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PROBLEMS IN THE CONSTRUCTION AND PERFORMANCE OF A 300 kHz HIGH POWER TRANSDUCER ARRAY

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1. Introduction

A replacement was required for a sector scanning sonar array which had been designed and constructed in the early 1950's. This had to fit the same housing and therefore be of similar performance and mechanical construction. Three arrays are described, the original, the replacement together with the problems which occurred when it was put into service, and finally an array built with expedience to replace this. Comparisons and the performance of the replacement transmitter arrays are shown and discussed.

2. The Original Array

Figure 1 shows the physical dimensions. The active elements were barium titanate, each being carefully tuned for the desired frequency and sidelobe level of -13 dB.

The arrays were mounted on a brass sub-assembly and housed in a castor oil filled aluminium bronze casting with a natural rubber diaphragm.

3. The Replacement Array

The performance of the replacement had to be similar to the above except that the elements were to be lead zirconate titanate and the bandwidth reduced to 10 kHz. It was necessary to change the diaphragm material to synthetic rubber because of the presence of hydraulic oil in the stabilisation system which attacked the original natural rubber.

The transducer sections were made by a contractor but assembled and wired by M.A.F.F. Each array has five sections, mounted on brass base plates which in turn are fixed to a brass mounting. Elements of PZT4 were mounted on a soft cellular natural rubber with an interleaving of copper foil for electrical contact. The rubber was bonded both to the brass base and the copper foil, with rubber adhesive. Individual elements were separated from each other with thin cellular neoprene bonded between them. All transmitter elements were wired in parallel.

4. Performance

The transducer was assembled and the chamber filled with dry de-aerated castor oil in May 1974 and was tested at sea three weeks later. A mean source level of 232.5 dB//µPa//m was determined from 28 observations at ranges varying from 50-250M. The beam angles were determined as $30^{\circ} \times 5^{\circ}$ at -3 dB and sidelobe level as -11 dB.

After five months of use a deterioration in performance was noticed with the range capability becoming reduced and with strong sidelobe interference on the display. A second series of tests gave a source level of 225 dB//µPa//m and a sidelobe level of -6 dB.

5. Laboratory Investigation

A check made against the original measurements showed that the ceramic face efficiency had dropped from 48% to 32%. When a section was removed from the array and physically examined, it was found that castor oil had infiltrated the cellular rubber backing. Under microscopic examination the rubber backing was seen to be intercellular. The bond between the neoprene strip separating the elements was broken in many places allowing castor oil to soak in, causing higher inter-element coupling.

An investigation began of the performance of possible backing materials before and after evacuation in castor oil. Two materials were selected, one being a hard cellular natural rubber as an alternative to the original soft natural rubber which could no longer be supplied, and the other a syntactic polyurethane foam, supplied as a two part mix, which was considered to be a robust material with the advantage of being more resistant to the infiltration of castor oil.

A synopsis of the tests on single elements mounted on backings of different physical properties is shown in the following table:-

Test	Backing material	Mechanico-acoustic efficiency (%)	Q $(\frac{fr}{\Delta f})$ Air	Q $(\frac{fr}{\Delta f})$ Water	Sensitivity S_{RT} (dB/V/µPa)	Sidelobe level (dB down on main lobe)	Change in air Y circle dia. (%)
1	Hard natural rubber	64	76	34	- 195.5	- 5	-
2	As (1) with 2% oil	54	65	35	- 197.5	- 5	25
3	Syntactic polyurethane foam with air < 3 mm	80	100	31	- 195.7	- 10	-
4	As (3) with air < 1 mm	77	144	39	- 193.6	- 10	-
5	As (4) with 3½% oil	60	69	44	- 194.3	- 9.5	40
6	As (3) with air < .1 mm	64	70	31	- 196.3	- 10	-
7	As (6) with 1½% oil	57	63	29	- 195.6	- 10	12
8	Syntactic foam casting	67.9	75	32	- 198.7	- 10	-
9	As (8) with 1½% oil	67.4	72.4	32	- 197.2	- 10	1½

From these tests the problems to be overcome were considered to be ingress of oil into the backing and between the elements. The materials with least ingress showed the smallest changes but these were not necessarily the most efficient originally.

