[54] **TRANSITION SECTION FOR ACOUSTIC WAVEGUIDES**

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[22] Filed: **Nov. 21, 1974**

[21] Appl. No.: **526,038**

[52] **U.S. Cl.**............... 73/556; 176/19 R; 181/400; 310/8.7; 340/8 MM
[51] **Int. Cl.²** **G01H 3/10**
[58] **Field of Search** ...... 73/69, 552, 556; 176/19 R; 179/1 N; 181/139, 175, 400; 310/8.7; 333/30 R, 32; 340/8 MM

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[57] **ABSTRACT**

A means of facilitating the transmission of acoustic waves with minimal reflection between two regions having different specific acoustic impedances comprises a region exhibiting a constant product of cross-sectional area and specific acoustic impedance at each cross-sectional plane along the axis of the transition region. A variety of structures that exhibit this feature is disclosed, the preferred embodiment comprising a nested structure of doubly reentrant cones. This structure is useful for monitoring the operation of nuclear reactors in which random acoustic signals are generated in the course of operation.
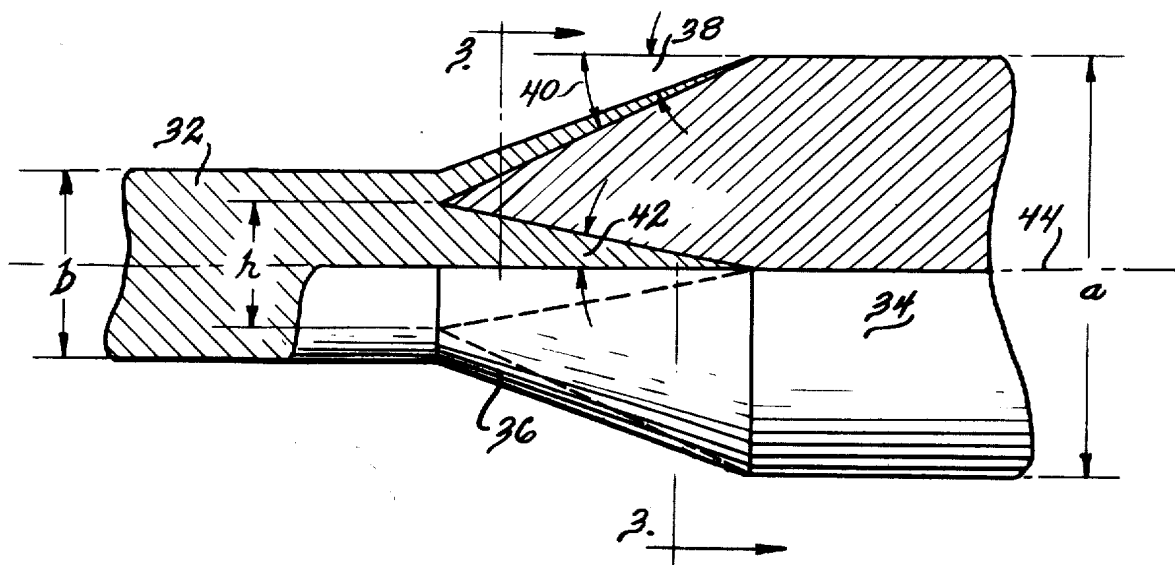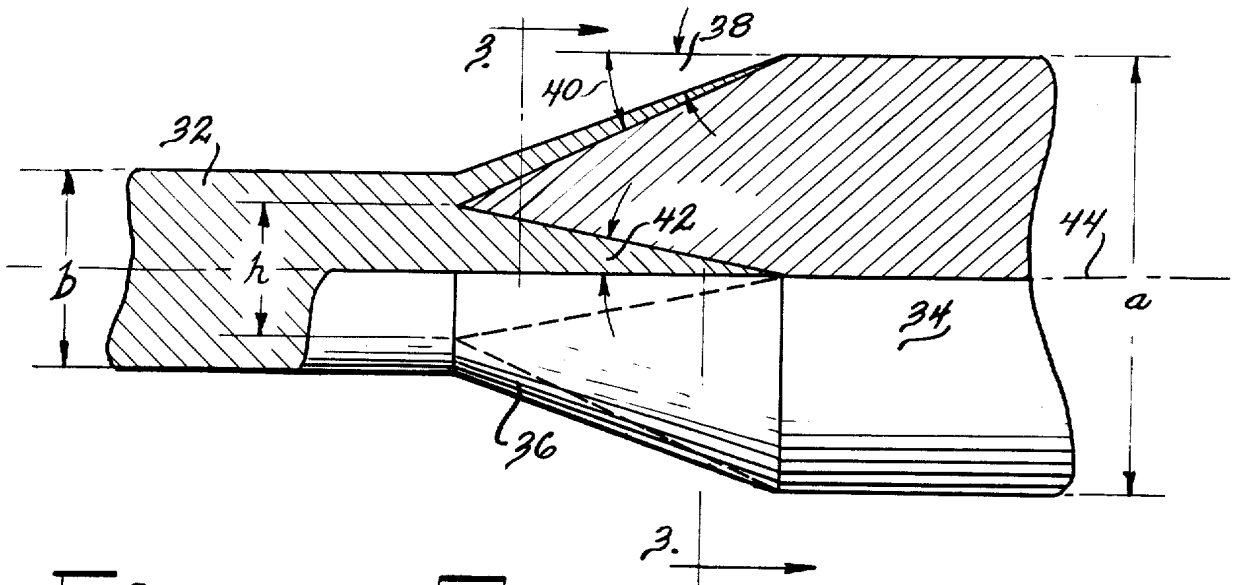
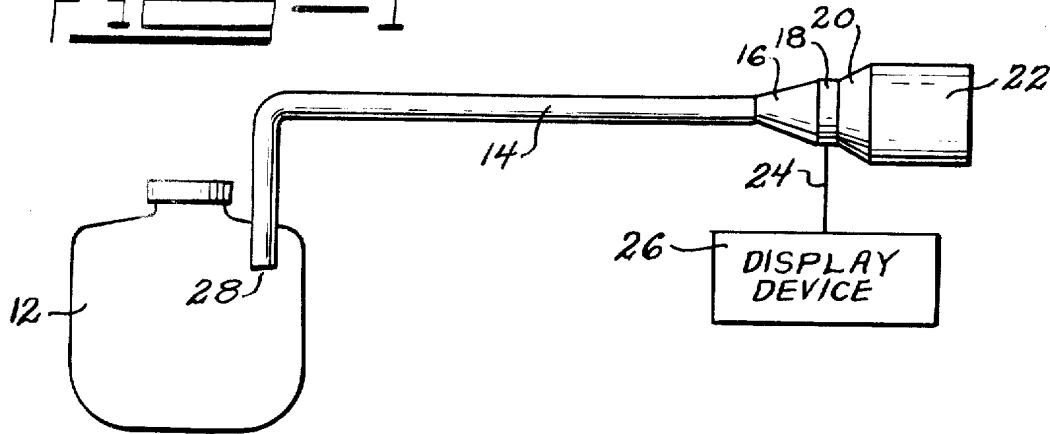**5 Claims, 10 Drawing Figures**

