THE DESIGN OF SIDESCAN ARRAYS AND THE ELIMINATION OF VERTICAL SIDELOBES

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1. INTRODUCTION

Lloyd mirror interference fringes are a common phenomenon on sidescan records and arise in calm sea conditions because reflections via the surface interfere with the direct path signals from the sea bed. In the case of a rougher sea surface the interference must remain but will not appear as well formed interference fringes because of the fluctuating conditions. The interference will instead impose a noiselike background on the record which, assuming the sidescan receiver is suitably designed to handle a wide dynamic range of signals, will mask the weak signals. These weak signals may well convey important information about the sea bed and the elimination of surface multipath interference by the use of an array with a suitable vertical directional response is therefore an important objective. Unfortunately the necessity for low cost prevents the use of multiple elements across the narrow dimension of the array and standard amplitude shading techniques are therefore precluded. The main purpose of this paper is to describe an alternative and very inexpensive technique of tailoring the vertical directional response of sidescan arrays, namely by the use of side baffles.

2. SIDELOBE REDUCTION USING ASYMMETRIC SIDE BAFFLES

The following technique follows previously established principles (1) (2). In simplified terms the procedure is to place a reflecting or absorbing plate above the array in such a way that acoustic signals to or from the sea surface are shadowed by it. An example of the geometry used for one array is shown in Fig.1(a) and the resultant directional response is given in Fig.1(b). The sidebaffle in this case was a reflecting one made of pressure release closed cell rubber. The response without it is shown in Fig.1(c).

The array itself consisted of 15 ceramics in a line, each 11 mm wide by 25 mm long by 5 mm thick, thus making overall front face dimensions of 11 mm by 375 mm. The backing material was a mixture of graded pulverized fuel ash and epoxy resin. A slot was milled into a cured slab of this backing material and the ceramics were inserted. Following the completion of electrical connections the array was laid perfectly flat and a small quantity of a low viscosity epoxy resin poured over it so that, after curing, a thin protective layer was created. Based on circle diagrams made in air and in water the efficiency was estimated to be somewhat low at around 26%. This is a penalty for using a backing whose acoustic impedance is 2×10^6 Rayls but is not regarded as a major drawback since the maximum radiated power for this particular array is in any case constrained to the quite modest power level of about 45 watts[3] by extra attenuation effects in the water. (Extra attenuation affects are caused by non linearity in the water and have been described by Blackstock[4]). The measured resonant frequency of 410 kHz agreed closely with the value predicted by dividing the frequency constant for a thin plate by the thickness of the ceramic (For PZT-4 N_{3t} equals 2000 Hertz metres/second). Thus the overall front face dimensions of the 15 ceramics were

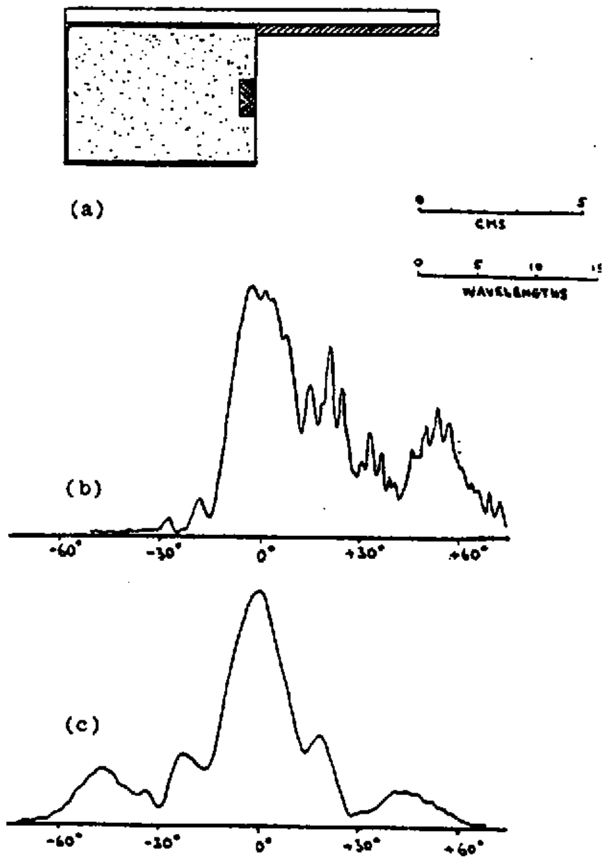

FIGURE 1. (a) Side baffle geometry. The directional response of the array (b) with the side baffle (c) without the side baffle.

