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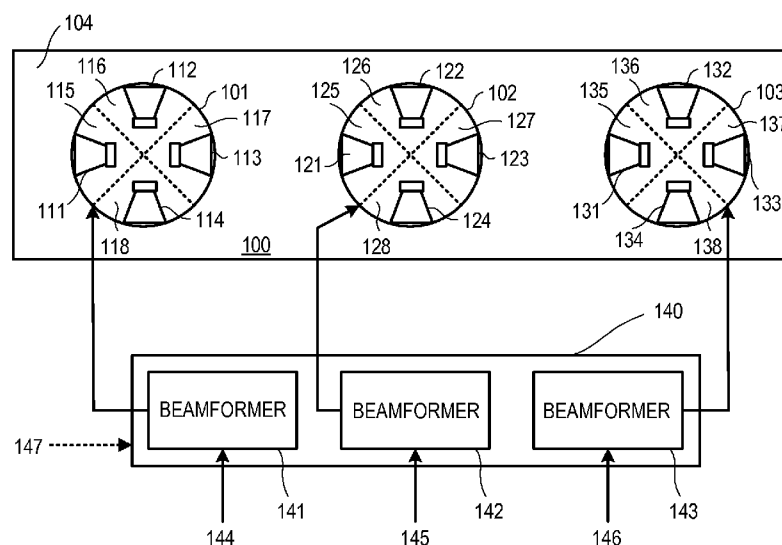


FIG 1

(57) Abstract: At least two closely spaced identical or similar loudspeaker assemblies, each loudspeaker assembly comprising at least two identical or similar loudspeakers pointing in different directions so that the loudspeaker assemblies have adjustable, controllable or steerable directivity characteristics. For example, a control module may drive adjust, control or steer the loudspeaker assemblies so that at least one acoustic wave field is generated at least at one listening position.

MULTI-MEDIA REPRODUCTION FOR A MULTIPLICITY OF RECIPIENTS

TECHNICAL FIELD

[0001] The disclosure relates to multi-media reproduction systems and methods.

BACKGROUND

[0002] In the fields of video gaming, television and video entertainment it is often the case that numerous persons wish to view separate video contents in physical proximity to each other. To this end, many televisions offer features known as picture-in-picture or split screen viewing, by which video images from different sources are shown on the television at the same time. It is also common for more than one video monitor to be placed in a room at the same time for viewing different contents. In most cases audio content corresponding to the video content is presented simultaneously. However, there is a recurring drawback involving viewers of one video image being distracted by the acoustics corresponding to another video content. Headphones are commonly used to provide the recipients of a video content with the respective audio content, but headphones are considered unpleasant and annoying in the situations described above. Thus, there is a general need for a system or method which facilitates split screen viewing in connection with the reproduction of corresponding audio content.

SUMMARY

[0003] An exemplary multi-media system includes a display array comprising at least one electronic visual display and a video control module configured to operate the display array in a split screen mode to provide different video content at least at two different recipient positions. The multi-media system further includes a loudspeaker arrangement comprising at least two identical or similar loudspeakers so that the loudspeaker arrangement has adjustable, controllable or steerable directivity characteristics. The multi-media system further includes an audio control module configured to drive, adjust, control and/or steer the loudspeaker arrangement so that at least one acoustically isolated acoustic wave field is generated at each of the at least two recipient positions to provide different audio content at the at least two different recipient positions.

[0004] An exemplary multi-media reproduction method includes reproducing different video content with a display array that comprises at least one electronic visual display at least at two different recipient positions, and reproducing different audio content with a loudspeaker arrangement comprising at least two identical or similar loudspeakers so that the loudspeaker arrangement has adjustable, controllable or steerable directivity characteristics. The method further includes driving, adjusting, controlling and/or steering the loudspeaker arrangement so that at least one acoustically isolated acoustic wave field is generated at each of the at least two recipient positions to provide different audio content at the at least two different recipient positions.

[0005] Other systems, methods, features and advantages will be, or will become, apparent to one with skill in the art upon examination of the following figures and detailed description. It is intended that all such additional systems, methods, features and advantages be included within this description, be within the scope of the invention, and be protected by the following claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] The systems, arrangements, assemblies and methods may be better understood with reference to the following drawings and description. The components in the figures are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the invention. Moreover, in the figures, like referenced numerals designate corresponding parts throughout the different views.

[0007] Figure 1 is a schematic top view illustrating an exemplary soundbar based on three higher-order loudspeaker assemblies for creating a two-dimensional acoustic wave field at a desired position (sweet spot) in a room.

[0008] Figure 2 is a schematic side view illustrating the soundbar shown in Figure 1.

[0009] Figure 3 is a schematic diagram illustrating an exemplary listening environment with one sweet area.

[0010] Figure 4 is a schematic diagram illustrating an exemplary listening environment with two sweet areas.

[0011] Figure 5 is a signal flow chart illustrating an exemplary modal beamformer employing a weighting matrix for matrixing.

[0012] Figure 6 is a signal flow chart illustrating an exemplary modal beamformer employing a multiple-input multiple-output module for matrixing.

5 [0013] Figure 7 is a two-dimensional depiction of the real parts of the spherical harmonics up to an order of $M = 4$ in Z direction.

[0014] Figure 8 is a diagram illustrating the directivity characteristic of a cardioid radiation pattern of 9th order.

10 [0015] Figure 9 is a diagram illustrating the directivity characteristic of the real part of the spherical harmonic of third order.

[0016] Figure 10 is a schematic diagram illustrating an exemplary optical detector for determining the direction of arrival of sound waves.

[0017] Figure 11 is a schematic diagram illustrating an exemplary split screen arrangement using one display.

15 [0018] Figure 12 is a schematic diagram illustrating an exemplary split screen arrangement using two displays.

[0019] Figure 13 is a perspective view illustrating an exemplary one-display split screen arrangement adapted for use at two recipient positions.

20 [0020] Figure 14 is a perspective view illustrating an exemplary one-display screen arrangement for multi-angle windowing adapted for use at two recipient positions.

DETAILED DESCRIPTION

[0021] Two-dimensional or three-dimensional audio may be realized using a sound field description by a technique called Higher-Order Ambisonics. Ambisonics is a full-sphere surround sound technique which may cover, in addition to the horizontal plane, sound sources
25 above and below the listener. Unlike other multichannel surround formats, its transmission

channels do not carry loudspeaker signals. Instead, they contain a loudspeaker-independent representation of a sound field, which is then decoded to the listener's loudspeaker setup. This extra step allows a music producer to think in terms of source directions rather than loudspeaker positions, and offers the listener a considerable degree of flexibility as to the layout and number of loudspeakers used for playback. Ambisonics can be understood as a three-dimensional extension of mid/side (M/S) stereo, adding additional difference channels for height and depth. In terms of First-Order Ambisonics, the resulting signal set is called B-format. The spatial resolution of First-Order Ambisonics is quite low. In practice, that translates to slightly blurry sources, and also to a comparably small usable listening area or sweet spot.

[0022] The resolution can be increased and the sweet spot enlarged by adding groups of more selective directional components to the B-format. In terms of Second-Order Ambisonics, these no longer correspond to conventional microphone polar patterns, but look like, e.g., clover leaves. The resulting signal set is then called Second-, Third-, or collectively, Higher-Order Ambisonics (HOA). However, common applications of the HOA technique require, dependent on whether a two-dimensional (2D) and three-dimensional (3D) wave field is processed, specific spatial configurations notwithstanding whether the wave field is measured (decoded) or reproduced (encoded): Processing of 2D wave fields requires cylindrical configurations and processing of 3D wave fields requires spherical configurations, each with a regular distribution of the microphones or loudspeakers.

[0023] Figures 1 and 2 illustrate a sound reproduction system 100 which includes three (or, if appropriate, only two) closely spaced steerable (higher-order) loudspeaker assemblies 101, 102, 103, here arranged, for example, in a horizontal linear array (which is referred to herein as higher-order soundbar). Loudspeaker assemblies with omnidirectional directivity characteristics, dipole directivity characteristics and/or any higher order polar responses are herein referred to also as higher-order loudspeakers. Each higher-order loudspeaker 101, 102, 103 has adjustable, controllable or steerable directivity characteristics (polar responses) as outlined further below. Each higher-order loudspeaker 101, 102, 103 may include a horizontal circular array of lower-order loudspeakers (e.g., omni-directional loudspeakers). For example, the circular arrays may each include, e.g., four lower-order loudspeakers 111 to 114, 121 to 124, 131 to 134 (such as common loudspeakers and, thus, also referred to as loudspeakers), the four lower-order loudspeakers 111 to 114, 121 to 124, 131 to 134 each directed in one of four

perpendicular directions in a radial plane in this example. The array of higher-order loudspeakers 101, 102, 103 may be disposed on an optional base plate 104 and may have an optional top plate 201 on top (e.g., to carry a flat screen TV set). Alternatively, instead of four lower-order loudspeakers only three lower-order loudspeakers per higher-order loudspeaker assembly can be employed to create a two-dimensional higher-order loudspeaker of the first order using Ambisonics technology.

[0024] Alternative use of the multiple-input multiple-output technology instead of the Ambisonics technology allows for creating a two-dimensional higher-order loudspeaker of the first order even with only two lower-order loudspeakers. Other options include the creation of three-dimensional higher-order loudspeakers with four lower-order loudspeakers that are regularly distributed on a sphere using the Ambisonics technology and with four lower-order loudspeakers that are regularly distributed on a sphere using the multiple-input multiple-output technology. Furthermore, the higher-order loudspeaker assemblies may be arranged other than in a straight line, e.g., on an arbitrary curve in a logarithmically changing distance from each other or in a completely arbitrary, three-dimensional arrangement in a room.