Fig-1

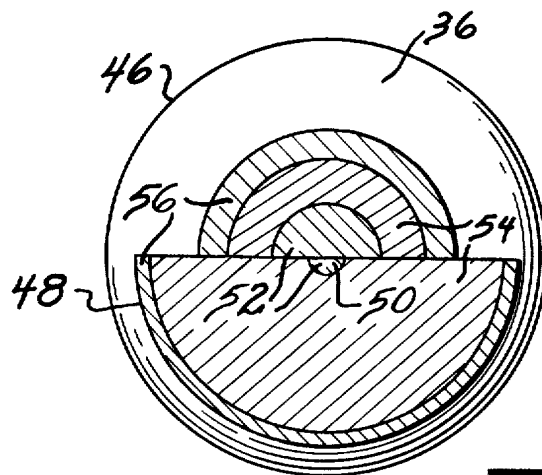12 28 14 16 18 20 22 24 26 DISPLAY DEVICE

Fig-2

32 38 40 42 44 34 36 b h a

Fig-3

46 36 56 54 48 52 50

Fig — 4

60
72
74
82
70
84
80
76
78
66
62
68
64

Fig — 5

80
84
86
88
82

Fig—6

Fig—7

Fig—8

Fig—9

Fig —10

140
144 146 148 150 152
142
159
161
154
156
CHARGE
AMPLIFIER
158
160
SPECTRUM
ANALYZER
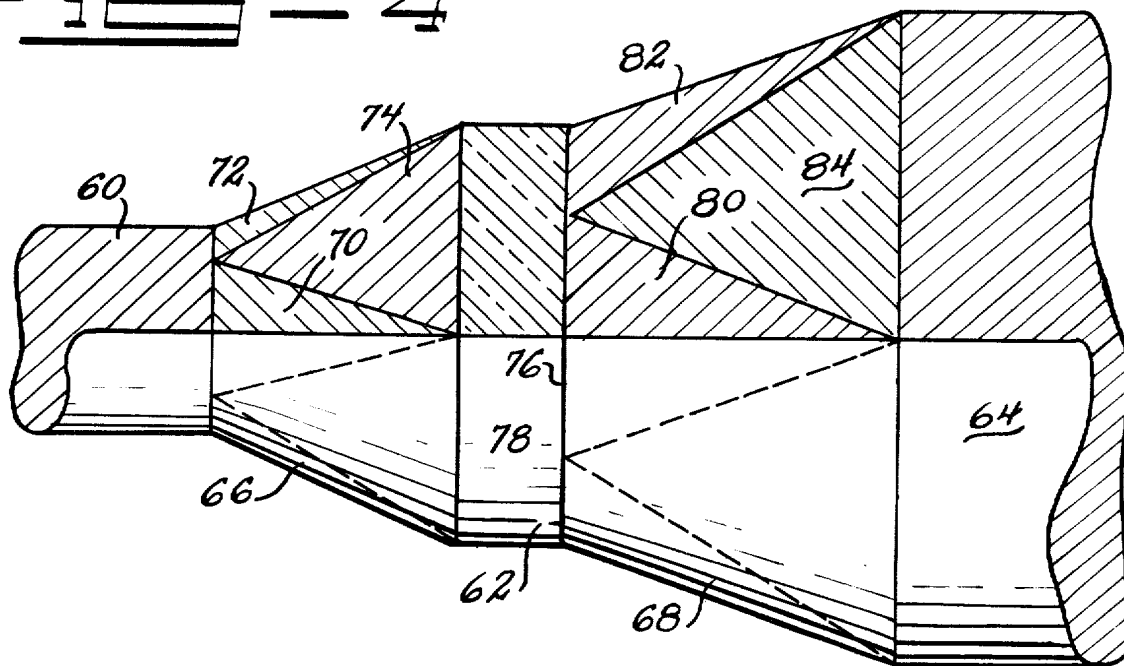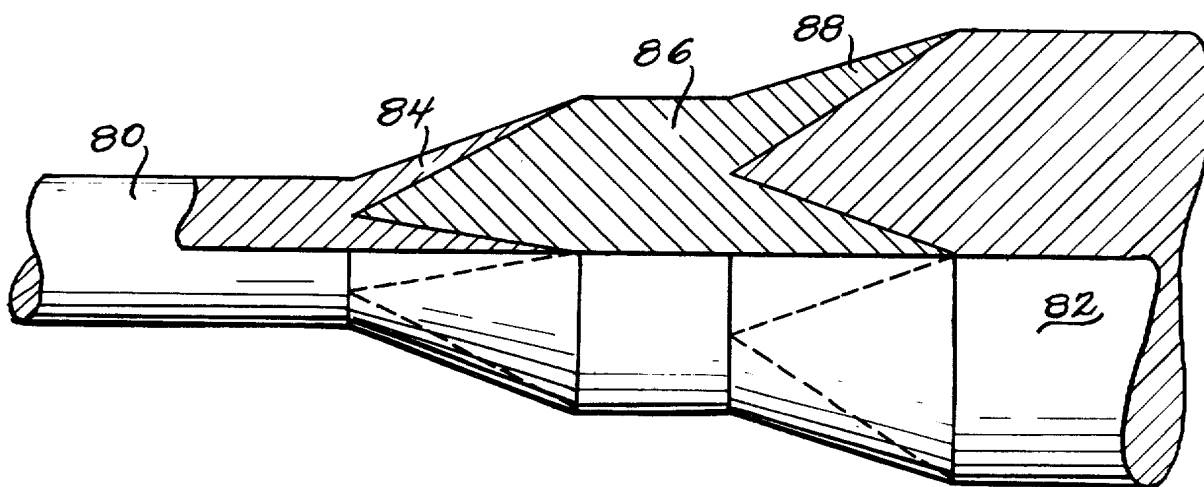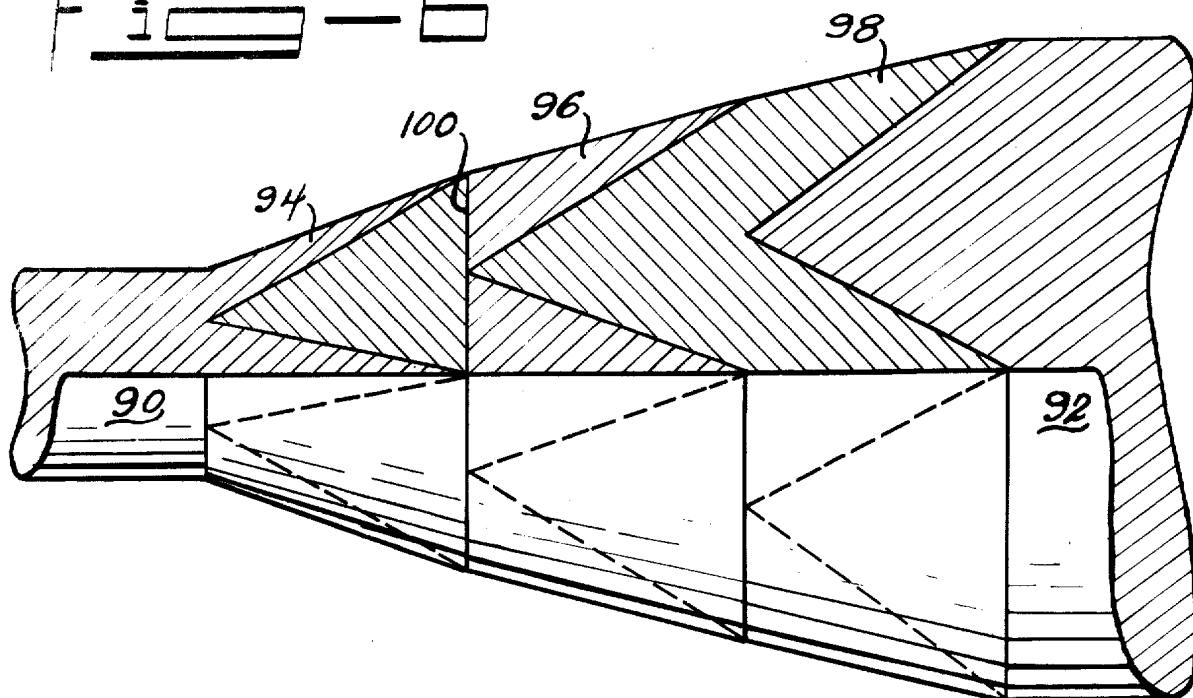
TRANSITION SECTION FOR ACOUSTIC WAVEGUIDES

