Theoretical Analysis of Sheathed Dipole Antenna with PVC-cover for Seawater Use

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SUMMARY In this report, the structure of sheathed dipole antenna with PVC-cover is studied by theoretical analysis. The transmission line theory is used to calculate the input impedance behavior of sheathed dipole antennas with PVC-cover. The effective approximate equation of the antenna to obtain the input impedance is presented.
key words: *theoretical analysis*, *sheathed dipole antenna*, *PVC-cover*, *input impedance*

1. Introduction

Recently, high quality of wireless communications underwater is required. In the previous studies [1, 2], the sheathed dipole antenna was proposed. It was shown that the transmission coefficient can be greatly improved by exposing the conducting wire from the sheath. Slightly exposed sheath dipole antenna in seawater has been studied by theoretical analysis and formulas of the input impedance have been obtained [3]. However, influence caused by PVC-cover cannot be ignored in experiment. In this report, the structure of sheathed dipole antenna with PVC-cover is studied by the theoretical analysis and input impedance behavior in the cases of full sheath and exposed sheath dipole antenna with PVC-cover is discussed. The results of approximated expression of the input impedance of exposed sheath and full sheath dipole antenna with PVC-cover are obtained.

2. Structure of model

Figure 1 shows the structure of sheathed dipole antenna with PVC-cover in the seawater. a, b and c represent the radius of the conducting wire, sheath and PVC-cover, respectively. L is the half length of the dipole antenna. δ is the length of the exposed region of the antenna. Region 1 is the sheath of the antenna with the relative permittivity and the conductivity of ε_{r1} and σ_1, respectively. Region 2 is the PVC-cover of the antenna with the relative permittivity and the conductivity of ε_{r2} and σ_2, respectively. Region 3 is seawater with the relative permittivity and the conductivity of ε_{r3} and σ_3, respectively. k_L is the wave number along the z direction. k_1, k_2 and k_3 are the wave numbers of the region 1, region 2 and region 3, respectively.

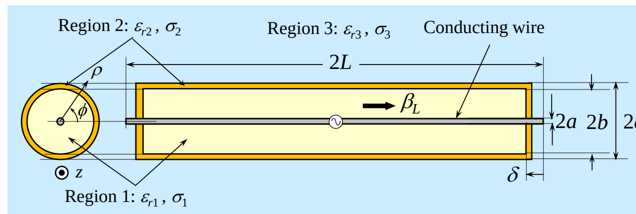

Fig. 1 Structure of sheathed dipole antenna with PVC-cover in seawater.

3. Theoretical analysis

In this structure, both the relative permittivity of sheath and seawater are 80 (ε_{r1}=ε_{r3}=80). The relative permittivity of PVC-cover is 3 (ε_{r2}=3). When both σ_1 and σ_2 are sufficiently smaller than σ_3, the relation $|k_1|<<|k_3|$ and $|k_2|<<|k_3|$ can be satisfied. When the outside medium is highly conducting at the operating frequency, the insulated antenna is essentially a coaxial line with a very extensive imperfect outer conductor in which the electromagnetic field is that associated with the volume density of free-charge current through the constitutive relation $J=\sigma E$ [4]. Conventional transmission-line theory is applicable. By applying boundary condition and thin wire approximation to electromagnetic field formulas [5], wave number k_L can be obtained as follows.

$$k_L = k_1\sqrt{\frac{\ln\left(\frac{c}{a}\right)}{\ln\left(\frac{b}{a}\right)+n_{12}{}^2\ln\left(\frac{c}{b}\right)}}\sqrt{1+\frac{H_0^{(1)}(k_3c)}{k_3cH_1^{(1)}(k_3c)\ln\left(\frac{c}{a}\right)}} \quad (1)$$

where

$$n_{12} = {k_1}^2/{k_2}^2. \quad (2)$$

When the conducting wire is exposed to the sheath and PVC-cover (δ > 0), the exposed regions are connected by the seawater. Therefore, it can be considered as a model composed of two transmission lines of length L, with each end is loaded with a parasitic part, Z_t. Z_t is produced by the conductive current in seawater between two ends of the antenna. The formula of input impedance is given by

