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Analysis of the Crosstalk in an Underwater Planar Array Transducer using the Equivalent Circuit Method

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1. Introduction

Underwater acoustic transducer is utilized for detection and tracking of objects in underwater environment. Normally, however, it is difficult to achieve desired performance by using a single transducer element. Hence, various arrangements of transmitting and receiving transducers are employed to meet the specifications for different purposes. In the array of transducers, however, crosstalk is likely to take place in between the elements composing the array. The acoustic performance of the array transducer is deteriorated by the induced crosstalk [1, 2].

In this study, an equivalent circuit has been developed to analyze the crosstalk between projectors and hydrophones of a planar array transducer. The equivalent circuit can facilitate the analysis of the crosstalk than using other methods. The validity of the equivalent circuit analysis was verified by comparing the results with those analyzed with the finite element method (FEM).

2. Underwater Planar Array Transducer Model

The planar array transducer in this study consists of one projector and many hydrophones. All of them are arranged on an acoustic window. A Tonpilz transducer was used for the projector while piezoelectric bar type transducers were used for the hydrophones. The active material for both the projector and the hydrophone was $Pb(In_{1/2}Nb_{1/2})O_3$-$Pb(Mg_{1/3}Nb_{2/3})O_3$-$PbTiO_3$ (PIMNT) [3].

The drive section of the projector was composed of eight active elements laminated in alternating poling directions to achieve low electro-mechanical impedance and high power at a resonant frequency. The hydrophone has a piezoelectric bar attached to an epoxy backing and works like a simple spring mass system. The hydrophone was designed to have an anti-resonant frequency that coincided with the resonant frequency of the projector.

A finite element model of the planar array transducer composed of 5 x 5 elements was constructed as shown in **Fig. 1** to analyze the crosstalk level between the array elements. The planar array transducer is composed of one projector and twenty four hydrophones which have inter element spacing of 8 mm. The twenty five transducers were distinguished by the numbering order as shown in **Fig. 2**.

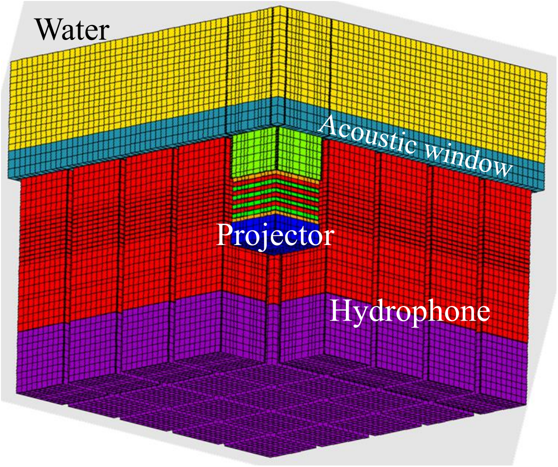
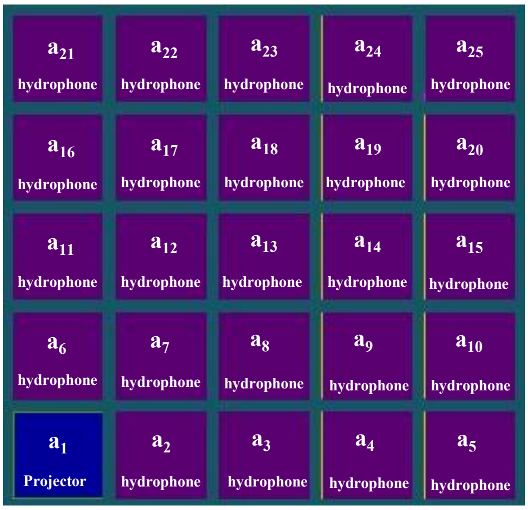


Fig. 1 Finite element model of the planar array transducer.



a_{21} hydrophone	a_{22} hydrophone	a_{23} hydrophone	a_{24} hydrophone	a_{25} hydrophone
a_{16} hydrophone	a_{17} hydrophone	a_{18} hydrophone	a_{19} hydrophone	a_{20} hydrophone
a_{11} hydrophone	a_{12} hydrophone	a_{13} hydrophone	a_{14} hydrophone	a_{15} hydrophone
a_6 hydrophone	a_7 hydrophone	a_8 hydrophone	a_9 hydrophone	a_{10} hydrophone
a_1 Projector	a_2 hydrophone	a_3 hydrophone	a_4 hydrophone	a_5 hydrophone

Fig. 2 Numbering of the elements.

