DIRECTIONAL TRANSDUCERS WITH ACCURATELY CONTROLLED BEAMWIDTH AND SIDE LOBES

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Introduction

This paper describes a method of designing arrays shaded to give specific directivity characteristics, and graphically illustrates that the polar sensitivity response in two dimensions along the major axes represents only a small portion of the three dimensional polar pattern.

The materials and design techniques described enable the construction of narrow beamwidth arrays with controlled side lobes at considerably reduced cost.

Background

During the development of 150mm square hydrophones for large area low profile arrays, it was observed that the sensor material Polyvinylidene Fluoride (PVdF) had remarkably consistent sensitivity characteristics. Further it was noted that polar plots taken over a wide frequency range were very close to the far field predicted values. However as most measurements would be taken at a range of 1 metre it was decided to calculate the theoretical sensitivity polar response at the closer distance to obtain better correlation between the actual and predicted performance. A simple finite element analysis program was written and a good correspondence was obtained between the practical and predicted results.

It can be easily shown that for a piece of flat piezoelectric material working in the thickness mode only that the sensitivity at any segment along its length is proportional to the width of the material at that point. Hence by shaping the width at points along its length it is possible to modify the sensitivity along the length, thus a shaded array may be made by continuously varying the width of the material.

To prove this hypothesis a model was required that could be made to precise mechanical tolerances, and that the directivity could be calculated by the analysis program.

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The Linear Taper

For mechanical simplicity a linear taper was constructed and mounted on an acoustic absorbing material to reduce the effect of reflections and unwanted sensitivity along the draw plane of the material.

This had a directivity function:-

$$D(K) = \frac{0.5(\sin K.L/4)^2}{(K.L/4)}$$

From figure 1 it can be seen that the measured and the predicted results are similar.

This proved that a single sheet of piezo-sensitive plastic could be used to make a complex weighted array without any electronics other than a simple preamplifier, and would not suffer any of the difficulties experienced when making shaded arrays from discrete elements.

Cos^n and Hamming Taper Functions

Further development of hydrophone materials and assembly techniques made construction of elements with more complex weighting functions a realisable aim. The choice of Cos^3 and Hamming functions was because they represented most of the characteristics that a systems engineer would require.

Figure 2a and 2b show the predicted and measured polar patterns for a Hamming taper function at 50 KHz.

Similarly Figures 3a and 3b show the results for a cos^3 taper function at 100 KHz. The measured results were taken on the ISAACS Range at ARE Bincleaves, Portland where the required fine angular resolution could be obtained. Although the results were good for a low cost array, they showed unexpected deviations from the two dimensional prediction. This was largely due to vigourous water movement during the tests exacerbated by a lack of rigidity in the mounting bracket. Further tests showed that the alignment of narrow beam arrays in the third dimension was very critical particularly in relation to the amplitude of the side lobes at angles away from the major axes.

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Thus the two dimensional plot is considered to be a useful design proving tool but gives the system designer an incomplete picture of the transducer performance.

Three Dimensional Polar Plots

The performance of an array is normally described by it's relative sensitivity along two axes. However the system function requires that the sensitivity is known throughout the solid angle in which it is desired to perform.

A computer program has been written to calculate and plot the total three dimensional characteristics of shaded arrays. This has revealed that side lobe levels may differ considerably from that which may be anticipated from the two dimensional plot.

Circular Hydrophone

A simple flat hydrophone with it's predicable symmetry is a good case study. Figure 4a shows the two dimensional plot and Figure 4b shows the three dimensional projection. As predicted the main lobe is symmetrical and evenly surrounded by side lobes. The prediction program has the ability to rotate the pattern in space to observe hidden areas. This feature is more relevant to non-symmetrical arrays.

Cos^3 Taper Function

Both width and length of a continuous taper can be varied. Essentially the length of the taper controls the breadth of the main lobe and the width of the element controls the position and amplitude of the side lobes away from the major axes. Figure 5a and 5b show the two dimensional plots of a Cos^3 taper function with a low aspect ratio, taken at 0 degrees and 90 degrees to the length axis. The three dimensional plot shows that off axis side lobe structure is complex and not foreseeable from the two dimensional plots. Hence the performance away from the major axes is considerably worse than that which the original design criteria indicated. The measured results on the cos^3 hydrophone shown in figure 3 indicated some asymmetry, and a more detailed examination revealed that the measurements were not taken exactly along the axis and this may be part of the apparent error.

The side lobe structure can be varied by changing the aspect ratio of the element, this is illustrated by considering the high aspect ratio cos^3.

