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(54) MANIFOLD FOR MULTIPLE COMPRESSION DRIVERS WITH A SINGLE POINT SOURCE EXIT

(71) Applicant: **Harman International Industries, Inc**, Stamford, CT (US)

(72) Inventor: **Douglas J. BUTTON**, Simi Valley, CA (US)

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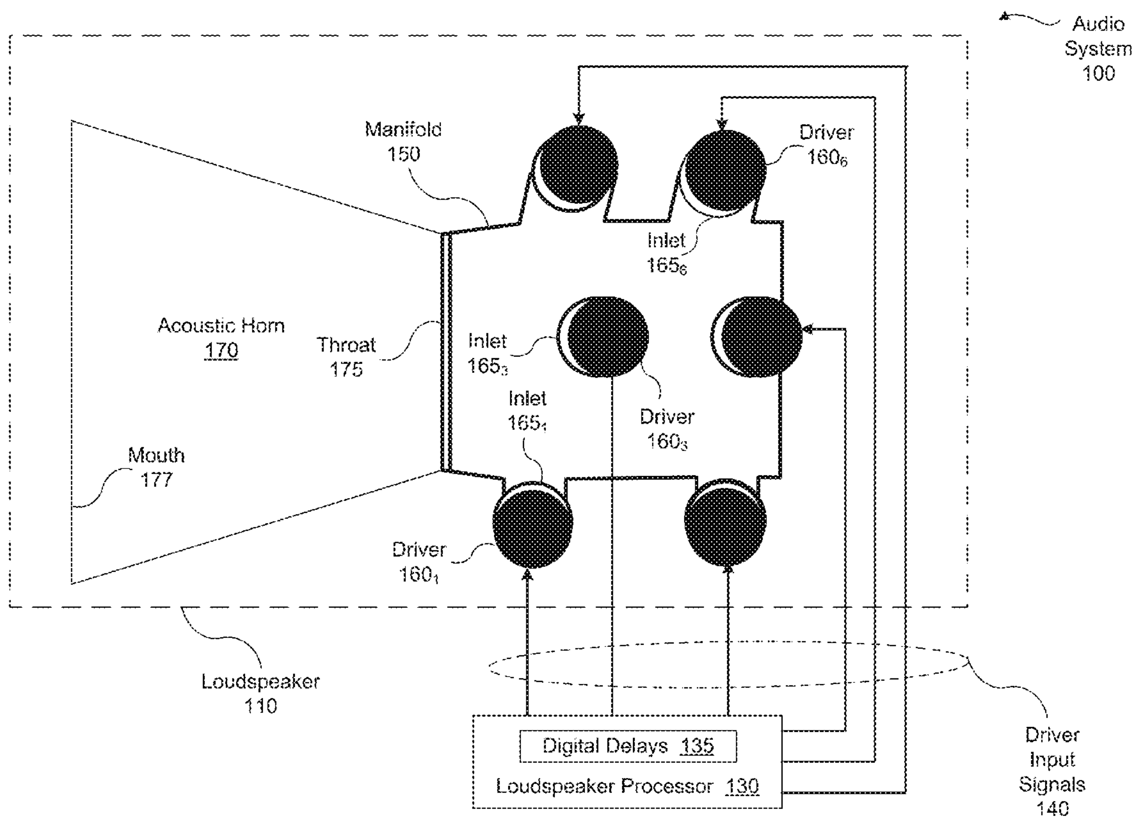
(57) **ABSTRACT**

In one embodiment of the present invention, a manifold composites sound from multiple drivers into a single aperture that includes multiple concentric rings. In operation, channels within the manifold isolate the sound generated by each driver from the sound generated by the other drivers. The channels within the manifold are intertwined to route the sound from each driver to a separate location in one of the multiple concentric rings. When the sound generated by each of the drivers is judiciously and deterministically delayed, the manifold generates a single point source of sound that may be fed into an acoustic horn. Notably, by isolating the sound generated by each driver, the manifold minimizes reflections and resonances that often degrade the sound fidelity of conventional horn loudspeakers. Consequently, the disclosed manifold enables an acoustic horn to project coherent sound for significantly longer distances than the acoustic horn would achieve using a conventional manifold.



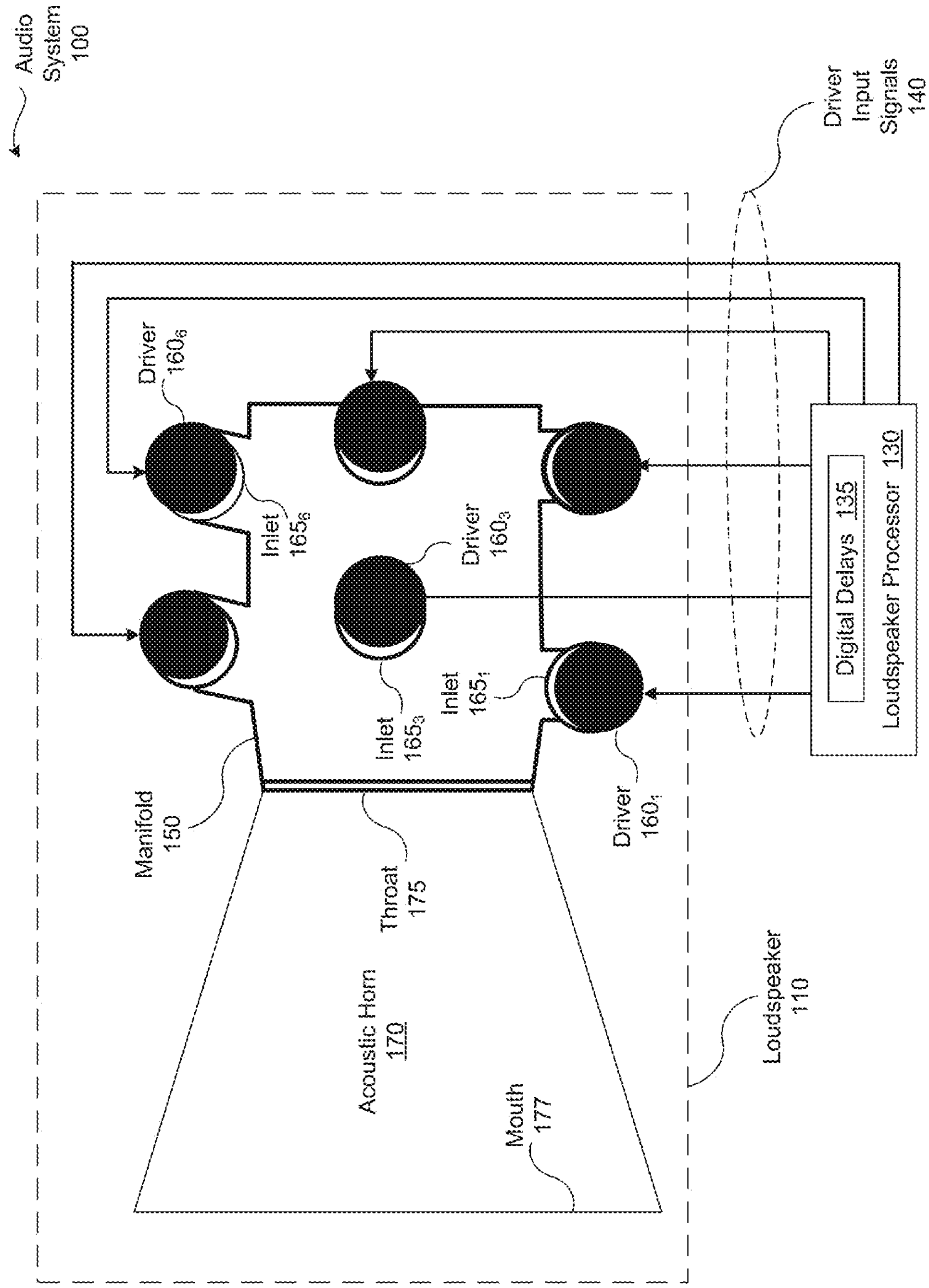

Audio System 100
Driver Input Signals 140
Driver 160₆
Inlet 165₆
Driver 160₃
Inlet 165₃
Inlet 165₁
Driver 160₁
Digital Delays 135
Loudspeaker Processor 130
Manifold 150
Throat 175
Acoustic Horn 170
Mouth 177
Loudspeaker 110

