A simple form of construction for multi-element arrays

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1. Introduction

There is a need in marine and freshwater fisheries research for lightweight and compact 300 kHz multi-element transducer arrays. To give adequate angular resolution and be compatible with an electronic sector scanning sonar system already built, a transducer was designed consisting of two 15-element receiving arrays each giving an angular resolution of 1½° x 10° and two identical transmitting arrays each giving a 25° x 5° beam. The arrays are mounted perpendicular to one another to allow the illumination and scanning of volumes of water in two planes. The transducer is for use either in a small boat as a portable unit, mounted on a hand trained pole for fish tracking exercises in lakes or estuaries or as part of a system for observing current meter stations (1) where it is needed to check the position of the subsurface float. For the latter use the transducer is mounted on a carriage together with other equipment and lowered down an instrumentation tube on the research vessel. In either case the transducer has to be as compact and as light as possible and be capable of use in conjunction with acoustic transponders (2).

2. The initial design approach

Our previous experience in the 300 kHz transducer field has been with large arrays mounted in castor oil-filled aluminium bronze housings with an acoustic window of natural or synthetic rubber (3). However, this method of construction or the alternative encapsulation method, pioneered by Loughborough University of Technology (4), would have resulted in a unit too large for the space allowed, so a new construction method was sought.

Some experiments with polycarbonate sheet have resulted in this being used successfully as an acoustic window material on a large array. It was thus thought that this may be a suitable material for a lightweight housing (see Table 1).

Table 1 Properties of Lexan 9030 polycarbonate

Ultimate tensile strength (kg m^{-2})	6.7×10^6
Compressive strength (kg m^{-2})	8.8×10^6
Flexural strength (kg m^{-2})	9.5×10^6
Modulus of Elasticity (kg m^{-2})	2.2×10^8-2.4×10^8
Elongation at break (%)	110
Specific gravity	1.2
Poissons ratio	0.37

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A problem with high frequency arrays has always been the availability of suitable pressure release or backing material for the transducer elements and also the interelement decoupling material (3). Since polycarbonate sheet has good mechanical and acoustic properties it was decided to use this also as the front face material. Mounting the elements on this directly gives an air backed and spaced array, thus eliminating the aforementioned problems.

3. First experiments

Using the formula $c = \sqrt{\dfrac{E(1-\sigma)}{\rho(1-2\sigma)(1+\sigma)}}$,

where c = speed of sound

E = modulus of elasticity

ρ = density

σ = Poissons ratio,

the speed of sound in polycarbonate was estimated to be between 1800 and 1900 m s^{-1}. This was also measured acoustically using an ultrasonic thickness measuring instrument by comparing the transmission of sound along a known path length in polycarbonate with a similar path length in water. The result was between 1900 and 2000 m s^{-1}.

Hence at 300 kHz the wavelength (λ) of sound in polycarbonate lies between 6 and 7 mm. To find the required front face dimension for the array a test piece of varying thicknesses was made up (Fig. 1). An acrylic adhesive was used to attach all elements except element 6 which was attached with flexible epoxy. Slots were machined between elements 3, 4 and 5 to enable coupling tests to be made. For the acrylic adhesive mounted elements the results were as follows:

3.1 The resonant frequency in air of the polycarbonate-ceramic combination rose slightly in all cases except the 2 and 6 mm thicknesses.

3.2 The cross talk between adjacent elements was noticeably higher for those with no slots, and the 2 mm deep slot was 5 dB better in water than the 1 mm deep slot.

3.3 The electrical conductance was lowest for the 6 mm thickness (0.65 ms) and highest for the 4 mm thickness (0.85 ms).

3.4 Tank tests on each element or array with a hydrophone as sensor showed that the highest power was transmitted into the water by the 2 and 6 mm thicknesses, the lowest by the 4 mm (5 dB less) and 2 dB less by the 7.5 mm thickness. Another method used to test power transfer through the polycarbonate was to cover the face of the test piece with a thin layer of water and to excite the element under test with a carrier wave of sufficient power to cause a fountain at its resonant frequency. The height of this indicated the amount of power transferred.