[0025] The four lower-order loudspeakers 111 to 114, 121 to 124, 131 to 134 may be substantially the same size and have a peripheral front surface, and an enclosure having a hollow, cylindrical body and end closures. The cylindrical body and end closures may be made of material that is impervious to air. The cylindrical body may include openings therein. The openings may be sized and shaped to correspond with the peripheral front surfaces of the lower-order loudspeakers 111 to 114, 121 to 124, 131 to 134, and have central axes. The central axes of the openings may be contained in one radial plane, and the angles between adjacent axes may be identical. The lower-order loudspeakers 111 to 114, 121 to 124, and 131 to 134 may be disposed in the openings and hermetically secured to the cylindrical body. However, additional loudspeakers may be disposed in more than one such radial plane, e.g., in one or more additional planes above and/or below the radial plane described above. Optionally, the lower-order loudspeakers 111 to 114, 121 to 124, 131 to 134 may each be operated in a separate, acoustically closed volume 115 to 118, 125 to 128, 135 to 138 in order to reduce or even prevent any acoustic interactions between the lower-order loudspeakers of a particular higher-order loudspeaker assembly. Furthermore, the lower-order loudspeakers 111 to 114, 121 to 124, 131 to 134 may each be arranged in a dent, hole, recess or the like. Additionally or

alternatively, a wave guiding structure such as but not limited to a horn, an inverse horn, an acoustic lens etc. may be arranged in front of the lower-order loudspeakers 111 to 114, 121 to 124, 131 to 134.

[0026] A control module 140 receives, e.g., three Ambisonic signals 144, 145, 146 to process the Ambisonic signals 144, 145, 146 in accordance with steering information 147, and to drive and steer the higher-order loudspeakers 101, 102, 103 based on the Ambisonic signals 144, 145, 146 so that at least one acoustic wave field is generated at least at one position that is dependent on the steering information. The control module 140 comprises beamformer modules 141, 142, 143 that drive the lower-order loudspeakers 111 to 114, 121 to 124, 131 to 134. Examples of beamformer modules are described further below.

[0027] Figure 3 depicts various possibilities of how to use a horizontal linear array of high-order loudspeakers (referred to herein also as horizontal high-order soundbar or just high-order soundbar) in order to realize virtual sound sources in home entertainment. For example, such a linear array may be disposed under a television (TV) set for reproducing e.g. the front channels of the commonly used layout in home cinema, the 5.1 surround sound. The front channels of a 5.1 sound system include a front left (Lf) channel, a front right (Rf) channel and a center (C) channel. Arranging a single high-order loudspeaker underneath the TV set instead of the horizontal high-order soundbar would mean that the C channel could be directed to the front of the TV set and the Lf and Rf channels to its sides, so that the Lf and Rf channels would not be transferred directly to a listener sitting (at sweet spot or sweet area) in front of the TV set but only indirectly via the side walls, constituting a transfer path which depends on a lot of unknown parameters and, thus, can hardly be controlled. Therefore, in a multi-channel system with at least two channels to be reproduced, a high-order soundbar with (at least) two high-order loudspeakers that are arranged in a horizontal line allows for directly transferring front channels, e.g., the Lf and Rf channels, directly to the sweet area, i.e., the area where the listener should be.

[0028] Furthermore, a center channel, e.g., the C channel, may be reproduced at the sweet area by way of two high-order loudspeakers. Alternatively, a third high-order loudspeaker, disposed between the two high-order loudspeakers, may be used to separately direct the Lf and Rf channels and the C channel to the sweet area. Since with three high-order loudspeakers each

channel is reproduced by a separate unit, the spatial sound impression of a listener at the sweet area can be further improved. Furthermore, with each additional high-order loudspeaker added to the high-order soundbar a more diffuse sound impression can be realized and further channels such as, e.g., effect channels may be radiated from the rear side of the high-order soundbar, which is in the present example from the rear side of the TV set to, e.g., the rear wall where the sound provided by the effect channels is diffused.

[0029] In contrast to common soundbars in which the lower-order loudspeakers are arranged in line, higher-order soundbars provide more options for the positioning of the directional sound sources, e.g., on the side and rear, so that in a common listening environment such as a living room, a directivity characteristic that is almost independent from the spatial direction can be achieved with higher-order soundbars. For example, a common side bar having 14 lower-order loudspeaker equidistantly distributed inline over a distance of 70 cm can only generate virtual sound sources in an area of maximum $\pm 90^\circ$ (degree) from the front direction, while higher-order soundbars allow for virtual sound sources in an area of $\pm 180^\circ$.

[0030] Figure 3 illustrates an exemplary set-up with a higher-order soundbar including three higher-order loudspeaker 310, 311, 322. A sound system 301 receiving one or more audio signals 302 and including a control module such as control module 140 shown in Figure 1 drives the three higher-order loudspeaker 310, 311, 322 in a target room 313, e.g., a common living room. At a listening position or sweet area (represented by a microphone array 314), the wave field of at least one desired virtual source can then be generated. In the target room 313, further higher-order loudspeakers, e.g., a higher-order loudspeaker 324 for a rear left (Ls) channel, a lower-order sub-woofer 323 for the low frequency effects (Sub) channel, and a higher-order loudspeaker 312 for a rear right (Rs) channel are arranged. The target room 313 is acoustically very unfavorable as it includes a window 317 and a French door 318 in the left wall and a door 319 in the right wall in an unbalanced configuration. Furthermore, a sofa 321 is disposed at the right wall and extends approximately to the center of the target room 313 and a table 320 is arranged in front of the sofa 321.

[0031] A television set 316 is arranged at the front wall (e.g., above the higher order soundbar) and in line of sight of the sofa 321. The front left (Lf) channel higher-order loudspeaker 310 and the front right (Rf) channel higher-order loudspeaker 311 are arranged under the left and

right corners of the television set 316 and the center (C) higher-order loudspeaker 322 is arranged below the middle of television set 316. The low frequency effects (Sub) channel loudspeaker 323 is disposed in the corner between the front wall and the right wall. The loudspeaker arrangement on the rear wall, including the rear left (Ls) channel higher-order loudspeaker 324 and the rear right (Rs) channel under loudspeaker 312, do not share the same center line as the loudspeaker arrangement on the front wall including the front left (Lf) channel loudspeaker 310, the front right (Rs) channel loudspeaker 311, and low frequency effects (Sub) channel loudspeaker 323. An exemplary sweet area 314 may be on the sofa 321 with the table 320 and the television set 316 in front. As can be seen, the loudspeaker setup shown in Figure 3 is not based on a cylindrical or spherical base configuration and employs no regular distribution.

[0032] In the set-up shown in Figure 3, the main directions are depicted as solid arrows and the sub-directions are depicted as dotted arrows. As depicted, not only precise stereo impressions but also natural, wide staging can be achieved. If further (higher-order) loudspeakers are used, e.g., for the surround channels Ls and Rs, behind the sweet area and in front of the rear wall, or somewhere above (not shown) the level of the soundbar, the surround impression can be further enhanced. Furthermore, it has been found that the number of (lower-order) loudspeakers can be significantly reduced. For example, with five virtual sources of 4th order surrounding the sweet area, wave fields can be approximated similar to those achieved with 45 lower-order loudspeakers surrounding the sweet area, or, in the exemplary environment shown in Figure 3, a higher-order soundbar with three higher-order loudspeakers, which is built from 12 lower-order loudspeakers in total, and exhibits a better spatial sound impression than with the common soundbar with 14 lower-order loudspeakers in line at comparable dimensions of the two soundbars.

[0033] If effect channels or surround channels (e.g., the Ls and Rs channels) are to be disposed between the sweet area and the rear wall, where not sufficient room may be available, higher-order loudspeaker may be implemented as “bulbs” in the same sockets as light bulbs. Such bulb-type higher-order loudspeakers may provide not only sound, but also light in connection with space-saving light emitting diodes. The power required for the bulb-type higher-order loudspeakers (including signal processing and amplifying circuitry) can be supplied via the

mains as with common light bulbs. Signals to be reproduced (and others if required) may be provided via a wired (e.g., power-line) or wireless connection such as Bluetooth or WLAN.

[0034] By way of a set-up similar to that shown in Figure 3 other sweet areas may be established besides sweet area 325 depicted in Figure 4. For example, sweet area 325 may receive direct sound beams from the soundbar to allow the same acoustic impressions as those at the sweet area 314 or, alternatively, to reproduce a different acoustic content. Different acoustic content may be in connection with split screen TV sets or separate TV sets (not shown) in the room.

[0035] For each of the higher-order loudspeakers of the soundbar (and the other higher-order loudspeakers) a beamformer module 500 or 600 as depicted in Figures 5 and 6 (e.g., applicable as beamformers 141, 142, 143 in Figures 1 and 2) may be employed. The beamforming module 500 shown in Figure 5 controls a loudspeaker assembly with Q loudspeakers 501 (or Q groups of loudspeakers each with a multiplicity of loudspeakers such as tweeters, mid-frequency range loudspeakers and/or woofers) dependent on N (Ambisonics) input signals 502, also referred to as input signals $x(n)$ or Ambisonic signals $Y_{n,m}^\sigma(\theta, \varphi)$, wherein for two dimensions N is $N_{2D} = (2M+1)$ and for three dimensions $N_{3D} = (M+1)^2$. The beamforming module 500 may further include a modal weighting sub-module 503, a dynamic wave-field manipulation sub-module 505, a regularization sub-module 509 and a matrixing sub-module 507. The modal weighting sub-module 503 is supplied with the input signal 502 $[x(n)]$ which is weighted with modal weighting coefficients, i.e., filter coefficients $C_0(\omega), C_1(\omega) \dots C_N(\omega)$ in the modal weighting sub-module 503 to provide a desired beam pattern, i.e., radiation pattern $\psi_{Des}(\theta, \varphi)$, based on the N spherical harmonics $Y_{n,m}^\sigma(\theta, \varphi)$ to deliver N weighted Ambisonic signals 504, also referred to as $C_{n,m}^\sigma Y_{n,m}^\sigma(\theta, \varphi)$. The weighted Ambisonic signals 504 are transformed by the dynamic wave-field manipulation sub-module 505 using $N \times 1$ weighting coefficients, e.g. to rotate the desired beam pattern $\psi_{Des}(\theta, \varphi)$ to a desired position $\theta_{Des}, \varphi_{Des}$. Thus N modified (e.g., rotated, focused and/or zoomed) and weighted Ambisonic signals 506, also referred to as $C_{n,m}^\sigma Y_{n,m}^\sigma(\theta_{Des}, \varphi_{Des})$, are output by the dynamic wave-field manipulation sub-module 505.

