United States Patent [19]

Karplus

[11] **3,915,018**

[45] **Oct. 28, 1975**

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

[75] Inventor: **Henry H. B. Karplus,** Hinsdale, Ill.

[73] Assignee: **The United States of America as represented by the United States Energy Research and Development Administration,** Washington, D.C.

[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

[56] **References Cited**

UNITED STATES PATENTS

2,900,039	8/1959	Burnett	181/400
3,264,863	8/1966	Maropo	179/19
3,546,498	12/1970	McMaster et al.	333/30
3,590,288	6/1971	Michenko	310/8.7

Primary Examiner—Herbert Goldstein
Attorney, Agent, or Firm—Dean E. Carlson; Arthur A. Churm; Donald P. Reynolds

[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

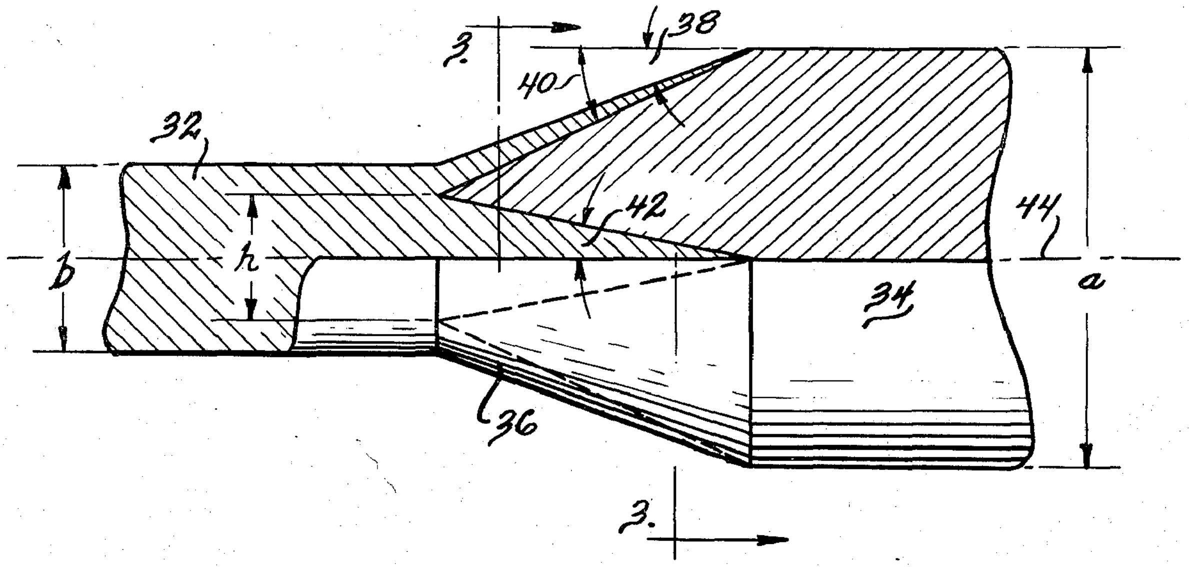
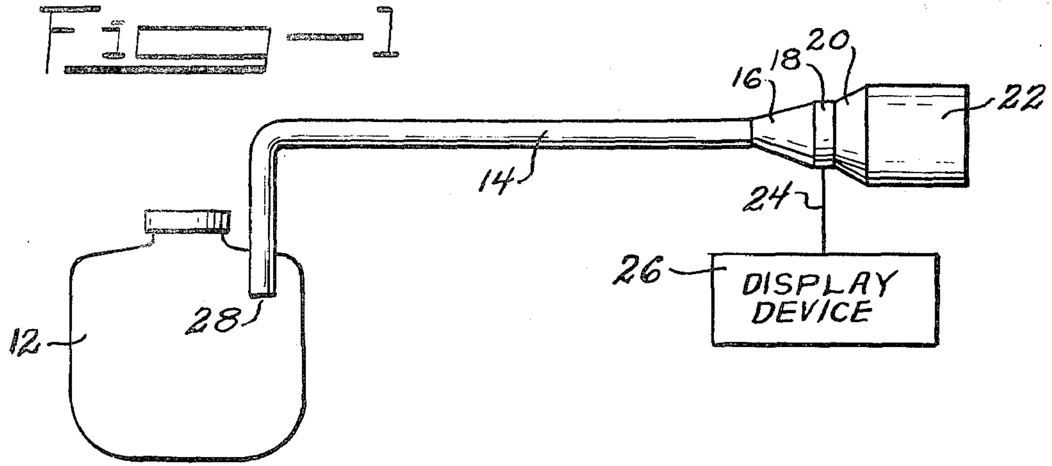