$$Z_{in}^E = 2Z_{ca}\frac{Z_t+jZ_{ca}tank_LL}{Z_{ca}+jZ_ttank_LL} \quad (3)$$

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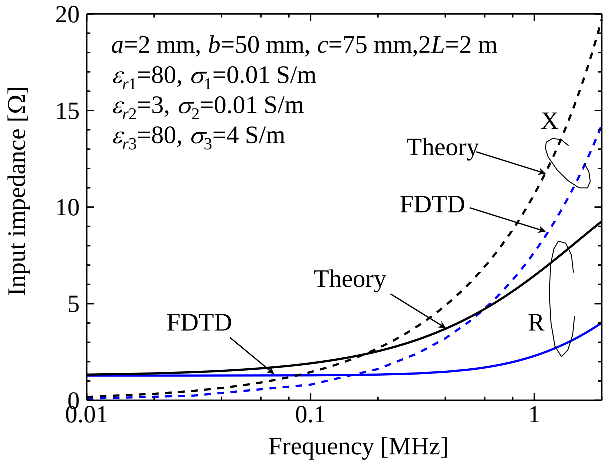

Fig. 2 Input impedance of half sheath dipole antenna with PVC-cover in seawater.

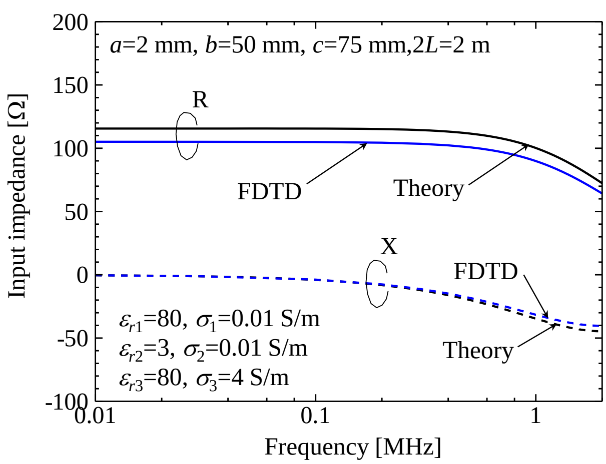

Fig. 3 Input impedance of full sheath dipole antenna with PVC-cover in seawater.

where Z_{ca} is the characteristic impedance of the transmission line, and Z_t is obtained from full-wave analysis.

When the conducting wire is inside the sheath and PVC-cover ($\delta < 0$), it can be considered as a model composed of two transmission lines of length L, with ends are open. The formula of input impedance is given by

$$Z_{in}^{O} = -j2Z_{ca}cotk_L L \tag{4}$$

Figure 2 and Figure 3 show the results of input impedance of half sheath and full sheath dipole antenna with PVC-cover in seawater obtained by theoretical analysis and FDTD analysis. It can be observed that the theoretical results almost agree with the FDTD results in the low frequency region in both cases. Although the full wave analysis has been used in the case of exposed sheath dipole antenna with PVC-cover in the seawater, it is only used to obtain the parasitic part, Z_t. In addition, it will save time to calculate a model with only one antenna compared to calculating a transmission model with two antennas by using full wave analysis.

4. Conclusion

In this report, theoretical analysis of the input impedance of the full-sheath and exposed sheath dipole antenna with PVC-cover in seawater has been performed.

In the case of exposed sheath dipole antenna with PVC-cover in seawater, the formula of input impedance has been derived by using theoretical analysis. Because of conductive current in seawater between two ends of the antenna, a parasitic part, Z_t, has been added. The effective approximate formula has been obtained. The results show that the theoretical analysis has good agreement with FDTD analysis in low frequency band. In the case of full sheath dipole antenna with PVC-cover in seawater, the formula of input impedance has been derived and results show that the theoretical analysis has good agreement with FDTD analysis in low frequency band.

This theoretical method can make the calculation of the input impedance for sheathed dipole antenna with PVC-cover in seawater in short time easily. Although in the case of exposed sheath antenna with PVC-cover in seawater, full wave analysis has been used, it takes less time to calculate one antenna than the transmission model. In addition, this theoretical analysis considers thickness of PVC-cover, which is useful in the experiment. In this way, the value of input impedance of sheathed antenna in seawater can be obtained, which will make it possible to calculate the received power and transmission factors in transmission model by theoretical analysis.

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