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Graber

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(54) **SUBWOOFER WITH CASCADED LINEAR ARRAY OF DRIVERS**

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H04R 1/20 (2006.01)

(52) **U.S. Cl.** **381/341**; 381/342; 381/97; 381/186; 181/152; 181/145; 181/177

(58) **Field of Classification Search** 381/340, 381/341, 342, 343, 97, 186; 181/177, 187, 181/188, 152, 145
See application file for complete search history.

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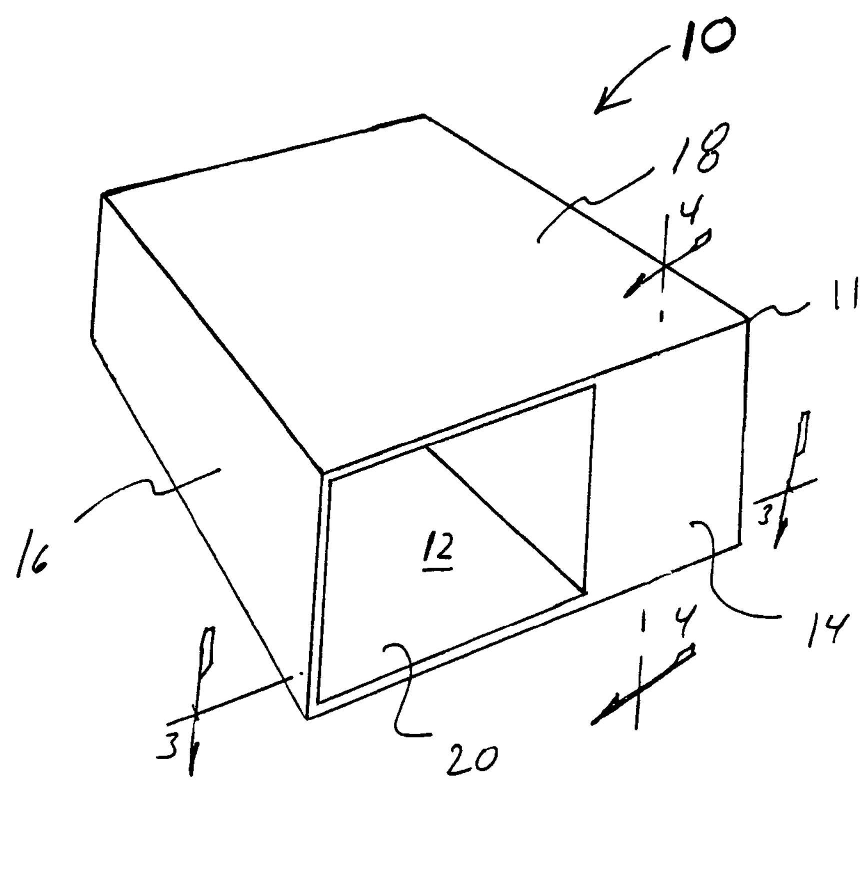
(57) **ABSTRACT**

A single folded, expanding horn loudspeaker reproduces low frequency audible sound at high power output levels. A compact enclosure houses a plurality of identical transducers, characterized by small vibrational surface areas. The throats for each transducer into the horn are acoustically differentially spaced from the mouth of the horn. Transducer drive circuitry adjusts a drive signal for the transducers to compensate for the different impedance and propagation time to the horn mouth at each throat.

