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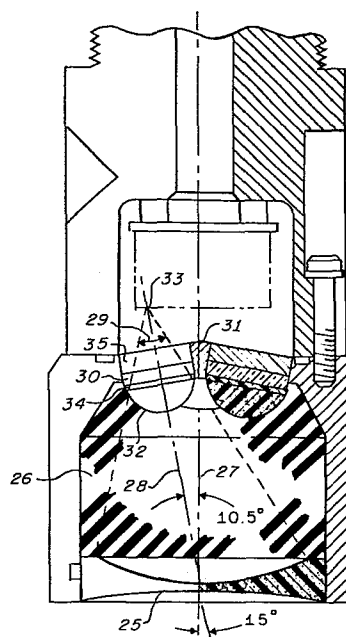
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Bulletin 84/27(72) Inventor: **Kritz, Jacob Abraham, 692 Sherman Court, Westbury New York 11590 (US)**(84) Designated Contracting States: **DE FR GB IT NL SE**(74) Representative: **Singleton, Jeffrey et al, Eric Potter & Clarkson 5 Market Way Broad Street, Reading Berkshire, RG1 2BN (GB)**(54) **Multiple beam lens transducer with collimator for sonar systems.**

(57) A compact apparatus for transmitting and receiving multiple sonar beams utilises an acoustic lens (25) to direct plane waves incident in desired directions to collimating lenses (32) for presentation in phase to electroacoustic transducers (30) having planar surfaces. The electroacoustic transducers (30) emit sound waves which are transformed by the lenses (32) into plane waves emergent in the desired directions.



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MULTIPLE BEAM LENS TRANSDUCER WITH  
COLLIMATOR FOR SONAR SYSTEMS

The present invention relates generally to  
electroacoustic transducers employed in sonar systems,  
and more particularly to an electroacoustic transducer  
capable of accommodating multiple sonar beams which  
5 utilises collimating acoustic lenses.

Sonar systems utilise narrow beams of sound energy  
projected in certain desired directions from a marine  
vehicle, and receive reflected energy from these  
directions, as described, for example, in U.S. Patent  
10 Specification No.3,257,638. Conventionally, these beams  
are produced by vibrating piezoelectric discs having  
diameters which are large compared to the wavelength of  
the sound wave propagated or to be received. When  
multiple beams are utilised, the transducer assembly must  
15 be enlarged to accommodate the multiplicity of necessary  
elements. Multiple beam transducers of the prior art  
create installation difficulties, particularly on small  
ships, and provoke increased installation costs due to  
the necessity for larger gate valves and stronger  
20 structural supports. Thus, there is a need for  
relatively compact multiple beam transducers which will  
facilitate installation and mitigate attendant costs.

European Patent Specification No.0,088,569  
discloses a compact apparatus for transmitting and  
25 receiving multiple sonar beams. An acoustic lens directs  
plane waves incident in desired directions to  
electroacoustic transducers disposed in spherical shell  
segments centred in the focal regions of the lens  
associated with the incident beams. The electroacoustic  
30 transducers transmit spherical waves which are  
transformed by the acoustic lens to plane waves emergent  
in the desired directions. The manufacture of this  
transducer entails some difficulty and expense resulting  
from the need to fabricate piezoceramic crystal elements  
35 in the form of spherical shell segments.

An object of the invention is to maintain the compact configuration of the above-mentioned co-pending application whilst eliminating the need for electroacoustic transducers in the shape of spherical  
5 shell segments.

The invention is defined in the appended claims and a sonar transducer embodying the principles of the present invention includes means for converting incident plane sound waves to sound waves that converge at a focal  
10 region in the focal surface thereof. Plane waves incident in different predetermined directions are converged to different focal regions. Sound waves emitted from the focal regions are converted to plane sound waves which are radiated in these predetermined  
15 directions. Electroacoustic transducers having planar surfaces may be employed for receiving and transmitting sound waves and means for presenting the focused sound waves in phase at the planar surfaces of the transducers may be provided. Sound waves emitted by the planar  
20 surfaces of the transducers are converted to diverging beams which are radiated as plane waves in the predetermined directions.