Fig-1



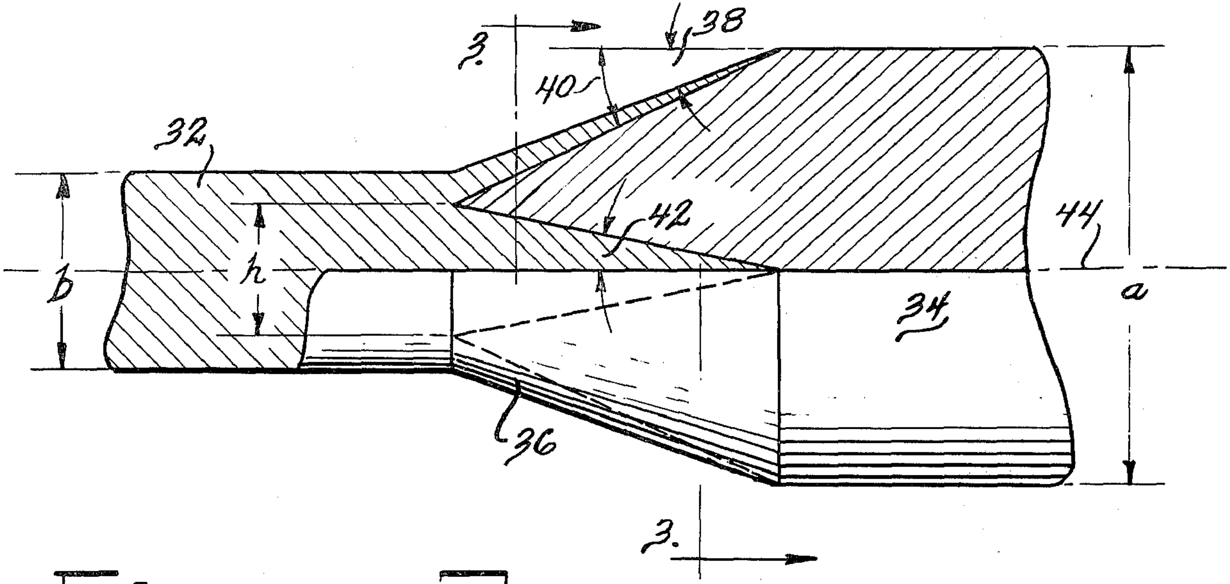


Fig-2

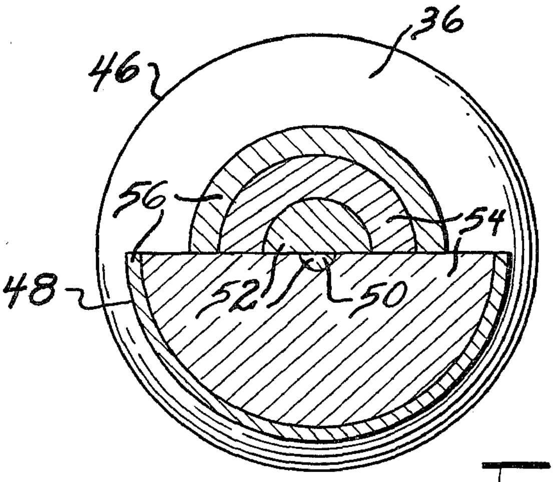


