An Approach for Implementation of Underwater Acoustic Communication Channel using 2-D TLM Modeling and Cross-Correlation Function

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***Abstract*— In underwater acoustic communication, acoustic signals from transducers or hydrophones are used. And the underwater acoustic communication channels are very complicated, because of vertical distribution of acoustic velocity according depths, and reflections from boundaries like as surface or bottom. For the implementation of the underwater acoustic communication channel, the image method or ray tracing method have been used. In this paper, we introduce a new approach for implementation of underwater acoustic communication channel using the simulation of the Transmission Line Matrix Modeling and cross-correlations from the input and output signals.**

***Index Terms*— Cross-correlation function, Image Method, Transmission Line Matrix Modeling, Underwater Acoustic Communication Channel.**

I. INTRODUCTION

For the telecommunication, radio waves are used in the air, whereas acoustic waves are used in underwater using transducers and hydrophones. And the underwater acoustic communication channels are very complicated than in the air, because of vertical distribution of acoustic velocity according depths, and multi-reflections from boundaries like as surface or bottom, and etc. For the implementation of the underwater acoustic communication channel, traditionally the image method or ray tracing method has been used [1]. But in image method, it is impossible to consider effects of acoustic velocities according water depths. While in ray tracing method, it needs sound rays between input and output sensors by trial and error for all directions.

In this paper, we introduce a new approach for implementation of underwater acoustic communication on channel using two-dimensional transmission line matrix (TLM) modeling and cross-correlation function. TLM modeling [2]-[5] is used for simulation of the underwater acoustic wave propagations; cross-correlation function [6] is used for extract the impulse response from the signals on input and output sensors.

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II. 2-DIMENSIONAL TLM MODELING

TLM modeling is based on the Huygens' principle, which provides time domain solution through the wave propagations [2]. In TLM modeling, the region to be calculated is divided into two-dimensional elements with *L-C* as shown in Fig. 1. The circuit equation is produced from this element, and then it is corresponding with the wave equation on acoustic filed.

The circuit equation about voltage V on TLM element and the wave equation about sound pressure p on acoustic field are given as

$$\frac{\partial^2 V}{\partial x^2}+\frac{\partial^2 V}{\partial y^2}=2LC\frac{\partial^2 V}{\partial t^2} \tag{1}$$

$$-\frac{\partial^2 p}{\partial x^2}+\frac{\partial^2 p}{\partial y^2}=\frac{1}{c^2}\frac{\partial^2 p}{\partial t^2}=\frac{\rho}{\kappa}\frac{\partial^2 p}{\partial t^2} \tag{2}$$

From Eqs. (1) and (2), the sound velocity and the characteristic impedance on TLM element are given as

$$c=\sqrt{\frac{\kappa}{\rho}}=\frac{1}{\sqrt{2LC}} \tag{3}$$

$$Z_0=\rho c=\sqrt{\frac{L}{2C}} \tag{4}$$

where, ρ, c, κ are respectively the medium density, the propagation velocity in the medium, and the bulk modulus.

For the acoustic speed changes in boundaries like as surface or bottom, the fifth short-circuited branch [5] with the characteristic impedance Z_0/η is considered as shown Fig. 2. Then the propagation velocity on different medium is given as

$$c_T=\sqrt{\frac{4}{\eta+4}}c \tag{5}$$

So we can model the surface effect, bottom effect and velocity variable effect using η.

