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Optimal Design of a Sparse Planar Array Transducer for Underwater Vehicles by Inclusion of Crosstalk Effect

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1. Introduction

Planar underwater array transducer is comprised of various uniform or random arrangements of radiating elements, which may serve as either transmitters or receivers or both at the same time. A uniform fully sampled array transducer provides good imaging, yet, it is limited in performance owing to crosstalk, high cost and complexities in fabrication. The drawbacks associated with the fully sampled array transducer can be overcome by reducing the number of active elements in the array. The sparse array technique is a promising approach, which can be achieved either by periodic or random selection of the best set of active elements, but it demands a very careful investigation to find the performance level that matches a fully sampled array. One important aspect of such arrays is mutual acoustic impedance and should not be ignored when considering arrays of closely spaced transducer elements and can govern their interaction [1].

This work focuses on inclusion of the cross talk effect in the optimal sparse planar array in order to achieve more realistic performance estimation. The analytical computation of radiation pattern of the optimal sparse planar array was carried out to include the mutual acoustic interaction of the array elements.

2. Radiation Pattern Computation including the Crosstalk Effects

Sparse-array is a technique which effectively decreases the number of elements either randomly or periodically by deactivating some elements of the 2-D planar array [2]. The resultant radiation pattern can be computed by multiplying the array of simple sources with element source radiation pattern, i.e. product theorem [3], as specified in Eq. (1).

$$H_{eff}(\theta,\phi) = H_E^2(\theta,\phi)\times H_T(\theta,\phi)\times H_R(\theta,\phi) \quad (1)$$

where, H_{eff} is an effective array radiation pattern of a transmit-receive array, H_E is a single element radiation pattern, and H_T & H_R are transmitter and receiver array radiation patterns, respectively.

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When the array transducer comprises more than two sources such as the sparse array and the fully dense planar array we should take mutual interference between sound sources into consideration to predict realistic array performance. Acoustic interaction is caused when acoustic force generated by one source is exerted on the other sources in the array transducer as shown in **Fig. 1**.

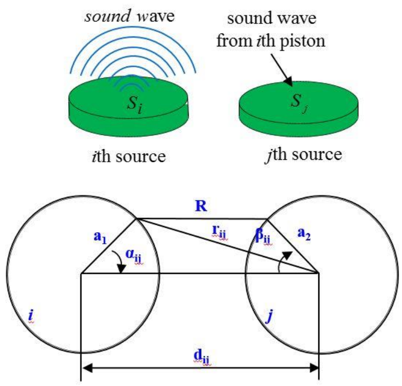

Fig. 1 Two piston sources in close vicinity with respective nomenclature.

To include the effect of acoustic interactions, the mutual and self-radiation impedances were computed for each of the piston sources of the optimal sparse array. For the array of in phase piston sources with similar shape and cross sectional area arranged along x-axis and y-axis on a rigid baffle, far field acoustic pressure including the cross-talk effect of the piston sources can be calculated by summation of the product of mutual radiation admittance and directivity function of the two sources at a time to calculate the total pressure field in term of the special coordinates(φ & θ), and can be expressed as Eq. (2).

$$p(\theta,\phi) = A\sum_{v=1}^{V}\sum_{w=1}^{W}[Y_{vw}]H_E(\theta,\phi)(\cos\gamma + i\sin\gamma) \quad (2)$$

where, $\gamma = k(x\sin\theta\cos\varphi + y\sin\theta\sin\varphi)$, A is the intensity of the source, V and W are total number of sources along x-axis and y-axis, respectively ($V = W$), $[Y_{vw}]$ is the mutual radiation admittance matrix which is the inverse of the mutual radiation impedance matrix, k is wave number, and x and y are inter-element spacing along x-axis and y-axis respectively.

3. Finite Element Analysis (FEA) of Array

The planar array quarter model with symmetries about x and y axes was used for the radiation pattern computation at a far field point. The finite element model of the quarter array is shown in **Fig. 2**. Radiation patterns were computed using the finite element method (FEM) for three azimuth planes of interest, including 0°, 22.5° and 45°, respectively.

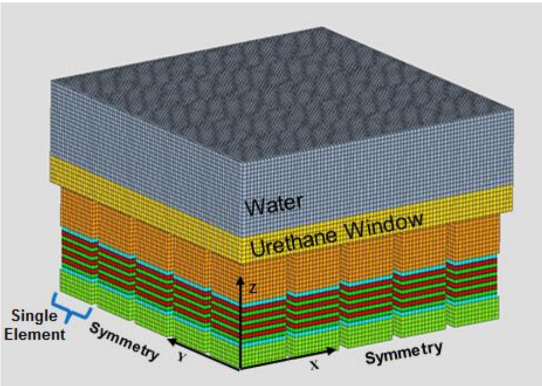

Fig. 2 Finite element model of quarter planar array.

FEA results showed a good agreement with analytical results for both the main performance parameters including peak side lobe level (PSLL) and main lobe beam width (MLBW). The radiation pattern computed by including the crosstalk effect showed excellent agreement in contrast to the radiation pattern computed without inclusion of the crosstalk.

4. Results and Discussion

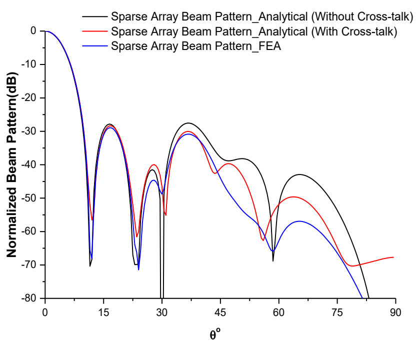

Fig. 3 Radiation pattern comparison for optimal sparse planar array for the azimuth angle of $\phi = 0°$.

Analytical radiation pattern calculation results for optimal sparse array by considering the mutual acoustic interaction of the array elements were compared with those computed without considering these interaction in **Fig. 3** that includes the result of FEA as well. Normalized PSLL optimal sparse array was -27.9 dB using analytical calculations without crosstalk, -28.4 dB with crosstalk included and -28.9 dB through FEA, respectively**.** A similar agreement of results was achieved for the -6 dB MLBW between analytical calculation by considering crosstalk effect and that using FEA. All the summarized results for optimal sparse array for 0° azimuth angle are presented in **Table I.**

Table I. Comparison of optimal sparse arrays performance for three methods.

Performance Parameter	Method	Azimuth Angle(φ)
		0°
PSLL	Analytical (without crosstalk)	-27.9 dB
	Analytical (with crosstalk)	-28.4 dB
	FEA	-28.9 dB
MLBW (-6 dB)	Analytical (without crosstalk)	10.2°
	Analytical (with crosstalk)	10.3°
	FEA	10.3°

5. Conclusion

The optimal sparse array transducer designed in this work could provide performance equivalent to that of a fully dense array while using a half of the initial array elements. Analytical radiation pattern by including the crosstalk effect showed excellent agreement with those computed using the FEM.

Acknowledgment

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