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Graber

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(54) ACOUSTIC ENERGY PROJECTION SYSTEM

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G10K 11/28 (2006.01)

(52) **U.S. Cl.** **181/191**; 181/153; 181/155; 181/176; 381/336

(58) **Field of Classification Search** 181/155, 181/176, 191, 188, 153; 381/197, 157, 335, 381/336, 389, 89, 147
See application file for complete search history.

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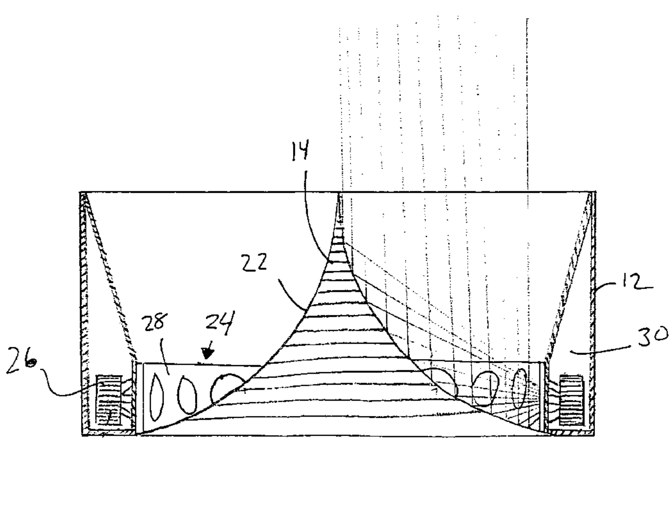
Primary Examiner—Jeffrey Donels
Assistant Examiner—Jeremy Luks
(74) *Attorney, Agent, or Firm*—Paul W. O'Malley; Susan L. Firestone

(57) **ABSTRACT**

The sound generating and transmitting apparatus is based on a radiator including at least a first, and possibly two or more, shaped reflecting surface(s) having a forward radiant axis. Each of the shaped reflecting surfaces defines sets of equivalent acoustic input locations, with each set being a ring of non-zero circumference centered on the forward radiant axis. The sound source is a distributed, functionally continuous sound source adapted to exploit this feature. In its preferred form the sound source is a sort of closed line array of loudspeakers providing a torodial shaped acoustic source to direct at the hyperbolic cone, the transducers being disposed in a circle with all of the loudspeakers oriented inwardly toward or outwardly from the forward radiant axis.

9 Claims, 16 Drawing Sheets



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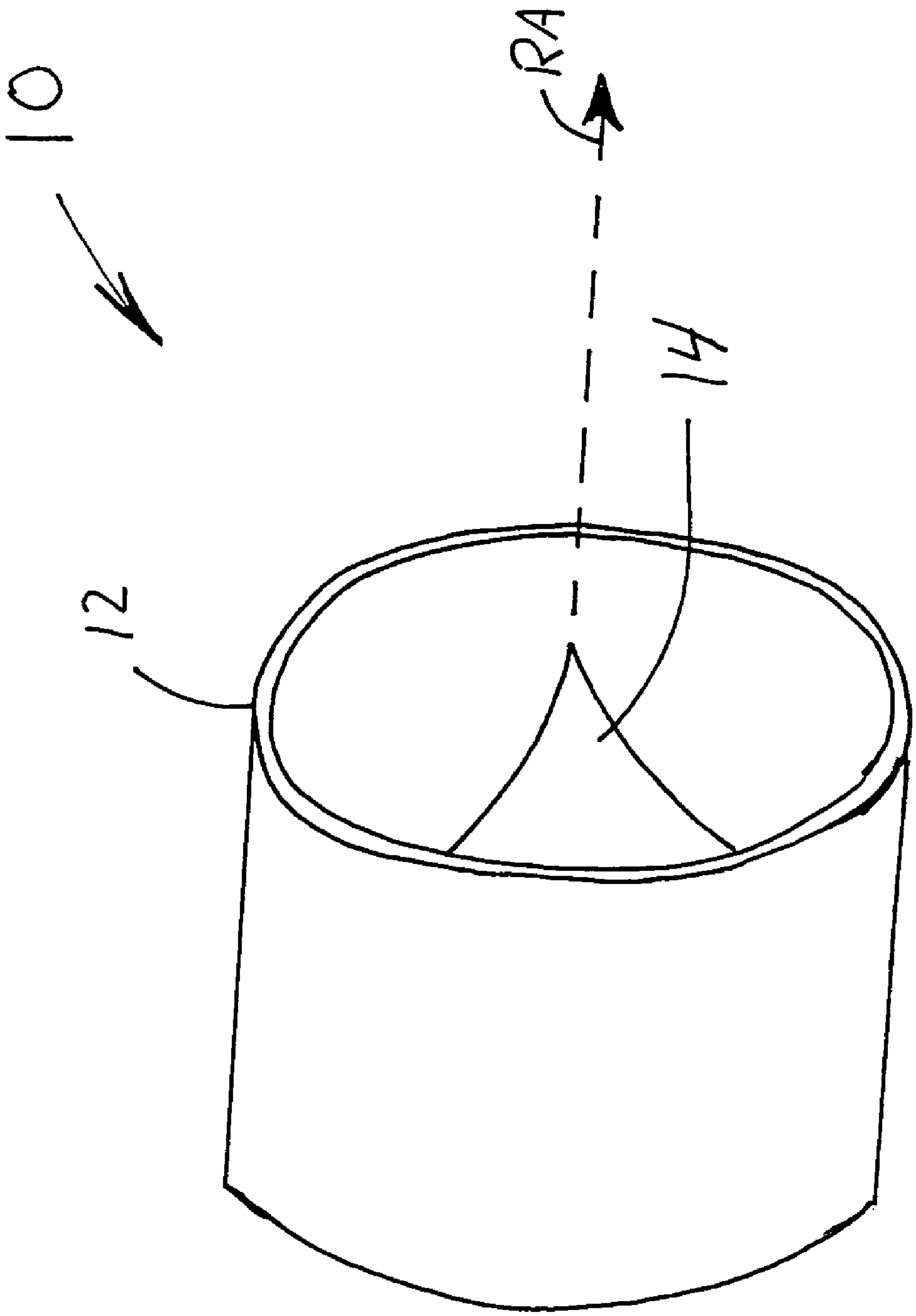