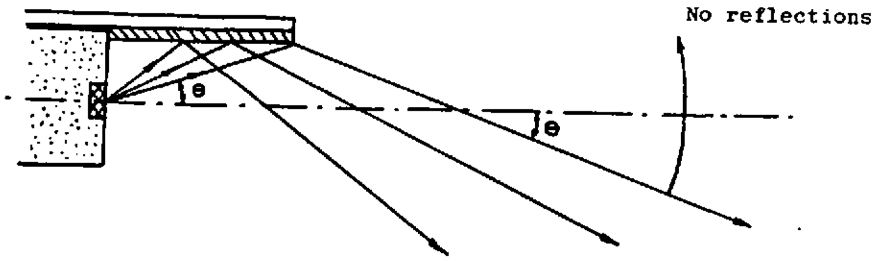

FIGURE 2. Ray diagram of baffle reflections

3 wavelengths by 102.5 wavelengths giving expected 3 dB beamwidths of 20^{o} in elevation and 0.6^{o} in azimuth.

The directional response of Fig.1(c), taken without the side baffle, deviates quite substantially from the classical result

$$D(\theta) = \frac{\sin(kd \sin\theta/2}{kd \sin\theta/2}$$

and various causes are suggested below: The 3dB beamwidth is approximately 25% less than that expected for a width of 11 mm and it seems likely that the finite impedance of the fuel ash/epoxy resin backing mixture permits a finite particle velocity in the plane of the ceramics, outside the ceramics themselves, in such a way that the classical theory based upon a piston in an infinite plane rigid baffle is invalid. The second major deviation from the classical sin x/x result is the high sidelobe level and the absence of deep nulls. However it is believed that this is a measurement error due to an inadequate separation of the transducer array and hydrophone during the recording of the directional response. Although the separation was greater than the Fresnel distance corresponding to the 11 mm of the array it was unfortunatley less than the 38.5 m Fresnel distance corresponding to the 375 mm dimension.

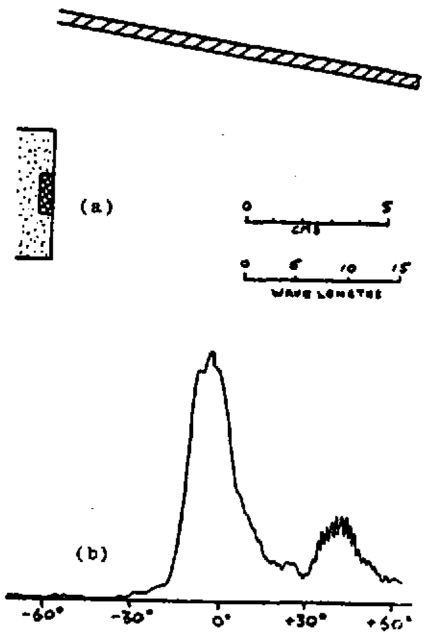

FIGURE 3. (a) Geometry of sloping baffle (b) Resulting directional response.

In spite of the limitations to measurement accuracy caused by the inadequate separation of transducer and hydrophone the effect of a side baffle is clear. On one side the acoustic radiation is largely eliminated. On the other side it is increased, presumably because a component reflected from the baffle is added to the direct path signal, and shows a rapid change with angle as would be expected from an interference effect.