The acoustic pressure generated by the projector is transferred to adjacent hydrophones through omnidirectional propagation of the wave. Further, since the planar array transducer has an acoustic window that the entire array elements share, the lateral sound wave radiated from the projector can affect adjacent hydrophones. These interactions cause the crosstalk that results in electric voltage signals in the hydrophones.

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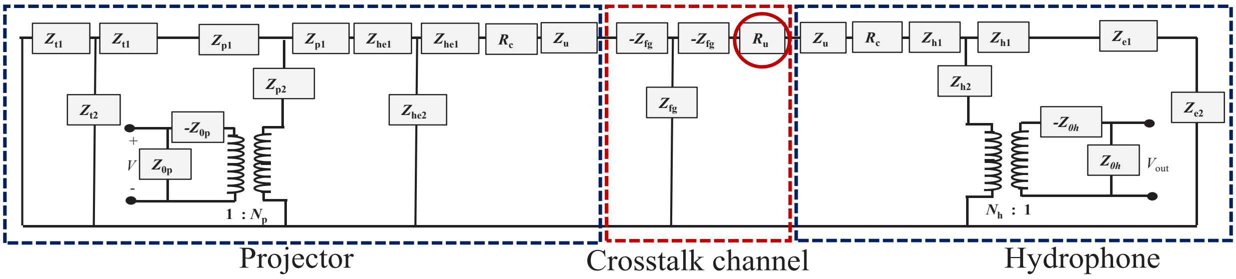

Fig. 3 Equivalent circuit for calculation of the crosstalk level.

The voltage generated on the hydrophone was analyzed in relation to the spike voltage (1V) on the projector in time domain. The voltage was also transformed to frequency domain for further analysis.

3. Analysis of the Crosstalk Level with the Equivalent Circuit

Equivalent circuit in **Fig. 3** describes the same transducer structure as that planar array transducer analyzed in the FEA, which consists of a Tonpilz projector and a bar type hydrophone. The equivalent circuit in Fig, 3 allows the analysis of the crosstalk signal that was generated by the projector and received by the hydrophone. The projector and the hydrophone were connected by a T-network that describes mutual radiation impedance between the array elements [4]. The wave generated by the projector radiates to the acoustic window, and the wave is received by the adjacent hydrophones that share the acoustic window. Then the hydrophones generate voltage signals in proportion to the crosstalk signals. The equivalent circuit in Fig. 3 is a series connection of the projector, self-radiation impedance in the acoustic window of the projector, mutual radiation impedance between the array elements, self-radiation impedance in the acoustic window of the hydrophone, and the hydrophone.

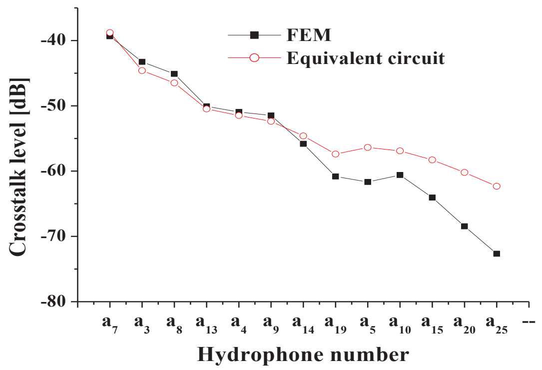

Fig. 4 Comparison of the crosstalk levels calculated by the equivalent circuit with that by the FEM.

The crosstalk level was analyzed using the FEM and then was compared with that calculated with the equivalent circuit as shown in **Fig. 4**. The horizontal axis of the graph is the hydrophone number (a_3~a_{25}), which enumerates the hydrophone from the nearest one to the farthest one from the center of the projector placed on a_1. The two crosstalk levels showed quite good agreement with each other up to a certain range from the projector. The multiple crosstalk between hydrophones limits the effective range of the circuit within a certain distance from the projector. Consequently, the equivalent circuit in Fig. 3 was confirmed to be suitable for analysis of the crosstalk within a certain distance from the projector.

4. Conclusions

We developed the equivalent circuit to analyze the crosstalk in a planar array transducer and verified the validity of the circuit. The equivalent circuit can analyze the crosstalk level in a much more simple and efficient way than other numerical methods like the FEM. However, the analysis with the circuit is valid only within a certain distance from the projector because the circuit cannot include the multiple interference between distant hydrophones.

Acknowledgment

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