FIG. 1

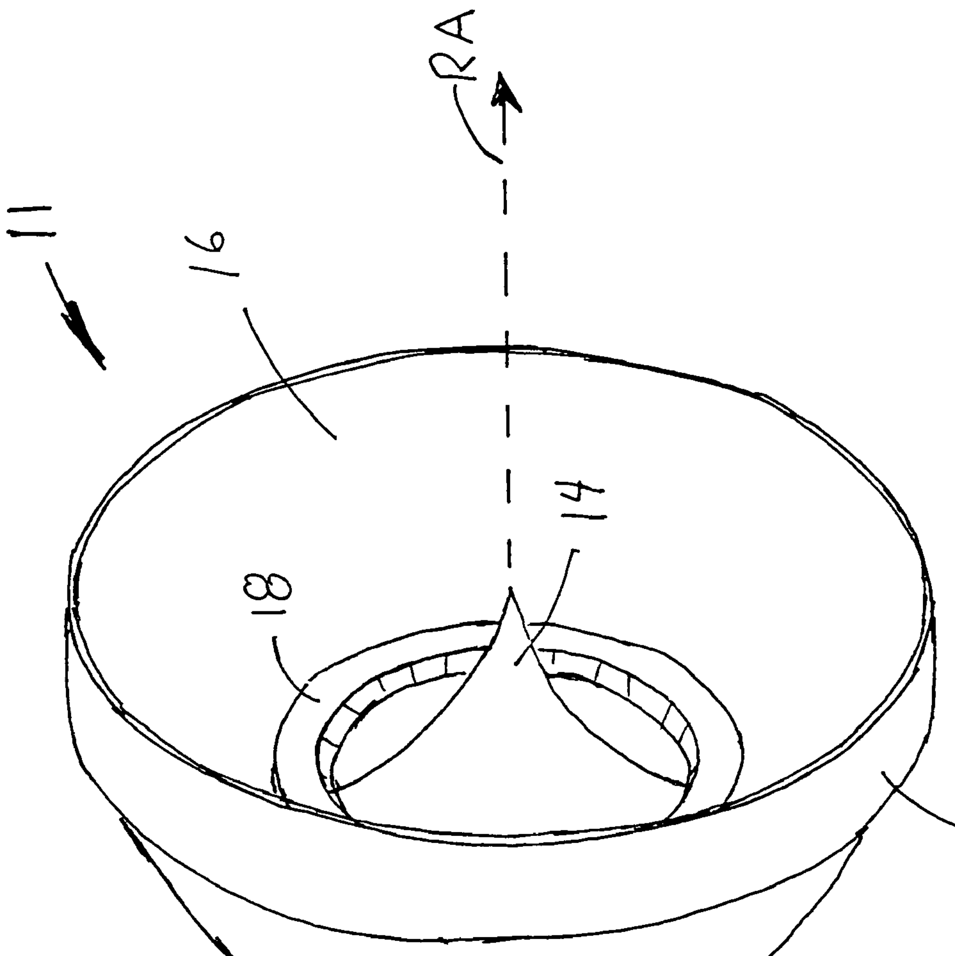


FIG. 2

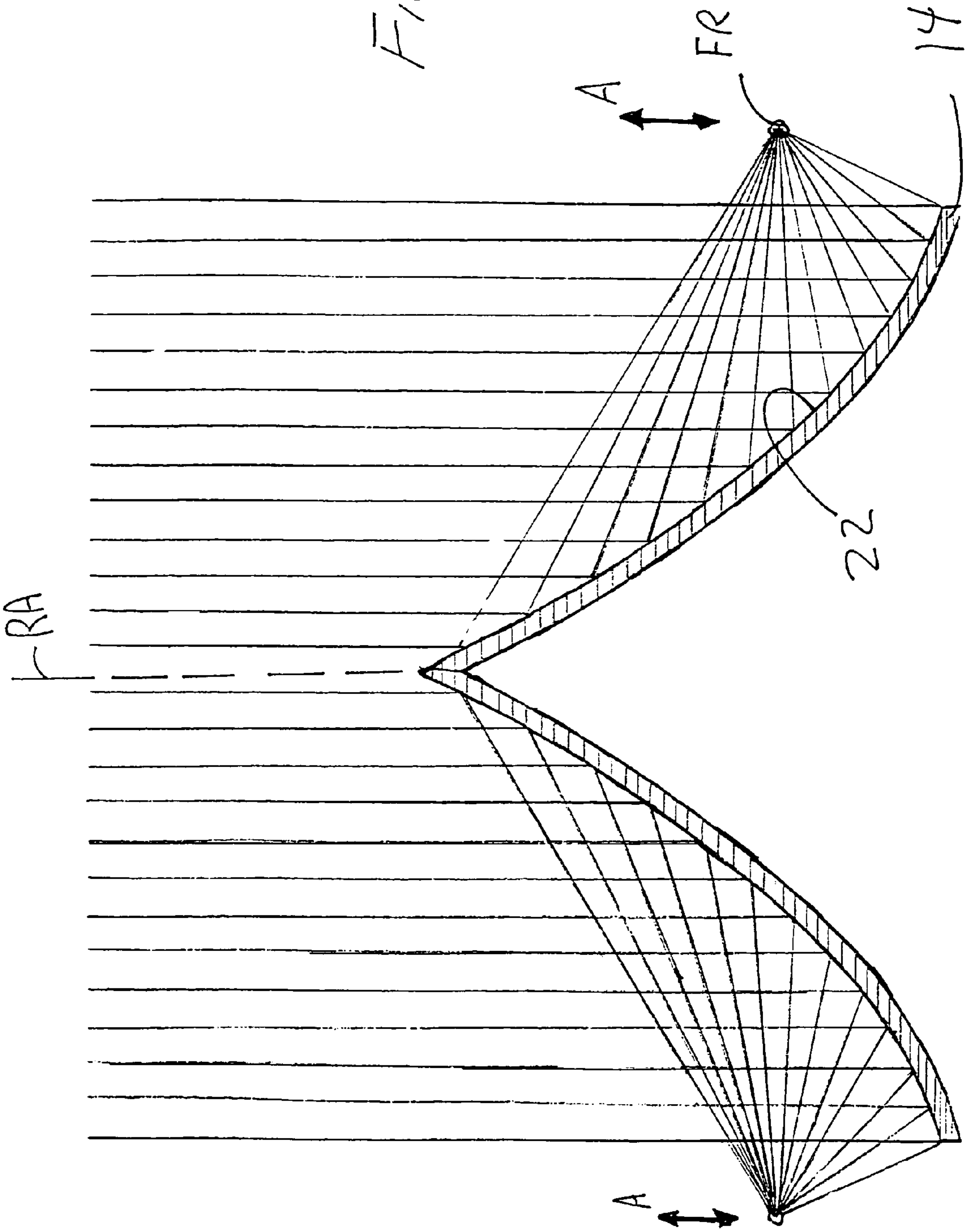


FIG. 3

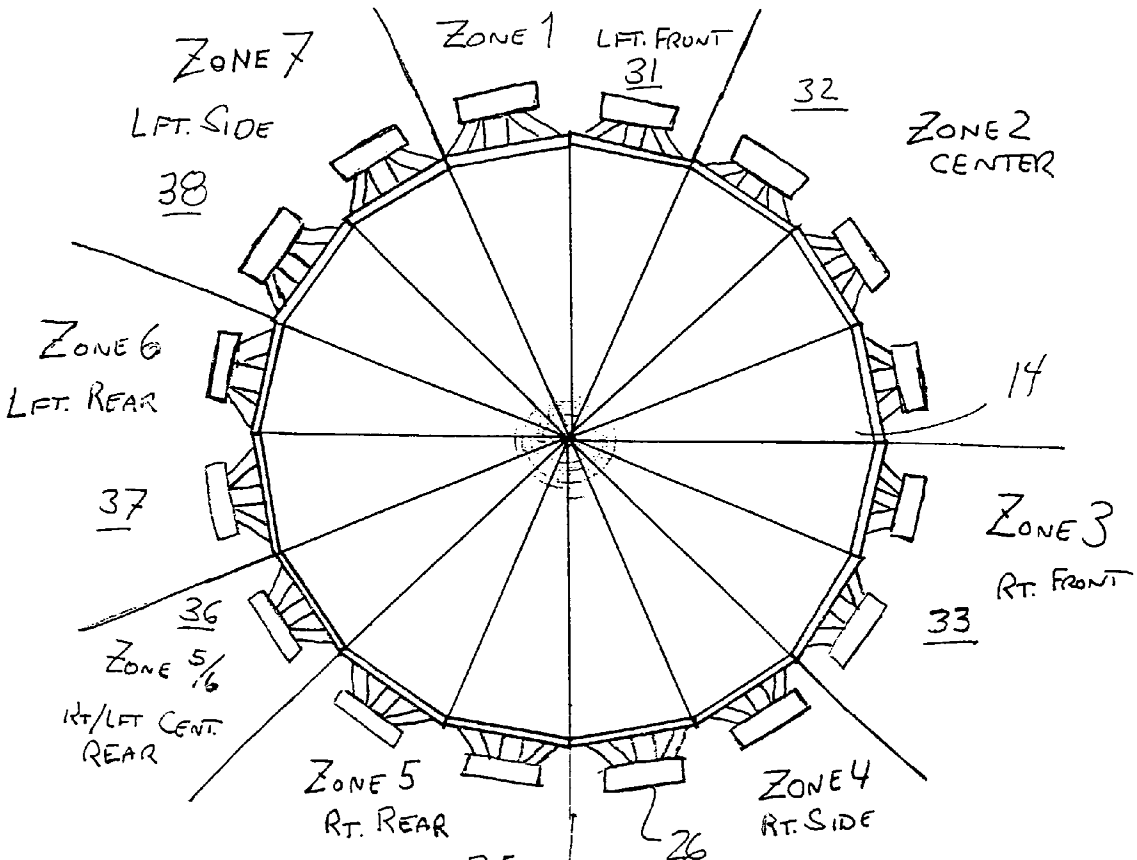
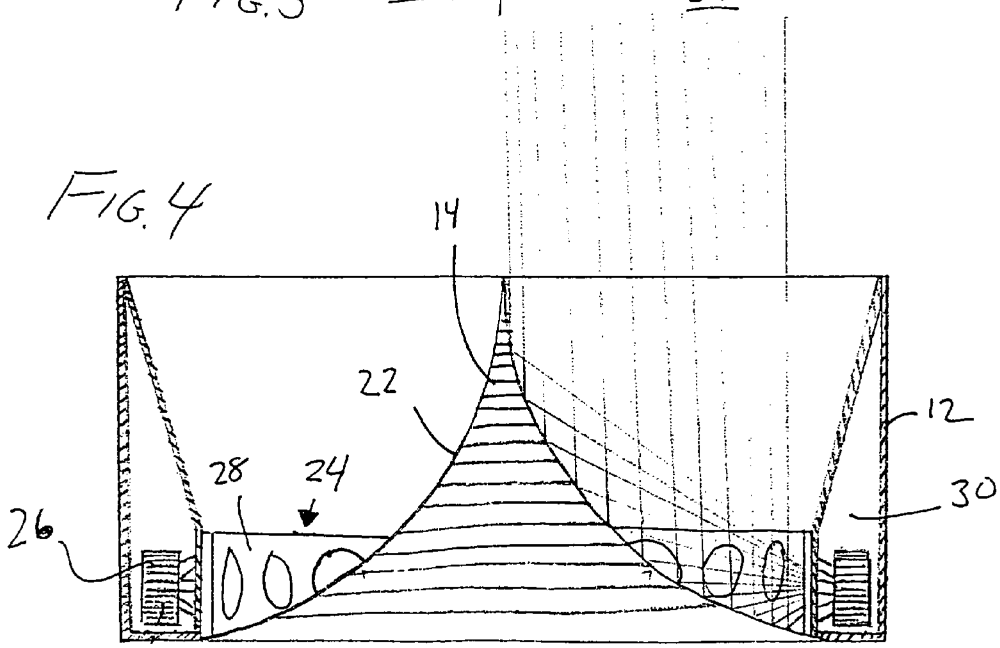

ZONE 7
LFT. SIDE
38
ZONE 1
LFT. FRONT
31
32
ZONE 2
CENTER
14
ZONE 6
LFT. REAR
37
ZONE 3
RT. FRONT
33
36
ZONE 5/6
RT/LFT CENT. REAR
ZONE 5
RT. REAR
ZONE 4
RT. SIDE
26
35
34

