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A 75 kHz TRANSDUCER USING TRANSVERSE DRIVE

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1.0 The specification for the array

A transducer array was required for an active system which was to be used for the tracking of fish carrying transponding tags. These tags are triggered on the receipt of a pulse at 73 kHz and reply on 76 kHz; free-running pinger tags are also used, which transmit on 77.5 kHz. The array was therefore designed for a centre frequency of 75 kHz, with a target for the bandwidth of at least 5 kHz. It was considered to be easier to make all the sections resonant at the same frequency, rather than to have a separate section for the transmitter. In the latter case a narrower bandwidth would have been acceptable, since the pulse duration is relatively long (2.4 msec. for transponders, 1.5 msec. for pingers).

The system measures range in the transponding mode in the conventional manner by the time delay between transmission and reception, and bearing in the horizontal plane by the phase difference between the signals arriving at a pair of receiving elements. So that there is no ambiguity within the 180° sector in front of the array, one pair of receivers must be spaced half a wavelength apart centre to centre; for reliable and sufficient resolution in bearing, specified as 10° or better over the whole sector, a pair spaced two wavelengths centre to centre is also needed. In the original design of the signal processor a pair spaced one wavelength was also needed, but in the final version this was discarded. Thus the system design called for a line array of five elements, spaced at intervals of half a wavelength, the centre one being used for transmission and one next to the centre being in fact redundant. A good vertical coverage is required, and so each element was made a nominal half wavelength (10 mm) square.

The intended maximum working depth is only 2 to 3m. for operation on a small boat, so there were no great problems in providing adequate mechanical strength. However there was a significant constraint on the design, in that the inter-element acoustic coupling must be low, since high coupling could lead to errors in the measurement of the relative phase between the acoustic signals arriving at a pair of elements. The design of the signal processor is such that the final accuracy depends only on the electrical signals from the pair of elements with the widest spacing, and the pair with the narrowest spacing is used only to resolve the ambiguities between the four sectors in 180° for which the phase derived from the two-wavelength pair is repeated. In this way the performance is not critically dependent on very low coupling between adjacent elements, and it is to be expected that the coupling between the widest spaced elements should be the least.

2.0 Design considerations

2.1 The basic design

The working frequency in this application is in a somewhat difficult region. For frequencies below about 60 kHz the preferred type of transducer is the 'sandwich' element, generally with a circular cross-section and consisting of piezo-electric rings in the centre and metal head and tail pieces. A wide range of characteristics may be obtained by a suitable choice of materials and their relative proportions, in particular making the rings smaller in cross-section than the head and tail leads to wider bandwidths. Such an element is most conveniently mounted within a cylindrical housing by an 'O' ring round the head. To meet the present requirement the diameter of the head would have to be less than 10 mm., i.e. half a wavelength at 75 kHz, and with this small size the elements would be difficult to make and mount. A modified technique which is used successfully for transducers working at 80 to 100 kHz is to machine the heads for several elements out of the same piece of metal, so that each head is continuous with the mounting; it may be either within its own cavity (1) or one of a closely spaced group. The former is difficult and expensive to make, and the latter would lead to excessively high inter-element coupling, although in other respects it would be highly recommended. Constant cross-section sandwich elements of a simpler construction without a pre-stressing bolt were also considered, but there were doubts about the reliability of the bonds; these could have been mounted in the same way as the elements actually used. For all these reasons, and because there were no demanding requirements in the specification for the individual elements, the sandwich construction was rejected in favour of simple pieces of ceramic.

Conventional simple piezo-electric ceramic transducers for high frequencies are most frequently poled and driven in the same axis as the wanted mechanical vibration, but the thickness for resonance at 75 kHz is about 23 mm. for PZT-4. This is too great for poling, since the voltage necessary is impracticably large (of the order of 100 KV). A more practical scheme is to use a side-electroded bar, in which the thickness is chosen as suitable for poling and the length is limited by mechanical, not electrical, difficulties in the manufacture of the basic ceramic. An added advantage is that the length can easily be shortened by grinding, and hence the resonant frequency raised, without the need to remake the electrodes. The external properties of the transducer are nearly identical for the two coupling modes (transverse and longitudinal), apart from the electrical admittance being of a different order of magnitude. The coupling coefficient is lower for transverse drive, 0.334 against 0.710 for PZT-4, but this is of little consequence here, since the widest possible bandwidth is not required.