FIGURE 1

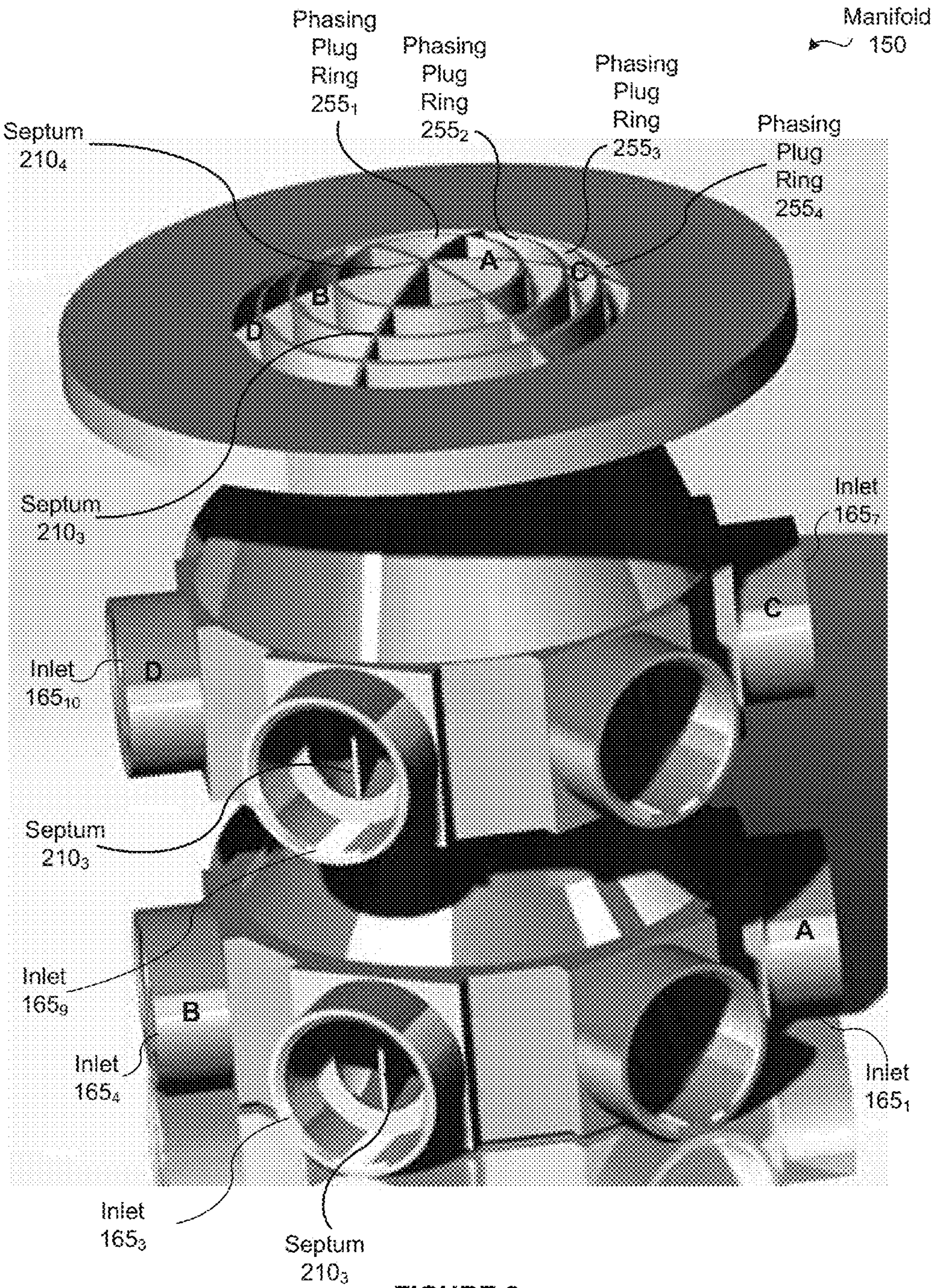

Manifold 150
Phasing Plug Ring 255_1
Phasing Plug Ring 255_2
Phasing Plug Ring 255_3
Phasing Plug Ring 255_4
Septum 210_4
A
B
C
D
Septum 210_3
Inlet 165_7
C
Inlet 165_{10}
D
Septum 210_3
A
Inlet 165_9
B
Inlet 165_4
Inlet 165_1
Inlet 165_3
Septum 210_3

FIGURE 2

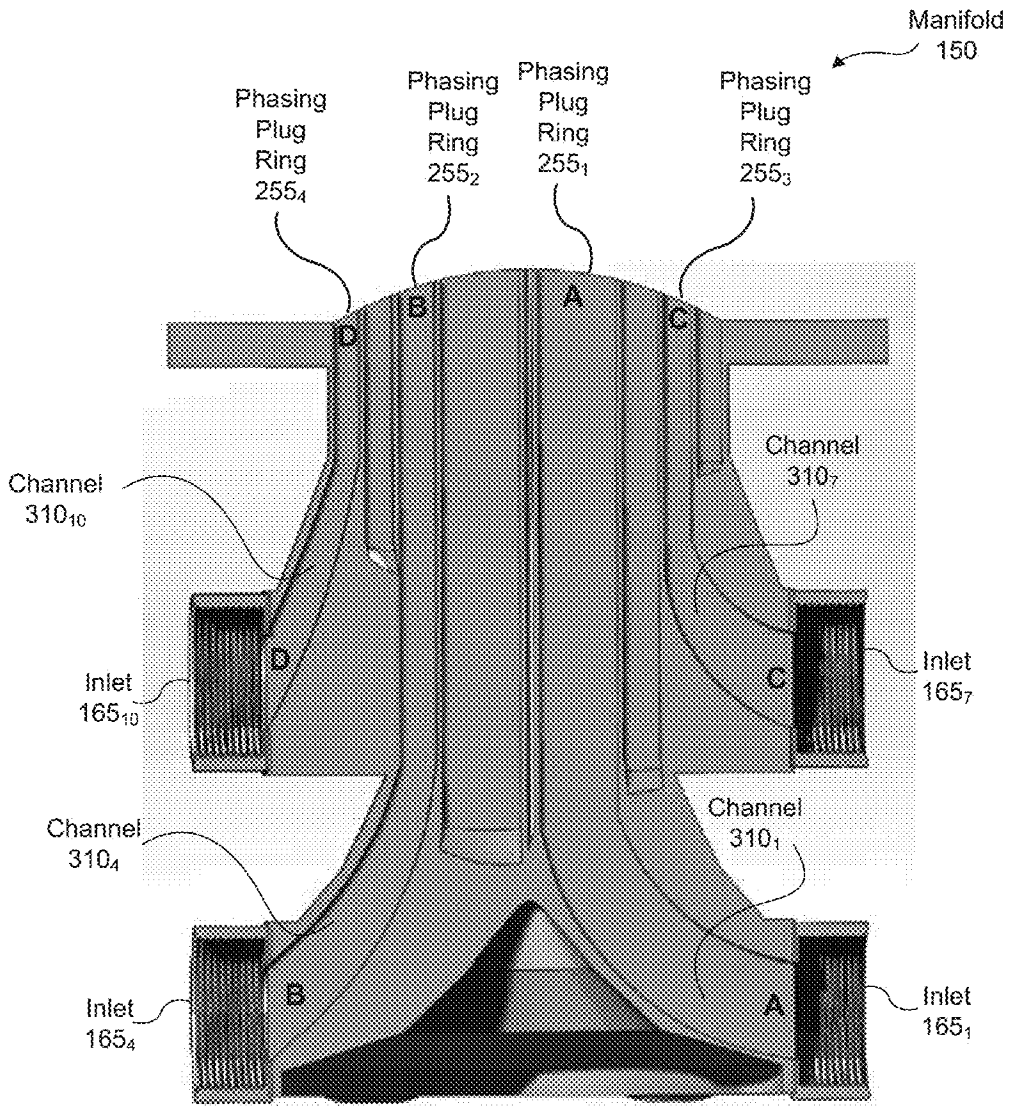

Manifold
150
Phasing
Plug
Ring
255_4
Phasing
Plug
Ring
255_2
Phasing
Plug
Ring
255_1
Phasing
Plug
Ring
255_3
D
B
A
C
Channel
310_{10}
Channel
310_7
Inlet
165_{10}
D
C
Inlet
165_7
Channel
310_4
Channel
310_1
Inlet
165_4
B
A
Inlet
165_1