FIG. 5

FIG. 4


14
22
12
28
24
30
26

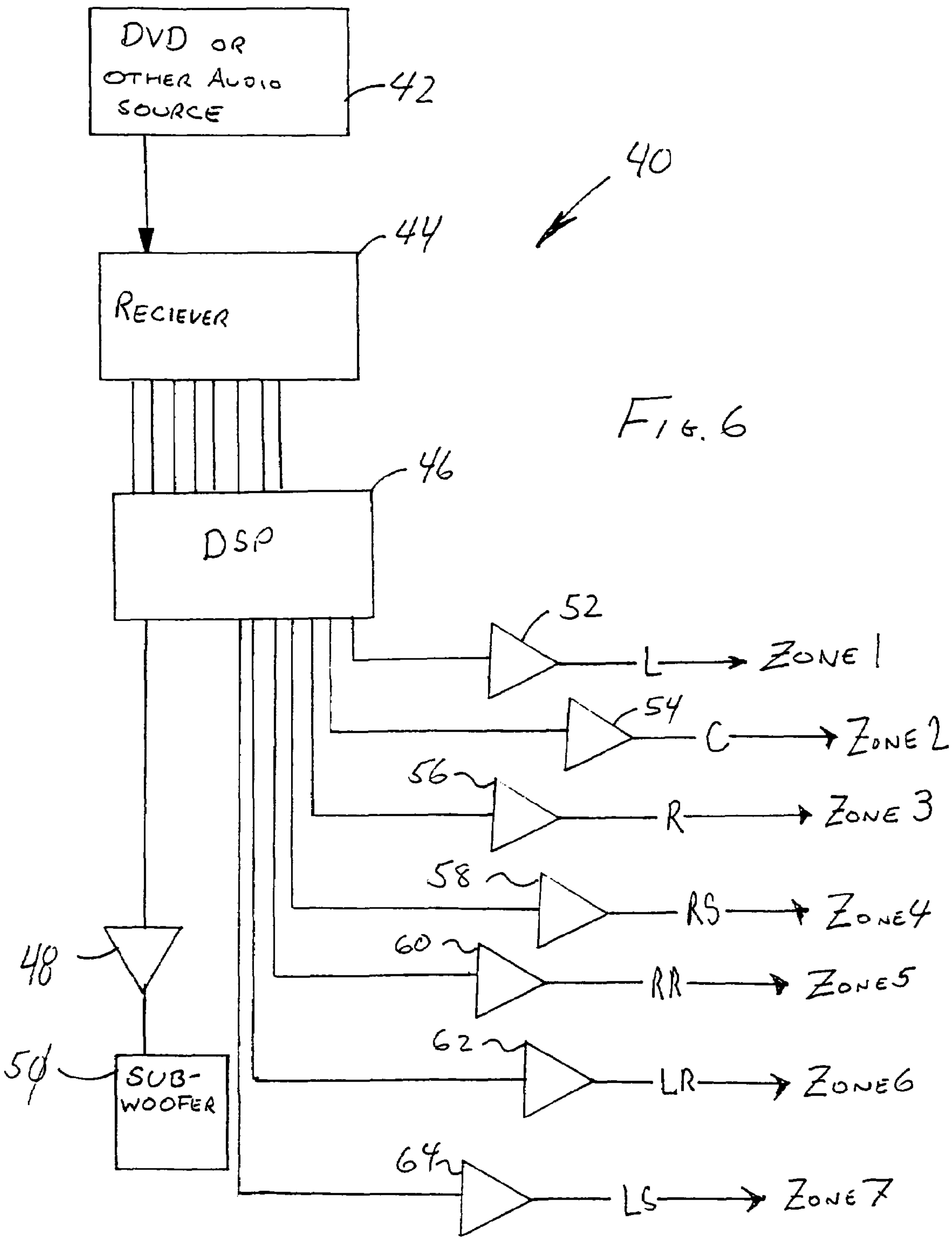

DVD OR OTHER AUDIO SOURCE
42
40
44
RECIEVER
46
DSP
52
L
ZONE 1
54
C
ZONE 2
56
R
ZONE 3
58
RS
ZONE 4
60
RR
ZONE 5
62
LR
ZONE 6
64
LS
ZONE 7
48
50
SUB-WOOFER