3.5 A prolonged life test at a power level of 60 W cm^{-2} at a PRF of 10 s^{-1} and pulse length of 500 μs, equivalent to six months' use, was made and after this the elements were tested for bond strength. It was found that all had to be hammered off the face plate leaving parts of the ceramic behind.

3.6 One drawback of using polycarbonate was found on building up the first test pieces. Within 24 hours of attaching the ceramic, when the adhesive had reached its full strength, stress cracks appeared in the machined surfaces. This was thought to be due to overheating the material when machining. A series of test pieces were consequently machined with the milling tool being cooled by compressed air: half of the test pieces were stress relieved after machining by heating to 120°C. A combination of glues and initiator with and without ceramic pieces were tried but the previous problem did not arise so it was thus thought safe to make a second test piece using compressed air as a coolant.

It is worth recording that the flexible epoxy adhesive was unsuitable, although the bond appeared to be strong initially. The conductance was high at 2.5 ms and the power transmitted to the water 9 dB less than the best acrylic both of which indicated losses in the adhesive. After the life tests the bond had been weakened by the power dissipation and the element was easily removed from the polycarbonate.

4. Second experiment

A test piece consisting of two arrays was made. The thicknesses chosen were (a) 7 mm, which meant less machining and therefore less risk of stress (b) 6 mm, since this together with the 2 mm thickness was the optimum from the previous experiment. (The 2 mm thickness was thought to be impractical). Isolation slots of 2 and 1 mm depth were machined between the elements. The results of tests on these arrays confirmed the previous work. The 6 mm thick array was some 5 dB better than the 7 mm on transmission and reception, and the 2 mm slots were 6 dB better than the 1 mm slots for cross talk reduction. The final design was a 6 mm thick face with 2 mm deep isolating slots between the element and around the arrays.

5. Construction of final array

The two receiver arrays scan at 90° with respect to one another, (Fig. 2). These are wired separately and switched at the receiver.

To give the required source level the two transmitting arrays consist of three staves of three elements in line, with the outer staves inclined at 10° to the axis of the centre stave to give a fan beam of approximately 25° by 4°. No isolating slots are machined between the elements, thus preserving mechanical strength, and the fact that the material thickness tapers on the two outer banks is ignored as there was no time to investigate its effect prior to the trials cruise.

The face plate is made of sufficient thickness to allow the fixing screws to be recessed and consequently the amount of machining for the transducer array faces was considerable. This was done with extreme care, using new cutting tools at a high cutting speed and compressed air cooling. After attaching the face connection the ceramic elements were precisely positioned and fixed down individually with uniform pressure and clamped until the adhesive had gained strength. Any adhesive that had entered the isolating slot was carefully removed before releasing the clamp.

It has been estimated that a set of arrays including internal connections, external cabling and case can be made in 10 man/days.

This particular prototype has an anodized aluminium case for test purposes but it is envisaged that a polycarbonate case with a top mounting point and printed circuit connectors would reduce the face to back dimensions to 30 mm.

6. The performance at sea

Trials took place on Cruise 13/78 of the MAFF Research Vessel CLIONE. The transducer performed well; passive targets could be detected out to 300 m range. The receiving arrays showed no sign of excessive sidelobe level. The transmitting arrays could be pulsed separately or jointly without ill effect and gave a source level of 211 dB/µPa/m which enabled a transponder to be triggered at 350 m range. It was possible to identify the return signal from the transponder and measure its position in the water column relative to the sea bed (the aim of the trial) to an accuracy of 3 m at 250 m range. Sea-bed features could also be observed and large single passive targets, such as the anchor, identified at ranges of 150 m.

7. Laboratory tests

After the cruise further tests were made in the laboratory tank.

