Dipole Antenna With Sheath-Cover for Seawater Use

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Abstract **– To design antennas for underwater communication systems using LF band, the transmission factor of dipole antennas with the sheath immersed in seawater are investigated by numerical study. Comparison of antenna characteristics between dipole antennas with different sheath structure is presented.**

Index Terms **—Dipole antenna, Transmission factor, Conjugate matching condition.**

1. Introduction

Based on the development of recent digital wireless communication systems, expectation for high quality in seawater wireless communications using radio waves is increasing [1]. Compared with wireless communications using acoustic waves and optical waves, radio waves could be expected for accurate location estimation of under-seawater divers in muddy seawater.

Researches on seawater antennas have been carried out for a long time mainly for submarine communications. Propagation loss in uniform seawater or in the case with effect of the sea-surface have been studied by the theoretical analysis using Green function and impedance matching between circuits and antennas in seawater was also performed. However, it is difficult to obtain exact solutions of antennas with the sheath-cover and maximum received power between Tx/Rx antennas at short distance have not been evaluated so far in broadband frequency range including LF band.

In this report, FDTD analysis of dipole antennas with the sheath-cover in seawater are presented. The transmission factor between two dipole antennas separated 2 m is obtained and comparison of antenna characteristics between dipole antennas with different sheath structure is performed. Impedance behavior under the effect of sheath-cover is discussed.

2. Analysis model

Fig. 1 shows the model for numerical analysis. Relative permittivity of ε_r=80 and conductivity of σ=4 S/m was used as surrounding seawater. A dipole antenna with length of 2 m are located in seawater and analysis region was enclosed by the dispersive perfectly matched layer (DPML). Three type of dipole antenna were calculated as shown in Fig. 1 (a), (b) and (c). In case of Fig. 1 (c), a conducting dipole is partially covered by the freshwater sheath-cover (ε_r=80, σ=0.01 S/m) with half-length of dipole. Fig. 1 (a) is the case without the sheath and Fig. 1 (b) is the case with the full sheath.

3. Results

Fig. 2 shows the input impedance of dipole antennas in seawater calculated in a frequency range of 10 kHz to 40 MHz. In order to interpret the mechanism of impedance behavior, the equivalent circuits were also shown in Fig. 3 for each frequency range. Observations are listed below.

- In the case without sheath (Fig. 1 (a)), current from the antenna conductor flows through the conducting seawater and forms a loop. Therefore, resistance component of seawater and inductance component of loop appear.
- In the case with full sheath (Fig. 1 (b)), relatively high resistance value appears due to the small conductivity of the freshwater sheath at low frequencies. As the frequency becomes higher, impedance curves similar to those of dipole antennas in freshwater are observed.
- In the case with half sheath (Fig. 1 (c)), almost the same curves as the case without sheath appear at low frequencies. However, since loop becomes large compared with the case without sheath, resistance and inductance component increase which enabling easy impedance matching to the load. At high frequencies, impedance curves is similar to those of full sheath.

In order to evaluate the maximum received power between Tx/Rx antennas in the seawater, the transmission factor was calculated [3]. Considering 2-port equivalent circuit as shown in Fig. 3, the relative received power P_L/P_{inc} where P_{inc} and P_L are the incident power and the received power is given by

$$\frac{P_L}{P_{inc}} = \frac{1}{1-|\Gamma_S\Gamma_{in}|^2}|S_{21}|^2\frac{1-|\Gamma_L|^2}{|1-S_{22}\Gamma_L|^2} \qquad (1)$$

where Γ_S is the reflection coefficient toward the source Z_S, Γ_L is the reflection coefficient toward the load Z_L and Γ_{in},

Γ_{out} are input/output reflection coefficient toward port 1 and port 2, given by

$$\Gamma_S = \frac{Z_S - Z_0}{Z_S + Z_0}, \Gamma_L = \frac{Z_L - Z_0}{Z_L + Z_0} \quad (2)$$

$$\Gamma_{in} = S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1 - S_{22}\Gamma_L}, \Gamma_{out} = S_{22} + \frac{S_{12}S_{21}\Gamma_S}{1 - S_{11}\Gamma_S} \quad (3)$$

Appling the conjugate matching condition given by

$$\Gamma_S = \Gamma_{in}^*, \Gamma_L = \Gamma_{out}^* \quad (4)$$

to the equation (1), the relative maximum received power called the transmission factor τ is given by

$$\tau = \left.\frac{P_L}{P_{inc}}\right|_{\Gamma_S=\Gamma_{in}^*, \Gamma_L=\Gamma_{out}^*} = \frac{1}{1-|\Gamma_S|^2}|S_{21}|^2 \frac{1-|\Gamma_L|^2}{|1-S_{22}\Gamma_L|^2} \quad (5)$$

As a special case, the equation (5) reduced to $|S_{21}|^2$ when Z_S= Z_L = 50 Ω.