Cos^3 Taper Function - High aspect ratio

Figure 6 shows the comparative plots of a narrower array; the side lobes have been reduced considerably at angles away from the major axes. The cost of producing the polar pattern enhancement is a reduction in charge sensitivity, because of reduced area, and difficulty in manufacturing the fine structure of the array. However, techniques are now available to get round this problem.

These patented techniques can be further extended to other forms of array and by folding and laminating the PVdF extremely complex weighting functions can be created.

Further Applications

PVdF is acoustically transparent at normal frequencies encountered in sonar systems. Hence overlapped and laminated, weighted arrays can be used to generate a wide variety of directivity patterns. To date, pencil beam and flat topped directivity patterns have been designed and by reversing segments along the array superdirective arrays have been implemented.

Conclusion

This paper has shown that three dimensional polar projections enable the transducer designer to optimise the performance of an array, and by using piezoelectric polymers and the right assembly techniques the array may be implemented with great accuracy.

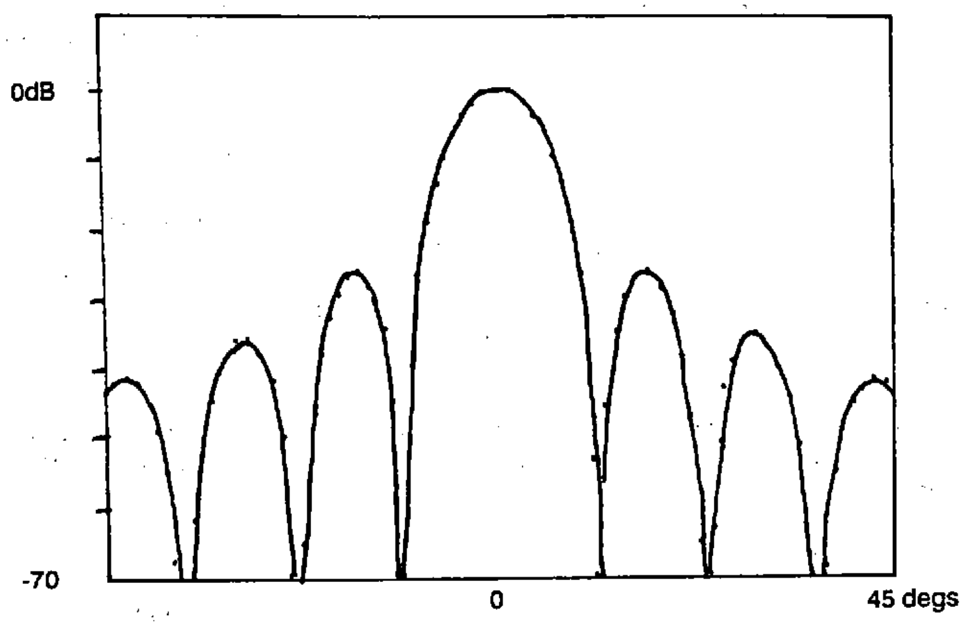

Fig 1a. Theoretical Response

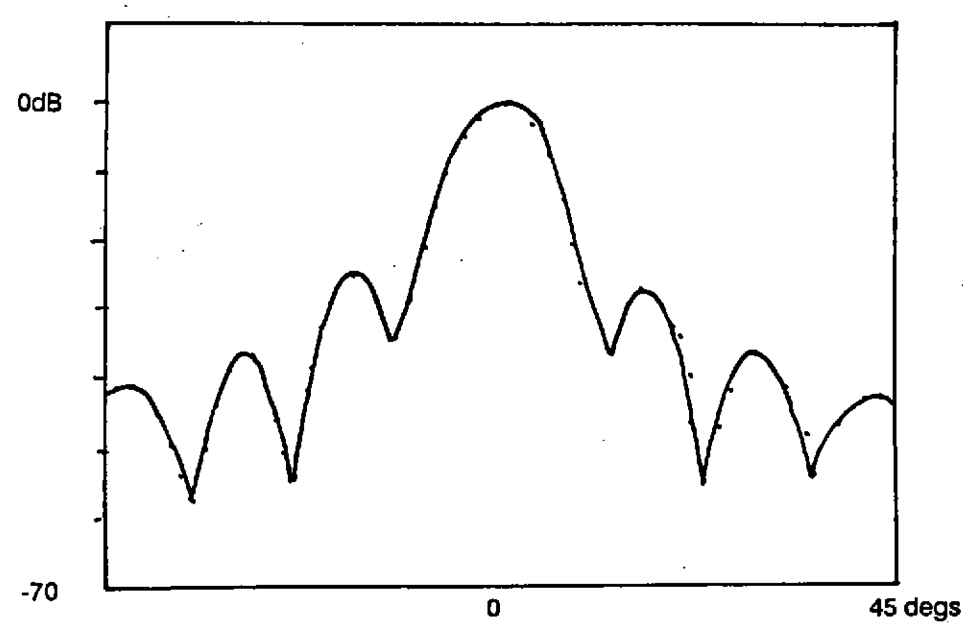