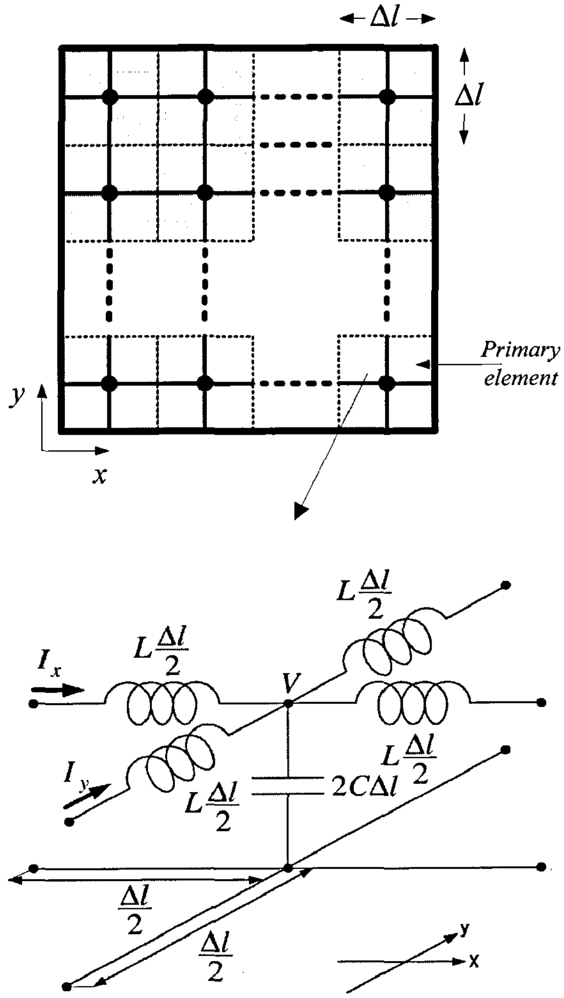

Fig. 1. 2-D TLM primary element.

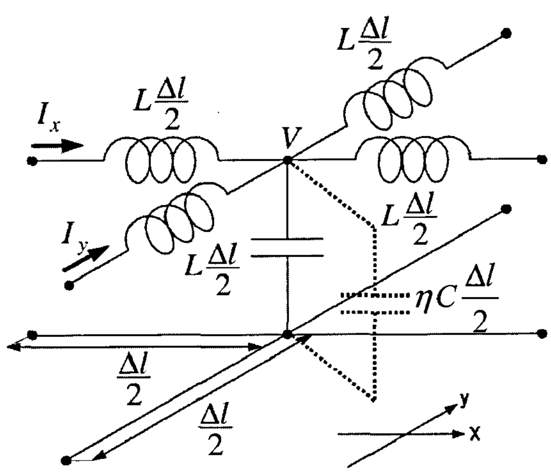

Fig. 2. TLM element with a variable velocity branch.

III. THE PROCEDURE OF THE IMPLEMENTATION OF THE UNDERWATER ACOUSTIC COMMUNICATION CHANNEL USING CROSS-CORRELATION FUNCTIONS AND THE IMAGE METHOD

For the implementation of the underwater acoustic communication channel, we first simulated the wave propagation in the underwater acoustic model, and then calculated the cross-correlation functions between the input signal and the output signal. If the input signal is $x(t)$, then the auto-correlation of input signal and the cross-correlation between the input signal and the output signal are respectively given by

$$\gamma_{xx}(\tau)=\frac{1}{N+1}\sum_{t=0}^{N}x(t)x(t-\tau) \tag{6}$$

$$\gamma_{xy}(\tau)=\sum_{k=0}^{N}A_k\gamma_{xx}(\tau-\phi_k) \tag{7}$$

where, k=0 means the direct-path signal, the others are reflection signals from top or bottom. A_k, ϕ_k respectively mean the amplitude and the phase delay on k-th signal. In the deep sea, N becomes 1 because there are a direct-path signal and a reflection signal from top. In the shallow sea, N becomes 2 if there are the direct-path signal and 1st reflection signal from top and 2nd reflection signal from bottom.

From the propagation, we used the cross-correlation functions between the input signal and the output signal to extract the underwater acoustic communication channels. Figure 3 shows the procedure of implementation of the underwater acoustic communication channel. In Fig. 3, (a) shows the auto-correlation function of the input signal, (b) shows the first cross-correlation function between input and output signals, (c) shows the result, subtract (a)'s signal from (b)'s signal using shift operation and scale operation, (d) shows the result, subtract (a)'s signal from (c)'s signal, and (e) shows the underwater acoustic communication channels implemented from above results.

For the numerical simulations, we use three simulation models as shown as Fig. 4 – only water, air-water, and air-water-mud. We put a transmitter and 4 receivers with the same distances in the model. The pair of a transmitter and 1st receiver was regarded as the vertical channel. The pair of a transmitter and 4th receiver was regarded as the horizontal channel. The material property are as follow – the velocity and density of air are respectively 340*m/s*, 1.2*kg/m*^{2}, the velocity and density of water are respectively 1,500*m/s*, 1,000*kg/m*^{2}, and the velocity and density of mud are respectively 1,800*m/s*, 1,800*kg/m*^{2}.