FIG. 6

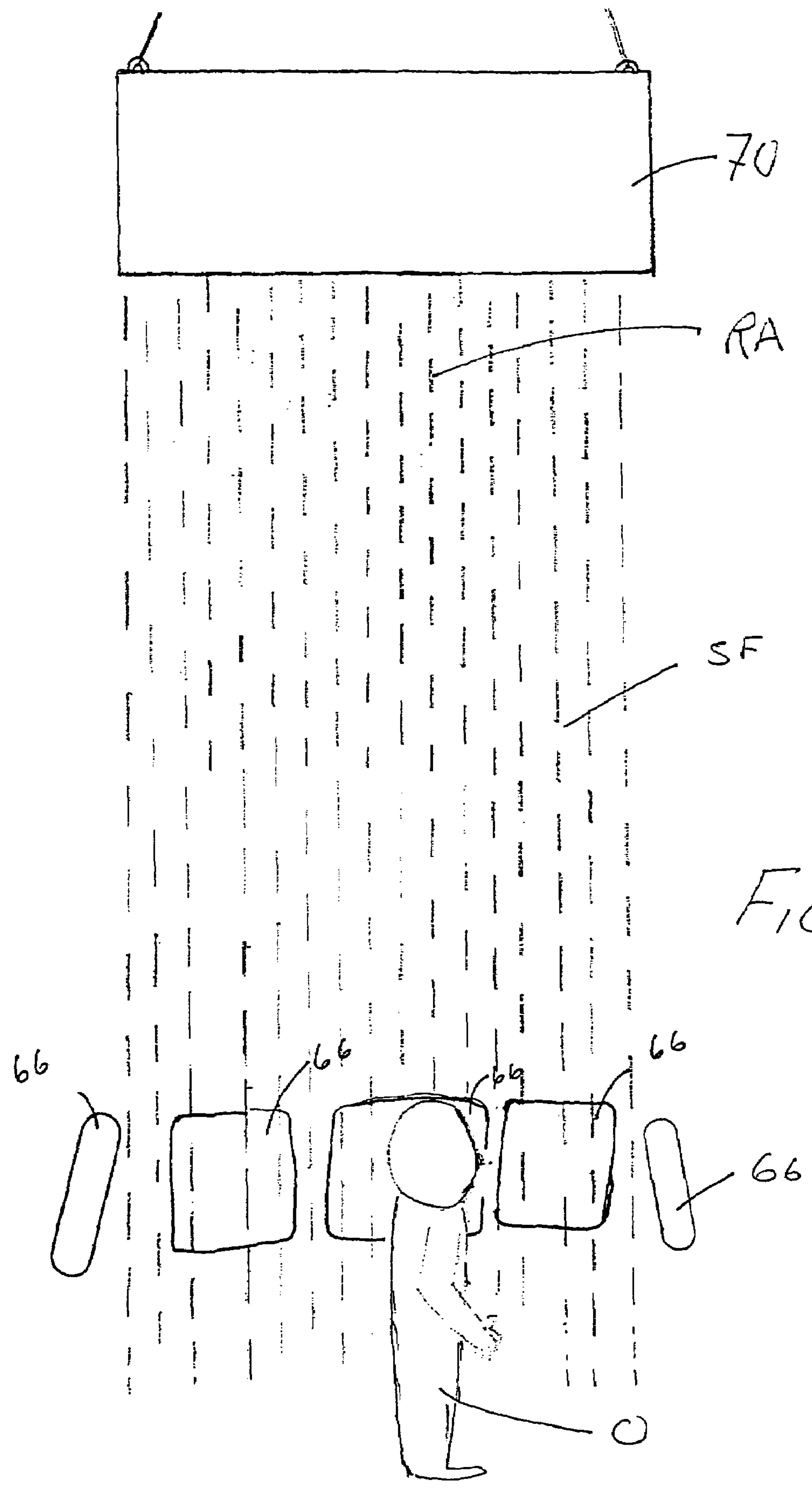


FIG. 7

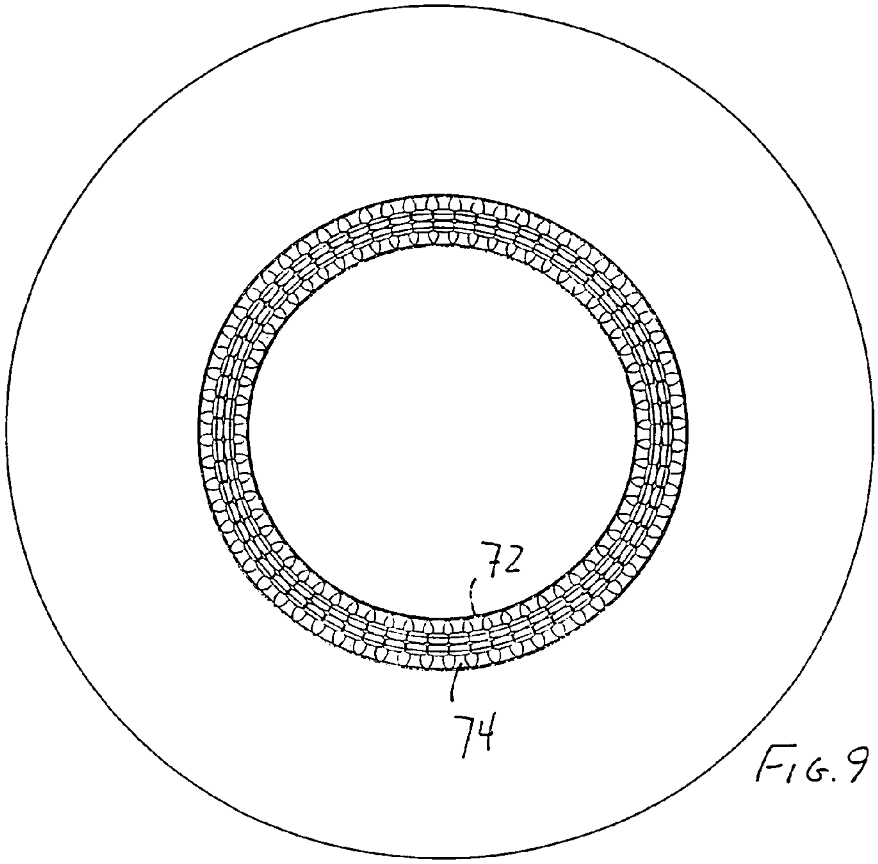


FIG. 9

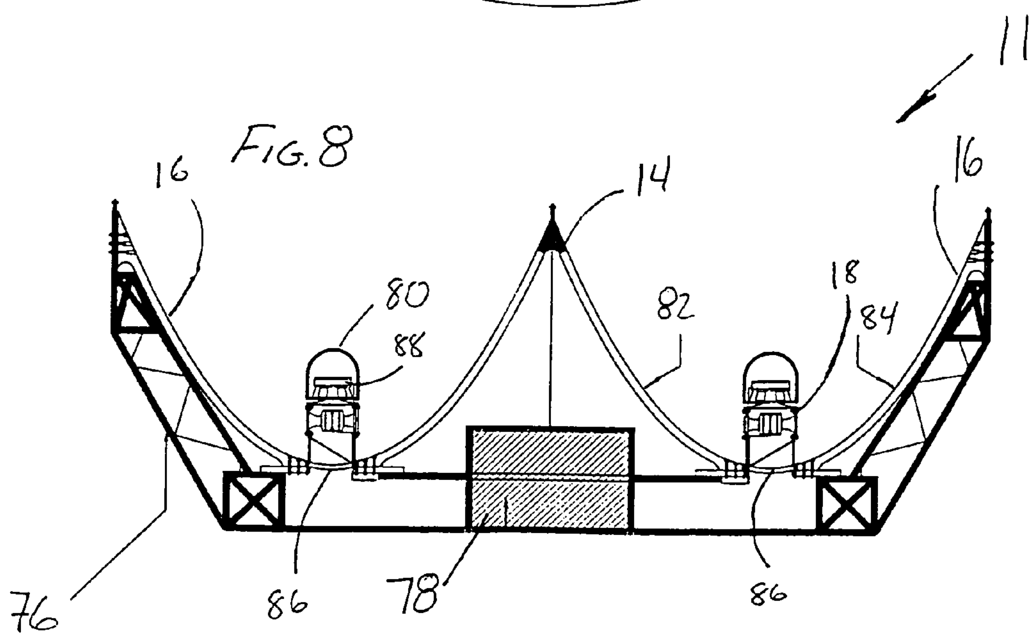


FIG. 8

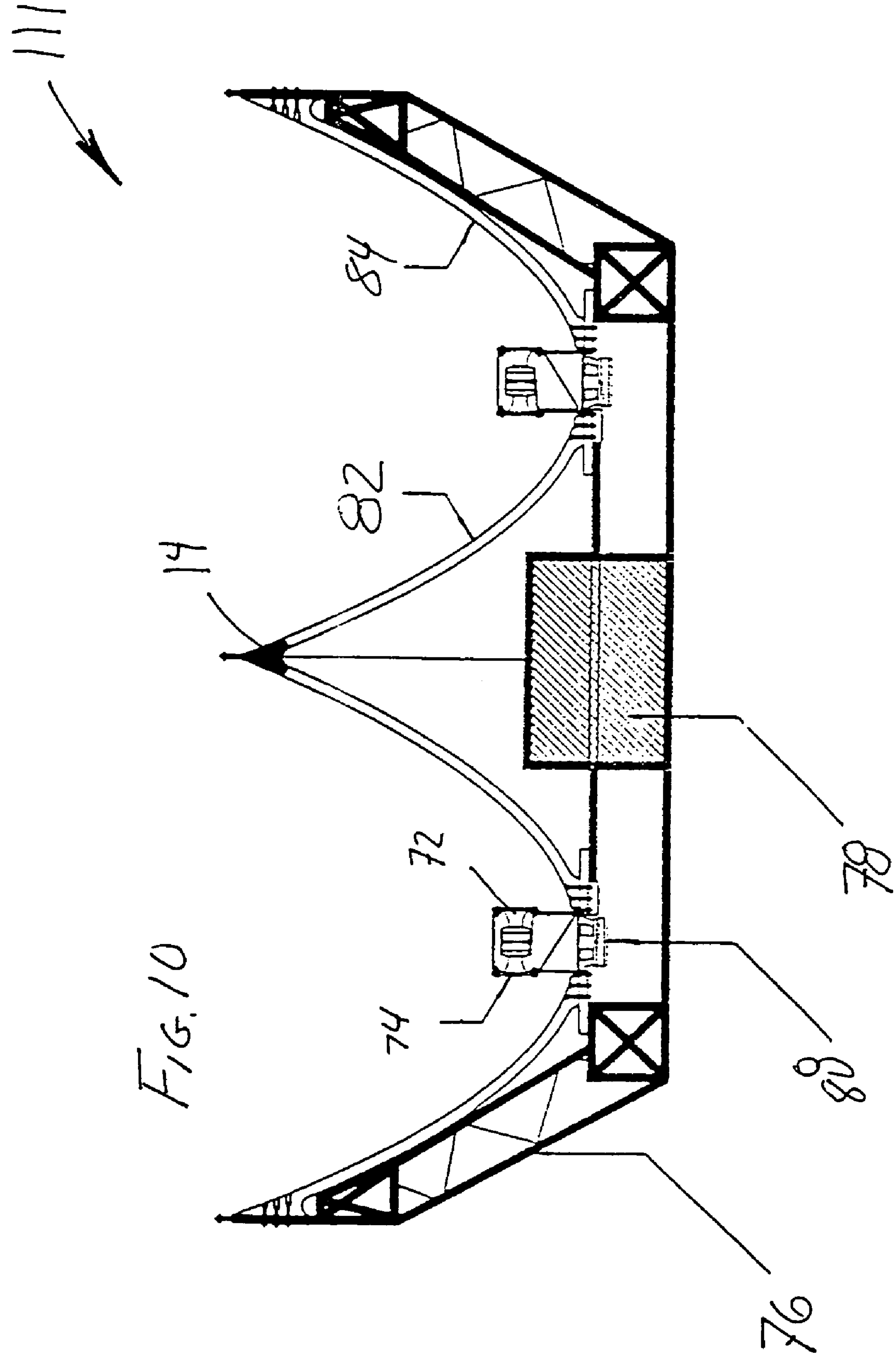


FIG. 10

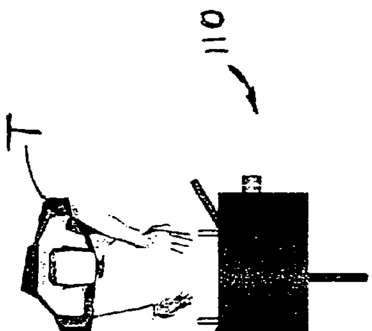


FIG. 11A

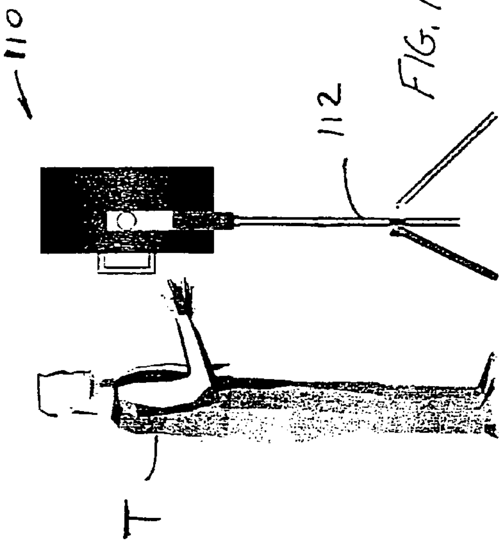


FIG. 11B

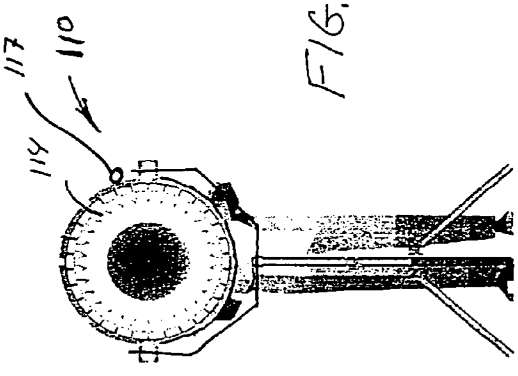


FIG. 11C

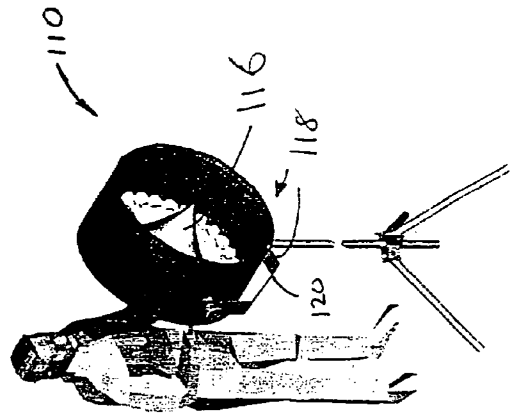
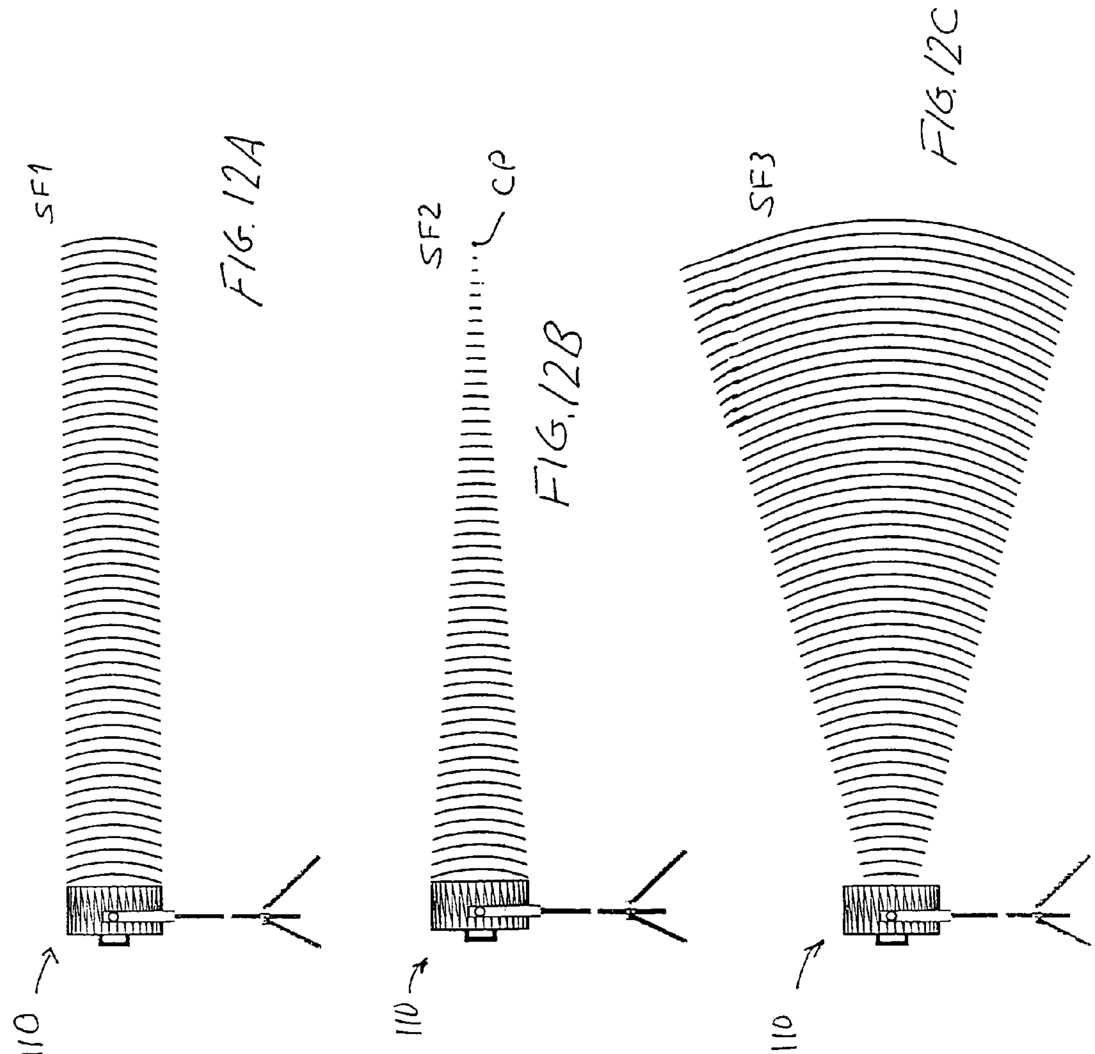