12 Claims, 9 Drawing Sheets



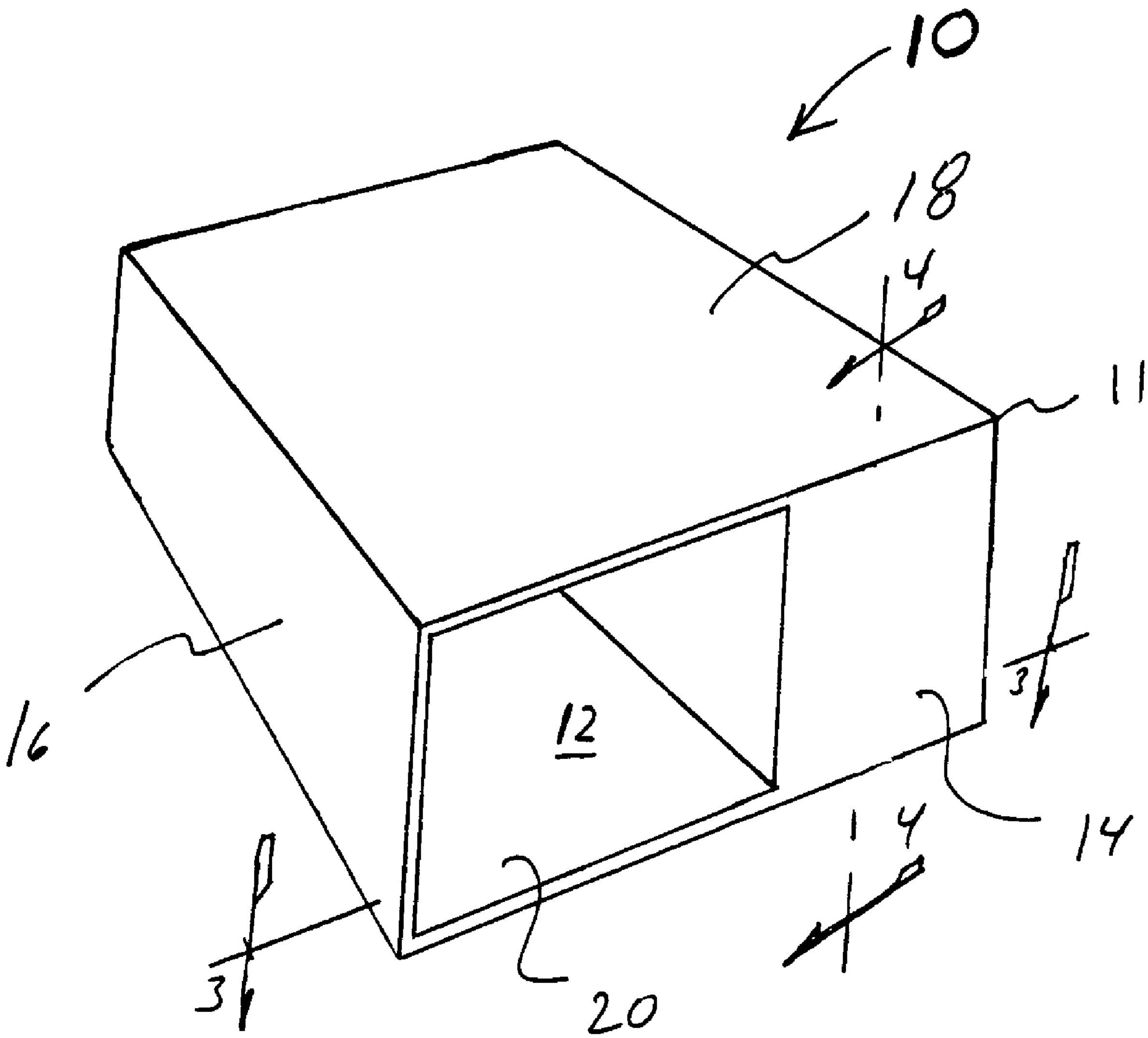


FIG. 1

FIG. 2

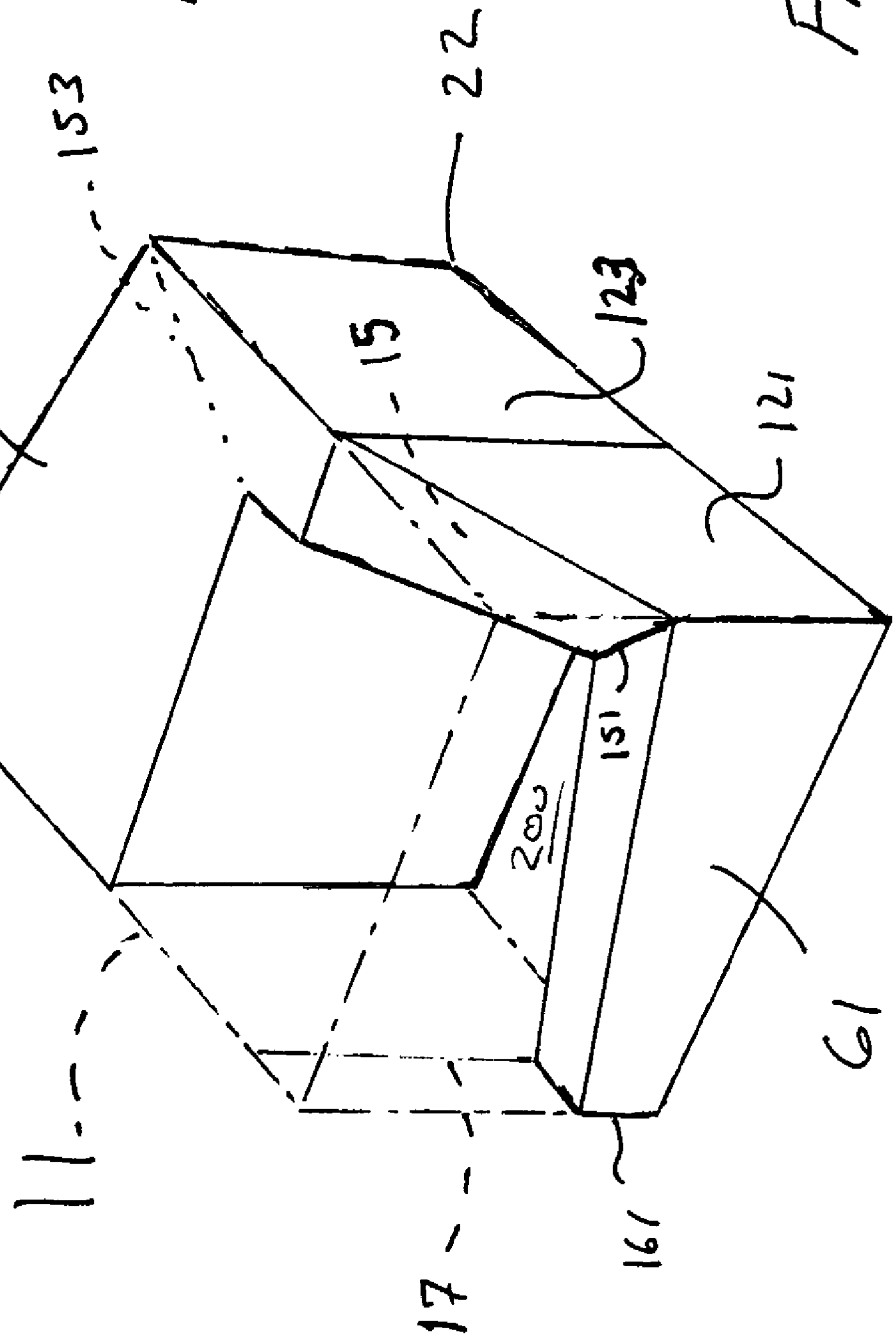
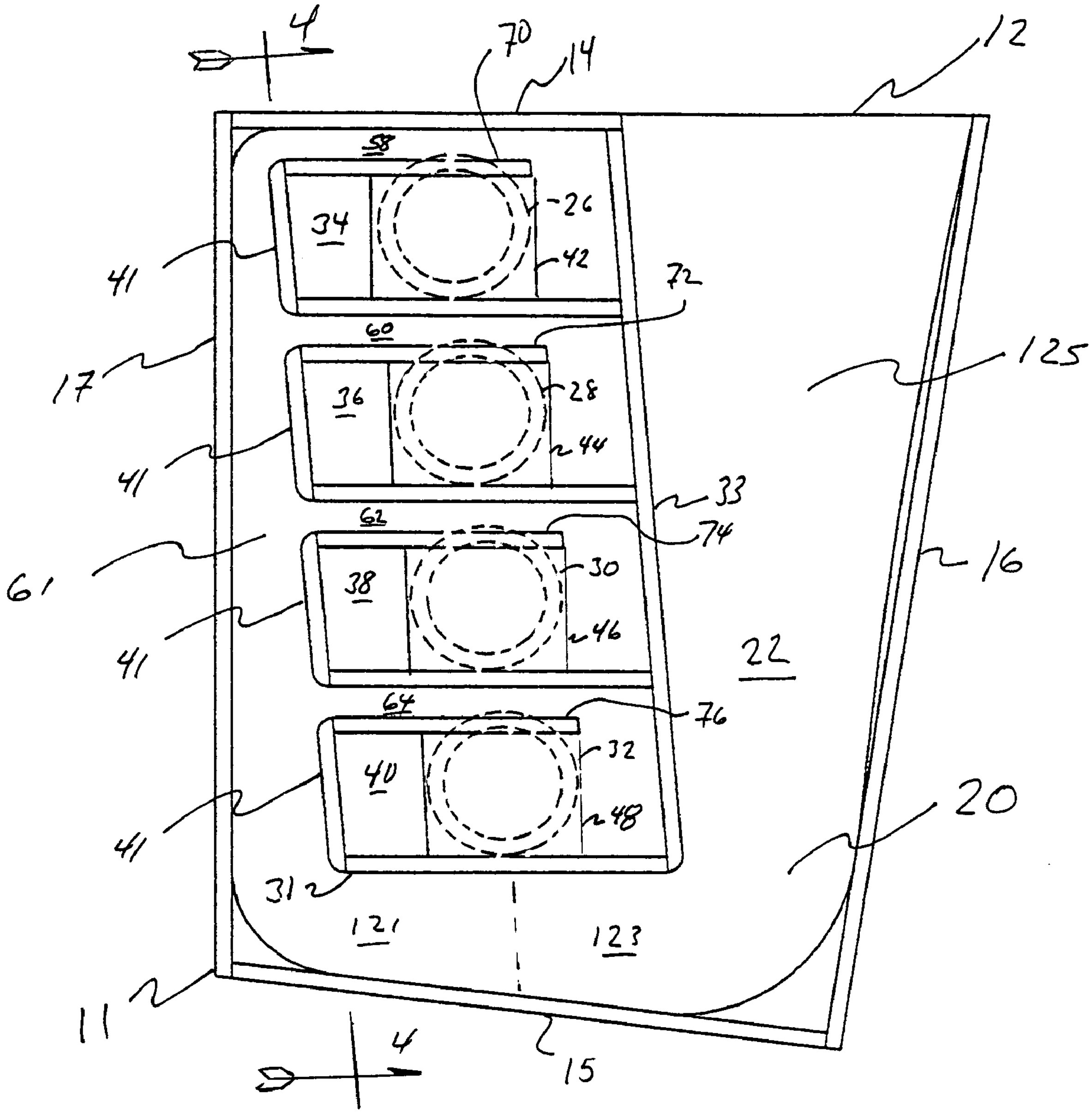


