RADIATION OF MILLIMETER-WAVES FROM TWO PARALLEL CORRUGATED DIELECTRIC SLAB WAVEGUIDES

Masayuki MATSUMOTO, Makoto TSUTSUMI, and Nobuaki KUMAGAI
Faculty of Engineering, Osaka University
Suita-shi, 565 Japan

ABSTRACT

Radiation characteristics of a grating antenna consisting of two parallel corrugated dielectric slab waveguides are investigated. It is shown that the main beam direction can be switched between two different directions by changing the phase difference between even and odd incident guided modes.

INTRODUCTION

The dielectric grating structure, for antennas in millimeter-wave integrated circuits, has advantages of electronic beam steering and being conveniently fabricated from uniform dielectric waveguides. For these reasons, a number of studies have been made on this type of antennas[1]. However, most of studies reported were concerned with a dielectric slab waveguide loaded with a periodic structure on a side of it.

In this paper, we study radiation characteristics of a dielectric grating antenna consisting of two parallel corrugated dielectric slab waveguides, and show that the main beam direction can be switched between two different directions by changing the phase of incident guided waves.

THEORETICAL BACKGROUND

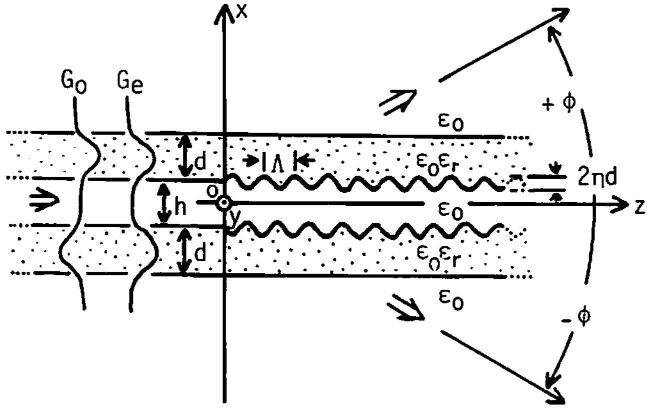


Fig.1 Two dimensional model of the grating antenna.

The two dimensional model of the grating antenna is depicted in Fig.1. Two parallel dielectric slab waveguides are corrugated sinusoidally with modulation index η and periodicity Λ. Field distributions are assumed to be independent of the y coordinate, and we treat only TE modes.

With a guided mode being incident from $z<0$, radiation modes are excited in the region $z>0$, so the guided-wave energy leaks into free space. The equations governing the nature of coupling between guided and radiation modes in z>0 are[2]

$$\begin{cases} \dfrac{d\,G_i(z)}{d\,z} = \displaystyle\int_0^{k_0} K_i(\beta)R_i(\beta,z)e^{-j(\beta-\Gamma_i)z}\frac{\beta}{\rho}d\beta & \text{(1a)} \\ \dfrac{d\,R_i(\beta,z)}{d\,z} = -K_i^*(\beta)G_i(z)e^{j(\beta-\Gamma_i)z} & \text{(1b)} \end{cases}$$

$$\rho = \sqrt{k_0^2-\beta^2} \quad , \quad \Gamma_i = \beta_i - \frac{2\pi}{\Lambda} \qquad i = \begin{cases} e : \text{for even modes} \\ o : \text{for odd modes} \end{cases}$$

where G_i, R_i, β_i, k_0 and K_i are the amplitude of the guided mode, that of the radiation mode, the propagation constant of the guided mode, the free space wavenumber, and the coupling coefficient, respectively.

Since the structure depicted in Fig.1 is symmetrical about the yz plane, an even guided mode couples only to even radiation modes, while an odd guided mode couples to odd radiation modes.