CONTRACTUAL ORIGIN OF THE INVENTION

The invention described herein was made in the course of, or under, a contract with the UNITED STATES ATOMIC ENERGY COMMISSION.

BACKGROUND OF THE INVENTION

This invention is in the field of acoustic transmission devices. In particular, it is a device adapted to produce minimal acoustic losses and minimal reflections at the transition between an acoustic transmission device having a given value of specific acoustic impedance and another acoustic transmission device having 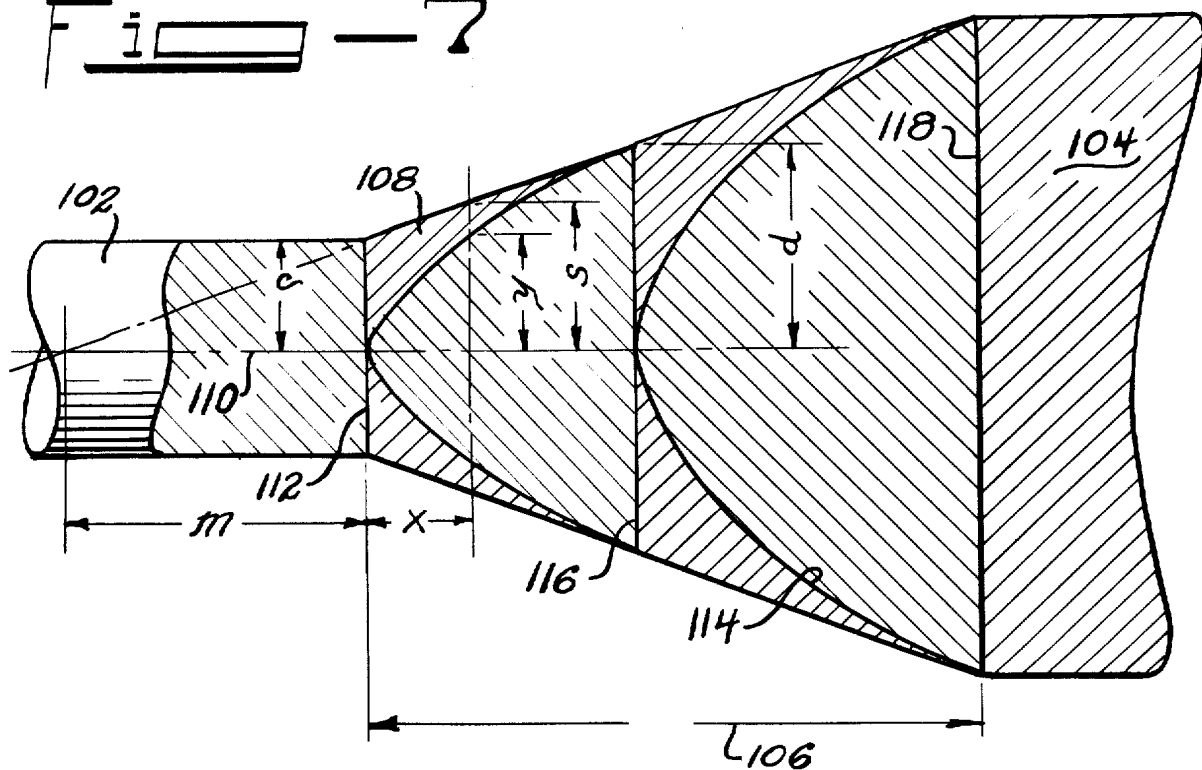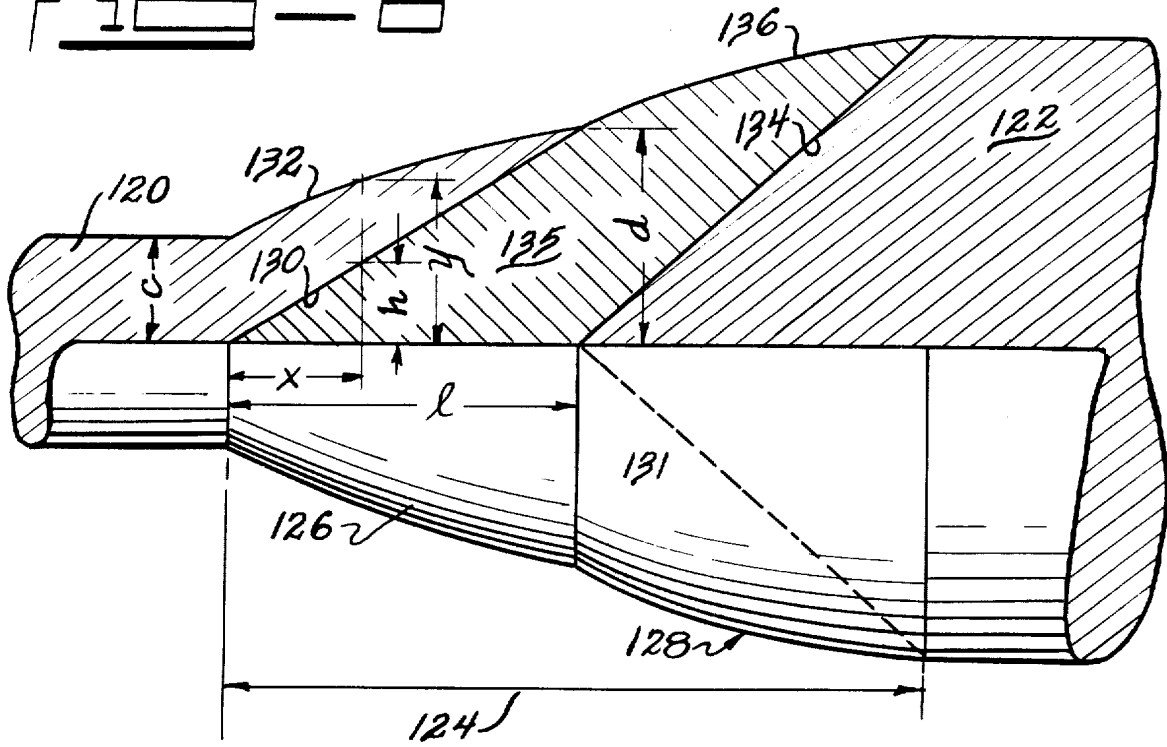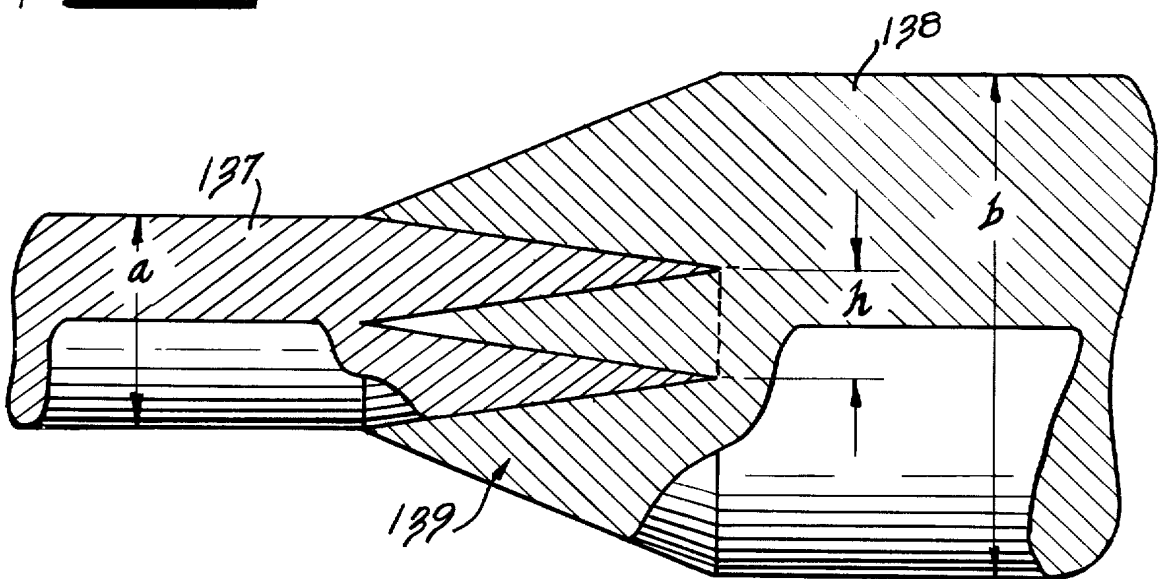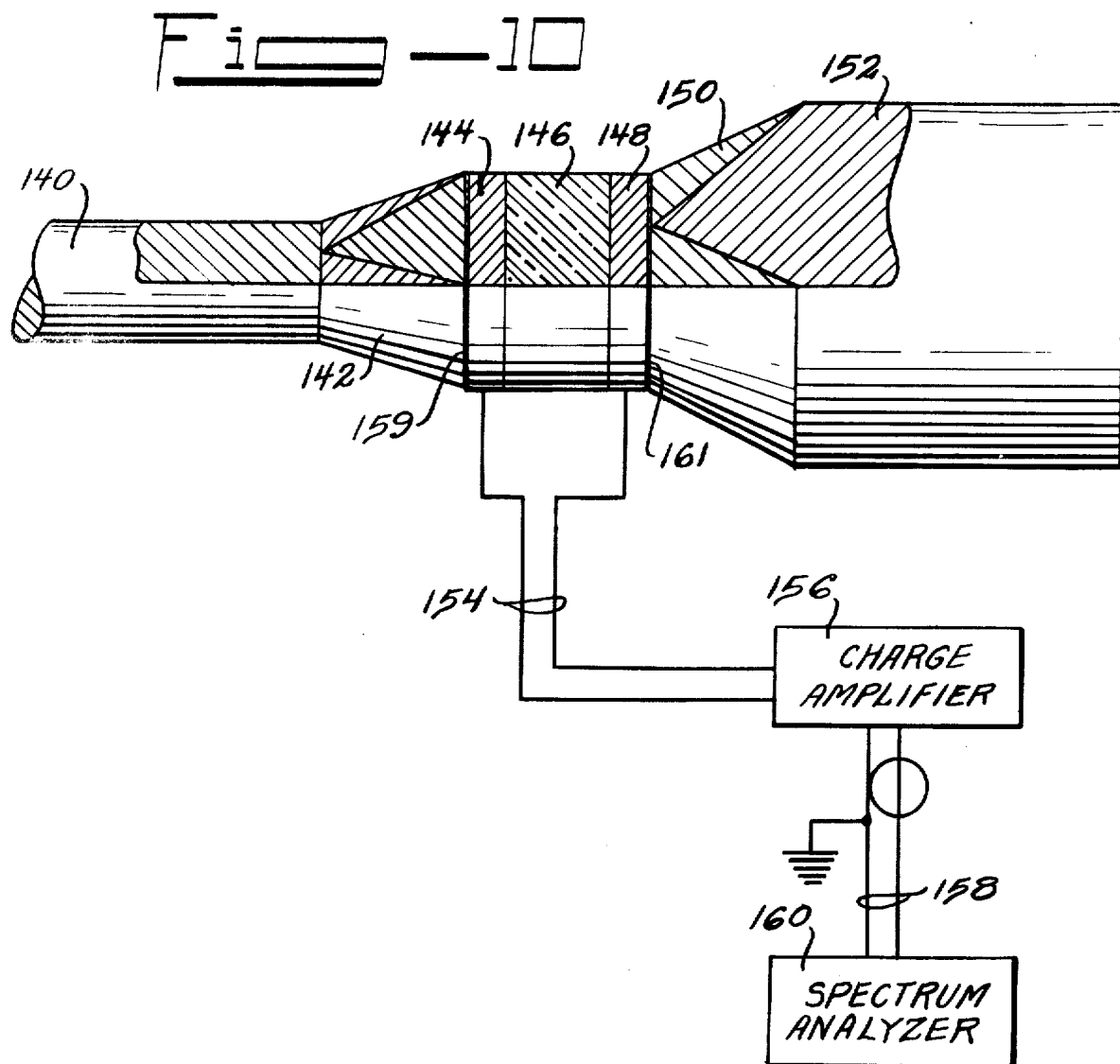a different value of specific acoustic impedance. Such properties are necessary in making a transition from one type of acoustic waveguide to another. They are also necessary in making a transition from an acoustic waveguide to a transducer or to a termination to minimize reflections from the end of a chain of acoustic devices.