Fig. 4 shows the transmission factor τ of dipole antennas separated 2 m. In any cases, τ increase significantly in frequency range f < 2 MHz. The wavelength λ_g in the seawater at 2 MHz is about 1 m, and a near-field coupling appears between Tx/Rx antennas with distance d <2 λ_g. Even though frequency is 10 kHz, the wavelength is λ_g= 16 m, and the distance d = 2 m is λ_g / 8. Predicting from this results, it can be considered that near-field coupling can be obtained when the equation f [MHz] < 10/ d^2 [m] is satisfied. For an example, when d = 20 m, frequency should be f <25 kHz to obtain near-field coupling. It is also observed that extremely low τ in the case of full sheath, in frequency range f < 2 MHz. On the other hand, the transmission factor τ of -20 dB at 100 kHz is observed in cases without sheath and with half sheath. Considering that the transmission factors τ at 10 MHz are less than -120 dB for all cases and it is obvious that the improvement effect using near-field coupling.

4. Conclusion

The transmission factor between two dipole antennas in seawater has been evaluated by using FDTD analysis. It has been found that near-field coupling can be obtained when distance between two dipole antennas of d <2 λ_g. Also it has been found that half freshwater sheath-cover contribute to increase both resistance and reactance compared with the case without sheath-cover.

References

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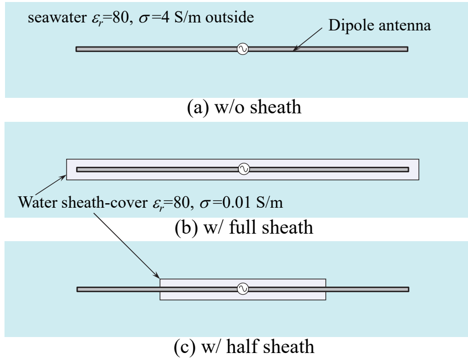

Fig. 1. Analysis model.

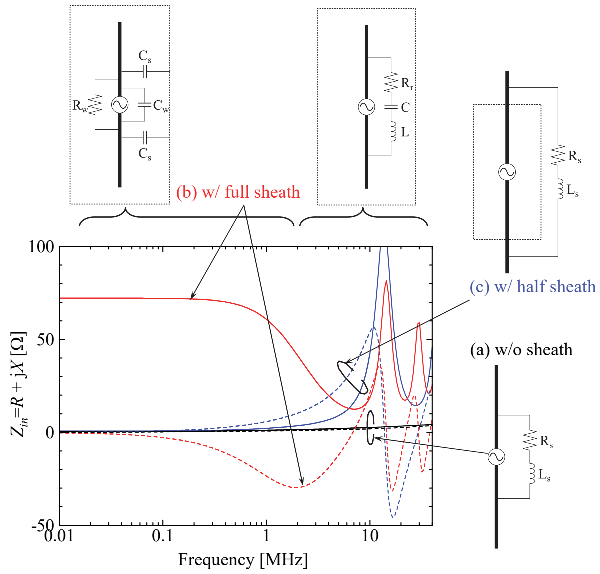

Fig. 2. Input impedances of dipole antenna and equivalent circuits for each frequency band.

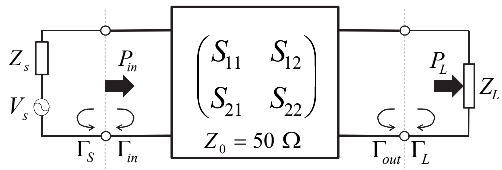

Fig. 3. Two port equivalent circuit.

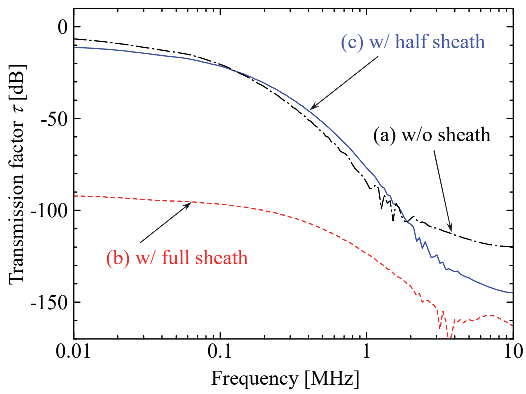

Fig. 4. Ttransmission factor τ between two dipole antennas separated d=2 m.