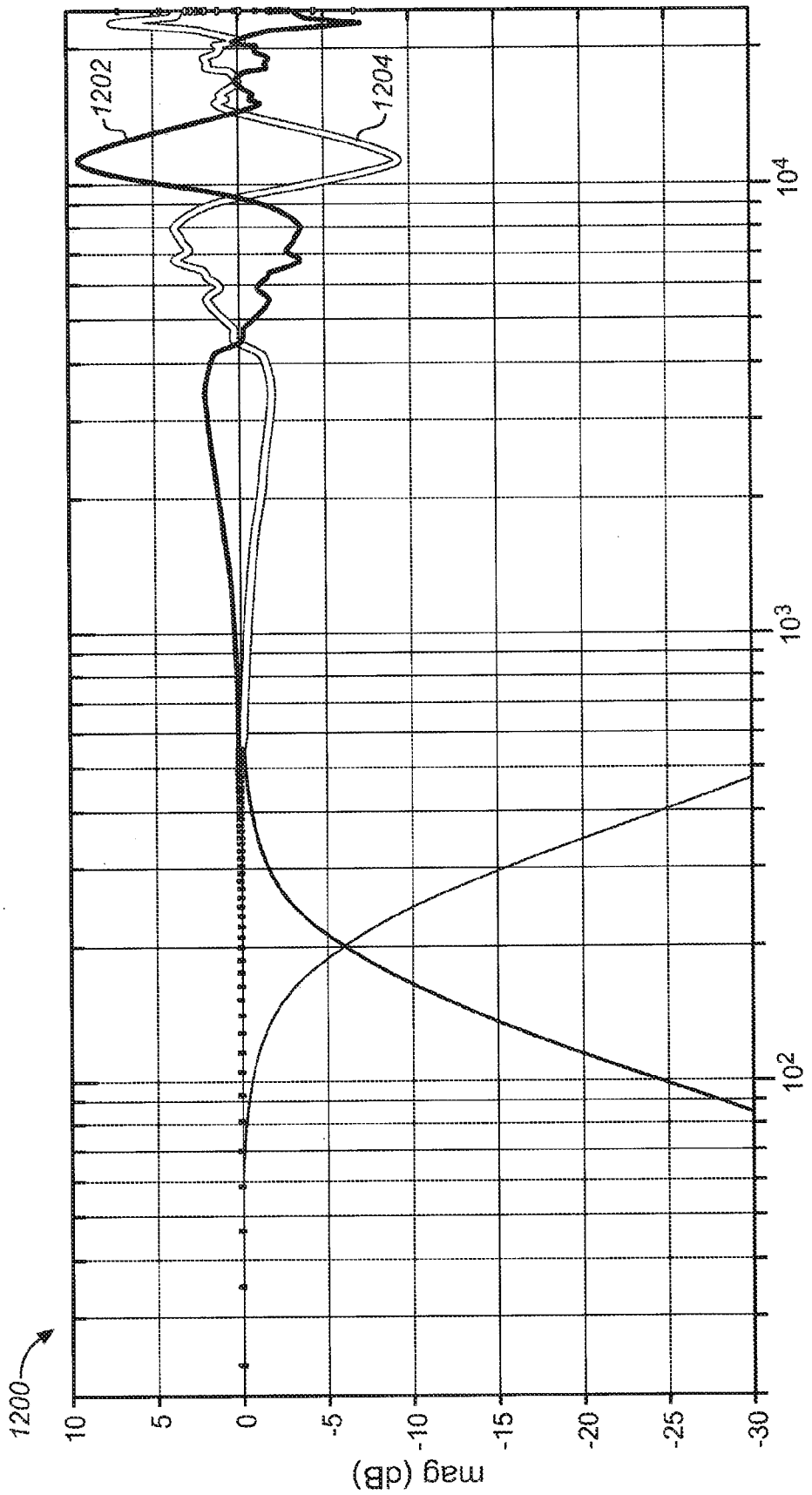


FIG. 12

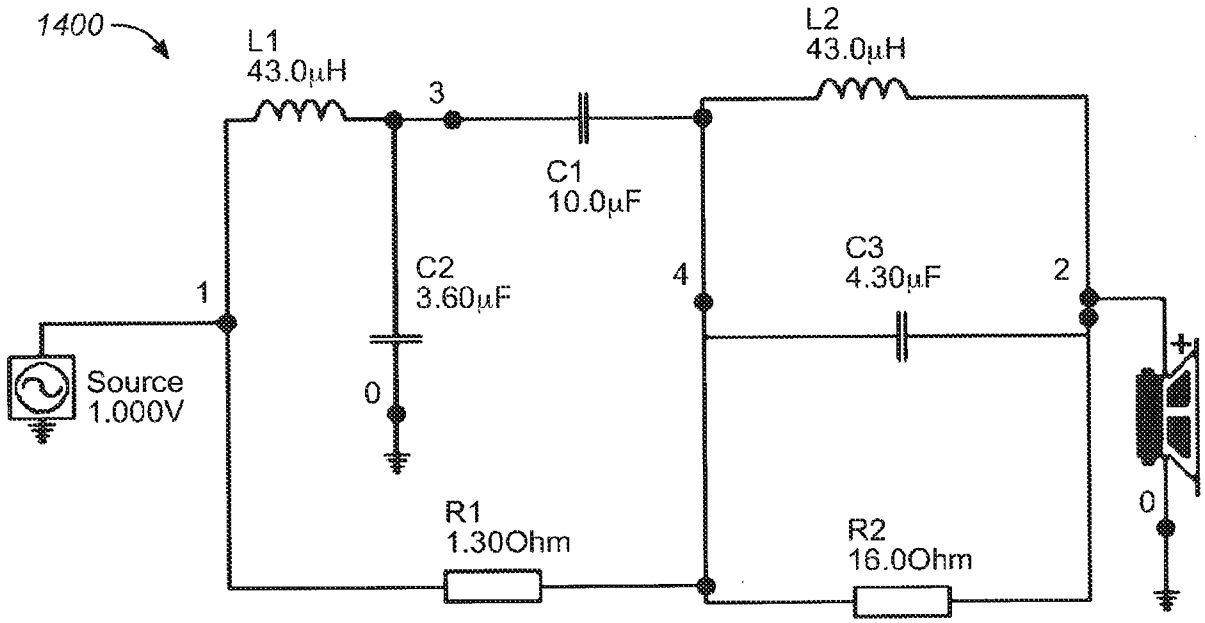


FIG. 14A

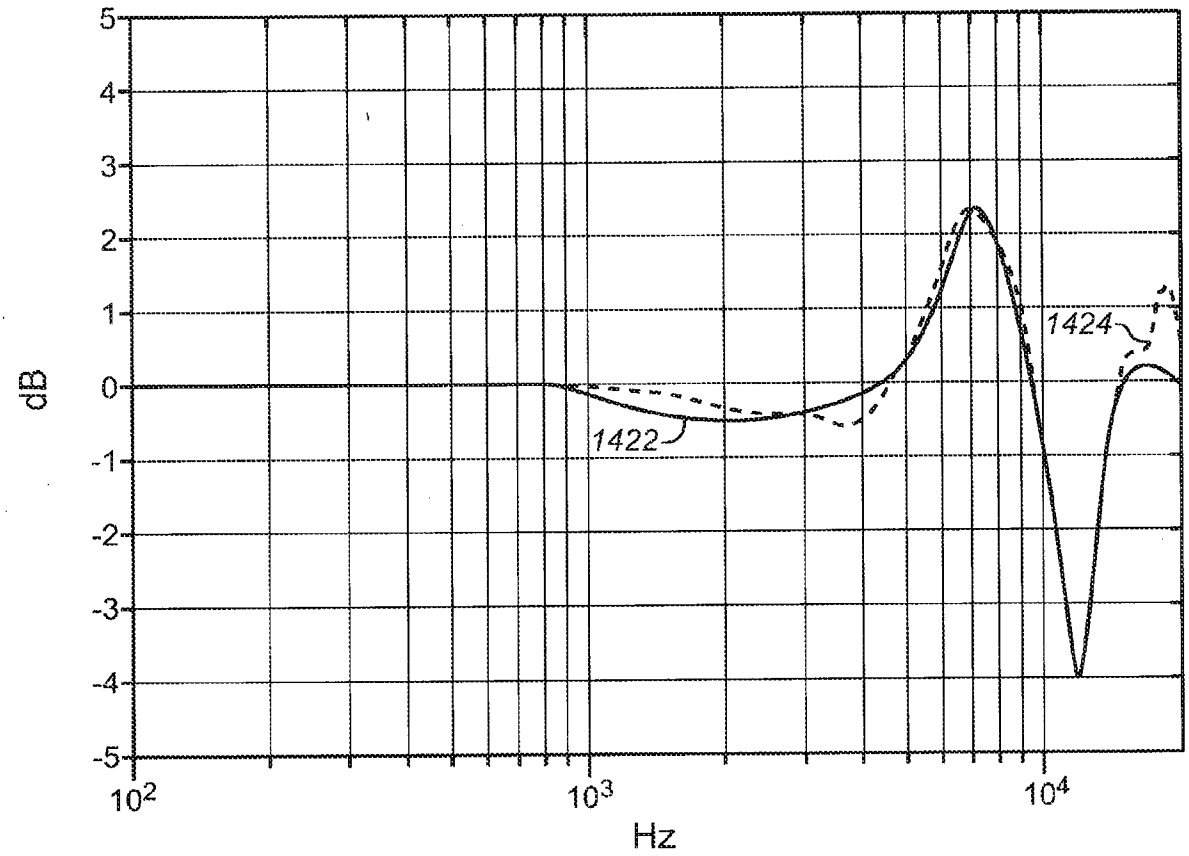


FIG. 14B

$$H(z) = \frac{0.9911 - 1.3044z^{-1} + 1.3382z^{-2} - 0.8314z^{-3} + 0.3840z^{-4}}{1.000 - 1.3143z^{-1} + 1.2533z^{-2} - 0.6224z^{-3} + 0.2656z^{-4}}$$

