Letters

TM-Wave Radiation from Grooves in a Dielectric-Covered Ground Plane

Jae W. Lee, Hyo J. Eom, Kyung H. Park, and Wan J. Chun

***Abstract*—This letter describes the radiation characteristics from multiple rectangular grooves in a dielectric-covered ground plane. The theoretical far-zone radiation pattern is compared with the measured data at 10 and 11 GHz using a wavenumber conversion procedure.**

***Index Terms*—Fourier transform, groove scattering, leaky wave antenna.**

I. Introduction

Recently, millimeter-wave and microwave antenna systems have received much attention to due their applications to satellite communications. The antenna systems often require the characteristics of simple design, electrical beamsteering, high gain, low cost, etc. A two-dimensional (2-D) planar leaky-wave antenna consisting of a finite number of grooves in a dielectric-covered ground plane was proposed in [1] and [2], and theoretically studied to analyze the TE- and TM-wave radiations from the antenna. In particular, we have presented in [2] a numerically efficient series solution for the antenna with a finite number of grooves by utilizing the technique of Fourier transform and mode matching. In this paper, we will investigate a three-dimensional (3-D) planar leaky-wave antenna with multiple grooves in a dielectric-covered ground plane and compare its measured data with the 2-D theoretical results in [2]. The radiation characteristics of the 3-D planar leaky-wave antenna are described in terms of a conversion process that transforms the 3-D problem into an equivalent 2-D problem. In the next section, we briefly summarize the 2-D theoretical result presented in [2] and the 3-D antenna structure. A comparison with measurements is shown using the wavenumber conversion procedure.

II. Antenna and Radiation Characteristics

Consider a TM surface wave impinging on multiple grooves of width $2a$ and depth d, which are periodically engraved in a dielectric-covered ground plane (see Fig. 1). The number of multiple grooves is assumed to be a finite N. A time factor $e^{-i\omega t}$ is suppressed throughout. By matching the boundary conditions on tangential E- and H- field continuities at $z=0$ and $z=-b$, we obtain the simultaneous equations for the modal coefficients in each regions (see [2] for detailed derivation). Fourier transform and mode matching are used to represent the series solution in numerically efficient form. The far-zone scattered field of $H_y^I(x, z)$ at $x = r\sin\theta_s$ and $z = r\cos\theta_s$ in region (I) is

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J. W. Lee was with the Department of Electrical Engineering, Korea Advanced Institute of Science and Technology, Taejon, Korea. He is now with the Radio Technology Department, Radio and Broadcasting Technology Laboratory, Electronics and Telecommunications Research Institute, Taejon 305-350, Korea.

H. J. Eom is with the Department of Electrical Engineering, Korea Advanced Institute of Science and Technology, Taejon, Korea.

K. H. Park was with the Department of Electrical Engineering, Korea Advanced Institute of Science and Technology, Taejon, Korea. He is now with DACOM Co., Taejon 305-350, Korea.

W. J. Chun is with the Access Network Laboratory, Korea Telecom, Seoul, Korea.

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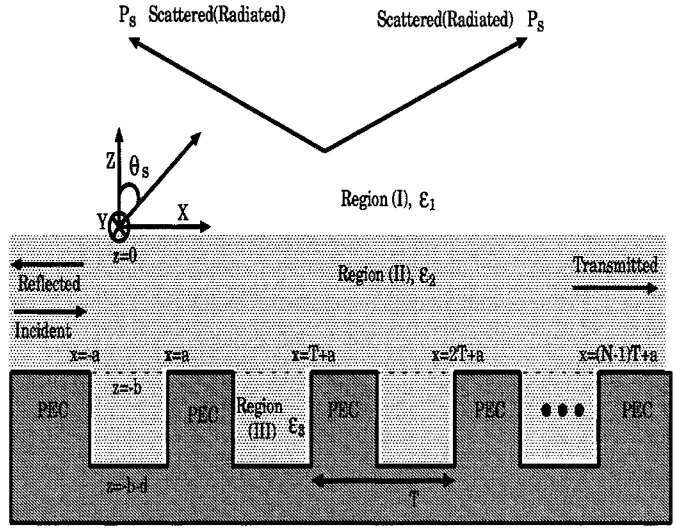

