Approximate Analysis of a Microstrip Antenna with Meshed Ground Plane

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1. Introduction

Microstrip antennas with meshed ground planes [1] are suitable for large satellite array antennas because they can attain drastic weight reduction and prevent antenna substrate from warping by a bimetallic structure. However, it has been experimentally reported by Wu [2] that they have some electrical problems such that the resonant frequency decreases as the conducting metal area of ground plane becomes smaller. In order to investigate this frequency shift analytically, we have proposed the approximate closed-form formula for the resonant frequency. However, it had some restrictions that the aperture shape of a meshed ground plane was assumed to be circular and calculation errors increased when the conducting metal area of ground plane became smaller.

In this paper, a novel analysis method is proposed in order to overcome the above restrictions. The proposed method is more rigorous and can be applied not only to circular apertures but also to various shaped apertures because the integral equations are solved for the unknown aperture fields and the unknown fields are expanded with adequate basis functions that are determined by the aperture shape. In order to validate the proposed method, the calculated results are compared with the conventional and measured ones.

2. Theory

Figure 1 shows the analysis model investigated here. The model is a microstrip antenna that consists of a conducting patch, a meshed ground plane and a single-layer dielectric substrate with the permittivity of ε (relative pemittivity:ε_r), the permeability of μ and the thickness of h. The meshed ground plane is assumed to be a conducting plane with periodically arranged apertures. The following theory is independent of the shape of the patch and aperture.

In general, the resonant frequency of the cavity with lossy walls slightly shifts from the one with ideal conducting walls. By applying the perturbational technique, the resonant frequency with lossy walls is obtained as follows[4]:

$$\omega_1 = \omega_0 - \frac{jP_L}{2W_t} \tag{1}$$

where ω_0 and ω_1 are the resonant angular frequencies of the cavity with ideal and lossy walls, respectively. P_L is the loss on the wall, W_t is the stored energy inside the cavity with ideal conducting walls.

The microstrip antenna shown in Fig.1 can be considered as the cavity with lossy walls whose losses are radiation losses thorough the meshed ground plane. Therefore, the losses can be given by:

$$P_L = \sum_i \frac{1}{2} \iint_{S_i} \left(\mathbf{E} \times \mathbf{H}\right) \cdot \mathbf{n} ds \tag{2}$$

where $\mathbf{E}$ and $\mathbf{H}$ are the electric and magnetic fields inside the microstrip antenna with meshed ground plane, $\mathbf{n}$ is the outward normal vector and S_i is the i-th aperture surface of the meshed ground plane. Although the calculation formula represented by Eqs. (1) and (2) can be also obtained by the perturbational method presented in [3], the radiation losses in [3] are evaluated by the equivalent electric and magnetic dipole moments at the center of apertures which are given by the electrostatic approximation when the incident fields are the uniform static ones. In this paper, the radiation losses represented by Eq. (2) are calculated by solving the integral equations for the unknown aperture fields. In this analysis, we assume that the patch is sufficiently large compared with the apertures. On this assumption, the problem results in the boundary value problem in the unit cell of the infinite aperture array model illustrated in

Fig. 2 and the radiation loss through each aperture depends only on incident waves at each aperture. In this model, if the variation in *z* direction is neglected in the substrate and the thickness of the meshed ground plane is very small, the following equation for unknown magnetic currents at the *i*-th aperture is obtained from the boundary condition:

$$
\begin{aligned}
&-\frac{1}{d_x d_y}\sum_m\sum_n \begin{bmatrix} k^2-k_x'^2 & -k_x'k_y' \\ k_x'k_y' & k^2-k_y'^2 \end{bmatrix}\cdot \overline{\mathbf{G}}_1\left(k_x',k_y'\right)\begin{bmatrix} \tilde{M}_x\left(k_x',k_y'\right) \\ \tilde{M}_y\left(k_x',k_y'\right) \end{bmatrix} e^{jk_x'x}e^{jk_y'y} \\
&+\frac{1}{d_x d_y}\sum_m\sum_n \begin{bmatrix} k_0^2-k_x'^2 & -k_x'k_y' \\ k_x'k_y' & k_0^2-k_y'^2 \end{bmatrix}\cdot \overline{\mathbf{G}}_2\left(k_x',k_y'\right)\begin{bmatrix} \tilde{M}_x\left(k_x',k_y'\right) \\ \tilde{M}_y\left(k_x',k_y'\right) \end{bmatrix} e^{jk_x'x}e^{jk_y'y} = \begin{bmatrix} H_x^i \\ H_y^i \end{bmatrix}
\end{aligned}
\tag{3}
$$