FIG. 2


4
70
14
12
58
26
34
42
41
72
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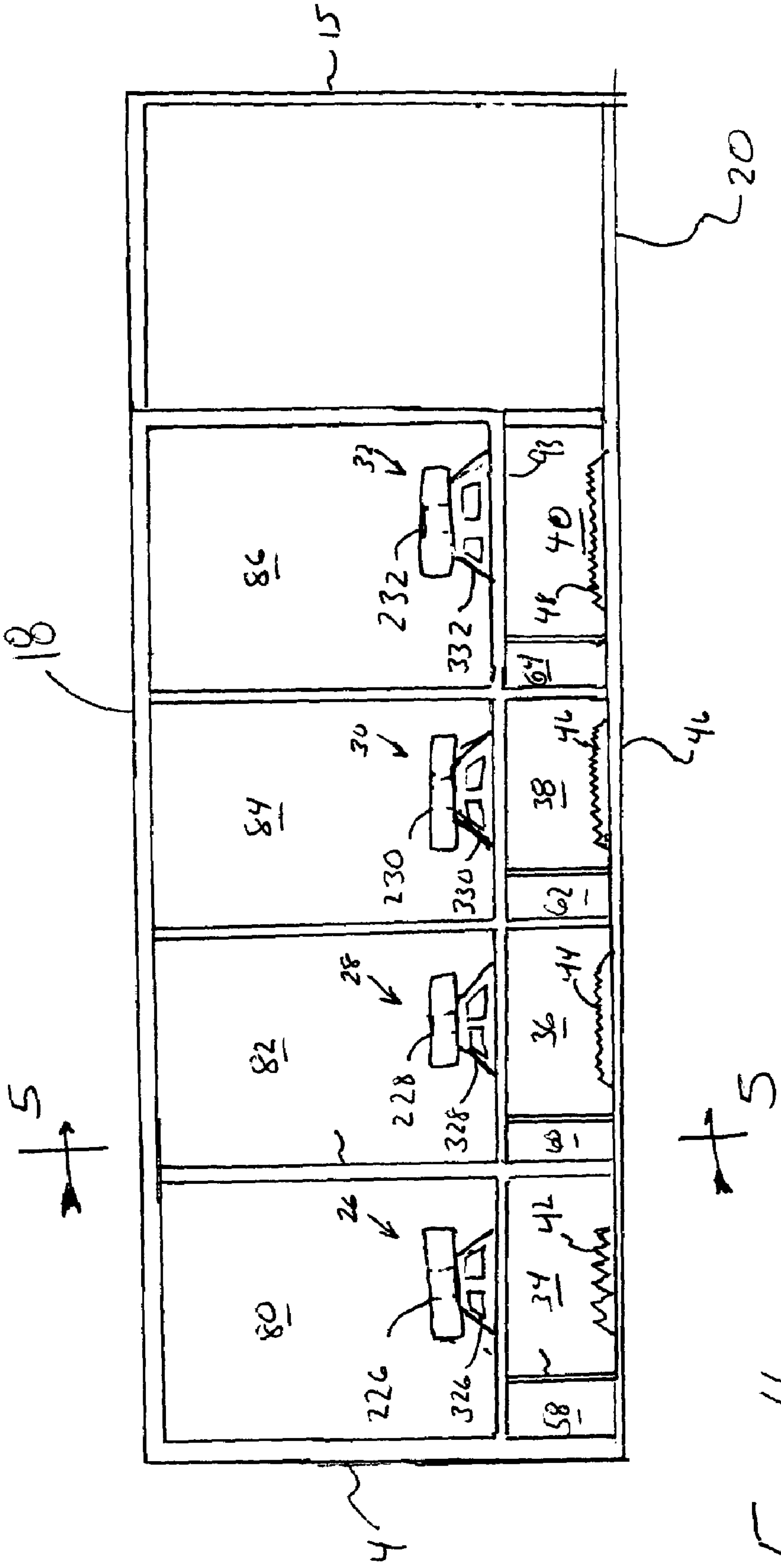
17
125
28
36
41
44
33
62
74
61
30
16
38
41
46
22
64
76
32
40
20
41
48
31
121
123
11
15
4

FIG. 3


15
20
18
14
5
5
80
82
84
86
26
28
30
32
226
228
230
232
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34
36
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42
44
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48
58
60
62
64
93