Fig. 1. Scattering geometry of grooves in a dielectric-covered ground plane.

$$H_y^s(r, \theta_s) = \sqrt{\frac{k_1}{2\pi r}} \cdot \cos\theta_s \cdot e^{i(k_1 r - \pi/4)} \cdot \sum_{l=0}^{N-1} \sum_{m=0}^{\infty} c_m^l \frac{\epsilon_1\epsilon_2\xi_m \sin(\xi_m d)\zeta}{\epsilon_3(\zeta^2 - a_m^2)} \cdot \frac{[e^{i\zeta(lT+a)}(-1)^m - e^{i\zeta(lT-a)}]}{[\epsilon_2\kappa_1\cos(\kappa_2 b) - i\epsilon_1\kappa_2\sin(\kappa_2 b)]}\Bigg|_{\zeta=-k_1\sin\theta_s}. \quad (1)$$

Note that (1) is applicable for calculating radiation from the antenna with a finite number (N) of grooves of any size. We have computed the angular radiation pattern for a single groove and confirmed that our results agree with [3, Fig. 5].

We fabricated the antenna consisting of a WR90 X-band rectangular waveguide feeder, a hog-horn part, and a grooved radiator part. A similar structure of the slot array antenna was discussed in [4]. The hog-horn part was fed with the X-band waveguide, and the radiator part was connected with the hog-horn part. The curved reflector inside the hog-horn part was chosen to make the wave emanating from the X-band waveguide constitute approximately a uniform phase front along the y-direction inside the parallel plate. In the ground plane of radiator [size $=$ 59 cm (x-direction) $\times$ 22 cm (y-direction)], multiple grooves were engraved, and the radiator was filled with a paraffin ($\epsilon_r = 2.24$). The number of grooves was made large enough ($N = 30$) to reduce the end effect of a dielectric layer (region II) truncation at $\overline{CC'}$ in the x-direction (see Fig. 2). Fig. 2 shows the top and side views of physical antenna dimension. The hog-horn antenna part was designed with a length (from A to A') 324.9 mm and width (from B to B') 461.9 mm. In the parallel plate of Fig. 2(b), multiple grooves have been engraved with a depth $d = 3$ mm, inside width $2a = 6$ mm, and distance between two grooves (i.e., period) $T = 15.5$ mm. The thickness of dielectric layer on the parallel plate is $b = 2.5$ mm. A wavenumber conversion procedure is necessary to compare the measured data of the 3-D antenna to the theory based on the 2-D assumption. In the hog-horn parallel-plate waveguide (the lowest mode is TM_0

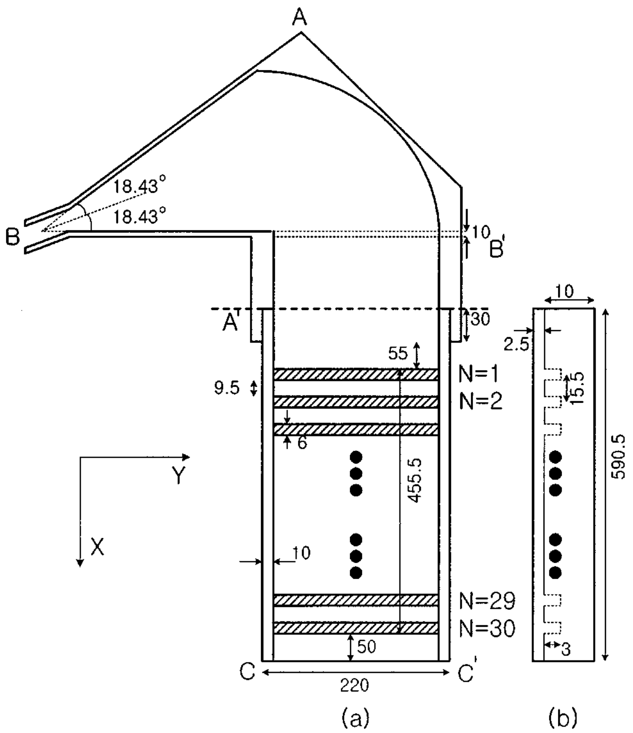

Fig. 2. The physical antenna description. (a) Top view. (b) Side view. Unit: mm. $\overline{AA'} = 324.9$ mm, $\overline{BB'} = 461.9$ mm, and $\overline{CC'} = 220$ mm.