FIG. 11D


SF1
FIG. 12A
110
SF2
CP
FIG. 12B
110
SF3
FIG. 12C
110

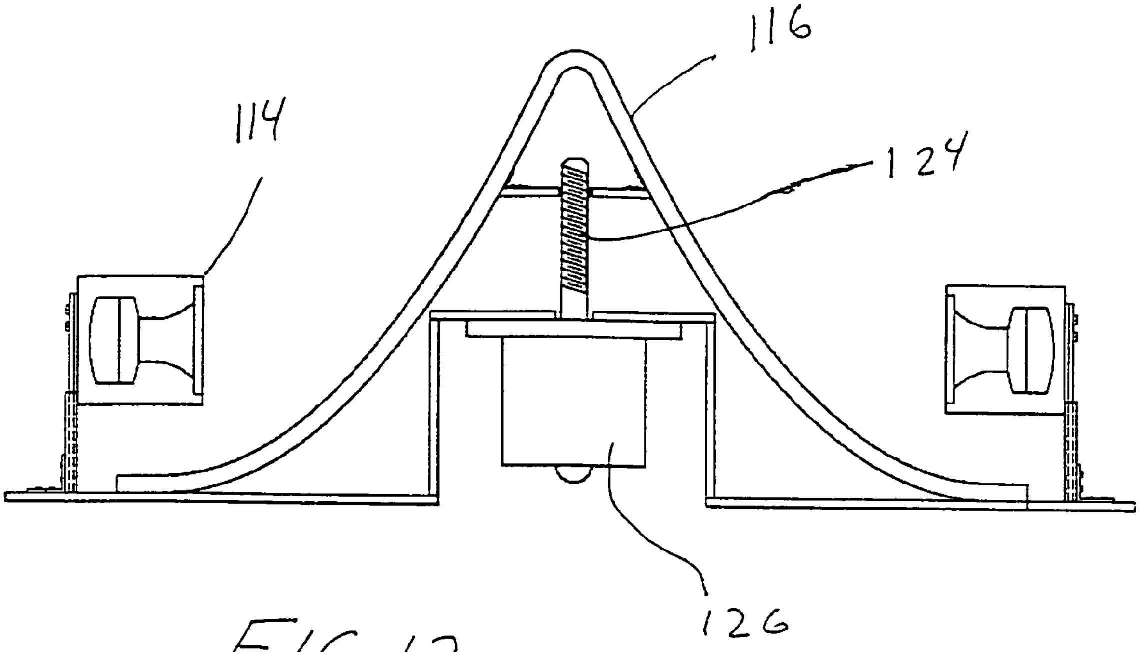


FIG. 13

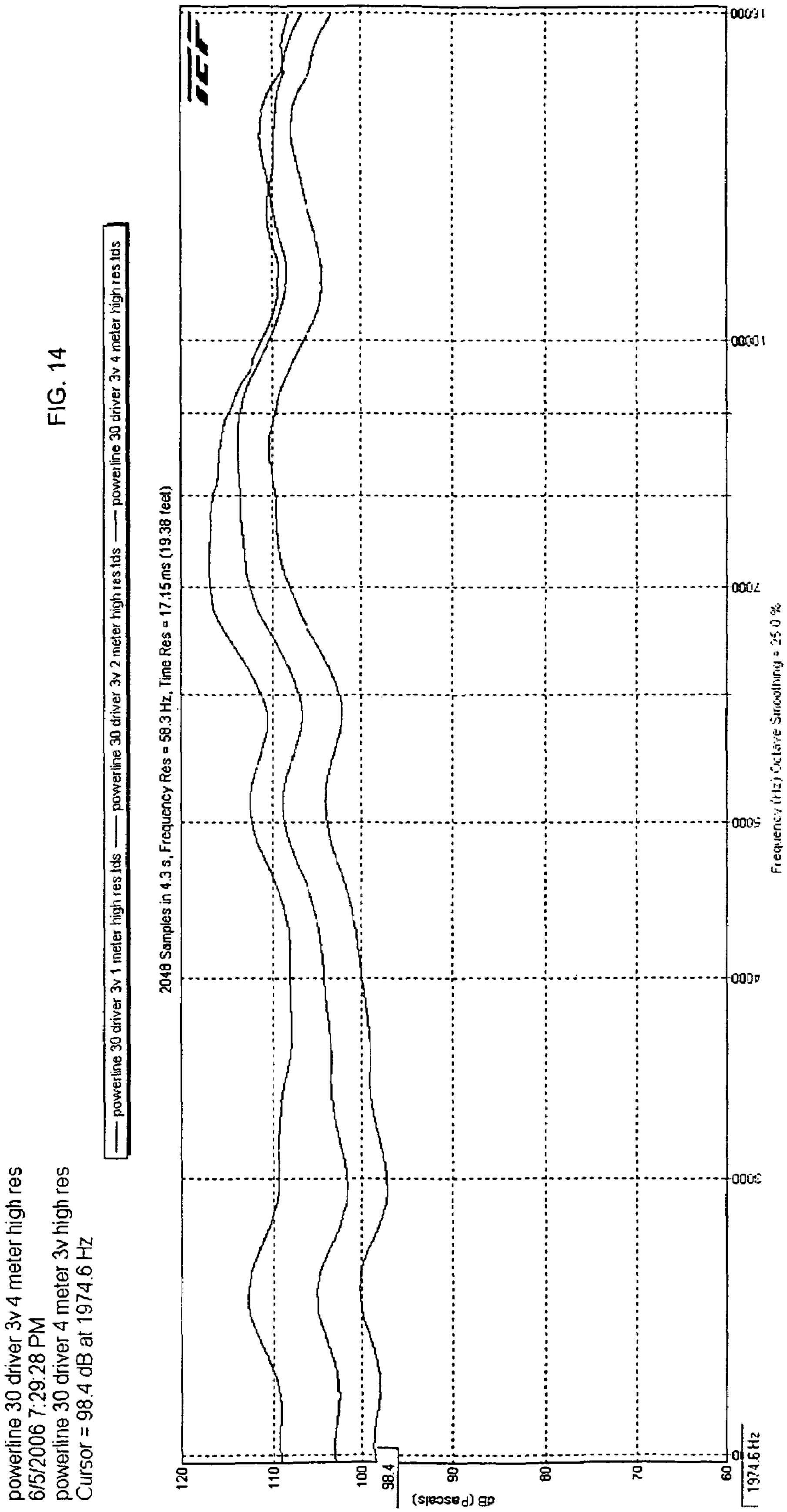

powerline 30 driver 3v 4 meter high res
6/5/2006 7:29:28 PM
powerline 30 driver 4 meter 3v high res
Cursor = 98.4 dB at 1974.6 Hz
powerline 30 driver 3v 1 meter high res tds
powerline 30 driver 3v 2 meter high res tds
powerline 30 driver 3v 4 meter high res tds
2048 Samples in 4.3 s, Frequency Res = 58.3 Hz, Time Res = 17.15 ms (19.38 feet)
dB (Pascals)
120
110
100
98.4
90
80
70
60
1974.6 Hz
Frequency (Hz) Octave Smoothing = 25.0 %