FIG. 15A

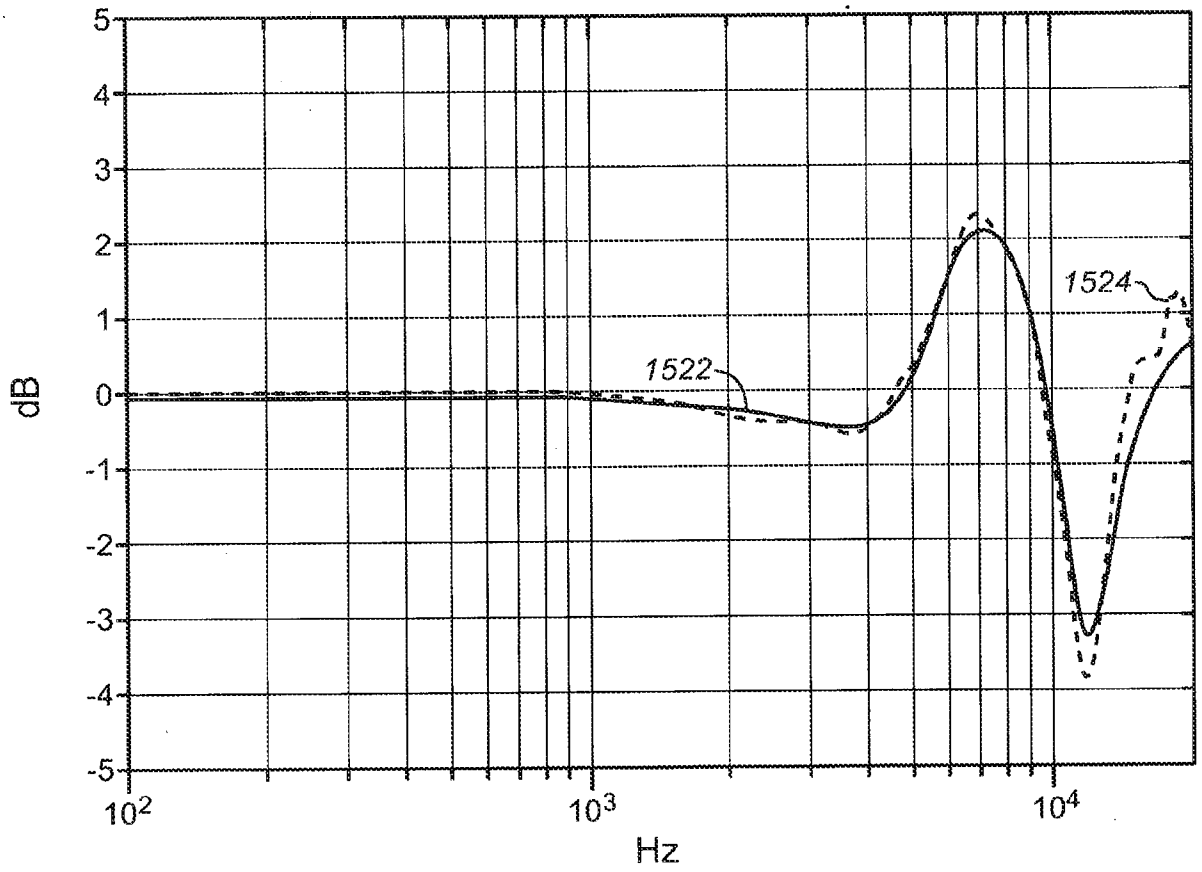


FIG. 15B

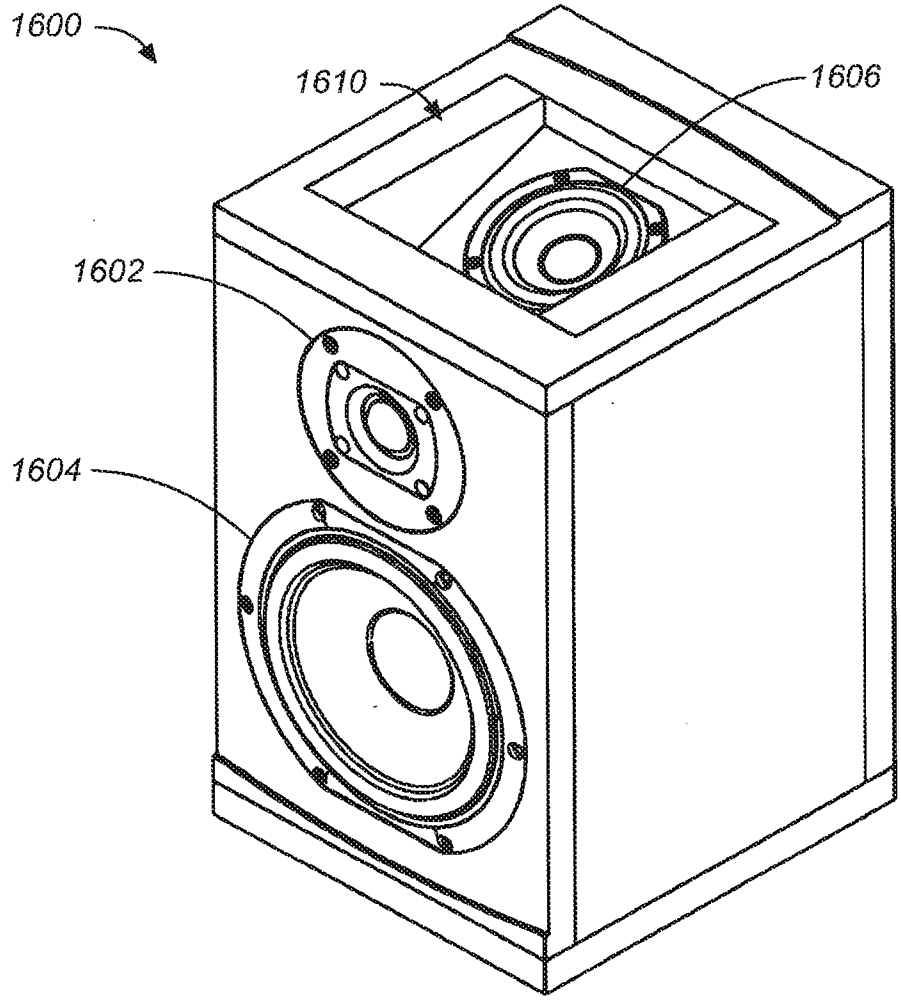


FIG. 16

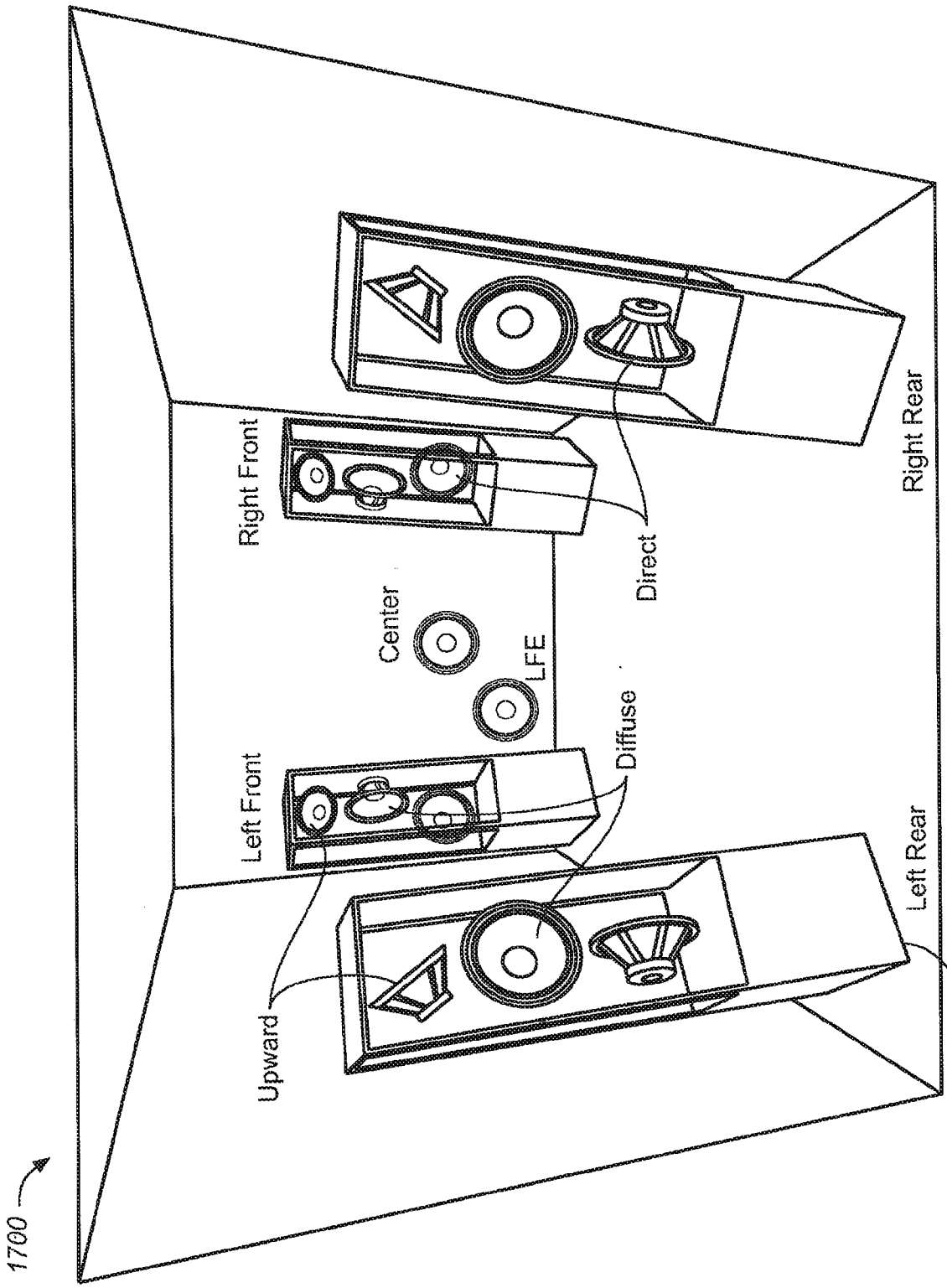

1700
Upward
Left Front
Diffuse
Left Rear
1702
Center
LFE
Direct
Right Front
Right Rear

FIG. 17

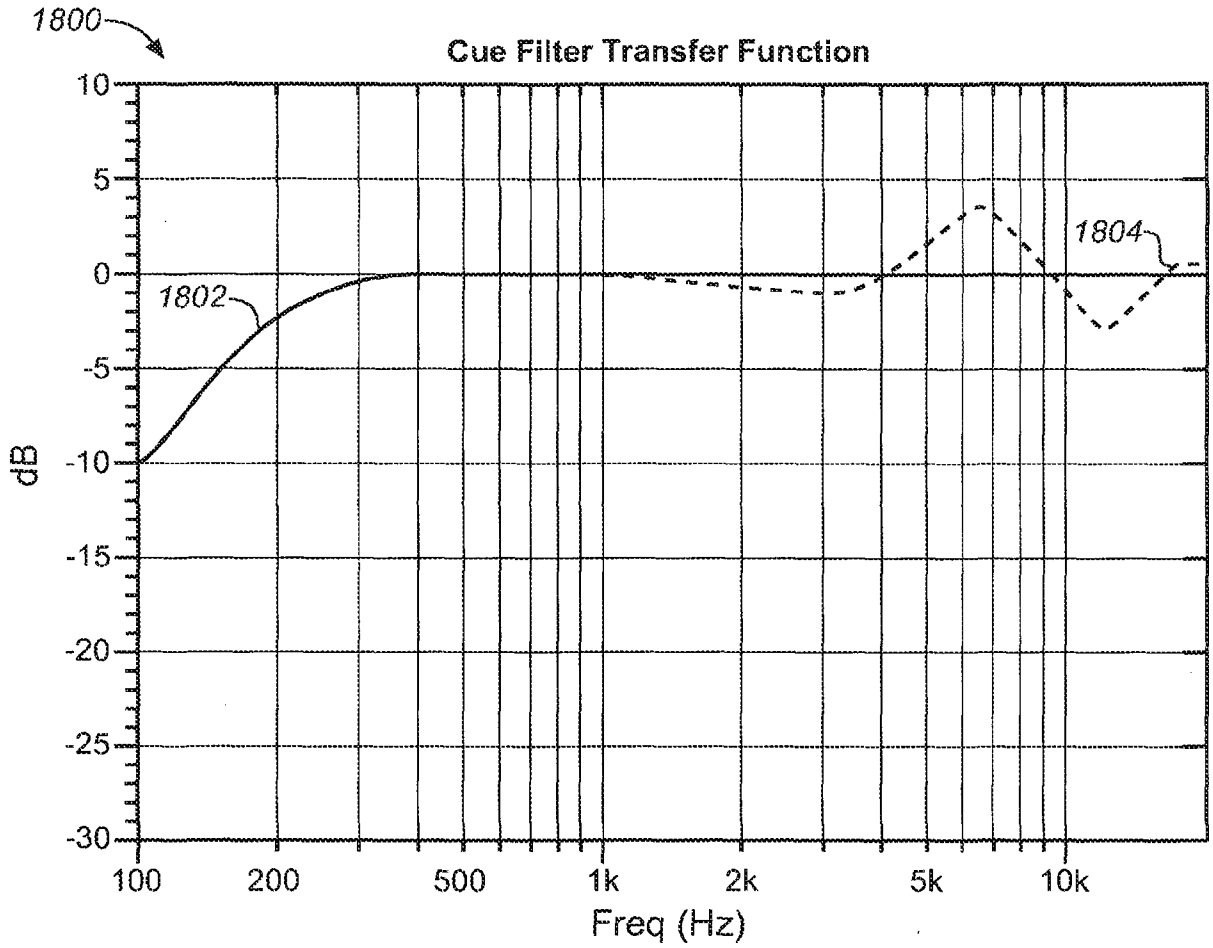

1800
Cue Filter Transfer Function
10
5
0
-5
-10
-15
-20
-25
-30
dB
1802
1804
100
200
500
1k
2k
5k
10k
Freq (Hz)

FIG. 18

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- US 61749789 B **[0001]**
- US 61835466 B **[0001]**