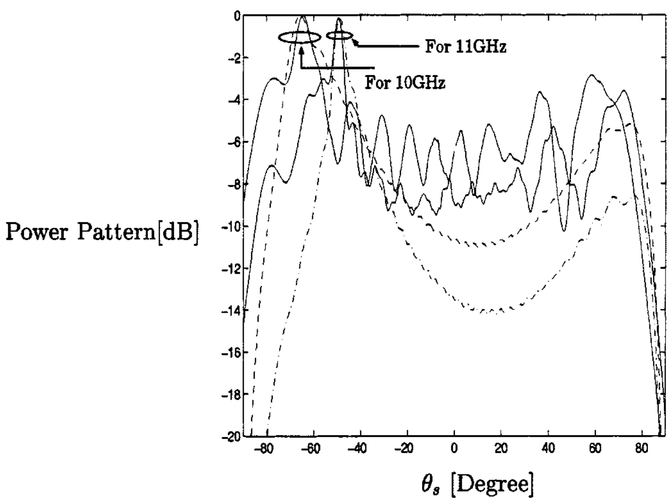

Fig. 3. Comparison between the theory and experimental data when frequency $= 10$ and 11 GHz, $b = 2.5$ mm, $T = 15.5$ mm, $a = 3.0$ mm, $d = 3.0$ mm, $\epsilon_2 = \epsilon_3 = 2.24\epsilon_1$, and $N = 30$. —: experimental; –: theory.

mode), the wavenumber in the x-direction is k_1. In rectangular waveguide (the lowest mode is TE_{10} mode), the wavenumber in the x-direction is $k_g = \sqrt{k_1^2 - (\pi/h)^2}$, where parameter h is the width of the broadside wall in the rectangular waveguide. This implies that a wavenumber conversion process is needed in terms of k_1 and k_g to take into account the phenomena associated with TE_{10} mode, which bounces between two narrow walls of the rectangular waveguide. When the wave emanates from the rectangular waveguide into the parallel plate, the wavenumber in the x-direction changes from k_g to k_1. Since the wavenumber in the x direction increases from k_g to k_1, the effective geometries seen by k_1 in the parallel-plate waveguide also increase by (k_1/k_g). Thus, in numerical computation, the parameters $V(\sqrt{\epsilon_2}$, $\sqrt{\epsilon_3}, d, T, a$, and $b)$ in Fig. 1 need to be replaced by their corresponding fictitious values $V \times (k_1/k_g)$ to account for an increase in the effective geometries. The measurements were performed in an electromagnetic anechoic chamber (13 m length $\times$ 10 m width $\times$ 9 m height) with a quiet-zone 2 $\times$ 2 m^2 in size. Fig. 3 represents the angular radiation patterns at 10 and 11 GHz, indicating good agreement with the theory in the main lobes. The sidelobe levels, however, deviate from the theoretical predictions. The possible reasons for the deviation could be the following.

1) The end effect caused by the dielectric-layer truncation in the x-direction is ignored in the theory.
2) The phase front of the incident wave excited by the hog-horn is not perfectly uniform along the y-direction, whereas the theoretical incident wave is assumed to be independent of y.

III. Conclusion

TM-wave radiation from multiple rectangular grooves in a dielectric-covered ground plane is considered. The solution is presented in a series form, which is amenable to numerical computation. The antenna is fabricated and its radiation is measured in the far zone. The measured main lobes favorably agree with the theory when the wavenumber conversion is taken into account.

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