FIG. 4

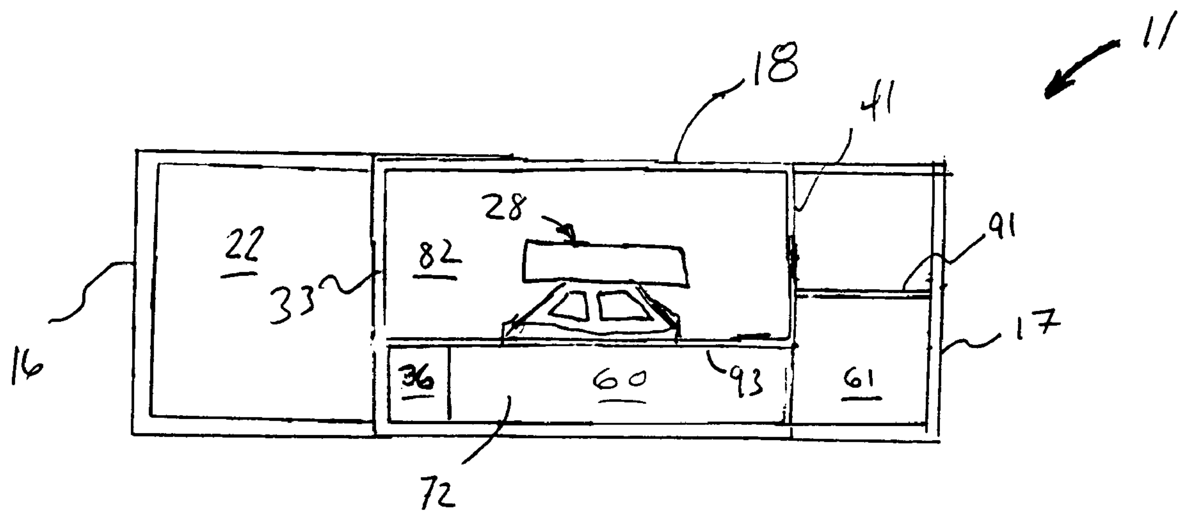


FIG. 5

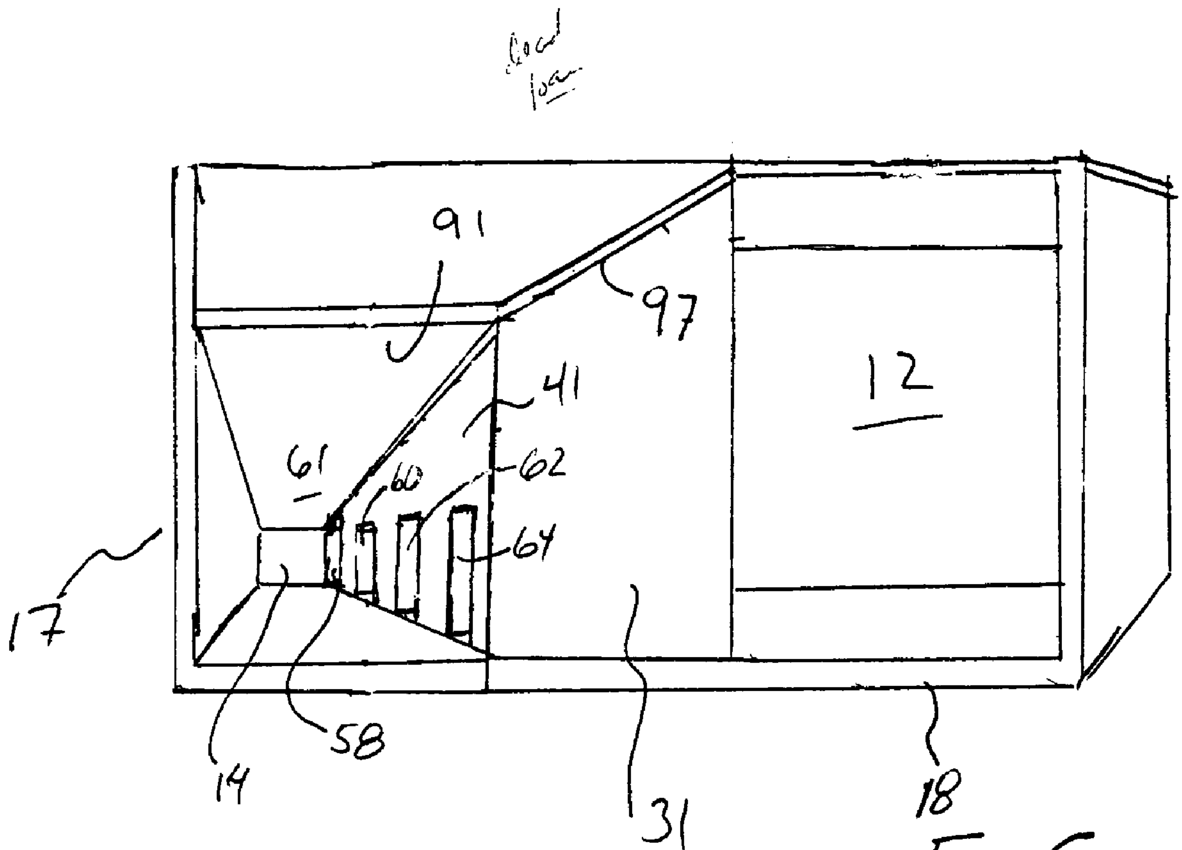
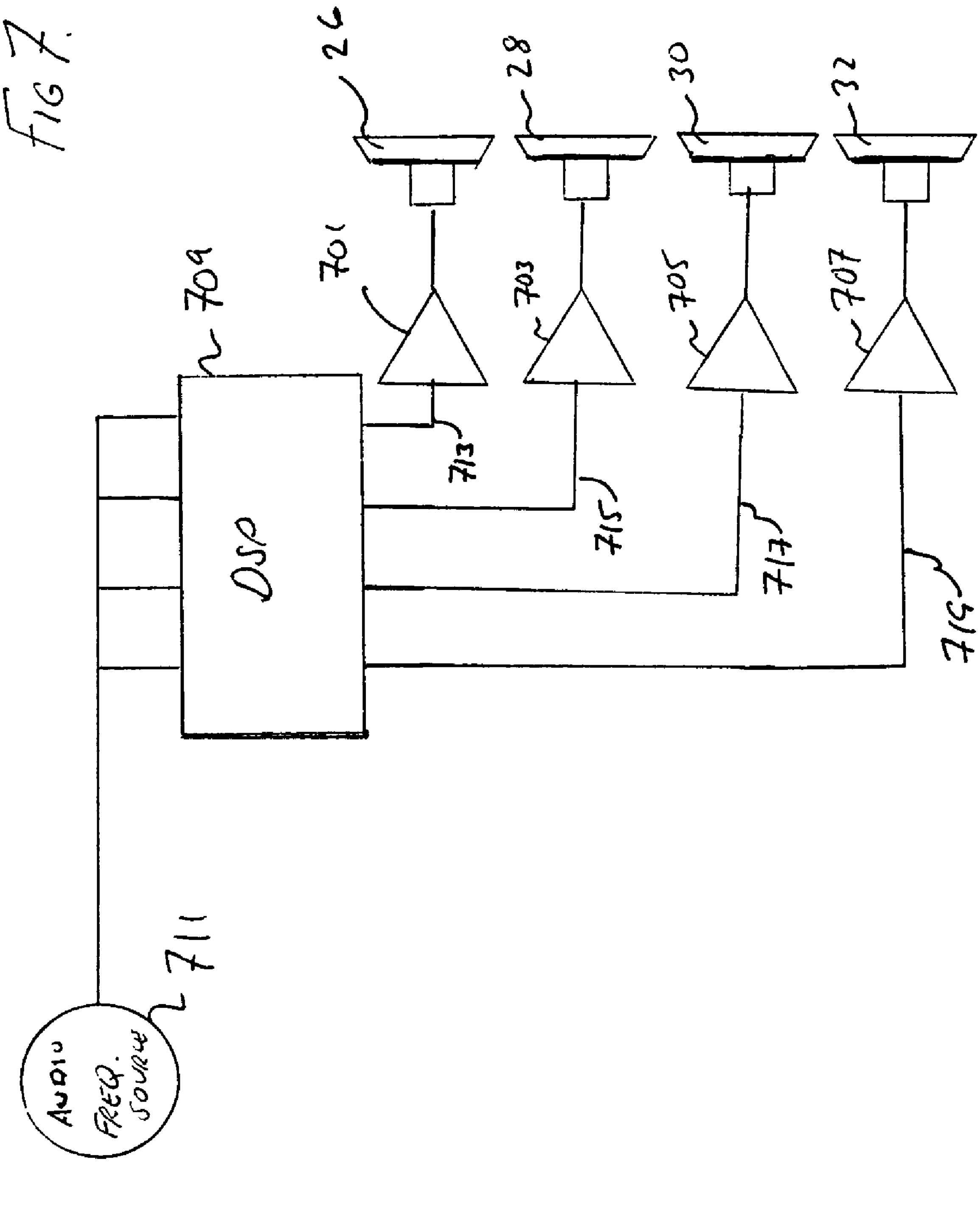


FIG. 6

FIG 7.