For the purpose of convenience it is useful to classify acoustic devices into two groups. The first of these is that in which an active signal is generated for the purpose of producing a response which is detected. This includes such applications as sonar and nondestructive testing. The instant invention has utility in these areas but is not needed as much because the designer is capable of tailoring the signal generated in each of these cases and hence has information about the expected response. In particular, he can select a parameter such as frequency to allow signal-processing techniques to cope with reflections generated at various points within the system. The designer may still have reason to use the present invention to minimize losses in transitions, but the minimization of reflections is likely to be of less importance where an externally applied signal generates the response that is observed. The second group is that of listening devices which detect an acoustic signal generated within the device or subject being observed. This is typical of the medical stethoscope and of the application that led to the present invention, namely, acoustic monitoring of nuclear reactors. In the latter cases, the designer has less reason to expect a periodicity in received signals that can be improved by signal-processing techniques. In particular, in the case of the nuclear reactor, the received signal exhibits the typical randomness of noise. Since reflected noise is also noise, it is difficult to separate reflections from desired signals by signal-processing techniques. It therefore becomes urgent to minimize the generation of reflected signals.

The typical arrangement for acoustic monitoring of a nuclear reactor comprises two basic elements. One is a combination acoustic transducer and waveguide. This is typically a rod or a laminated strip, capable of withstanding the hostile environment on the interior of a nuclear reactor, and capable of detecting and transmitting acoustic signals to a less hostile environment. The second element is a piezoelectric or other electromechanical transducer coupled acoustically to the waveguide and capable of generating an electrical signal in response to the acoustic signal transmitted to it along the waveguide. It is generally true that the waveguide exhibits different transmission properties from the transducer. The transducer also typically exhibits different transmission properties from the air or other backing medium beyond it. Each of these differences

in transmission properties represents a potential generator of reflected signals which will be reflected into the transducer to appear as an apparent signal from the nuclear reactor.

It is an object of the present invention to provide a transition section between acoustic transmission media of different properties to minimize reflection at the transition.

It is a further object of the present invention to provide a transition section between an acoustic waveguide and an electro-acoustic transducer to minimize reflections generated at the transition.

It is a further object of the present invention to provide a transition section between an acoustic transducer and a medium backing the acoustic transducer to minimize reflections therebetween.

Other objects will become apparent in the course of a detailed description of the invention. constructing a transition between the two media which maintains at each cross-sectional plane a constant sum of the products of cross-sectional area and specific acoustic impedance. In the passage from one material to the other, a particularly useful structure embodying this transition comprises a structure of nested doubly reentrant cones formed of the material of the two media.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram of a nuclear reactor with an acoustic monitoring device embodying the principles of the present invention.

FIG. 2 is a partial sectional side view of a transition section between two acoustical transmission media according to the principles of the present invention.

FIG. 3 is a sectional end view of the transition section of FIG. 2.

FIG. 4 is a partial sectional side view of a waveguide, a transducer and absorber, each having therebetween a transition section according to the principles of the present invention.

FIG. 5 is a partial sectional side view of a combination of two transition sections according to the present invention with a continuous section therebetween.

FIG. 6 is a partial sectional side view of a composite set of several transitions according to the principles of the present invention.

FIG. 7 is a partial sectional side view of a first alternate embodiment of the present invention.

FIG. 8 is a partial sectional side view of a second alternate embodiment of the present invention.

FIG. 9 is a partial sectional side view of a third alternate embodiment of the present invention.

FIG. 10 is a partial sectional side view of a waveguide, transducer, and termination together with a block diagram of an electric circuit.

DETAILED DESCRIPTION OF THE INVENTION

FIG. 1 is a schematic drawing of a nuclear reactor having connected to it an acoustic monitoring system. In FIG. 1 reactor 12 may be any type of nuclear reactor. This invention is particularly adapted to but is in no way limited in application to a liquid-metal fast-breeder reactor. In FIG. 1 acoustic waveguide 14 is placed to extend into reactor 12 so as to make acoustic contact with the interior of reactor 12. This is typically a region that is hostile to many materials and is not readily accessible for repairs and adjustments. For this reason, a criterion in the selection of material for acoustic wave-

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guide 14 is durability under high temperature and possibly under intense radiation. Acoustic waveguide 14 should also be made of a material that will conduct acoustic signals to a remote location. First transition section 16 is connected physically and coupled acoustically to acoustic waveguide 14 and to transducer 18 to effect the objects of this invention by providing acoustical coupling with minimal reflection therebetween. A second transition 20 is coupled to transducer 18 and to absorber 22 to minimize reflections from absorber 22 back to transducer 18. Electrical connection 24 is connected to transducer 18 to couple electrical variations generated by transducer 18 in response to acoustical signals detected by transducer 18. Electrical connection 24 transmits these electrical signals to electrical display device 26 which provides means for detecting and displaying acoustic signals generated within reactor 12. It can be seen from an examination of FIG. 1 that a number of points of reflection exist, each of which can generate spurious signals that would be difficult to distinguish from actual signals generated in reactor 12. First, any signal that is launched in the direction from transducer 18 toward reactor 12 may be reflected at ends 28 of acoustic waveguide 14 and thereby directed back toward transducer 18 appearing as an apparently newly directed signal. The first transition 16 between acoustic waveguide 14 and transducer 18 is a potential source of reflections, since in the usual situation acoustic waveguide 14 and transducer 18 are selected to meet different criteria and, in general, will have different values of specific acoustic impedance. The specific acoustic impedance is defined as the complex ratio of the phasor representing a sinusoidal variation in acoustic pressure at a point in a medium to the phasor representing the sinusoidal variation in particle velocity at this point. The unit of specific acoustic impedance in the MKS system is the kg/m^2-sec or rayl. The specific acoustic impedance is a property of the material, the effect of which is most readily visualized as a direct analog to the characteristic impedance of the medium as applied in the theory of electrical transmission lines and waveguides. Like its electrical analog, the specific acoustic impedance is, in general, a complex quantity that is a function of frequency and whose real and imaginary parts are associated respectively with the propagation and attenuation of waves. Changes in impedance along a waveguide tend to generate reflections. The present invention deals with reflections by minimizing their generation. To return to the electrical analog, the present invention is an acoustical analog to the matching of electrical impedances at an interface.

