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Limitations of Impedance Loaded Wire Grid Model for Analyzing a Lossy Dielectric Object

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INTRODUCTION

Several numerical methods has been proposed to analyze the scattered field of an arbitrary-shaped lossy dielectric object(1). The advanced wire grid method(2) has the advantages of relatively small calculation time and simple modeling. In this method, as the calculating model is constructed by the impedance loaded wire-grid plane as a substitute for the surface of the lossy dielectric object, there is the possibility of increasing error in the electric field normal to the surface of the object. Accordingly, it is important to chose the appropriate model parameters and to recognize the limitations of this method depending on the shape and the electric constant of the object and the analyzing frequency. The manner of constructing the appropriate model has been examined(2).

This paper studies the limitations of the advanced wire grid method. The problem of the vertical and horizontal short dipole antennas over a lossy dielectric ground plane is considered. This problem has been studied for antennas over lossy earth [*e.g., Sommerfeld, 1909*] and the formulas for the antenna characteristics have been devised(3). Hence, the limitations of the advanced wire grid method is clarified by comparing the theoretical radiation resistances with those calculated by using the loaded wire-grid model in this problem. It was found that the advanced wire grid method is applicable when the skin depth of the analyzed object is under 0.3 of the free space wavelength. This result was confirmed by calculating the radiation patterns for vertical monopole antennas on the lossy dielectric ground plane.

PRPBLEM AND CALCULATION METHOD

The problem considered on this study is shown in Fig.1. Radiation resistances of a vertical electric short dipole antenna(VED) and a horizontal one(HED) over a lossy dielectric ground plane are examined. The radiation patterns of a 0.25 wavelengths vertical electric monopole(VEM) antenna on the plane are also calculated. Region 1 is free space($\mu 0,\varepsilon 0$) and region 2 has the electric constant of $\mu 2,\varepsilon 2,\sigma 2$. The analyzing frequency is 900MHz. When the advanced wire grid method is applied to this problem, the surface of the lossy dielectric ground plane is made of a metal wire-grid and four impedances are loaded into each wire junction as shown in Fig.2. In this examination, the size of the wire-grid ground plane is 1.0×1.0 wavelengths and there are 11 wires dividing each edge. The length of short dipole antenna is 0.15 wavelengths.

Figure 3 illustrates the method of modeling the equivalent impedance of a small surface(a1+a2,b1+b2) made of lossy dielectric material($\mu 2,\varepsilon 2,\sigma 2$). Each impedance value is expressed as follows:

$$Zp=\frac{b1}{a1+a2}\eta,\ Zq=\frac{a2}{b1+b2}\eta,\ Zr=\frac{b2}{a1+a2}\eta,\ Zs=\frac{a1}{b1+b2}\eta \quad ....<1>$$

$$\eta=\sqrt{\frac{j\omega\mu_2}{\sigma_2+j\omega\varepsilon_2}} \quad ....<2>$$

where $\varepsilon 2$ and $\mu 2$ are, respectively, electric and magnetic permittivity, $\sigma 2$ is conductivity, ω is $2\pi f$ and f is the frequency. Each value of these loaded impedances are decided by using the concept of the surface impedance method(4), and a cross wire model is adopted to achieve correspondence to the arbitrary direction of surface currents. Each of the model units must have the three expansion functions(F1,F2,F3) used in applying a moment method. The self and mutual impedances for each function are:

$$Z11'=Z11+(Zq+Zs)$$
$$Z22'=Z22+(Zp+Zr) \qquad Z13'=Z13+Zq$$
$$Z33'=Z33+(Zp+Zq) \quad ....<3> \qquad Z23'=Z23+Zp \quad ....<4>$$

Z11 is the self impedance for F1 without loaded impedances Zq and Zs. Z13 is the mutual impedance between F1 and F3 without Zq. Z11' and Z13' are self and mutual impedances with loaded impedances. Other self and mutual impedances are defined in the same way. The elements of the impedance matrix are changed to the impedances marked prime in this moment method.

EXAMINATION FOR THE RADIATION RESISTACE

The limitations of this numerical method is clarified by comparing the radiation resistances provided by the theoretical formulas and calculated by using the loaded wire-grid (L.W.) model. The reason for choosing a radiation resistance as a testing parameter is that the main objective of this numerical method is to calculate an amplitude radiation pattern or an absorbing power. Radiation resistance is a real part of an antenna input impedance. The relation between the radiation resistance R and antenna height h when a dipole antenna is over a metal ground plane ($\sigma 2=\infty$ s/m) and over a lossy dielectric ground plane ($\mu 2=\mu 0,\varepsilon 2=55\varepsilon 0,\sigma 2=1.5$s/m) is shown in Fig.4 and 5, respectively. The short dipole antenna has the radiation resistance of 3.6Ω in free space, as shown by the dashed line in these figures.