FIGURE 3

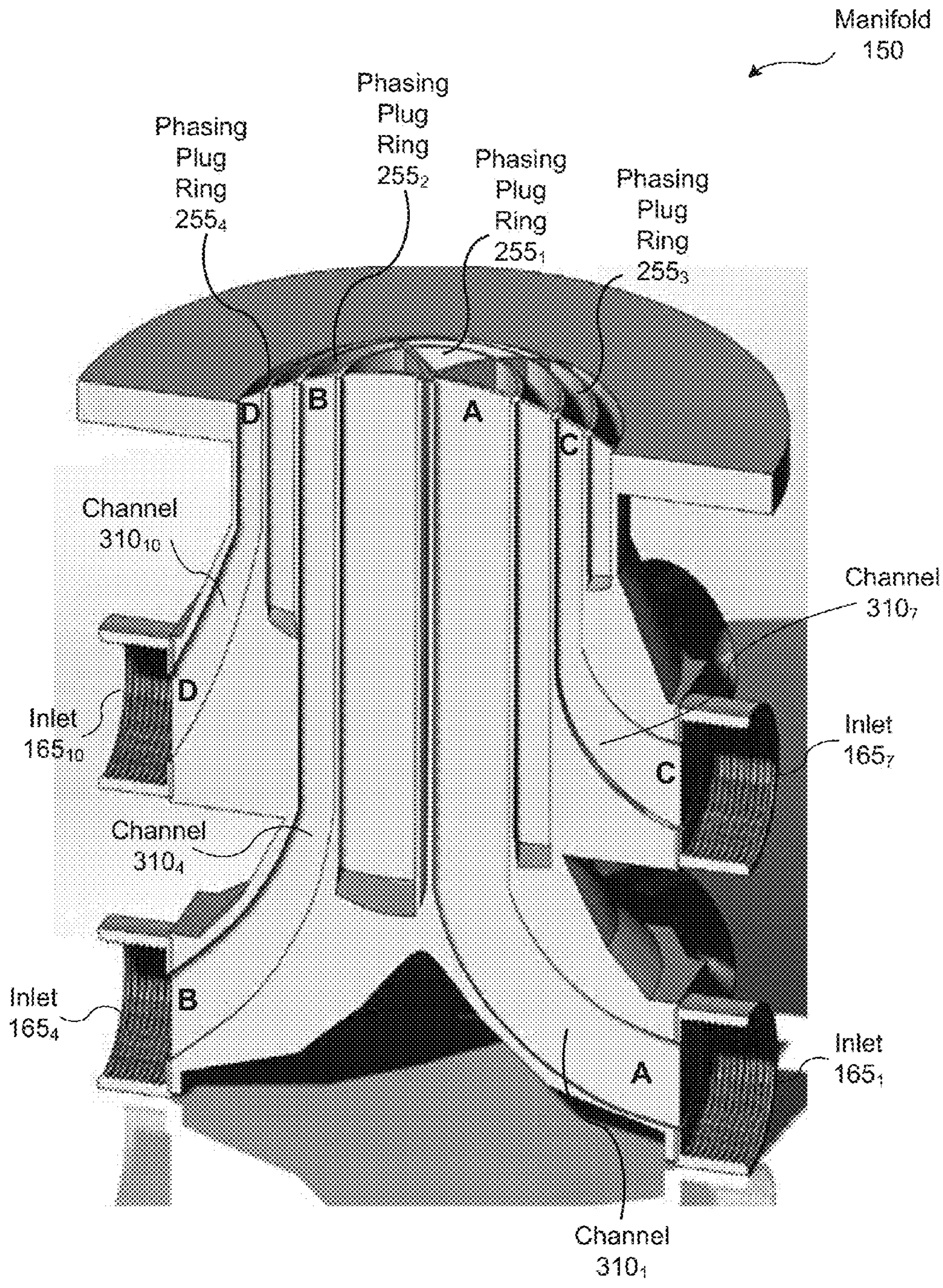
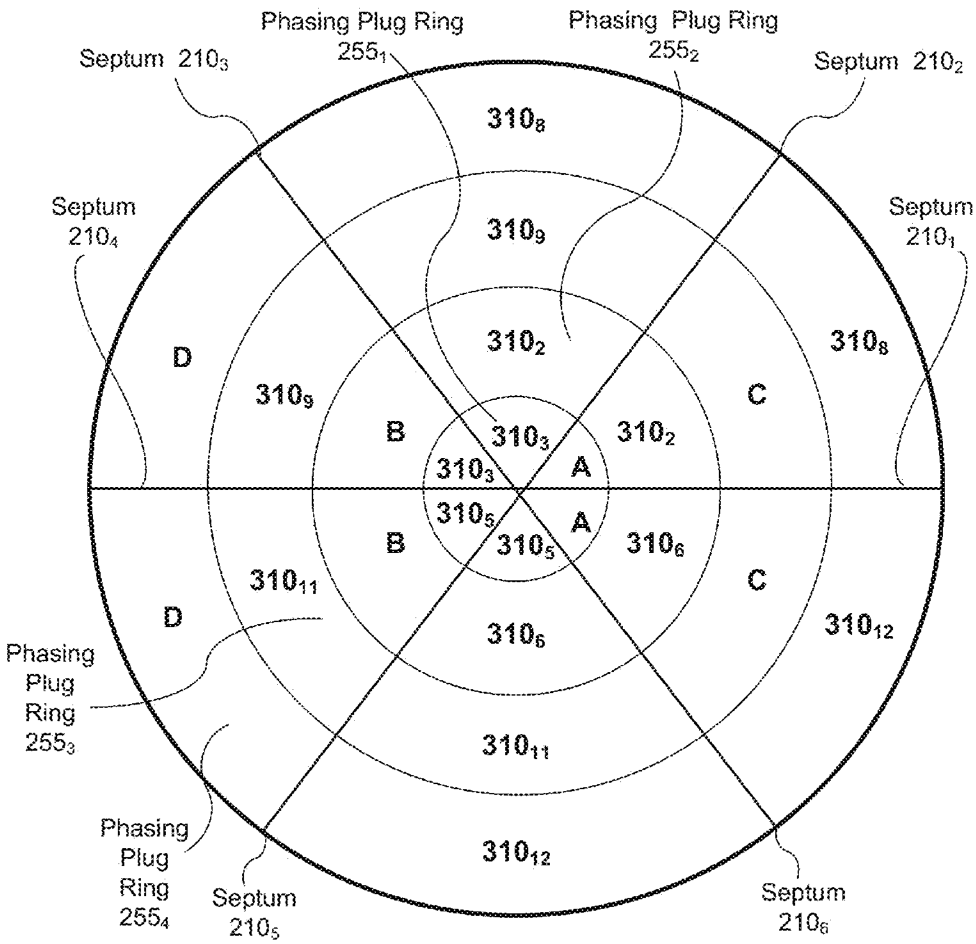

Manifold
150
Phasing
Plug
Ring
255_4
Phasing
Plug
Ring
255_2
Phasing
Plug
Ring
255_1
Phasing
Plug
Ring
255_3
D
B
A
C
Channel
310_{10}
Channel
310_7
Inlet
165_{10}
D
Inlet
165_7
C
Channel
310_4
Inlet
165_4
B
Inlet
165_1
A
Channel
310_1

FIGURE 4



Channel Length / Time Delay Constraints 555					
Group	Phasing Plug Ring	Channel Length / Time Delay	Drivers		
A	255_1	$length_1$ / $time_1$	160_1	160_3	160_5
B	255_2	$length_2$ / $time_2$	160_2	160_4	160_6
C	255_3	$length_3$ / $time_3$	160_7	160_9	160_{11}
D	255_4	$length_4$ / $time_4$	160_8	160_{10}	160_{12}