2.2 Practical realisation

For the size of the radiating face, nominally 10 mm. square, a single side-electroded bar could have been used. However a supply was available of 25 mm. square by 3 mm. thick PZT-4 plates, which could be cut up and ground to size, and it was decided that the 10 mm. high stack could best be made up with three bars with thin spacers to allow electrical contacts to be made to the inside electrodes. The bars are connected electrically in parallel, the higher admittance being more convenient than that for the series connection. The spacers are polythene sheet 0.5 mm. thick, making the height of each stack 10 mm; this was made the vertical, non-critical, dimension of the array. The width of each bar is 8.5 mm., and there is a spacer 1.5 mm. thick between sections of the array so that the elements are spaced accurately at 10 mm. intervals centre to centre. These thick spacers are made of a fine closed-cell rigid plastic foam with good compressive strength, which is also used (with a thickness of 4 mm.) to surround the block of five elements. All the spacers are the same length as the ceramic bars. The front of the array is sealed by a layer of epoxy resin, cast under vacuum and ground flat to a nominal thickness of 2 mm. At the back the leads come out axially and are sealed in with a thin layer of resin; the ends of the elements are left unloaded so as to maximise the radiating efficiency and to avoid setting up standing waves in the short space within the housing. An exploded view of the construction is shown in fig. 1a.

Since it was expected that there would be a shift in the resonant frequency from the free unmounted condition to the final mounting with the radiation load, a test section was first made up, equivalent to a single element of the array. Some of this shift would be due to loading on the sides of the bars and some due to the radiation load having a significant reactive component equivalent to an added mass. The test bars had a free resonance at 74.91 kHz for a length of 22.6 mm., and this dropped to 71.19 kHz when mounted, but then rose to

72.74 kHz in water. The main batch of bars was therefore adjusted to a mean frequency of 78.65 kHz in air, with the expectation of the final resonance at 76.7 kHz in the complete mounting in water. For the latter the block of five elements is set within the overall housing in a block of a composite material of hollow epoxy spheres about 2 mm. in diameter and epoxy resin; this must have changed the effective mechanical load on the array, since the final resonant frequency is 78.43 kHz in air and 78.12 kHz in water. This is rather high for transmitting at 73 kHz, but acceptable for reception at 76 to 77.5 kHz; the design could however be easily modified by making the transmitting section longer on the inside to lower the resonance and keeping the radiating face in one plane as at present.

3.0 Results

3.1 Electrical measurements

The usual measurements of admittance (circle diagrams) were made in air and in water, and the circle diagram for one receiving section with its tuning transformer in water is shown in fig.2. The average results are as follows :

Conductance at resonance	:	0.47 mS
Resonant frequency	:	78.12 kHz
Effective coupling coefficient	:	0.230
Radiating efficiency	:	71%
Q in water	:	10.6

The coupling coefficient agrees well with the value of 0.304 calculated from theory and the manufacturer's data (2). The bandwidth is wider than expected, and this is not due to a wide scatter in the resonances of the bars in one section, the circle diagrams in air being well behaved without signs of multiple resonances; a possible cause is that the effective radiation load on each element is greater than that directly associated with the actual active face area, and there is further evidence for this in the form of the directional response as discussed below. However this additional bandwidth has led to greater radiating efficiency.