Fig 1b. Measured Response

Figure 1 Linear Taper Function

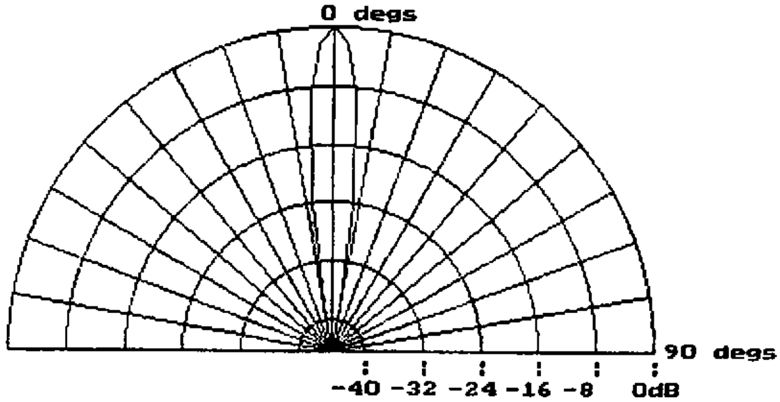

Fig 2a. Theoretical Directivity--90 deg view

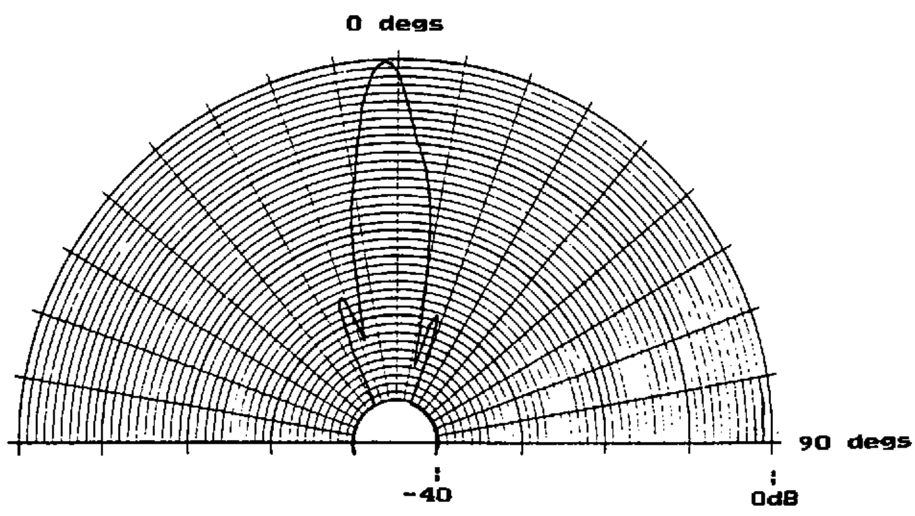

Fig 2b. Measured Directivity--90 deg view

Figure 2. Hamming Taper Function

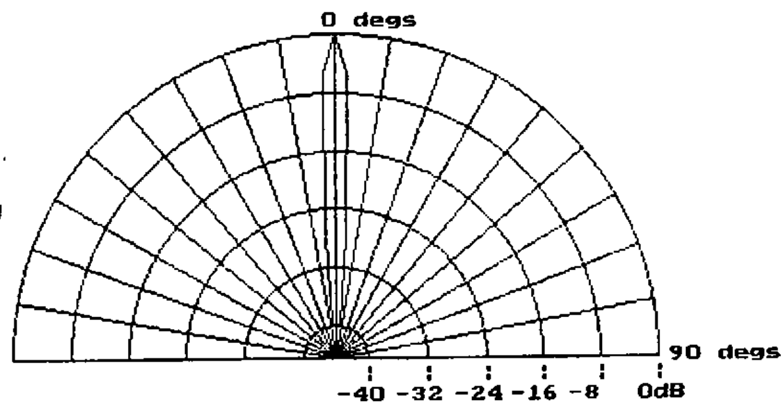

Fig 3a. Theoretical Directivity--90 deg view

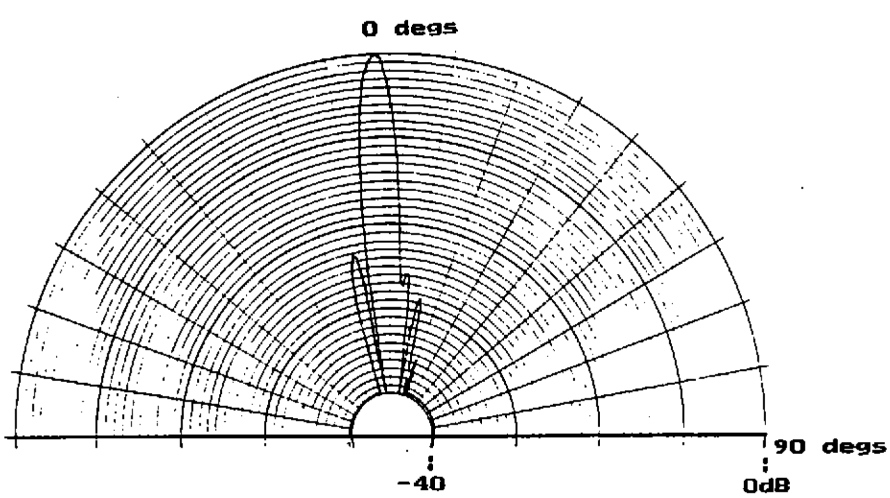

Fig 3b. Measured Directivity--90 deg view

Figure 3. Cos^3 Taper Function

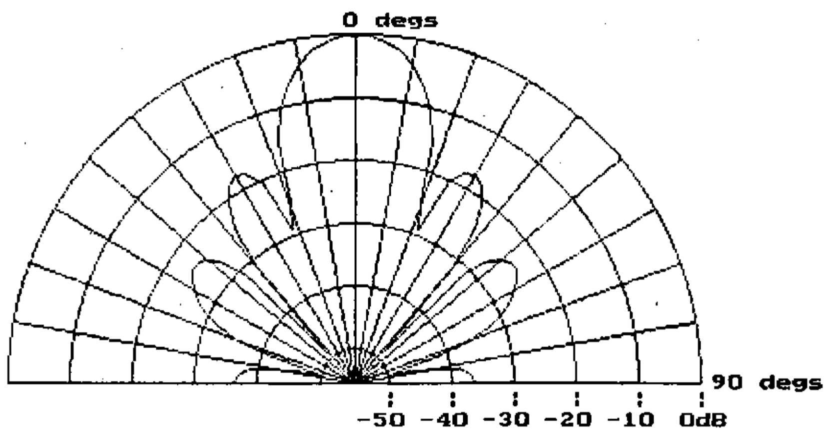

Fig 4a. 2-dimensional Polar Plot--90 deg view

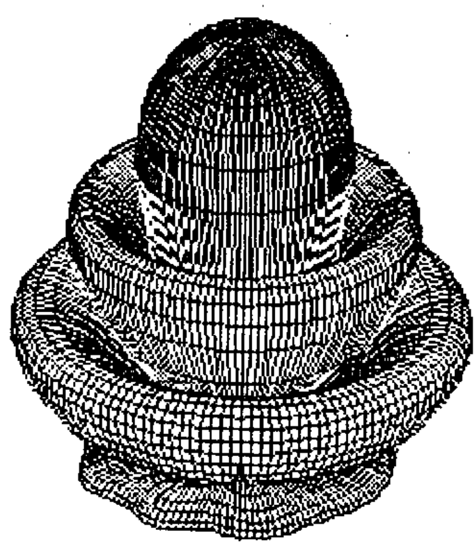

Fig 4b. 3-dimensional Polar Plot

Figure 4. Circular Hydrophone