A preferred embodiment of the invention comprises a doubly concave acoustic lens which focuses plane waves  
25 incident from a plurality of predetermined directions to a plurality of focal regions in corresponding relationship with the incident directions. A medium of silicone rubber is bonded to the inner surface of the lens. The low speed of sound in rubber produces a short  
30 focal length, thus diminishing assembly depth. Acoustic lenses having spherical surfaces are positioned to collimate the focused sound waves to provide plane waves at the planar surface of three piezoelectric ceramic crystal transducers. Positioned between the collimating  
35 lenses and the planar surfaces of the transducers are epoxy matching sections. A matching section provides favourable electrical characteristics when measured at

the electrical terminal of a crystal by transforming the low acoustic impedance of a collimating lens to a higher value for presentation to the crystal. Aluminium backing plates are positioned behind the transducers. The

5 backing plates provide both structural strength and heat transport or conduction for the crystals. The planar surfaces of the transducers are positioned to receive and transmit beams which are each inclined  $15^{\circ}$  from the central axis of the doubly concave lens.

10 Apparatus in accordance with the invention for transmitting and receiving a plurality of sonar beams will now be described in greater detail, by way of example, with reference to the accompanying drawings in which:-

15 Figure 1 is a schematic diagram of a doubly concave acoustic lens, an electroacoustic transducer having a planar surface, and a collimating acoustic lens disposed therebetween, with a superposed ray diagram illustrating the action of the lenses,

20 Figure 2 is a schematic diagram of a ray impinging upon a collimating acoustic lens used for calculating the curvature of the lens, and

Figure 3 is a cross-sectional view of a preferred embodiment of the invention.

25 Identical numerals in different figures correspond to identical elements.

The invention is concerned with the construction of a multiple beam transducer with a single aperture in the form of an acoustic lens which provides the required  
30 aperture to wavelength ratio. A ray diagram depicting the focusing action of the acoustic lens is shown in Figure 1. Parallel rays of incident plane wave 10, propagating in water medium 11, impinge on an acoustic lens 12. To focus an incident plane wave, the acoustic  
35 lens 12 is chosen doubly concave and constructed of a medium in which the velocity of sound is greater than that in water 11 and an adjacent medium 13. The focusing action results from the beam being first bent away from

the normal to the surface of the lower refractive index lens 12 as it enters the lens, and then upon emergence from the lens, being bent towards the normal.

Accordingly, incident plane sound wave 10 is focused to a focal point 14 by the lens 12. Conversely, a point source at 14 radiating lens 12 with a sound wave will cause the projection of a plane wave depicted by the parallel rays 10. Characteristic of a lens constructed in this fashion is a unique correspondence between the direction of incidence of a plane wave, and the associated focal point in the focal plane of the lens. Simply, collimated beams incident from different directions have different focal points. For example, the plane wave represented by parallel rays 15 will be focused at a second focal point 16. Thus a multiplicity of such focal points lie in a focal plane 16a of the lens 12, each focal point defining a different beam direction for reception or projection of sound waves. A multiplicity of small electroacoustic transducers placed at different focal points can then be used to transmit and receive sound beams such that the beam width is characterised by the lens diameter.

A major deterrent to the implementation of such an arrangement is the inability of the small transducers to operate at significant power levels. The sound intensity (watts per unit area) in the medium 13 in the vicinity of a transducer is intense because of the small transducer surface area, causing cavitation and disruption of the medium. In addition, heat dissipation produced by transducer losses is confined to the small transducer surface, thus causing high temperatures to be generated if significant electrical power is supplied. The present invention utilises larger transducers having significantly larger surface areas and which are placed forwardly of the focal points. An electroacoustic transducer 17, having a planar surface 18 for receiving and transmitting waves, is disposed between the focal point 14 and the lens 12. A lens 19, disposed between

the electroacoustic transducer 17 and the lens 12, presents rays in phase to the surface 18 of the electroacoustic transducer 17. The lens 19 achieves this by refracting the converging rays and directing them perpendicular to the planar surface 18 of the electroacoustic transducer 17. The material of the lens 19 possesses a sound velocity greater than that of the medium 13, and a specific acoustic impedance preferably near that of the medium 13 in order to minimise unwanted reflections. With this arrangement, substantially all the acoustic energy received by the lens 12 is thus available for conversion to electrical energy by the electroacoustic transducer 17. Conversely, when transmitting, the transducer 17 in conjunction with the lens 19 projects rays as though the focal point 14 were the source. An advantage obtained by this arrangement is that small changes in the position of the focal point do not cause drastic changes in performance since all rays are still intercepted by the transducer 17 with only slight out of phase interference. With small transducer elements disposed directly at the focal points, small changes in focal point location can precipitate large changes in the captured energy. As a further advantage, the depth of the entire apparatus is reduced, since the apparatus need not extend behind the lens 12, in the medium 13, to the focal plane.