An indication of the performance of the backing material was the degree of change in air admittance circle diameter: this showed the increase in coupling into the material by the oil. It is interesting to note that tests (2) and (5) show that with 2% and 3½% ingress of oil not only did the efficiency change the most but the sidelobe level was also marginally higher. The sensitivity difference between pairs of tests was mainly due to the different elements used and the experimental tolerances, but it is thought significant that there was a reduction in the two cases mentioned, especially since it was coupled with an increase in sidelobe level.

The oil test was not made on sample (3) because at the time this was felt to have too high a content of air. The amount of air retained by the samples of syntactic material is related to the length of evacuation time that it was possible to allow in the initial manufacture, and this is why a variety of samples were available as manufacturing techniques were evolved.

6. Manufacture of syntactic foam backed array

From the above investigations it was decided to attempt the manufacture of a prototype section at the laboratory using syntactic polyurethane foam (Eccofoam V.I.P.) because no alternative material could be found. One difficulty was that no one could produce a 0.5 mm separating strip in cellular neoprene or natural rubber, but this had been achieved in syntactic foam using a combination of heat, vibration and evacuation. The original method of building up the array was by individually bonding the elements to the strips and backing with adhesive. The change to a casting method, producing a full section of elements, gave better control over the surface flatness, curvature and overall dimensions of the sections. Initial tests on the prototype section indicated a satisfactory performance and beam pattern. Inter-element coupling was measured and compared with the previous array and is shown in Figure 2. The section was then put on a prolonged test of 125 hrs running at a power level of $0.6W/mm^2$. This indicated, after a repeat of the electrical tests and physical examination, that the material was durable and that the bonds between the elements had remained intact. A complete array was then made by a local contractor under supervision.

7. Sea trials

Tests were made in April 1976. The beam pattern and overall performance showed an improvement on the previous array.

A source level of 223 dB//µPa//m and sidelobe level of -11 dB were measured. A beam efficiency of 70% was calculated and compares with 50% for the previous array. Recent tests have confirmed that the transducer has maintained this performance after 7 months of use.

8. Discussion Points

During the tests it was found that the measured source level in the case of the syntactic foam transducer did not follow the predicted curve. In Figure 3, the graph shows a distinct knee in the measured case at 2 kW. There is thus a high possibility that the 9 mm thick syntactic foam backing changes its properties at power densities exceeding $0.02W/mm^2$. The confirmation of source level and beam pattern after seven months suggests that this is not due to deterioration.

Investigation of the cellular rubber backed array also showed a fall off in measured source level, once infiltrated by castor oil, but this is calculated to be caused by the change in directivity with increase in power, as shown in Figure 4. The source level of this array when new followed the theoretical curve but is displaced on the graph by a calibration error.

Finally, the array with elements separated by syntactic foam gives a similar beam pattern at high power to that with neoprene separated elements at low power shown in Figure 5. High inter-element coupling in the latter case due to broken bonds (see Figure 2) is the most likely cause of the directivity change at high power levels when this coupling will have a greater effect.

In conclusion an acceptably robust array has been produced, which was the main aim of the project, at the expense of projector efficiency. However, the syntactic polyurethane foam is suitable as an element separating material without any modification.