FIGURE 5

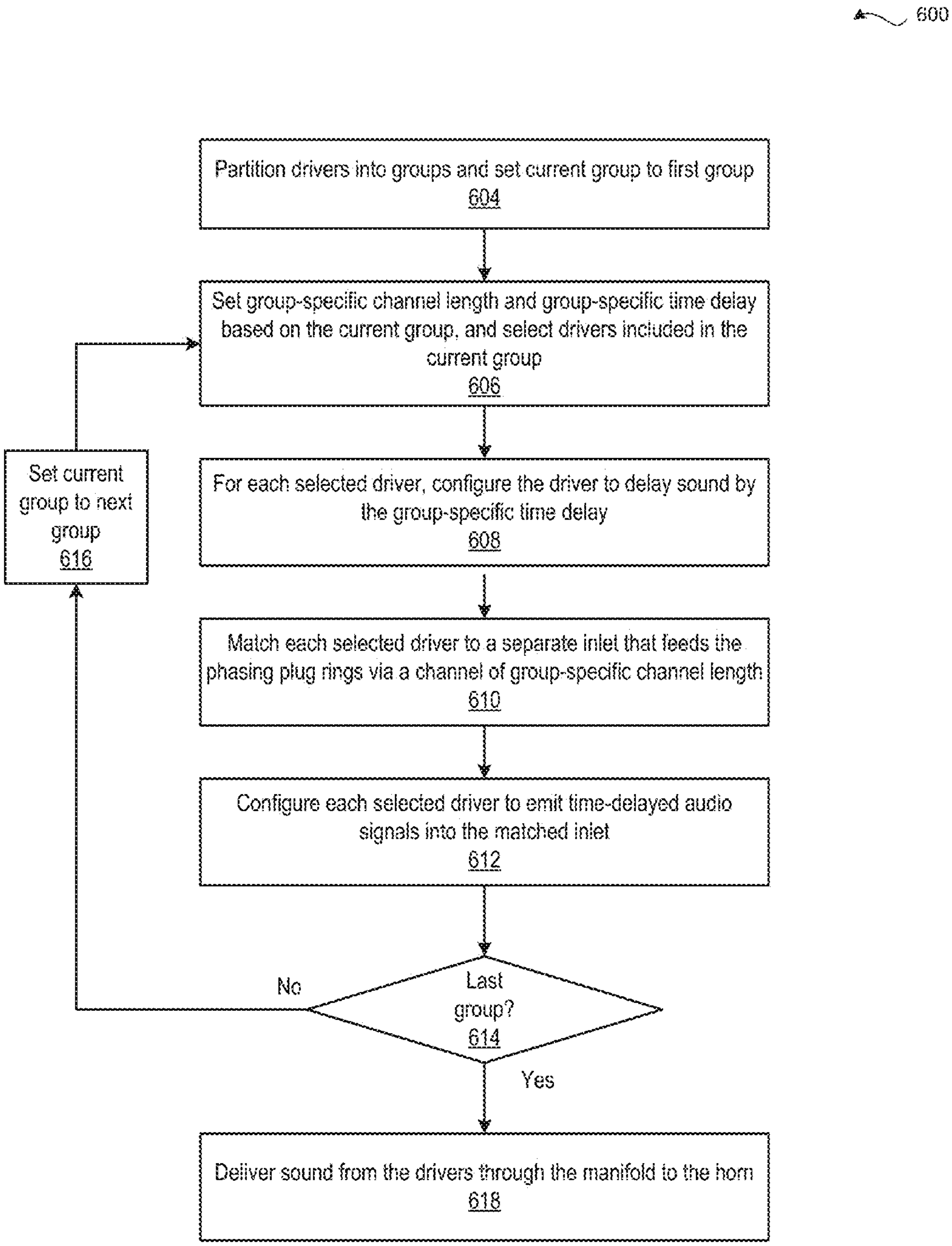

600
Partition drivers into groups and set current group to first group
604
Set group-specific channel length and group-specific time delay based on the current group, and select drivers included in the current group
606
For each selected driver, configure the driver to delay sound by the group-specific time delay
608
Match each selected driver to a separate inlet that feeds the phasing plug rings via a channel of group-specific channel length
610
Configure each selected driver to emit time-delayed audio signals into the matched inlet
612
Last group?
614
No
Yes
Set current group to next group
616
Deliver sound from the drivers through the manifold to the horn
618

FIGURE 6

MANIFOLD FOR MULTIPLE COMPRESSION DRIVERS WITH A SINGLE POINT SOURCE EXIT

BACKGROUND

[0001] Field of the Invention

[0002] Embodiments of the present invention relate generally to loudspeaker systems and, more specifically, to a manifold for multiple compression drivers with a single point source exit.

[0003] Description of the Related Art

[0004] Multiple compression drivers are commonly used to drive acoustic horns in loudspeakers that are designed to project sound for relatively long distances. For example, a loudspeaker in a public address system that is capable of projecting sound for hundreds of feet would typically include numerous compression drivers. However, when two compression drivers emit sound waves, the sound waves may generate acoustical reflections and interference. Such reflections and interference can lead to comb filtering (i.e., reinforcement of some sound waves and cancellation of other sound waves) and/or acoustic interference patterns that compromise the fidelity and intelligibility of the overall sound for the audience.

[0005] In an effort to achieve high sound pressure levels and, consequently, audio volumes while reducing comb filtering and acoustic interference patterns, various techniques for arranging multiple compression drivers have been employed. In such techniques, multiple compression drivers are usually mounted in a manifold that delivers sound to the throat end of the acoustic horn of the loudspeaker. In one such design, four compression drivers can be arranged within a relatively small manifold area. Two of the compression drivers form a skewed (i.e., "Y") configuration, and the other two compression drivers are directly opposed to each other. With this overall configuration, the manifold routes the sound waves from the skewed drivers at angles of approximately forty-five degrees, reflects the sound waves from the opposed drivers at approximately ninety degrees, and then combines the four resulting sound waves to create an aggregated sound.

[0006] One drawback of this particular approach is that acoustic reflections and interference still persist within the manifold that can degrade the overall quality of the sound emanating from the manifold. In particular, the interactions of the four sound waves within the manifold can produce artifacts, such as crossmodes, that remain present when the four waveforms are combined. Those crossmodes and other similar artifacts degrade the quality of the sound ultimately produced via the manifold, which hinders the ability to produce high fidelity sound. In general, conventional approaches to combining multiple compression drivers suffer similar sound degradation that is attributable to interference and/or reflections within the manifold.

[0007] As the foregoing illustrates, more effective techniques for generating high fidelity sound through loudspeakers would be useful.

SUMMARY

[0008] One or more embodiments set forth include a manifold for a loudspeaker. The manifold includes multiple inlets, where each inlet is designed to receive sound waves from a different compression driver; an output section that includes multiple concentric rings and is designed to deliver a point source of sound to a throat section of an acoustic horn; and a first channel that is configured to guide sound waves received at a first inlet to a first location within a first concentric ring and to isolate the sound waves received at the first inlet from sound waves received at the other inlets.

[0009] Other embodiments include, without limitation, a method to implement one or more of the aspects of the disclosed methods as well as a speaker configured to implement one or more of the aspects of the disclosed methods.

[0010] At least one advantage of the disclosed techniques is they enable loudspeakers to combine compression drivers in a manner that minimizes both comb filtering and acoustic interference patterns that can compromise the fidelity and intelligibility of the overall sound. As a result such loudspeakers generate high sound pressure levels without suffering from sound quality degradation typically associated with loudspeakers that are designed using conventional multi-driver techniques.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] So that the manner in which the above recited features of the present invention can be understood in detail, a more particular description of the invention, briefly summarized above, may be had by reference to embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only typical embodiments of this invention and are therefore not to be considered limiting of its scope, for the invention may admit to other equally effective embodiments.

[0012] FIG. **1** illustrates an audio system configured to implement one or more aspects of the various embodiments;

[0013] FIG. **2** is a three-dimensional (3D) view of the manifold of FIG. **1**, according to various embodiments;

[0014] FIG. **3** is a two-dimensional (2D) cross-section of the 3D view of FIG. **2**, according to various embodiments;

[0015] FIG. **4** is a second two-dimensional (2D) cross-section of the 3D view of FIG. **2**, according to various embodiments;

[0016] FIG. **5** is a more detailed illustration of the phasing plug rings depicted in FIG. **2**, according to various embodiments; and

[0017] FIG. **6** is a flow diagram of method steps for configuring a loudspeaker for operation, according to various embodiments.

DETAILED DESCRIPTION

[0018] In the following description, numerous specific details are set forth to provide a more thorough understanding of the present invention. However, it will be apparent to one of skill in the art that the present invention may be practiced without one or more of these specific details.

Audio System

[0019] FIG. **1** illustrates an audio system **100** configured to implement one or more aspects of the various embodiments. As shown, the audio system **100** includes, without limitation, a loudspeaker **110** and a loudspeaker processor **130**. In alternate embodiments, the audio system **100** may include any number of loudspeakers **110** and any number of loudspeaker processors **130**. Further, the loudspeaker processor **130** may be integrated into the loudspeaker **110** or replaced with any other integrated or stand-alone control unit. In various embodiments, the audio system **100** may include any number and type of audio equipment in any combination.

