UNDERWATER ARRAY DESIGN AS INFLUENCED BY BACKGROUND NOISE AND PROPAGATION EFFECTS

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ABSTRACT

Research directed toward the improvement of array/signal-processor design techniques is described. System models exist with realistic propagation and anisotropic noise effects but have been too expensive to use for large arrays. However, by incorporating the Toeplitz symmetry of lattice arrays, computer requirements have been reduced substantially. Costs are moderate to analyze systems with different processors and hundreds of hydrophones and look-directions. Characteristics of shipping and surface noise components are discussed since they introduce different array/processor design considerations. Various studies of large arrays are presented such as comparisons of different configurations for the measurement of horizontal directionality of ambient noise.

1. INTRODUCTION

It is desirable to obtain design/performance comparisons for arrays of various sizes and configurations in realistic ocean media. Often designs are obtained inexpensively based upon simple models such as an infinite constant-velocity medium with isotropic or dipole noise. To go beyond such simplistic models for effects of the medium, early work [1] dealt with continuous array distributions in a medium with realistic propagation and vertical noise directionality but uniform horizontal noise character. It was found that array gains from such a model differed by 5 to 10 dB from those for isotropic and dipole models. Horizontal circular arrays were studied [2] and it was found that cardioid hydrophones or vertical array height led to increased gain.

An elaborate system model has been developed [3] at this Center that has very realistic propagation and noise forms and considers the array to have elements located at arbitrary positions in space. Although this versatility is useful and important, the computer program is time consuming and costly, even with conventional beamforming. Therefore the model is not used frequently with arrays of more than 100 elements. To reduce the cost of computation, the possible use of symmetry was suggested by this author. This paper describes the application of symmetry considerations to models and its large reduction of computer requirements, discusses the noise environment and existing models thereof, and presents representative results obtained for large arrays.

2. TOEPLITZ SYMMETRY IN ARRAY ANALYSES

These improvements arise for lattice* arrays [4]. For receiving arrays, the cross-power spectral matrices are Hermitian, positive-definite and have Toeplitz symmetry. An NxN Toeplitz matrix, M, has components,

* A lattice array has uniform inter-element spacing in 1, 2 or 3 dimensions.

M(r,c), that are equal to Q(r-c) where each Q is a scalar for linear arrays and is a matrix for multi-dimensional arrays. Lattice source arrays have similar Toeplitz symmetry but they are complex symmetric, not Hermitian. A decade ago this author developed techniques for the analyses of such source arrays using the recursive method of Trench [5] to invert the system matrix. Another earlier recursive method was developed by Levinson [6]. In the receive array system, the optimal beamformer output can be obtained by inverting the matrix.

The Toeplitz symmetry leads to several reductions in analytical_labor for N-element arrays: (1) the number of unique matrix elements to be computed is proportional to N rather than N^2; (2) each conventional beamformer output requires N rather than N^2 arithmetic operations; (3) the optimal beamformer requires N^2 rather than N^3 operations for the first output but then operations are proportional to N for each subsequent* output; and (4) conventional beamformer complex weight factors can be computed recursively. Additional changes in innermost loop calculations are used to reduce costs and computer hardware requirements.

3. AMBIENT SEA NOISE

The level of the noise environment for arrays in the low- to medium-frequency region [7] is illustrated in Fig. 1. The low frequencies are dominated by distant shipping with discrete azimuthal arrivals from open-ocean and bottom-coupled contributions along certain vertical arrival angles. The middle frequencies are dominated by surface wind noise that is predominantly uniform in azimuthal distribution. Thus, realistic noise models must include contributions from discrete ships in real oceans as well as surface effects. The array design issue is to assess the importance of noise anisotropy and provide techniques to operate in this environment.

Examination of the noise level as a function of frequency reveals a change in the dominant noise mechanism above 200 Hz. System performance will be improved generally due to the lower noise levels and the higher prospective array gain for a fixed-size array. The degree to which beamformer output noise can be decreased depends upon the directional behavior of noise and the ability to use array configurations and optimal and/or conventional beamformers to discriminate between signal and noise in this environment.

The Naval Ocean Systems Center system model used in this study applies to a static time-fixed ocean with ships radiating noise in certain fixed locations. The case in which near-by ships dominate the results was not represented. However, the model allows one to consider the deployment of arrays at various depths, locations and seasons with realistic but time-invariant ambient sea noise. The performance of various systems of array configuration and processor can be evaluated and compared in the same anisotropic noise field and ocean medium.

