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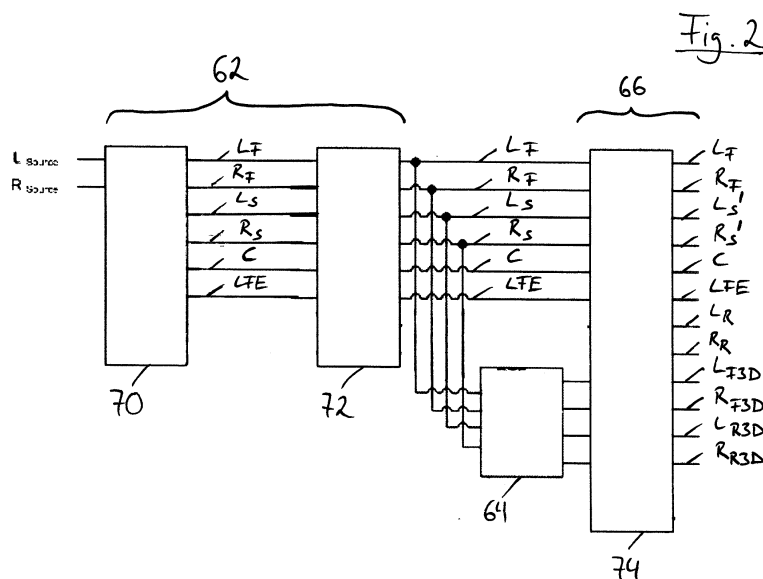
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(54) **Signal processing apparatus for a vehicle sound system and signal processing method for a vehicle sound system**

(57) A signal processing apparatus (6) for a vehicle sound system (2) includes a signal input section (62), through which in operation a multi-channel audio signal is provided, the multi-channel audio signal having at least a left front signal (L_F), a left surround signal (L_S), a right front signal (R_F) and a right surround signal (R_S), a room simulation module (64) adapted to receive the multi-channel audio signal and to generate at least a left 3D signal (L_{F3D}) and a right 3D signal (R_{F3D}), with the room simulation module (64) having a left room simulation

function generating the left 3D signal (L_{F3D}), with the left front signal (L_F) and the left surround signal (L_S) being inputs thereto, and a right room simulation function generating the right 3D signal (R_{F3D}), with the right front signal (R_F) and the right surround signal (R_S) being inputs thereto, and a signal output section (66) for outputting the left 3D signal (L_{F3D}) and the right 3D signal (R_{F3D}) to a left 3D speaker (25) and a right 3D speaker (26) disposed in an upper portion of a vehicle.



Description

[0001] The present invention is in the field of sound systems for passenger transport vehicles, such as cars, buses and trucks. In particular, the present invention is in the field of a signal processing apparatus for a vehicle sound system and a signal processing method for a vehicle sound system.

[0002] It has long been known in the art to equip passenger transport vehicles with sound systems. Such sound systems are in use for listening to music, news, audio books, audio documentaries and other audio content. As compared to home sound systems, the room acoustics inside a vehicle provide a perceived sound quality that is significantly more inferior to a perfect listening room. Accordingly, it would be beneficial to provide means for a vehicle sound system that increase the perceived sound quality / sound experience for the user and that, in particular, provides an improved sound quality for various different types of audio content.

[0003] Exemplary embodiments of the invention include a signal processing apparatus for a vehicle sound system, comprising a signal input section, through which in operation a multi-channel audio signal is provided, the multi-channel audio signal comprising at least a left front signal, a left surround signal, a right front signal and a right surround signal, a room simulation module adapted to receive the multi-channel audio signal and to generate at least a left 3D signal and a right 3D signal, with the room simulation module comprising a left room simulation function generating the left 3D signal, with the left front signal and the left surround signal being inputs thereto, and a right room simulation function generating the right 3D signal, with the right front signal and the right surround signal being inputs thereto, and a signal output section for outputting the left 3D signal and the right 3D signal to a left 3D speaker and a right 3D speaker disposed in an upper portion of a vehicle.

[0004] The signal processing apparatus performs an up-conversion of the multi-channel audio signal. It generates at least two 3D audio signals, namely at least the left 3D signal and the right 3D signal, in addition to the multi-channel audio signal. As the left 3D signal and the right 3D signal are provided in addition to the left front signal, the left surround signal, the right front signal and the right surround signal, and as these signals are output via speakers in an upper portion of the vehicle, the passenger's audio experience is more voluminous. The passenger has the impression that he/she is listening to the audio content in a larger space. The left 3D signal and the right 3D signal may also be referred to as a left 3D height signal and a right 3D height signal, because these signals create the perceived height of the listening room, when output via the speakers in the upper portion of the vehicle.

[0005] The left front signal and the left surround signal are separate inputs to the left room simulation function. Analogously, the right front signal and the right surround signal are separate inputs to the right room simulation function. With these signals being separate inputs, the room simulation functions are able to provide 3D sound that is adapted to the kind of audio content present. For example, with orchestra music having a large diffuse surround component, also referred to as uncorrelated sound component or reverb, the room simulation functions may provide strong 3D signals. In contrast thereto, in the example of the audio content being a news reader, which audio content typically has low or no reverb, the room simulation functions may provide weaker 3D signals. In this way, the signal processing apparatus allows for adding a high degree of 3D sound when appropriate in light of the type of audio content, while preventing an artificially sounding, excessive expansion of audio content when a large 3D sound component is not appropriate. At the same time, the signal processing apparatus allows for adding some 3D sound for all types of audio content, leading to an improved listening experience for all types of audio content. In other words, the signal processing apparatus may always add some 3D sound component, but only add a large amount of 3D sound component when appropriate in light of the type of audio content. This can all be done in a fairly simple way through a single set of room simulation functions. No explicit distinction between different kinds of audio content and no application of different room simulation functions for different kinds of audio content is necessary.