26
28
30
32
701
703
705
707
709
DSP
713
715
717
719
711
AUDIO FREQ. SOURCE

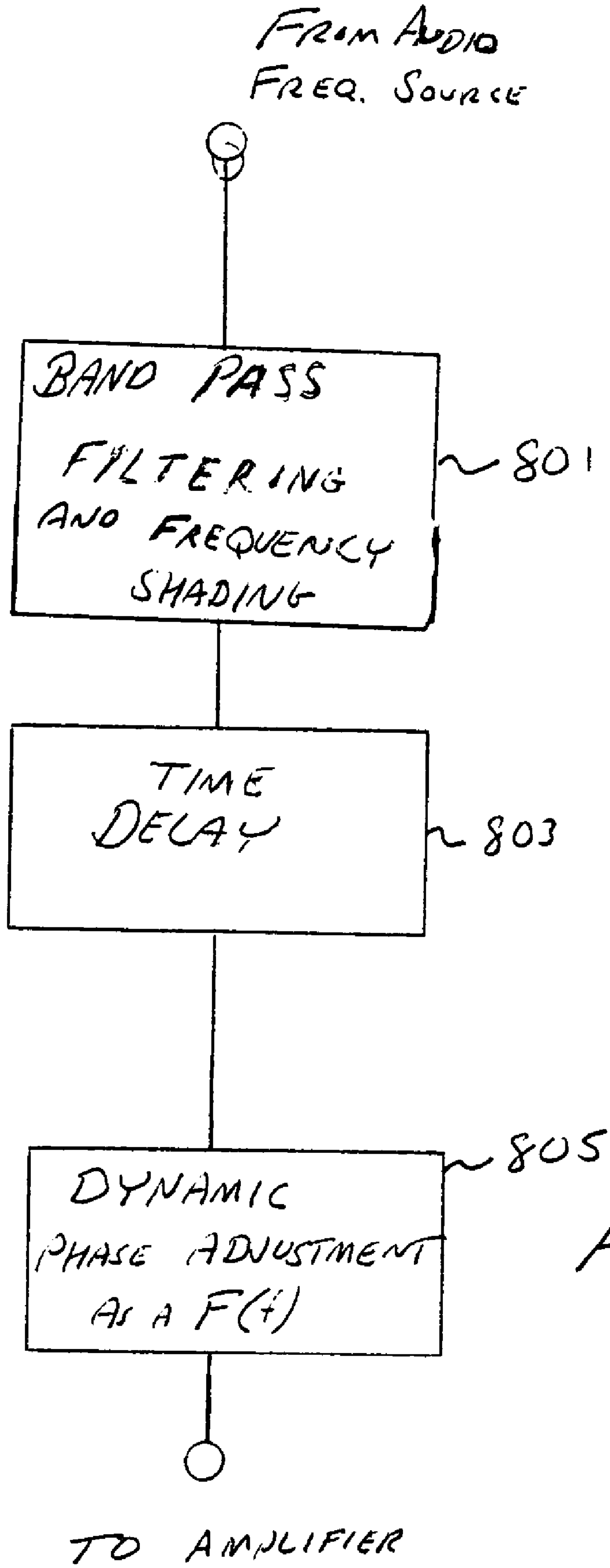

FROM AUDIO
FREQ. SOURCE
BAND PASS
FILTERING
AND FREQUENCY
SHADING
801
TIME
DELAY
803
805
DYNAMIC
PHASE ADJUSTMENT
AS A F(t)
TO AMPLIFIER

FIG. 8

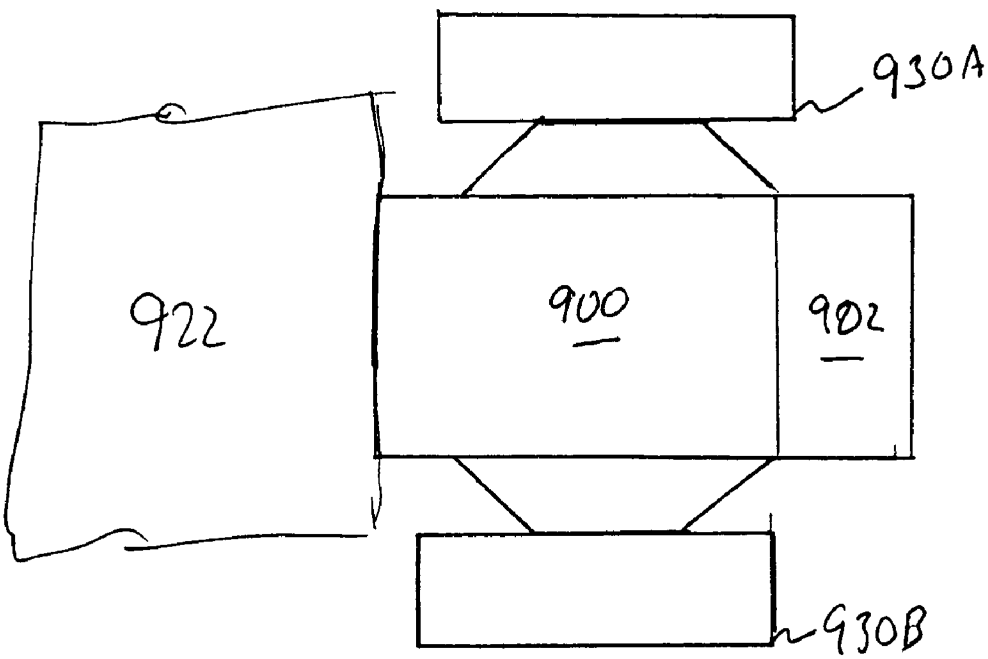


FIG. 9

SUBWOOFER WITH CASCADED LINEAR ARRAY OF DRIVERS

BACKGROUND OF THE INVENTION

1. Technical Field

The invention relates to an electro-acoustical device and, more particularly, to a folded horn loudspeaker for reproducing low frequency audible sound at high output levels from electric-acoustic transducers having relatively small diaphragms.

2. Description of the Problem

The reproduction of low frequency audible sound, with high fidelity and at high intensity levels, poses a number of challenges. To do so from a small, energy efficient package, portable enough to be moved and suitable for open air use is especially difficult. Generally, high output, high efficiency, low frequency loudspeakers have been built around a horn. A horn is in effect an acoustic transformer, allowing the designer to obtain the output performance of a driving unit having a large area diaphragm from a unit having a smaller area diaphragm while minimizing cone/diaphragm resonance issues that exist with direct radiator devices. Increasing the effective diaphragm area renders radiation impedance increasingly resistive with the result that increasing power is radiated at the desired low frequencies. However, increasing acoustic power output from most horn designs has required increasing diaphragm piston travel in order to move the required volume velocity of air. Piston travel becomes an important limiting factor relating to the amount of power that can be delivered to the horn.