Fig-3

Fig. 4

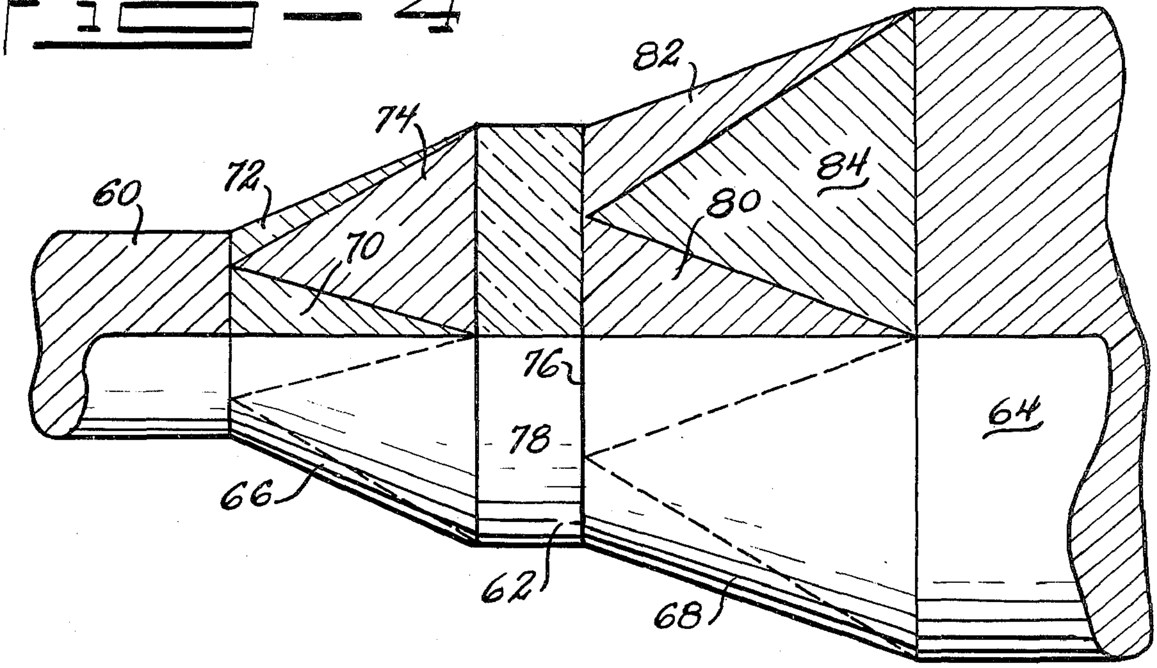


Fig. 5