[0006] The room simulation functions simulate an auditory space. In other words, they add a simulated room effect to the multi-channel audio signal. They provide a simulated room transfer function to the multi-channel audio signal. While the room simulation functions rely on multiple inputs for adding the appropriate amount of room simulation, the overall perceived room is more than an extraction of particular signal components, such as reverb, from the source signal. The room simulation functions add a synthetic room which may depend in size and character on the room signal extracted from the original signal by the surround upmix at the input.

[0007] The left 3D speaker and the right 3D speaker are positioned in an upper portion of an interior space of a vehicle. They may be positioned towards the front of the interior space or towards the rear of the interior space. It is also possible that there are more than two 3D speakers, such as four 3D speakers. In that case, the signal processing apparatus may provide the same 3D signal to two 3D speakers, respectively, or may provide distinct signals to all four 3D speakers. The term 3D speaker refers to a speaker that emits sounds in an upper portion of a vehicle, such as above a passenger's ear level and/or above the other main loudspeakers.

[0008] The signal input section is coupled to the room simulation module. Further, the room simulation module is coupled to the signal output section. In addition, the signal output section may be coupled to the signal input section. In particular, the multi-channel audio signal may be provided directly from the signal input section to the signal output

section. The signal input section may comprise a first stage of signal processing. However, it is also possible that the signal input section is only provided for passing an audio signal on from an audio source.

[0009] The term speaker, as used throughout this disclosure, may refer to a single speaker, also referred to as loud-speaker. However, the term speaker may also refer to a set of speakers, covering different frequency ranges. For example, the term speaker may refer to a set of two speaker of selected frequencies. In particular, the term speaker may refer to the combination of a low frequency speaker and a high frequency speaker. It is equally possible that the term speaker refers to a set of three speakers, outputting low, medium and high frequencies, respectively. In the example of a right 3D speaker, it is possible that two or three speakers of different frequencies are provided in the right upper portion of the vehicle. These limited frequency speakers may be arranged in one housing or in separate housings in proximity of each other.

[0010] According to a further embodiment, the left room simulation function weighs the left front signal and the left surround signal differently and the right room simulation function weighs the right front signal and the right surround signal differently. In other words, the left room simulation function has different weighing coefficients for the inputs of the left front signal and the left surround signal. Analogously, the right room simulation function has different weighing coefficients for the right front signal and the right surround signal. The room simulation functions may then perform the room simulation on this weighed combination of the respective front and surround signals. This weighing of the front and surround signals provides for a fairly simple, closed implementation of the room simulation functions, applicable to all kinds of audio content.

[0011] According to a further embodiment, the left room simulation function comprises a left room simulation component calculated as $f_1(\alpha_1 * L_s + \beta_1 * L_F)$, with L_s denoting the left surround signal and L_F denoting the left front signal and with α_1 being greater than β_1 , and wherein the right room simulation function comprises a right room simulation component calculated as $f_2(\alpha_2 * R_s + \beta_2 * R_F)$, with R_s denoting the right surround signal and R_F denoting the right front signal and with α_2 being greater than β_2 . The given formulas with the given relationship between the weighing coefficients α and β allow for an optimized addition of room simulation, depending on the type of audio content, implemented as a single set of room simulation functions. The diffuse surround component is weighed stronger than the uncorrelated front signal. This leads to a very natural sound experience to the passenger, with the reverb portion of the multi-channel audio signal being the dominant portion in the processing and in the 3D speaker outputs. At the same time, a comparatively smaller 3D component is provided on the basis of the correlated front signal, leading to a voluminous sound experience also for highly correlated audio sources.

[0012] The expressions " f_1 " and " f_2 " refer to functions that simulate an auditory space, thus contributing a room simulation that is an addition as compared to the multi-channel audio signal and that cannot be merely extracted from the multi-channel audio signal. In a particular embodiment, f_1 and f_2 can be the same. In other words the left room simulation component may be calculated in accordance with the same function as the right room simulation component. However, it is also possible that f_1 and f_2 are different functions. Also, while it is possible that α_1 equals α_2 and/or that β_1 equals β_2 , it is also possible that α_1 is different from α_2 and/or that β_1 is different from β_2 . In a particular embodiment, α_1 is much greater than β_1 , i.e. more than 10 times greater. It is also possible that α_2 is much greater than β_2 , i.e. at least 10 times greater. Such a relationship between the weighing coefficients allows for a particularly good compromise between some added room simulation for all types of audio content and a strong addition of room simulation when appropriate in light of the type of audio content in question.

[0013] The left room simulation function may have the left room simulation component as the only signal component or may have other signal components, as discussed below. Analogously, the right room simulation function may have the right room simulation component as the only signal component or may have other signal components.

[0014] According to a further embodiment, the left room simulation function comprises the left front signal and/or the left surround signal as an additive term, weighed by a respective coefficient, and the right room simulation function comprises the right front signal and/or the right surround signal as an additive term, weighed by a respective coefficient. The expression "additive term" refers to a component that contributes to the room simulation functions purely by addition. In other words, it refers to a linear term. For this additive term, no function adding room simulation or any other simulation is applied to the front signal and/or surround signal. The inclusion of such an additive term results in a greater sound stability, increasing the ease of listening as compared to a pure room simulation component being output via the 3D speakers.