Another limitation on the total energy input that can be introduced to a horn has been the limited scalability of horns. Though examples of multiple driver horns are known, typically only a single driving unit for a given frequency range has been provided. One example of a multiple driver horn (U.S. Pat. No. 5,898,138) positions a pair of low frequency transducers having throats located equidistant from the horn's mouth. While effective such an arrangement is still not readily scalable.

SUMMARY OF THE INVENTION

According to the invention there is provided a folded, expanding horn loudspeaker having a selectable plurality of acoustic drivers for a given frequency range. The loudspeaker unit provides a compact enclosure defining the folded, expanding horn and housing the acoustic drivers. A scalable number of identical acoustic drivers is provided, each having a relatively small cone or diaphragm, and each being located in a sealed back chamber (e.g. a closed box baffle). The acoustic drivers radiate into volumetrically identical high pressure chambers located in front of the drivers. The acoustic drivers are preferably positioned with respect to one another in a linear array and may vary in number from 2 to 12. Each high pressure front chamber is coupled to a summing throat for the horn by an extended port which operates as a air pressure or air volume velocity step up transformer. The outlets of the ports are acoustically spaced from one another and differentially spaced from the mouth of the horn. Transducer drive circuitry applies drive signals to the acoustic transducers derived from a common source. The signals to the respective acoustic transducers are delayed to reflect the distance of the throats for the respective acoustic transducers from the mouth of the horn. The source signal is also as filtered and phase adjusted as required for clear reproduction of the sound.

Additional effects, features and advantages will be apparent in the written description that follows.

BRIEF DESCRIPTION OF THE DRAWINGS

The novel features believed characteristic of the invention are set forth in the appended claims. The invention itself however, as well as a preferred mode of use, further objects and advantages thereof, will best be understood by reference to the following detailed description of an illustrative embodiment when read in conjunction with the accompanying drawings, wherein:

FIG. **1** is a perspective view of a loudspeaker enclosure;

FIG. **2** is a perspective view of the loudspeaker horn.

FIG. **3** is a cross sectional view of the loudspeaker enclosure of FIG. **1** taken along section line **3-3**.

FIG. **4** is a cross sectional view of the loudspeaker enclosure of FIG. **1** taken along section line **4-4**.

FIG. **5** is a cross section of a transducer housing taken along section line **5-5** in FIG. **3**.

FIG. **6** is a rear elevation of the enclosure of FIG. **1** with the back panel of the enclosure removed.

FIG. **7** is a block diagram schematic of drive circuitry for the loudspeaker.

FIG. **8** is a block diagram schematic of the operation of the circuitry of FIG. **7**.

FIG. **9** is a side elevation of a high pressure chamber exited by paired drivers.

DETAILED DESCRIPTION OF THE INVENTION

Referring now to the figures and in particular to FIG. **1** there is illustrated a loudspeaker system **10** for use as a high output, transportable unit. Loudspeaker system **10** comprises a right trapezoid enclosure or cabinet **11** which houses sound radiators and a folded waveguide or horn having a mouth **12** in front wall **14**. Mouth **12** directs sound radiated from loudspeaker system **10** forward from the unit. Enclosure **11** is constructed from front wall **14**, a back wall, a first side wall **16**, a second side wall (described below), a cover **18** and a base **20**. The bases and walls are conventionally made of plywood or some other material which does not readily absorb sound.

Referring to FIG. **2**, enclosure **11** is presented in phantom at a reverse angle from the view of FIG. **1**. Folded horn **22** is optimized for low frequency use and is constructed from flat sides and incorporates a flair, as is conventional. Folded horn **22** is disposed along side walls **16**, **17** and the back wall **15** of enclosure **11** which form portions of the horns walls. Folded horn **22** expands cross-sectionally along its entire length from a base end **161**, adjacent which the horn has its minimum cross-sectional area, to end **163** where the mouth of the horn is located. Folded horn **22** expands initially both vertically and horizontally, but eventually only in the horizontal dimension. A summing throat **61** is disposed along side **17** which expands in both the vertical and horizontal directions to a fold **151**, where it matches with a first backside section **121**. Backside section **121** continues to expand in two mutually perpendicular directions up to a second backside section **123**. Section **123** is characterized by horn **22** having a constant vertical dimension, however expansion continues in the horizontal dimension at a rate consistent with the horn's flair constant. Vertical expansion is stopped in second backside section **123** not for functional reasons, but for external packaging reasons. Section **123** meets the final horn section **125**, which continues to expand in the horizontal dimension, along fold **153**. Loudspeakers are nestled in the pocket **200** formed by and partially enclosed by the exterior faces of folder horn **22**.

FIG. **3** is a cross sectional view of enclosure **11** taken along section line **3-3** in FIG. **1**. Four walls form the perimeter, exterior sides of enclosure **11** including front wall **14**, first side wall **16**, back wall **15** and a second side wall **17**. The perimeter formed by these walls is broken only by mouth **12** which provides a radiating outlet from the waveguide, i.e. folded, expanding horn **22**. Folded horn **22** comprises four major sections and two bends or folds and, as described above, a rectangular cross sectional shape. A horn flare is provided by increasing the area of the section with distance through the horn **22**. Initially, the cross-sectional dimensions of folded horn **22** increase in both the vertical and horizontal dimensions, but eventually only in the horizontal. Folded horn **22** includes a summing throat **61** into which four ports or extended throats **58**, **60**, **62** and **64** are directed. Folded horn **22** expands both vertically and horizontally for the entire length of summing throat **61**. Folded horn **22** is divided into two sections **121** and **123** along back wall **15** of enclosure **11**. Section **121** continues the two dimensional cross sectional expansion of fold horn **22** from summing throat **61**. Section **123** expands only horizontally. Running from section **123** to mouth **12** is the final horn section **125**, which also expands only in the horizontal direction.

Four acoustic drivers or transducers **26**, **28**, **30** and **32** are positioned in enclosure **11** (the latitudinal positions of which are illustrated in phantom) and oriented to direct sound downwardly into four high pressure (or preload) chambers **34**, **36**, **38** and **40** located directly above base **20**. The upper surface of base **20** forms the bottom surfaces of high pressure chambers **34**, **36**, **38** and **40** which are aligned with one another. Acoustically absorbent pads **42**, **44**, **46** and **48** are positioned on the upper surface of bottom board **20** within each of chambers **34**, **36**, **38** and **40** to deaden resonance. Pads **42**, **44**, **46**, **48** correspond to and are vertically aligned with acoustic drivers **26**, **28**, **30**, **32**, respectively. High pressure chambers **34**, **36**, **38** and **40** have acoustic outlet ports formed by extended throats **58**, **60**, **62** and **64**, respectively. Extended throats **58**, **60**, **62** and **64** direct energy into summing throat **61**. The outlets from extended throats **58**, **60**, **62** and **64** act as diaphragms aligned along one side of the summing throat **61** of folded throat **22**. These outlets are at different distances from mouth **12** and, as a consequence, see different output impedances and have different propagation times for the sound energy they emit to mouth **12**. The phase and frequency response of horn **22** will differ with respect to extended throats **58**, **60**, **62** and **64**, sometimes in ways difficult to predict in advance for particular horn parameters and thus empirical evaluation may be required to determine the best dynamic phase adjustments, frequency band widths and roll offs to be used with the drive signal for each of the acoustic drivers **26**, **28**, **30** and **32**. High pressure chambers **34**, **36**, **38**, **40** each have the same volume as one another and the throats **58**, **60**, **62** and **64** have the same cross sectional areas as one another.