In the metal ground plane case, the difference in the calculated and the theoretical results is under 1Ω. It is supposed that this error is caused by the inference of the finite ground plane. The calculated results for lossy dielectric ground plane are in good agreement with the theoretical ones for both the VED and HED. In this case, the skin depth is 27mm. Therefore, it is accepted that the loaded wire-grid model is applicable in the case of the thin skin depth whether the dipole antennas over the wire-grid plane are vertical or horizontal.

The dependence of theoretical and calculated radiation resistance characteristics depend on skin depth δ is shown in Fig.6. Skin depth δ is varied by the value of conductivity $\sigma 2$ when $\mu 2=\mu 0,\varepsilon 2=\varepsilon 0$. The difference in theoretical and calculated results is almost under 1Ω for the HED, even though the skin depth is 533mm. But the difference between the two becomes large for the VED when the skin depth δ is over 100mm. The length of 100mm is about 0.3 of the free space wavelength.

RADIATION PATTERN CHARACTERISTICS

As it is clarified that error arises when the skin depth δ of the analyzed object is over 100mm for the VED, the vertical radiation patterns of the VEM for the thin and thick skin depths δ are compared in Fig.7. In this case, the size of the ground plane is 2×2 wavelengths, number of wires dividing the each edge is 21 and 0dB is the maximum level in the metal ground plane case. For the thin skin depth δ of 27mm in Fig.7 (a), the level and the shape of the theoretical and calculated patterns are in fairly good agreement until coming under the influence of the edge diffraction in the region of the near ground plane. On the other hand, when the skin depth δ is thick of 533mm in Fig.7 (b), the theoretical pattern is different from the calculated patterns. Then, it is confirmed that the loaded wire-grid model is applicable within a skin depth of 100mm(0.3 of the free space wavelength) by calculating the radiation patterns for vertical monopole antennas on the lossy dielectric ground plane.

CONCLUSION

The limitation of the impedance loaded wire-grid model in the advanced wire grid method has been clarified. It has been achieved by comparing with the theoretical and numerical calculated results for the radiation resistance of the vertical and horizontal dipole antennas over a lossy dielectric ground plane. As a result, it was found that this method can be used when the skin depth of the analyzed object is under 0.3 of the free space wavelength. This limitation was confirmed by calculating the radiation patterns for vertical monopole antennas on the lossy dielectric ground plane.

[REFERENCES]

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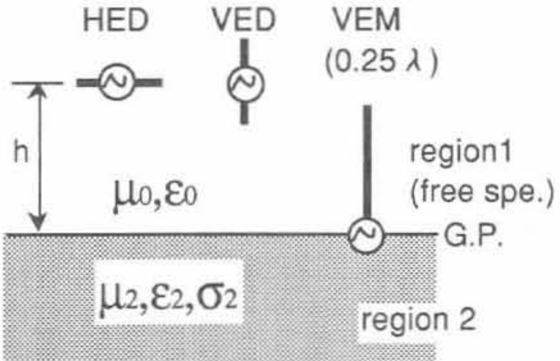


Fig.1 Electric dipole antennas over or on a G.P..

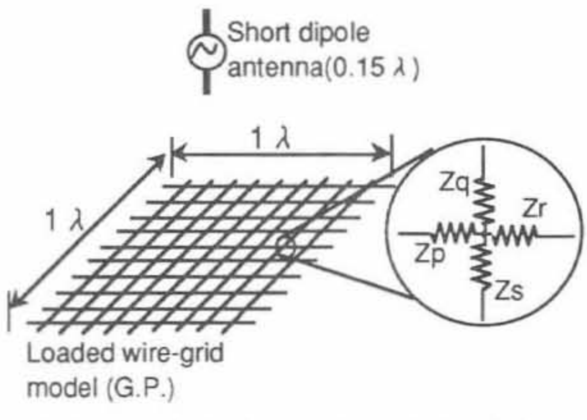


Fig.2 Loaded wire-grid model of G.P..

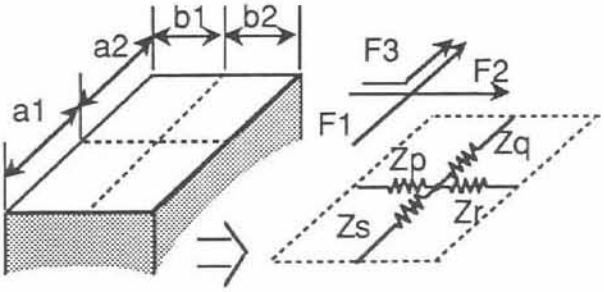


Fig.3 An individual unit of the loaded wire-grid model.