[0036] The N modified and weighted Ambisonic signals 506 are then input into the regularization sub-module 509, which includes the necessary radial filter $W_{n,m}^\sigma(\omega)$ for considering the susceptibility of the playback device Higher-Order-Loudspeaker (HOL)

preventing e.g. a given White-Noise-Gain (WNG) threshold from being undercut. Output signals 510 $[W_{n,m}^{\sigma}(\omega) C_{n,m}^{\sigma} Y_{n,m}^{\sigma}(\theta_{Des}, \varphi_{Des})]$ of the regularization sub-module 509 are then transformed, e.g. by pseudo-inverse $Y^{+} = (Y^T Y)^{-1} Y^T$, which simplifies to $Y^{+} = \frac{1}{Q} Y^T$, if the Q lower-order loudspeakers are arranged at the body of the higher-order loudspeakers in a regular fashion, into Q loudspeaker signals 508 $[y_1(n), \dots, y_Q(n)]$ by the matrixing sub-module 507 using a $N \times Q$ weighting matrix as shown in Figure 5. Alternatively, the Q loudspeaker signals 508 may be generated from the N regularized, modified and weighted Ambisonic signals 510 by a multiple-input multiple-output sub-module 601 using an $N \times Q$ filter matrix as shown in Figure 6. The systems shown in Figures 5 and 6 may be employed to realize two-dimensional or three-dimensional audio using a sound field description such as Higher-Order Ambisonics.

[0037] An example of a simple Ambisonic panner (or encoder) takes an input signal, e.g., a source signal S and two parameters, the horizontal angle θ and the elevation angle φ . It positions the source at the desired angle by distributing the signal over the Ambisonic components with different gains for the corresponding Ambisonic signals W ($Y_{0,0}^{+1}(\theta, \varphi)$), X ($Y_{1,1}^{+1}(\theta, \varphi)$), Y ($Y_{1,-1}^{-1}(\theta, \varphi)$) and Z ($Y_{1,0}^{+1}(\theta, \varphi)$):

$$w = S \cdot \frac{1}{\sqrt{2}},$$

$$x = s \cdot \cos \theta \cdot \cos \varphi,$$

$$y = s \cdot \sin \theta \cdot \cos \varphi, \text{ and}$$

$$z = s \cdot \sin \varphi.$$

Being omnidirectional, the W channel always delivers the same signal, regardless of the listening angle. In order that it has more-or-less the same average energy as the other channels, W is attenuated by w, i.e., by about 3 dB (precisely, divided by the square root of two). The terms for X, Y, Z may produce the polar patterns of figure-of-eight. Taking their desired weighting values at angles θ and φ (x, y, z), and multiplying the result with the corresponding Ambisonic signals (X, Y, Z), the output sums end up in a figure-of-eight radiation pattern pointing now to the desired direction, given by the azimuth θ and elevation φ , utilized in the calculation of the weighting values x, y and z, having an energy content that can cope with the W component, weighted by w. The B-format components can be combined to derive virtual radiation patterns that can cope with any first-order polar pattern (omnidirectional, cardioid, hypercardioid, figure-of-eight or anything in between) and point in any three-dimensional

direction. Several such beam patterns with different parameters can be derived at the same time to create coincident stereo pairs or surround arrays.

[0038] Referring now to Figure 7, higher-order loudspeakers or loudspeaker assemblies like those described above in connection with Figure 1 to 4, including beamformer modules such as those shown in Figure 5 and 6, allow for approximating any desired directivity characteristic by superimposing the basic functions, i.e., the spherical harmonics. Figure 7 is a two-dimensional depiction (magnitudes vs. degrees) of the real spherical harmonics with orders of $M = 0$ to 4 in the Z direction of the exemplary higher-order loudspeaker described above.

[0039] For example, when superimposing the five basic functions depicted in Figure 7 using modal weighting coefficients $C_m = [0.100, 0.144, 0.123, 0.086, 0.040]$, wherein $m = [0 \dots 4]$, a directivity characteristic of an approximated cardioid of 9th order can be generated as shown in Figure 8. Whereas, when superimposing the five basic functions depicted in Figure 7 using modal weighting coefficients $C_m = [0.000, 0.000, 0.000, 1.000, 0.040]$, wherein again $m = [0 \dots 4]$, a directivity characteristic of the real part of the spherical harmonic of third order in Z direction can be generated as shown in Figure 8.

[0040] The matrixing module 601 may be implemented as a multiple-input multiple-output system that provides an adjustment of the output signals of the higher-order loudspeakers so that the radiation patterns approximate as closely as possible the desired spherical harmonics, as shown e.g. in Figure 7. To generate a desired wave-field at a certain position or area in the room utilizing several higher-order loudspeakers, it may be sufficient in the adaptation process to adapt only the modal weights $C_{n,m}^\sigma$ of the individual higher-order loudspeakers employed, i.e. to run the adaptation directly in the wave domain. Because of this adaptation in the wave field domain, such a process is called Wave-Domain Adaptive Filtering (WDAF). WDAF is a known efficient spatio-temporal generalization of the also known Frequency-Domain Adaptive Filtering (FDAF). Through incorporation of the mathematical foundations on wave fields, WDAF is suitable even for massive multiple-input multiple-output systems with highly cross-correlated broadband input signals. With wave domain adaptive filtering, the directional characteristics of the higher-order loudspeakers are adaptively determined so that the superpositions of the individual sound beams in the sweet area(s) approximate the desired sound wave field.

[0041] To adjust or (singularly or permanently) adapt the sound reproduced by the soundbar to the specific room conditions and the specific requirements of the sweet area of the loudspeaker set-up, which includes the high-order soundbar and, possibly, other (high-order) loudspeakers, the wave field needs to be measured and quantified. This may be accomplished by way of an array of microphones (microphone array) and a signal processing module able to decode the given wave-field, that, e.g., form a higher-order Ambisonic system to determine the wave field in three dimensions or, which may be sufficient in many cases, in two dimensions, which requires fewer microphones. For the measurement of a two-dimensional wave field, S microphones are required to measure sound fields up to the M th order, wherein $S = 2M + 1$. In contrast, for a three-dimensional wave field, $S = (2M + 1)^2$ microphones are required. Furthermore, in many cases it is sufficient to dispose the microphones (equidistantly) on a circle line. The microphones may be disposed on a rigid or open sphere or cylinder, and may be operated, if needed, in connection with an Ambisonic decoder. In an alternative example, the microphone array 314 may be integrated in one of the higher-order loudspeakers (not shown).

[0042] Furthermore, a master-slave loudspeaker set-up may be employed. The master unit may include a higher-order soundbar, a microphone array, and a signal processing and steering module. The slave unit(s) may include (a) further higher-order loudspeaker(s) electrically connected (wired or wireless) to the master unit. The microphone array may be detachable, so that it can be used standing alone to conduct the measurements, e.g., in connection with a battery driven power supply and a wireless connection to the master unit. When the microphone array is attached to the master unit again it can be used for other tasks such as speech control of the audio system (e.g., volume control, content selection), or hands-free operation of a telephone interface (e.g., a teleconference system) including adapting (steering) the speaker. The sound reproduction system may also include a DOA module for determining the direction of arrival (DOA) of a sound wave, which, in this application, would suffice to be purely triggered by speech signals, i.e., no optical DOA detection is required.

[0043] The DOA module may include one or more optical detectors such as one or more cameras to detect the position of a listener and to reposition the sweet area by steering the direction of the higher-order loudspeakers. In this case an optical DOA detector, optionally in combination with the previously mentioned purely speech triggered DOA detection, is

necessary since now the sound-field should be adjusted in respect to the current position of the listener, which by no means implies that the person has to be speaking. An exemplary optical detector is shown in Figure 10. As shown, a camera 1001 with a lens 1002 may be disposed at an appropriate distance above (or below) a mirrored hemisphere 1003 with the lens 1002 pointing to the curved, mirrored surface of the hemisphere 1003, and may provide a 360° view 1004 in a horizontal plane. For example, when such a detector is mounted in the listening room, the position of the listener can be spotted everywhere in the room. Alternatively, a so-called fisheye lens may be used (as lens 1002) that also provides a 360° view in a horizontal plane when mounted, e.g., to the ceiling of the room, so that the mirrored hemisphere 1003 can be omitted.

[0044] Referring to Figures 11 to 13, a display or an array of displays with multi-content reproduction mode use a technique that consists of dividing graphics and/or text into movable or non-movable adjacent or overlapping parts, for example two, three, four or more rectangular areas. This is done in order to allow the simultaneous presentation of (usually) related graphical and textual information on a display. Split screen differs from windowing systems (e.g., picture-in-picture systems) in that the latter allows overlapping and freely movable parts of the screen (the "windows") to present related as well as unrelated application data to the user, while the former conforms more strictly to dividing graphics and/or text into non-movable adjacent parts. The split screen technique can also be used to run two instances of an application, possibly with another user interacting with the other instance such as in non-networked video games with multiplayer options. Another technique for multi-content operations is, for example, the angle-dependent presentation windowing.

[0045] In the arrangement shown in Figure 11, a screen 1101 of a display 1102 is divided into two fields 1103 and 1104. One field 1103 displaying a content A and the other field displaying a content B. The display is connected with a combined audio-video controller 1105 that provides two video channels representative of the video content A and B to the display 1102 and provides two stereo audio channels (or two monaural channels) corresponding to the video content A and B to loudspeakers (not shown) of a sound reproduction system, e.g., the sound reproduction system 100 described above in connection with Figures 1 and 2. The combined audio-video controller 1105 may be further coupled to a camera (not shown) such as the camera 1001 described above in connection with Figure 10, which provides information for the

combined audio-video controller 1105 to steer the wave fields to the actual positions of the two recipients.

[0046] Alternatively, as shown in Figure 12, an array of (at least) two displays 1201 and 1202, each having a screen 1203 and 1204, may be used instead of a single display (array). One screen
5 1203 displays content A and the other screen 1204 displays content B. Both displays as well as their loudspeakers (not shown) are controlled by a combined audio-video controller 1205 which may operate in a similar manner as the combined audio-video controller 1105 shown in Figure 11.