Each extended throat **58**, **60**, **62** and **64** has a cross sectional area which is at least 20% of the area of the diaphragm for the corresponding acoustic drivers **26**, **28**, **30** and **32**. Preferably the diaphragms of drives **26**, **28**, **30** and **32** are each about 3-½ times the area of the cross section of the extended throats. As the diaphragms move back and forth in alternating fashion to form compression waves in the air mass, the air in high pressure chambers **34**, **36**, **38** and **40** varies in pressure. The extended throats are relatively constricted in area when constructed the preferred ratio and function as pneumatic amplifiers increasing the volume velocity of the air. Accordingly the movement of driver diaphragms **326**, **328**, **330**, **332** can be made much smaller than is the case on the prior art because changes in air pressure in high pressure chambers **58**, **60**, **62** and **64** are relatively stiff. At the same time, the high pressure compression chambers **58**, **60**, **62** and **64** absorb much more power per unit of movement of the diaphragm allowing much larger driver motors **226**, **228**, **230** and **232** to be employed than in prior art devices. These motors may be two to three times as powerful as is conventional. For maximum power input diaphragms **326**, **328**, **330** and **332** may be pushed at velocities up to the point of destructive turbulence in the extended throats **58**, **60**, **62** and **64**.

The high pressure chambers, back chambers, extended throat and summing throat **61** are formed in part by vertical interior walls supported from base **20**. Vertical interior wall **33** provides a portion of one side of folded horn **22** adjacent mouth **12** opposite the side provided by first exterior side wall **16**. Vertical interior wall **33** and side wall **16** diverge from one another toward mouth **12** to provide an expanding cross-sectional area for horn **22**. Vertical side wall **33** also provides an interior wall for each of extended throat **58**, **60**, **62**, **64** and for front chambers **34**, **36**, **38** and **40**. The horizontal perimeter of preload or high pressure chamber **34** is completed by vertical walls **25**, **41** and **70**. The horizontal perimeter of high pressure chamber **36** is completed by vertical walls **27**, **41** and **72**. The horizontal perimeter of high pressure chamber **38** is completed by vertical walls **29**, **41** and **74**. The horizontal perimeter of high pressure chamber **40** is completed by vertical walls **31**, **41** and **76**. Wall **41** is broken in three places by outlets from throat extension guides **61**, **62** and **64**. The horizontal perimeters of high pressure chambers **34**, **36**, **38**, **40** are broken by throats **50**, **52**, **54**, **56**. The horizontal perimeter of throat extension section **58** is completed by vertical walls **14** and **70**. The horizontal perimeter of throat extension section **60** is completed by vertical walls **25** and **72**. The horizontal perimeter of throat extension section **62** is completed by vertical walls **27** and **74**. The horizontal perimeter of throat extension section **64** is completed by vertical walls **29** and **76**. Vertical walls **33**, **50**, **72**, **74** and **76** all continue upwardly to provide perimeter elements of substantially sealed back chambers (or closed-box baffles) for acoustic drivers **26**, **28**, **30** and **32**.

Referring to FIG. **4**, which is a cross sectional view taken along section line **4-4** in FIGS. **1** and **2** and to FIG. **5**, which is view taken into enclosure **11** along section line **5-5** in FIG. **4**, the positioning of acoustic drivers **26**, **28**, **30**, **32** over high pressure chambers **34**, **36**, **38** and **40** is illustrated. Acoustic drivers **26**, **28**, **30**, **32** are housed in sealed back chambers **80**, **82**, **84** and **86**, respectively. The term "sealed" as used here has its conventional meaning in the acoustical arts to mean that the back chambers have no acoustic outlet port. The only acoustic opening from sealed back chambers **80**, **82**, **84** and **86** are those directly in front of the diaphragms of acoustic drivers **26**, **28**, **30** and **32**. Back chambers **80**, **82**, **84** and **86** do slowly exchange air with their ambient environment, as is conventional.

In FIG. **5** the position of extended **60** in front of wall **72** illustrates the interface of a representative high pressure chamber **36** to its extended throat **60** and further into summing throat **61**. Because the upper cover section **91** is not horizontal, but slants upwardly from the base of summing throat **61** toward the back wall **15**, the outlet from extended throats into summing throat **61** differs for each extended throat. Extended throat **60** includes some freeboard on wall **41** above the outlet and below upper cover section **91**. As illustrated in FIG. **6** and described with reference to the figure below, the amount of freeboard for each port will differ.

Acoustic driver **28** rests on a support plane **93**. Sealed back chamber **82**, like the remaining back chambers, is closed on one side by a planer wall **95**.

Referring now to FIG. **6**, which is an end view of enclosure **11** with back wall **15** removed, the interior of folded horn **22** is illustrated in greater detail, particularly the summing throat **61**. Summing throat **61** is formed by portions of side wall **17**, cover **91**, base **18** and wall **41**. Summing throat **61** collects sound output from the four throat extension sections **58**, **60**, **62**, **64**, the radiating outlets of which are visible along a side of summing section **61** defined by vertical wall **41**. The surfaces forming summing throat **61** diverge from one another moving toward the back wall **15** from the base of the horn along front wall **14**. The divergence of the upper and lower surfaces of folded horn **22** is provided in the upward slant of board **97**. While the output port from extended throat **58** has a vertical extent substantially equal to the local height of summing throat **61**, the outlets of downstream extended throats **60**, **62** and **64**, which are all of the same height, will have increasing amounts of freeboard.

Any given horn has differing horizontal and polar frequency responses. And while a horn may operate well at certain frequencies its performance can degrade markedly at other frequencies. These changes in performance are highly dependent on the length of the horn. While each of transducers **26**, **28**, **30**, **32** is coupled to the folded horn by an identical high pressure chamber and extended throat, the extended throats in **56**, **60**, **62** and **64** are coupled to summing junction **61** at points which are differently spaced from the mouth **12**. In other words, horn **22** will have different performance characteristics for each transducer including, different optimal frequency operating range. Accordingly, each driver circuit differentially treats the signal applied to each transducer.

