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A METHOD FOR THE MEASUREMENT OF HORIZONTAL OCEAN-NOISE DIRECTIO--ETC(U)

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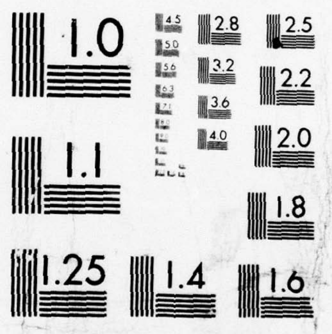

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A METHOD FOR THE MEASUREMENT OF HORIZONTAL OCEAN-NOISE DIRECTIONALITY

by

T.C. CHESTON

1 MARCH 1979

NORTH ATLANTIC TREATY ORGANIZATION

LA SPEZIA, ITALY

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Memorandum rept.,

A METHOD FOR THE MEASUREMENT OF HORIZONTAL OCEAN-NOISE DIRECTIONALITY.

by

T.C Cheston

1 March 1979

12p.

This memorandum has been prepared within the SACLANTCEN Underwater Research Division as part of Project 15(77).

G.C. VETTORI
Division Chief

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FIGURE

A METHOD FOR THE MEASUREMENT OF
HORIZONTAL OCEAN-NOISE DIRECTIONALITY

by

T.C. Cheston

ABSTRACT

Shipping noise dominates in the ocean at lower frequencies and can be resolved by a horizontally directive system into targets and lower noise areas where enhanced ASW detection becomes possible. A method is described for measuring the horizontal ocean noise directionality with a line array system that is towed in a tight circle. Left/right ambiguities are resolved by processing multiple beams from the array.

INTRODUCTION

Ambient noise is normally dominated by shipping noise at lower frequencies and surface-generated noise at higher frequencies. The cross-over varies with sea-state, traffic, and propagation conditions, but when measured with a single omni-directional hydrophone it occurs normally in the region of 200 to 800 Hz.

Surface-generated noise has primarily vertical directionality. Shipping noise has both vertical directionality, due to propagation paths having near-horizontal angles of arrival, and horizontal directionality, due to the actual distribution of the ships. The two sources of noise may be reduced separately. For example, a system having vertical directivity should be able to discriminate against at least some surface-generated noise. A vertical line array will therefore show less noise at the higher frequencies than a single omni-directional hydrophone and thus have shipping noise dominate up to higher frequencies.

Shipping noise can be resolved with a horizontal array having a narrow beamwidth into a number of distinct targets at specific bearings. The residual noise level in the holes between the resolved targets offers regions of substantially enhanced detection. The actual value of the residual noise is due to remaining unresolved shipping noise, with a final limitation being surface-generated noise or other noises that may be present. The situation is dynamic and changes with the shipping pattern.

In shallow waters, ambient noise is likely to be greater and complicated by modal propagation.

Since surface and shipping noise can be separated and their directionality exploited individually, it becomes of considerable interest to attempt a separate assessment of both these quantities.

Surface-noise directionality may be assessed with a vertical array, with shipping-noise contributions decreasing in importance as both frequency and sea-state increase.

Horizontal noise directionality measurements are difficult *[1]*. They require a narrow, horizontal beam that can be rotated in azimuth without significant changes in beam shape during a period that is short in comparison with the time it takes for the ship distribution pattern to change. In shallow water, where the influence of the bottom is of importance, all measurements must be made in substantially the same area, which precludes, for example, towing an array in a large circle or polygon. Lastly, left/right ambiguities must be resolved. All these requirements are likely to be fulfilled with the simple technique suggested below.

1 MEASUREMENT OF HORIZONTAL NOISE DIRECTIONALITY

The general principle of the measurement method is shown in Fig. 1. A line array is towed in a tight circle, with a radius of typically 500 to 1000 m, and at a speed of some 5 kn. The array will roughly follow the tow-ship. Its exact shape is uncertain, but the parameters are chosen such that the deformation does not appreciably exceed $\lambda/4$. Such deformations have only a small effect on the beam pattern *[2]*. A wide range of frequency and array size is possible but at low frequencies the errors become too large with a high resolution array, as discussed later, and a correction becomes necessary.

The array output is fed to a beamformer that forms a number of shaded, low sidelobe beams looking substantially broadside. The beams look both right and left relative to the direction of the array, as indicated in Fig. 1 where three beams are shown by way of example. As the array rotates by being towed around the circle, a target on the right of the array will walk through the beams in the sequence 1, 2, and 3. A target on the left, on the other hand, will walk through the beams in the opposite sequence, 3, 2, and 1. This change of sequence may be used to resolve the left/right ambiguities with various levels of sophistication. In principle, the beams are added incoherently with proper time delay, advancing or retarding respectively for targets on one side or the other. The time delay is equal to the time taken to rotate the array through the angular spacing between the beams and can be derived from the ship's compass if steady-state towing conditions have been achieved. A full 360° of coverage is obtained by towing the array through little more than a semi-circle.