[0047] In the arrangement shown in Figure 13, a screen 1301 of a display 1302 is divided into
10 at least two fields 1303 and 1304 with each of the fields having a polarization that is different from the polarization of the other field. The screen 1301 may include at its surface a polarized film (not shown) which allows for a high transmission of light. The film may be made from a variety of different materials such as glass, plastic, carbon composites, or any other translucent material through which light can pass and be polarized. In a simple implementation the screen
15 1301 may be divided into two linearly polarized fields 1303 and 1304 that are perpendicular to each other and divided along the line of the respective polarization fields. The screen 1301 may be split horizontally, vertically, or at some other angle or mode of polarization. The film may be fixedly attached or removably attached by to the screen 1301.

[0048] Paired with the film are viewing glasses 1305 and 1306. These viewing glasses 1305
20 and 1306 are polarized to correspond with the matching polarized field 1303 or 1304. There is at least one pair of viewing glasses corresponding with each polarized field 1303 and 1304 of the screen 1301. Thus, in the exemplary arrangement where the screen 1301 is split into two polarized fields 1303 and 1304 having polarizations perpendicular to each other, there will also be two pairs of viewing glasses 1305 and 1306, one having horizontal polarization and the
25 other having vertical polarization. With regard to the structure of the glasses 1305 and 1306, any type of removable glasses, add-ons or clip-on eyewear which effectively allows the users 1307 and 1308, i.e., recipients at respective recipient positions, to wear the glasses 1305 and 1306 etc. may be used. The display 1302 may be disposed on and electrically coupled through an audio-video control module (not shown) to a loudspeaker arrangement 1309 such as the
30 sound reproduction system 100 described above in connection with Figures 1 and 2.

[0049] Particularly in an automotive environment such as the interior of a car, polarizing glasses can be impractical or even disturbing. Figure 14 schematically shows an exemplary display 1401 for two users (recipients) 1402 and 1403 at different positions allowing the users to look under different angles at a display 1401. The display 1401 is arranged to generate a first view 1404 in a first direction 1405 relative to the display 1401 and to generate a second view 1406 in a second direction 1407 relative to the display 1401, wherein the second direction 1407 is different from the first direction 1405. The display 1401 is supplied with video signals and controlled by a video controller 1408, which is provided with multi-channel audio and video signals from a respective source (not shown), and which forwards selected video signals to the display 1401 and the corresponding audio signals to an audio controller 1409. The audio controller may process these audio signals to provide a beamforming functionality in connection with at least one loudspeaker assembly (not shown) having a multiplicity of loudspeakers.

[0050] The display 1401 and/or the video controller 1408 may include one or more luminance modulation units (not shown) to visualize respective sequences of images being provided by means of multiple image video sources. In the case of a single luminance modulation unit, temporal or spatial multiplexing is applied to render the images of the respective sequences. Video (and audio) sources may be DVD players, receivers for receiving broadcast video, set-top boxes, satellite-tuners, VCR players or any types of computers or processors arranged to render graphical images. The luminance modulation units can be based on known display technologies like CRT (Cathode Ray Tube), LCD (Liquid Crystal Display) or PDP (Plasma display panel).

[0051] The display 1401 further comprises optical means (not shown) to direct a first sequence of images in the first direction 1405, resulting in the first view 1404 (video content A), and to direct a second sequence of images in the second direction 1407, resulting in the second view 1406 (video content B). The first view 1404 can only be seen by the first user 1402 and the second view can only be seen by the second user 1406. The audio controller 1409 generates at least two sound fields that spatially correspond to the positions of the users 1402 and 1403, and whose audio contents correspond to video contents A and B. By using, e.g., an array of higher-order loudspeakers (e.g., in form of a higher-order soundbar), each of them having a versatile directivity, arbitrary wave fields can be approximated, even in reflective venues such as living

rooms where home audio systems are typically installed. This is possible because, due to the use of higher-order loudspeakers, versatile directivities can be created, radiating the sound only in directions where no reflective surfaces exist, or deliberately making use of certain reflections if those turn out to positively contribute to the creation of a desired wave field to be approximated. Thereby, the approximation of the desired wave field at a desired position within the target room (e.g. a certain region at the couch in the living room) can be achieved by using adaptive methods, such as an adaptive multiple-input multiple-output (MIMO) system, given e.g. by the multiple-FXLMS filtered input least mean squared (multiple-FXLMS) algorithm, which could also operate not just in the time or spectral domain, but also in the so-called wave-domain.

[0052] Utilizing wave domain adaptive filters (WDAF) is of special interest, since this promises very good results in the approximation of the desired wave field. WDAF can be used if the recording device fulfills certain requirements. For example, circular (for 2D) or spherical microphone arrays (3D), equipped with regularly distributed microphones at the surface, may be used to record the wave field, having, depending on the desired order in which the wave field has to be recorded, respectively reproduced a number of microphones that have to be chosen accordingly. However, if beamforming filters are calculated using e.g. a MIMO system, arbitrary microphone arrays having different shapes and microphone distributions can be used as well to measure the wave field, leading to high flexibility in the recording device. The recording device can be integrated in a main unit of the complete new acoustic system. Thereby it can be used not only for the already mentioned recording task, but also for other needed purposes, such as enabling a speech control of the acoustic system to verbally control e.g. the volume, switching titles, and so on. Further, the main unit to which the microphone array is attached could also be used as a stand-alone device e.g. as a teleconferencing hub or as a portable music device with the ability to adjust the acoustic in dependence of the relative position of the listener to the device, which is only possible if a video camera is integrated in the main unit as well

[0053] Loudspeaker arrangements with adjustable, controllable or steerable directivity characteristics include at least two identical or similar loudspeakers which may be arranged in one, two or more loudspeaker assemblies, e.g. one loudspeaker assembly with two loudspeakers or two loudspeaker assemblies with one loudspeaker each. The loudspeaker

assemblies may be distributed somewhere around the display(s), e.g., in a room. With the help of arrays of higher-order loudspeakers, it is possible to create wave fields of the same quality, but with fewer devices as compared with ordinary loudspeakers. An array of higher-order loudspeakers can be used to create an arbitrary wave field in real, e.g., reflective environments.

5 The necessary recording device (microphone array) can be of arbitrary shape and microphone distribution if special beamforming concepts are used, which can be achieved e.g. by using a suitable adaptive MIMO system, such as the multiple-FXLMS algorithm. This new concept is able to create a much more realistic acoustic impression, even in reflective environments such as those given in living rooms.

10 **[0054]** The description of embodiments has been presented for purposes of illustration and description. Suitable modifications and variations to the embodiments may be performed in light of the above description. The described assemblies, systems and methods are exemplary in nature, and may include additional elements or steps and/or omit elements or steps. As used in this application, an element or step recited in the singular and proceeded with the word “a”
15 or “an” should be understood as not excluding plural of said elements or steps, unless such exclusion is stated. Furthermore, references to “one embodiment” or “one example” of the present disclosure are not intended to be interpreted as excluding the existence of additional embodiments that also incorporate the recited features. The terms “first,” “second,” and “third,” etc. are used merely as labels, and are not intended to impose numerical requirements or a
20 particular positional order on their objects. A signal flow chart may describe a system, method or software implementing the method dependent on the type of realization. e.g., as hardware, software or a combination thereof. A module may be implemented as hardware, software or a combination thereof.

CLAIMS

1. A multi-media system comprising:

a display array comprising at least one electronic visual display;

5 a video control module configured to operate the display array in a multiple content mode to provide different video contents at least at two different recipient positions;

a loudspeaker arrangement comprising at least two identical or similar loudspeakers so that the loudspeaker arrangement has adjustable, controllable or steerable directivity characteristics; and

10 an audio control module configured to drive, adjust, control and/or steer the loudspeaker arrangement so that at least one acoustically isolated acoustic wave field is generated at each of the at least two recipient positions to provide different audio content at the at least two different recipient positions.

15 2. The system of claim 1, wherein:

the loudspeaker arrangement comprises at least two closely spaced identical or similar loudspeaker assemblies, each loudspeaker assembly comprising at least two identical or similar loudspeakers pointing in different directions so that the loudspeaker assemblies have adjustable, controllable or steerable directivity characteristics; and

20 the audio control module is configured to drive, adjust, control and/or steer the loudspeaker assemblies so that at least one acoustically isolated acoustic wave field is generated at each of the at least two recipient positions to provide different audio content at the at least two different recipient positions.

25 3. The system of claim 2, wherein each loudspeaker assembly comprises a horizontal circular array of loudspeakers, and the audio control module comprises beamformer modules that drive the loudspeakers of each loudspeaker assembly.

4. The system of claim 3, wherein at least one circular array comprises four
30 loudspeakers, the four loudspeakers pointing in four perpendicular directions.

5. The system of any of the preceding claims, wherein the audio control module comprises a modal beamformer.

6. The system of claim 5, wherein the beamformer comprises a matrixing module with a weighting matrix or comprises a multiple-input multiple output filter matrix.

7. The system of any of claims 1 to 6, wherein the audio control module is operatively coupled to a microphone array with at least two microphones, the microphone array disposed at or circumventing one of the at least two recipient positions.

8. The system of claim 7, wherein the microphone array is movable between the at least two recipient positions.

9. The system of any of claims 1 to 8, wherein the audio control module is operatively connected to a camera, and the audio control module is further configured to detect via the camera at least one of the at least two recipient positions and to steer at least one of the at least two acoustic wave fields to the corresponding one of the at least two recipient positions.

10. The system of any of claims 1 to 9, wherein the display array comprises an electronic visual display and the video control module is configured to operate the electronic visual display in a split screen mode so that the electronic visual display provides different video content at the at least two different recipient positions.

11. The system of any of claims 1 to 9, wherein the display array comprises at least two electronic visual displays and the video control module is configured to operate the at least two electronic visual display in a split screen mode so that each electronic visual display provides different video content at one of the at least two different recipient positions.

12. A multi-media reproduction method comprising:
reproducing different video content with a display array that comprises at least one electronic visual display at least at two different recipient positions;

reproducing different audio content with a loudspeaker arrangement comprising at least two identical or similar loudspeakers so that the loudspeaker arrangement has adjustable, controllable or steerable directivity characteristics; and

5 driving, adjusting, controlling and/or steering the loudspeaker arrangement so that at least one acoustically isolated acoustic wave field is generated at each of the at least two recipient positions to provide different audio content at the at least two different recipient positions.