7.1 Receiving array: Admittance tests gave an efficiency of over 90%. The inter-element coupling was -25 dB in air and -40 dB in water (Fig. 3). The beam pattern on a single element as a projector (Fig. 4) showed a main lobe of 30^{o} as predicted from theory, with sidelobes -13 dB relative to the main but a complex lobe of 30^{o} rather than the theoretical single lobe of 15^{o}. This test was repeated with the element as a receiver and the pattern confirmed. The beam pattern for a seven-element array was much closer to the theoretical than that of the single element (Fig. 5). It was concluded that the receiver array did not require further development for the present applications.

7.2 Transmitting array: The beam pattern in the curved plane (Fig. 6) was rather narrow on the main lobe and appeared to be more closely allied to a 34 mm flat array. The overall coverage of the main lobe was 25^{o} between zeros.

In the flat plane of the array (Fig. 7) the beam pattern was close to that predicted but the sidelobe level was high. Further development is therefore proceeding on this array to improve the beam pattern but the amount of ceramic will not be reduced owing to the source level required and the front face will be flat if possible.

8. Comments

No attempt has been made to analyse the results of the first experiment in terms of wavelengths or resonances in the material although it can be surmised that the 6 mm of polycarbonate, plus adhesive, gives a good impedance match to the water. The aim was to produce an array quickly with the minimum of effort and expense: the entire project to be completed in seven weeks.

The construction method described is simple in principle but more sophisticated transducers could be produced. For example, an array can be built on a flat sheet of material which is then flexed by mechanical means to produce either a variable beam width sonar or a focussed array. Complete housings in moulded polycarbonate could also be produced cheaply with little or no machining. These would have the advantages of being light, durable, unaffected by salt or fresh water and, if in transparent material, easily inspected during maintenance periods. Polycarbonate is readily available from many suppliers and low in price compared with more conventional materials of similar strength and corrosion resistance.

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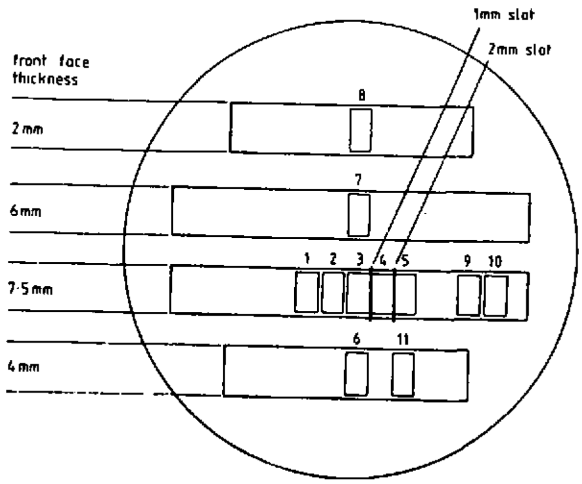

Figure 1 First test piece.

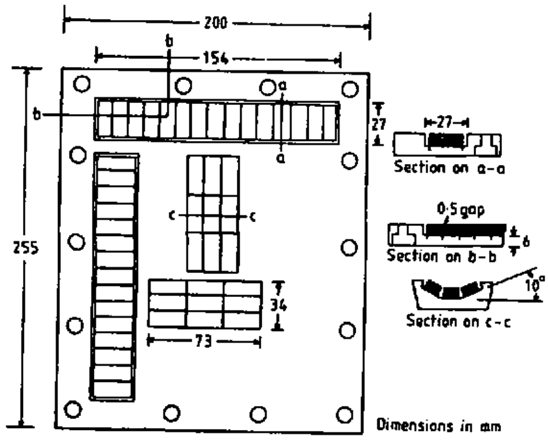

Figure 2 Final array construction.

