United States Patent [19]

Rolle

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[54] **ACOUSTIC LENS**

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[73] Assignee: **The United States of America as represented by the Secretary of the Navy**, Washington, D.C.

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[52] **U.S. Cl.** ..... **181/.5 A**, 340/8 L

[51] **Int. Cl.** **G01v 1/16**

[58] **Field of Search** ..... 340/8 L, 8 M, 8 S, 340/8 R; 181/.5 A

[56] **References Cited**

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[57] **ABSTRACT**

An acoustical lens doublet of the type particularly useful for focusing sonic energy on the energy converter array of an electroacoustical transducer having image resolution powers that are substantially unaffected by varying temperatures and pressures ambient thereto is disclosed. Included therein is a rearward shell containing a low density polyethylene acoustically clear forward wall-hemispherical lens combination. A forward shell is telescopically mounted on the front end of said rearward shell, with the forward end of said forward shell having a thin low density polyethylene acoustically clear window located therein. An interface fluid, preferably consisting of a predetermined quantity of m-chloroanoline ($ClC_6H_4NH_2$), is located under a predetermined pressure within a chamber effected between the forward ends of said rearward and forward shells, as a result of the telescopic relationship thereof.

15 Claims, 7 Drawing Figures

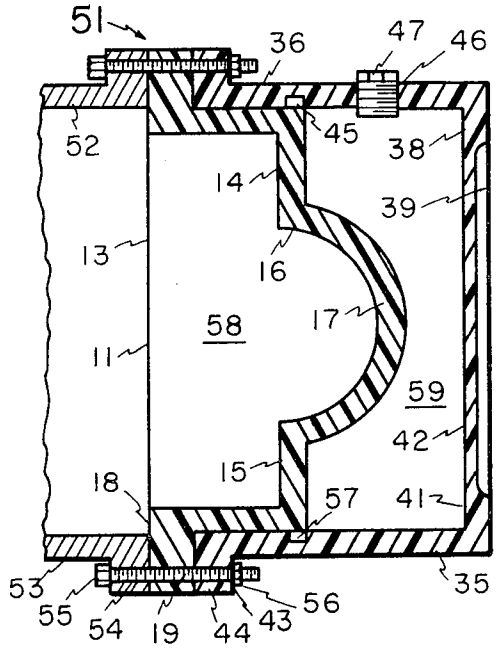


FIG. 1

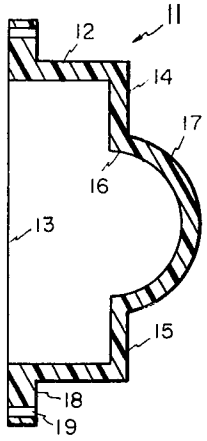


FIG. 2

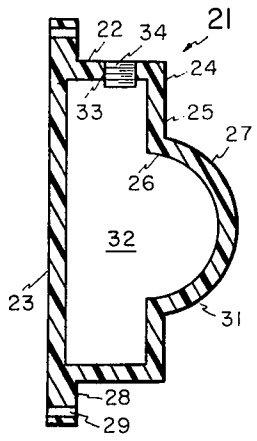


FIG. 3

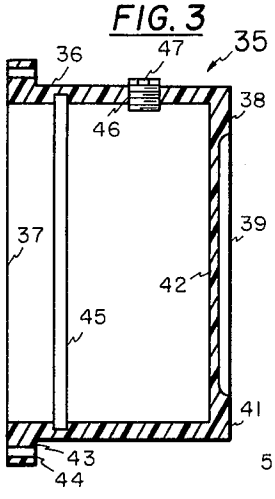


FIG. 4

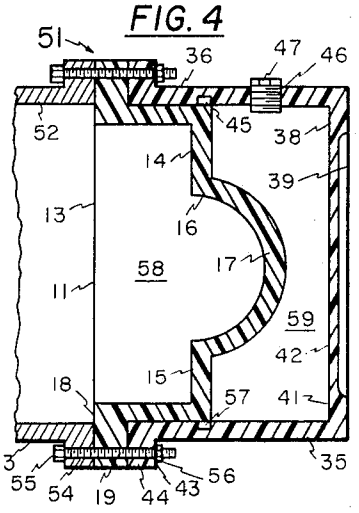


FIG. 5

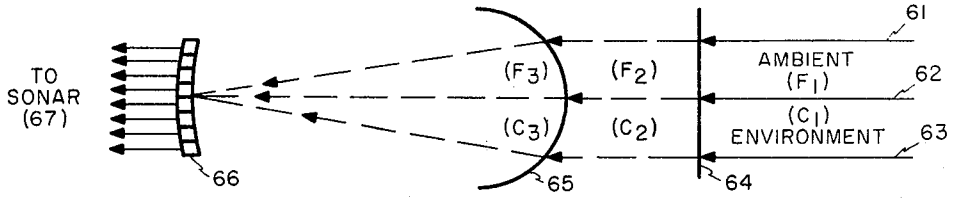


FIG. 6

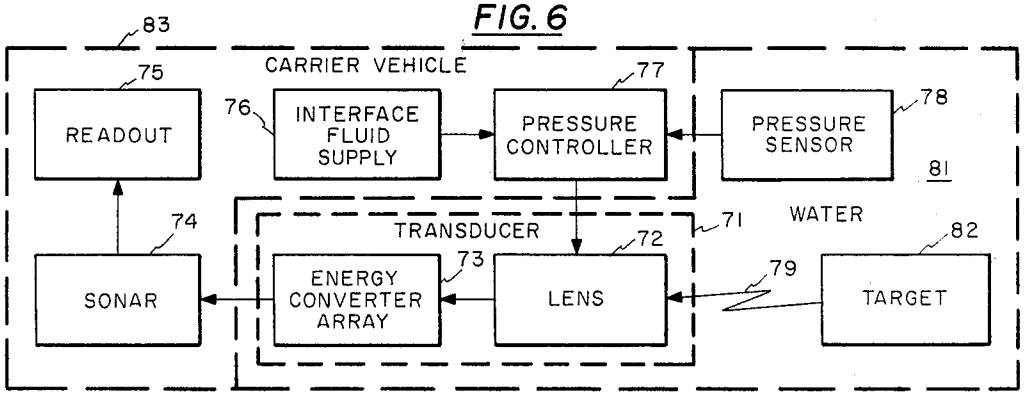
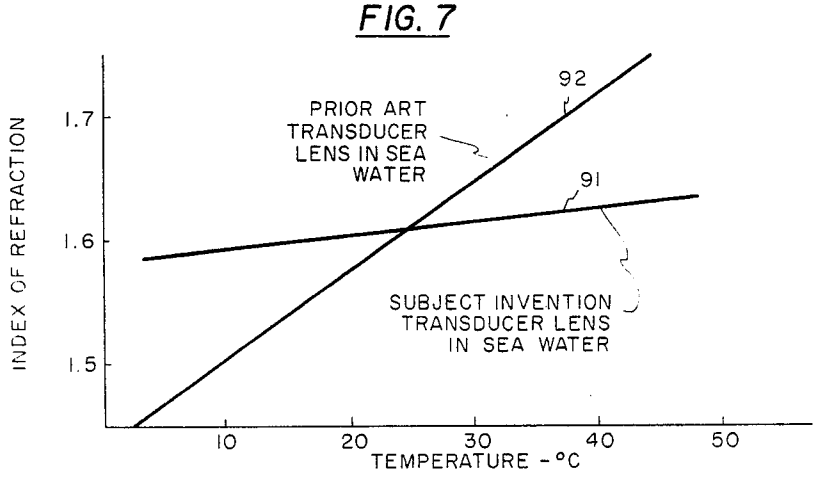


FIG. 7



ACOUSTIC LENS

STATEMENT OF GOVERNMENT INTEREST

The invention described herein may be manufactured and used by or for the Government of the United States of America for Governmental purposes without the payment of any royalties thereon or therefore.

FIELD OF THE INVENTION