[0015] According to a further embodiment, the left room simulation function comprises a left sound stability component calculated as $(\gamma_1 * L_s + \delta_1 * L_F)$, with L_s denoting the left surround signal and L_F denoting the left front signal and with γ_1 being greater than δ_1 , and the right room simulation function comprises a right sound stability component calculated as $(\gamma_2 * R_s + \delta_2 * R_F)$, with R_s denoting the right surround signal and R_F denoting the right front signal and with γ_2 being greater than δ_2 . In this way, both the respective front signal as well as the respective surround signal are included into the room simulation functions in a linear manner. Accordingly, above described addition of stability may be implemented in a straightforward manner on the basis of the same front signal and surround signal inputs, without a distinction with respect to the type of audio content being necessary. With the surround signal being weighed stronger than the front

signal, a hollow overall sound due to the front signal being output from the upper portion of the vehicle in a dominant manner is prevented. In a particular embodiment γ_1 is much greater than δ_1 , i.e. at least 10 times greater. It is also possible that γ_2 is much greater than δ_2 , i.e. at least 10 times greater. Again, it is possible that γ_1 and γ_2 are the same or different and that δ_1 and δ_2 are the same or different.

[0016] According to a further embodiment, α_1 , α_2 , β_1 and β_2 are greater than γ_1 , γ_2 , δ_1 and δ_2 . In this way, it may be ensured that the respective room simulation components are greater than the respective sound stability components. In particular, α_1 , α_2 , β_1 and β_2 may be much greater than γ_1 , γ_2 , δ_1 and δ_2 , i.e. at least 10 times greater. However, it is also possible that the particular implementations of f_1 and f_2 ensure that the room simulation components are greater than the sound stability components.

[0017] According to a further embodiment, the left room simulation function comprises a left room simulation component and a left sound stability component, with the left room simulation component being greater than the left sound stability component, and wherein the right room simulation function comprises a right room simulation component and a right sound stability component, with the right room simulation component being greater than the right sound stability component. In this way, a comparatively larger room simulation component is combined with a comparatively smaller sound stability component, thus allowing for a dominant 3D room simulation, while at the same time ensuring a relaxing listening experience to the passenger. In a particular embodiment, the respective room simulation components may be much greater than the respective sound stability components, i.e. at least 10 times greater. The comparison between the components may be carried out on the basis of the component amplitudes or component powers or any other suitable metric. In a particular embodiment, the respective room simulation functions may consist of the respective room simulation component and the respective sound stability component. In other words, the respective room simulation and sound stability components may be the only components of the room simulation function in question.

[0018] According to a further embodiment, the left and right room simulation functions are configured to simulate an auditory space that is larger than an interior space of a vehicle. In this way, the vehicle sound system makes the passenger feel like he is listening to the audio content in a room that is larger than the actual interior of the vehicle. In this way, superior acoustics can be simulated than can be achieved within the interior of the vehicle with prior art sound systems. In particular, the left and right room simulation functions may be adapted to simulate the reverb generated in an enclosed space when an audio source is played. In a particular embodiment, the left and right room simulation functions are configured to simulate an ideal auditory space. In a further particular embodiment, the left and right room simulation functions are configured to simulate an ideal auditory space of 4m x 6m x 2.5m.

[0019] According to a further embodiment, the left 3D signal is a left front 3D signal and the right 3D signal is a right front 3D signal. Accordingly, the left 3D signal and the right 3D signal may be provided to the signal output section for being output to a left front 3D speaker and to a right front 3D speaker. Accordingly, the left 3D speaker may be a left front 3D speaker and the right 3D speaker may be a right front 3D speaker.

[0020] According to a further embodiment, the room simulation module further comprises a left rear room simulation function generating a left rear 3D signal, with the left front signal and the left surround signal being inputs thereto, and a right rear room simulation function generating a right rear 3D signal, with the right front signal and the right surround signal being inputs thereto. In this way, front and rear signals are generated in the third dimension, leading to a surrounding of the passenger with speakers from all sides. In other words, an additional stereo surround sound is created in the upper portion of the vehicle, leading to an even more voluminous listening experience. The left rear 3D signal and the right rear 3D signal may be output to a left rear 3D speaker and a right rear 3D speaker. Accordingly, the output signal section may be configured for outputting the left rear 3D signal and the right rear 3D signal to a left rear 3D speaker and a right rear 3D speaker.

[0021] Above discussed features and modifications of the left room simulation function and the right room simulation function can be implemented with respect to the left rear room simulation function and the right rear room simulation function in an analogous manner. According to a further embodiment, the left 3D signal is a left rear 3D signal and the right 3D signal is a right rear 3D signal. Accordingly it is also possible that the room simulation is implemented via rear speakers in the upper portion of the vehicle, in particular only via rear speakers in the upper portion of the vehicle.

[0022] According to a further embodiment, the multi-channel audio signal is an input signal stemming from an audio source. For example, the vehicle sound system may comprise a DVD drive or CD drive or a hard disk drive or any other suitable means for reading out a memory containing the audio source signal. It is also possible that the audio source signal is transferred to the vehicle in a wireless manner. Notwithstanding which source the audio input signal is coming from, the input signal may be a multi-channel signal that already contains the left front signal, the left surround signal, the right front signal, and the right surround signal. An example for such an input signal is a 5.1 surround sound signal. It is also possible that the input signal is a different kind of multi-channel audio signal having above discussed four signals.

[0023] According to an alternative embodiment, the input signal section comprises an audio signal conversion module, with the audio signal conversion module being adapted to generate the multi-channel audio signal from an input signal missing at least one of the left front signal, the left surround signal, the right front signal and the right surround signal, such as from a two-channel stereo input signal. In this way, the room simulation module can also be put to use for audio

source signals that lack one of above discussed four signals. In particular, the audio signal conversion module may be adapted to extract a left surround signal and a right surround signal from a two-channel stereo input signal. Accordingly, above-discussed features of room simulation simulation can be achieved via subsequent operations of audio signal conversion and room simulation generation. For this purpose, the audio signal conversion module may be coupled to the room simulation module, either directly or via other signal processing modules, such as via a volume and/or fading and/or balance adaptation module. With an appropriate audio signal conversion module, any kind of audio source can be pre-processed for the ensuing room simulation simulation by the room simulation module. For example, the audio source may be any of a 1.0 mono source, a 2.0 stereo source, a 5.1 surround source, a 5.2 surround source, a 7.1 surround source or any other audio source. In an exemplary embodiment, the audio signal conversion module may be implemented in any of the manners described in EP 1 722 598 A2 with respect to the audio device of said document. The contents of said document is incorporated herein in its entirety.