$$
\overline{\mathbf{G}}_1 = \frac{j\omega\varepsilon}{k^2\gamma^2 h}\bar{\mathbf{I}} \qquad \overline{\mathbf{G}}_2 = \frac{\omega\varepsilon_0}{k_0^2\gamma_0}\bar{\mathbf{I}}
$$

$$
\gamma^2 = k^2 - k_x'^2 - k_y'^2 \qquad \gamma_0^2 = k_0^2 - k_x'^2 - k_y'^2
$$

$$
k_x' = \frac{2\pi m}{d_x} \qquad k_y' = \frac{2\pi n}{d_y} - \frac{2\pi m}{d_x \tan\xi}
$$

where *m* and *n* are the Floquet mode numbers, $\bar{\mathbf{I}}$ is the identity tensor, k_0 is the free-space wave number and *k* is the wave number inside the substrate. $\tilde{M}_x\left(k_x',k_y'\right)$ and $\tilde{M}_y\left(k_x',k_y'\right)$ are the Fourier transforms of the *x* and *y* components of the unknown magnetic currents at the aperture, respectively. H_x^i and H_y^i are the incident magnetic fields at the *i*-th aperture which are the ones inside the microstrip antenna with non-meshed ground plane and are analytically given by the cavity model analysis. After the unknown magnetic currents are expanded with adequate basis functions that are determined by the aperture shape, Eq.(3) are solved by the Galerkin's method and the solution yields the electric and magnetic fields at the *i*-th aperture and the radiation losses through it. By solving Eq.(3) for all apertures and summing up the radiation losses, the resonant frequency represented by Eq.(1) can be obtained.

The resonant frequency shift represented by Eq.(1) can be considered to be equivalent to the shift of the equivalent permittivity of the substrate. Therefore, the frequency characteristic of the microstrip antenna with meshed ground plane can be approximately evaluated by means of the following equivalent permittivity:

$$
\varepsilon_r' = \left(\omega_0 / \omega_1\right)^2 \varepsilon_r \tag{4}
$$

3. Calculation and Experimental Results

Circular microstrip antennas shown in Fig.1 are analyzed to validate the proposed analysis method. In the analyzed meshed ground plane, circular apertures with radius of 0.4mm are in triangular lattice, i.e. d_x=1.5-10.0mm, $d_y=d_x\tan\xi/2$, ξ=60 [deg.].

Figures 3 and 4 show the calculated resonant frequencies in comparison with the conventional analysis method when *R*=30mm, *h*=0.6 or 1.2 mm and ε_r=1.1. In these figures, the ordinate represents the resonant frequency for meshed ground plane that is normalized by the one for non-meshed one and the abscissa represents the aperture spacing d_x. The basis functions presented in [6] are used in the proposed analysis method. From these figures, it is found that the proposed results are in good agreement with the conventional results.

Figure 5 shows the calculated and measured resonant frequencies with the variation of patch radius *R* when *h*=1.0mm, d_x=1.5mm and ε_r=1.07. In Fig 6, the impedance characteristics calculated by the equivalent permittivity given by Eq.(4) are presented in comparison with the measured ones. Both the resonant frequencies and impedance characteristics calculated by the proposed analysis method are in good agreement with the measured ones. Furthermore, it is found that the agreement between the calculated and measured resonant frequencies are improved by the proposed analysis method.

4. Conclusions

An approximate analysis method was proposed in order to evaluate the resonant frequency and frequency characteristics of microstrip antennas with meshed ground planes. The proposed method is based on the perturbational calculation for lossy cavity and the infinite array analysis for meshed ground plane. The calculated results were compared with the one by conventional analysis method and the measured one and the validity was confirmed.

Appendix

For the FDTD results shown in Figs. 3 and 4, the cell sizes are 0.2mm in x and y direction, and 0.1mm in z direction. The analysis area is 349X349X41 cells and the PML boundary condition is used. One time step is 0.27ps and the maximum number of time iterations is about 18000 steps.