The present invention relates, in general, to lens and lens systems, and, in particular, it is an athermal acoustic refractor that may be advantageously combined with an array of electroacoustical energy converter devices for the focusing of acoustical images thereon or therefrom. In even greater particularity, but not by way of limitation, it is an improved, reversible, temperature and salinity compensated, compound, ultrasonic, electroacoustical transducer lens that is eminently suitable for being incorporated in both active and passive sonar systems, in sonic echo-search-ranging systems, and in any other devices or systems requiring the accurate focusing of acoustical energy under ambient environmental conditions of varying temperature and/or salinity.

DESCRIPTION OF THE PRIOR ART

Heretofore, numerous electroacoustical transducers have incorporated various and sundry acoustic lenses, in order to effect more accurate focusing of sonic energy therein. For many practical purposes, such lenses have been quite satisfactory; however, in the event that environmental medium ambient thereto varies in temperature, the index of refraction thereof is changed, thereby, in turn, effecting a change in the focal lengths thereof. Of course, such changes in focal length ordinarily change the focus of such prior art transducers enough to cause unwanted acoustical image aberrations to occur therein.

In the past, the adverse effects of changing temperatures on the index of refraction of an acoustical lens was compensated by adjusting the distance between the lens and the electroacoustic energy converter elements, so that the refracted acoustic images would be properly in focus therein. Unfortunately, if such lens is employed to form several acoustic beams over a significantly large field of view, a change in focal length also necessitates a change in the curvature of the transducer's energy converter array at the image plane. Because it is exceedingly difficult to accurately control lens focal lengths and image plane curvatures, using such procedures is usually impractical.

Another means for compensating an acoustical lens for changing temperature is to change the composition of the lens itself, so as to correct the index of refraction thereof and, thus, adjust the focus thereof. Again, for most practical purposes, so doing is too difficult and time consuming to be effective, at least within most practical time limits.