The reflection problem can be avoided by the use of absorbing baffles. It is interesting to note however that if the reflecting side baffle is parallel to the boresight direction and if its edge is at an elevation angle Θ above the boresight, then simple ray theory predicts reflections only at declination angles below the boresight of greater than Θ (Fig.2). Since it is any case good practice to place the edge of the baffle at the angle of the first null in order to minimize the effect of edge diffraction, it follows that reflection effects will be absent throughout the main lobe. The small perturbations around the boresight direction in Fig.1 (b) are presumed caused by baffle edge diffraction.

In many applications it is anticipated that reflections outside the main lobe will not constitute a problem. It is interesting to note however that they can be pushed further out in angle by sloping the side baffle inwards. Figs. 3(a) and 3(b) show one such geometry and the resulting directional response. The results were taken with a somewhat shorter array, 11 mm by 75 mm, operating at 410 kHz and this enabled true far field measurements to be made. Without the baffle the response was close to the ideal far field $^{\sin x}/x$ shape, though still 25% more narrow than predicted from the width of the ceramics. With the side baffle the reflection effects are now much further off the boresight and show a greater rate of change with angle due to the greater distance of this particular baffle from the ceramics. Again the main lobe shows small interference effects caused probably by edge diffraction.

In some applications the side baffles just described and the resultant directional responses will be regarded as very acceptable. If however the array is mounted on a towed body the side baffle dimensions may be regarded as excessive.

Furthermore a basic array having a much wider beamwidth might be used in which case it might not possess a suitable null in which to place the baffle edge and edge diffraction effects might then be expected to be greater. Also a symmetrical directional response may be regarded as desirable. In any of these events the smaller symmetrical side baffles described in the next section may be more useful.

3. SIDELOBE REDUCTION USING SYMMETRIC SIDE BAFFLES

In order to obtain far field directional responses, the following results were made using just one element of a 29 element array. Side baffle dimensions are so small in terms of wavelengths that the concept of simple shadowing is inapplicable. An example of the geometry which has been proved experimentally to give the best results so far is shown in Fig.4(a) along with the resultant directional response in Fig.4(b). The side baffle was made of a closed cell PVC material known as Plasticell. The result for the element without side baffles is shown in Fig.4(c). It will be noted that the effect of side baffles is to narrow the beamwidth and to produce a directional response which is symmetrical and totally without sidelobes and which careful measurements demonstrate to correspond very closely with a Gaussian distribution. The 3 dB beamwidth is 30°. Since the Fourier transform of a

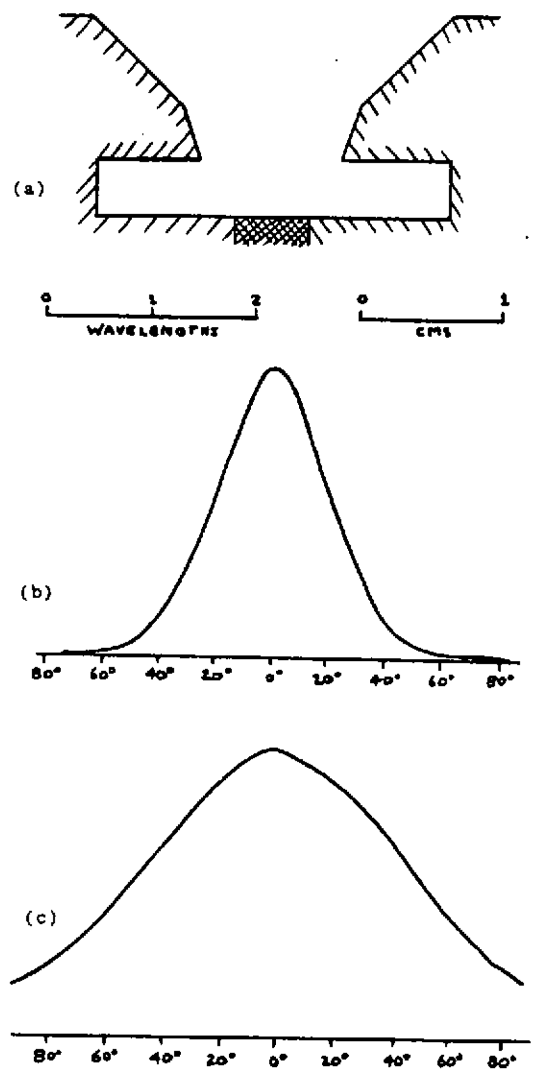

FIGURE 4. (a) Side baffle geometry giving best results, (b) directional response of (a), (c) Directional response of plane element.