[0020] The loudspeaker **110** is a "horn" loudspeaker that is designed to transform electrical audio signals into sounds characterized by relatively high sound pressure levels. Accordingly, horn loudspeakers are widely used in audio systems that are tailored to deliver intelligible sound volumes to audiences dispersed across large areas, such as public address systems in auditoriums. As shown, the loudspeaker **110** includes, without limitation, a manifold **150** and an acoustic horn **170**.

[0021] To facilitate the generation of high sound pressure levels, the manifold **150** includes multiple inlets **165**. Although only six of the inlets **165** are visible in FIG. **1**, the manifold **150** also includes six inlets **165** that are "hidden" from view. In operation, each of the inlets **165** receives sound waves generated by a separate driver **160** (also known as a compression driver). The manifold **150** guides the sound waves from the inlets **165** to a throat **175** of the acoustic horn **170**. As the sound waves travel from the relatively narrow throat **175** to a relatively wide mouth **177** of the acoustic horn **170**, the gradual increase in width of the acoustic horn **170** effectively increases the efficiency of the drivers **160**. In this fashion, the loudspeaker **110** coherently combines the sound waves produced by the drivers **160** to provide high sound pressure levels in a relatively small footprint.

[0022] In alternate embodiments, the loudspeaker **110** may include any number of driver **160**/inlet **165** pairs (i.e., the driver **160** connected to the inlet **165**), and the inlets **165** may be distributed in any fashion across the manifold **150**. The manifold **150** may be created in any technically feasible fashion and using any types of material in any combination. For example, and without limitation, three-dimensional (3D) printing techniques may be used to generate the manifold **150** from industrial grade plastic material. Further, each inlet **165** may be coupled to the corresponding driver **160** is any technically feasible fashion. For example, and without limitation, in some embodiments the inlets **165** may include female threads, the drivers **160** may include male threads, and as part of assembling the loudspeaker **110**, the drivers **160** may be screwed into the inlets **165**.

[0023] In conventional multiple driver horn loudspeakers, to achieve high sound pressure levels at the mouth of the acoustic horn, the fidelity of the overall sound emitted by the loudspeaker is compromised. More specifically, although typical manifolds in such loudspeakers attempt to judiciously control the sound waves generated by the drivers, the sound waves are subject to interference and reflections within the manifold that often lead to unexpected and uncompensated interactions between sound waves. The combinations of such uncompensated side-effects incurred as the sound waves travel through the manifold will noticeably degrade the sound quality for the audience.

Generating Coherent Sound

[0024] To address the foregoing concerns, the manifold **150** is designed to minimize reflections, resonances, and undesirable sound wave interactions within the manifold **150**, and then emit a single point source of sound (e.g., a relatively small emission region that drives the throat **175** of the acoustic horn **170**). As is well known, a single point source of sound provides highly coherent sound. Because the manifold **150** both maintains the integrity of the sound waves travelling through the manifold **150** and then delivers the sound waves as a single point source of sound, the manifold **150** provides high sound pressure levels while optimizing the sound quality.

[0025] To minimize sound wave interactions within the manifold **150**, the manifold **150** includes internal channels (not shown in FIG. **1**) that isolate the sound waves generated by each of the drivers **160** from the sound waves generated by the remaining drivers **160** throughout the manifold **150**. Further, to minimize reflections, crossmodes, and resonances, each of these channels is relatively thin. For example, and without limitation, in some implementations the channel width is no greater than half of the highest wavelength that is intended to be reproduced by the loudspeaker **110**.

[0026] Each of the channels terminates in at least one "slot" (i.e., narrow apertures) that subdivide one of multiple phasing plug rings (not shown in FIG. **1**)—a series of concentric rings that, together, define where the isolated sound waves exit the manifold **150** and enter the throat **175** of the acoustic horn **170**. For example, and without limitation, in some embodiments, the manifold **150** includes four phasing plug rings, each of the phasing plug rings is subdivided into three slots, and each of the twelve inlets **165** is connected via a channel to one of the slots in one of the phasing plug rings. In this fashion, the manifold **150** ensures that the sound waves from each of the drivers **160** are isolated from where the sound waves enter the manifold **150** at the inlet **165** to a corresponding slot in one of the phasing plug rings where the sound waves exit the manifold **150**. Advantageously, this structure dramatically reduces the multipath wave propagation that is characteristic of sound waves travelling through conventional manifolds.

[0027] The length travelled by the sound waves emitted from each of the drivers **160** to reach the phasing plug ring depends on the routing of the channel within the manifold **150**, the location of the corresponding inlet **165** and the location of the slot and the phasing plug ring. To facilitate time-alignment of sound waves that travel through channels of differing lengths and, consequently, increase the coherence of the sound that exits the manifold **150**, each inlet **165** included in the manifold **150** is associated with a time delay that compensates for the differing channel lengths. In some embodiments, to simplify the time-alignment process, the channels are interwoven in a pattern that subdivides the channels into groups, where the channels in a particular group are characterized by an equal length and a corresponding per-group time delay. For example, and without limitation, in one embodiment, for each phasing plug ring, the phasing plug ring is associated with a group and the manifold **150** is structured such that the channels that terminate at the phasing plug ring are of substantially the same length.

[0028] In operation, to ensure that the sound waves from each of the drivers **160** exit the manifold **150** at substantially the same time, the loudspeaker processor **130** is configured to apply appropriate digital delays **135** to the electrical audio signals that are to be broadcast via the loudspeaker **150**. The resulting signals, shown as driver input signals **140**, are routed in any technically feasible fashion (e.g., speaker wiring, etc.) to the corresponding drivers **160**. In general, the loudspeaker processor **130** is configured to impose the digital delays **135** that reflect the per-group time delays. For instance, and without limitation, the digital delays **135** that the loudspeaker processor **130** applies to the drivers **160** that drive relatively short channels are longer than the digital delays **135** that the loudspeaker processor **130** applies to the drivers **160** that are routed via relatively long channels. Performing these time-alignment operations enables the manifold **150** to deliver the optimized single point source of sound to the throat **175** of the acoustic horn **170** with a desired wave front curvature from flat to suitably spherical depending on the application.

[0029] In alternate implementations, the loudspeaker processor **130** may be replaced by any type of device that controls the inputs to the drivers **160**. Further the digital delays **135** may be replaced by any sort of delay mechanism that enables the time-alignment process, and the delay mechanism may be a stand-alone unit, integrated in the loudspeaker processor **130**, integrated into the drivers **160**, or applied via the manifold **150**.

[0030] For illustrative purposes, FIGS. **1-5** describe particular embodiments of the manifold **150**, the loudspeaker **110**, and the audio system **100**. It will be appreciated that the various units, including and without limitation, the manifold **150**, the loudspeaker **110**, and the audio system **100** shown herein are illustrative and that variations and modifications are possible. Notably, and without limitation, the manifold **150** may be of any size and shape that enables implementation of the general techniques (e.g., thin, isolated channels, time-alignment, etc.) described herein. In alternate embodiments, the manifold **150** may include, without limitation, any number of channels, the inlets **165**, and the drivers **160** disposed in any manner across the manifold **150**. Further, the manifold **150** may terminate in any number of the phasing plug rings, with any number of slots included in each of the phasing plug rings, and the number of slots may differ between the phasing plug rings. In other embodiments, the phasing plug rings may be implemented in some manner other than concentric rings that enables the manifold **150** to deliver a single point source of sound to the throat **175** of the acoustic horn **170**.

Three-Dimensional (3D) View of the Manifold

[0031] FIG. **2** is a three-dimensional (3D) view of the manifold **150** of FIG. **1**, according to various embodiments. In the manifold **150**, the inlets **165** are arranged into two rows that each include six of the inlets **165**. Although only six of the inlets **165** are visible in FIG. **1**, the manifold **150** also includes six inlets **165** that are "hidden" from view. The manifold **150** also includes four phasing plug rings **255**.

[0032] As shown, the manifold **150** includes, without limitation, six septa **210**. Each channel may have multiple divisions (e.g. septa **210**) to minimize channel width. Together, the septa **210** divide the phasing plug rings **255** into a total of twenty-four exit slots. The septa **210** then extend internally from the exit slots, defining the channels followed by wave forms that enter the manifold **150** via the inlets **165**. Notably, the septa **210** are interwoven in a manner such that each of the septa **210** serves as the "wall" for two of the channels and bisects another two of the channels. For example, and without limitation, the septum $\mathbf{210}_3$ serves as the left wall of the inlets $\mathbf{165}_2$ (situated on the bottom row) and $\mathbf{165}_8$ (situated on the top row), serves as the right wall of the inlets $\mathbf{165}_4$ (situated on the bottom row) and $\mathbf{165}_{10}$ (situated on the top row), and bisects the inlets $\mathbf{165}_3$ (situated on the bottom row) and $\mathbf{165}_9$ (situated on the top row). Advantageously, the septa **210** not only facilitate the routing and separation of sound waves within the manifold **150**, but also structurally reinforce the manifold **150**.