4. ILLUSTRATION: ARRAYS TO MEASURE THE HORIZONTAL DIRECTIONALITY OF NOISE

This new ability to analyze large-array systems has been used to study the behavior of arrays of various sizes and configurations. More

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* This property holds for all plane-wave-arrival beamforming.

results will be presented in the paper; however, horizontal directional responses of arrays for a typical noise field are used in this extended abstract as an illustration. Figure 2 shows noise gains for horizontal arrays consisting of square and line arrays with 256 elements spaced one-quarter wavelength apart at 150 Hz. Two lines are used, one oriented North-South and one East-West. The noise gain, which is proportional to the inverse of the response of the conventional beamformer, is plotted for one-degree increments of azimuth. The square array has minima at bearings of 340 degrees and 60 degrees where the shipping density is very high. The square has high noise gains for directions of low-level noise. The agreement of the inverse relation between noise gain and directional noise level indicates that the square array measures the noise directionality well. Furthermore, the horizontal planar array provides for simultaneous multi-directional beams of nearly equal width.

The linear arrays oriented East-West and North-South are illustrated here. They have noise gains that do not indicate noise directionality as clearly because the array directional response is rotationally symmetric and, therefore, ambiguous. Methods to reduce the effects of ambiguity are available but measurement of horizontal noise levels in quiet directions is a problem, especially with arrays with horizontal ambiguity.

5. PROCEDURES FOR ANALYSES OF VERY LARGE ARRAYS

The analyses for very large arrays can be reduced further in cost. The directionality of noise gain has been found to be not highly dependent upon array size. Thus, arrays of moderate size can be analyzed to determine general trends and then a few appropriate computations can be done for the large array as verification. In fact, even some non-lattice arrays can be studied using the lattice-array results to show general trends much as the discrete Fourier transform (DFT or FFT) yields results for functions that are not uniformly discrete.

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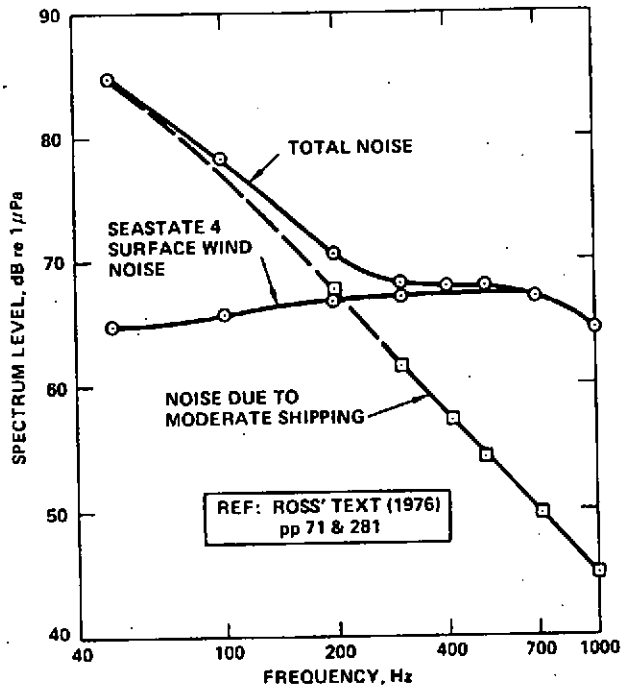

FIGURE 1. TYPICAL AMBIENT SEA NOISE

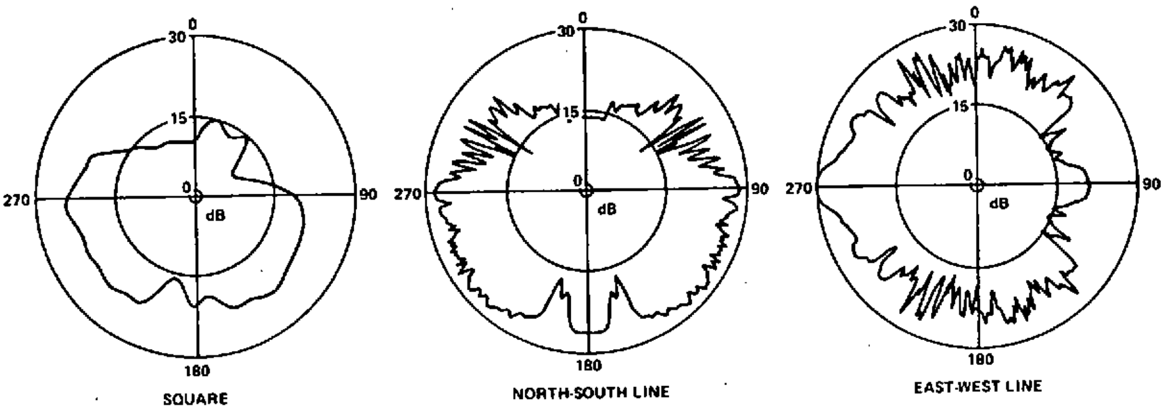

FIGURE 2. HORIZONTAL NOISE GAIN RESPONSE FOR ARRAYS WITH
N = 256, D = 8 FT, f = 150 Hz, STEERED 10° UPWARD