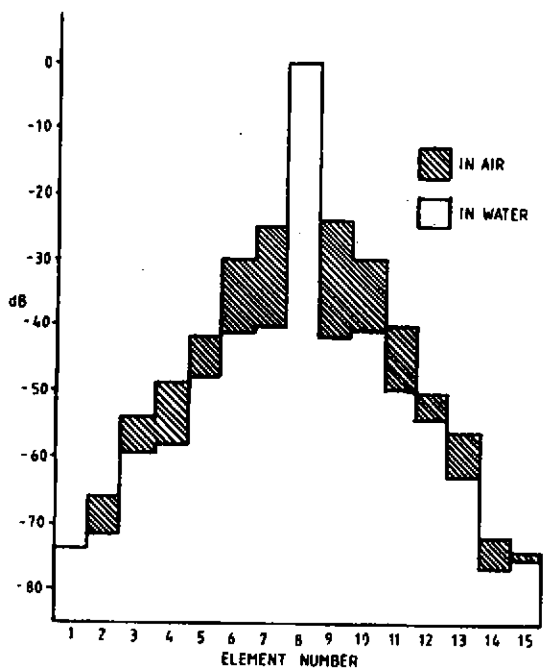

Figure 3 Receiver inter-element coupling.

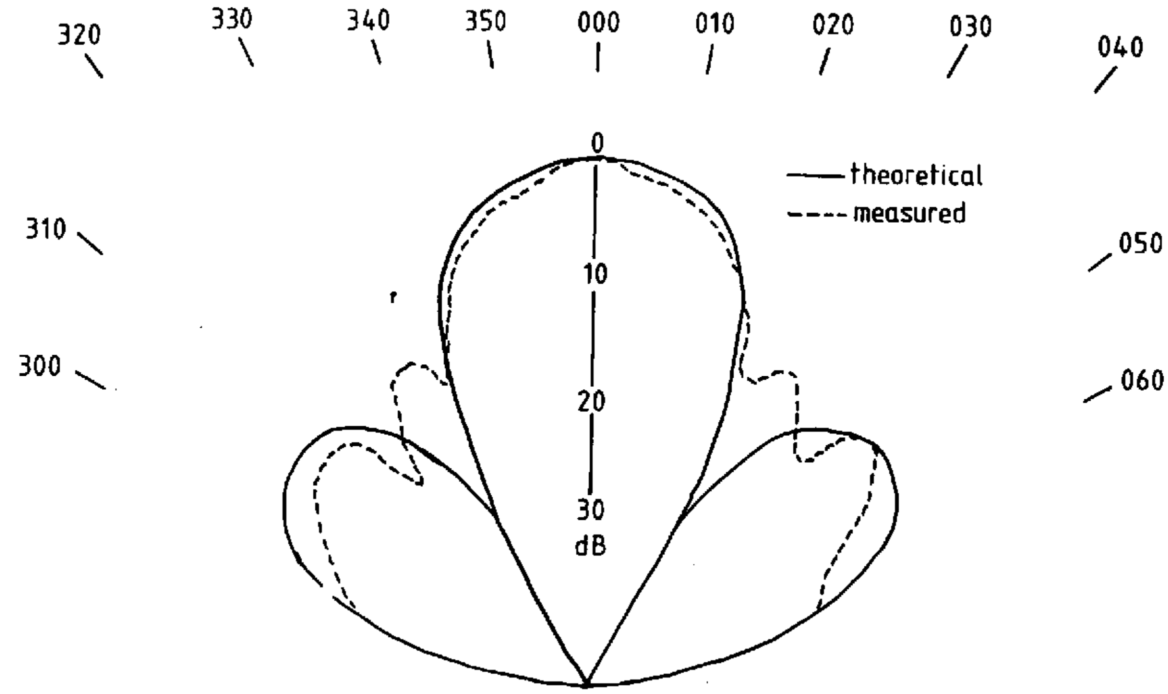

Figure 4 Beam pattern of single receiver element.