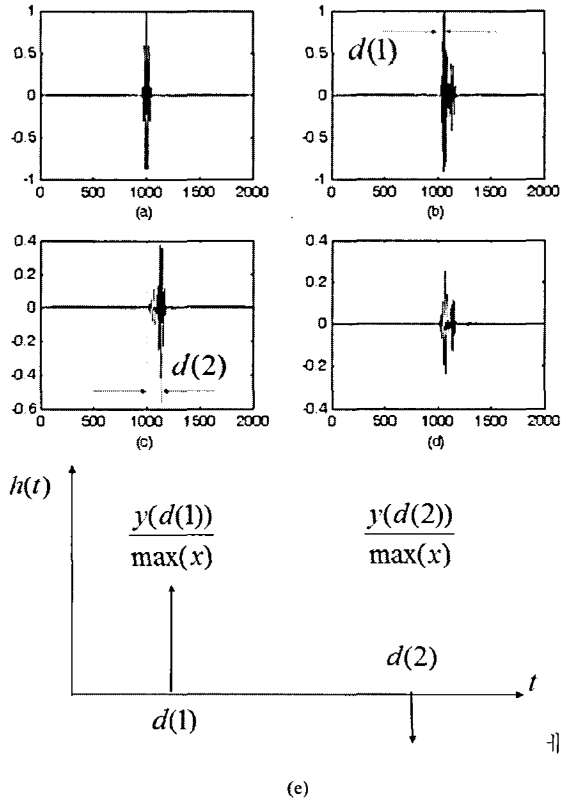

Fig. 3. Procedure of implementation of the underwater acoustic communication channel.

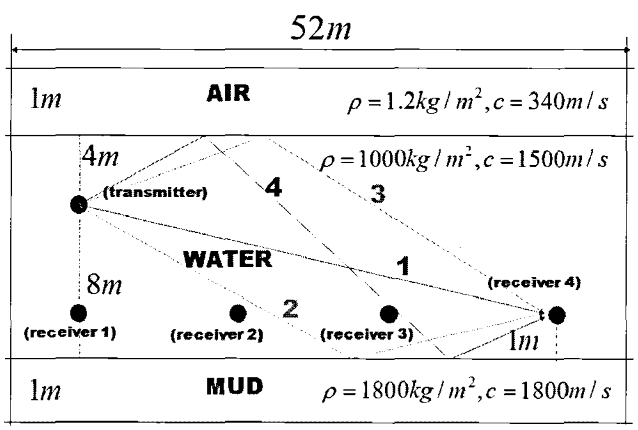

Fig. 4. The simulation model

First model has not any boundaries, it is regarded the homogeneous region. We can only get the first signal through path 1. Second model has no bottom assumed the deep water. We can expect two signals through path 1 and 3. Third model, assumed the shallow water, has mud region in bottom. We can expect four signals through path 1, 2, 3 and 4.

For the comparison of the results, we calculated the underwater acoustic communication channel using the image method [1]. The image method is suitable for the case which has no changes of acoustic velocities according to water depths. It is just considered amplitudes and time delays according to distances between the transmitter and the receiver shown as Fig. 5.