As an example and check of feasibility, a set of parameters is examined in the following chapter.

2 TYPICAL PARAMETERS (see Fig. 1 for geometry)

Frequency, f		500 Hz
Wavelength, $\lambda = \frac{1500}{f}$		3 m
Geometry:		
	Towing circle radius, R	750 m
	Length of tow-cable, L	650 m
	Angle: array to centre to tow-ship, $\alpha = \frac{360L^\circ}{2\pi R}$	50°
	Angle array subtends at centre, $\gamma = \frac{360\ell^\circ}{2\pi R}$	4.6°
	Direction of tow-ship relative to array broadside, $90 - \frac{\alpha}{2}$	65°
Array:	Effective length, ℓ	60 m
	No. of hydrophones, N	40
	Spacing between hydrophones, $s = \frac{\ell}{N}$	1.5 m
	Beamwidth with shading for low side-lobes *[2]*, $BW \simeq \frac{60^\circ}{\ell/\lambda}$	3°
	Deformation of array, $\Delta = R - R\cos\frac{\gamma}{2} \simeq \frac{\ell^2}{8R}$ (i.e. deformation is $\frac{\lambda}{5}$ at 500 Hz)	0.6 m
Beams:	Total no. of beams	10
	First beam at angle, θ_1 (i.e. 6° forward from broadside)	+6°
	Spacing between beams, $\delta\theta$	3°
	Last beam at angle, θ_n (i.e. 21° aft from broadside)	-21°

Rates:

Tow ship speed, V — 5 kn

Time taken to complete circle, $T_o = \frac{2\pi R}{30V}$ — 31 min

Time taken for 360° surveillance using left and right beams, $T_{min} = \frac{180+\theta_1-\theta_n}{360} T_o$ — 18 min

Angular rate, $r = \frac{360}{T_o}$ — 12°/min

Time delay between beams, $\delta T = 60 \frac{\delta\theta}{r}$ — 15 seconds

Time taken to rotate through all 10 beams, $\frac{\theta_1-\theta_n}{r}$ — 2.25 min

The above figures show that it appears reasonable to tow a 60 m long array giving a 3° beamwidth (500 Hz) in a circle 750 m in radius. Using a beamformer with 10 beams suitably delayed or advanced, one could unambiguously measure the total noise field in 18 minutes.

3 MEASUREMENT OF ARRAY SHAPE

The array configuration may be measured initially to check that the array actually deploys properly and as expected. This can be done with a second vessel or buoy, located at the centre of the circle of Fig. 1, from which high-frequency pulses are transmitted both acoustically underwater and by radio. The difference in the time of arrival of the acoustic pulses at some selected hydrophones of the array (with known spacing) and the radio signal, determines the array geometry. A suitable high frequency would be in the region of 2 kHz, with a peak power that may be as low as one watt. Measurements of this type may be carried out continuously for low-frequency systems, as discussed later.

A rougher check of the geometry can be carried out by transmitting from the tow-ship (at 65° from broadside with the parameters previously described). The approximate alignment of the array relative to the tow-ship may be obtained by beamforming on the tow-ship noise or on a signal transmitted from the tow-ship.

The array is expected to tow on a somewhat tighter circle than that followed by the tow-ship.

4 LOW-FREQUENCY MEASUREMENTS

At low frequencies the array becomes very long for high resolution and the deformation from a straight line becomes excessive. If the deformation