Producing sound of maximum intensity from loudspeaker system **10** requires that acoustic pressure waves from the outlets of extended throats be synchronized at the points where they merge. Due to the different distances sound travels to reach mouth **12** from the outlets from extended throats **58**, **60**, **62** and **64**, the drive signal applied to transducers **26**, **28**, **30**, **32** is time differentiated so that the sound waves constructively reinforce one another in summing section **61** rather than cancel or interfere with one another. While the same signal is the genesis of the signal used to drive each of the four transducers **26**, **28**, **30**, **32**, this source signal must be processed differently before application to the respective transducers' voice coils to assure good phase matching at the mouth **12** and a good match of output from the extended throats **58**, **60**, **62** and **64** to the frequency response characteristic of folded horn **22** for a given outlet port from one of extended throats **58**, **60**, **62** and **64**. The signal for the transducer associated with the throat radiating end removed by the greatest distance from mouth **12** is delayed least, while the signal driving the transducer associated with the throat radiating end closest to mouth **12** is delayed by the greatest period. Differences in impedance matching of the extended throat for each driver to summing section **61** require some band pass filtering and shading of the source signal for optimal system performance. The source signal may require dynamic phrase adjustment (i.e. adjustment of the signal phase as a function of frequency) of the source signal due to the frequency response characteristics of the horn which vary with frequency at each extended throat outlet port.

Referring to FIGS. **7** and **8**, a common source **711** of audio frequency signals is applied to four inputs of a digital signal processor (DSP) **709** which differentially processes the signals to accommodate the relative positions of acoustical drivers **26**, **28**, **30**, **32**. DSP **709** provides the four differentiated outputs on each of four channels **713**, **715**, **717**, **719** to four amplifiers **701**, **703**, **705** and **707** associated with acoustical drivers **26**, **28**, **30**, **32**. In general, the input signal is processed in the same general way for all four channels, with only the parameters applied by the processing steps changing. For each channel, the signal is fed through a band pass filter **801** which passes frequency ranges best handled by a particular horn/driver configuration. Typically, the broadest band of frequencies is applied to the acoustic driver couple to the summing junction **61** at the furthest point from mouth **12**. The roll off of the signal range applied to a driver may also be adjusted. Next, the filtered signal is applied to a time delay **803** which synchronizes the signals based on the differing distances of the speakers from the horn mouth. Lastly, the filtered, delayed signal for a channel is applied to a dynamic phase adjustment module **805**, which adjusts the phase of the signal as a function of frequency. The specific parameters used will change along with changes in horn dimensions and the number of transducers used.

FIG. **9** illustrates an alternative embodiment of the invention whereas two acoustic drivers **930**A and **930**B are coupled to a common high pressure chamber **900**. Sound is coupled from compression chamber **900** to a horn **922** by an extended throat **902** which has a cross sectional area which is a fraction of the area of the diaphragms of acoustic drivers **930**A-B. Extended throat **902** operates as a kind of pneumatic amplifier greatly accelerating air velocity. Still other arrangements of transducers and horn types will now occur to those skilled in the art.

The invention provides high acoustic output power for low frequency sound from a minimally sized, portable cabinet, suitable for use at outdoor, temporary venues. The package is well suited for bass line reproduction required for rock music reproduction.

While the invention is shown in only one of its forms, it is not thus limited but is susceptible to various changes and modifications without departing from the spirit and scope of the invention.

What is claimed is:

1. A loudspeaker comprising:

an enclosure including a folded horn having a base end and a mouth;

a summing throat forming a portion of the folded horn including the base end, the summing throat increasing in cross sectional area in a direction of acoustic energy propagation;

a plurality of acoustic transducers housed in the enclosure;

a plurality of radiating ports, each radiating port providing for coupling sound energy from each respective acoustic transducer into the summing throat, each radiating port being disposed at a discrete, acoustically spaced location along the summing throat with successive locations of the radiating ports occurring at points along the summing throat exhibiting increasing cross sectional area to initiate and synchronously reinforce an acoustic pressure wave building from the base end toward the mouth;

a source of an acoustic range signal;

transducer drive signal processing circuitry having an individual channel for each of the audio transducers, the individual channels each being coupled to receive the acoustic range signal and each channel including means for setting a relative phase angle for the acoustic range signal in a channel as a function of the acoustic spacing of the radiating outlets to build an acoustic pressure wave in a cascade in the summing throat toward the mouth;

a plurality of high pressure chambers, at least one acoustic transducer being positioned to direct sound energy into each high pressure chamber, and each high pressure chamber being connected by one of the plurality of radiating ports to the summing throat; and

each radiating port terminating along a side of the summing throat at successive locations progressing from the base end of the summing throat toward the mouth of the folded horn with a direction of sound propagation transverse to the direction of sound propagation in the summing throat.

2. A loudspeaker as set forth in claim **1**, each channel of the transducer drive signal processing circuitry further comprising:

a band pass filter receiving the acoustic range signal and producing a filtered signal therefrom;

the time delay element receiving filtered signal and producing a delayed, filtered signal; and

a dynamic phase adjustment element receiving the delayed, filtered signal and adjusting the phase of the signal as a function of frequency to produce a drive signal for an acoustic transducer.

3. A loudspeaker as set forth in claim **2**, wherein the band pass filters, delay elements and dynamic phase adjustment elements are realized in a digital signal processor.

4. A loudspeaker as set forth in claim **2**, further comprising:

the acoustic transducers having a small vibrational surface area relative to the predominant range of frequencies to be reproduced; and

a plurality of sealed back chambers, one sealed back chamber housing each acoustic transducer.

5. A loudspeaker as set forth in claim **4**, further comprising:

the audio transducers being positioned with respect to one another in a linear array, one to each high pressure chamber.

6. A loudspeaker as set forth in claim **4**, further comprising:

a plurality of acoustic transducers coupled to each high pressure chamber.

7. A loudspeaker unit comprising:

a plurality of low frequency acoustic transducers;

a plurality of pre-load chambers, at least one pre-load chamber being associated with each of the plurality of low frequency acoustic transducers;

each low frequency acoustic transducer being disposed to radiate into its associated pre-load chamber;

a horn having a base end and a mouth and formed at least in part by a surface extending from the base end to the mouth; and

a plurality of ports connecting the plurality of pre-load chambers into the horn, each of the plurality of ports having a radiating opening on the surface of the horn, the radiating openings being disposed along the surface extending in line from adjacent the base end toward the mouth substantially parallel to the direction of sound propagation in the horn to support cascade formation of pressure waves from the base end toward the mouth, and with the radiating openings being oriented to direct sound into the horn locally substantially transverse with respect to an axis of sound propagation defined by the horn.

8. The loudspeaker unit in accord with claim **7**, further comprising:

a right trapezoid enclosure for the horn, which is folded within the right trapezoid enclosure.

9. The loudspeaker unit in accord with claim **7**, further comprising:

means for coordinating operation of the low frequency acoustic transducers so that the pressure waves from the radiating ends emitting from the radiating openings reinforce one another.

10. The loud speaker unit in accord with claim **9**, wherein the acoustic transducers are housed to emit from sealed back chambers.

11. The loudspeaker unit in accord with claim **9**, the means for coordinating further comprising drive circuitry for the low frequency acoustic transducers including delay means for synchronizing merger of the pressure waves upon their meeting in the horn.

12. The loudspeaker unit in accord with claim **11**, the drive circuitry including a pass band filter and a dynamic phase adjustment element for each of the low frequency acoustic transducers.

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