In addition, acoustic lenses have been made of materials that inherently change the index of refraction thereof in compensating proportion to the temperature change to which they are exposed, and again, for many practical purposes, such lenses have proven to be quite satisfactory. But, to date, for some purposes—say, for example, during deep sea sonar operations—the temperature compensation effected thereby is not sufficient or is not sufficiently proportional to the actual temperature gradients encountered to be as accurate as desired. Hence, in many instances, they leave a great deal to be desired when actually employed in various and sundry operational circumstances.

SUMMARY OF THE INVENTION

Perhaps the perfect method and means for compensating for temperature changes in acoustical lenses for all operational circumstances may not be found for quite some time, if ever; nevertheless, for many practical purposes, the temperature compensating ultrasonic lens of the subject invention constitutes a vast improvement over most of the prior art, in that the index of refraction thereof varies less per degree change in temperature for a very important and useful temperature range, due to the new and unique inherent temperature compensation characteristics existing therein, as will be shown more vividly subsequently. As a result, the versatility of electroacoustical transducers incorporating such lenses has become considerably greater than heretofore obtainable from those of the prior art.

Briefly, the instant invention consists of a pair of cylindrical shells that are constructed of acoustically clear material which are assembled together in such manner that the forward one — herein defined as being an interface shell — is telescopically mounted on and partially around the rearward one — herein defined as being a lens shell. When so assembled, a forward looking chamber is formed between the interface and lens shells that is filled or partially filled with an organic fluid — herein defined as being the interface fluid — the change of acoustical index of refraction of which is opposite that of the environmental medium ambient thereto for any given identical temperature change in both thereof. As will be described in greater detail subsequently, said interface fluid may be supplied under pressure from an external source or a predetermined quantity thereof may be confined therein, depending upon the operational circumstances — such as, for example, the considerable ambient pressures encountered at great water depths in an ocean.

The aforesaid lens shell of the unique interface shell — lens shell assembly constituting this invention is constructed to have such a convex configuration as to cause it to inherently refract acoustical energy in such manner as to effect the focusing thereof at a focal point or spot located at a given radius or focal length ($f1$) therefrom in the rearward direction. In contact with the rearward face, and optionally, but preferably, filling a predetermined space behind it, is another organic fluid — herein defined as being the lens fluid — which may or may not have an acoustical index of refraction that varies inversely with that of the aforesaid environmental medium for any given identical temperature in both thereof.

Because the electroacoustic energy converters of the transducer are also either actually or effectively located in the aforementioned lens fluid, and because they are ordinarily located along the focal length or radius of the lens shell, the acoustical energy received by the lens shell is focused thereon with a relatively high degree of accuracy, regardless of the fact that the temperature ambient thereto may be changing rapidly. Hence, the entire transducer has a responsiveness, a resolution, and an image fidelity hitherto unattainable by any known prior art.

It is, therefore, an object of this invention to provide an improved acoustical lens.

Another object of this invention is to provide an acoustical lens having improved automatic temperature compensation characteristics.

Still another object of this invention is to provide a new and unique system for acquiring and image-processing the acoustical energy emanating from an underwater target object.

A further object of this invention is to provide an acoustical lens having an acoustical index of refraction that varies only a small amount with temperature.

Another object of this invention is to provide an acoustical lens which is not put out of focus as a result of being transferred from a medium having a particular sound velocity to another medium having a different sound velocity, such as, for example, when going from fresh water into sea water and vice versa.

Another object of this invention is to provide an improved method and means for focusing acoustical energy.

Still another object of this invention is to provide an improved electroacoustical transducer sonic lens that requires no focus adjustment over a relatively large temperature range.

Still another object of this invention is to provide an electroacoustical transducer lens with improved power transfer characteristics and reduced internal reflections.

A further object of this invention is to provide a more versatile method and means for focusing sonic and ultrasonic energy.

Another object of this invention is to provide an acoustic refractor that is substantially uneffected by changes in the temperature thereof and its ambient environment.

Another object of this invention is to provide a compound lens having fast sound velocity propagation components.

Another object of this invention is to provide an improved sonic and ultrasonic compound lens which exhibits small changes in focus over relatively wide temperature ranges.

Another object of this invention is to provide improved method and means of forming high fidelity acoustical images when incorporated in a compatible sonar system.