[0024] Exemplary embodiments of the invention further include a vehicle sound system comprising a plurality of speakers, the plurality of speakers comprising a left 3D speaker and a right 3D speaker, the left 3D speaker and the right 3D speaker being configured to be disposed in an upper portion of a vehicle, the vehicle sound system further comprising a signal processing apparatus in accordance with any of the embodiments described above, with the signal processing apparatus being coupled to the left 3D speaker and the right 3D speaker for outputting the left 3D signal and the right 3D signal thereto. The additional features and modifications described above with respect to the signal processing apparatus may equally be applied to the vehicle sound system. Above discussed advantages are also attainable with the vehicle sound system.

[0025] The plurality of speakers of the vehicle sound system may comprise a left front speaker, a left surround speaker, a right front speaker, a right surround speaker. It may also include additional speaker, such as a center front speaker, a subwoofer, left and right rear speakers. The left and right 3D speakers may be left and right front 3D speakers or left and right rear 3D speakers. It is also possible that the vehicle sound system has left and right front 3D speakers as well as left and right rear 3D speakers. The signal processing apparatus may be coupled to all speakers present in the vehicle sound system. The vehicle sound system may also comprise an audio source reading apparatus, such as a CD player or DVD player or hard disk drive, and/or an audio signal reception apparatus, such as a radio receiver.

[0026] Exemplary embodiments of the invention further include a passenger transport vehicle, such as a car, bus or truck, comprising a vehicle sound system, as described above, which includes a signal processing apparatus, as described in any of the embodiments above, with the vehicle sound system being installed in the passenger transport vehicle with the left 3D speaker and the right 3D speaker being disposed in an upper portion of the passenger transport vehicle. The additional features and modifications described above with respect to the signal processing apparatus and with respect to the vehicle sound system may equally be applied to the passenger transport vehicle. Above discussed advantages are also attainable with the passenger transport vehicle.

[0027] Exemplary embodiments of the invention further include a signal processing method for a vehicle sound system, the method comprising the steps of receiving a multi-channel audio signal comprising at least a left front signal, a left surround signal, a right front signal and a right surround signal, generating at least a left 3D signal and a right 3D signal for providing a room simulation by the vehicle sound system, with the left front signal and the left surround signal being inputs to a left room simulation function that generates the left 3D signal and with the right front signal and the right surround signal being inputs to a right room simulation function that generates the right 3D signal, and outputting the left 3D signal and the right 3D signal to a left 3D speaker and a right 3D speaker disposed in an upper portion of a vehicle. The additional features and modifications described above with respect to the signal processing apparatus may equally be applied to the signal processing methods. According modifications of the signal processing methods are herewith disclosed. Above discussed advantages are also attainable with the signal processing method.

[0028] Embodiments of the invention are described in greater detail below with reference to the figures, wherein:

Fig. 1 shows a perspective schematic view of an exemplary vehicle having an exemplary vehicle sound system in accordance with the invention installed therein.

Fig. 2 shows a block diagram of an exemplary signal processing apparatus in accordance with the invention.

[0029] Fig. 1 shows a perspective schematic diagram of a passenger transport vehicle 4, having a vehicle sound system 2 in accordance with an exemplary embodiment of the invention. The vehicle sound system 2 comprises twelve speakers. In particular, the vehicle sound system comprises a left front speaker 21, a left rear speaker 31, a left surround speaker 23, a right front speaker 22, a right rear speaker 32, a right surround speaker 24, a left front 3D speaker 25, a right front 3D speaker 26, a left rear 3D speaker 27, a right rear 3D speaker 28, a center front speaker 29, and a subwoofer 30. All of these speakers are coupled to a signal processing apparatus 6 by individual signal lines (shown in dashed lines in Fig. 1). It is also possible that all of the speakers 21-32 and the signal processing apparatus 6 are coupled via a bus architecture or any other means of signal communication.

[0030] The vehicle sound system 2 may comprise an audio signal receiving apparatus, such as a tuner, for receiving wireless audio source signals, such as radio broadcast waves or any other kind of signal / data transmission. Additionally/alternatively, it is possible that the vehicle sound system 2 is coupled to an audio source reading apparatus, such as a CD player or a DVD player or a hard disk drive or any other kind of signal / data storage device. The audio signal receiving apparatus and/or the audio source reading apparatus may be coupled to the signal processing apparatus 6 for providing the audio source signal to the signal processing apparatus 6. No matter what the audio source is, the signal processing apparatus is adapted to receive the audio source signal and to generate respective output signals for the plurality of speakers.

[0031] Fig. 2 shows a signal processing apparatus 6 in accordance with an exemplary embodiment of the invention. The signal processing apparatus 6 comprises a signal input section 62, a room simulation module 64, and a signal output section 66. The exemplary signal processing apparatus 6 is described with a stereo signal being the audio source, which consists of the left source signal L_{Source} and the right source signal R_{Source} , and with the output signal consisting of twelve signals for being output to the twelve speakers of the vehicle 4 described above.