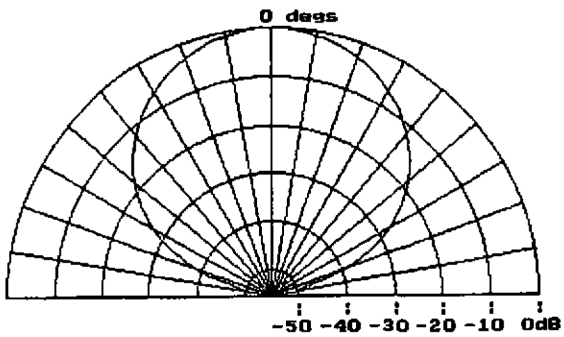

Fig 5a. 2-dimensional Polar Plot--0 deg view

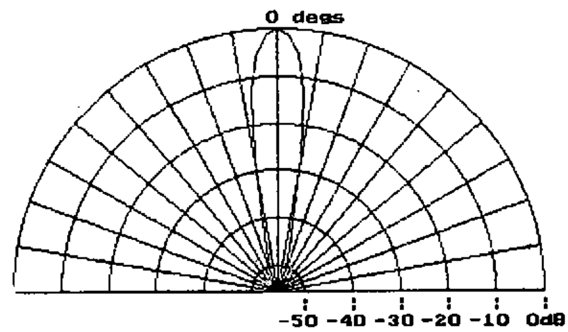

Fig 5b. 2-dimensional Polar Plot--90 deg view

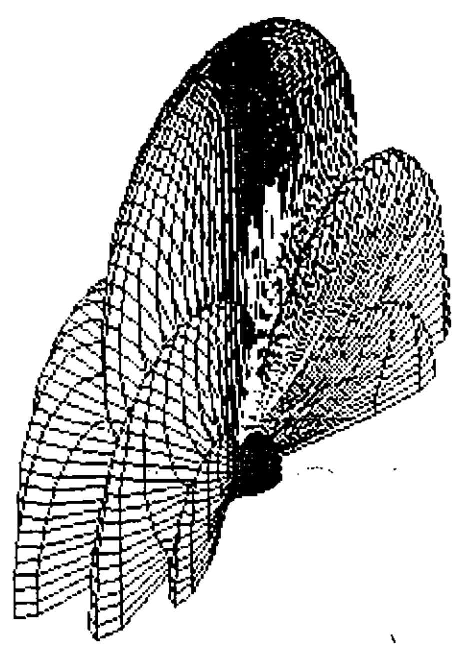

Fig 5c. 3-dimensional Polar Plot

Figure 5. Cos^3 Taper Function--low aspect ratio

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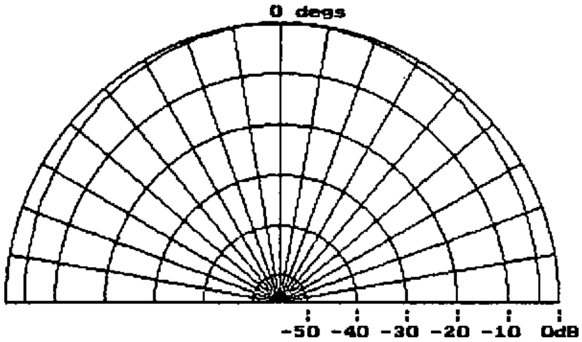

Fig 6a. 2-dimensional Polar Plot--0 deg view

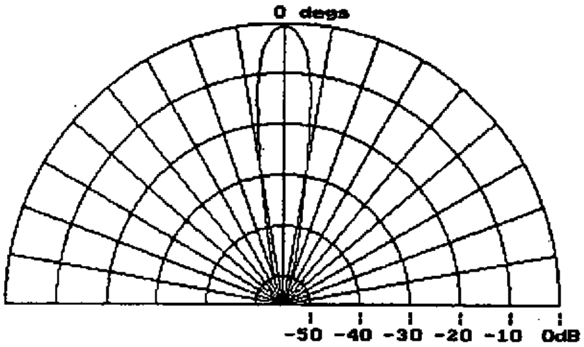

Fig 6b. 2-dimensional Polar Plot--90 deg view

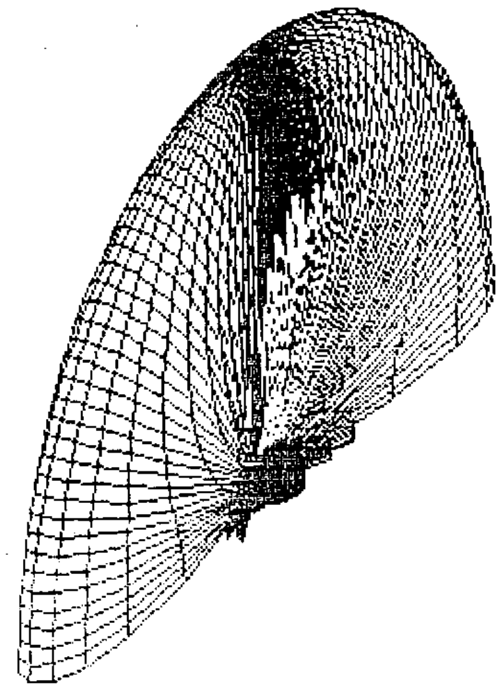

Fig 6c. 3-dimensional Polar Plot

Figure 6. Cos^3 Taper Function--high aspect ratio