Other objects and many of the attendant advantages will be readily appreciated as the subject invention becomes better understood by reference to the following detailed description, when considered in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWING

FIG. **1** is a cross-sectional view of the cylindrical lens shell of the subject acoustical lens invention;

FIG. **2** is a cross-sectional view of another species of a cylindrical lens shell that may be incorporated in the instant acoustical lens invention;

FIG. **3** is a cross-sectional view of the cylindrical interface shell of the subject acoustical lens invention;

FIG. **4** is a cross-sectional view of a preferred embodiment of the cylindrical compound lens constituting the invention, which includes the lens shell of FIG. **1** and the interface shell of FIG. **3** combined as a unitary assembly and which, by implication, portrays how the lens shell of FIG. **2** may be incorporated therein by the artisan instead of the lens shell of FIG. **2**, if so desired;

FIG. **5** is a schematic representation of the invention which will be used subsequently in disclosing the theory of the operation thereof;

FIG. **6** is a block diagram of a sonar system which may incorporate the instant invention to an advantage; and

FIG. **7** is a graphical representation of typical index of refraction versus temperature curves for electro-acoustical transducers operating within approximately a forty-five degree Centigrade temperature range, both with and without the incorporation of an M-chloroaniline ($ClC_6H_4NH_2$) interface fluid therein.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIG. **1**, there is shown an acoustical lens shell **11** having a cylindrical section **12**, with an open rearward end **13** and a closed forward end wall **14**. In the disclosed embodiment of forward end wall **14**, a flat wall **15** is included, and in the center of said flat wall is an aperture **16** to which a hemispherical lens **17** is integrally connected at substantially the maximum diameter thereof. At this time, it would perhaps be noteworthy that said flat wall **15** and said hemispherical lens **17** are constructed of acoustically clear material, and that the thickness and diametrical dimensions thereof should be such as would optimize the acoustical clearness thereof, respectively. For example, but not by way of limitation, wall **15** and lens **17** may be constructed of low density polyethylene having a thickness of the order of 0.070 inches, with the inside radius of lens **17** being of the order of 0.75 inches. Of course, although the foregoing polyethylene material and dimensions are quite satisfactory, it should be understood that others may be used if operational circumstances so warrant. Moreover, the entire shell constituting lens shell **11**, including forward flat wall **15** and hemispherical lens **17**, may be so designed as to be of other plastics, rubber, metal or any other suitable acoustically clear materials. Of course, under such circumstances, the dimensions therefor would have to be selected, respectively, if optimum operation is to be obtained therefrom for any predetermined purpose. Obviously, the selection of the appropriate materials and dimensions for lens shell **11** would be well within the purview of one skilled in the art having the benefit of the teachings presented herein.

At the rearward end of cylindrical lens shell **11**, and preferably integrally connected to cylindrical section **12** thereof, is a circular flange **18** having a plurality of holes **19** extending therethrough and disposed uniformly around it adjacent to the periphery thereof. Said flange **18** and holes **19** are adapted to be respectively complementary and in line with those components (not shown) of a transducer case or housing to which flange **18** is to be bolted, and, in addition, with other lens elements to be described subsequently.

FIG. **2** depicts another preferred embodiment of an acoustical lens shell **21** that may be substituted for the aforementioned lens shell **11** in the completed lens assembly, which, likewise, will be discussed below. Shown therein is a cylindrical section **22**, with a flat, acoustically clear wall **23** located at the rearward end thereof for the closure thereof and a closed forward end **24** effected by a flat wall **25** effectively having an aperture **26** located at the center thereof. Integrally connected to wall **25** at the periphery of aperture **26** is

a hemispherical lens **27.** Like the aforementioned acoustical lens shell **11,** acoustical lens shell **21** is made of any acoustically clear material and have whatever dimensions are suitable therefor, in order to optimize the operation thereof for any given purpose within any given environmental medium. Hence, the previously mentioned materials and dimensions are quite satisfactory for the lens shell embodiment being discussed at this time.

At the rearward end of cylindrical lens shell **21** and preferably integrally connected to cylindrical section **22** thereof is a circular flange **28** having a plurality of holes **19** extending therethrough and disposed uniformly around it adjacent to the periphery thereof. Said flange **28** and holes **29,** like the aforesaid flange **18** and holes **19** of lens embodiment **11,** are so designed as to be respectively compatible with those components (not shown) of a transducer case or housing to which flange **18** is intended to be bolted, and again, in addition, with other lens elements to be described subsequently.

The foregoing structure of FIG. **2** obviously forms a closed chamber **31** which is filled with an organic sound conducting fluid **32,** the sound velocity of which is inversely proportional to the temperature thereof and, thus, decreases with an increase in temperature and vice versa. Although numerous conventional organic fluids exist which have suitable characteristics for acoustic lens purposes, it has been determined that dibromethylene (CH_2BR_2), carbon tetrachloride (CCl_4), chloroform ($CHCl_3$), methylene iodide (CH_2I_2), and Halocarbon Oil, Ser. No. 208, manufactured by the Halocarbon Products Corporation of Hackensack, N.J., are satisfactory for such purpose, since the velocity of sound passing therethrough is such as facilitates the focusing thereof on an energy converter array, as will be discussed more fully below.

