Scaled Transmission Measurement Between Dipole Antennas in Proximity to PVC Pipe in Seawater

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***Abstract* - The authors have investigated the feasibility of establishing a undersea electromagnetic communication system for maintenance and inspection of floating offshore wind turbines. Wireless communication in seawater is known to have a serious problem of high attenuation of electromagnetic waves. To solve this difficulty, the authors paid attention to undersea support structures and considered that the lower floating concrete tube could be used as a waveguide to reduce propagation loss. In this paper, using a scale model of the concrete tube, vinyl chloride pipe is immersed in simulated seawater, and the transmission characteristics between dipole antennas placed near the vinyl pipes were measured, confirming that the presence of the dielectric tube reduces the propagation loss between the dipole antennas.**

***Keywords* — offshore wind turbines, undersea radio propagation, scale model, dielectric tube, transmission.**

I. INTRODUCTION

In recent years, there has been a lot of technological development in renewable energy, and offshore wind power generation has been paying attention in Japan. At present, visual inspections by divers are the main method of maintenance for these underwater support structures, but this poses a problem of lack of trained personnel. Drones are being used for inspections to deal with this problem, but ordinary underwater drones are connected to a mothership with cables (tethers), making it difficult for them to move around freely.

Wireless underwater drones using electromagnetic waves are expected to be introduced, but underwater radio propagation has limitations in communication distance and capacity. To solve this problem, we propose to use the interior of concrete as a propagation path as shown in Fig. 1 [1]. It is believed that using the concrete structure of an offshore wind farm will reduce the attenuation of electromagnetic waves in seawater and enable more efficient communication.

In this paper, we experimentally confirm that the presence of a lower floating structure can significantly reduce attenuation in the entire propagation path. It can be modeled by a concrete tube, and the transmission distance characteristics were measured using a scaled model with vinyl chloride pipe (hereafter referred to as “PVC pipe”). As a result, we find that the transmission distance characteristics clearly differ depending on the presence or absence of the PVC pipe.

II. CYLINDRICAL CONCRETE TUBE

Figure 2 shows a schematic diagram of a concrete tube, which is the underwater support structure for the offshore wind turbine. A cylindrical coordinate system (ρ, φ, z) is set up such that the central axis is the z-axis. We set the inner and outer radii of the circular concrete cross section to be a and b, respectively. Let $\rho < a$ and $\rho > b$ be filled with seawater and be referred to as Regions 1 and 3, respectively. Also, $a < \rho < b$ is filled with concrete and referred to as Region 2.

III. SCALE MODEL OF CYLINDRICAL CONCRETE TUBE USING PVC PIPE

A. Scale Model of a Cylindrical Dielectric Tube

The lower floating structure is a cylindrical structure with an inner diameter of 6.8 m, an outer diameter of 7.8 m, and a length of 30 m, so it is not easy to experimentally verify our idea. Therefore, a scale model [2] is used, and the distance characteristics are measured in a tank set up in the laboratory to investigate the change in transmission distance characteristics with and without the presence of the structure.

It can be assumed that the seawater in Regions 1 and 3 is perfect conductor. In other words, we consider applying the scale model only to Region 2 of the cross sections of the concrete tube and PVC pipe. In the usual scale model, the relative permittivity is not changed before and after scaling [3], but in the present model, it is necessary to apply a scale model that also allows the relative permittivity to change. In other words, we use a scale rule that introduces scale factors n and e for the length and relative permittivity. Some conversion rules are summarized in Table I.

B. Scale Factor Settings

The scale factor n is determined by the ratio of the average of the inner and outer radii of the cylindrical concrete tube and PVC pipe, and its value is given as 87.95. The scale factor e requires knowledge of the relative permittivity of both concrete tube and PVC pipe. The relative permittivity of concrete can be selected as 6.3 [4]. The relative permittivity of the PVC pipe was measured using the coaxial probe method such as DAK, SPEAG and found to be 2.5. Therefore, the scale factor e is estimated as 0.397.