- US 61914854 B **[0001]**
- JP 2010258653 B **[0010]**
- US 61636429 B **[0017]**

Virtuális magasság szűrő visszavert hang létrehozásához felfelé irányított hangszórók használatával

Szabadalmi igénypontok

1. Hangsugárzó hangszóró hang létrehozásához, egy lehallgatási környezet felső felületéről való visszaverődés céljára, a hangszóró tartalmaz:

egy hangszóró membránt,

SZTNH-100025692

a hangszóró középső részéhez rögzített membrán porsapkát; és

a membránt rögzítő kosarat annak egy hangsugárzó házba való beszereléshez, ahol a hangszóró membrán, porsapka és kosár közül legalább egy úgy van konfigurálva, hogy egy olyan frekvenciamenetű magasság szűrőként hasson, amely úgy van konfigurálva, hogy legalább részben megszüntesse az egy hangszóró elhelyezésből fakadó irány jelzéseket, és legalább részben egy visszavert hangszóró elhelyezésből fakadó irány jelzéseket illesszen be, ahol a frekvenciamenet a következőkön alapul:

egy olyan szűrő egy első frekvenciamenetén, mely szűrő a visszavert hangszóró elhelyezéstől egy lehallgatási pozícióban elhelyezkedő hallgató füleihez közvetlenül eljutó hangot modellez a visszavert hangszóró elhelyezésből fakadó irány jelzések említett beillesztése céljából, és

egy olyan szűrő egy második frekvenciamenetén, mely szűrő az egy hangszóró elhelyezéstől közvetlenül egy lehallgatási pozícióban elhelyezkedő hallgató füleihez eljutó hangot modellez, a hallgatóhoz a hangszóró elhelyezéstől közvetlenül vezető útvonal mentén eljutó hang irány jelzéseinek eltávolítása céljából.