For the purpose of filling chamber **31** with fluid **32,** a threaded hole **33** is located through the wall of cylinder section **22.** And for the purpose of containing fluid **32** in chamber **31,** a threaded plug **34** is screwed in threaded hole **33.** Because, as previously suggested, the interface shell will be telescopically mounted on and around lens shell **21,** plug **34** should be so designed as to make the outer end thereof at least flush with and preferably recessed from the outer diameter cylinder section **22,** when it is inserted in hole **33.**

Referring now to FIG. **3,** there is shown a preferred embodiment of an interface shell **35** which may be telescopically mounted on and around either lens shells **11** or **21** of FIG. **1** or FIG. **2,** in order to effect the new combination of elements constituting this invention. Disclosed therein is a cylindrical section **36** having an open rearward end **37** and a closed forward end **38.** The closure at the forward end is, in fact, effected by a wall having a thick section **41** near the periphery thereof and a relatively thin circular acoustical window section **42** at the center portion thereof. For example, said thick wall section **41** may be of the order of 0.125 inches thick, and said thin acoustical window **42** may be of the order of 0.025 inches thick. Integrally attached to the rearward end of cylindrical section **36** is a flange **43** having a plurality of holes **44** extending therethrough and uniformly spaced therearound.

As will be more fully disclosed below, the inside diameter of interface shell **35** should be such as would cause it to fit snugly around the outer diameter of either of the lens shells **11** and **21** of FIGS. **1** and **2,** respectively, and thereby effect a fluid tight seal therebetween. Moreover, flange **43** and holes **44** should be so designed as to have a complementary fit and be in alignment with flanges **18** or **28** and holes **19** or **29,** respectively, when telescopically mounted around either of lens shells **11** or **21.**

Located around the inside diameter of cylindrical section **36** of interface lens **35** is a groove **45** adapted for having a resilient O-ring (not shown in FIG. **3**) inserted therein that will, as will be subsequently disclosed, provide further liquid or fluid seal between the inner surface of interface shell **35** and the outer surface of the lens shell telescopically mounted therein.

As in the shells of FIGS. **1** and **2,** the walls of interface shell **35** is made of an acoustically clear material, such as, for instance, a low density polyethylene, rubber, metal, or the like. Again, the material selected therefor should be compatible with the material selected for the co-acting lens shell combined therewith.

Located in the wall of the cylindrical section **36** of shell **35** is a threaded hole **46** adapted to be used for filling the interface shell with an organic liquid or fluid after it is assembled with its lens shell. A threaded plug **47** is inserted in threaded hole **46** to prevent leakage of the organic fluid or fluid therefrom.

As an alternate possibility, hole **46** of interface shell **35** may have a pipe nipple screwed therein, which would facilitate the connection of other suitable piping thereto, in the event the subject lens were incorporated, for example, in a system such as that illustrated in FIG. **6.**

FIG. **4** consists of an acoustical lens assembly **51** of the aforementioned lens shell **11** in combination with the interface shell **35.** In order to keep this disclosure as simple as possible, only an assembly incorporating lens shell **11** has been shown; however, it should be understood, as previously suggested, that lens shell **21** may be substituted therefor, in the event that a unitary, self-contained, compound, acoustical lens is desired. Obviously, so doing would be well within the ability of the artisan constructing and using it, inasmuch as the teachings thereof are explicitly included herein. Furthermore, insofar, as it is possible, in order to correlate the various and sundry elements of the acoustical lens of FIG. **4** with identical parts of the shells depicted in FIGS. **1** and **3,** like reference numerals have been employed for like parts. Moreover, because all of the elements of acoustical lens **51** would readily be recognized by the artisan as being the same as those shown in FIGS. **1** and **3,** respectively, it will only be discussed briefly from a structural standpoint, with only those additional structural explanations made which are deemed necessary for the teaching thereof as an assembled unit. Hence, lens shell **11** is shown as being telescopically disposed within interface shell **35,** with the rearward surface of flange **43** of interface lens **35** being in complementary abutment with the forward surface of flange **18** of lens shell **11.** Of course, the respective pluralities of the aforesaid holes **44** and **19** are in alignment, too.

The particular acoustical lens embodiment of FIG. **4** intended to be attached to the housing of the overall electroacoustical transducer. Because said transducer could have any of many suitable, conventional, geometrical configurations, it is not disclosed in detail herein. Suffice to say, however, that the forward end thereof should be designed in such manner that it

would form a complementary connection with the rearward surface of flange **18** of lens shell **11.** Thus, a transducer housing **52** likewise contains a flange **53** at the forward end thereof which, in turn, contains a plurality of holes **54** that are located therein in such manner that they are in alignment with holes **19** and **44,** respectively, of flanges **18** and **43** of shells **11** and **35.**

In order to secure housing **52** to acoustical lens assembly **51,** a plurality of threaded bolts **55** are inserted through the aligned ones of holes **54, 19,** and **29,** and a like plurality of nuts **56** are screwed on the forward ends thereof. Of course, any suitable conventional means, such as, for instance, lock washers or additional nuts, may also be used to insure that the aforesaid nuts **56** will not come loose.