A structure used to accomplish this match is made evident in the preferred embodiment of FIG. 2 which is a partial sectional side view of a transition section such as those of first transition 16 or second transition 20 of FIG. 1. In FIG. 2 an input transmission section 32 appears at the left and an output section 34 appears at the right. Transition section 36 spans the distance between input section 32 and output section 34. If FIG. 2 were to indicate the first transition 16 of FIG. 1, then input section 32 would be a portion of acoustic waveguide 14 of FIG. 1 and output section 34 would be a portion of transducer 18 of FIG. 1. On the other hand, if FIG. 2 were to represent second transition 20 of FIG. 1, then input section 32 would comprise a portion of transducer 18 of FIG. 1 and output section 34 would

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comprise a portion of absorber 22 of FIG. 1. Alternatively, it might become desirable to split acoustic waveguide 14 of FIG. 1 into a plurality of sections if, for example, operating conditions within the reactor made it necessary to use as a waveguide medium a material that was expensive or that was unsatisfactory to use for a complete run to a transducer. In this case, the transition section 36 might be one of a plurality of such sections comprising a several-stage transition between an input section 32 and output section 34. All these possibilities are inherent in the structure of FIG. 2 in which transition section 36 comprises a pair of nested doubly reentrant cones sized so that the summed products of the area and specific impedances of the materials across any cross section of transition section 36 maintain a constant value at each cross section. This is accomplished as follows. Call the diameter of output section 34 a and the diameter of input section 32 b; define angles 38, 40 and 42 as indicated in FIG. 2. If the specific acoustic impedance of input section 32 is Z_b and the specific acoustic impedance of output section 34 is Z_a, then a constant sum of the products of area and specific impedance across each plane normal to the axis 44 of the transition section of FIG. 2 is maintained when the quantity

$$(Z_b/Z_a)^{1/2} = a/b = \tan(<42)/\tan(<40) = ((1 - \tan(<38))/\tan(<40))^{1/2}$$

In this expression, "tan" refers to the trigonometric tangent function. It can be shown mathematically that, when the preceding expression is satisfied, the impedance transition between input section 32 and output section 34 results in a gradual change from the material of input section 32 to the material of output section 34 while maintaining the equality of the products of area and specific acoustic impedance at each cross section in input section 32, transition section 36 and output section 34. An equivalent method of achieving the same result is to select the diameter h of the inner cone in FIG. 2 so that

$$h = (ab)/(a + b).$$

The structure of transition section 36 of FIG. 2 is further illustrated in FIG. 3 which is a split end view along section line 3—3 of FIG. 2. In FIG. 3 upper half 46 is a section that is taken along a plane that is closer to input section 32 of FIG. 2 than lower half 48. Looking outward from center 50, there first appears section 52 which comprises a conical continuation of input section 32 of FIG. 2. Section 54 shows portions of a reentrant cone comprising a continuation of output section 34 of FIG. 2. Finally, in FIG. 3 section 56 comprises a portion of a reentrant cone formed of the material of input section 32 of FIG. 2.

The principles of the present invention are put to practice in FIG. 4 which is a partial sectional view of a waveguide transducer and absorbing termination connected by transitions according to the present invention. In FIG. 4 it is desired to accomplish a minimum-reflection transition of waveguide 60 to transducer 62 and to connect absorber 64 to transducer 62 to minimize reflections therefrom. This is accomplished by connecting waveguide 60 to transducer 62 through a first transition 66 and by connecting transducer 62 to absorber 64 through a second transition 68. Both first transition 66 and second transition 68 are formed according to the principles of the present invention. In first transition 66 inner cone 70 and outer structure 72 are made of a material having the same specific acoustic impedance as waveguide 60. One way

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to accomplish this is to make inner cone 70 and outer structure 72 of the same material as waveguide 60. Alternatively, knowing this specific acoustic impedance of waveguide 60, the designer can select a material having the same specific acoustic impedance for inner cone 70 and outer structure 72. Similarly, intermediate structure 74, a reentrant cone, is connected to transducer 62 and is made of a material having the same specific acoustic impedance as transducer 62. The shapes of inner cone 70, outer structure 72 and intermediate structure 74 are calculated to maintain the constant impedance-area product described in the calculations accompanying the description of FIG. 2. It is to be noted that a joint 76 is indicated between waveguide 60 and first transition 66. Such a joint 76 simplifies construction and is well adapted for the practice of this invention provided firm acoustical contact is maintained between waveguide 60 and first transition 66. The same requirements for maintaining good sound physical contact exist between inner core 70 and intermediate structure 74 and between intermediate structure 74 and inner cone 70. Similarly, joint 78 between first transition 66 and transducer 62 requires a good contact if the intermediate structure 74 is not formed to comprise a continuation of transducer 62. It has been found satisfactory to make such joints with commercial epoxy binders or by mechanical compression with threads. A comparable situation exists in second transition 68 in which inner cone 80 and outer structure 82 are made of a material having the same specific acoustic impedance as transducer 62. In the second transition 68 and intermediate structure 84 is made of a material having the same specific acoustic impedance as absorber 64. With shapes of inner cone 80, outer structure 82 and intermediate structure 84 calculated according to the steps described in connection with FIG. 2, second transition 68 comprises a low-reflection impedance match between transducer 62 and absorber 64 and will therefore minimize reflections between transducer 62 and absorber 64. As with first transition 66, joint 76 between transducer 62 and outer structure 82 and between transducer 62 and inner cone 80 are bonded with means such as epoxy cement or with a mechanically threaded connector for making a good acoustic contact therebetween. Joint 78 between intermediate structure 84 and absorber 64 is similarly bonded to provide good mechanical and hence good acoustic contact.

An alternate embodiment of the present invention is shown in FIG. 5 which is a partial sectional view of a two-stage transition. In FIG. 5 a structure is shown to effect a low-reflection impedance match between a first acoustical waveguide 80 and a second acoustical waveguide 82. These are taken as waveguides for purpose of illustration. Either could be a transducer or an absorber. Since first acoustic waveguide 80 has a different diameter from second acoustic waveguide 82, however, it is apparent that they must have different specific acoustic impedances which need to be matched to minimize reflections. This is carried out in two stages. One stage comprises a first transition 84 from first acoustic waveguide 80 to intermediate section 86. Next, a second transition 88 matches intermediate section 86 to second acoustic waveguide 82. Both first transition 84 and second transition 88 are designed according to the principles described. Such a two-stage transition is useful where there is a large difference of

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acoustic impedance between first acoustic waveguide 80 and second acoustic waveguide 82. The length of intermediate section 86 is immaterial as are the lengths of first transition 84 and second transition 88. All three of these lengths are open to the designer to choose for convenience in machining or construction or for any other basis upon which he wishes to choose.

The multistage principle illustrated in FIG. 5 is further extended two ways in FIG. 6 which is a partial sectional view of a three-stage transition according to the principles of the present invention. In FIG. 6 the transition between first acoustic waveguide 90 and second acoustic waveguide 92 is accomplished through a first transition section 94 which is connected to a second transition section 96 which is, in turn, connected to a third transition section 98 and thence to second acoustic waveguide 92. In FIG. 6 there is no intermediate section such as intermediate section 86 of FIG. 5. Instead, each transition section in FIG. 6 terminates with the beginning of the next. Thus, joint 100 between first transition section 94 and second transition section 96 could be thought of as an intermediate section of zero length. The portions of all three transition sections are selected to provide the constant sums of the products of the specific acoustic impedance and cross-sectional area across each cross-sectional plane by the technique described earlier. The different materials of the acoustic waveguides and transition sections of FIG. 6 are bonded together to make firm acoustic contact by some connecting means such as epoxy cement or by a threaded mechanical connection.