Reference

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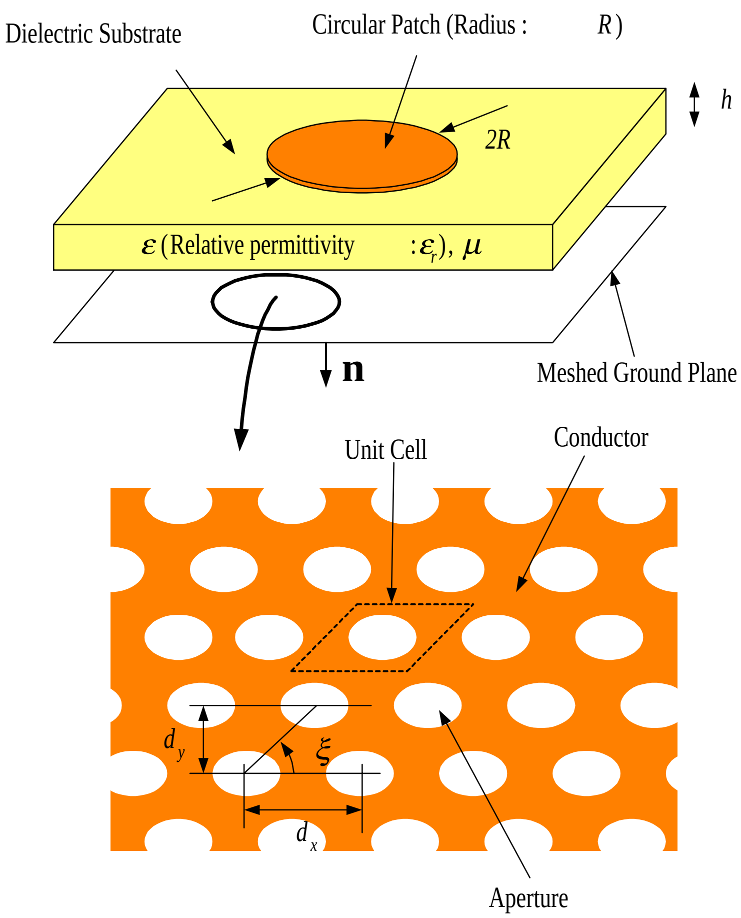