10 13. The method of claim 12, wherein reproducing different audio content is performed with at least two closely spaced identical or similar loudspeaker assemblies, each loudspeaker assembly comprising at least two identical or similar loudspeakers pointing in different directions so that the loudspeaker assemblies have adjustable, controllable or steerable directivity characteristics; and

15 driving, adjusting, controlling and/or steering the loudspeaker assemblies is configured so that at least one acoustically isolated acoustic wave field is generated at each of the at least two recipient positions to provide different audio content at the at least two different recipient positions.

20 14. The method of claim 13, wherein reproducing different audio content comprises beamforming when driving the loudspeakers of each loudspeaker assembly.

15. The method of claim 14, wherein beamforming comprises matrixing with a weighting matrix or comprises a multiple-input multiple output filter matrixing.

25

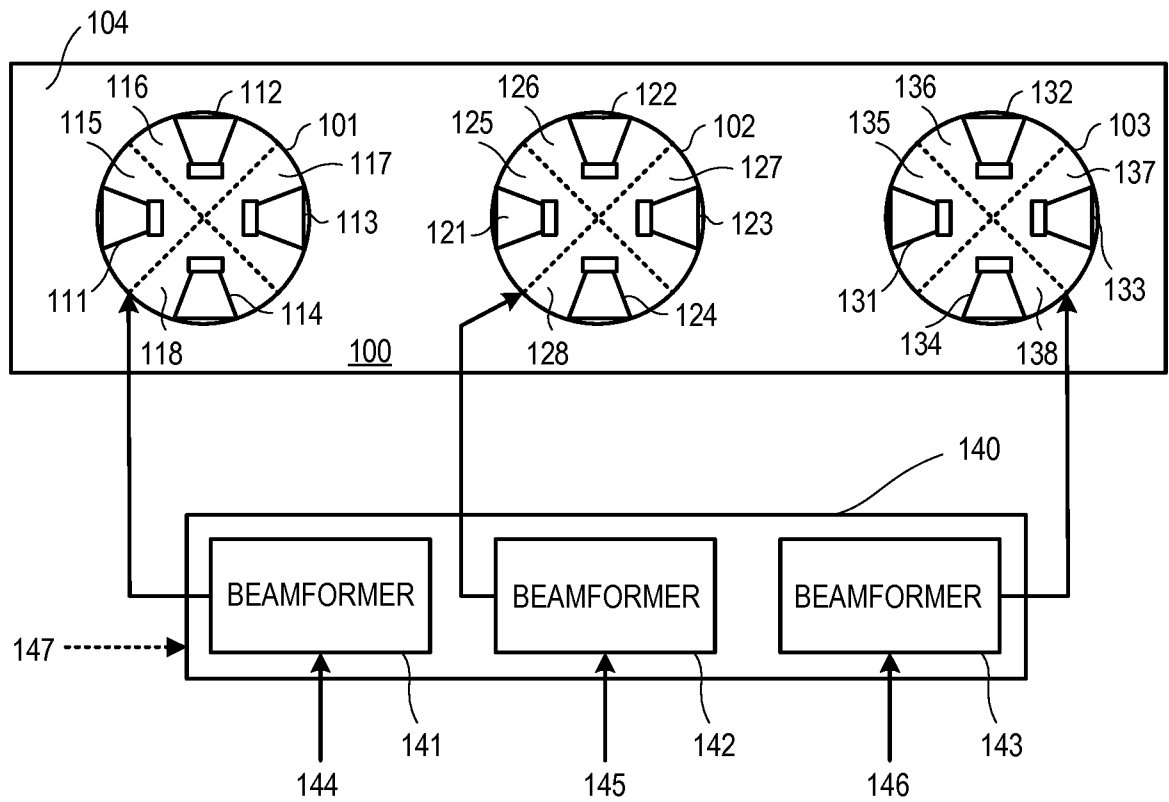


FIG 1

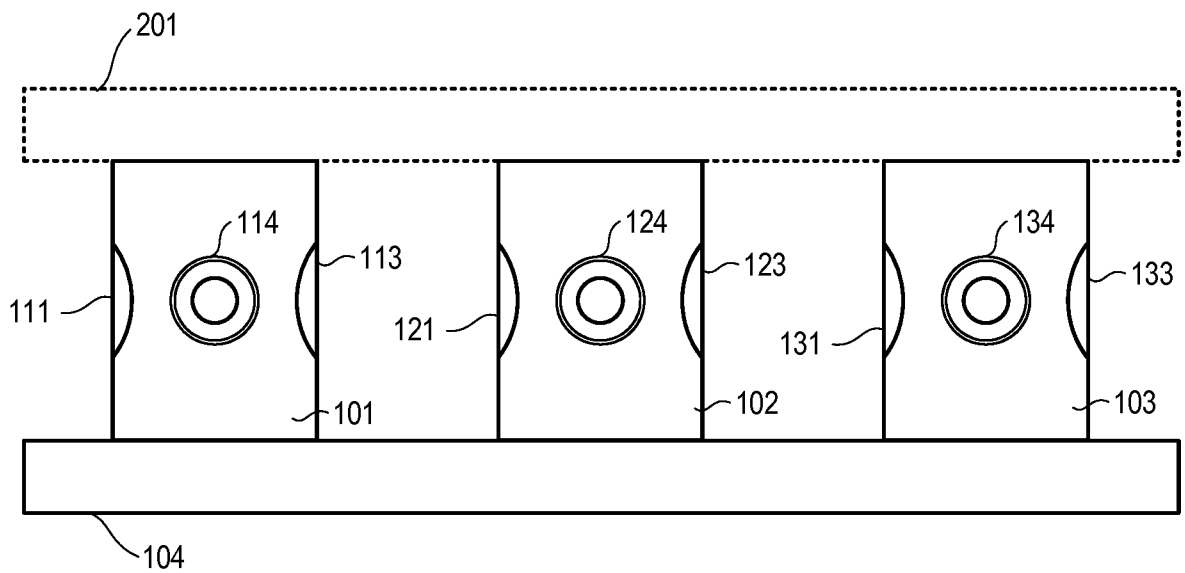


FIG 2

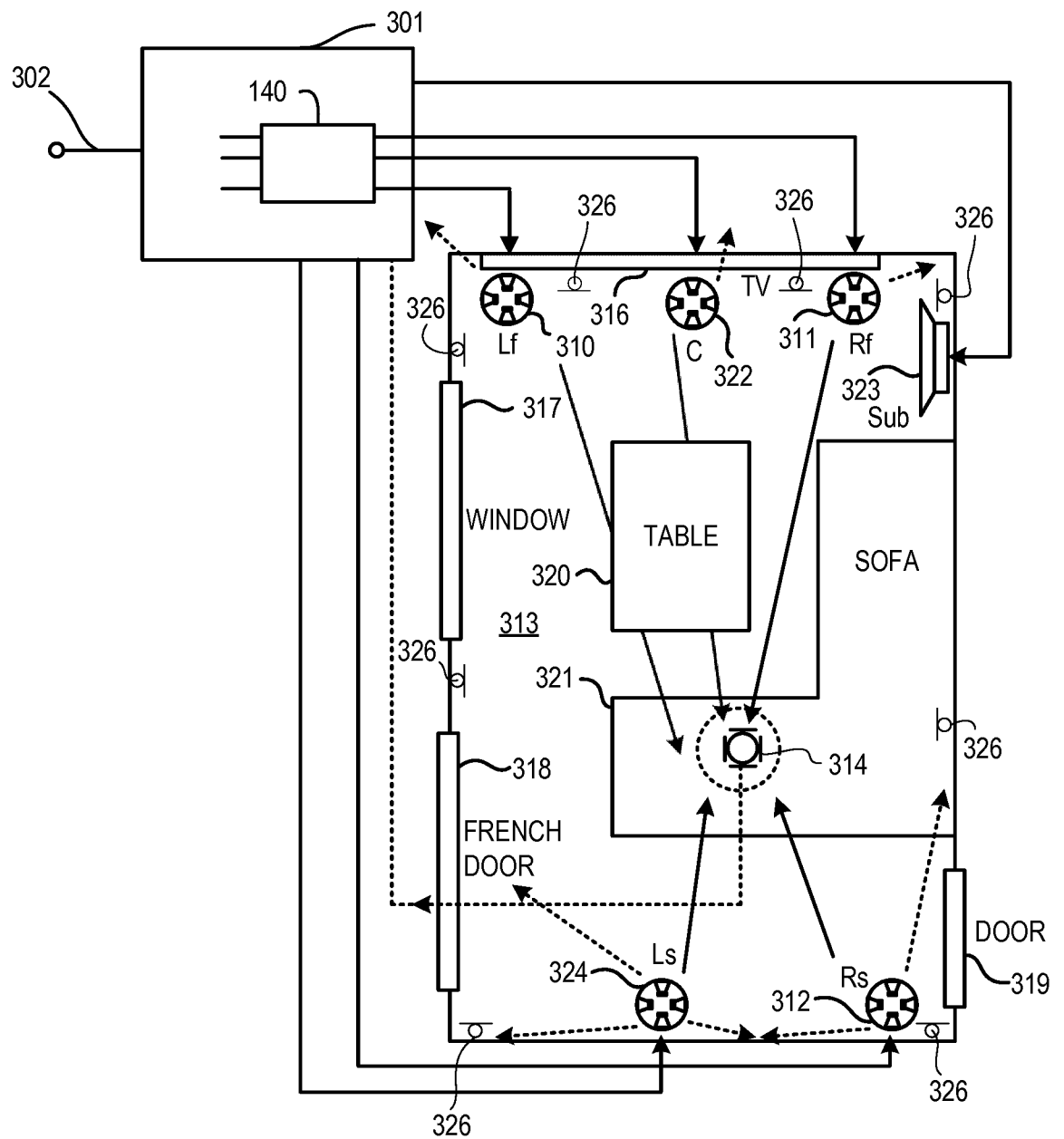


FIG 3

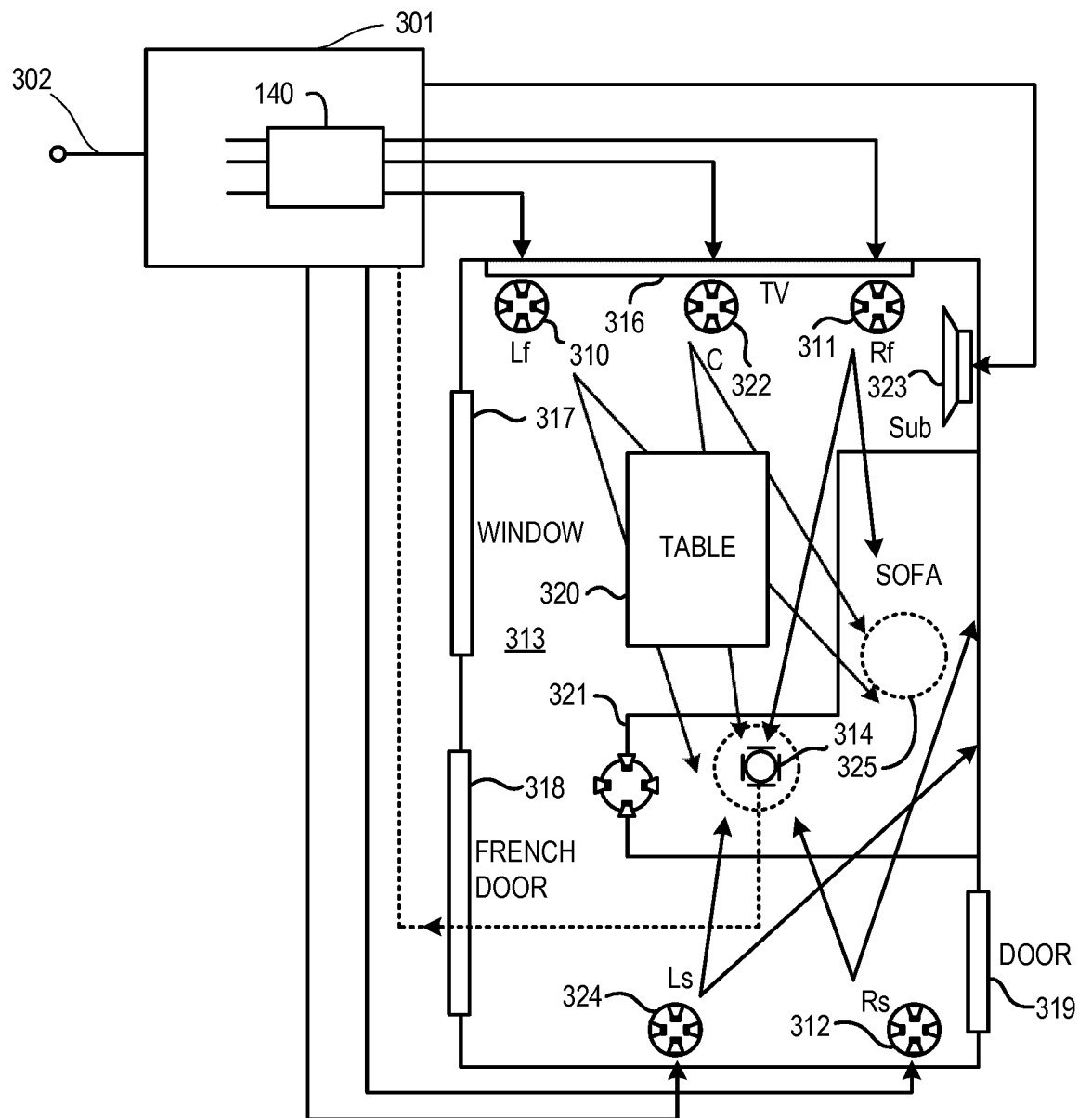


FIG 4

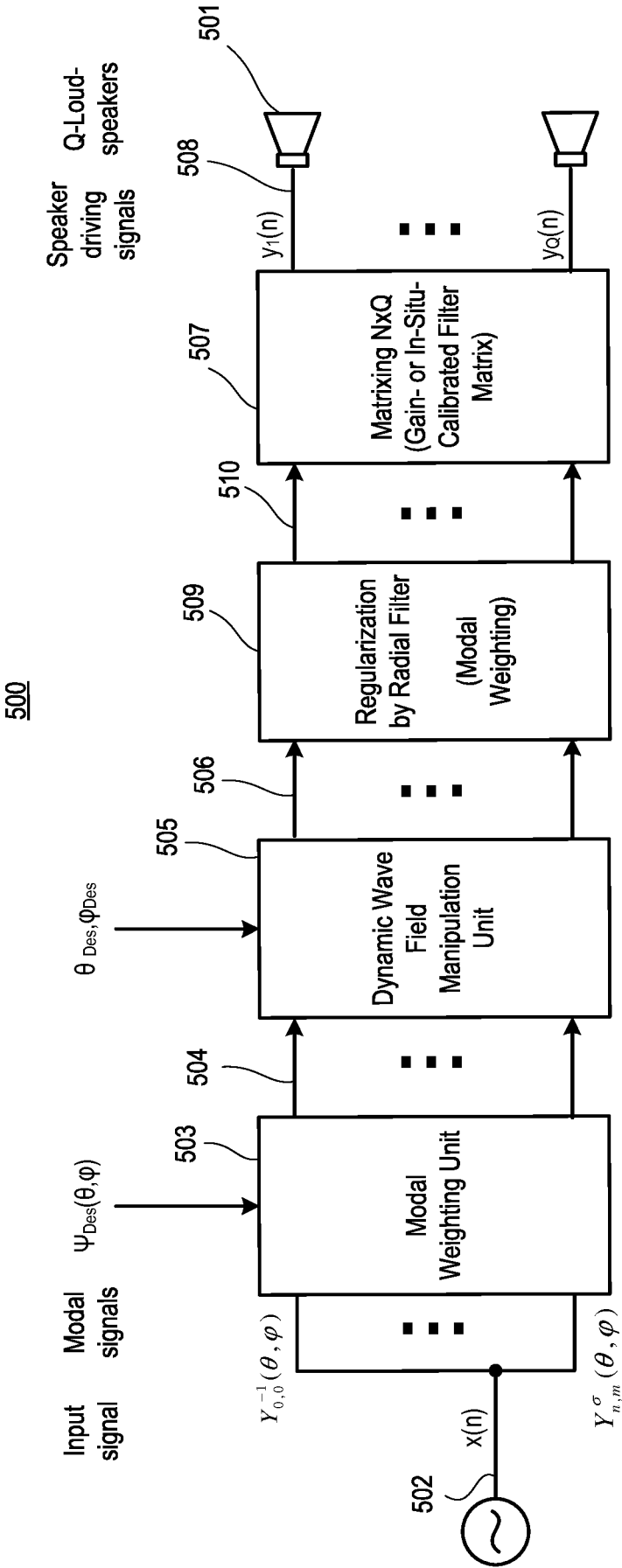


FIG 5

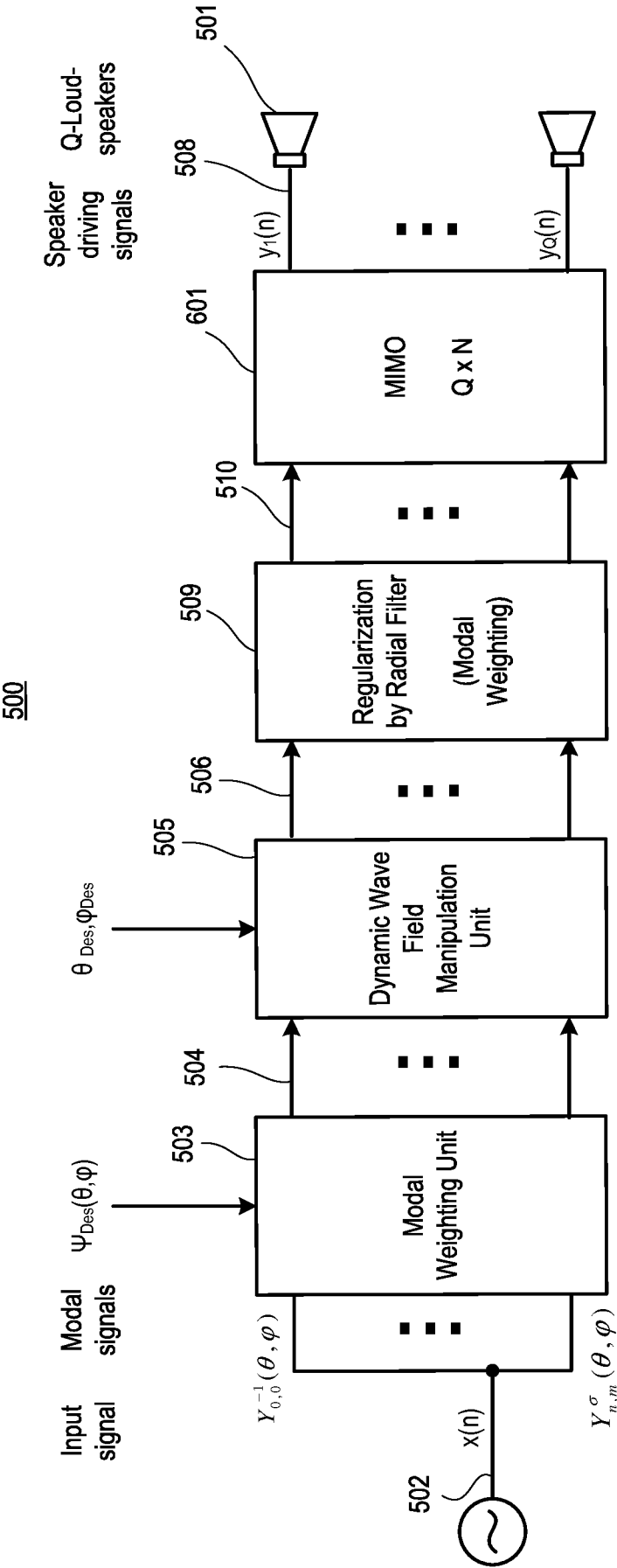