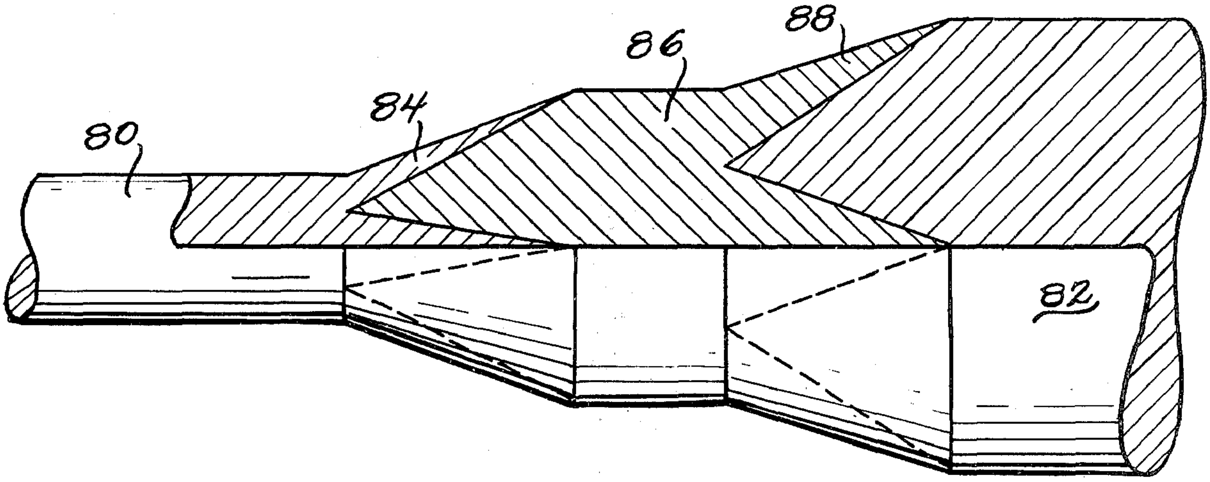


Fig-6

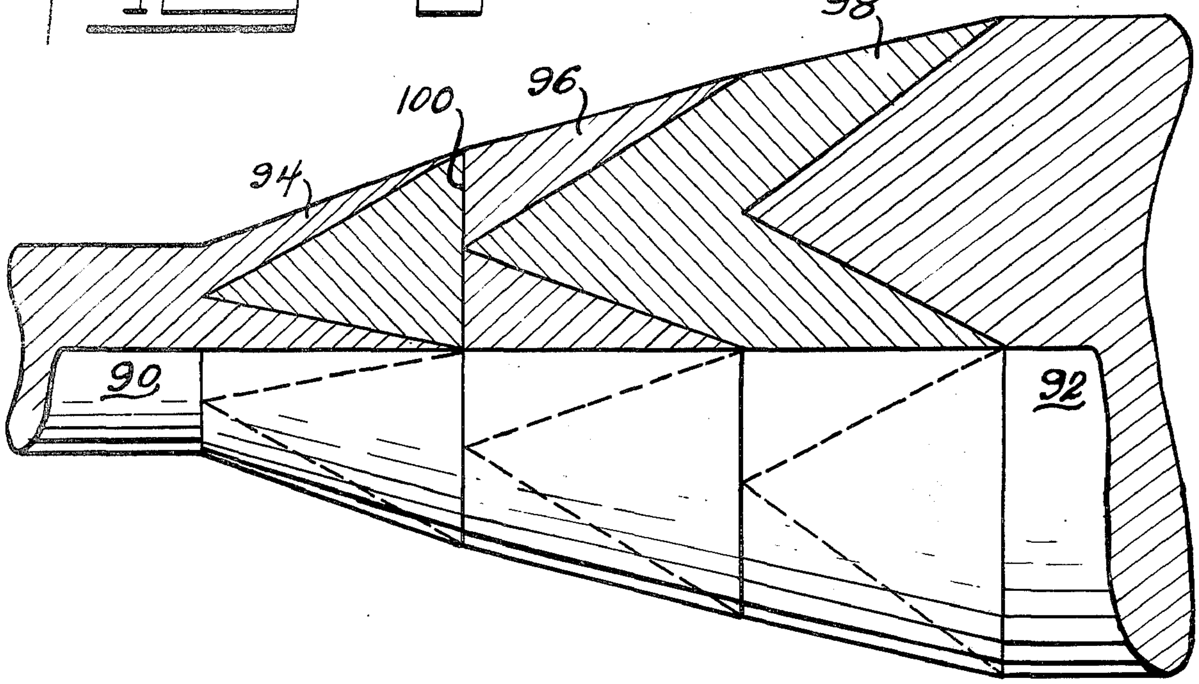


Fig-7

