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An Experimental System Based on Pseudo-Scale Model of Air-Sea Two-Layer Problem Operated at 100 MHz

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***Abstract*— To study the electromagnetic field distribution in air-sea two-layer problem for a 10 kHz band undersea location estimation, a 100 MHz band transmitter-receiver experimental setup is constructed in our laboratory using the pseudo-scale model and the electromagnetic field distribution is measured. The received power distribution when the transmitting antenna is placed on the liquid surface and the receiving antenna is scanned underwater is a good agreement with FDTD simulation results, confirming that the measurement is possible even in locations with low receiving strength, including lateral waves.**

Keywords—air-sea two-layer problem, pseudo-scale model, received power distribution, FDTD simulation

I. Introduction

A diver position estimation system using electromagnetic waves in shallow waters has been studied by the authors [1]. For this reason, we have been investigating the behavior of electromagnetic waves in two layers composed of air and seawater. Since experiments on electromagnetic wave propagation in water are difficult due to time and cost, we have proposed a model based on the pseudo-scale model law and have conducted laboratory experiments to validate the proposed model [2].To address the air-sea two-layer problem at a frequency of 10 kHz, an experimental system with a scale factor of $n = 100$ has been constructed in the 100 MHz band to measure the received power distribution from a diver's underwater dipole antenna at several different locations. However, in our experimental system, the received power distribution is sometimes disturbed due to the installation of multiple receiving antennas and asymmetry in the received power distribution due to variance the fabrication accuracy of each antenna. In order to improve the measurement accuracy of the experimental setup for the 100 MHz band pseudo-scale model ,this paper reports the results of measuring the received power distribution using the modified experimental setup and comparing it with the results of FDTD simulation [3] .

II. Experimental System for Pseudo-Scale Model

Figure 1 shows our proposed model for estimating the position in seawater at 10 kHz [1]. The lower half-space $z > 0$ corresponds to a sea water area of 50 m × 50 m × 9 m. Nine cross dipole antennas R_n $(n = 1, 2, \ldots, 9)$ are installed as receiving antennas. The diver is equipped with an x-oriented dipole antenna as the transmitting antenna and a depth gauge to measure the water depth. The operating frequency is 10 kHz. The antenna elements of the cross dipole antenna are oriented in x- or y- direction.

Figure 2 shows the pseudo-scale model experimental system corresponding to the underwater location estimation model. In this experiment, salt water with conductivity $\sigma = 4.12$ S/m is poured into a water tank, The scale factor is chosen to be $n = 100$, so the frequency of 10 kHz in the original model is converted to 100 MHz in the pseudo-scale model. The transmitting and receiving dipole antennas are composed of two inner conductors bent of two semi-rigid cables at right angle and a 180 degree hybrid coupler [4]. The transmitting antenna is a 20 mm long crossed dipole, with its center located 1 mm below the liquid surface, connected directly to the signal generator. The receiving antenna consists of a 20 mm long dipole oriented in the x direction and is connected to a spectrum analyzer via pre-amplifier. To reduce the effects of the coaxial cables including semi-rigid cables connecting the antennas and 180 degree hybrid coupler.

The dimensions of the tank used for the measurements were 1200 mm × 600 mm × 450 mm. The movable range of the receiving antenna attached to the 3-axis slider system is set to -200 mm $\leq x \leq 200$ mm, 0 mm $\leq y \leq 400$ mm, and 10 mm $\leq z \leq 90$ mm. The measurement interval is set to 20 mm in the x, y, and z direction. The slider is paused at the scanning grid points, and the signal received by the receiving antenna is measured with a spectrum analyzer.

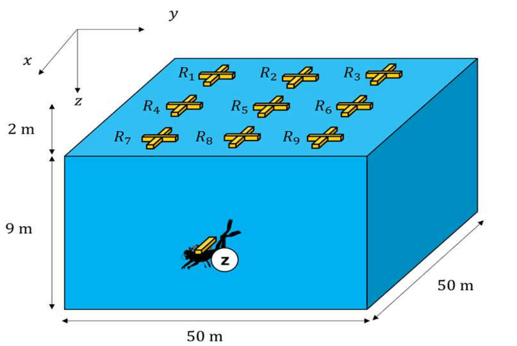

Fig. 1. Overview of underwater location estimation.

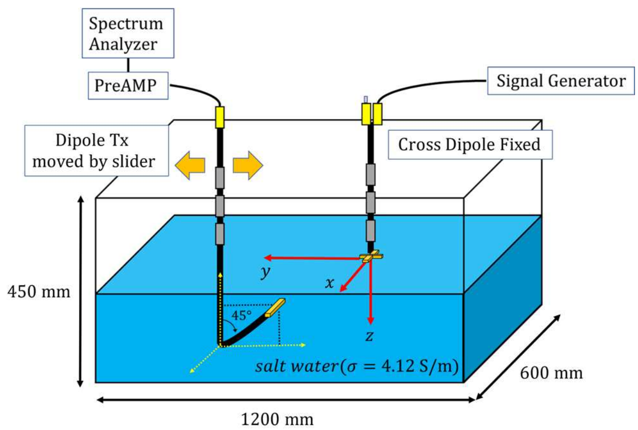

Fig. 2. Laboratory experiment system using pseudo-scale model.