[0032] The signal input section 62 comprises an audio signal conversion module 70 and an audio signal conditioning module 72. The audio signal conversion module 70 performs an up-conversion of the two-channel stereo input signal. In particular, the audio signal conversion module 70 generates a left front signal L_F , a right front signal R_F , a left surround signal L_S , a right surround signal R_S , a center front signal C and a subwoofer signal LFE (with LFE denoting "low frequency effects"). Such up-conversion of a two-channel stereo signal into a 5.1 surround signal via the audio signal conversion module 70 is per se known in the art.

[0033] The up-converted audio signal is then input into the audio signal conditioning module 72. The audio signal conditioning module 72 is configured to adapt the volume, fading, balance and subwoofer levels of the audio signals. Such signal conditioning is also per se known in the art. Depending on the complexity of the vehicle sound system, the audio signal conditioning module 72 may have different functionality and different degrees of signal conditioning. It is also possible that the audio signal conditioning module 72 is dispensed with and that only a simple volume scaling takes place. The only essential aspect with respect to the signal input section 62 is that a multi-channel signal is provided via the signal input section, which multi-channel audio signal contains a left front signal, a left surround signal, a right front signal and a right surround signal. If the audio source already provides such multi-channel audio signal, such as a 5.1 surround signal, the signal input section may consist of a mere passing on of the source signal.

[0034] The room simulation module 64 is coupled to the signal input section 62 in such a way that the left front signal L_F , the left surround signal L_S , the right front signal R_F and the right surround signal R_L are provided by the signal input section 62 to the room simulation module 64. Based on these four signals, the room simulation module 64 generates four 3D signals, which are configured to be output to four speakers disposed in the upper portion of the vehicle. In particular, the room simulation module 64 generates a left front 3D signal, a right front 3D signal, a left rear 3D signal and a right rear 3D signal. These four 3D signals are generated by the room simulation module 64 in the manner described below.

[0035] The left front 3D signal L_{F3D} is generated by a left front room simulation function in accordance with the following formula:

$$L_{F3D} = f_1(\alpha_1 * L_S + \beta_1 * L_F) + (\gamma_1 * L_S + \delta_1 * L_F).$$

[0036] The right front 3D signal R_{F3D} is generated by a right front room simulation function in accordance with the following formula:

$$R_{F3D} = f_2(\alpha_2 * R_S + \beta_2 * R_F) + (\gamma_2 * R_S + \delta_2 * R_F).$$

[0037] The left rear 3D signal L_{R3D} is generated by a left rear room simulation function in accordance with the following formula:

$$L_{R3D} = f_3(\alpha_3 * L_S + \beta_3 * L_F) + (\gamma_3 * L_S + \delta_3 * L_F).$$

[0038] The right rear 3D signal R_{R3D} is generated by a right rear room simulation function in accordance with the following formula:

$$R_{R3D} = f_4(\alpha_4 * R_S + \beta_4 * R_F) + (\gamma_4 * R_S + \delta_4 * R_F).$$

[0039] The parameters α_x , β_x , γ_x and δ_x are weighing coefficients that allow for a relative scaling of the impact of the left front signal L_F , the left surround signal L_S , the right front signal R_F and the right surround signal R_S on the respective 3D signal. In the exemplary embodiment described, α_x is much greater than β_x , in particular at least 10 times greater, for x being 1, 2, 3 and 4. Also, in the exemplary embodiment described, γ_x is much greater than δ_x , in particular at least 10 times greater, for x being 1, 2, 3 and 4. In the exemplary embodiment of Fig. 2, α_x and β_x are greater than γ_x and δ_x , in particular much greater, i.e. at least 10 times greater, for x being 1, 2, 3 and 4.

[0040] The four room simulation functions given above each comprise a room simulation component and a sound stability component. The room simulation components are calculated via the functions f_1 , f_2 , f_3 and f_4 . These functions simulate an auditory space. In particular, the functions f_1 , f_2 , f_3 and f_4 are adapted - on the basis of the weighed inputs - to mimic the audio experience a listener would have in a space that is larger than the interior of the passenger transport vehicle. In particular, the functions f_1 , f_2 , f_3 and f_4 may be configured to generate the reverb that would be generated by the structure of an enclosed room. In particular, the functions f_1 , f_2 , f_3 and f_4 may simulate an ideal auditory space, such as an auditory space of 4m x 6m x 2.5m.

[0041] The respective sound stability components consist of an addition of the respective left or right surround signal and of the respective left or right front signal, weighed by a respective weighing coefficient γ_x or δ_x . No further function apart from the weighing coefficients is applied to the inputs for the sound stability components.

[0042] In this way, multiple effects are achieved, as already discussed in detail above. As the room simulation is dependent on both the respective surround signal and the respective front signal and as these two inputs are weighed differently, an appropriate room simulation is generated for all types of audio content. Audio content with a large surround sound component, such as orchestra music, leads to strong 3D signals, i.e. to a strong room simulation. In this way, an appropriate amount of 3D simulation is presented to the listener. In contrast thereto, for audio content not having a large surround component, such as news speakers or similar content, the room simulation functions generate a lower amount of room simulation. This lower amount of room simulation ensures that the news speaker is not perceived as talking in a large hall with a lot of echo effect on the one hand. On the other hand, the generation of a comparatively low level of room simulation still provides for a voluminous sound experience in the vehicle environment.

[0043] The signal output section 66 is coupled to both the signal input section 62 and the room simulation module 64. It is configured to receive the left front signal, the left surround signal, the right front signal, the right surround signal, the center front signal and the subwoofer signal from the input section 62. Further, it is configured to receive above discussed four 3D signals, namely the left front 3D signal L_{F3D} , the right front 3D signal R_{F3D} , the left rear 3D signal L_{R3D} , and right rear 3D signal R_{R3D} from the room simulation module 64. The signal output section 66 is provided for outputting twelve signals to the respective speakers in the passenger transport vehicle.