FIG. 14

FIG. 15

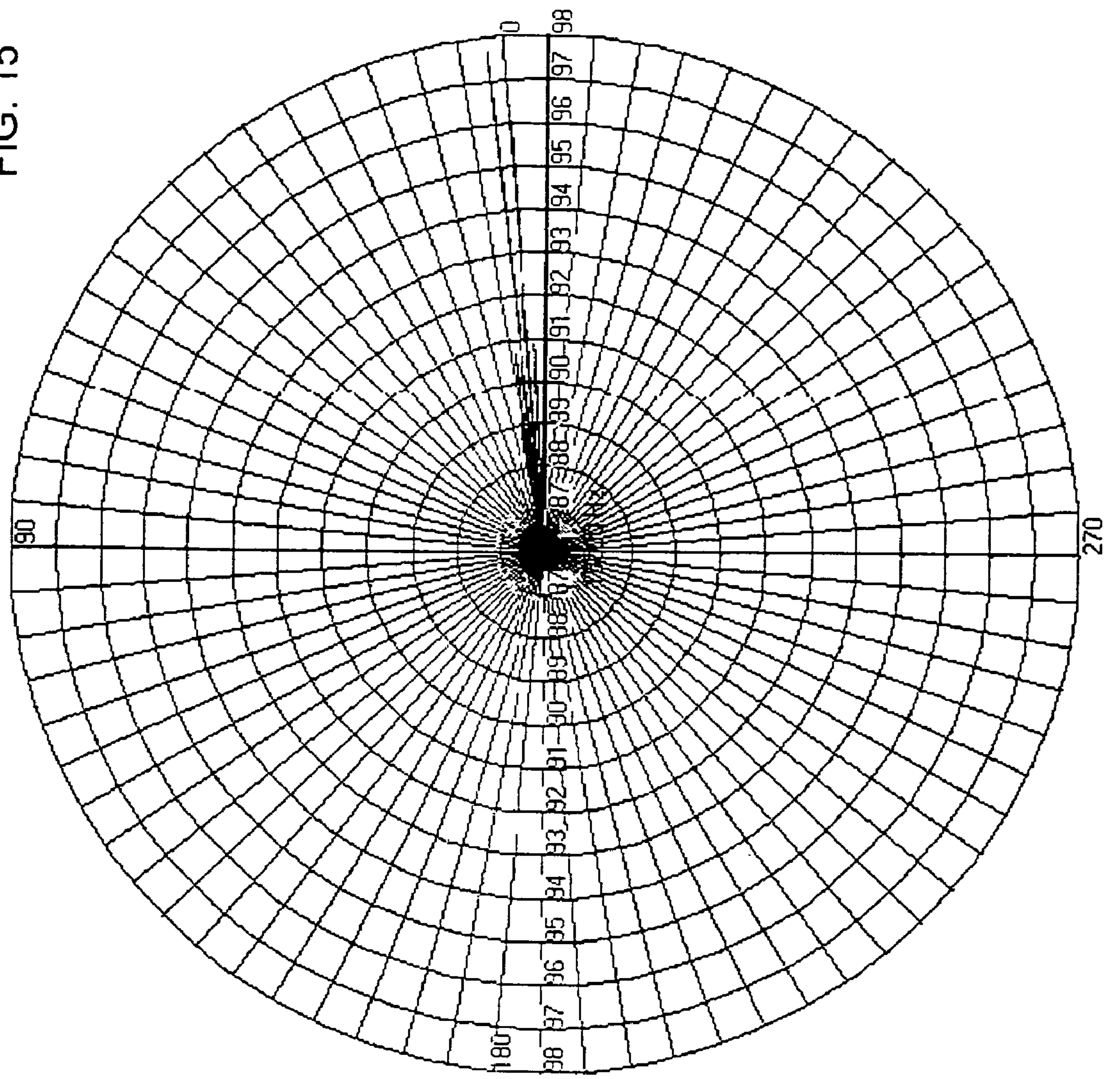
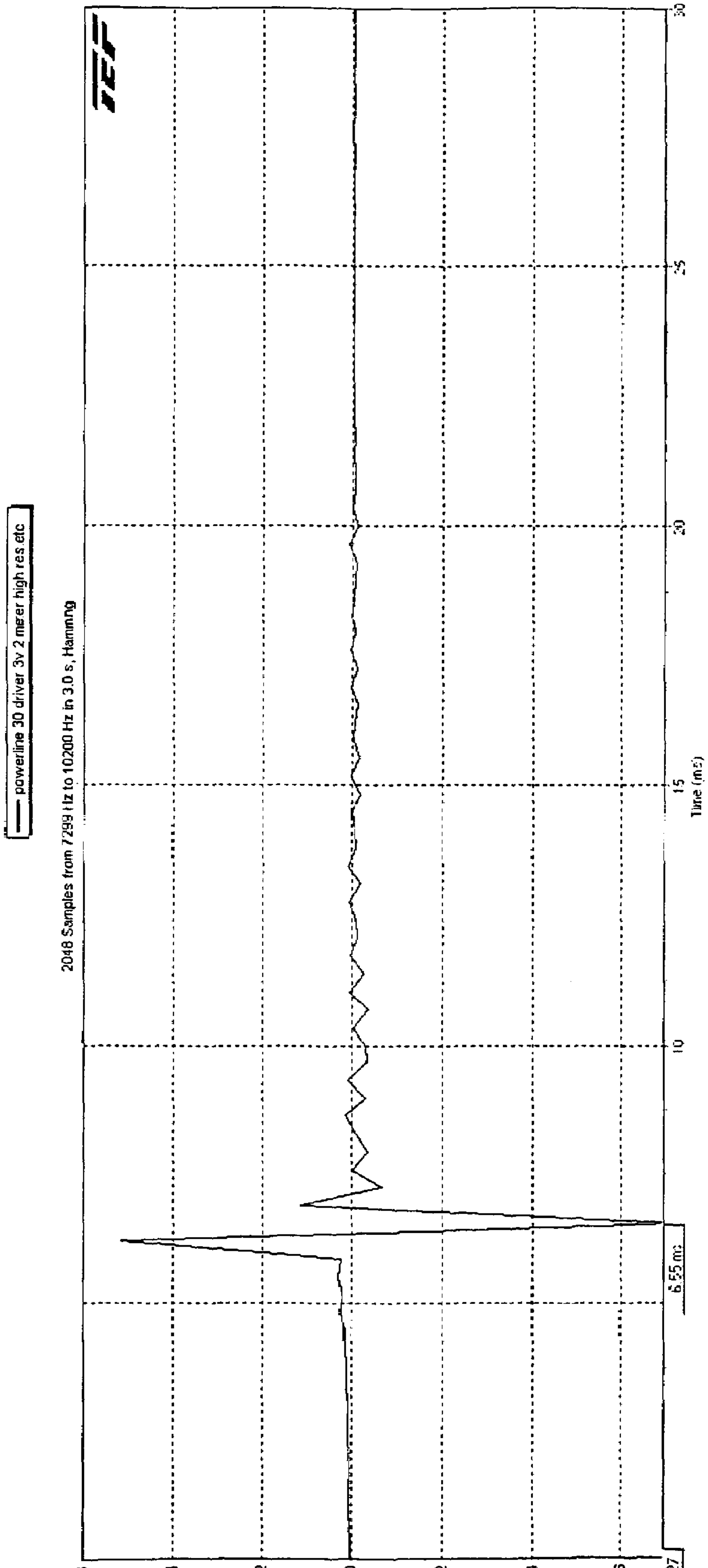
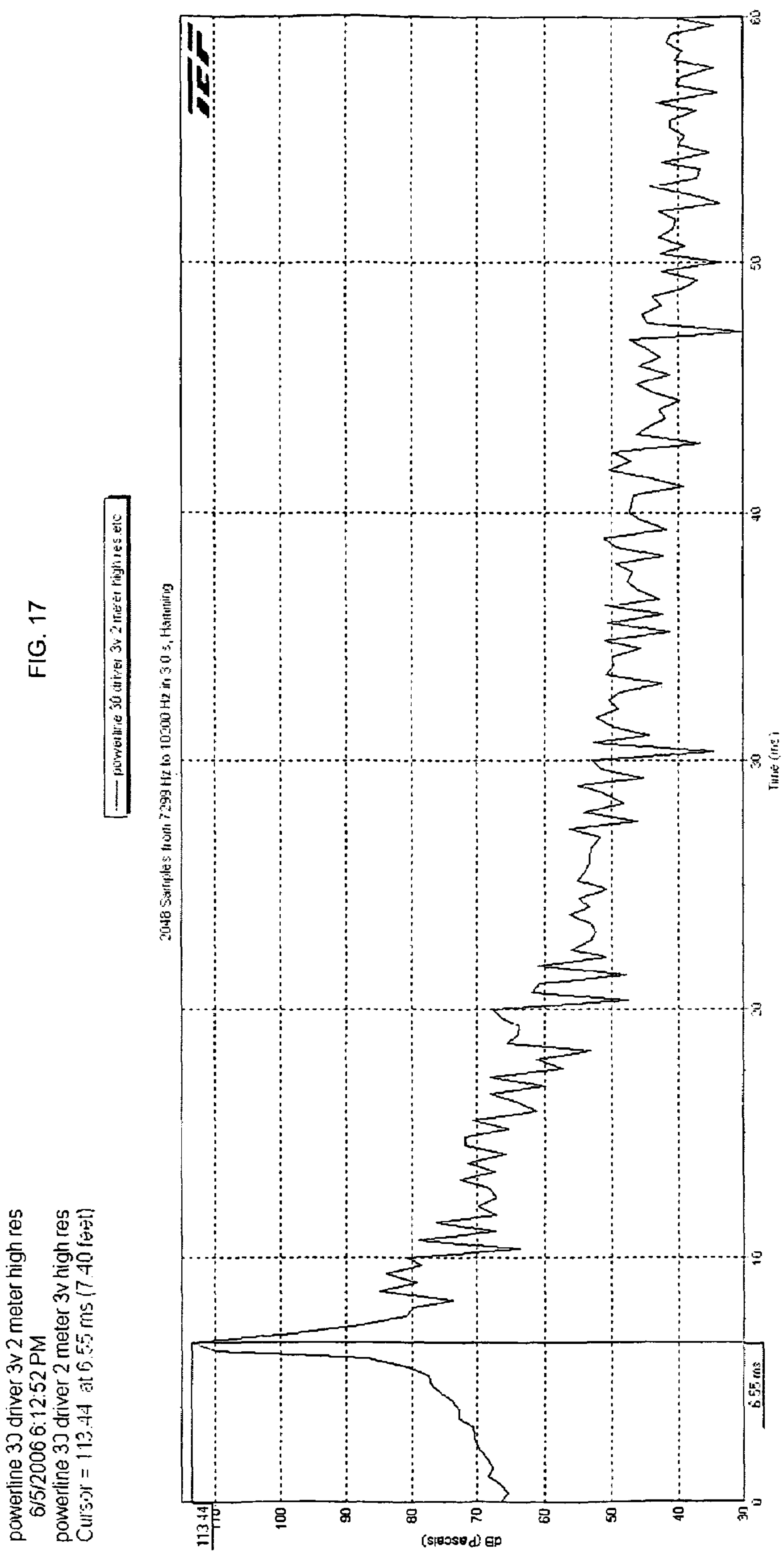


FIG. 16


powerline 30 driver 3v 2 meter high res
6/5/2006 6:12:52 PM
powerline 30 driver 2 meter 3v high res
Cursor = -7.27 m at 6.55 ms (7.40 feet)
powerline 30 driver 3v 2 meter high res etc
2048 Samples from 7299 Hz to 10200 Hz in 3.0 s, Hamming
Impulse (mV)
Time (ms)
6.55 ms
-7.27
6
4
2
0
-2
-4
-6
10
15
20
25
30



powerline 30 driver 3v 2 meter high res
6/5/2006 6:12:52 PM
powerline 30 driver 2 meter 3v high res
Cursor = 113.44 at 6.55 ms (7.40 feet)
powerline 30 driver 3v 2 meter high res etc
2048 Samples from 7299 Hz to 10000 Hz in 3.0 s, Hamming
dB (Pascals)
113.44
110
100
90
80
70
60
50
40
30
0
6.55 ms
10
20
30
40
50
60
Time (ms)