FIG 6

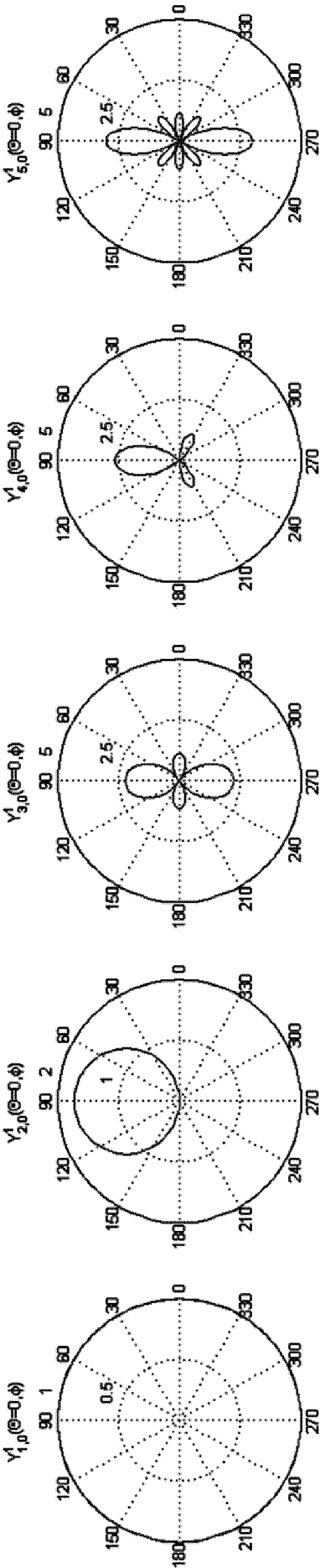


FIG 7

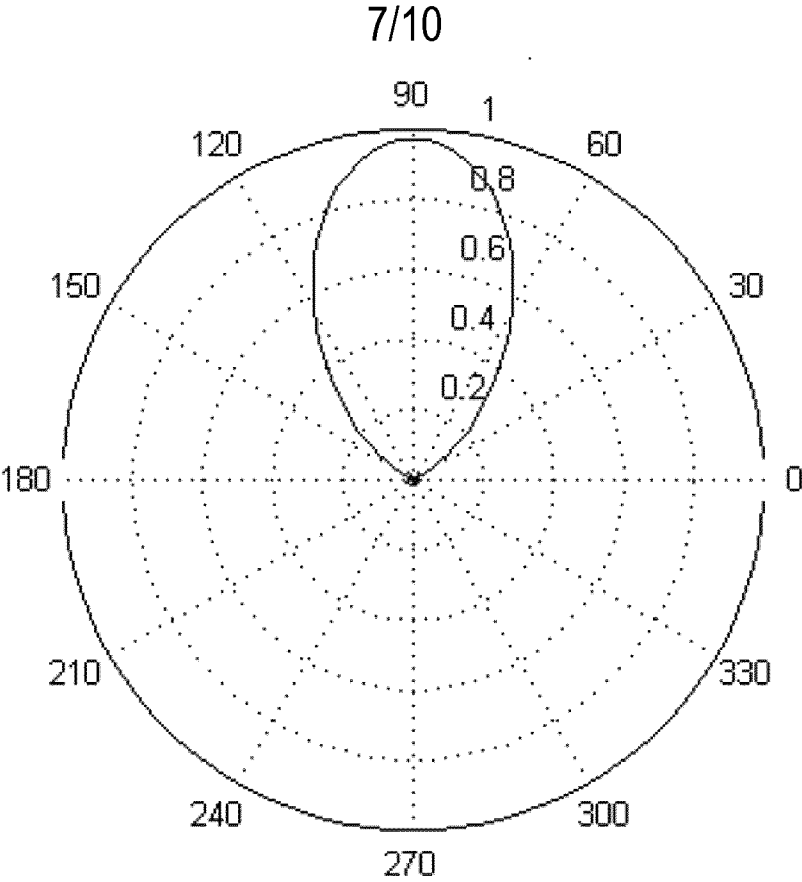


FIG 8

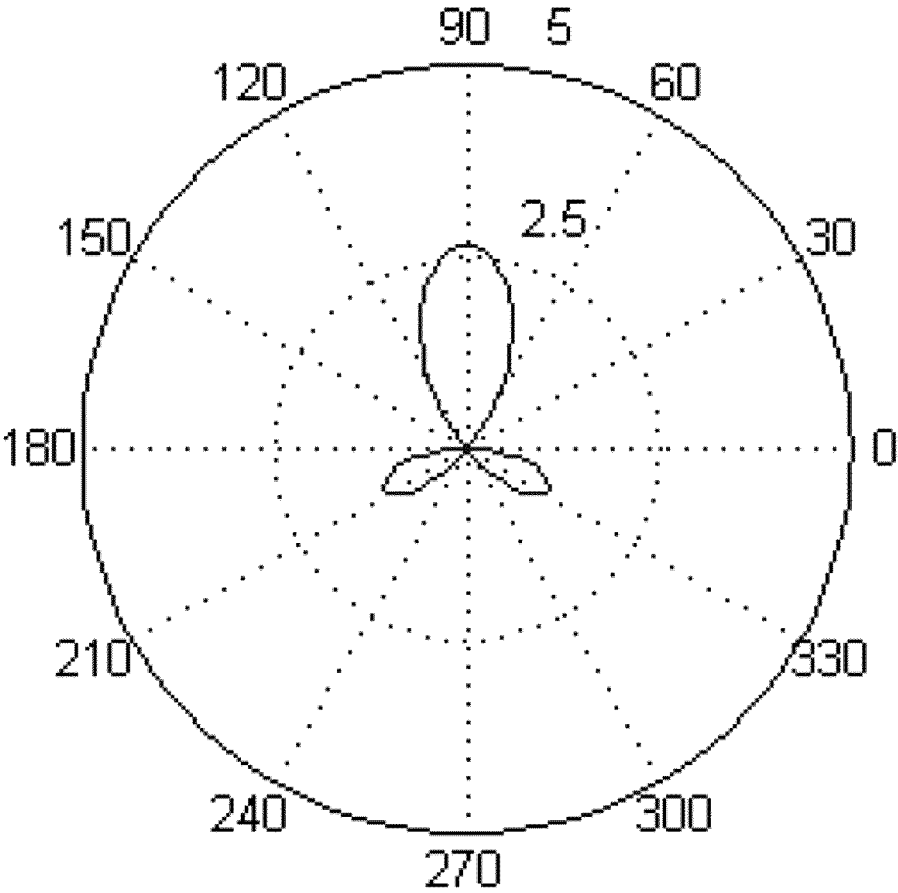


FIG 9

8/10

FIG 10

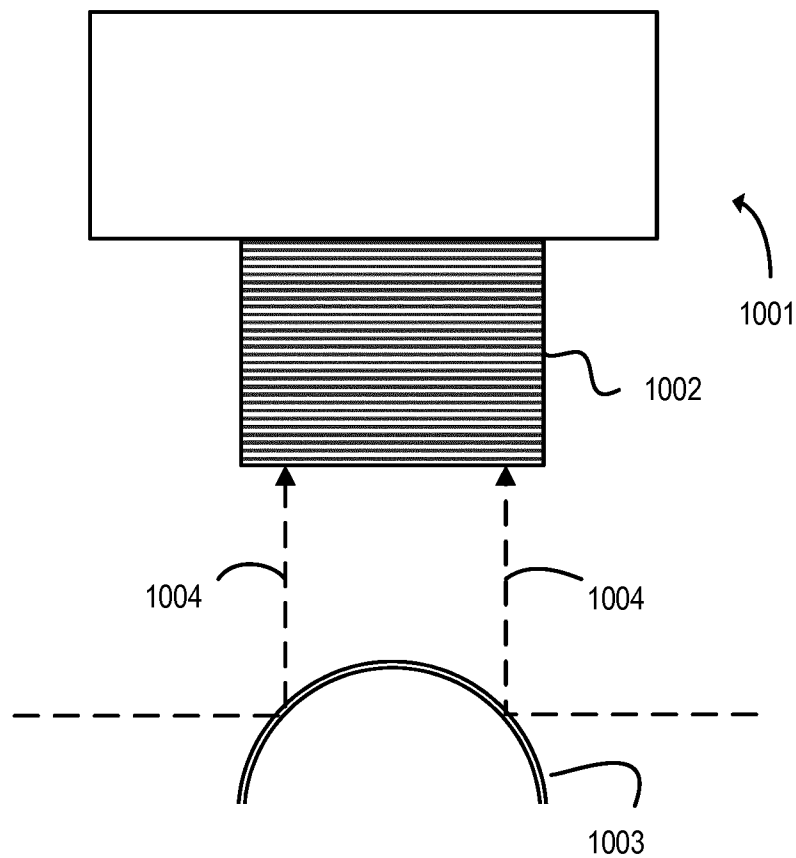


FIG 11

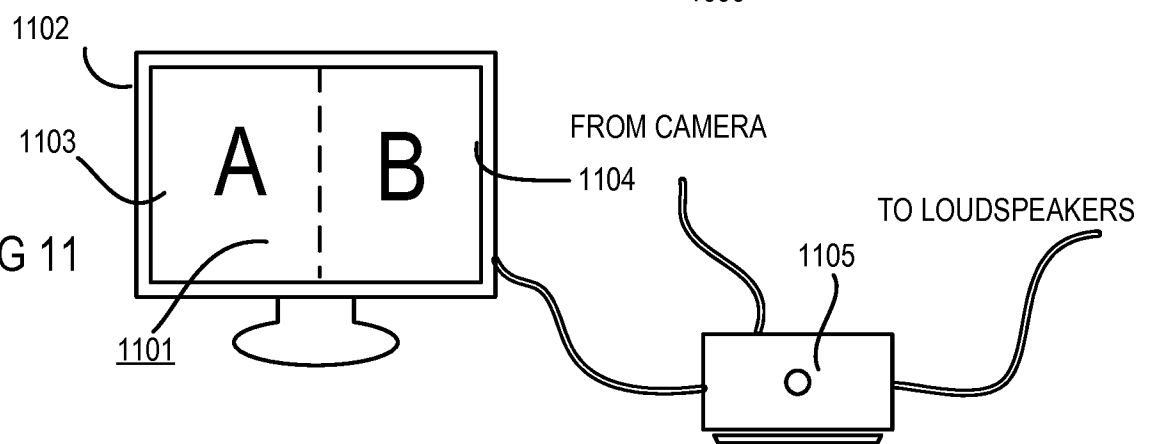
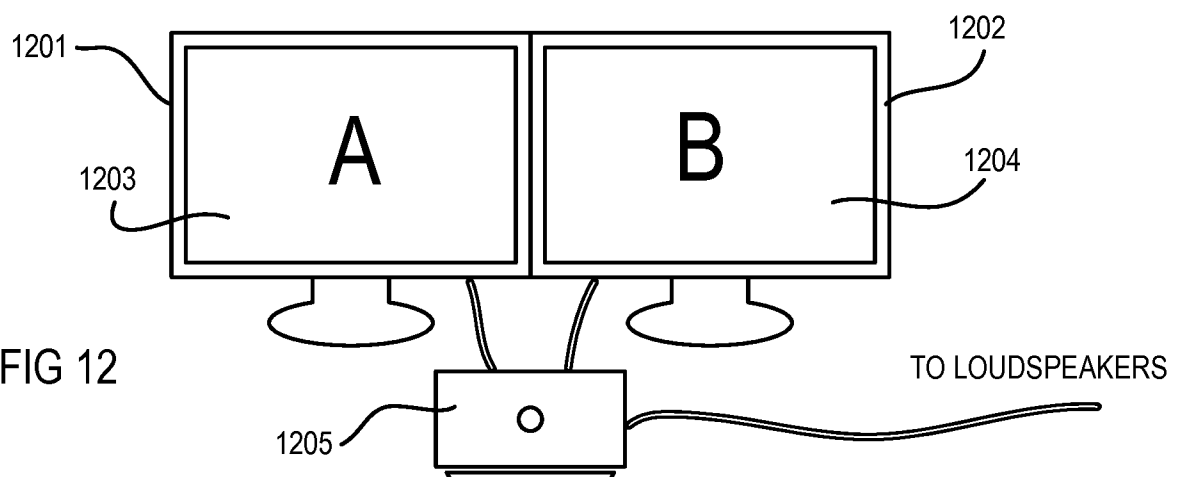
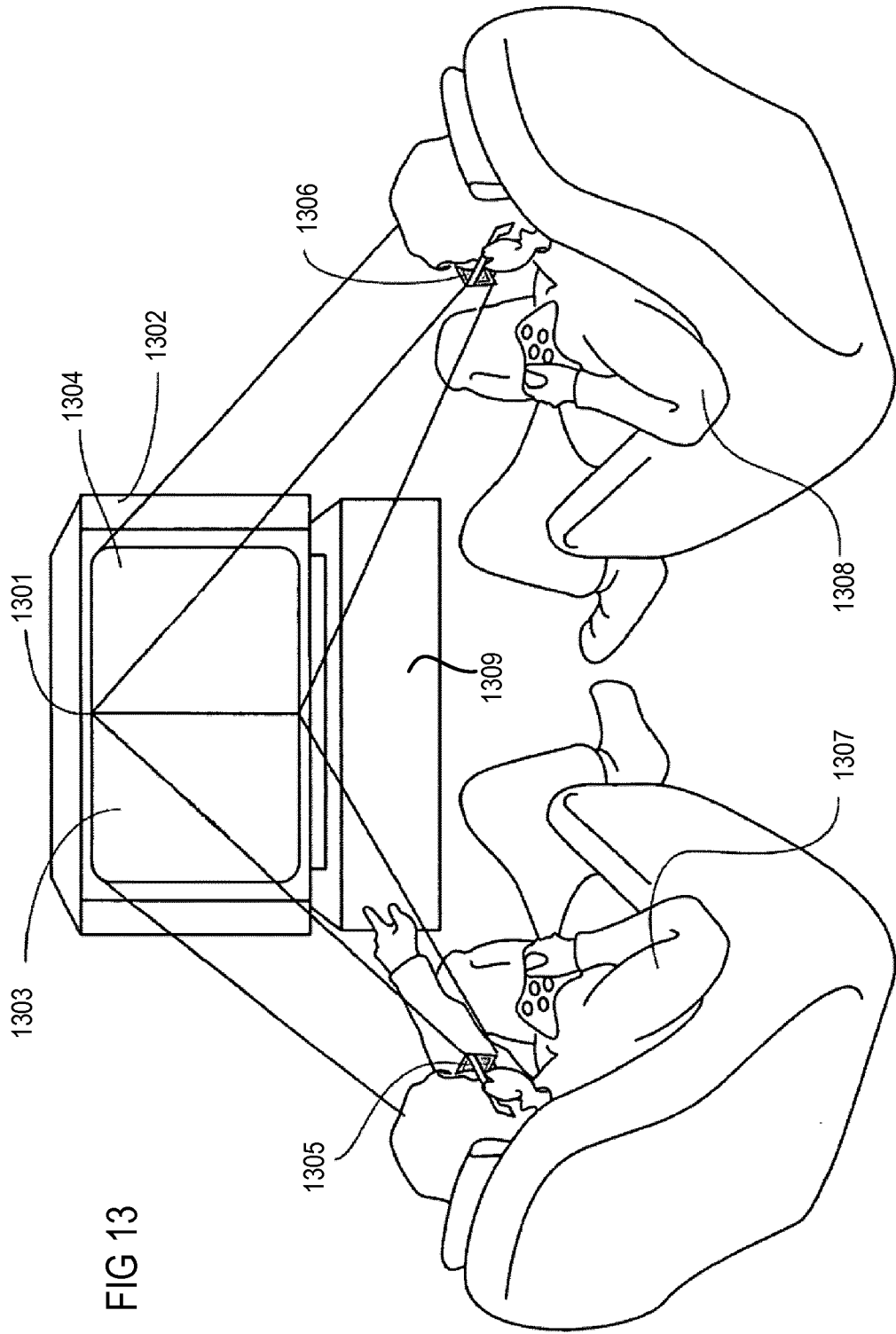
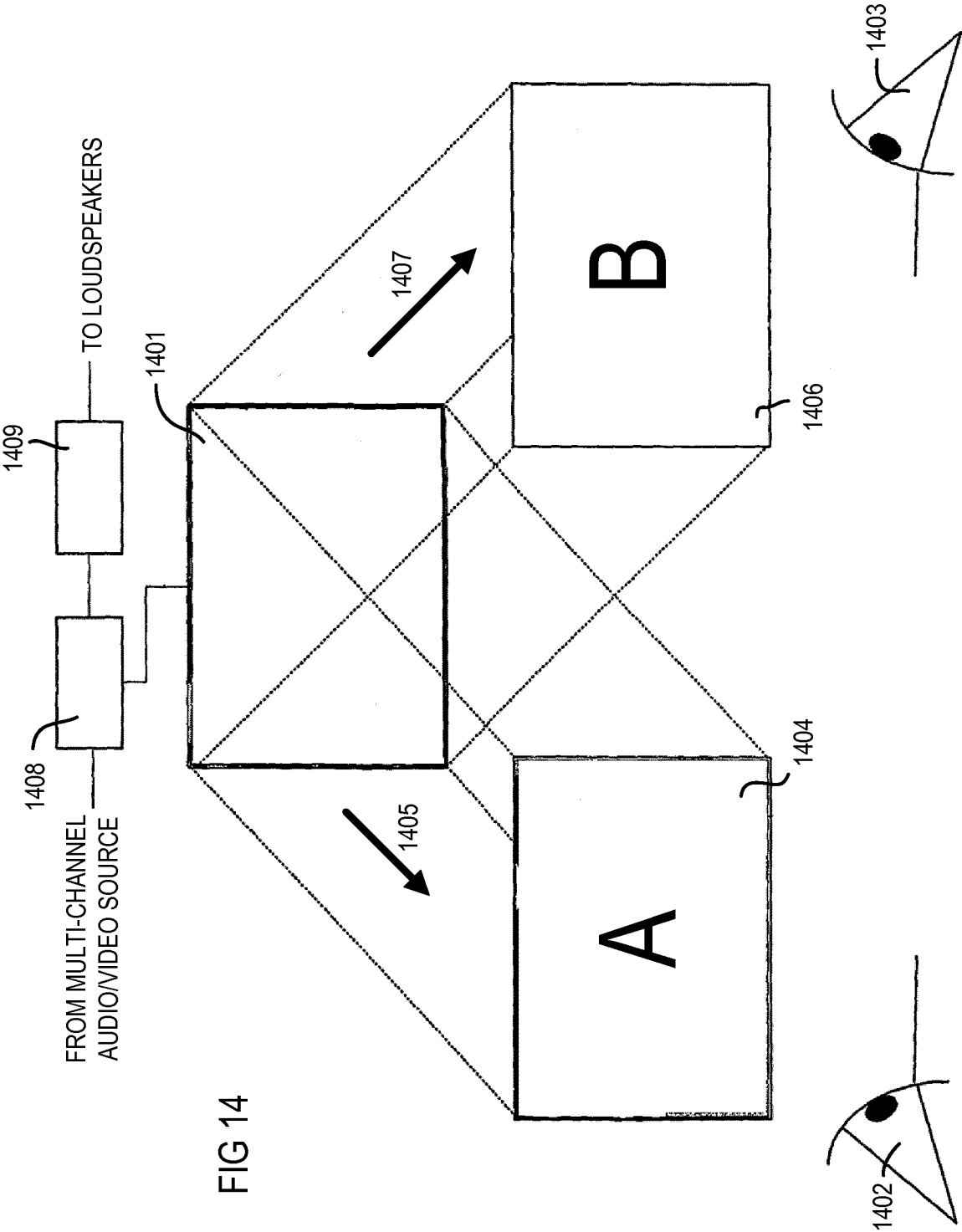


FIG 12







INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2016/081010

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04R1/32 H04R1/40
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 1 699 259 A1 (YAMAHA CORP [JP]) 6 September 2006 (2006-09-06) page 6, paragraph 24 - page 7, paragraph 38	1,5-8, 10-12,15
X	----- US 2007/092099 A1 (NAKANO KENJI [JP]) 26 April 2007 (2007-04-26) page 2, paragraph 20 - page 3, paragraph 32	1-4,9, 12-14
X	----- JP H11 27604 A (SANYO ELECTRIC CO) 29 January 1999 (1999-01-29) abstract	1,12



Further documents are listed in the continuation of Box C.



See patent family annex.

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

3 March 2017

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Authorized officer

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2016/081010

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