A critical factor in the intended use of this transducer is the cross-talk between elements. A simple way of measuring it is to drive one element electrically and to measure the voltage induced on the others with the array in the water and in the absence of standing waves. It is not clear how this relates to the electrical output on one element due to the acoustic input on another, since it is not possible to drive elements independently by acoustic signals while still keeping the same conditions of radiation loading on all. The measurements were done with pulsed signals and with the receiving sections connected to their pre-amplifiers; the element which is not used, next but one to one end, remained open-circuit and not tested. The average cross-talk ratio is about -30 dB., but there is some evidence that the direct level is a few dB lower and there is a significant contribution from reverberation around the front end of the housing. In the practical use of the complete sonar system this level of cross-talk is low enough, as the worst errors in the measurement of bearing are about $\pm 2^{\circ}$ relative to the mean straight-line relation between actual and indicated bearing (there is a $\pm 1^{\circ}$ quantisation error in the signal processing).

3.2 Directional response

This was measured only for the central (transmitting) element, since at the time the receiving channels were not available, and the results are shown in fig.3 for the two planes. They depart from ideal in two respects. Firstly, the response is much lower at the edges ($\pm 90^{\circ}$) than expected from a simple (sin x)/x pattern, which should be only 4 dB down for a half wavelength wide element, and secondly there is a ripple at a higher frequency in bearing. The former is consistent with an aperture nearer to one wavelength wide, and this could be caused by the epoxy resin over the face acting as a rigid piston beyond the actively driven area; this is consistent with the Q being much lower than expected. The latter is at a rate corresponding to eight peaks over 180°, equivalent to an aperture four wavelengths wide, i.e. about 80 mm; this is consistent with radiation from the edge of the housing, which is 85 mm in diameter, acoustic energy being obviously coupled across the epoxy spheres/resin mixture. This fall in response at the sides is clearly going to reduce the maximum range at which transponders can be tracked, but any improvement would probably mean a more complicated structure to make each element behave as a true half wavelength square.

4.0 References

1. M.L.Somers, J.S.Rusby : A high-power wide-band transducer operating at 75 kHz. Institute of Acoustics/Underwater Acoustics Group specialist meeting : Transducer Workshop, 15th December 1976, Paper No.2.

