Design and Evaluation of Antennas in Seawater

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Abstract

To design antennas for seawater use at LF band, the transmission characteristics of dipole antennas with the sheath immersed in seawater are investigated by numerical study. Comparison of antenna impedance characteristics with different sheath structure is presented and the mechanism of sheathed dipole antenna is evaluated.

Keywords

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 [1, 2]. Propagation loss in uniform seawater or in the case of 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 [3]. 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 is 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 are performed. Impedance behavior under the effect of sheath-cover is discussed [4].

2. Sheathed dipole antenna

Fig. 1 shows the model for numerical analysis. Relative permittivity of $\varepsilon_r=80$ and conductivity of $\sigma=4$ S/m is assumed as the electric constants of surrounding seawater. A dipole antenna with length
of 2 m is located in seawater and analysis region was enclosed by the dispersive perfectly matched layer (DPML). Three types of dipole antenna are 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 ($\varepsilon_r=80$, $\sigma=0.01$ 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. Transmission factor

In order to evaluate the maximum received power between Tx/Rx antennas in the seawater, the transmission factor was calculated [5]. Considering 2-port equivalent circuit as shown in Fig. 2, 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

$$\frac{P_L}{P_{inc}} = \frac{1}{1 - \Gamma_i - \Gamma_o} \left| S_{21} \right|^2 \frac{1 - |\Gamma_{in}|^2 + |\Gamma_{out}|^2}{1 - \left| S_{21} \right|^2}$$

(1)

where $\Gamma_i$ is the reflection coefficient toward the source $Z_s$, $\Gamma_L$ is the reflection coefficient toward the load $Z_L$ and $\Gamma_{in}$, $\Gamma_{out}$ are input/output reflection coefficient toward port 1 and port 2, given by

$$\Gamma_i = \frac{Z_s - Z_n}{Z_s + Z_n} \quad \Gamma_L = \frac{Z_L - Z_n}{Z_L + Z_n}$$

(2)

$$\Gamma_{in} = S_{11} + \frac{S_{12}S_{21} \Gamma_L}{1 - S_{21} \Gamma_L} = S_{22} + \frac{S_{21}S_{12} \Gamma_L}{1 - S_{12} \Gamma_L}$$

(3)

Applying the conjugate matching condition given by

$$\Gamma_s = \Gamma_{in} = \Gamma_{out}$$

(4)

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

$$\tau = \frac{P_L}{P_{inc}} \left| S_{21} \right|^2 \frac{1 - |\Gamma_{in}|^2 + |\Gamma_{out}|^2}{1 - \left| S_{21} \right|^2}$$

(5)

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

Fig. 3 shows the transmission factor $\tau$ of dipole antennas separated 2 m. In any cases, $\tau$ increase significantly in frequency range $f < 2 \, \text{MHz}$. The wavelength $\lambda_f$ in the seawater at 2 MHz is about 1 m, and a near-field coupling appears between Tx/Rx antennas with distance $d < 2 \lambda_f$. Even though frequency is 10 kHz, the wavelength is $\lambda_f = 16 \, \text{m}$, and the distance $d = 2 \, \text{m}$ is $\lambda_f / 8$. From this results, it can be considered that near-field coupling is possible when the equation $f \,[\text{MHz}] < 10/ \, d^2 \,[\text{m}]$ is satisfied. For an example, when $d = 20 \, \text{m}$, frequency should be $f < 25 \, \text{kHz}$ to obtain near-field coupling. It is also observed that extremely low $\tau$ in the case of full sheath, in frequency range $f < 2 \, \text{MHz}$. On the other hand, the transmission factor $\tau$ of -20 dB at 100 kHz is observed in cases without sheath and with half sheath. Considering that the transmission factors $\tau$ at 10 MHz are less than -120 dB for all cases and it is obvious
that the improvement effect using near-field coupling.

4. **Design and Evaluation**

In order to interpret the mechanism of impedance behavior, input impedance of the sheathed dipole antenna was calculated. Fig. 4 shows the resistance and reactance of sheathed dipole antennas in seawater under the situation of \( l \) changed from 0 to 1850 mm in a frequency range of 0 to 20 MHz.

In the case without sheath, a current loop is formed through the conducting seawater. Therefore, the inductance component of loop appear.

It is observed that both reactance and resistance increase when the length of sheath increases in frequency rage \( f < 6 \) MHz. As the frequency becomes higher, anti-resonance occurs and the anti-resonant frequency decreases as the length of sheath increases. Since the antenna has a sheath, current flows through the conducting seawater and forms a path between the two ends of the sheath. Therefore, it can be considered that the structure of sheathed dipole antenna is similar with the gamma-matched dipole antenna as shown in Fig. 5.

5. **Conclusion**

The transmission factor between two dipole antennas in seawater has been evaluated by using FDTD analysis. It has been found that the structure of sheathed dipole antenna is similar with the gamma-matched dipole antenna. Also it has been found that the freshwater sheath-cover contribute to increase both resistance and reactance at lower frequency band.

### References