2. Az 1. igénypont szerinti hangszóró, ahol a frekvenciamenet egy olyan univerzális magasság szűrő frekvenciamenet, amely több egyedi magasság szűrő frekvenciagörbék átlagát jelenti, ahol minden egyes egyedi magasság szűrő frekvenciamenet egy-egy eltérő visszavert hangszóró elhelyezés, lehallgatási pozíció és fizikai hangszóró elhelyezés kombinációhoz tartozik.

3. A 2. igénypont szerinti hangszóró, ahol a magasság szűrő frekvenciamenet 7 kHz környéki csúccsal és 12 kHz környéki völggyel rendelkezik.

4. Rendszer hang létrehozására visszavert hang elemek használatával, amely tartalmaz:

egy hangsugárzó helyen elhelyezett hangsugárzót, amely az alapsíkhoz képest ferde szögben irányított, felfelé sugárzó hangszórót magában foglaló házat tartalmaz, és amely úgy van konfigurálva, hogy egy lehallgatási környezet egy felső felületéről hangot verjen vissza egy visszavert hangsugárzó elhelyezés létrehozásához; és

a felfelé sugárzó hangszóróhoz eljuttatott audió jelre egy frekvenciamenetet alkalmazó virtuális magasság szűrőt, ahol a virtuális magasság szűrő legalább részben megszünteti az egy hangszóró elhelyezésből fakadó irány jelzéseket, és legalább részben egy visszavert hangszóró elhelyezésből fakadó irány jelzéseket illeszt be, ahol a frekvenciamenet a következőkön alapul:

egy olyan szűrő egy első frekvenciamenetén, mely szűrő a visszavert hangszóró elhelyezéstől egy lehallgatási pozícióban elhelyezkedő hallgató füleihez közvetlenül eljutó hangot modellez a visszavert hangszóró elhelyezésből fakadó irány jelzések említett beillesztése céljából, és

egy olyan szűrő egy második frekvenciamenetén, mely szűrő az egy hangszóró elhelyezéstől közvetlenül egy lehallgatási pozícióban elhelyezkedő hallgató füléhez eljutó hangot modellez, a hallgatóhoz a hangszóró elhelyezéstől közvetlenül vezető útvonal mentén eljutó hang irány jelzéseinek eltávolítása céljából.

5. A 4. igénypont szerinti rendszer, ahol a frekvenciamenet egy olyan univerzális magasság szűrő frekvenciamenet, amely több egyedi magasság szűrő frekvenciagörbék átlagát jelenti, ahol minden egyes egyedi magasság szűrő frekvenciamenet egy-egy eltérő visszavert hangszóró elhelyezés, lehallgatási pozíció és fizikai hangszóró elhelyezés kombinációhoz tartozik.

6. Az 5. igénypont szerinti rendszer, ahol a magasság szűrő frekvenciamenet 7 kHz környéki csúccsal és 12 kHz környéki völggyel rendelkezik.

7. A 4. igénypont szerinti rendszer, ahol a dőlésszög változtatható, és a rendszer tartalmaz továbbá:

egy hely összetevőt, amely úgy van konfigurálva, hogy egy optimális lehallgatási pozíciót határozzon meg a lehallgatási környezeten belül;

egy kommunikációs összetevőt, amely úgy van konfigurálva, hogy az optimális lehallgatási pozíciót közölje a hangsugárzóval; és

egy vezérlő összetevőt, amely úgy van konfigurálva, hogy megváltoztassa a dőlésszöget, hogy visszaverje a hanghullámokat a felső felületről az optimális lehallgatási pozícióba.

8. A 4. igénypont szerinti rendszer, amely tartalmaz továbbá:

egy detektáló összetevőt, amely úgy van konfigurálva, hogy detektálja a virtuális magasság szűrő jelenlétét a lehallgatási környezetben,

vagy

egy megkerülő kapcsolót a virtuális magasság szűrő egy kalibrálási művelet alatti megkerülésére, amely felkészíti az audió lejátszó készüléket a hanghullámok eljuttatására a lehallgatási környezethez.