FIG. 7 shows an alternate means of construction for practicing the principles of the present invention. In the partial sectional side view of FIG. 7 first acoustic waveguide 102 is connected to second acoustic waveguide 104 by a transition section 106. Transition section 106 is a two-stage section which is constructed to fit smoothly within an exterior bounding conical surface 108 and also to maintain a constant product of specific acoustic impedance in cross-sectional area across each plane normal to axis 110 in moving from first acoustic waveguide 102 to second acoustic waveguide 104. The latter objective is achieved by bounding the interior surfaces 112 and 114 with hyperboloids of revolution, each of which is tangent to conical surface 108 at the terminating joints 116 and 118 respectively. This is established as follows. Referring to FIG. 7, let the radius of first acoustic waveguide 102 be equal to c and that of terminating joint 116 be equal to d. Let the specific acoustic impedance of first acoustic waveguide 102 be Z_c and that at terminating joint 116 be Z_d. Let the conical surface 108 intersect the axis 110 a distance m from transition section 106. Measure a variable horizontal distance x to the right from the beginning of transition section 106. Let s be the perpendicular distance from axis 110 at x to conical surface 108 and let y be the perpendicular distance at x from axis 110 to interior surface 112. Then the following equations hold.

$$c^2 Z_c = d^2 Z_d = y^2 Z_d + s^2 Z_c - y^2 Z_c \qquad (1)$$

$$\frac{c}{m} = \frac{s}{x+m} \qquad (2)$$

lelation (1) is required to maintain the equality of the summed products of area and specific acoustic impedance at each cross-sectional plane. Relation (2) follows from similar triangles. Since

$$Z_d = Z_c \frac{c^2}{d^2}$$

nd

$$s = \frac{c}{m}(x + m),$$

ubstitution in (1) produces the equation

$$c^2 = (x + m)^2 \frac{c^2}{m^2} - y^2 \left(1 - \frac{c^2}{d^2}\right). \tag{3}$$

:quation (3) is a hyperbola in the variables y and $(x + 1)$.

The two-stage structure of FIG. 7 accomplishes a ow-reflection impedance match in the manner described for the earlier figures by keeping a constant roduct of cross-sectional area and specific acoustic mpedance of each cross section. The structure shown n FIG. 7, however, has the advantage of a smooth, unroken, conical surface 108 bounding the structure on he outside. A second alternate embodiment of the resent invention is shown in the partial sectional view if FIG. 8 in which first acoustic waveguide 120 is natched to second acoustic waveguide 122 through natching section 124. Matching section 124 comprises . first portion 126 and a second portion 128 which are lesigned according to the same principles. In FIG. 8 irst portion 126 is divided into two parts by a first coni-:al surface 130. First hyperboloid of revolution 132 iounds first portion 126 on the outside. Similarly, second portion 128 is divided into by second conical surace 134 and is bounded on the outside by second hyerboloid of revolution 136. A calculation applied to 'IG. 8 in a manner similar to that performed above for 'IG. 7 shows that, if one bounding surface is conical vith the apex of the cone at a point on the axis marking i joint between two sections, then the bounding surface if the other material must necessarily be a hyperboloid if revolution. That calculation is as follows. Referring o FIG. 8, let c be the radius of first waveguide 120 and et d be the radius of the base 131 of first conical surace 130. Let Z_c and Z_d be the specific acoustic impednces of first acoustic waveguide 120 and the interior 35 bounded by first conical surface 130. At a distance : into first portion 126, let the height to first conical urface 130 be h and let the height to first hyperboloid if revolution be y. Let the length of first portion 126 ie 1. Then the following relations hold.

$$h/x = d/l \tag{1}$$
$$c^2 Z_c = d^2 Z_d = h^2 Z_d + y^2 Z_c - h^2 Z_c. \tag{2}$$

$$\text{Thus } h = \frac{dx}{l} \text{ and } Z_d = \frac{c^2}{d^2} Z_c.$$

:ubstituting shows that

$$c^2 = y^2 - (d^2 - c^2) \left(\frac{x}{l}\right)^2. \tag{3}$$

This is a hyperbola in y and x, generating a hyperboloid upon revolution about an axis.

The only criterion then for selecting among the doubly reentrant conic structures of FIGS. 2 through 6 and the hyperboloidally bounded structures of FIGS. 7 and 8 is the ease of constructing the mating parts. The operating consideration for each such selection is the maintenance of equal products or acoustic impedance and area of the material across each cross section normal to the axis of the waveguide and transition structure.

FIG. 9 is a third alternate embodiment of the present invention. In FIG. 9, first cylindrical waveguide 137 is connected to second cylindrical waveguide 139 that comprises a pair of nested reentrant cones. In FIG. 9, however, the distance h is measured along second waveguide 138 rather than first waveguide 137 as shown in the earlier embodiments. It is still necessary that the following conditions hold: where Z_a is the specific acoustic impedance of first cylindrical waveguide 137 that has a diameter a, and Z_b is the specific acoustic impedance of second cylindrical waveguide 138 that has a diameter b, then

$$a^2 Z_a = b^2 Z_b, \text{ and}$$
$$h = (ab)/(a + b).$$

FIG. 10 is a partial sectional view and block diagram of an apparatus that was used to practice the present invention. In FIG. 10 waveguide 140 was a stainless steel rod used to couple an acoustic signal from a nuclear reactor through a first transition section 142 and a first electrical conductor 144 to an electro-acoustic transducer 146, a piezoelectric ceramic formed of commercially obtained lead zirconate titanate. First electrical conductor 144 and also second electrical conductor 148, which was placed in contact with the backside of electro-acoustic transducer 146, both comprised brass disks. This choice was made because brass exhibits the same acoustic impedance as the lead zirconate titanate. Thus both brass disks effected a good impedance match to electro-acoustic transducer 146 while providing at the same time a means of establishing electrical connections responsive to the piezoelectric signals generated in electro-acoustic transducer 146 in response to acoustic waves incident thereon. Other materials such as quartz could readily be used for electro-acoustic transducer 146. In such a case, first and second electrical conductors 144 and 148 might well comprise plated or vapor-deposited thin layers of an electrical conductor such as aluminum or gold. Insulating layers 159 and 161 maintain electrical isolation of first and second electrical conductors 144 and 148 from other electrically conducting portions of the system. Thin deposits of alumina serve effectively for insulating layers 159 and 161.

Second electrical conductor 148 is connected to second transition section 150 which effects an impedance match to termination 152. Such terminations have been made by casting lead, iron or tungsten in powdered form in an elastomer plastic material or silicone foam. These materials are chosen to provide a combination of good acoustical coupling together with damping of propagation resulting from frictional coupling to the elastically suspended particles of heavy metal. Particles of lead and tungsten that were used were in the

range from 40 to 3000 micrometers in diameter. When cast in an elastomer for use as an absorber, the composite material for termination 152 had a density of 6 kilograms per liter and a sound velocity of 80 meters per second.