In addition, although not shown, if so desired for any given operational circumstances, appropriately designed gaskets may be disposed between all of the foregoing mating surfaces. One particular sealing means disposed between shells **11** and **35** is an O-ring **57** that is located in the aforementioned groove **45** of shell **35** and, thus, is in resilient sealing contact with the outer surface of the cylindrical section of lens shell **11.** Hence, the seals between the assembled shells of lens **51** are fluid tight, thereby preventing the entrance of ambients fluids therein, and also preventing the escape of any of the acoustical energy refracting fluids therefrom.

The transducer in which acoustical lens **51** is incorporated is what is commonly known in the art as a liquid lens transducer. Consequently, housing **52** thereof is filled with an acoustical energy refracting organic liquid, herewith defined as being organic lens fluid **58.** Again, as indicated previously with respect to lens fluid **32,** lens fluid **58** may be any conventional transducer lens liquid, such as, for example, dibromethylene (CH_2Br_2), carbon tetrachloride (CCl_4), chloroform $CHCl_3$), methylene iodide (CH_2I_2), or Halocarbon oil. Because it also fills the rearward portion of lens shell **11,** and because the piezoelectric electroacoustical energy converters (not shown) are also flooded thereby, said lens fluid **58** likewise constitutes a medium which transmits the sonic energy passing through lens wall **17** to said energy converters. And because fluid **58** is a sonic energy refracting liquid, it and hemispherical lens **17** cause the focusing of said sonic energy on the aforesaid electroacoustical energy converters.

Another sonic refracting liquid, interface fluid **59,** fills or substantially fills the space between the forward surface of hemispherical membrane lens **17** and the rearward surface of flat wall **42** of interface lens **35.** This fluid is preferably the organic compound M-chloroanaline ($ClC_6H_4NH_2$) and has an index of refraction that is inversely proportional to that of water. Interface fluid filling may be effected through threaded hole **46,** after which plug **47** is inserted. Interface fluid **59,** like lens fluid **58,** provides a suitable medium for transmitting the operative sonic energy received through forward window **42** to the forward surface of acoustical hemispherical lens **17.** Although the aforementioned M-chloroanaline (ClC_6H_4 NH_2) is the fluid considered to be optimum for this purpose at the present time, other such fluids — such as, for instance, nitrobenzoil ($C_6H_5NO_2$), O-kersol (C_7H_8O), **and M-nitrotoluol** ($C_7H_7NO_2$) — would be satisfactory for some operational situations, too.

At this time it would perhaps again be noteworthy that lens shell **21** may be substituted for lens shell **11** in lens assembly **51.** In such case, it would, of course, be independently filled with one or more lens fluids similar to those mentioned above as lens fluid **58.** The filling thereof would be effected through hole **46,** after which plug **47** would be inserted therein. Obviously, if such arrangement were employed, housing **52** would also have to be filled with the same or some other suitable sonic energy transmitting fluid, so as to transfer the operative sonic energy from flat acoustically clear rearward wall **23** to the piezoelectric energy converter elements of the transducer.

Perhaps at this time it would also be noteworthy that although lenses **17** and **27** are disclosed herein as being hemispherical lenses, it is within the contemplated scope of this invention that they may be designed by the artisan to have whatever geometrical configurations — that is, sizes, radius of curvatures, thickness, etc. — will give whatever focal characteristics required for any given transducer design and operational circumstances.

It is also important, of course, as previously suggested, that the aforesaid sonic energy refracting fluid used as interface lens fluid **59** be such that the ratio of sound velocity therein to sound velocity of the ambient water — and, hence, the index of refraction — decreases with an increase of temperature and vice versa, so as to thereby automatically effect a compensation for the focal distortions that would otherwise occur as a result of a temperature variation in said environmental medium. For such purpose, as also previously suggested, M-nitrotoluol ($C_7H_7NO_2$) appears to be an optimum selection for interface lens fluid **59.**

Referring now to FIG. **5,** there is shown, in schematic form, the typical operation of the invention. Disclosed is an ambient environmental fluid F_1 having a sound velocity C_1 within which sonic energy rays **61, 62,** and **63** are traveling in such manner as to pass through acoustical window **64** and into interface fluid F_2 having a sound velocity C_2. From interface fluid F_2, said acoustical rays pass through acoustical lens **65** and into lens fluid F_3 having a sound velocity C_3. But because of the shape of acoustical lens **65** and the ratio of sound velocities of C_2/C_3, said acoustical rays are focused at some radial focal length (*f*1) on electroacoustical energy converter array **66,** the outputs of which are supplied to a sonar receiver **67.** Under such circumstances, as will be discussed more fully during the explanation of the operation of the invention presented below, the controlling index of refraction, Ω, of such lens system, as far as temperature is concerned, is equal to C_2/C_3, since fluid F_2 is interposed between ambient environment F_1 and lens fluid F_3.

FIG. **6** illustrates a representative system that will enable the acoustical lens of FIG. **4** to be used to an advantage at various water depths, but especially at useful ocean depths. Shown is an electroacoustical transducer **71** containing a temperature compensating lens **72,** similar to that indicated as acoustical lens assembly **51** in FIG. **4,** the output of which is supplied to an electroacoustical energy converter array **73,** the output of which is, in turn, connected to the input of a sonar receiver **74.** A readout **75** is calibrated and connected to the output of sonar receiver **74** for suitable display and/or recording of the signals received therefrom.