The curvature of the lens 19 required to present the rays in phase to the planar surface 18 of the electroacoustic transducer 17 may be determined with the aid of Figure 2. A ray 20 directed towards the focal point 14 impinges on the surface of the lens 19. Absent the lens 19, and the ray 20 would travel through the medium 13, whose propagation speed is  $C_M$ , a distance R to the focal point 14. With lens 19 present, the ray 20 travels through the lens medium, whose propagation speed is C, a distance X to Y axis 21 drawn through focal point 14. For all the rays refracted by lens 19 to arrive at the Y axis 21 in phase, the propagation time

( $t_m$ ) that would have been experienced in the medium 13 by an individual ray, if the lens 19 were not present, must be equal to the time ( $t_L$ ) taken by that ray to traverse the lens material, plus an additive constant  $k$ .

Accordingly,

$$t_m = \frac{R}{c_m} = t_L + k = \frac{X}{c_L} + k$$

Thus,

$$\left(\frac{R}{c_m}\right)^2 = \left(\frac{X}{c_L} + k\right)^2 = \left(\frac{1}{c_L} (X + c_L k)\right)^2$$

By the pythagorean theorem  $R^2 = X^2 + Y^2$ , so that

$$\frac{R^2}{c_m^2} = \frac{X^2 + Y^2}{c_m^2} = \frac{1}{c_L^2} (X + c_L k)^2 \text{ and}$$

$$X^2 + Y^2 = \left(\frac{c_m}{c_L}\right)^2 (X + c_L k)^2.$$

This is the well-known equation for a conic with eccentricity equal to  $\frac{c_m}{c_L}$  and a directrix equal to  $c_L k$ . Since the material of the lens 19 has a higher propagation velocity than the medium 13,  $\frac{c_m}{c_L}$  is less than one and, therefore, the curve is an ellipse.

The elliptical shape of the lens 19 may be approximated by a sphere whose radius is selected to provide the best fit over the region of interest.

A typical design embodying the invention is shown in Figure 3. A solid lens 25, of syntactic foam, 6.75 inches (17.15cm) in diameter, 0.376 inches (0.96cm) centre thickness, with internal radius 7.18 inches (18.24cms) and external radius 23.82 inches (60.5cms) is in contact with water on its outer surface and bonded on its inner surface to a medium 26 of silicone rubber. The arrangement shown provides for three transmitting or receiving beams each oriented in the water  $15^\circ$  off a central axis 27 of the lens 25. The low speed of sound in rubber produces a short focal length 28 of 10.91 inches (27.71cms) thus diminishing the assembly depth. The subtended angle 29 is  $33^\circ$ .

Each of three piezoelectric ceramic crystals 30 has a planar surface for receiving and transmitting beams, and each crystal has a diameter of 2.5 inches (6.35cms) and is disposed  $10.5^{\circ}$  off the central axis 27 of the lens 25. The crystals are each of such a thickness that they resonate at 122 kHz, and are bonded to a metal support 31. Collimating lenses 32 comprised of the same syntactic foam material as lens 25 and associated with respective crystals 30, collimate the rays of a focused beam for presentation to the planar surface of the related crystal. The elliptical surface of each collimating lens 32 is approximated by a spherical surface of radius 2.15 inches (5.46cms) centred 1.85 inches (4.7cms) forwardly of the related focal point 33. Interposed between each crystal 30 and its associated collimating lens 32 is a plastic matching section 34 preferably comprised of epoxy. Each matching section has a diameter of 2.5 inches (6.35cms) and has a thickness of 0.21 inches (0.53cms) equal to an odd multiple of a quarter wavelength, in this embodiment a quarter wavelength. The matching section 34 provides favourable electrical characteristics when measured at the electrical terminals of a crystal 30 by transforming a low acoustic impedance to a higher value for presentation to the crystal. The section 34 creates an acoustic impedance match between a crystal 30 and its collimating lens 32. Essentially two purposes are served by the matching section 34: it broadens bandwidth, and it increases efficiency of the transducer (see The Effect of Backing and Matching on the Performance of Piezoelectric Ceramic Transducers, by George Kossoff, I.E.E.E. Transactions on Sonics and Ultrasonics, Volume SU-13, No. 1, March 1966) Disposed on the surface of each crystal opposite the receiving surface is a metallic backing plate 35, preferably aluminium, having a diameter of 2.5 inches (6.35cms) and thickness an integral multiple of a half wavelength, in this case 1.02 inches (2.59cms). The backing plate 35