FIG. 17

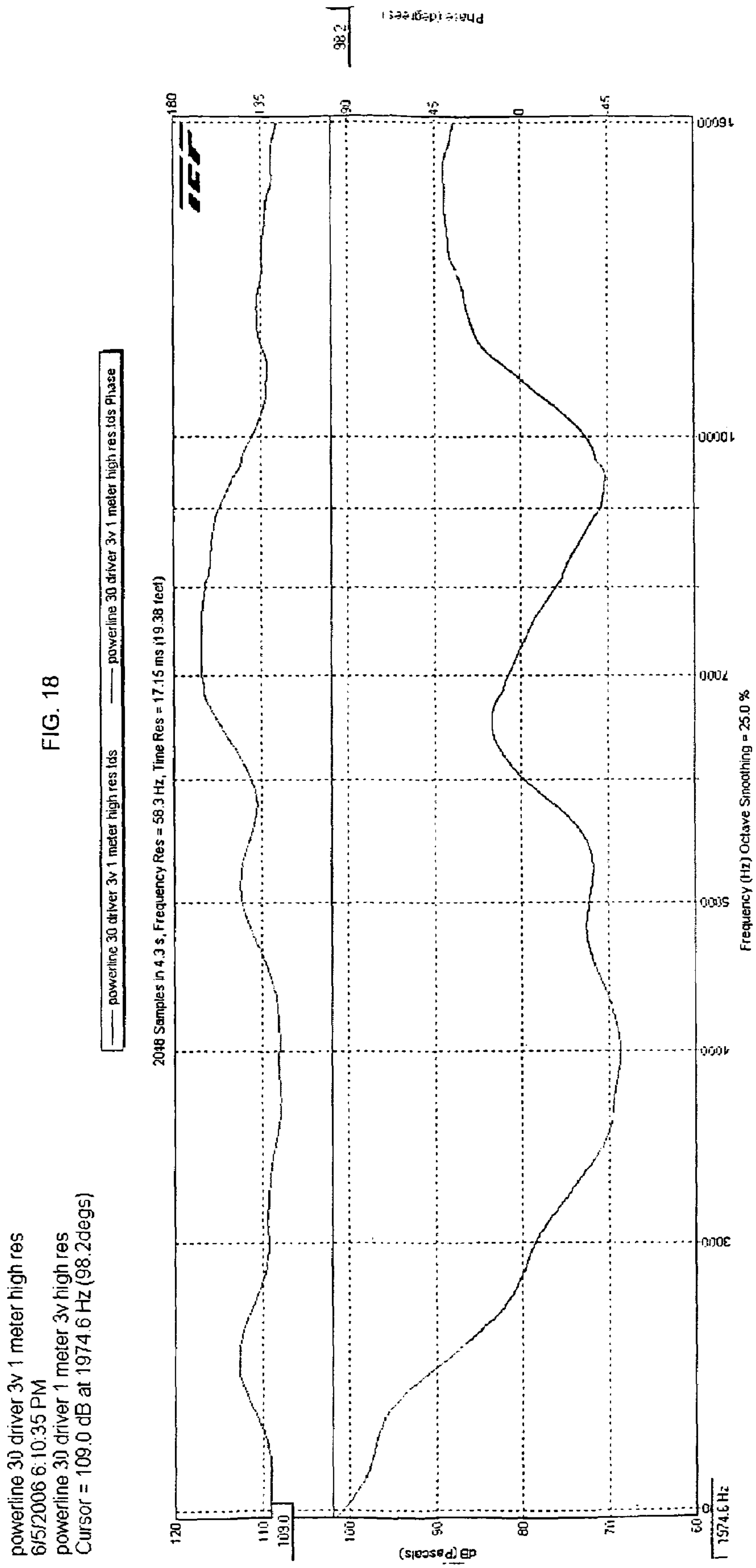

powerline 30 driver 3v 1 meter high res
6/5/2006 6:10:35 PM
powerline 30 driver 1 meter 3v high res
Cursor = 109.0 dB at 1974.6 Hz (98.2degs)
powerline 30 driver 3v 1 meter high res.tds
powerline 30 driver 3v 1 meter high res.tds Phase
2048 Samples in 4.3 s, Frequency Res = 58.3 Hz, Time Res = 17.15 ms (19.38 feet)
dB (Pascals)
120
110
109.0
100
90
80
70
60
Phase (degrees)
98.2
180
135
90
45
0
-45
0
3000
4000
5000
7000
10000
16000
1974.6 Hz
Frequency (Hz) Octave Smoothing = 25.0 %

FIG. 18

ACOUSTIC ENERGY PROJECTION SYSTEM

BACKGROUND OF THE INVENTION

1. Technical Field

The invention relates to a directional sound system and more particularly to an acoustic source and sound reinforcement system for delivering particularly intense sound energy to a remote location or for providing a particularly rich, but highly localized, surround-sound sound field.

2. Description of the Problem

At issue is the construction of a sound reinforcement system which can accept inputs from a large plurality of transducers and non-destructively sum the inputs to produce a sound beam which can be directed to a particular location. Of particular interest is producing a device capable of producing a beam with high acoustic energy intensities. Also of interest is providing a system which produces a highly localized sound field and one in which an listener can enjoy a highly realistic auditory environment, including providing auditory cues corresponding to the listener's locational perspective as presented by a video system.

The parabolic dish is of natural interest at any time focusing and intensification of a propagated field is desired. Meyer et al., in U.S. Pat. No. 5,821,470 described a Broadband Acoustical Transmitting System based on a parabolic reflector incorporating two loudspeaker transducers. One transducer was spaced from the dish, forward along the intended axis of propagation of sound at the focal point of the dish, a conventional arrangement. This transducer was horn loaded and oriented to propagate sound backward along the radiant axis and into the dish for reflection in a collimated beam. The horn loaded transducer was intended to handle the higher frequency components of the overall field. A second transducer for low frequency components was located opposed to the horn loaded transducer on the radiant axis, preferably flush mounted in the dish and oriented for forward propagation of sound. At this location the low frequency transducer would derive relatively little benefit from the dish as such, though the dish would serve as a baffle.

SUMMARY OF THE INVENTION

The invention provides a sound generating and projection apparatus. The apparatus is based on a radiator including at least a first, and possibly additional, shaped reflecting surface(s) having a forward radiant axis. Where more than one reflecting surface is used the radiant axes of the surfaces are coincident. Each shaped reflecting surface defines its own sets of equivalent acoustic input locations, with each set being a ring of non-zero circumference centered on the forward radiant axis. The sound sources used on the focal rings are distributed but functionally continuous sources. In its preferred form, a sound source is, in effect, a line array of loudspeakers disposed in a closed loop. The transducers are disposed in a circle with all of the loudspeakers oriented inwardly toward or outwardly from the forward radiant axis, depending upon which shaped reflecting surface is used.

In its preferred embodiments the radiator includes an inner reflecting surface or both inner and outer reflecting surfaces. The inner reflecting surface is formed from a cone reflector having its axis aligned on an intended radiant axis. The outer reflecting surface, if present, is a forward concave annular ring disposed around the cone reflector. Preferably the shapes of the reflecting surfaces are parabolic relative to the forward radiant axis and define an inner surface focal ring and an outer surface focal ring. A plurality of transducers is placed along each focal ring with the individual transducers turned into the reflecting surfaces. The transducers are arrayed with spacing between the transducers chosen by reference to the highest intended operating frequency of the device.

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 sound projector based on an interior cone reflector.

FIG. **2** is a perspective view of a second embodiment sound projector having inner and outer reflecting surfaces with coincident forward radiant axes.

FIG. **3** is a cross sectional diagram depicting operation of an inner reflecting surface for a sound radiator in accordance with the invention.

FIG. **4** is a cross sectional view of the sound generating and transmitting apparatus of a first embodiment of the invention.

FIG. **5** is a plan view illustrating operational divisions of the loudspeaker array for the first embodiment of the invention.

FIG. **6** is a high level schematic of circuitry for the sound projector of FIG. **5**.

FIG. **7** illustrates an application for the embodiment of the invention illustrated in FIGS. **5** and **6**.

FIG. **8** is a cross sectional illustration of a embodiment of the invention having first and second reflecting surfaces.

FIG. **9** illustrates an arrangement of high frequency transducer elements for the projector of FIG. **8**.

FIG. **10** is a cross sectional view of a variation of the projector of FIG. **8**.

FIGS. **11**A-D are, respectively, a top plan, a side elevation, a front elevation and a perspective view of a portable sound projector incorporating the radiator and toroidal radial array of the invention.

FIGS. **12**A-C are side elevations illustrating characteristic dispersion for sound fields produced by the projector of FIGS. **11**A-D.

FIG. **13** is a cross sectional view of the radiator and loudspeaker array of the projector of FIGS. **11**A-D.

FIG. **14** is a graph of frequency response over distance for a representative system incorporating the invention.

FIG. **15** is a polar graph of the conical output.

FIG. **16** is a impulse response graph.

FIG. **17** is a time over energy graph.

FIG. **18** illustrates phase and energy over frequency.

DETAILED DESCRIPTION OF THE INVENTION

Referring to the Figures and in particular to FIG. **1** a first embodiment of the invention is illustrated. A sound projector **10** projects a sound field forward on the radiant axis RA of the device. Sound projector **10** incorporates a first reflecting surface formed by a cone reflector **14** mounted inside a cylindrical shell **12** to produce a highly collimated sound field. The central axis of cone reflector **14** lies on the radiant axis RA.

In an alternative embodiment of the invention illustrated in FIG. **2**, a sound projector **11** provides two primary acoustically reflective surfaces, the first corresponding to the outer surface of cone reflector **14** and a second surface formed by a forward concave annular ring **16** which is disposed outwardly from and surrounding the cone reflector **14**. Both surfaces are housed within a shell **20**. Also located within shell **20** circumferentially surrounding and just outside the base of cone reflector **14** is an annular transducer array section **18** from which sound is directed both inwardly on and outwardly from the radiant axis RA against the reflecting surfaces.

An advantageous location of the annular transducer array section **18** is illustrated by reference to FIG. **3**, which shows a cone reflector **14** which is shaped so that sections of the cone reflector, taken in planes including the radiant axis RA, are parabolic providing a global hyperbolic reflective surface **22** with a focal ring FR. The focal ring FR has a non-zero circumference and surrounds the cone reflector **14** and is centered on the radiant axis RA. Transducers are located on the focal ring of the cone reflector **14** and oriented to direct sound energy against the cone reflector. Such placement of the transducers results in a highly collimated forward sound field exhibiting little dispersion. It might be observed that if the transducers are moved forward and backward parallel to the radiant axis RA (as indicated by double headed arrow A), the field can be made more dispersive, or given a far field convergence point forward from cone reflector **14**.

FIG. **4** illustrates placement of a plurality of loudspeaker transducers **26** at discrete, evenly spaced locations along a focal ring surrounding cone reflector **14**. In the illustrated embodiment the loudspeakers **26** are directed inwardly on the radiant axis RA with generated sound being reflected forward along the radiant axis in a low dispersion collimated beam. Some leakage occurs toward the tip of the cone reflector **14** due to lack of reflective surface area. In some embodiments a substantial portion of the tip of cone reflector **14** may be dispensed with. Loudspeakers **26** are arranged in what is in effect an annular, closed loop line array **24**, with the loudspeakers **26** installed in a sealed enclosure **30** and emitting sound through an annular baffle **28**. Loudspeakers **26** are located discretely spaced from one another by no more than one quarter of a wavelength of the highest intended operating frequency of the device.