2. W.P.Mason (Ed). : Physical Acoustics, Vol.1A, chap.3. Academic Press New York, 1964.

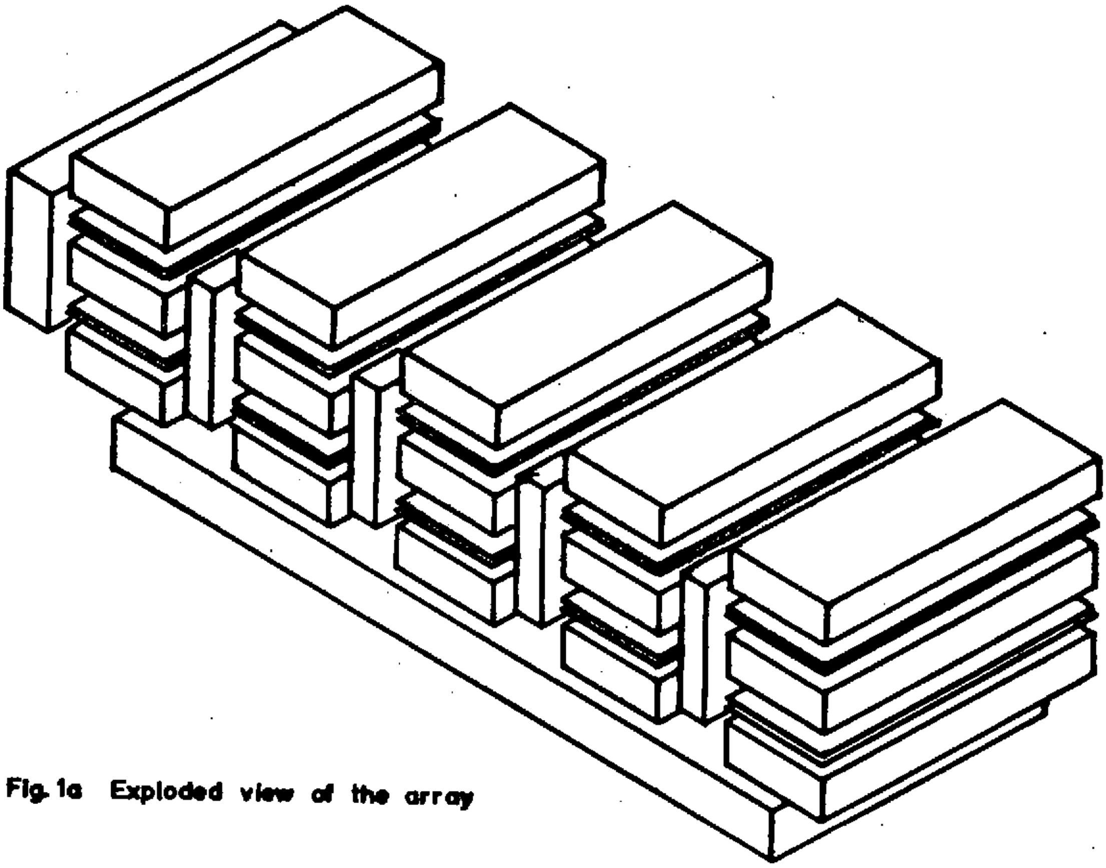

Fig. 1a Exploded view of the array