9. A 4. igénypont szerinti rendszer, amely továbbá egy olyan helyiségkorrekciós összetevőt tartalmaz, amely vagy:

egy előkiemelő szűrési műveletet hajt végre a lehallgatási környezethez továbbított hanghullámokon, hogy kompenzálja a felfelé sugárzó hangszóróhoz eljuttatott jelen alkalmazott virtuális magasság szűrő hatását, vagy

előállítja a lehallgatási környezet cél frekvenciamenetét egy vizsgálójel használata, és egy alapértelmezett virtuális magasság szűrő frekvenciamenet lehallgatási környezet cél frekvenciamenetéhez történő hozzáadása révén.

10. A 4. igénypont szerinti rendszer, ahol a virtuális magasság szűrő egy algoritmust valósít meg, ahol egy skálázási tényezőt használ, hogy kompenzálja a lehallgatási környezeten át közvetlenül eljutó hanghullámokban jelen lévő magasság jelzéseket a lehallgatási környezet felső felületéről visszaverti hangban jelen lévő magasság jelzések javára, és opcionálisan

ahol a virtuális magasság szűrő egy egyedi frekvenciamenetet jelent, és

ahol a frekvenciamenet egy vagy több jellemzője a dőlésszög értéke alapján módosított.

11. A 4. igénypont szerinti rendszer, ahol a ház tartalmaz továbbá egy előre sugárzó hangszórót, amely úgy van konfigurálva, hogy egy hozzávetőlegesen az alapsíkhoz igazodó tengely mentén bocsásson ki hanghullámokat.

12. A 11. igénypont szerinti rendszer, ahol a hangsugárzó két bemeneti csatlakozót tartalmaz, ahol az első bemeneti csatlakozó úgy van konfigurálva, hogy a lehallgatási környezet felső felületéről visszaverendő hanghoz tartozó jeleket vegyen, és a második bemeneti csatlakozó úgy van konfigurálva, hogy a közel az alapsíkhoz igazodó tengely mentén eljuttatandó hanghullámokhoz tartozó jeleket vegyen.

13. A 11. igénypont szerinti rendszer, ahol a rendszer továbbá keresztváltó szűrőt tartalmaz, a keresztváltó szűrőnek van egy aluláteresztő szakasza, amely úgy van konfigurálva, hogy egy küszöbérték frekvencia alatti kisebb frekvenciás jeleket az előresugárzó hangszóróhoz juttassa, és egy felüláteresztő szakasza, amely úgy van konfigurálva, hogy a küszöbérték frekvencia feletti nagyobb frekvenciás jeleket a felfelé sugárzó hangszóróhoz juttassa.

14. Hangsugárzó egy lehallgatási környezet felső felületéről visszaverendő hanghullámok adására, a hangsugárzó tartalmaz:

egy házat,

egy a házon belüli felfelé sugárzó, egy alapsíkhoz képest ferde szögben irányított hangszórót, amely úgy van konfigurálva, hogy a lehallgatási környezet felső felületének egy visszaverődési pontjáról hangot verjen vissza; és

a felfelé sugárzó hangszóróhoz eljuttatott audió jelre egy frekvenciamenetet alkalmazó virtuális magasság szűrőt, ahol a frekvenciamenet a következőkön alapul:

egy olyan szűrő egy első frekvenciamenetén, mely szűrő a visszavert hangszóró elhelyezéstől egy lehallgatási pozícióban elhelyezkedő hallgató füleihez közvetlenül eljutó hangot modellez a visszavert hangszóró elhelyezésből fakadó irány jelzések említett beillesztése céljából, és

egy olyan szűrő egy második frekvenciamenetén, mely szűrő az egy hangszóró elhelyezéstől közvetlenül egy lehallgatási pozícióban elhelyezkedő hallgató füleihez eljutó hangot modellez, a hallgatóhoz a hangszóró elhelyezéstől közvetlenül vezető útvonal mentén eljutó hang irány jelzéseinek eltávolítása céljából.

15. A 14. igénypont szerinti hangsugárzó, ahol a frekvenciamenet egy olyan univerzális magasság szűrő frekvenciamenet, amely több egyedi magasság szűrő frekvenciagörbék átlagát jelenti, ahol minden egyes egyedi magasság szűrő frekvenciamenet egy-egy eltérő visszavert hangszóró elhelyezés, lehallgatási pozíció és fizikai hangszóró elhelyezés kombinációhoz tartozik.

16. A 15. igénypont szerinti hangsugárzó, ahol a magasság szűrő frekvenciamenet 7 kHz környéki csúccsal és 12 kHz környéki völggyel rendelkezik.