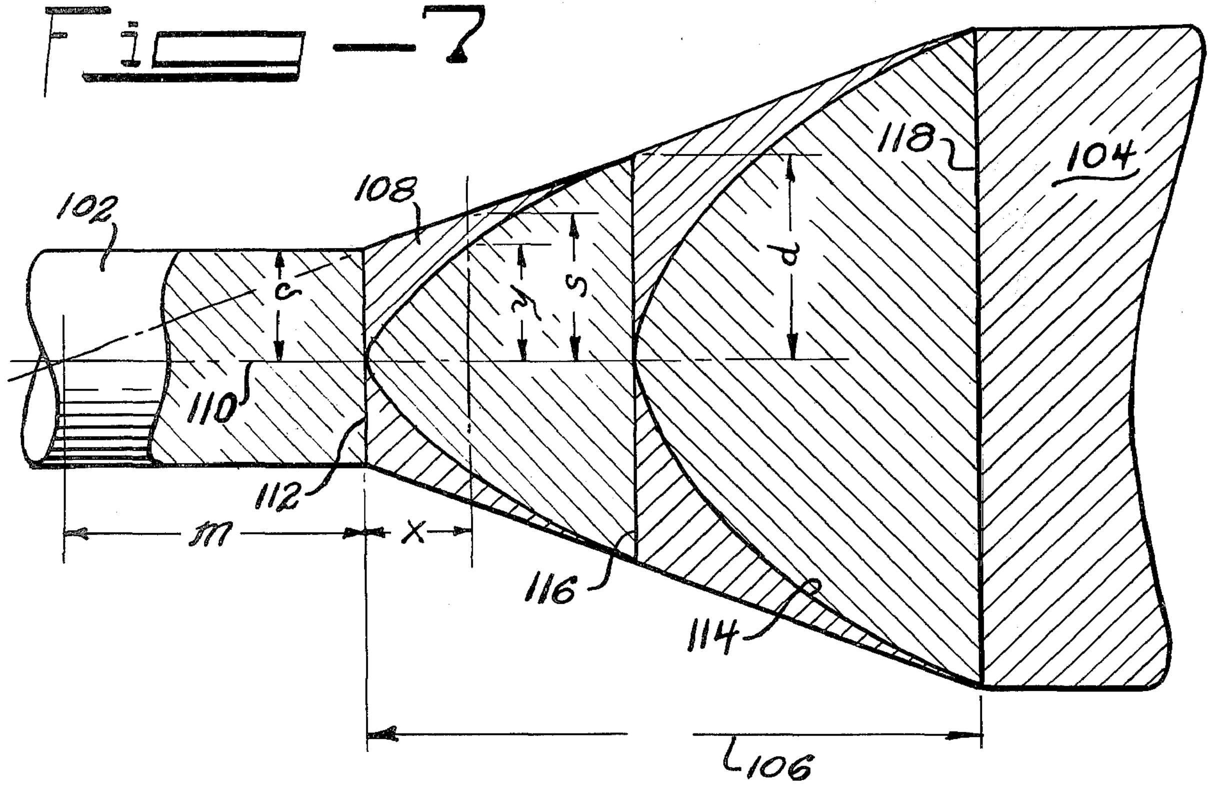


Fig-8

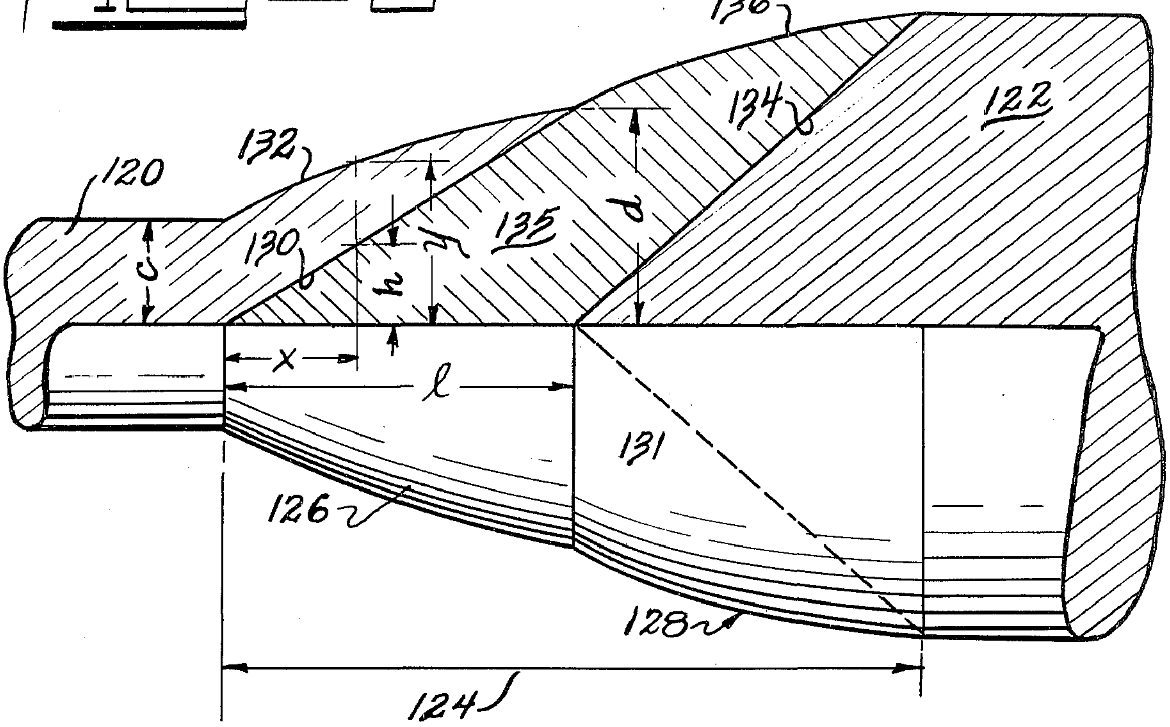