Lens **72**, as previously indicated, is capable of having the amount and pressure of its interface pressure controlled, so that it may, for instance, be operated at numerous useful ocean depth pressures. For this purpose, interface fluid **76** is supplied to a pressure controller **77** which regulates the pressure of the interface fluid supplied to lens **72**, so that it will be continuously equalized with the ambient environmental pressure as a result of said ambient pressure being sensed by a pressure sensor **78**. Hence, when acoustical energy **79** emanating through sea water **81** from an underwater target **82** is received by lens **72**, the image thereof is not distorted enough due to a change in water temperature to adversely affect the indication thereof by readout **75**.

There are obviously numerous ways in which the system of FIG. **6** could be deployed, in order to search for targets. Hence, the way exemplified in said FIG. **6** is by means of a carrier vehicle **83**, which, of course, may be a marine vehicle, such as a boat, ship, submarine boat or vehicle, or the like. Thus, it should be understood that said system is disclosed merely as an example, rather than as a limitation.

FIG. **7** graphically displays the change of index of refraction effected upon a liquid lens electroacoustical transducer by a change in ambient temperature, both with and without the lens constituting this invention incorporated therein.

THEORY OF OPERATION

The index of refraction at the interface of an ultrasonic lens determines the focal length of the lens. In the case where the ultrasonic lens is a fluid lens having an acoustically clear membrane container operating within water, then the index of refraction, n, thereof is expressed by the equation:

$n = C_w/C_f$

where

C_w is the velocity of sound in water, and

C_f is the velocity of sound in the lens fluid.

It has been determined that the velocity of sound in water increases with an increase in temperature, and it has also been determined that the velocity of sound in most acoustical lens fluids decreases with an increase in temperature. Hence, experience has shown that only a few degrees temperature change of liquid lens electroacoustical transducers submerged in water ordinarily causes the index of refraction of the lens thereof to change enough to change the focal length thereof and thereby defocus the lens. Of cousre, such defocusing, in turn, causes acoustical image resolution to be deleteriously effected to the extent that, for most practical purposes, the fidelity thereof is poor. But, if another fluid is inserted between the transducer lens fluid and the water or other ambient medium as an interface fluid, and if said interface fluid is so selected as to cause it to tract the sound velocity variation with temperature of the lens fluid, the combination thereof becomes independent of temperature — and, to a considerable extent, the salinity of the ambient medium, in the event it happens to be sea water, or the like. It has been found that M-chloroanaline ($ClC_6H_4NH_2$) is an is an optimum selection for the interface fluid. When it is included within interface lens shell **35** in combination with a fluid having appropriate sound velocity-temperature characteristics in acoustical lens shell **11** in the lens assembly **51** of FIG. **4** and said lens assembly **51** is made a part of an electroacoustical transducer, the temperature compensation characteristics which result are depicted by line **91** of FIG. **7**. As may readily be seen therefrom, the index of refraction of the total lens changes approximately 0.06 or 3.8 percent from 10° to 50°C. This, of course, is a considerable improvement over the adverse index of refraction change that would occur in a transducer not incorporating the subject lens, the latter of which is shown to be about 0.29 or 19 percent by line **92** in FIG. **7**. As a matter of fact, said improvement has been theoretically calculated to be about a factor of seven — a significant improvement, indeed.

Moreover, as may readily be seen, this invention is an acoustical lens that is not defocused as a result of going from one environmental medium — such as, for example, fresh water — having a given acoustic velocity characteristic to another environmental medium — say, salt water — having a different acoustic velocity characteristic and vice versa.

MODE OF OPERATION

The operation of the invention will now be discussed briefly in conjunction with all of the figures of the drawing.

Perhaps the best representation of an operational system which could incorporate the subject invention to an advantage is depicted in FIG. **6**. Assuming an underwater target **82** has been acquired by lens **72** of electroacoustical transducer **72**, the sonic image thereof will pass therethrough and be focused on energy converter array **73** (in the manner similar to that exemplarily portrayed in FIG. **5**). Of course, because lens **72** is similar to that shown in FIG. **4**, any temperature variation encountered thereby is compensated within it. Thus, sonar **74** and readout **75** can properly process the image signals impinging on array **73** to thereby effect a visual image of the aforesaid acoustically acquired target. And, in addition, in the event pressure compensation is required as well — say during great water depth operations — the interface fluid within lens **72** may be regulated by the combination of components herewith defined as interface fluid supply **76**, pressure controller **77**, and pressure sensor **78**.

As a result of very little change of the index of refraction with change in the ambient water temperature within this invention, as previously indicated, the fidelity of the acquired image is considerably improved. Hence, any search-echo-ranging or other systems incorporating the subject lens may be rapidly moved through the water — and especially through sea water — in any direction without distorting the images of targets acquired thereby for most practical purposes. Hence, the subject lens makes a significant contribution to the advancement of lens used in sonar and other electroacoustical transducers.