[0044] In the exemplary embodiment of Fig. 2, the signal output section 66 comprises a mixer module 74. This mixer module 74 allows for a combining or shuffling of the signals before being output to the speakers. In the exemplary embodiment of Fig. 2, the mixer module 74 passes some of the signals on and generates some signals by combination. In particular, the mixer module 74 passes on the left front signal L_F , the right front signal R_F , the center front signal C , the subwoofer signal LFE , the left front 3D signal L_{F3D} , the right front 3D signal R_{F3D} , the left rear 3D signal L_{R3D} , and right rear 3D signal R_{R3D} to the left front speaker 21, the right front speaker 22, the center front speaker 29, the subwoofer 30, the left front 3D speaker 25, the right front 3D speaker 26, the left rear 3D speaker 27, and the right rear 3D speaker 28, respectively. The mixer module 74 further generates an updated left surround signal L_S' , an updated right surround signal R_S' , a left rear signal L_R , and a right rear signal R_R . The updated left surround signal L_S' , the updated right surround signal R_S' , the left rear signal L_R , and the right rear signal R_R are output to the left surround speaker 23, the right surround speaker 24, the left rear speaker 31, and the right rear speaker 31. These signals are generated in accordance with the following formulas:

$$L_S' = (\alpha_5 * L_S + \beta_5 * L_F);$$

$$R_S' = (\alpha_6 * R_S + \beta_6 * R_F);$$

$$L_R = (\alpha_7 * L_S + \beta_7 * L_F);$$

$$R_R = (\alpha_8 * R_S + \beta_8 * R_F);$$

[0045] In the exemplary embodiment of Fig. 2, α_x is much greater than β_x , in particular at least 10 times greater, for x being 5 and 6. In this way, the updated surround signals L_S' and R_S' are dominated by the surround signals L_S and R_S , but have a slight component of the respective front signal L_F and R_F for a more voluminous sound experience. In the exemplary embodiment of Fig. 2, α_x and β_x are comparable in magnitude, i.e. they are less than a factor 10 different, in particular less than a factor 5 different, even more in particular less than a factor 2 different, for x being 7 and 8. In this way, the sound from the left and right rear speakers 31 and 32 provides for a natural sound experience between the left and right front speakers 21 and 22 on the one side and the left and right surround speaker 23 and 24 on the other side.

[0046] It is pointed out that the combining or shuffling provided by the mixer module 74 may be desirable in some application scenarios. However, it is also possible that the mixer module 74 be dispensed with, and that the audio signals may be passed on to the speakers as they are. In this case, it is for example possible to pass on the left surround signal L_S and the right surround signal R_S to the left and right surround speakers 23 and 24, as they are. It is further for example possible to provide the rear speakers 31 and 32 with the respective surround signals L_S and R_S or with the respective front signals L_F and R_F . In general, it is possible that the signal output section 66 is provided for passing on the audio signals to the speakers only.

[0047] The signal input section, the room simulation module, and the signal output section may be implemented in any appropriate manner. They may be implemented in hardware, such as in digital signal processing components. They may also be implemented in software or in any appropriate combination of hardware and software.

Claims

1. Signal processing apparatus (6) for a vehicle sound system (2), comprising:

a signal input section (62), through which in operation a multi-channel audio signal is provided, the multi-channel audio signal comprising at least a left front signal (L_F), a left surround signal (L_S), a right front signal (R_F) and a right surround signal (R_S),

a room simulation module (64) adapted to receive the multi-channel audio signal and to generate at least a left 3D signal (L_{F3D}) and a right 3D signal (R_{F3D}), with the room simulation module (64) comprising a left room simulation function generating the left 3D signal (L_{F3D}), with the left front signal (L_F) and the left surround signal (L_S) being inputs thereto, and a right room simulation function generating the right 3D signal (R_{F3D}), with the right front signal (R_F) and the right surround signal (R_S) being inputs thereto, and

a signal output section (66) for outputting the left 3D signal (L_{F3D}) and the right 3D signal (R_{F3D}) to a left 3D speaker (25) and a right 3D speaker (26) disposed in an upper portion of a vehicle.

2. Signal processing apparatus (6) according to claim 1, wherein the left room simulation function weighs the left front signal (L_F) and the left surround signal (L_S) differently and wherein the right room simulation function weighs the right front signal (R_F) and the right surround signal (R_S) differently.

3. Signal processing apparatus (6) according to claim 1 or 2, wherein the left room simulation function comprises a left room simulation component calculated as $f_1(\alpha_1 * L_S + \beta_1 * L_F)$, with L_S denoting the left surround signal and L_F denoting the left front signal and with α_1 being greater than β_1 , and wherein the right room simulation function comprises a right room simulation component calculated as $f_2(\alpha_2 * R_S + \beta_2 * R_F)$, with R_S denoting the right surround signal and R_F denoting the right front signal and with α_2 being greater than β_2 .

4. Signal processing apparatus (6) according to any of the preceding claims, wherein the left room simulation function comprises the left front signal (L_F) and/or the left surround signal (L_S) as an additive term, weighed by a respective coefficient, and wherein the right room simulation function comprises the right front signal (R_F) and/or the right surround signal (R_S) as an additive term, weighed by a respective coefficient.