provides both structural strength and heat transport or sink for the crystals 30 and is essentially transparent at the operating frequency. The transparency, that is the negligible effect upon the transmission of acoustic waves, follows from the standard sound transmission coefficient formula for waves traversing two boundaries (see, for example, Fundamentals of Acoustics, page 149 to 153, by Kinsler and Frey, Wiley, 1950). If only heat conduction is desired from the backing plate 35, it may be made thinner. The plate 35 may alternatively be positioned in contact with the receiving and transmitting surface of a crystal 30, whereby a matching section may then be utilised between the plate and a collimating lens to provide an acoustic impedance match between the plate and the lens.

Since a collimating lens has been constructed (see Figure 2) such that rays traversing its medium are in phase at the Y axis 21. the rays are necessarily in phase in the medium at any line parallel to the Y axis 21. Accordingly, rays immediately emerging from the planar surface of a lens are in phase, and remain so as they pass through mediums of uniform thickness en route to the planar surface of a crystal.

CLAIMS

1. Apparatus for transmitting and receiving a plurality of sonar beams characterised in that it comprises lens means (25) having a central axis (27) for converting incident plane sound waves to sound waves  
5 which converge at a focal region in the focal surface thereof such that plane waves incident in different predetermined directions converge to different focal regions, and for converting sound waves emitted from said focal regions to plane sound waves radiating from said  
10 lens means in said predetermined directions; a plurality of electroacoustic transducers (30) having planar surfaces for receiving and transmitting sound waves; and in-phase means (32) for presenting rays of sound waves in phase to the planar surfaces of the electroacoustic  
15 transducers (30) the rays deriving from the sound waves produced by the focusing action of the lens means (25) on the plane waves incident on the lens means in the predetermined directions, and for transforming sound waves emitted by the planar surfaces of the  
20 electroacoustic transducers (30) to sound waves which are converted by the lens means (25) to the plane sound waves radiated in the predetermined directions.

2. Apparatus according to claim 1, characterised in that lens means comprises a doubly concave acoustic lens  
25 (25) constructed of a material with an acoustic propagating velocity which is greater than the acoustic propagating velocity of water; and an acoustic propagating medium (26) having an acoustic propagating velocity which is less than the acoustic propagating  
30 velocity of the lens material, positioned between the lens and the in-phase means (32).

3. Apparatus according to claim 1 or 2, characterised in that the in-phase means comprises a plurality of collimating acoustic lenses (32) which substantially  
35 collimate rays of the sound waves produced by the focusing action of the lens means (25) on the plane waves incident on the lens means in the predetermined

directions, the substantially collimated rays being substantially perpendicular to the planar surfaces of the electroacoustic transducers (30).

4. Apparatus according to claim 3, characterised in that the in-phase means further comprises matching means (34) positioned between the electroacoustic transducers (30) and the collimating acoustic lenses (32) for providing an acoustic impedance match between the electroacoustic transducers and the collimating acoustic lenses.

5. Apparatus according to claim 3 or 4, characterised in that it further comprises backing plate means (35) positioned adjacent the surfaces of the transducers (30) opposite the planar surfaces for transmitting acoustic signals, conducting heat, and providing structural strength.

6. Apparatus according to claim 3, characterised in that the in-phase means further comprises window means, positioned between the electroacoustic transducers (30) and the collimating acoustic lenses (32), for transmitting acoustic signals, conducting heat, and providing structural strength; and matching means, positioned between the window means and the collimating acoustic lenses (32), for providing an acoustic impedance match between the window means and the collimating acoustic lenses.

7. Apparatus according to any of claims 3 to 6, characterised in that the collimating acoustic lenses (32) comprise elliptical surfaces facing the doubly concave acoustic lens (25), and planar surfaces facing, and being disposed parallel to the planar surfaces of the electroacoustic transducers (30).

8. Apparatus according to any of claims 3 to 6, characterised in that the collimating acoustic lenses (32) comprise spherical surfaces facing the doubly concave acoustic lens, and the planar surfaces facing, and being disposed parallel to the planar surfaces of the electroacoustic transducers.