[0033] In alternate embodiments, the manifold **150** may include any number of the septa **210**, including zero, and the septa **210** may serve any type of function. For example, and without limitation, the septa **210** may provide routing functionality, isolation functionality, and/or structural reinforcement in any combination and in conjunction with any other geometric features of the manifold **150**.

[0034] For illustrative purposes, FIG. **2** depicts the input and the output of four of the channels. As shown, a label "A" illustrates that the sound waves entering the manifold **150** via the inlet $\mathbf{165}_1$ (included in the bottom row) exit the manifold **150** via the two slots that are included in the innermost phasing plug ring $\mathbf{255}_1$ on either side of the septa $\mathbf{210}_1$. A label "B" illustrates that the sound waves entering the manifold **150** via the inlet $\mathbf{165}_4$ (included in the bottom row) exit the manifold **150** via the two slots that are included in the phasing plug ring $\mathbf{255}_2$ on either side of the septa $\mathbf{210}_4$. A label "C" illustrates that the sound waves entering the manifold **150** via the inlet $\mathbf{165}_7$ (included in the top row) exit the manifold **150** via the two slots that are included in the phasing plug ring $\mathbf{255}_3$ on either side of the septa $\mathbf{210}_1$. A label "D" illustrates that the sound waves entering the manifold **150** via the inlet $\mathbf{165}_{10}$ (included in the top row) exit the manifold **150** via the two slots that are included in the outermost phasing plug ring $\mathbf{255}_4$ and on either side of the septa $\mathbf{210}_4$.

Two-Dimensional (2D) Cross-Sections of the Manifold

[0035] FIG. **3** is a two-dimensional (2D) cross-section of the 3D view of FIG. **2**, according to various embodiments. As shown, the manifold **150** includes channels **310** that shield the sound waves from each of the drivers **160** against interactions with the sound waves from the other drivers **160** throughout the length of the manifold **150**. Eight of the channels **310** are visible in FIG. **3**, and another four of the channels **310** are hidden from view.

[0036] For illustrative purposes, FIG. **3** depicts the input and the output of the channels $\mathbf{310}_1$, $\mathbf{310}_4$, $\mathbf{310}_7$, and $\mathbf{310}_{10}$. As shown, a label "A" illustrates that the channel $\mathbf{310}_1$ routes sound waves entering the manifold **150** via the inlet $\mathbf{165}_1$ (included in the bottom row) to the innermost phasing plug ring $\mathbf{255}_1$. A label "B" illustrates that the channel $\mathbf{310}_4$ routes sound waves entering the manifold **150** via the inlet $\mathbf{165}_4$ (included in the bottom row) to the phasing plug ring $\mathbf{255}_2$. A label "C" illustrates that the channel $\mathbf{310}_7$ routes sound waves entering the manifold **150** via the inlet $\mathbf{165}_7$ (included in the top row) to the phasing plug ring $\mathbf{255}_3$. A label "D" illustrates that the channel $\mathbf{310}_{10}$ routes sound waves entering the manifold **150** via the inlet $\mathbf{165}_{10}$ (included in the top row) to the outermost phasing plug ring $\mathbf{255}_4$.

[0037] Notably, the length of the channel $\mathbf{310}_1$ is visibly longer than then length of the channel $\mathbf{310}_4$, the length of the channel $\mathbf{310}_4$ is visibly longer than then length of the channel $\mathbf{310}_7$, and the length of the channel $\mathbf{310}_7$ is visibly longer than then length of the channel $\mathbf{310}_{10}$. Accordingly, to ensure proper time alignment of the sound waves, the loudspeaker processor **130** is configured to apply a relatively small value for the digital delay $\mathbf{135}_1$ to the driver input signal $\mathbf{140}_1$ that feeds the driver $\mathbf{160}_1$, a larger value for the digital delay $\mathbf{135}_4$ to the driver input signal $\mathbf{140}_4$ that feeds the driver $\mathbf{160}_4$, a larger value for the digital delay $\mathbf{135}_7$ to the driver input signal 140_7 that feeds the driver 160_7, and a relatively large value for the digital delay 135_{10} to the driver input signal 140_{10} that feeds the driver 160_{10}.

[0038] FIG. **4** is a second two-dimensional (2D) cross-section of the 3D view of FIG. **2**, according to various embodiments. In addition to the features that are visible in FIG. **3**, FIG. **4** also illustrates the slots included in the phasing plug rings **255** in greater detail. As shown, the geometric shape of the slots may vary. For example, and without limitation, the slots included in the innermost phasing plug ring 255_1 are roughly three-sided. By contrast, the slots included in the outermost phasing plug ring 255_4 are roughly three-sided. In general, the number and/or geometries of the slots may vary across the phasing plug rings **255** and/or within each of the phasing plug rings **255**.

[0039] Further, each of the drivers **160** may be oriented at any angle with respect to the direction of the corresponding channel **310**. For example, and without imitation, in the embodiment depicted in FIG. **4**, based on the relative orientations of the inlet 165_i and the channel 310_i, the driver 160_i is oriented at approximately ninety degrees with respect to the direction of the channel 310_i. In alternate embodiments, without limitation, the exit of each of the drivers **160** may be "slanted" such that the angles of the inlets **165** and the entrances to the manifold **150** (as connected via the channels **310**), align along the same general vector.

[0040] drivers do not need to be 90 degrees from the direction of the channel. It may be more appropriate for the driver exit to be in the same general vector as the entrance of the manifold (slanted)

Phasing Plug Rings

[0041] FIG. **5** is a more detailed illustration of the phasing plug rings **255** depicted in FIG. **2**, according to various embodiments. In general, the phasing plug rings **255** organize the sound waves that the manifold **150** routes from the inlets **165** and through the channels **310** into a pattern at the exit of the manifold **150** that is consistent with a single point source of sound.

[0042] As shown, the phasing plug ring 255_1 is the innermost of the four phasing plug rings **255**, phasing plug ring 255_2 is an encompassing concentric ring that is adjacent to the phasing plug ring 255_1, phasing plug ring 255_3 is a encompassing concentric ring that is adjacent to the phasing plug ring 255_2, and phasing plug ring 255_4 is the outermost of the four phasing plug rings **255**. Six septa 210_1-210_6 subdivide each of the phasing plug rings **255** into six slots. Referring to FIG. **2**, each of the septa **210** bisects two of the inlets **165**—one in the bottom layer that includes six of the inlets **165** and one in the top layer that includes the remaining six of the inlets **165**. For example, and without limitation, the septum 210_3 bisects the inlets 165_3 and 165_9. Referring back now to FIG. **5**, the septum 210_3 bisects the channel 310_3 that routes sound waves from the inlet 165_3 to the two slots located in phasing plug ring 255_1 on either side of the septum 210_3. In a similar fashion, each of the remaining channels **310** route sound waves from one of the inlets **165** to two slots located in one of the phasing plug rings **255**.

[0043] In alternate embodiments, the septa **210** are omitted and each inlet **165** feeds a single slot in one of the phasing plug rings **255**. In general, any number of septa **210** may be included in the manifold **150** and may intersect any number of the inlets **165**, the channels **310**, and the phasing plug rings **255** in any technically feasible fashion that preserves the isolation between the inlets **165** throughout the manifold **150**. For example, and without limitation, in some embodiments, additional septa **210** may be included in the manifold **150** to physically bolster the manifold **510** and/or narrow the channels to minimize crossmodes.

[0044] As specified in channel length/time delay constraints **555**, each of the phasing plug rings **255** defines a different group—a set of the channels **310** having substantially the same channel length and, accordingly, sound waves that are optimally time aligned using substantially the same time delay. As part of the design of the manifold **150**, for each of the groups, the channels **310** in the group are of substantially the same channel length and independently route sound waves from the drivers **160** (i.e., the inlets **165**) in the group to the appropriate slots in the phasing plug ring **255** that defines the group.