The radiation loss coefficient of guided modes, which can be taken as a measure of strength of the radiated field, is obtained by solving Eq.(1) under perturbation assumptions as

$$\alpha_i = \frac{\pi\Gamma_i}{\sqrt{k_0^2-\Gamma_i^2}}\left|K_i(\Gamma_i)\right|^2 \quad , \quad i=e,o$$

The main beam direction of the radiated field is given by

$$\phi_i = \cos^{-1}\frac{\beta_i - 2\pi/\Lambda}{k_0} \quad , \quad i=e,o$$

Figs.2 and 3 show the normalized radiation loss coefficient $\alpha_i d/\eta^2$ and the main beam direction ϕ_i , respectively, as a function of normalized spacing between two slabs h/d.

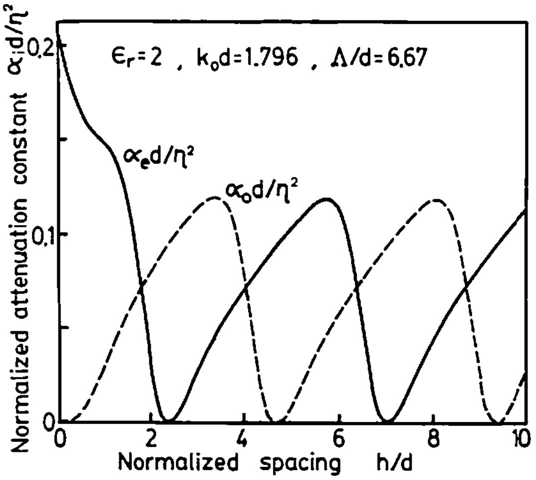


Fig.2 Radiation loss coefficients versus spacing between two slabs.

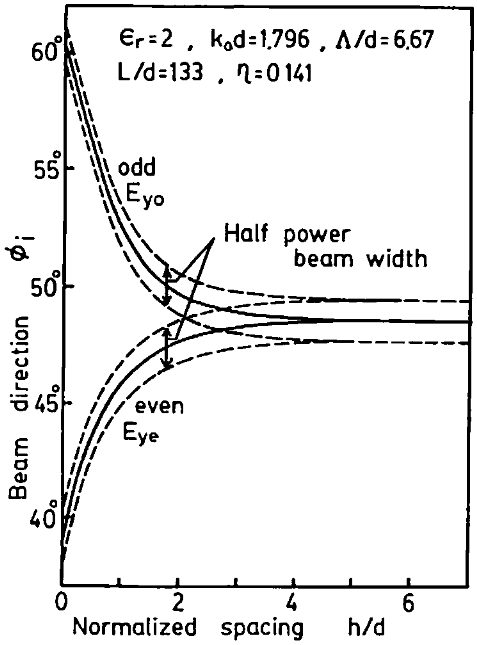


Fig.3 Main beam directions versus spacing between two slabs.

From these figures, it should be noted that the values of α_e and ϕ_e are nearly equal to those of α_0 and ϕ_0, respectively, for particular values of h/d such as 4.024, 6.356 and 8.690. Therefore, if both even and odd guided modes with equal amplitude and phase are fed into the grating structure having those particular values of h/d, the radiation toward $-\phi$ direction will disappear due to the superposition of even and odd radiated fields. While, in the case of the even and odd incident guided modes with equal amplitude and opposite phase, the radiation toward $+\phi$ direction will disappear.

Thus, the main beam direction can be switched between two different directions $+\phi/-\phi$ by changing the phase difference between even and odd incident guided modes by 180 degrees.

EXPERIMENTAL RESULT

Using teflon slabs of relative permittivity $\varepsilon_r=2$, radiation patterns were measured at 47.6 GHz. Configuration of a corrugated teflon slab and structure of the fabricated grating antenna are shown in Figs.4 and 5, respectively. In Fig.5, TE_0 guided mode is excited at point P by the electromagnetic horn. Phase difference between even and odd incident guided modes at z=0 is given approximately by

$$\delta = \int_{AA'}^{BB'} \{\beta_e(z)-\beta_0(z)\}\,dz$$

and δ can be controlled by changing the spacing W in the region $z<0$.

Radiation patterns were measured at a distance of 82 cm from the center of the grating antenna for three different values of W. The result is shown in Fig.6.