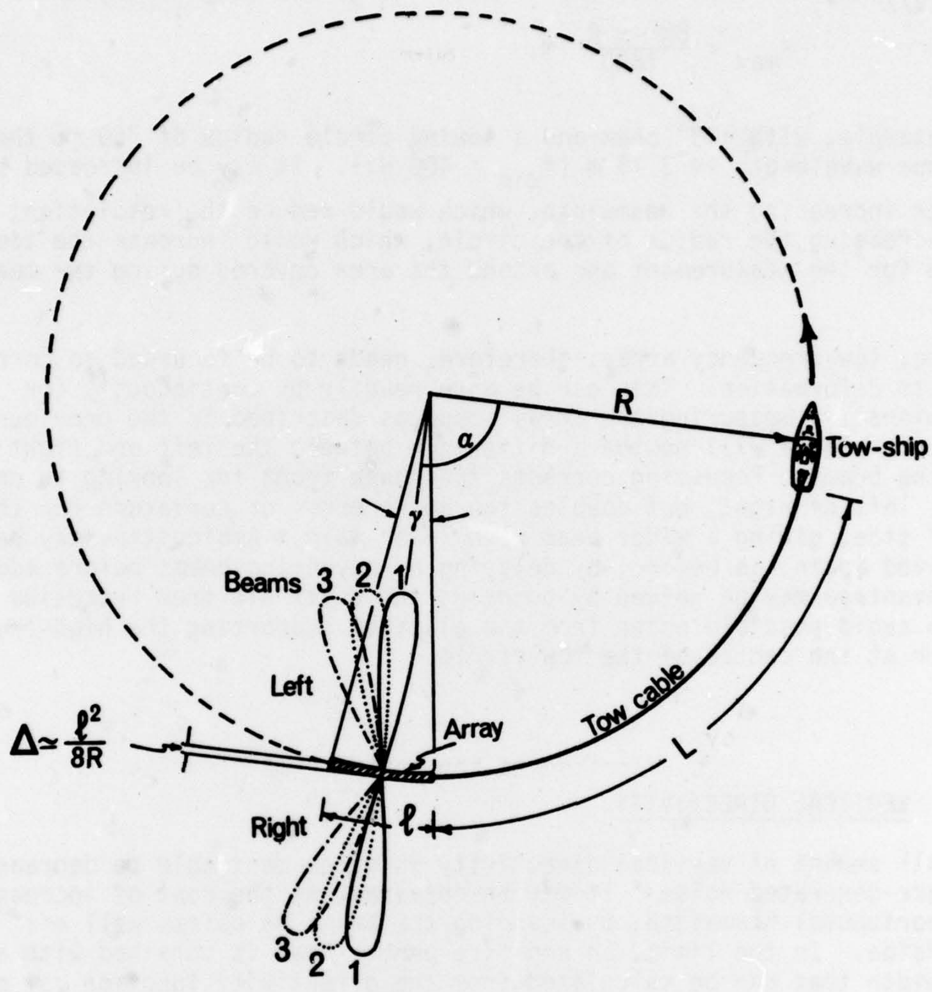

FIG. 1 TOWING GEOMETRY

$\Delta \simeq \frac{\ell^2}{8R}$, is kept below $\frac{\lambda}{4}$ and the aperture is shaded to give a beamwidth

$BW = \frac{60}{\ell/\lambda}$ degrees [2], then the maximum usable wavelength becomes

$$\lambda_{max} \simeq \frac{BW^2 \times R}{1800} \text{ m.}$$

For example, with a 3° beam and a towing circle radius of 750 m, the maximum wavelength is 3.75 m ($f_{min} \simeq 400$ Hz). It may be increased by either increasing the beamwidth, which would reduce the resolution, or by increasing the radius of the circle, which would increase the time taken for the measurement and extend the area covered during the measurement.

A long, low-frequency array, therefore, needs to be focussed to correct for its deformation. This can be done readily by continuously (or occasionally) measuring the array shape as described in the previous chapter. There will now be a difference between the left and right looking beams. Focussing corrects the phase front for looking to one side, left or right, but doubles the phase error or curvature for the other side, giving a wider beam with lower gain. Ambiguities may be resolved again, as before, by delaying or advancing beams before adding. An advantage may be gained by pointing the beams aft from broadside so as to avoid possible noise from the platform supporting the high-frequency pinger at the centre of the tow-circle.

5 VERTICAL DIRECTIVITY

A small amount of vertical directivity is often desirable to decrease surface-generated noise. It may be obtained, at the cost of increasing the horizontal beamwidth, by scanning the beams to points well off broadside. In the limit, an end-fire pencil beam is obtained with a beamwidth that can be calculated from the directivity function [3] of a beam steered to end-fire, as $BW \simeq 108 \sqrt{\frac{\lambda}{\ell}}$ degrees. This beam is wide, but free from ambiguities and may be used for additional processing or for first-order results.

SUMMARY AND CONCLUSIONS

Horizontal noise fields may be resolved into distinct targets and residual noise by means of a towed array system that is towed in a tight circle. Left/right ambiguities may be resolved by forming a number of beams and appropriately delaying and adding them, since targets on opposite sides of the array will walk through the beams with opposite sequence. Long, low-frequency arrays will require a correction for their deformation. This can be done relatively simply by measuring the array shape with short pulses emitted acoustically and by radio from a remote transmitter.

The suggested method of measuring the horizontal noise directionality seems simple and can readily be applied in both deep and shallow water. Further, it may offer some potential for ASW applications.

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