It is not necessary that every loudspeaker **26** be part of the same channel. An extraordinarily rich surround sound system can be provided a listener located directly forward of the unit by dividing the array into zones. FIG. **5** illustrates division of the transducers **26** of an array into eight zones. The zones are categorized by a visual context to provided the listener by an associated video system (See FIG. **7**). The direction "forward" from the observer, that is the expected focus of interest in a field of view, may be correlated with center zone **32** (zone **2**). Moving clockwise around the array are provided successively: a right front zone **33** (zone **3**); a right side zone **34** (zone **4**); a right rear zone **35** (zone **5**); a stub rear zone **36** (zone **5/6**) to which may be applied a mix of the signals from the fifth and sixth channels; a left rear zone **37** (zone **6**); a left side zone **38** (zone **7**); and a left front zone **31** (zone **1**). Each zone receives its own input channel as illustrated in FIG. **6**. In FIG. **6**, for purposes of the exemplary block diagram circuit **40**, it is assumed that an audio signal is provided from a DVD player **42** or comparable source. The audio signal is applied to a receiver **44** for recovery and division into the basic set of channels. Each channel is applied to a digital signal processor **46** and from there the preamplifier **48**, **52**, **54**, **56**, **58**, **60**, **62**, **64** for each channel plus the subwoofer **50** channel.

FIG. **7** illustrates how a listener o may be positioned relative to a sound projector **70** incorporating a cone reflector **14** and zonal division of its transducer array. A sound field SF is produced which provides a surround sound experience oriented based on the visual context provided by video devices **66**.

Referring to FIGS. **8-10** an alternative embodiment of the invention is illustrated incorporating a reflector with inner and outer reflecting surfaces. The inner reflecting surface **82** is provided by the cone reflector **14**, which is preserved from the first embodiment of the invention. A second, outer reflecting surface **84** is provided by a forward concave annular ring **16**. Outer reflecting surface **84** is preferably parabolic in its sections, but differs from a conventional parabolic dish in that the bases of the parabolic sections to not meet at a single point in the base of the dish, but instead surround an annular gap in which cone reflector **14** may be placed. The term "parabolic" is intended to include functionally equivalent surfaces constructed from flat segments which average to a parabola. The term parabola is applied to curves of the reflecting surfaces in planes. The overall reflective surfaces are considered hyperbolic because they do not have focal points but rather "focal rings". In addition, outer reflecting surface **84** would function without inner reflecting surface **82**, though such an arrangement would have a larger than necessary footprint.

In FIGS. **11**A-D an application of sound projector **110** mounted on a tripod **112** is illustrated from various perspectives and contrasted in size with an operator T, who may be taken as standing about 6 feet in height. The aperture A of projector **110** is about 30 inches and exposes a radial torodial array **114** disposed around the base of cone reflector **116**. Sound projector **110** is installed on an altazimuth mount **118** which allows rotation on the tripod **112** base to control azimuth and pivoting on a fork **120** to control altitude. A gun sight type element **117**, potentially including a camera for remote control, may be provided to aim sound projection **110**.

In FIGS. **12**A-C the characteristic sound field dispersions illustrating a polar sound field SF**1**, a focused sound field SF**2** with a far field convergence CP and a sound field SF**3** with 30 degrees of dispersion. Far field convergence CP and the angle of dispersion are selectable using the mechanism of FIG. **13**. For a hyperbolic cone reflector **116** which, by virtue of its parabolic sectional shape has a focal ring, the dispersion characteristics of a forward projected sound field are controllable by relative movement of the toroidial radial array **114** parallel to the radiant axis of the reflector. This of course can be achieved by movement of either the array **114** or the reflector **116**. As illustrated the reflector has been equipped with a worm drive **124** driven by a simple servo actuator motor **126** for displacing the cone reflector **116** relative to the ring array **114**. The worm drive **124** could also drive a pointer to a graph indicating neutral, dispersion angle and meters to the convergence point. Naturally the system could be equipped with sophisticated range finding allowing automation of focus selection once a target had been selected by an operator.

The parabolic section for a hyperbolic cone reflector follows the equation:

$$Y=X^2/4F$$

where F is the focus, X is width and Y is height. Non-parabolic section curves are conceivable, as is a cone reflector with flat faces. Most such faces would not provide focusing as do the preferred hyperboloids.

FIG. **14** illustrates frequency response over distance for a representative system incorporating the invention by a series of response curves, each representing a doubling of distance over the next higher curve along the center radiant axis of the projector. The projector response follows a near inverse square (−6 db per doubling of distance) in the lower frequencies but a substantially smaller drop at higher frequencies. In the highest frequency bands the output of the projector can be focused to a beam waist in a manner analogous to light allowing higher outputs at distance than close to the device. The lowest frequency knee point of the coherent focus phenomena is a function of the hyperboloid shape and the diameter (which effects the available surface area) of the cone reflector used. The larger diameter used the lower the frequency obtainable for coherent focus. The kneepoint wavelength seems to be about 4× the diameter of the cone reflector. The reflector works at lower frequencies, but outputs follow the inverse square law.

FIG. **15** is a polar graph for a radiator having a hyperbolic reflector and an 18 inch diameter and shows a 2 to 3 degree dispersion centered on the radiant axis of the device (0 degrees). The strongest line is just counterclockwise from 0 degrees (at 2 degrees) at the 97.5 db output level. The other eight lines are substantially less at the 90 to 91 db range and vary to both sides of the 0 degree line. The larger the diameter of the hyperboloid reflector the greater the degree of coherent focus obtainable. A 12 inch diameter device obtains 6 to 7 degrees of dispersion while a 48 inch device has less than 1 degree of dispersion in its usable bandwidth.

FIG. **16** is an impulse response graph showing that a sound beam produced by the device has almost no resonance relegated energy.

FIG. **17** is a graph of time versus energy. Showing an extremely sharp peak in the pulse defining the precise time alignment of a system incorporating **30** loudspeakers in a toroidal radial array. Again a high degree of coherence of the summation of multiple sources into a single beam with high efficiency.

FIG. **18** illustrates phase (bottom curve) and energy (top curve) over usable frequency (12 Khz to 23 Khz) for a system using 30 input sources. Typically high efficiency horn loaded loudspeakers exhibit several hundred degrees of phase shift over their operating range, however here the total phase shift over used bandwidth is less than 150 degrees. This result is highly consistent with very precise and linear high amplitude output.

The present sound system allows inputs from a potentially large plurality of sources located at acoustically equivalent locations with non-destructive collimation of the sources to produce a collimated sound field. Destructive summation is reduced compared to a planar array by use of a closed loop line array. In some embodiments different zones within the sound field can be used to produce a rich surround sound environment keyed to visual clues provided over visual display devices.

While the invention is shown in only a few 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 sound projector for generating a sound beam along a radiant axis, the sound projector comprising:

a reflector exhibiting symmetry with respect to the radiant axis and having a focal ring of non-zero circumference;

an annular sound source of non-zero circumference dimensionally matching the non-zero circumference of the focal ring, the annular sound source being centered on the radiant axis and oriented to radiate sound energy into the reflector for reflection forward along the radiant axis;

the annular sound source comprising a plurality of discrete sound sources arranged radially around and oriented into the reflector, the discrete sound sources being mutually spaced to operate as a linear array;

the annular sound source being located in a plane perpendicular to the radiant axis;

the reflector being a hyperboloid and having a contour along at least a portion of its length resulting in the focal ring lying in a plane perpendicular to the radiant axis; and

means for repositioning the annular sound source along the radiant axis and thereby positioning the annular sound source relative to the reflector to produce a dispersive sound field, a non-dispersive sound field when the annular sound source is substantially positioned at the annular focus of the reflector or a sound field having a convergence point forward from the reflector.

2. A sound projector for generating a sound beam along a radiant axis, the sound projector, comprising:

a reflector exhibiting symmetry with respect to the radiant axis and having a focal ring of non-zero circumference;

an annular sound source of non-zero circumference dimensionally matching the non-zero circumference of the focal ring, the annular sound source being centered on the radiant axis and oriented to radiate sound energy into the reflector for reflection forward along the radiant axis;

the annular sound source comprising a plurality of discrete sound sources arranged radially around and oriented into the reflector, the discrete sound sources being mutually spaced to operate as a linear array; and

the discrete sound sources being horn loaded, broad band acoustic transducers disposed in an closed toroidal radial array with the spacing between adjacent source points of the transducers being smaller than one quarter of the wavelength of the upper knee frequency of the individual acoustic transducers.

3. A sound projector as set forth in claim **2**, further comprising:

a plurality of channels providing differentiated inputs to selected sections of the closed annular array of transducers.

4. A sound projector comprising:

a cone reflector having its axis aligned on an intended radiant axis;

an annular sound source of non-zero circumference centered on the axis of the cone reflector and oriented with respect to the cone reflector to direct sound energy into the cone reflector for reflection forward along the radiant axis;

the annular sound source comprising a plurality of discrete sound sources arranged radially around and oriented inwardly toward the radiant axis; and

the discrete sound sources being horn loaded, broad band acoustic transducers disposed in a toroidally shaped linear array with the spacing between adjacent source points of the transducers being smaller than one quarter of the wavelength of an intended upper knee frequency.

5. The sound projector of claim **4**, further comprising:

the annular sound source being located in a plane perpendicular to the axis of the cone reflector.

6. The sound projector of claim **5**, further comprising:

the cone reflector having a contour along at least a portion of its length producing an annular focus in a plane perpendicular to the axis of the cone reflector.

7. The sound projector of claim **6**, the cone reflector being a hyperboloid.

8. The sound projector of claim **7**, further comprising:

means for repositioning the annular sound source along the radiant axis and thereby positioning the annular sound source to provide off the reflector cone, a dispersive sound field, a non-dispersive sound field when the annular sound source is substantially positioned at the annular focus of the cone reflector and a sound field having a positionable convergence point forward from the reflector cone.

9. A sound projector as set forth in claim **4**, further comprising:

a plurality of channels providing differentiated inputs to selected sections of the closed annular array of transducers.

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