CONCLUSION

Radiation characteristics of a dielectric grating antenna consisting of two parallel corrugated dielectric slab waveguides were studied.

This type of grating antenna can be developed to a electronically beam switch-able antenna in conjunction with a electronic phase shifter such as a built-in p-i-n structure [3].

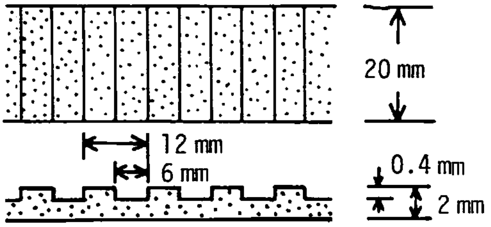


Fig.4 Configuration of a corrugated teflon slab.

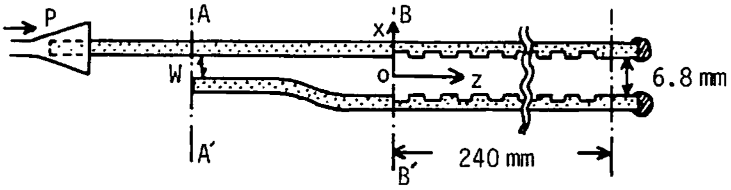
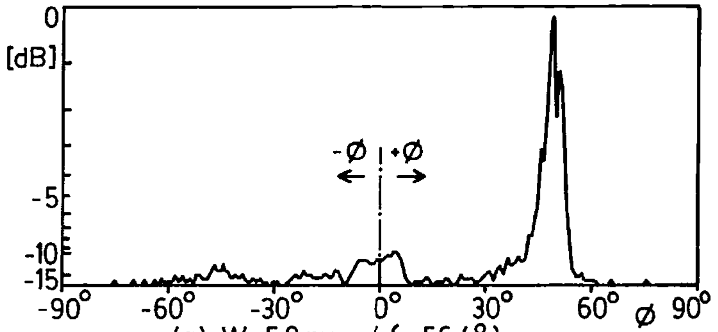
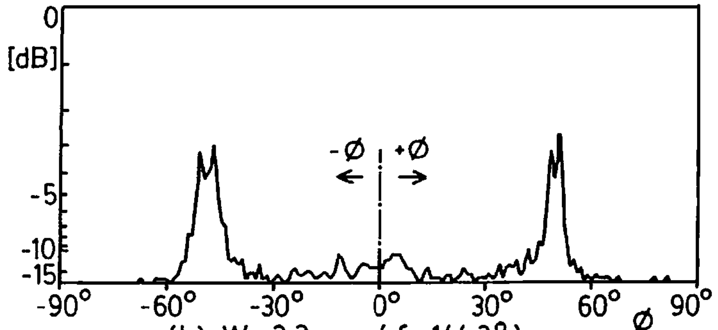


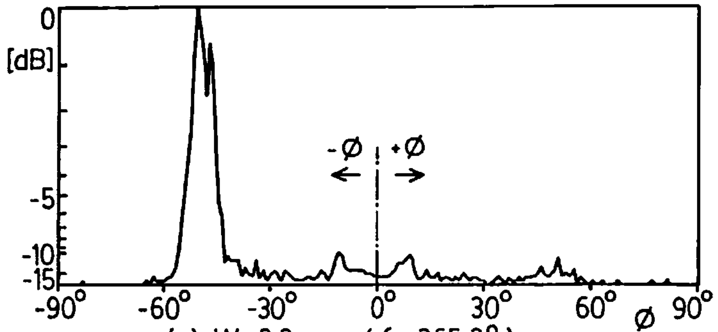
Fig.5 Structure of the fabricated grating antenna.



(a) W=5.0 mm (δ=56.4°)



(b) W= 3.3 mm (δ=144.3°)



(c) W=2.3 mm (δ= 265.2°)

Fig.6 Measured radiation patterns.
(a) Radiation toward +ϕ direction.
(b) Radiation toward ±ϕ directions.
(c) Radiation toward -ϕ direction.

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