[0045] In operation, for the group labelled "A," the loudspeaker processor **130** is configured to digitally delay the driver input signals **140** for drivers 160_1, 160_3, and 160_5 by the time delay time_1, and the delayed sound waves received at the inlets 165_1, 165_3, and 165_5 are routed via the channels 310_1, 310_3, and 310_5 through a distance of length, to the separate pairs of slots in the phasing plug ring 255_1. In a similar fashion, the group labelled "B" is associated with the time delay time_2, the inlets 165_2, 165_4, and 165_6, the channels 310_2, 310_4, and 310_6, the length_2, and the phasing plug ring 255_2. The group labelled "C" is associated with the time delay time_3, the inlets 165_7, 165_9, and 165_{11}, the channels 310_7, 310_9 and 310_{11}, the length_3, and the phasing plug ring 255_3. The final group, labelled "D," is associated with the time delay time_4, the inlets 165_8, 165_{10}, and 165_{12}, the channels 310_8, 310_{10}, and 310_{12}, the length_4, and the phasing plug ring 255_4.

[0046] The phasing plug rings **255** conform to various design criteria that ensure the integrity of the single point source of sound. For example, and without limitation, in some embodiments, the width of each of the phasing plug rings **255** is no greater than 0.25 inches. As persons skilled in the art will recognize, given the speed of sound, this constraint enables fine-tuning of the time delay with a time granularity of at least twenty microseconds. In other embodiments, without limitation, the phasing plug rings **255** are designed to maintain the width design constraints imposed on the channels **310**. For example, and without limitation, in some embodiments, the channels **310** are constrained to a width no greater than half of the highest wavelength that is intended to be reproduced via the manifold **150**. Correspondingly, in such embodiments, the radial distance between each of the phasing plug ring **255***i* and the adjacent phasing plug ring 255_{i+1} is no greater than half of this highest wavelength. In general, the phasing plug rings **255** may be designed in any technically feasible fashion based on any design criteria and/or constraint.

[0047] In alternate embodiments, any number and type of design criteria may be imposed on the phasing plug rings **255**, the channels **310**, the inlets **165**, and the drivers **160**. For example, and without limitation, some design criteria may represent constraints designed to optimize the fidelity of the sound emitted by the loudspeaker **110**, such as limitations that minimize reflections and resonances within the manifold **150**.

Configuring Loudspeakers

[0048] FIG. **6** is a flow diagram of method steps for configuring a loudspeaker for operation, according to various embodiments. Although the method steps are described in conjunction with the systems of FIGS. **1-5**, persons skilled in the art will understand that any system configured to implement the method steps, in any order, falls within the scope of the present invention. The context of FIG. **6** is that the loudspeaker processor **130** configures the loudspeaker **110** to emit a single point source of sound based on the channel length/time delay constraints **555** that are associated with the manifold **150**.

[0049] As shown, a method **600** begins at step **604**, where the loudspeaker processor **130** partitions the drivers **160** into groups and sets a current group to the first of the groups. To optimize the operation of the manifold **150**, the loudspeaker processor **130** assigns the drivers **160** to the groups based on the channel length/time delay constraints **555**. In alternate embodiments, the loudspeaker processor **130** may partition the drivers **160** into groups in any technically feasible fashion that is consistent with the properties of the manifold **150**, such as the number of unique values for the lengths of the channels **310**. For example, and without limitation, in some embodiments, each of the channels **310** may have a different length and the loudspeaker processor **130** may assign the channels **310** to the groups in a one-to-one fashion.

[0050] At step **606**, the loudspeaker processor **130** sets a group-specific channel length and a group-specific time delay based on the current group, and the select the drivers **160** that are included in the current group. More specifically, the loudspeaker processor **130** assigns the group-specific channel length and the group-specific time delay based on the channel length/time delay constraints **555** for the current group.

[0051] At step **608**, the loudspeaker processor **130** matches each of the selected drivers **160** to a separate one of the inlets **165** that feeds the phasing plug rings **255** via one of the channels **310** that has the group-specific channel length. The loudspeaker processor **130** may perform the matching operations in any technically feasible fashion. For example, and without limitation, the loudspeaker processor **130** may assign the selected drivers **160** in a one-by-one fashion and in a clockwise and upward direction to the inlets **165** that feed the channels **310** having the group-specific channel length (per the channel length/time delay constraints **555**).

[0052] At step **610**, the loudspeaker processor **130** configures each of the selected drivers **160** to emit time-delayed sound waves into the matched inlet **165**. In some embodiments, the loudspeaker processor **130** configures the driver input signals **140** that are associated with the selected drivers **160** to be delayed by the digital delays **135**. In other embodiments, the loudspeaker processor **130** may perform any operations that inject delay into either the driver input signals **140** to the selected drivers **160**, directly into the sound waves generated by the selected drivers **160**, or any combination thereof. As part of step **610**, the loudspeaker processor **130** also causes each of the selected drivers **160** to be coupled to the matched inlet **165**. The loudspeaker processor **130** may precipitate this coupling in any technically feasible fashion. For example, and without limitation, in some embodiments the loudspeaker processor **130** may generate a digital image of the manifold **150** that is superimposed with the desired connections as assembly instructions.

[0053] At step **612**, for each of the selected drivers **160**, the loudspeaker processor **130** configures the driver **160** to delay sound by the group-specific time delay. The loudspeaker processor **130** may configure the driver **160** in any technically feasible fashion that is consistent with the manner in which the driver **160** is configured to emit time-delayed sound waves (step **610**). For example, and without limitation, the loudspeaker processor **130** may set the value of the digital delay **135** that is associated with the selected driver **160** to the group-specific time delay.

[0054] At step **614**, the loudspeaker processor **130** determines whether the current group is the last group that is implemented in the manifold **150**. If, at step **614**, the loudspeaker processor **130** determines that the current group is not the last group, then the method **600** returns to step **616**. At step **616**, the loudspeaker processor **130** sets the current group to the next group specified in the channel length/time delay constraints **555**, and the method **600** returns to step **606** to process this group. The loudspeaker processor **130** continues to cycle through steps **606-614**, configuring the drivers **160** for each of the groups until the loudspeaker processor **130** has processed all of the groups that are characteristic of the design of the manifold **150**. In alternate embodiments, without limitation, any number and/or any types of processors may perform the functionality included in steps **606-614** in any combination. For example and without limitation, in some alternate embodiments, one processor may perform loudspeaker measurement and optimization operations and another processor may generate the appropriate time delays.

[0055] If, at step **616**, the loudspeaker processor **130** determines that the current group is the last group, then the method **616** proceeds directly to step **618**. At step **618**, the loudspeaker processor **130** generates the driver input signals **160** thereby delivering sound waves from the drivers **160** through the manifold **150** to the acoustic horn **170**. Notably, the loudspeaker processor **130** and the manifold **150** work together to ensure that the manifold **150** emits a single point source of sound into the throat of the acoustic horn **170**. Advantageously, this highly coherent single point source of sound enables the acoustic horn to emit sound that is characterized by both high sound pressure levels and relatively high fidelity.

[0056] In sum, the disclosed techniques enable manifolds to effectively composite audio signals from multiple drivers into a single point source that is suitable for driving the throat of an acoustic horn. The manifold includes multiple inlets, where each inlet is designed to be coupled with a different driver and multiple, concentric phasing rings that combine to generate the single point source of sound. In operation, the sound waves that are received at each inlet are routed via an "isolation" channel to a different location in one of the concentric phasing rings. More specifically, the channels ensure that the sound waves received at each of the inlets do not interact with the sound waves received at the other inlets while travelling within the manifold-eliminating interference patterns between sound waves within the manifold. Further, to minimize reflections within the channels, each channel is relatively thin with respect the wavelengths that are intended to be reproduced by the loudspeaker.

[0057] To facilitate generation of the single point source of sound, each of the concentric phasing rings is fed by channels of approximately a ring-specific length and is associated with a time delay that corresponds to the ring-specific length. Accordingly, each of the drivers is configured with a digital delay that corresponds to one of the ring-specific time delays and is then coupled to an inlet that is routed to a concentric phasing ring that is associated with the ring-specific time delay. The tailored digital time delays compensate for delays incurred as the sound travels through the length of the channels, thereby time-aligning the sound waves at the exit of the manifold.