Gaussian function is another Gaussian function it is thought interesting to show in Fig.5 the amplitude shading function which would produce the measured directional response. The baffle dimensions are drawn beneath it to the same scale.

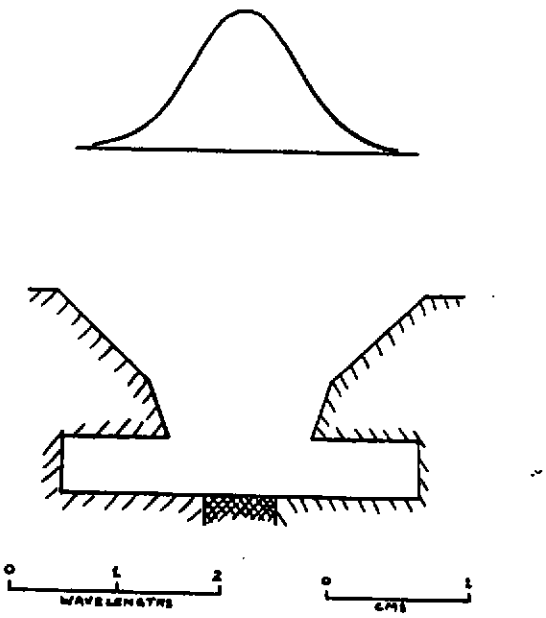

FIGURE 5. Gaussian amplitude shading function and baffle geometry to same scale.

Even without the baffles the array has some interesting features. Each ceramic is 7.5 mm wide and 25 mm long by 5 mm thick. With these particular dimensions experimental measurements have indicated a very strong interaction between the thickness and width resonances and the effect is to make the ceramic very compliant reducing the resonant frequency down from the thin plate value of 400 kHz to a value of 200 kHz. The presence of the two modes of resonance is confirmed by the observation that reasonably efficient radiation is possible either from the silvered face of the ceramic or from the unsilvered side face of the ceramic. Indeed, in order to allow a very thin layer of protective epoxy resin to be added to the radiating face, it was decided to use the unsilvered sides of the ceramic as the radiating faces. By doing this there were no outward facing solder contacts which needed to be covered by the epoxy.

Although the advantages or otherwise of using the unsilvered side as the radiating face are marginal it is felt that the existence of such a strong coupling between modes of resonance has a more far reaching significance. The reduction by a factor of two in the resonant frequency would mean that if a slightly thicker ceramic were used with the same width to thickness ratio of 1.5, resonant frequencies below 200 kHz could be obtained. This would bridge the gap between the operating frequency of sandwich transducers which is normally below 100 kHz, and the operating frequency of simple ceramic transducers which is normally constrained by the thickness of available ceramics to above 200 kHz.

Because of the use of the unsilvered face of the ceramic the actual dimensions of the radiating face of each element in the array are 5 mm x 25 mm. The experimental directional response in Fig. 4(c) corresponding to the 5 mm dimension is considerably more narrow than that expected of a 5 mm piston in an infinite rigid baffle. As with the array described in section 2 it is suggested that this is caused by a finite particle velocity in the plane of the ceramics, outside of the ceramics themselves.