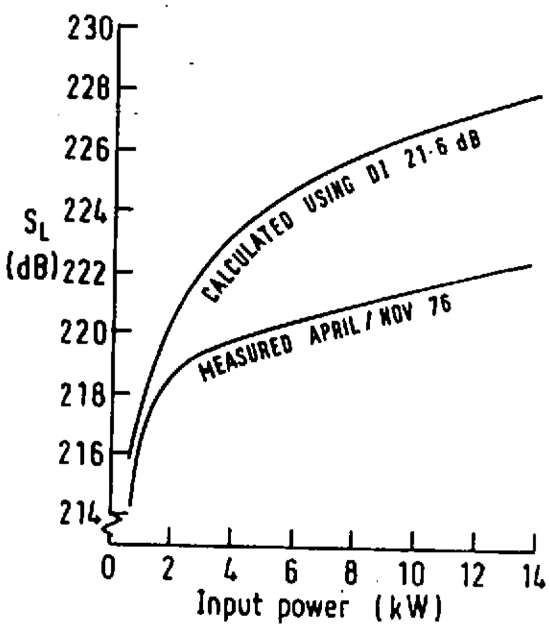


Figure 3 Source level / Input power
Syntactic foam backing

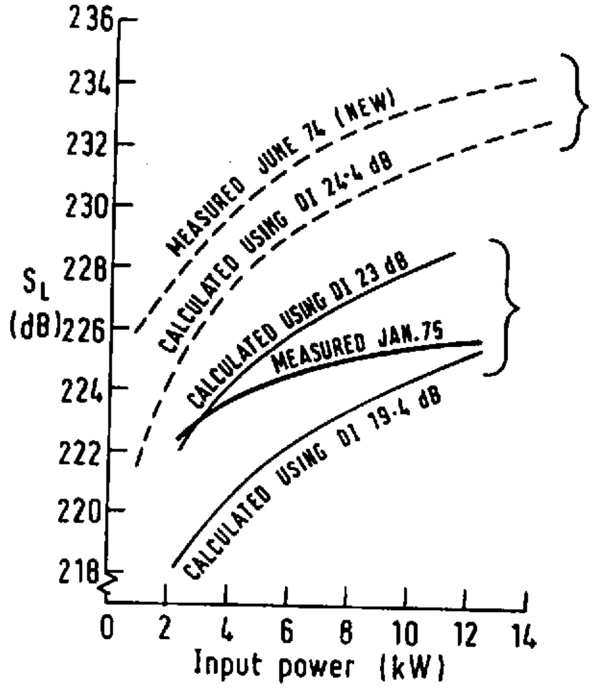
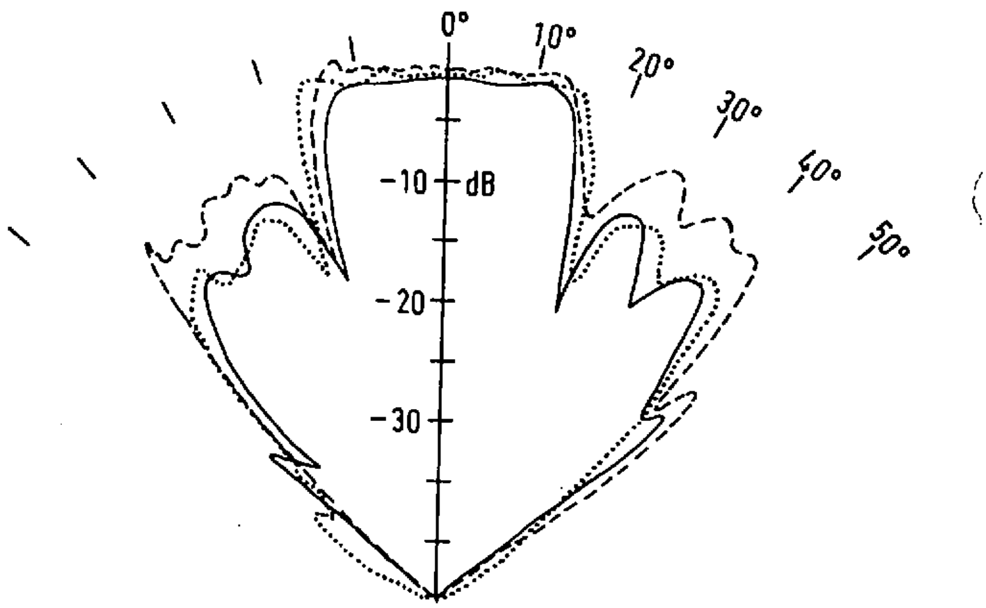
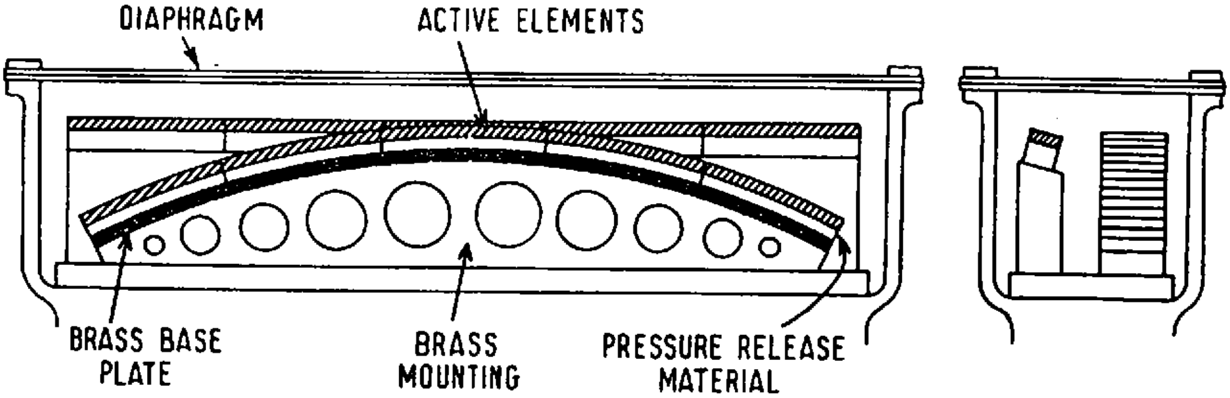