5. Signal processing apparatus (6) according to any of the preceding claims, wherein the left room simulation function comprises a left sound stability component calculated as $(\gamma_1 * L_S + \delta_1 * L_F)$, with L_S denoting the left surround signal and L_F denoting the left front signal and with γ_1 being greater than δ_1 , and wherein the right room simulation function comprises a right sound stability component calculated as $(\gamma_2 * R_S + \delta_2 * R_F)$, with R_S denoting the right surround signal and R_F denoting the right front signal and with γ_2 being greater than δ_2 .
6. Signal processing apparatus (6) according to any of the preceding claims, wherein the left room simulation function comprises a left room simulation component and a left sound stability component, with the left room simulation component being greater than the left sound stability component, and wherein the right room simulation function comprises a right room simulation component and a right sound stability component, with the right room simulation component being greater than the right sound stability component.
7. Signal processing apparatus (6) according to any of the preceding claims, wherein the left and right room simulation functions are configured to simulate an auditory space that is larger than an interior space of a vehicle.
8. Signal processing apparatus (6) according to any of the preceding claims, wherein the left room simulation function is a left front room simulation function, wherein the right room simulation function is a right front room simulation function, wherein the left 3D signal (L_{F3D}) is a left front 3D signal and wherein the right 3D signal (R_{F3D}) is a right front 3D signal.
9. Signal processing apparatus (6) according to claim 8, wherein the room simulation module (64) further comprises a left rear room simulation function generating a left rear 3D signal (L_{R3D}), with the left front signal (L_F) and the left surround signal (L_S) being inputs thereto, and a right rear room simulation function generating a right rear 3D signal (R_{R3D}), with the right front signal (R_F) and the right surround signal (R_S) being inputs thereto.
10. Signal processing apparatus (6) according to any of claims 1 to 7, wherein the left 3D signal is a left rear 3D signal and wherein the right 3D signal is a right rear 3D signal.
11. Signal processing apparatus (6) according to any of the preceding claims, wherein the multi-channel audio signal is an input signal stemming from an audio source.
12. Signal processing apparatus (6) according to any of claims 1 to 10, wherein the input signal section (62) comprises an audio signal conversion module (70), with the audio signal conversion module (70) being adapted to generate the multi-channel audio signal from an input signal missing at least one of the left front signal, the left surround signal, the right front signal and the right surround signal, such as from a two-channel stereo input signal.
13. Vehicle sound system (2) comprising a plurality of speakers, the plurality of speakers comprising a left 3D speaker (25) and a right 3D speaker (26), the left 3D speaker (25) and the right 3D speaker (26) being configured to be disposed in an upper portion of a vehicle (4),
the vehicle sound system (2) further comprising a signal processing apparatus (6) according to any of the preceding claims, with the signal processing apparatus (6) being coupled to the left 3D speaker (25) and the right 3D speaker (26) for outputting the left 3D signal (L_{F3D}) and the right 3D signal thereto (R_{F3D}).
14. Passenger transport vehicle (4), such as a car, bus or truck, comprising a vehicle sound system (2) according to claim 13, the vehicle sound system (2) being installed in the passenger transport vehicle with the left 3D speaker (25) and the right 3D speaker (26) being disposed in an upper portion of the passenger transport vehicle (4).
15. Signal processing method for a vehicle sound system, the method comprising the steps of:
receiving a multi-channel audio signal comprising at least a left front signal (L_F), a left surround signal (L_S), a right front signal (R_F) and a right surround signal (R_S),
generating at least a left 3D signal (L_{F3D}) and a right 3D signal (R_{F3D}) for providing a room simulation by the vehicle sound system, with the left front signal (L_F) and the left surround signal (L_S) being inputs to a left room simulation function that generates the left 3D signal (L_{F3D}) and with the right front signal (R_F) and the right surround signal (R_S) being inputs to a right room simulation function that generates the right 3D signal (R_{F3D}), and
outputting the left 3D signal (L_{F3D}) and the right 3D signal (R_{F3D}) to a left 3D speaker (25) and a right 3D speaker (26) disposed in an upper portion of a vehicle.