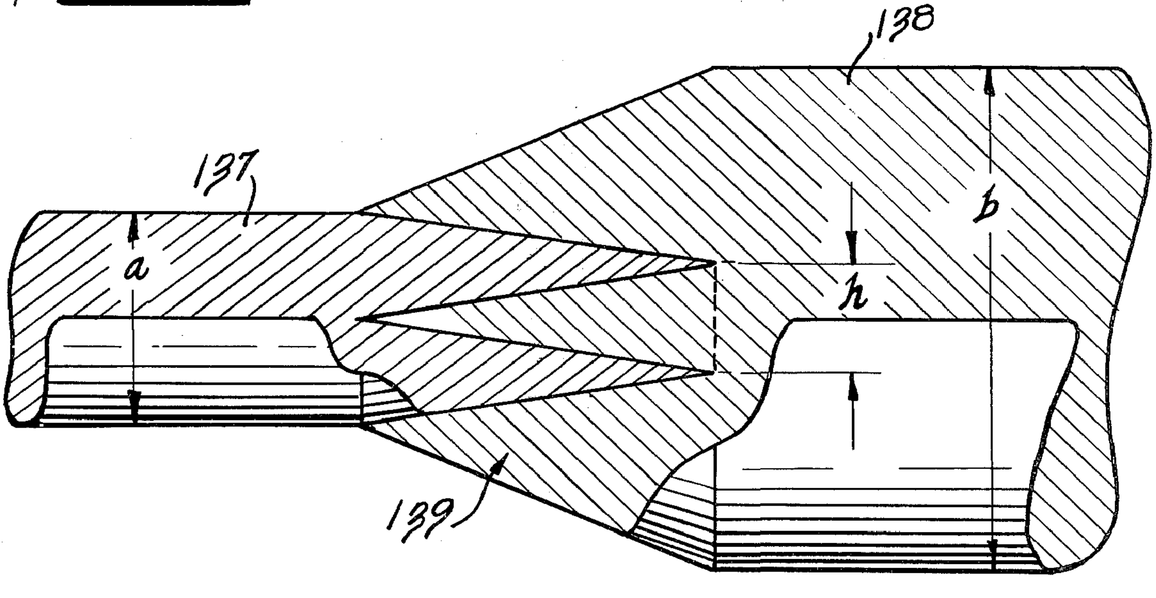
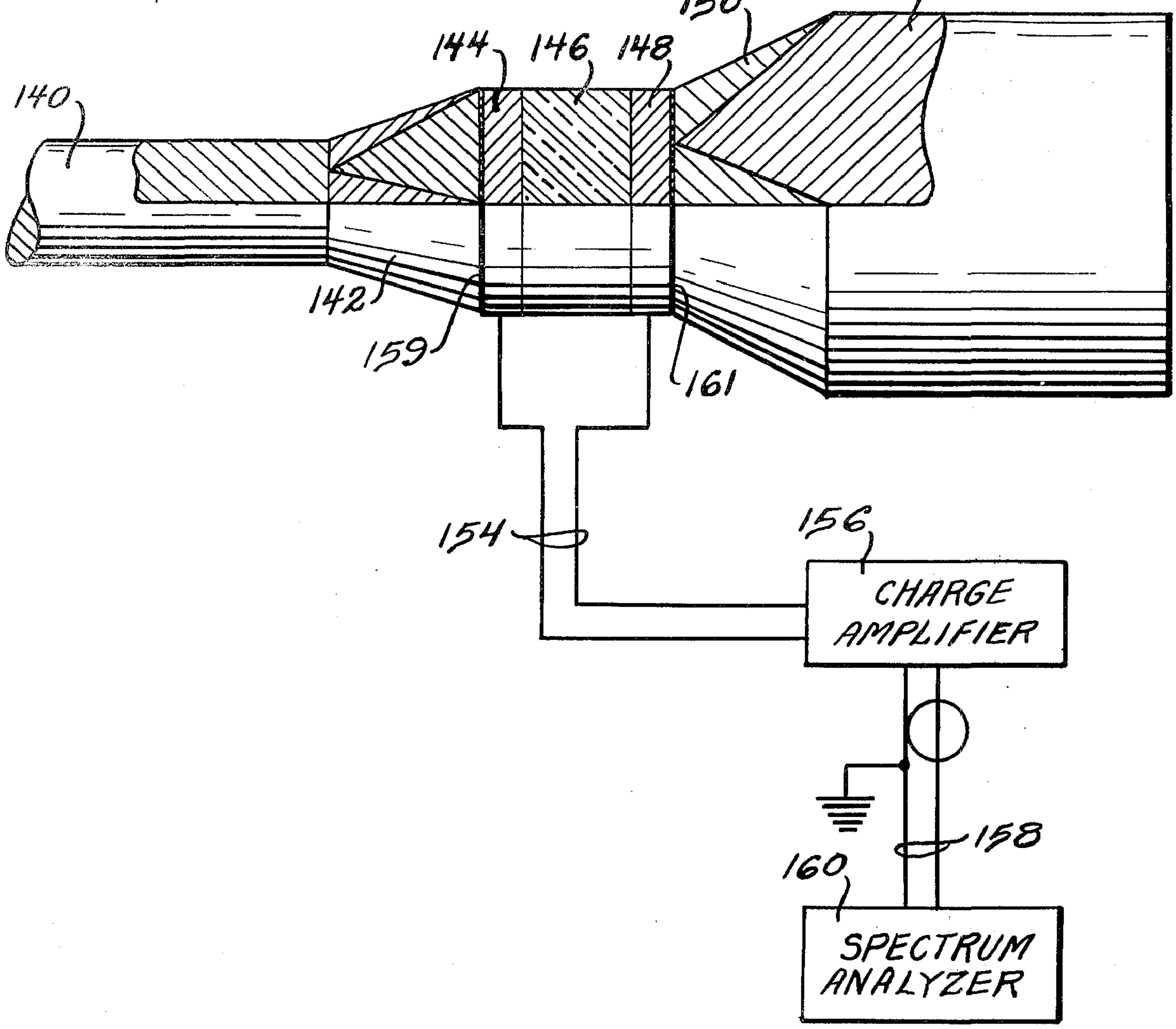