Figure 4 Source level / Input power.
Cellular rubber backing



	Beam efficiency
——— = Cellular rubber Low power	73%
- - - = Cellular rubber High power	50%
······ = Syntactic foam High power	70%

Figure 5 Horizontal beam pattern



TRANSMITTER	30°ARC.	ARC LENGTH 750 mm.	SURFACE AREA 37500 mm².	
RECEIVER	FLAT.	LENGTH 750 mm.	75 ELEMENTS.	BEAM ANGLE 0·33°.

Figure 1. 300 kHz array. Physical dimensions

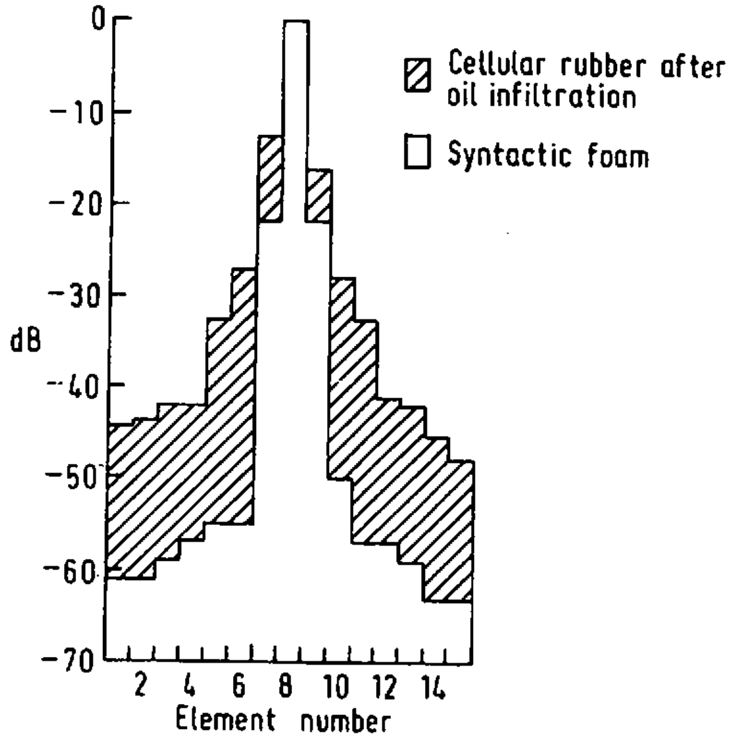


Figure 2. Inter-element coupling