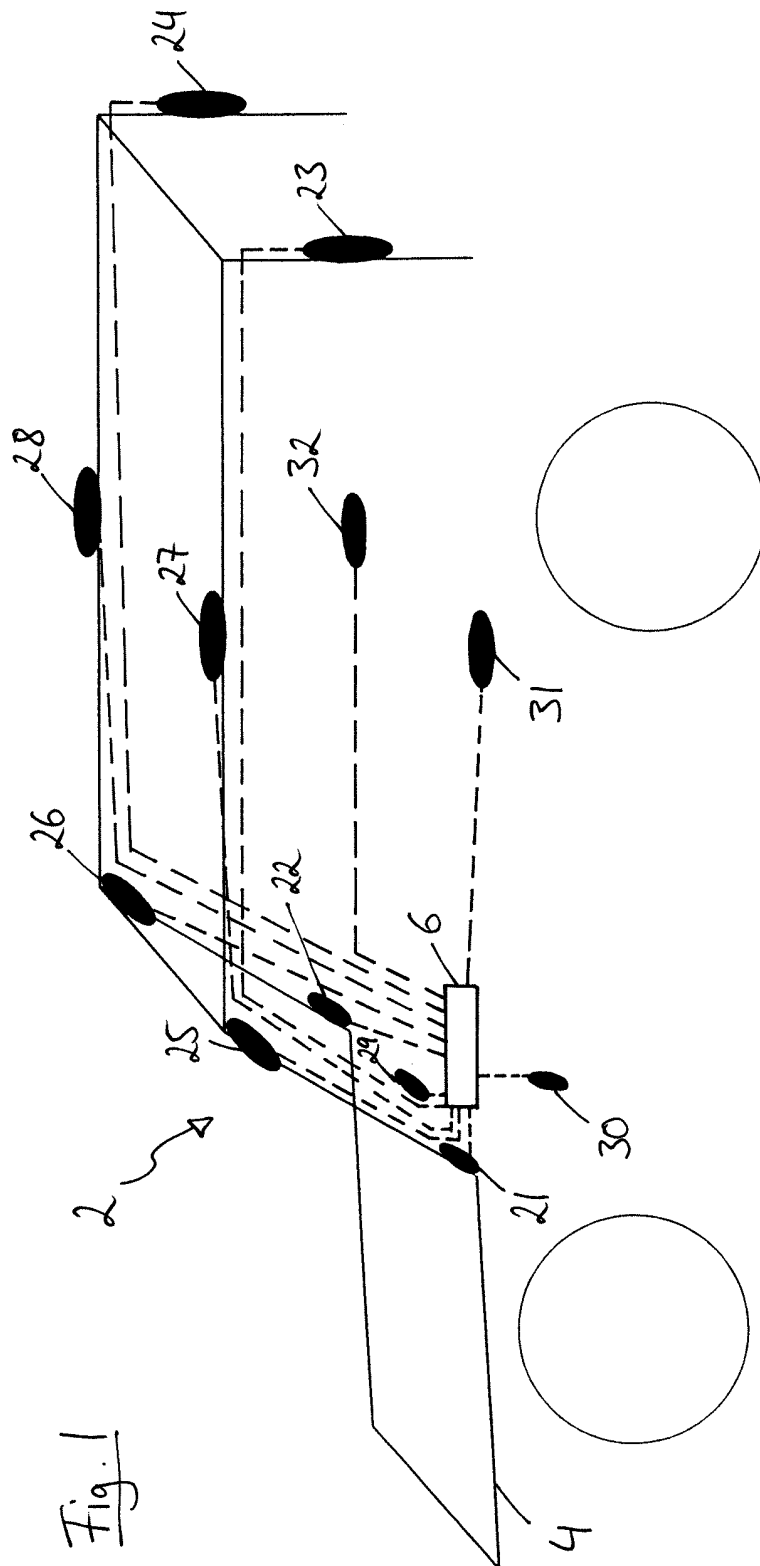
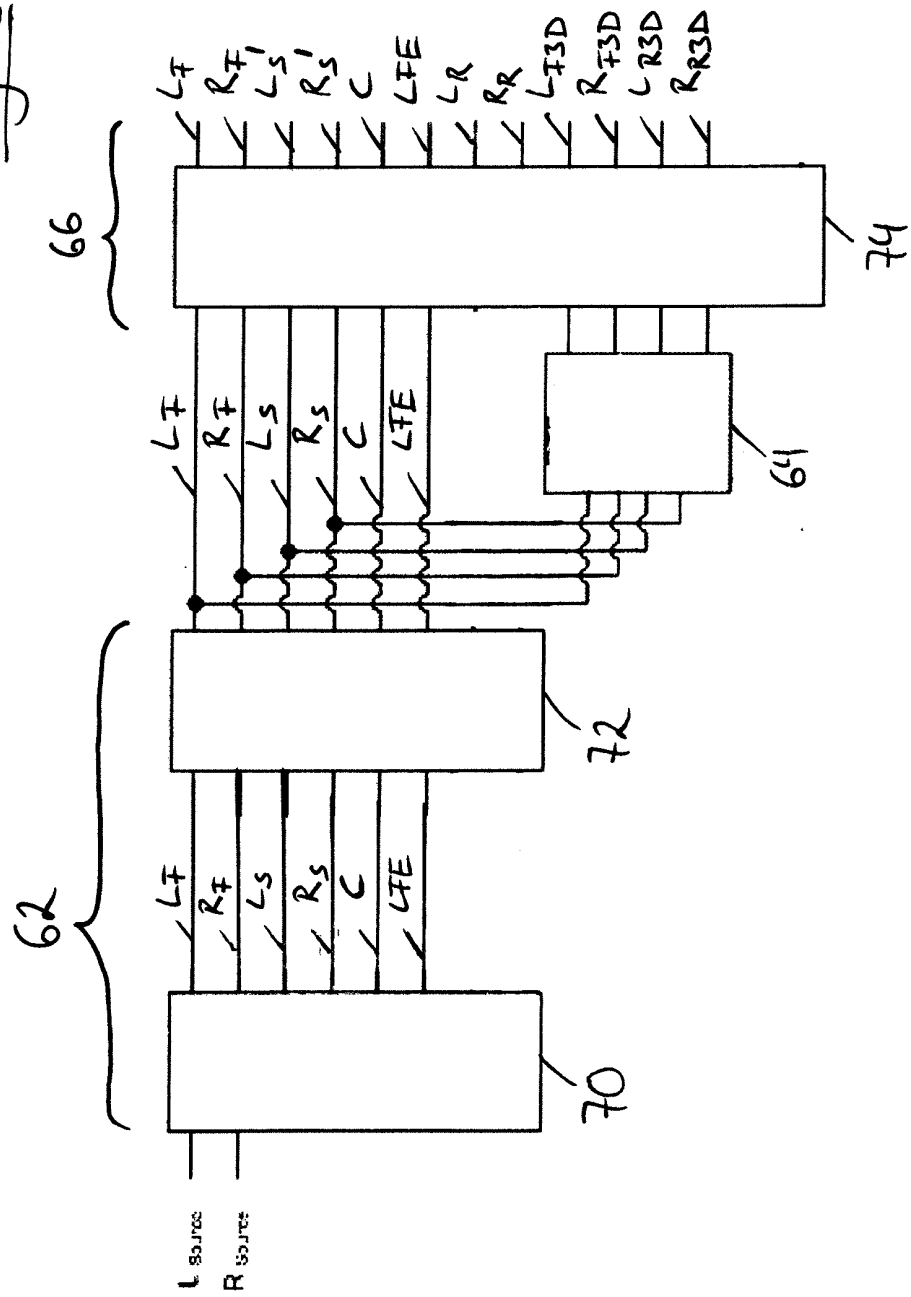


Fig. 2





EUROPEAN SEARCH REPORT

Application Number
EP 14 17 7369

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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Place of search		Date of completion of the search	Examiner
The Hague		9 October 2014	Marzocchi, Olaf
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X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

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09-10-2014

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