136
134
122
132
120
130
135
c
h
y
d
x
l
131
126
128
124

Fig-9


138
137
a
h
b
139

Fig—10


140
142
144
146
148
150
152
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 waveguide **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 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 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

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.

$$c^2 Z_c = d^2 Z_d = y^2 Z_d + s^2 Z_c - y^2 Z_c \tag{1}$$

$$\frac{c}{m} = \frac{s}{x+m} \tag{2}$$

Relation (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

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

and

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

substitution in (1) produces the equation

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

Equation (3) is a hyperbola in the variables y and $(x + m)$.

The two-stage structure of FIG. 7 accomplishes a low-reflection impedance match in the manner described for the earlier figures by keeping a constant product of cross-sectional area and specific acoustic impedance of each cross section. The structure shown in FIG. 7, however, has the advantage of a smooth, unbroken, conical surface **108** bounding the structure on the outside. A second alternate embodiment of the present invention is shown in the partial sectional view of FIG. **8** in which first acoustic waveguide **120** is matched to second acoustic waveguide **122** through matching section **124.** Matching section **124** comprises a first portion **126** and a second portion **128** which are designed according to the same principles. In FIG. **8** first portion **126** is divided into two parts by a first conical surface **130.** First hyperboloid of revolution **132** bounds first portion **126** on the outside. Similarly, second portion **128** is divided into by second conical surface **134** and is bounded on the outside by second hyperboloid of revolution **136.** A calculation applied to FIG. **8** in a manner similar to that performed above for FIG. 7 shows that, if one bounding surface is conical with the apex of the cone at a point on the axis marking a joint between two sections, then the bounding surface of the other material must necessarily be a hyperboloid of revolution. That calculation is as follows. Referring to FIG. **8,** let c be the radius of first waveguide **120** and let d be the radius of the base **131** of first conical surface **130.** Let Z_c and Z_d be the specific acoustic impedances of first acoustic waveguide **120** and the interior **135** bounded by first conical surface **130.** At a distance x into first portion **126,** let the height to first conical surface **130** be h and let the height to first hyperboloid of revolution be y. Let the length of first portion **126** be 1. Then the following relations hold.

$$h/x = d/l \tag{1}$$

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

$$\text{Thus } h = \frac{dx}{1} \text{ and } Z_d = \frac{c^2}{d^2} Z_c .$$

Substituting shows that

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

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

$a^2 Z_a = b^2 Z_b$, 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:

a first portion coaxial with said first and second waveguides, said first portion formed of a material having 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 circle having a diameter equal to the diameter of said second waveguide, said base congruent to said circle; 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 material 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 intersecting 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 second portions.

5. A transition section between a first solid cylindrical 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 second value of acoustic impedance, said transition section comprising:

a first portion coaxial with said first and second waveguides and formed of a material having a specific acoustic impedance equal to that of said first waveguide, 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 diameter equal to the diameter of said second waveguide, said first portion bounded on the inside by a hyperboloid of revolution coaxial with said first and second waveguides, said hyperboloid of revolution 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 perpendicular to the axis of said transition section equality of the sums of the products of area and specific acoustic impedance when the volume inside 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.

* * * * *