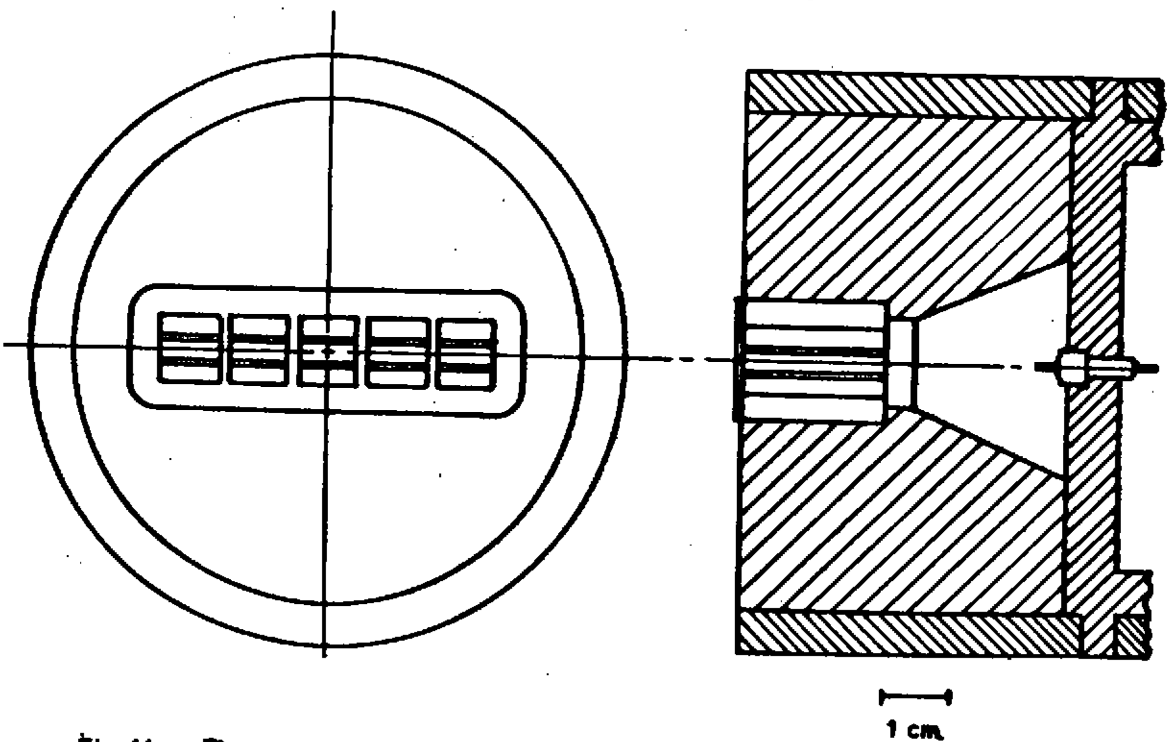

Fig. 1b The array assembled in the housing

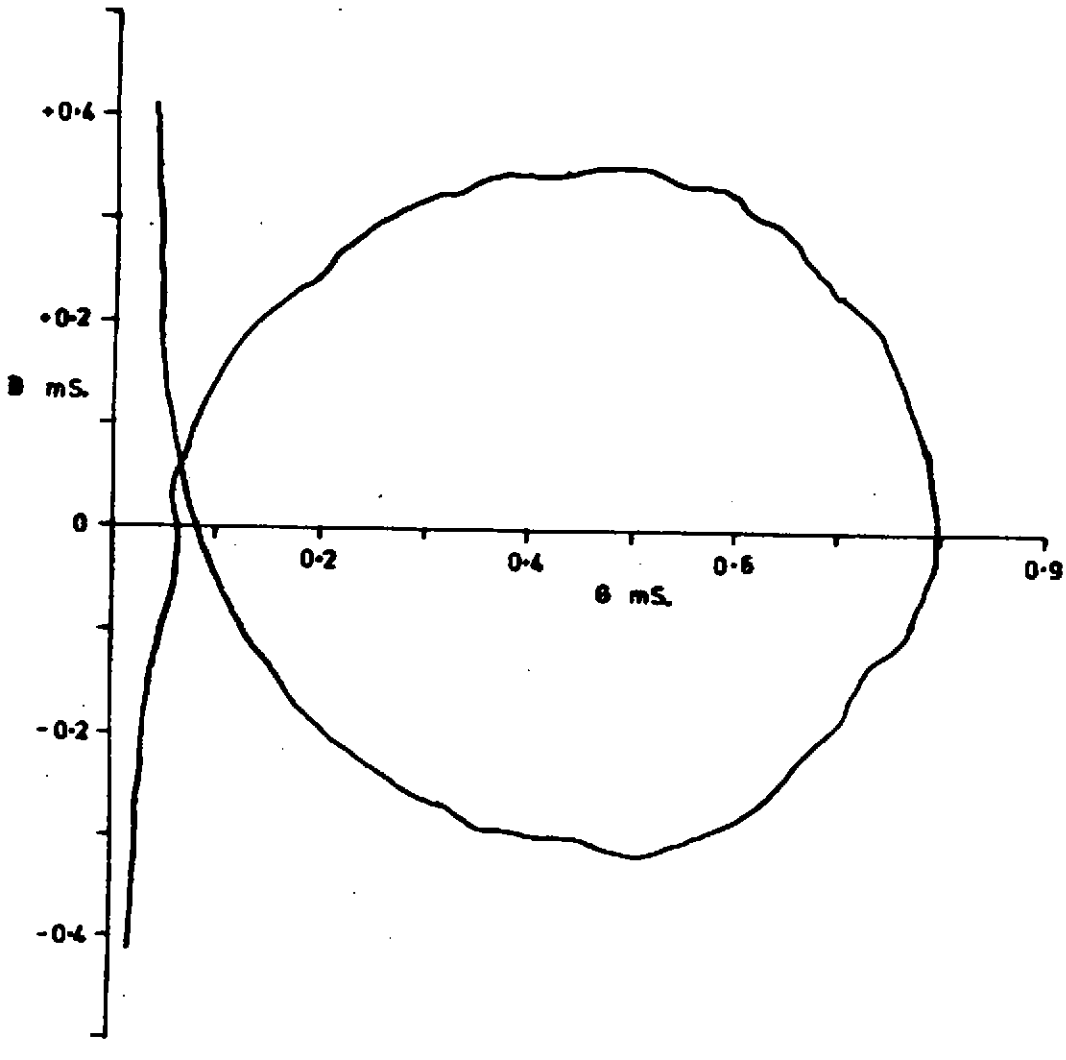