9. Apparatus according to claim 5 and any claims appended thereto, characterised in that the transducers (30) comprise cylinders, the matching means (34) comprises cylinders having a thickness that is an odd multiple of a quarter wavelength of an incident sound wave, and the backing plate means (35) comprises cylinders having a thickness that is an integral multiple of a half wavelength of the incident sound wave.
10. Apparatus according to claim 6 and any claim appended thereto, characterised in that the electroacoustic transducers (30) comprise cylinders, the window means comprises cylinders having a thickness that is an integral multiple of a half wavelength of an incident sound wave, and the matching means comprises cylinders having a thickness that is an odd multiple of a quarter wavelength of said incident sound wave.
11. Apparatus according to any of the preceding claims, characterised in that the electroacoustic transducers comprise three piezoelectric ceramic crystals (30) each inclined  $10.5^{\circ}$  from the central axis of the lens means (25).

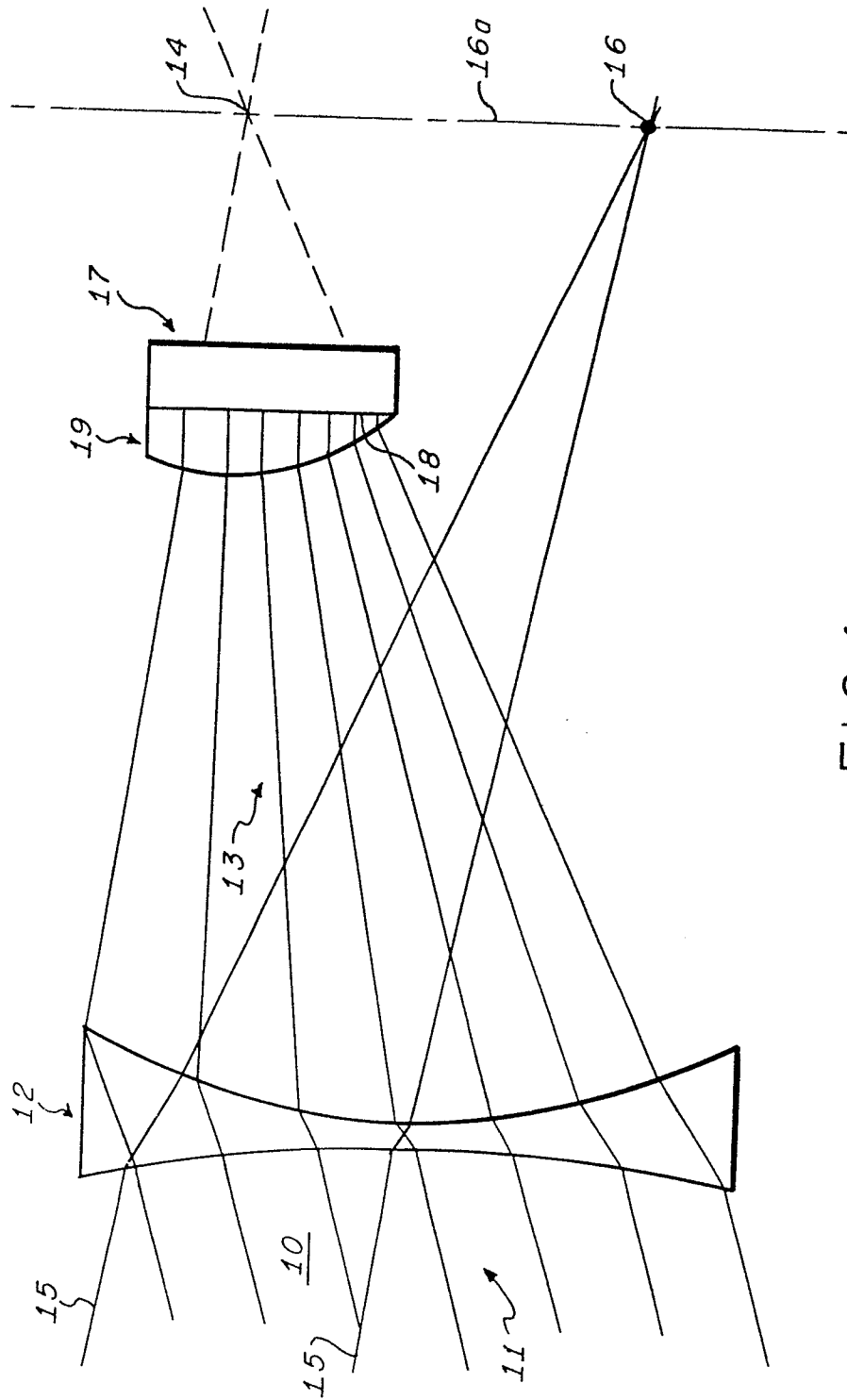


FIG. 1.