Obviously, other embodiments and modifications of the subject invention will readily come to the mind of one skilled in the art having the benefit of the teachings presented in the foregoing description and the drawing. It is, therefore, to be understood that this invention is not to be limited thereto and that said modifications and embodiments are intended to be included within the scope of the appended claims.

What is claimed is:

1. An acoustical lens, comprising in combination:

a first open-ended cylinder;

a first acoustically clear wall integrally connected to one of the open ends of said first open-ended cylinder;

an aperture centrally located within and through said first acoustically clear wall;

a second acoustically clear wall, having a convexley curved configuration, integrally connected to said first acoustically clear wall around the periphery of said apertures;

a second cylinder telescopically mounted in a fluid tight manner on and extending from that end of said first cylinder which is connected to said first acoustically clear wall;

a third acoustically clear wall, having a first predetermined thickness near the periphery thereof and a second predetermined thickness that is less than said first predetermined thickness which forms a substantially circular acoustically clear window near the center thereof, integrally connected to the periphery of the extended end of said second cylinder in such manner as to be spatially disposed from said first acoustically clear wall and the larger curved surface of the aforesaid convexley curved second acoustically clear wall, thereby effecting a closed chamber therebetween; and

an interface fluid, having an index of refraction that varies in an inverse proportion with that of water over a predetermined range of temperatures, disposed within said closed chamber.

2. The device of claim **1** whrein said first, second, and third acoustically clear walls consist of a low density polyethylene material.

3. The device of claim **1** wherein said first acoustically clear wall has thickness of the order of 0.070 inches.

4. The device of claim **1** wherein said second acoustically clear wall, having a convexley curved configuration, integrally connected to said first acoustically clear wall around the periphery of said aperture comprises a hemispherical acoustical lens.

5. The device of claim **1,** wherein said second acoustically clear wall having a convexley curved configuration, integrally connected to said first acoustically clear wall around the periphery of said aperture comprises a low density polyethylene acoustical lens having a thickness of the order of 0.070 inches and a radius of curvature of such dimension as to refract acoustical energy passing therethrough and focus it at a spot having a predetermined focal length therefrom.

6. The device of claim **1,** wherein said third acoustically clear wall, having a first predetermined thickness near the periphery thereof and a second predetermined thickness that is less than said first predetermined thickness which forms a substantially circular acoustically clear window near the center thereof, integrally connected to the periphery of the extended one of said second cylinder in such manner as to be spatially disposed from said first acoustically clear wall and the larger curved surface of the aforesaid convexley curved second acoustically clear wall, thereby effecting a closed chamber therebetween, comprises an acoustical lens with the window portion thereof having a thickness of the order of 0.025 inches.

7. The device of claim **1,** wherein said interface fluid, having an index of refraction that varies in an inverse proportion with that of water over a predetermined range of temperatures, disposed within said closed chamber comprises $ClC_6H_4NH_2$.

8. The invention of claim **1,** further characterized by:

a groove extending around the inner surface periphery of said second cylinder; and

a resilient O-ring located in said groove in such manner as to be urged thereagainst and against the outer surface of said first cylinder, so as to thereby effect a fluid-tight seal therebetween.

9. The invention of claim **1,** further characterized by:

a threaded filler hole extending through the longitudinal wall of said second cylinder; and

a threaded plug screwed into the aforesaid filler hole.

10. The invention of claim **1,** further characterized by a fourth acoustically clear wall connected to the end of said first cylinder that is opposite said first and second acoustically clear walls in such manner as to effect another closed chamber therebetween within said first cylinder.

11. The invention of claim **10,** further characterized by an acoustical energy conducting and refracting fluid disposed within said another closed chamber.

12. The device of claim **11,** wherein said acoustical energy conducting fluid disposed within said another closed chamber comprises a fluid having predetermined sound velocity-temperature characteristics.

13. The invention of claim **1,** further characterized by:

a first flange connected to the outside diameter of said first cylinder at the end thereof opposite said first and second acoustically clear walls;

a first plurality of bolt holes extending through and around said first flange, the axes of which are parallel to each other and to the longitudinal axis of said first cylinder;

a second flange connected to the outside diameter of said second cylinder at the end thereof opposite said third acoustically clear wall; and

a second plurality of bolt holes of like number as said first plurality of bolt holes extending through and around said second flange, the axes of which are parallel to each other and the longitudinal axis of said second cylinder, and the axes of which are respectively in alignment with the axes of the aforesaid first plurality of bolt holes.

14. The invention of claim **13,** further characterized by means respectively extending through said first and second pluralities of bolt holes for the securing of said first and second flanges in a fixed relationship together.

15. The invention of claim **13,** further characterized by means respectively extending through said first and second pluralities of bolt holes for securing said first and second flanges in fixed relationship together and to the housing of an electroacoustical transducer.

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