When compared with experimental measurements on a large number of alternative geometries, the baffle configuration of Fig. 4(a) has so far given the most useful directional response. It has not proved possible as yet to predict the response theoretically and indeed it would seem to present a very complex

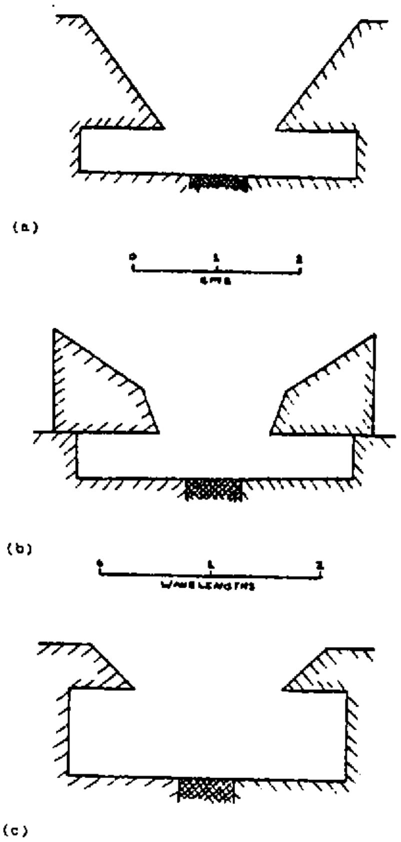

FIGURE 6. Baffle geometries
(a) single taper
(b) brass
(c) aperture.

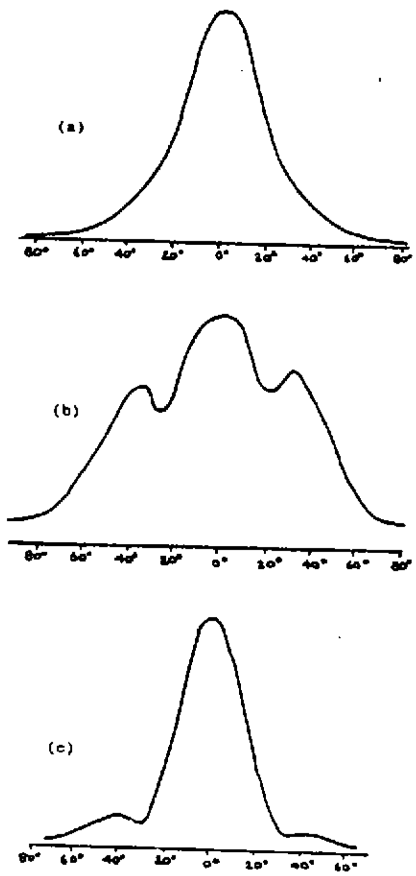

FIGURE 7. Directional responses
(a) single taper
(b) brass
(c) aperture

boundary value problem. It is interesting to examine experimentally how critical the baffle parameters are in determining the quality of the directional response. Fig. 6 shows various geometries and Fig. 7 the resultant directional responses. The geometry of Fig. 6(a) was similar to that of Fig. 4(a) except that the double taper was replaced by a single taper. The effect as shown in Fig. 7(a) was to raise the tails of the response while keeping the 3 dB beamwidth substantially unaltered. At $\pm 50^{o}$ for example the response was 5 dB greater. In Fig. 6(b) the Plasticell baffle was replaced by a brass baffle in an attempt to discover the significance of acoustic impedance. Two measurements were made, one with the brass polished and one with the brass heavily pitted in order to simulate the roughness of the Plasticell. In both cases the directional responses were similar and are as shown in Fig. 7(b). A distinct sidelobe is present and the response is considerably less useful than that using the Plasticell. Fig. 6(c) shows an attempt to obtain an improvement in the directional response by means of a simple aperture. However the result shown in Fig. 7(c) demonstrates that the omission of the side walls of the baffle is having a detrimental effect.

4. CONCLUSIONS

Side baffles provide a very powerful and inexpensive technique for tailoring the directional responses of transducers and transducer arrays. Compared with previously published results the improvements described in Section 3 are particularly interesting since they use very short baffles in terms of acoustic wavelengths. It has been shown possible to obtain the directional response resulting from a relatively wide Gaussian shading function even though a single narrow ceramic only is used. Much more work needs to be done however before a design procedure applicable to other ceramic dimensions can be established.

5. REFERENCES

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