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海中アンテナの設計と評価

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あらまし　LF 帯を用いた海中アンテナを設計するために，シース構造を有するダイポールアンテナの伝送特性を数値解析により評価している．また，異なるシース構造を持つダイポールアンテナの入力インピーダンス特性の比較を行い，動作メカニズムについて検討している．

キーワード　ダイポールアンテナ，伝送係数，共役整合条件

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

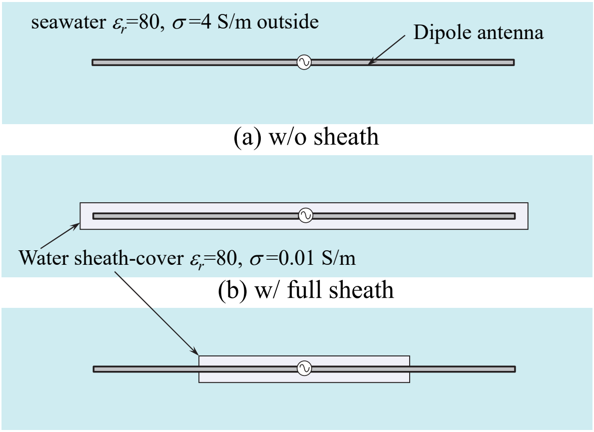
Based on the development of recent digital wireless communication systems, expectation for high quality in seawater wireless communications using radio waves is increasing [1]. Compared with wireless communications using acoustic waves and optical waves, radio waves could be expected for accurate location 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 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 [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 ε_r=80 and conductivity of σ=4 S/m is assumed as the electric constants of surrounding seawater. A dipole antenna with length



(a) w/o sheath

(b) w/ full sheath

(c) w/ half sheath

Fig. 1. Analysis model.

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 (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. 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

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

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

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

(2)

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

Appling the conjugate matching condition given by

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

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

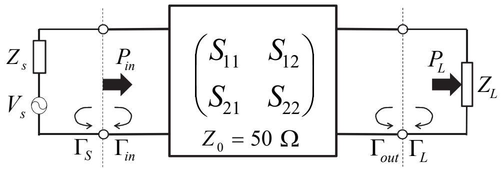


Fig. 2. Two port equivalent circuit.

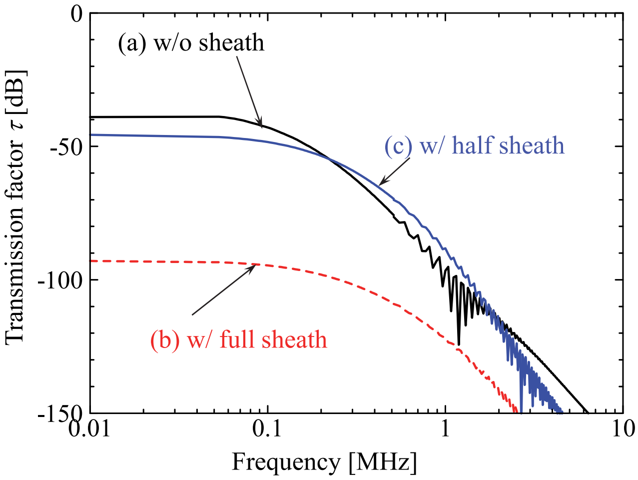
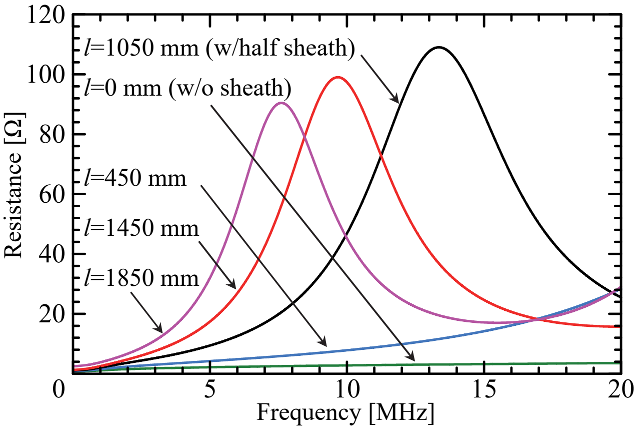


Fig. 3. Ttransmission factor τ between two dipole antennas separated by d=2 m.

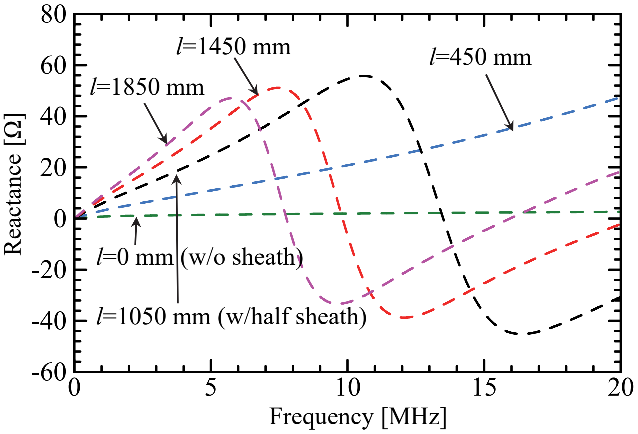
$$\tau = \left.\frac{P_L}{P_{inc}}\right|_{\Gamma_S=\Gamma_{in}^*,\Gamma_L=\Gamma_{out}^*} = \frac{1}{1-|\Gamma_S|^2}|S_{21}|^2\frac{1-|\Gamma_L|^2}{|1-S_{22}\Gamma_L|^2} \qquad (5)$$

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

Fig. 3 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 <2λ_g. Even though frequency is 10 kHz, the wavelength is λ_g= 16 m, and the distance d = 2 m is λ_g / 8. From this results, it can be considered that near-field coupling is possible 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



(a) Resistance



(b) Reactance

Fig. 4. Impedance of sheathed dipole antennas in seawater with different lengths of sheath.

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.

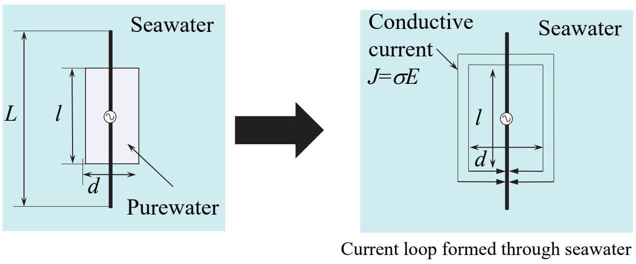


Fig. 5. Operating mechanism of sheathed dipole antenna.

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 frequeency band.

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