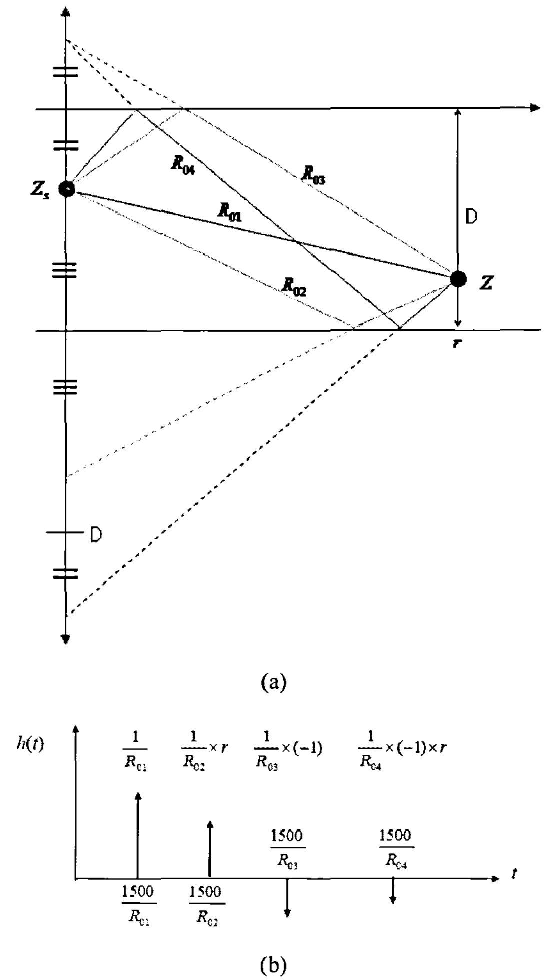

Fig. 5. Scheme of the image method according to Fig. 4's model.

IV. THE RESULTS OF THE SIMULATIONS

The used input signal is used *sinc* function as shown Fig. 6. The primary element size $\Delta l = 0.1m$ is used, so total divided region become $509 \times 130 \Delta l$ s. The wave propagation results using TLM modeling are shown in Fig. 7. In Fig. 7, (a) is wave propagation state in only the water, (b) is wave propagation state in deep water, (c) is wave propagation state in shallow water. In Fig. 7, (a) has just the direct signal, (b) has a direct signal and a reflect signal from top boundary, and (c) has a direct signal and several reflection signals from top and bottom boundary. In Fig. 7, (d) is time signal on (a) at receiver 4, (e) is time signal on (b) at receiver 4, and (f) is time signal on (c) at receiver 4. In Fig. 7(f), it appeared the complicated signal owing to the reflections on top and bottom boundaries.

To extract automatically the communication channel from this complex signal, cross-correlation functions are used. Figures 8, 9 and 10 show the results of implementation of underwater acoustic channels with two methods. In Fig. 8, both results are exactly same on each 4 receivers. The results from all receivers also correspond to the ones from the image method in Fig. 9, In Fig. 10, results from receiver 1 and 4 correspond the ones from the image method. But results from receiver 2 and 3 are some different from ones from the image method. We assume that different results owing to signal distortion like as wave dispersion or wave overlaps.