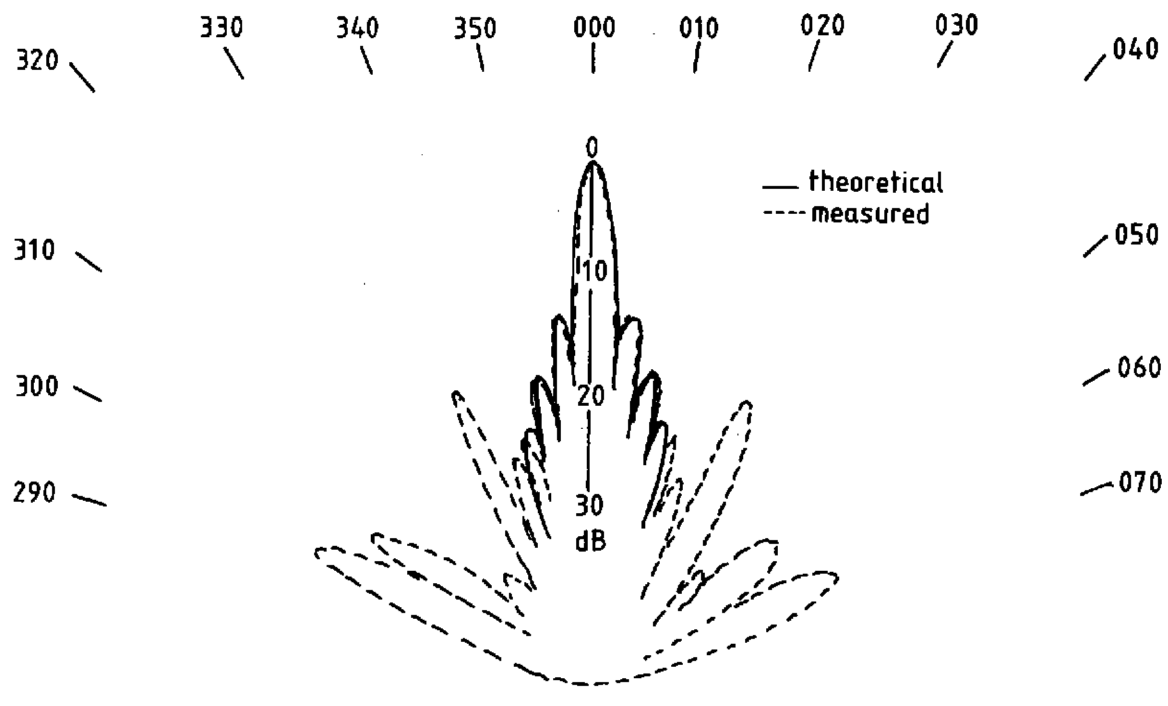

Figure 5 Beam pattern of seven element receiver array.