Fig. 1 Analysis model of a microstrip antenna with meshed ground plane

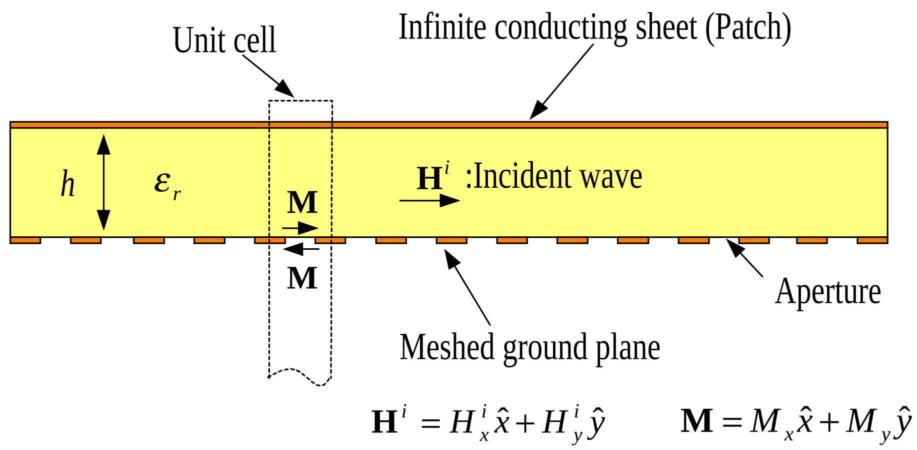

Fig. 2 Sideview of the infinite array analysis model for meshed ground plane

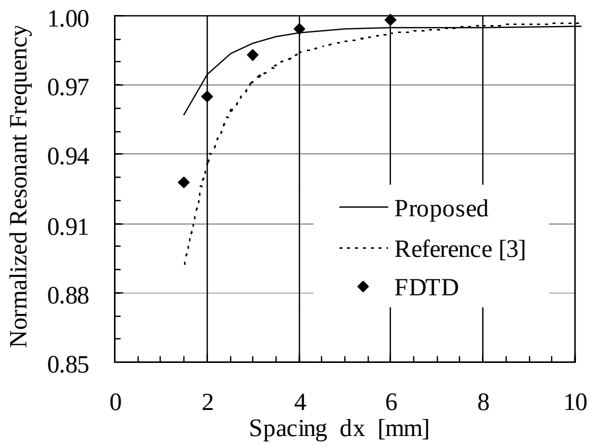

Fig. 3 Resonant frequency vs. aperture spacing d_x. R=30mm, h=0.6mm, ε_r=1.1, d_y=$d_x$tanξ /2 and ξ=60 [deg.]. The apereture is a circular one with the radius of 0.4mm.

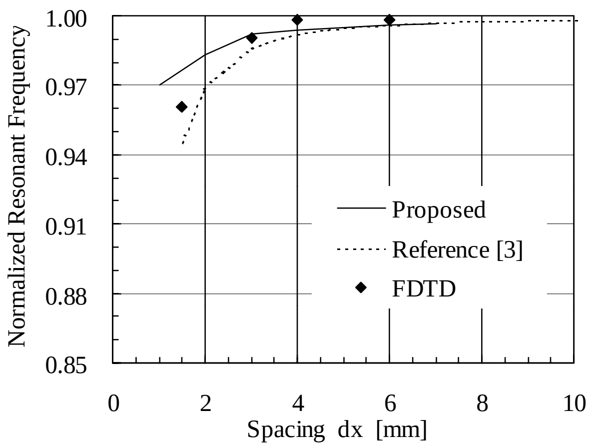

Fig. 4 Resonant frequency vs. aperture spacing d_x. R=30mm, h=1.2mm, ε_r=1.1, d_y=$d_x$tanξ /2 and ξ=60 [deg.]. The apereture is a circular one with the radius of 0.4mm.

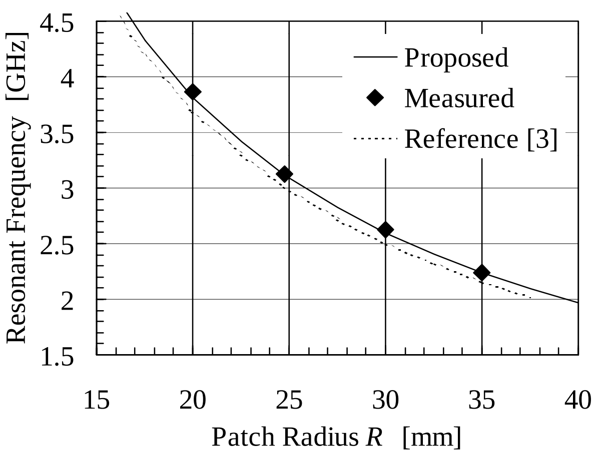

Fig. 5 Resonant frequency vs. patch radius R. h=1.0mm, ε_r=1.07, d_x=1.5mm, d_y=1.3mm and ξ=60 [deg.]. The apereture is a circular one with the radius of 0.4mm.

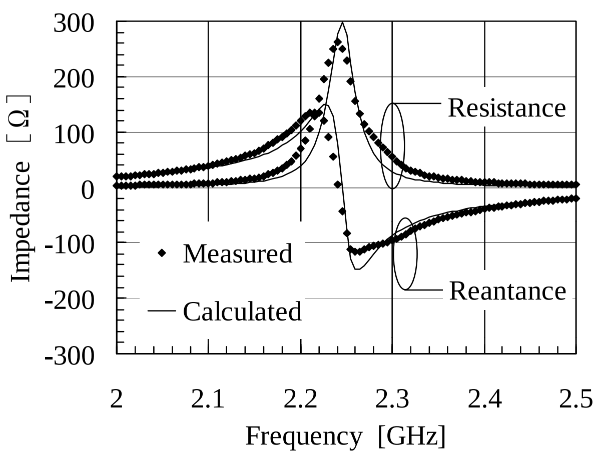

Fig. 6 Impedance characteristics. h=1.0mm, ε_r=1.07, d_x=1.5mm, d_y=1.3mm and ξ=60 [deg.]. The apereture is a circular one with the radius of 0.4mm.