The electrical signals generated in electro-acoustic transducer 146 in response to an acoustic signal were conducted by electrical leads 154 to a charge amplifier 156 and thence by electrical leads 158 to a spectrum analyzer 160. A charge amplifier was chosen because its low input impedance, high input resistance, and high sensitivity minimized the effect of varying lengths of electrical leads 154. Any amplifier capable of providing a satisfactory response to the output of a piezoelectric crystal over the frequency range to be expected could replace charge amplifier 156. Similarly, a spectrum analyzer was one of several possible choices for viewing the response obtained by the electro-acoustic transducer 146 in FIG. 9. Other possible alternatives for such viewing include an oscilloscope or a multichannel analyzer with counter or computer storage.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. An acoustic impedance matching section for effecting a transition between a first solid acoustic waveguide having a first specific acoustic impedance and a first cross-sectional area and a second solid acoustic waveguide having a second specific acoustic impedance and a second cross-sectional area, said second cross-sectional area equalling the product of the ratio of the first specific acoustic impedance to the second acoustic impedance times the first cross-sectional area, said matching section comprising:

a structure having a first end connected to the first waveguide with said first end congruent to said first cross-sectional area; a second end parallel to said first end connected to said second waveguide with said second end congruent to said second cross-sectional area; said matching section further being made of materials having values of specific acoustic impedance equal to said first and second specific acoustic impedances and faired from said first end to said second end to maintain at each cross section of said matching section parallel to said first and second ends an equal value of the sum of the products of the cross-sectional areas of each material and specific acoustic impedance thereof.

2. A transition section between a first cylindrical acoustic transmission medium having a first diameter, a first value of cross-sectional area and a first value of specific acoustic impedance, and a second cylindrical acoustic transmission medium having a second value of specific acoustic impedance and a second cross-sectional area equal to the product of the first value of cross-sectional area times the ratio of the first value of specific acoustic impedance to the second value of specific acoustic impedance, said second cylindrical acoustic transmission medium having a second diameter, said transition section having an axis, said transition section comprising: a first portion of a material having a value of specific acoustic impedance equal to said first value of specific acoustic impedance, said first portion a cone coaxial with said axis with a circular base connected to said first acoustic transmission medium and an apex touching said second acoustic transmission medium, said circular base having a diameter

equal to the ratio of the products of said first and second diameters to the sum of said first and second diameters; a second portion of a material having a value of specific acoustic impedance equal to said second value of specific acoustic impedance, said second portion coaxial with said first portion and connected to said first portion on the conical surface thereof, said second portion forming with said first portion a frustum of a cone having a base congruent to said second cross-sectional area and connected at said base to said second cylindrical acoustic transmission medium, said frustum bounded at an end opposite to said base by said circular base of said first portion; and a third portion of a material having a value of specific acoustic impedance equal to said first value of specific acoustic impedance, said third portion coaxial with said first and second portions, said third portion connected to said second portion on the conical surface thereof, said third portion forming with said first and second portions a frustum of a cone having a base that is the base of said second portion, said frustum having a top that is the base of said first portion.

3. An apparatus for detecting with minimal reflection and displaying acoustical signals from an acoustical source comprising:

a metal rod coupled acoustically to said source;

a first transition section constructed according to claim 2 connected at an input end to said rod;

a first thin layer of alumina connected to said first transition section at an output end to provide electrical insulation;

a first brass disk connected to said first layer of alumina and coupled acoustically therethrough to said first transition section;

a piezoelectric crystal of lead zirconate titanate connected electrically and acoustically to said first brass disk at a first side;

a second brass disk connected to said piezoelectric crystal at a second side opposite to said first side, said first and second sides selected to generate a piezoelectric voltage therebetween;

a second thin layer of alumina connected to said second brass disk to provide with said first thin layer electrical isolation of said first and second disks and said piezoelectric crystal from other parts of said apparatus;

a second transition section constructed according to claim 2 connected at an input end to said second thin layer of alumina and coupled acoustically therethrough to said second brass disk;

a termination section made of powdered metal cast in plastic, said termination section coupled mechanically and acoustically to said second transition section at an output portion thereof; and

display means connected electrically to said first and second brass disks and responsive to said piezoelectric voltage therebetween to generate a display signal in response to said piezoelectric voltage, which display signal displays said acoustical signals with minimal reflection.

4. A transition section between a first solid cylindrical acoustic waveguide having a first diameter and a first value of acoustic impedance and a second solid cylindrical acoustical waveguide coaxial with said first waveguide and having a second diameter and a second value of acoustic impedance, said transition section comprising:

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a first portion coaxial with said first and second wave-guides, said first portion formed of a material hav-ing the same specific acoustic impedance as said second waveguide, said first portion a cone with an apex at a first plane perpendicular to the axis of said first and second waveguides, said cone having a base connected to said second waveguide in a cir-cle having a diameter equal to the diameter of said second waveguide, said base congruent to said cir-cle; and

a second portion coaxial with said first and second waveguides, connected to said first waveguide at said first plane, said second portion made of a ma-terial having a value of specific acoustic impedance equal to the specific acoustic impedance of said first waveguide, said second portion bounded on the inside by said cone coaxial with said first and second acoustic waveguides, said cone having an apex in said first plane, said cone having a base congruent to said second waveguide, said second portion bounded on the outside by a hyperboloid of revolution intersecting said first waveguide on a circle formed by the intersection of said first plane with the outside of said first waveguide and inter-secting said second waveguide at said base of said cone, said hyperboloid of revolution calculated to maintain at each cross section of said transition section an equal value of the sum of the product of area and specific impedance of said first and sec-ond portions.

5. A transition section between a first solid cylindri-cal acoustic waveguide having a first diameter and a first value of specific acoustic impedance and a second solid cylindrical acoustic waveguide coaxial with said first waveguide and having a second diameter and a

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second value of acoustic impedance, said transition section comprising:

a first portion coaxial with said first and second wave-guides and formed of a material having a specific acoustic impedance equal to that of said first wave-guide, said first portion bounded on the outside by a frustum of a cone congruent in a circular plane with a cross section of said first waveguide and touching said second waveguide in a circle of a di-ameter equal to the diameter of said second wave-guide, said first portion bounded on the inside by a hyperboloid of revolution coaxial with said first and second waveguides, said hyperboloid of revo-lution tangent to said circular plane at its center, said hyperboloid of revolution terminating in said circle of a diameter equal to the diameter of said second waveguide, said hyperboloid of revolution calculated to maintain at each cross section per-pendicular to the axis of said transition section equality of the sums of the products of area and specific acoustic impedance when the volume in-side said hyperboloid of revolution is filled with a material having a specific acoustic impedance equal to the specific acoustic impedance of said second acoustic waveguide; and

a second portion of a material having a specific acoustic impedance equal to the specific acoustic impedance of said second acoustic waveguide, said second portion bounded by said hyperboloid of revolution and by said circle of a diameter equal to the diameter of said second acoustic waveguide, the combination of said first and second portions filling the volume of said frustum of a cone.

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