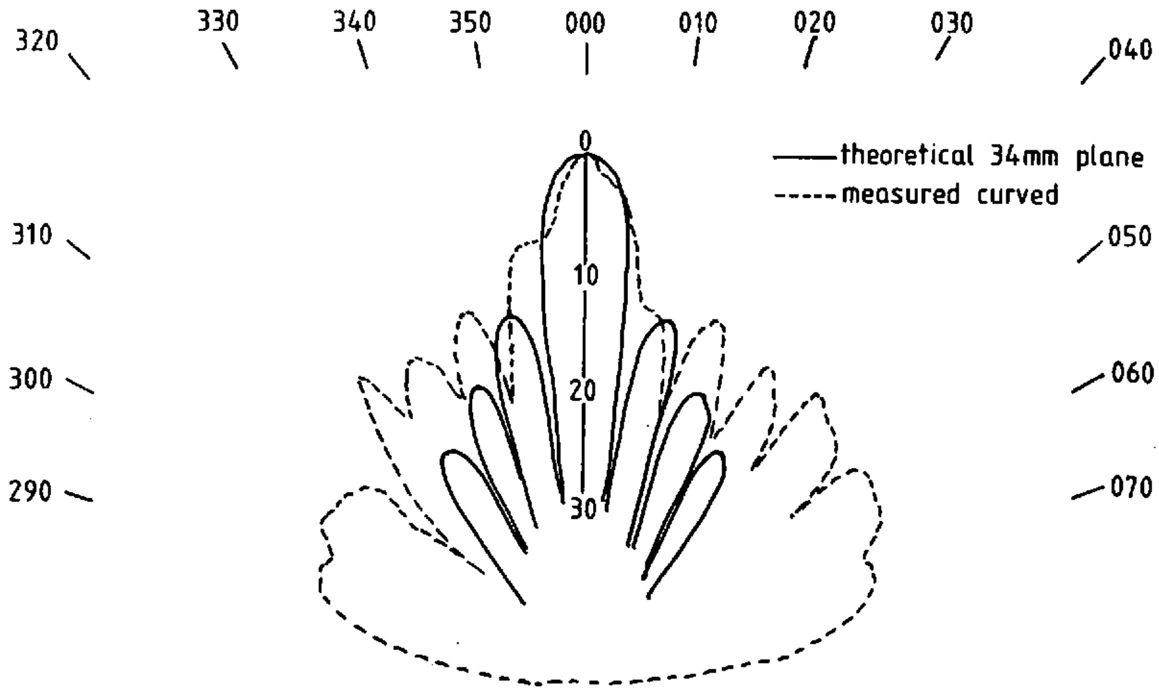

Figure 6 Beam pattern of transmitter curved plane.

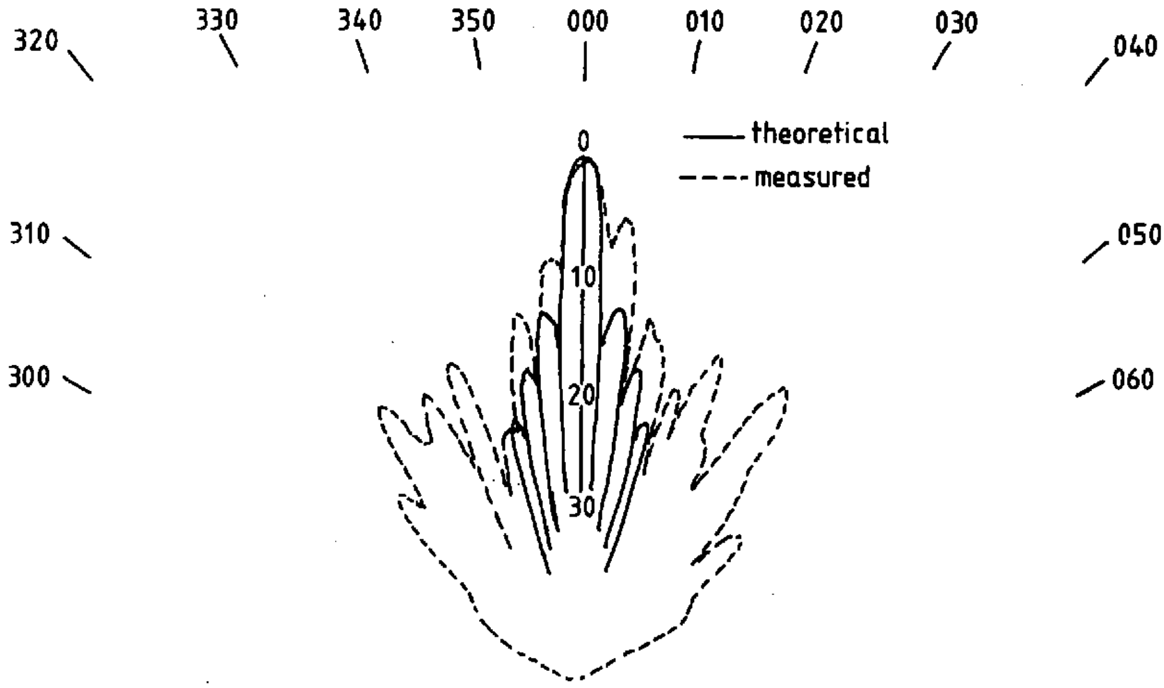

Figure 7 Beam pattern of transmitter flat plane.