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TABLE I SCALE CONVERSION

	Original Model	Scale Model
Length	l	$l' = l/n$
Frequency	f	$f' = nf/\sqrt{e}$
Conductivity	σ	$\sigma' = n\sqrt{e}\sigma$
Permittivity	ε	$\varepsilon' = e\varepsilon$
Permeability	μ	$\mu' = \mu$
Electric Field	$\boldsymbol{E}$	$\boldsymbol{E}' = \boldsymbol{E}/\sqrt{e}$
Magnetic Field	$\boldsymbol{H}$	$\boldsymbol{H}' = \boldsymbol{H}$

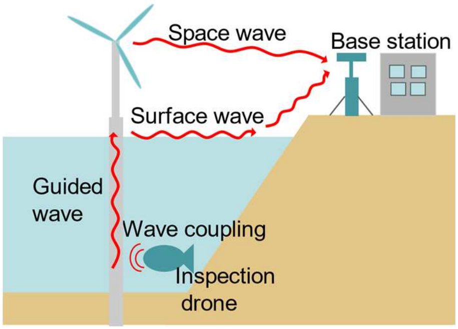

Fig. 1. Wireless underwater drone inspection system

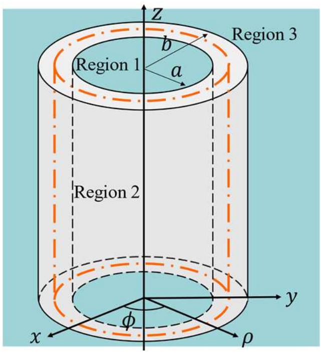

Fig. 2. Cylindrical concrete tube

C. Scaled Experimental System

As shown in Fig. 3, simulated seawater is poured into a glass tank and a PVC pipe is submerged. The antenna of the underwater drone is a dipole antenna with a length of 25 mm. In the experiment, the transmission distance characteristic S_{21} between two dipole antennas is measured using a network analyzer. The dipole antennas are placed 10 mm away from the outer surface of the PVC pipe and oriented in the z direction. The transmitting antenna is fixed and the receiving antenna is moved at 10 mm intervals from 60 mm to 450 mm between their centers. The frequency is changed from 25 MHz to 2 GHz at 25 MHz intervals.

IV. EXPERIMENTAL RESULTS FOR SCALE MODEL WITH AND WITHOUT PVC PIPE

The transmission distance characteristics at 1500 MHz are shown in Fig. 4. The red dots correspond to the case with PVC pipe, and the blue dots correspond to the case without PVC pipe. In the case without the PVC pipe, the direct wave behavior is dominant, with a drop in level up to a distance of 100 mm. Beyond this point, the measurable limit is exceeded and the measured values fluctuate around −130 dB.

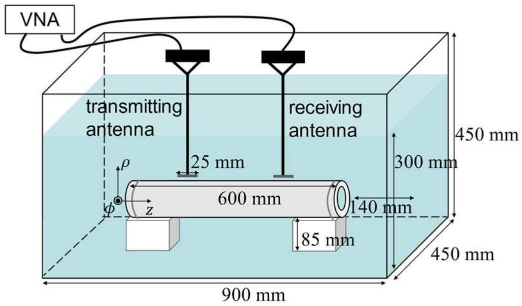

Fig. 3. Experimental setup for scale model

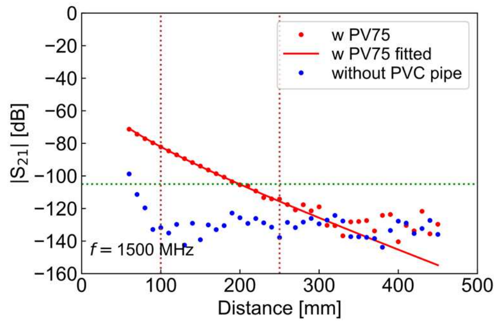

Fig. 4. Transmission distance characteristics at 1500 MHz

On the other hand, when the PVC pipe is moved closer to the dipole antenna, behavior consistent with propagation inside the PVC pipe can be observed. In other words, the distance over which the signal can be transmitted is greatly improved when the PVC pipe is moved closer.

V. CONCLUSION

A novel undersea electromagnetic wave transmission system using cylindrical dielectric tubes as a waveguide structure was experimentally demonstrated. For this purpose, the scaled system was developed to measure transmission distance characteristics between dipole antennas installed in close proximity on the surface of the PVC pipe immersed in seawater. It is confirmed that electromagnetic wave transmission with significantly reduced attenuation in seawater is possible due to the presence of dielectric tubes.

ACKNOWLEDGMENT

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