[0058] At least one advantage of the disclosed approaches is that they enable loudspeakers to generate coherent sounds with higher sound pressure levels than loudspeakers that are designed using conventional multi-driver techniques. Notably, by minimizing both comb filtering and acoustic interference patterns that can comprise the fidelity and intelligibility of the overall sound for the audience, the techniques described herein optimize the sound quality for audiences. Further, because the techniques outlined are applicable to any number of drivers arranged in any geometric fashion within the manifold, restrictions imposed on the design of the manifold are minimized. By contrast, multiple driver manifolds that employ conventional techniques are typically constrained to conform to relatively rigid design constraints, such as relative locations of the inlets.

[0059] The descriptions of the various embodiments have been presented for purposes of illustration, but are not intended to be exhaustive or limited to the embodiments disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art without departing from the scope and spirit of the described embodiments.

[0060] Aspects of the present embodiments may be embodied as a system, method or computer program product. Accordingly, aspects of the present disclosure may take the form of an entirely hardware embodiment, an entirely software embodiment (including firmware, resident software, micro-code, etc.) or an embodiment combining software and hardware aspects that may all generally be referred to herein as a "circuit," "module" or "system." Furthermore, aspects of the present disclosure may take the form of a computer program product embodied in one or more computer readable medium(s) having computer readable program code embodied thereon.

[0061] Any combination of one or more computer readable medium(s) may be utilized. The computer readable medium may be a computer readable signal medium or a computer readable storage medium. A computer readable storage medium may be, for example, but not limited to, an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system, apparatus, or device, or any suitable combination of the foregoing. More specific examples (a non-exhaustive list) of the computer readable storage medium would include the following: an electrical connection having one or more wires, a portable computer diskette, a hard disk, a random access memory (RAM), a read-only memory (ROM), an erasable programmable read-only memory (EPROM or Flash memory), an optical fiber, a portable compact disc read-only memory (CD-ROM), an optical storage device, a magnetic storage device, or any suitable combination of the foregoing. In the context of this document, a computer readable storage medium may be any tangible medium that can contain, or store a program for use by or in connection with an instruction execution system, apparatus, or device.

[0062] Aspects of the present disclosure are described above with reference to flowchart illustrations and/or block diagrams of methods, apparatus (systems) and computer program products according to embodiments of the disclosure. It will be understood that each block of the flowchart illustrations and/or block diagrams, and combinations of blocks in the flowchart illustrations and/or block diagrams, can be implemented by computer program instructions. These computer program instructions may be provided to a processor of a general purpose computer, special purpose computer, or other programmable data processing apparatus to produce a machine, such that the instructions, which execute via the processor of the computer or other programmable data processing apparatus, enable the implementation of the functions/acts specified in the flowchart and/or block diagram block or blocks. Such processors may be, without limitation, general purpose processors, special-purpose processors, application-specific processors, or field-programmable

[0063] The flowchart and block diagrams in the Figures illustrate the architecture, functionality, and operation of possible implementations of systems, methods and computer program products according to various embodiments of the present disclosure. In this regard, each block in the flowchart or block diagrams may represent a module, segment, or portion of code, which comprises one or more executable instructions for implementing the specified logical function (s). It should also be noted that, in some alternative implementations, the functions noted in the block may occur out of the order noted in the figures. For example, two blocks shown in succession may, in fact, be executed substantially concurrently, or the blocks may sometimes be executed in the reverse order, depending upon the functionality involved. It will also be noted that each block of the block diagrams and/or flowchart illustration, and combinations of blocks in the block diagrams and/or flowchart illustration, can be implemented by special purpose hardware-based systems that perform the specified functions or acts, or combinations of special purpose hardware and computer instructions.

[0064] The invention has been described above with reference to specific embodiments. Persons of ordinary skill in the art, however, will understand that various modifications and changes may be made thereto without departing from the broader spirit and scope of the invention as set forth in the appended claims. For example, and without limitation, although many of the descriptions herein refer to specific types of audiovisual equipment and sensors, persons skilled in the art will appreciate that the systems and techniques described herein are applicable to other types of performance output devices (e.g., lasers, fog machines, etc.) and sensors. The foregoing description and drawings are, accordingly, to be regarded in an illustrative rather than a restrictive sense.

[0065] While the preceding is directed to embodiments of the present disclosure, other and further embodiments of the disclosure may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

What is claimed is:

1. A manifold for a loudspeaker, comprising:
a plurality of inlets, wherein each inlet is designed to receive sound waves from a different compression driver;
an output section that includes a plurality of concentric rings and is designed to deliver a point source of sound to a throat section of an acoustic horn; and
a first channel that is configured to guide sound waves received at a first inlet to a first location within a first concentric ring and to isolate the sound waves received at the first inlet from sound waves received at the other inlets included in the plurality of inlets.

2. The manifold of claim 1, wherein each of the concentric rings included in the plurality of concentric rings is associated with a different time delay.

3. The manifold of claim 2, wherein a first concentric ring is associated with a first time delay, and further comprising a second channel that is configured to guide sound waves received at a second inlet to a location in a second concentric ring that is associated with a second time delay.

4. The manifold of claim 3, wherein the first time delay is inversely correlated to the length of the first channel, and the second time delay is inversely correlated to the length of the second channel.

5. The manifold of claim 3, wherein the first time delays equals the second time delay, and the length of the first channel approximately equals the length of the second channel.

6. The manifold of claim 3, wherein the sound waves received at the first inlet are delayed by the first time delay, and the sound waves received at the second inlet are delayed by the second time delay.

7. The manifold of claim 6, wherein the first time delay is a digital delay.

8. The manifold of claim 1, wherein a width of the first concentric ring is no greater than 0.25 inches and is configured to generate the point source of sound for the sound waves received at the first inlet with a time granularity of at least twenty microseconds.

9. The manifold of claim 1, wherein a radial distance between the first concentric ring and an adjacent concentric ring is no greater than half of a highest wavelength being reproduced via the manifold.

10. The manifold of claim 1, wherein the first channel is subdivided by at least one septum that extends from the first inlet to the first location in the first concentric region.

11. The manifold of claim 10, wherein the at least one septum structurally reinforces the manifold.

12. A loudspeaker comprising:
an acoustic horn;
a plurality of compression drivers; and
a manifold that is coupled to the acoustic horn and comprises:
a first inlet that receives sound waves from a first compression driver included in the plurality of compression drivers;
a second inlet that receives sound waves from a second compression driver included in the plurality of compression drivers;
an output section that includes a plurality of concentric rings, and is designed to deliver a point source of sound to a throat section of the acoustic horn;
a first channel that is configured to guide sound waves received at the first inlet to a first location within a first concentric ring and to isolate the sound waves received at the first inlet from sound waves received at the second inlet.

13. The loudspeaker of claim 12, wherein a radial distance between the first concentric ring and an adjacent concentric ring is no greater than half of a highest wavelength being reproduced via the manifold.

14. The loudspeaker of claim 12, wherein each of the concentric rings included in the plurality of concentric rings is associated with a different time delay.

15. The loudspeaker of claim 14, wherein the manifold further comprises a second channel that is configured to guide the sound waves received at the second inlet to a second location in the first concentric ring.

16. The loudspeaker of claim 14, wherein the first concentric ring is associated with a first time delay and a first compression driver is configured to deliver sound waves that are delayed by the first time delay to the first inlet.

17. A computer implemented method for configuring a loudspeaker for operation, wherein the loudspeaker includes a manifold that is designed to deliver a point source of sound to an acoustic horn, the method comprising:
partitioning a plurality of compression drivers into a plurality of groups, wherein each group is associated with a different channel length and a different time delay;
determining that a length of a first channel approximately equals a channel length that is associated with a first group, wherein the first channel guides sound waves receives at a first inlet included in a plurality of inlets to a first location in an output section of the manifold and isolates the sound waves received at the first inlet from sound waves received at the other inlets included in the plurality of inlets; and
configuring a compression driver included in the first group to deliver sound waves that are delayed by a time delay that is associated with the first group to the first inlet.

18. The method of claim 17, wherein the first location is within a first concentric ring included in a plurality of concentric rings.

19. The manifold of claim 18, wherein a radial distance between the first concentric ring and an adjacent concentric ring is no greater than half of a highest wavelength being reproduced via the loudspeaker.

20. The method of claim 17, further comprising:
determining that a length of a second channel approximately equals a channel length that is associated with a second group, wherein the second channel guides sound waves receives at a second inlet included in the plurality of inlets to a second location in the output section of the manifold and isolates the sound waves received at the second inlet from sound waves received at the other inlets included in the plurality of inlets; and
configuring a compression driver included in the second group to deliver sound waves that are delayed by a time delay that is associated with the second group to the second inlet.

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