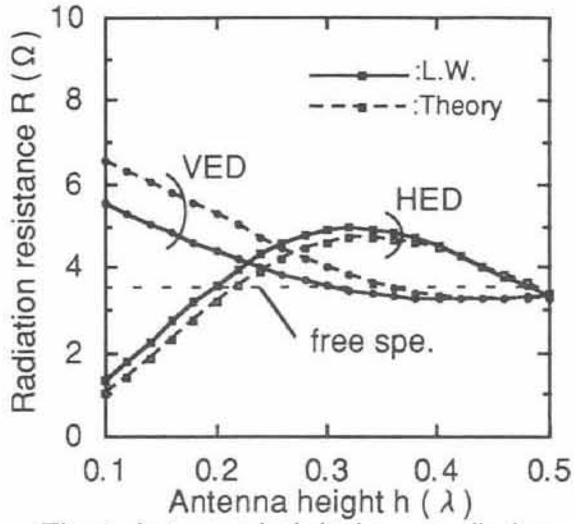


Fig.4 Antenna height h vs. radiation resistance R over metal G.P.. (fr=900MHz、 σ 2=∞s/m)

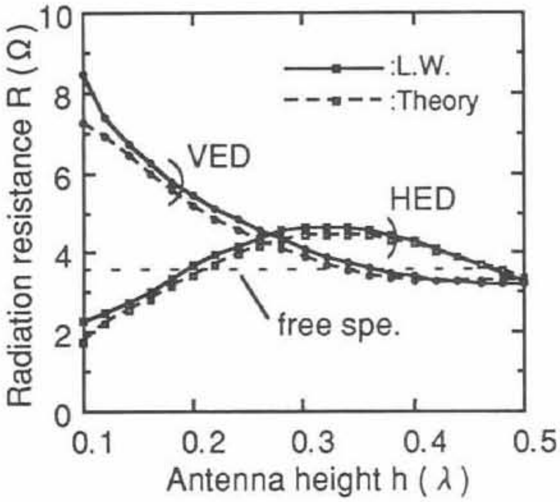


Fig.5 Antenna height h vs. radiation resistance R over lossy dielectric G.P.. (fr=900MHz,μ2=μ0,ε2=55ε0,σ2=1.5s/m)

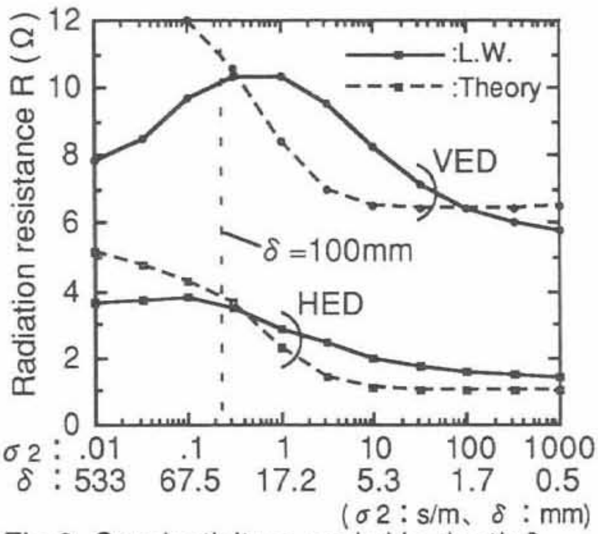
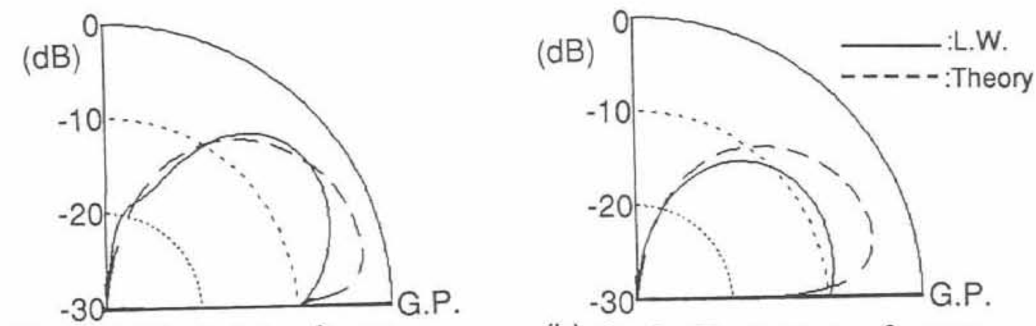


Fig.6 Conductivity σ and skin depth δ vs. radiation resistance R (fr=900MHz,μ2=μ0,ε2=ε0,h=0.1 λ)



(a) ε2=55ε0,σ2=1.5s/m, δ =27mm (b) ε2=ε0,σ2=0.01s/m, δ =533mm

Fig.7 Vertical radiation patterns for the VEM. (fr=900MHz,0dB:maximum level on metal G.P.,μ2=μ0)