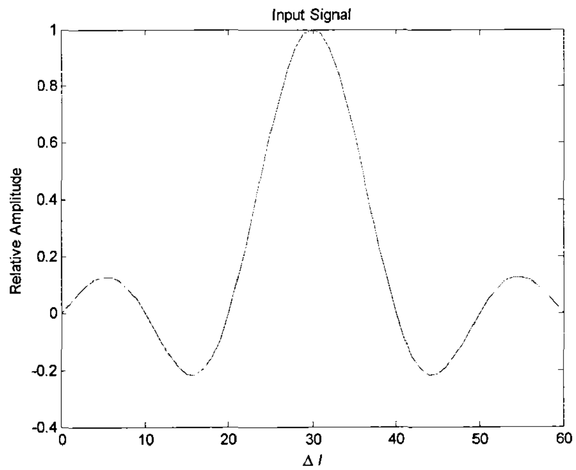

Fig. 6. Input signal

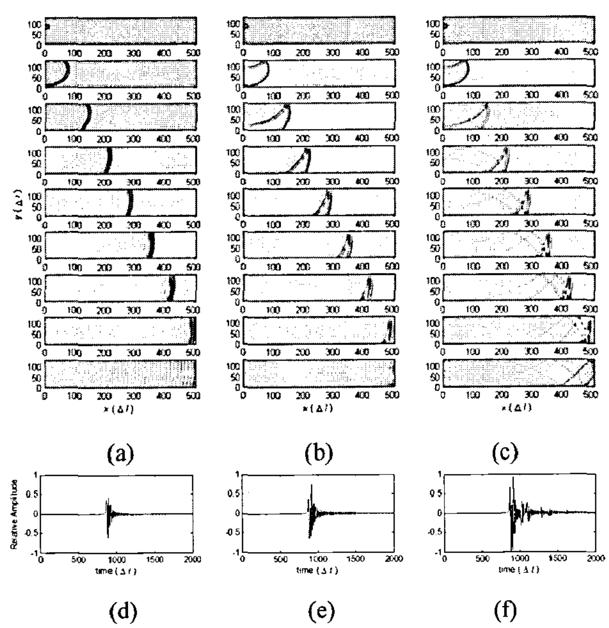

Fig. 7. Wave propagation results using TLM modeling

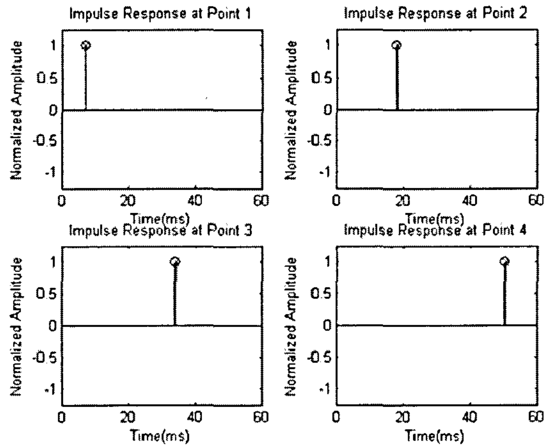

Fig. 8. Comparison of underwater acoustic communication channel for only the water (○: image method, ×: TLM modeling).

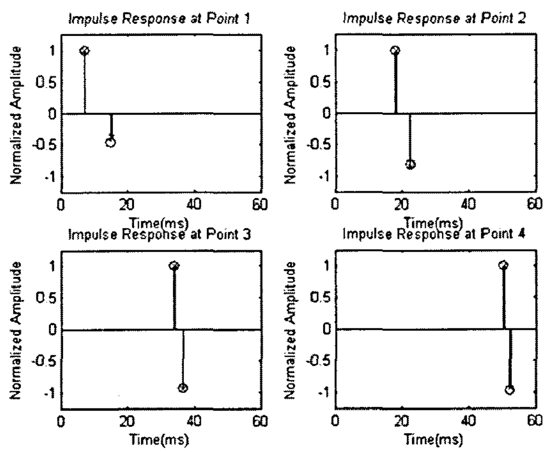

Fig. 9. Comparison of underwater acoustic communication channel for the deep water (○: image method, ×: TLM modeling).

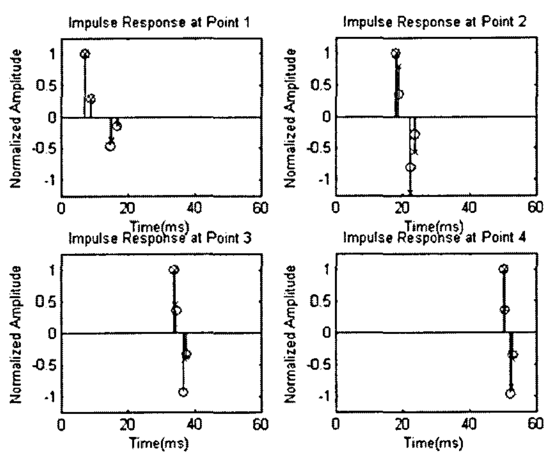

Fig. 10. Comparison of underwater acoustic communication channel for the shallow water (○: image method, ×: TLM modeling).

IV. CONCLUSIONS

We introduced a technique for implementation of underwater acoustic communication channel with TLM modeling and cross-correlation function. We got reasonable results from the introduced method, especially in only water model and deep water model. It means this approach can be used to implement the underwater acoustic communication channel under the homogeneous region. In the shallow water model, the results from receiver 2 and 3 had some differences from ones from the image method. We assume that different results owing to signal distortion like as wave dispersion or wave overlaps. So, further considerations are required on relationships between element sizes and input wave's shapes and its periods. In further study, we will apply this approach to the region with vertical sound velocity variation according the water depths.

Using this approach, first it is possible to implement the underwater acoustic communication channel by one single try, not like as the ray tracing method. Second, it can be also reduced the dimension of the simulation model and the calculation time by cross-correlation function. Third, it can be applied for the implementation the channel like as very complicated underwater boundaries, not like as the flat bottom. Finally, if it will be considered the effect of sound velocity according the water depths, it will be more powerful approach to implement the underwater acoustic communication channel, not like as the image method.

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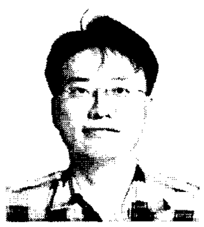

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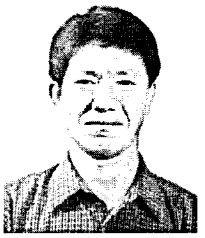

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