III. Measurement Results

Figure 3 shows the received power distribution at a depth of $z = 30$ mm when the transmitting antenna is placed at $x = 0$ mm and $y = 0$ mm. In this paper, we focus on the normalized received power T_x when the transmitting and receiving antennas are oriented in the x direction. T_x is defined as the ratio of received power to transmitted power. The distribution is symmetrical along the y-axis. The directivity of small dipole antenna can be observed, but large magnitude can be found along the dipole axis because two parallel dipole antennas are used in the measurement. When the distance between the transmitting and receiving antenna is short, the effect of direct waves is apparent, with the field intensity rapidly decreasing with distance. In contrast, when the distance is longer than 100 mm, the rate of decrease in field intensity becomes slower. This is considered to be due to the predominance of lateral waves. In addition, a region of smaller electric field intensity appears $x = \pm$ 200 mm, and $y =$ 100 mm. this is considered to be caused by the null of lateral waves. Although not shown in the figure, when unbalanced current countermeasures are not taken, the distribution is not y-axis symmetrical in the lateral wave region, and a distribution showing a constant level is obtained from the middle of the lateral wave region. These defects have been eliminated in the distribution as shown in Fig. 3.

Next, we compare the results with FDTD simulations. Figure 4 shows one-dimensional distributions along $x = 0$ mm, $z = 30$ mm, and 70 mm. Note that the field intensity from FDTD simulation is offset at its peak value to compare it with the measured results. The FDTD results show a steep change in slope at $y = 150$ mm and 200 mm for depths of $z = 30$ mm and 70 mm, respectively. This is because the electric field from the transverse path through the air in part is larger than the field from the direct path between the antennas in the sea. Also, the slope changes around $y =$ 380 mm, which may be due to the effect of the absorbing boundary. Comparing the measured and FDTD results, the attenuation characteristics along the y-axis are in good agreement. Although there is a slight deviation in the low reception strength region, the difference is within 3 dB. The received power distribution of the experimental pseudo-scale model at 100 MHz has the characteristic of gradually decreasing in the lateral wave region where the received power is small, and our prototype pseudo-scale model of the air-sea two-layer problem is experimentally verified. In other words, the above agreement in the lateral wave region confirms that the boundary conditions of this two-layer problem work well in the experimental system for our proposed pseudo-scale model.

IV. Conclusion

In this paper, we improve the experimental system for the pseudo-scale model of the air-sea two-layer problem in order to accurately measure the power distribution received by a small dipole antenna placed underwater from a transmitting dipole antenna placed on the liquid surface at 100 MHz. The measurement results agree well with the FDTD results, confirming that the improved experimental system is capable of measuring the electromagnetic field distribution of the air-sea two-layer problem.

In the future, we will evaluate our proposed underwater locating system [1][5] in the laboratory using the experimental pseudo-scale model that is validated in this paper.

Acknowledgment

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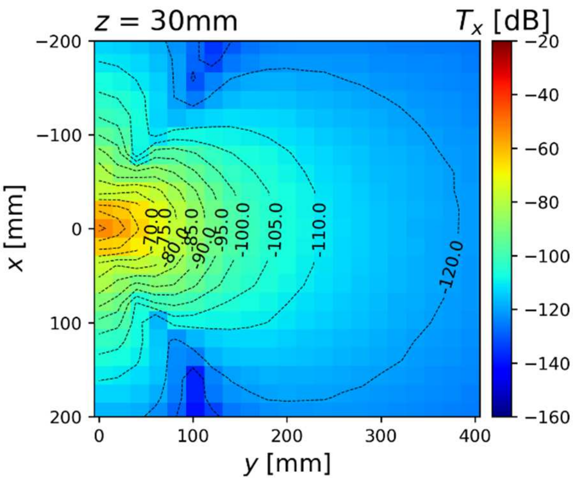

Fig. 3. Received power distribution at a depth of $z = 30$ mm when the transmitting antenna is placed at $x = 0$ mm and $y = 0$ mm.

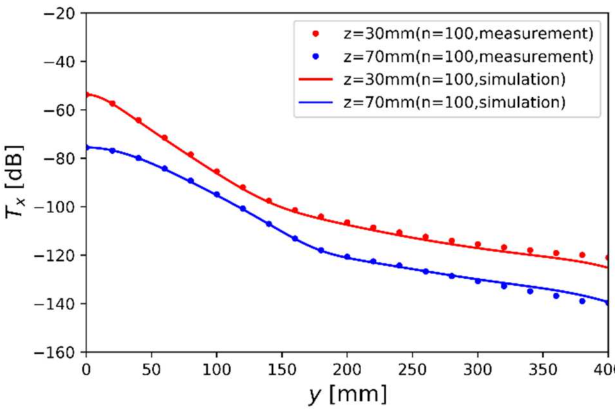

Fig. 4. Comparison of FDTD simulation and measurement results along $x = 0$ mm for depth of $z = 30$ mm and 70 mm.