Fig. 2 Admittance of one receiving element with its tuning transformer

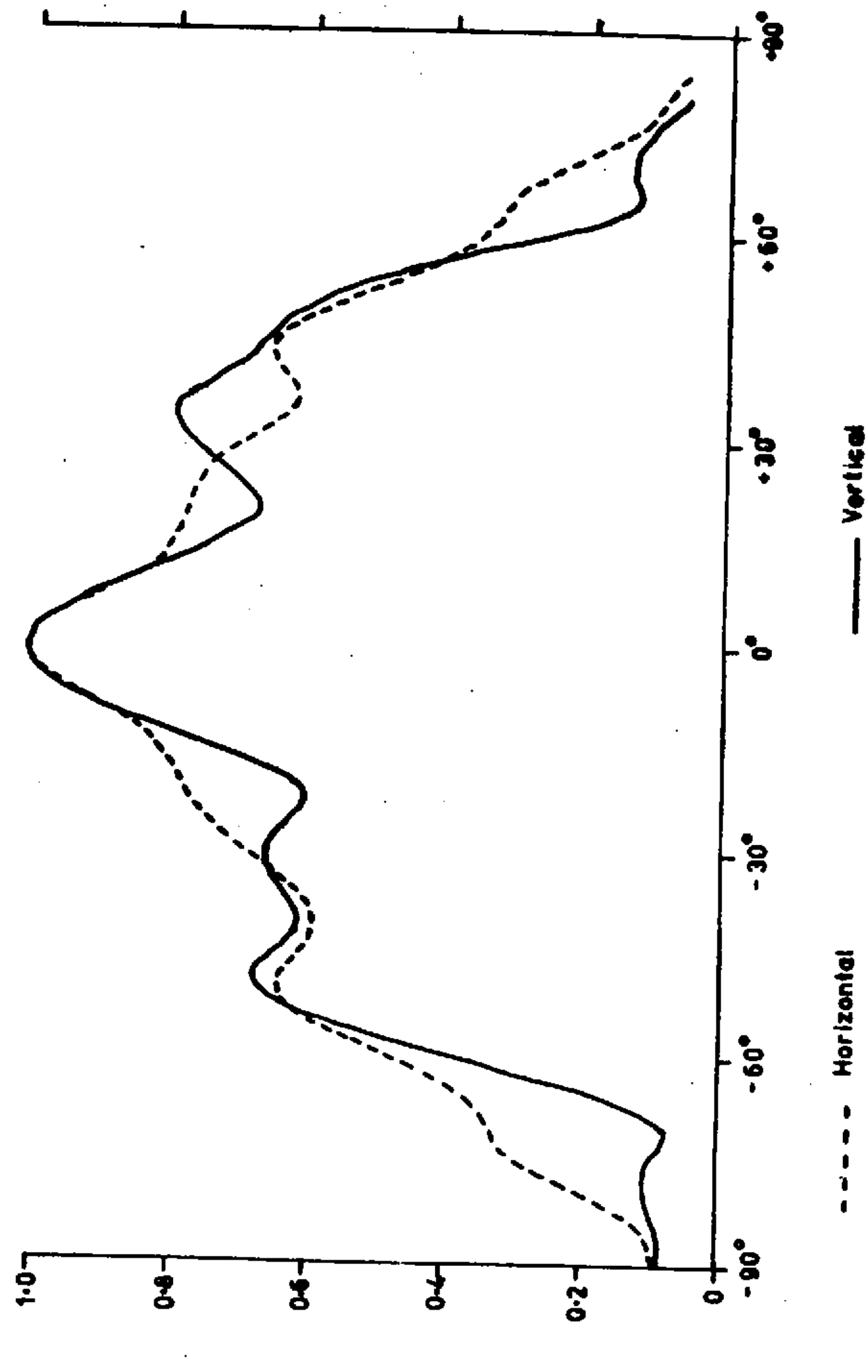

Fig. 3 **Directional response of transmitter**