EXPERIMENTS ON A BEAM-STEERABLE LEAKY WAVEGUIDE ANTENNA

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1. Introduction

Recently, planar antennas with low cost and high-efficiency characteristics have been well studied and used for Broadcasting Satellite receiving. Generally most of these antennas have non-steerable (tilted or non-tilted) antenna beams. They will increase facility of antenna installation, if beam-steering performances are provided. Such antennas could be directly attached to a wall or a roof of a building.

A rectangular waveguide with an inductive grid on the E-plane wall, hereinafter referred to as a leaky waveguide antenna, is one of attractive radiators applicable to such planar antennas because of its simple configuration and high radiation efficiency(1). By applying mechanical deformation to a leaky waveguide antenna, which varies the waveguide propagation constants, one dimensional beam-steering can be performed as predicted from theory. In this paper, experimental studies on the beam-steerable leaky waveguide antenna are presented.

2. Antenna Design

Figure 1(a) shows a cross section of a leaky waveguide with an inductive grid, which radiates a linearly polarized wave with a certain tilt angle(θ_0). From the viewpoint of frequency characteristics the grid width($\boldsymbol{w}$(x)) should be small enough in terms of the wavelength. A variable grid spacing($\boldsymbol{s}$(x)) with a constant $\boldsymbol{w}$ is advantageous for easy fabrication. Optimum parameters($\boldsymbol{s}$(x), $\boldsymbol{a}$(x):waveguide height) are uniquely determined for a given $\boldsymbol{w}$ and the prescribed θ_0 (1).

Displacement of the wall to vary $\boldsymbol{a}$ (x) results in one dimensional beam-steering to an angle θ_1 because the propagation constants in the waveguide, (α,β), are changed. A curved metal wall opposite to the grid, which is optimized for efficient radiation at θ_0, can be replaced by a flat wall(Fig.1 (b)) because it is estimated that the approximation will result in only a few % efficiency reduction after optimization of the waveguide heights($\boldsymbol{a}_1$, $\boldsymbol{a}_2$). The approximation is advantageous for easy fabrication of the antenna.

Design objectives of the beem-steerable leaky waveguide antenna are summarized in Table1. The following procedure for the antenna design was applied.

[1] Determine $\boldsymbol{w}$.

[2] Maximize the antenna gain at a certain θ_0 using $\boldsymbol{s}$(x), $\boldsymbol{a}_1$ and $\boldsymbol{a}_2$.

[3] Maximize the antenna gain at an arbitrary θ_1 in the beam-steering range using $\boldsymbol{a}_1$ and $\boldsymbol{a}_2$.

[4] Repeat [2] and [3] at the other θ_0, then maximize the minimum gain in the range using θ_0.

Figure 2 shows the maximized antenna gain over the steering range from 25° to 60° for a given θ_0. Details of the antenna were designed using the optimized θ_0 (50°).

3. Antenna Configuration

Figure 3 shows the configuration of the beam-steerable leaky waveguide antenna with an inductive grid sheet. The waveguide has an oversized crosssection along the E-plane. The waveguide heights, a_1, a_2, can be independently adjusted by a displacement of the flat plate opposite to the inductive grid sheet. At both ends of the waveguide there are buffer areas to avoid an abrupt change of the waveguide height. The inductive grid was chemically etched on a polyimide film(ε_r =3.5, t =50 μm). In order to excite the proper TE_{10} mode, the oversized waveguide was fed from a line source with uniform distribution, which was composed of a 16 element array of E-plane sectoral horns with a coaxial tournament feeder (which is not illustrated in Fig. 3).

4. Measurement Results

Because of the limited range of the facilities, the radiation characteristics and the beam-steering performance were evaluated in the Fresnel region (d=8.58 m). The results were compared with values calculated under the same conditions.

Figure 4 shows the typical H-plane radiation pattern (θ_1 = 45°). The measured characteristics of narrow beamwidth (2.4°), sharp roll-off of the main lobe, and low side-lobes in the broadside region agreed fairly with the calculated characteristics. The results prove that the aperture excitation was nearly uniform, as designed. Another measurement showed the excellent radiation characteristics in the E-plane (beamwidth:2.1°).

Figure 5 shows the beam-steering performance, where the radiated beam was steered from 25° to 60° with 5° increments. A beam-steering capability over 35° with a level reduction less than 3.6 dB was demonstrated. The envelope of the measured peak level shows almost the same variation as calculated (dashed line in Fig. 5). As a result, beam-steering of the fabricated antenna was well performed as designed.

Figure 6 shows the relation between frequency and relative amplitude of the steered beam. The amplitude reduction with frequency deviation is caused from so called "beam squint". At a larger steering angle (θ_1 = 60°), wider frequency characteristics were observed as predicted from theory.

In the Fresnel region the measured antenna characteristics agreed well with the calculations. Similar agreement as shown above is expected in the far-field measurements.

5. Conclusions

In order to perform beam-steering using low-cost and high-efficiency planar antennas, a leaky waveguide antenna with mechanical control of the propagation constants was investigated experimentally. This antenna consisted of an oversized waveguide and an inductive grid etched on a polyimide film. A fine radiation pattern (typical H-plane beamwidth:2.4°) and a beam-steering capability over 35° with a level reduction less than 3.6 dB were demonstrated. The measured radiation characteristics agreed well with the calculations.

Acknowledgement

The authors would like to thank Dr. Yoshihiko Mizuguchi of KDD for his useful guidance.

Reference

[1] R. C. Honey, "A flush-mounted leaky-wave antenna with predictable patterns", IRE Trans. Antennas Propagat., AP-7, pp.320-329, Oct. 1959.

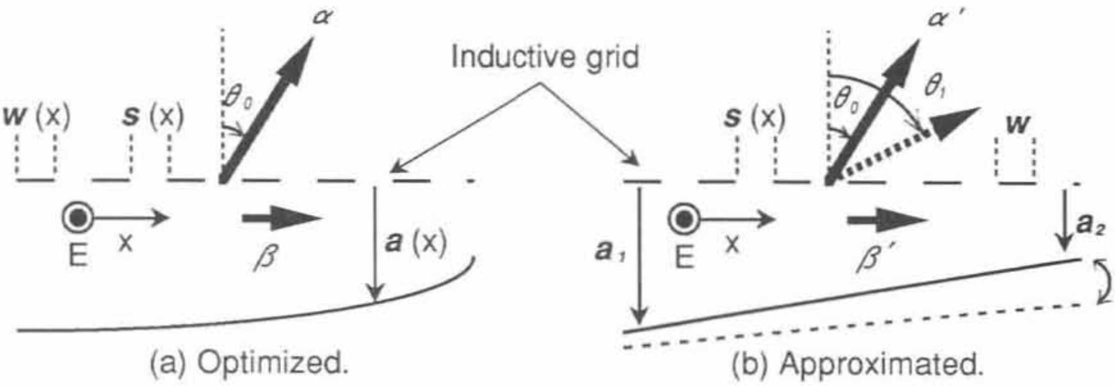

Fig.1. Cross section of leaky waveguide with inductive grid.

Table 1. Design objectives.

Center frequency	11.9 GHz (λ=2.52cm)
Steering angle	25° ~60°
Gain of steered beam	> 35dBi
Aperture size	90×60 cm^2 (36×24 λ^2)

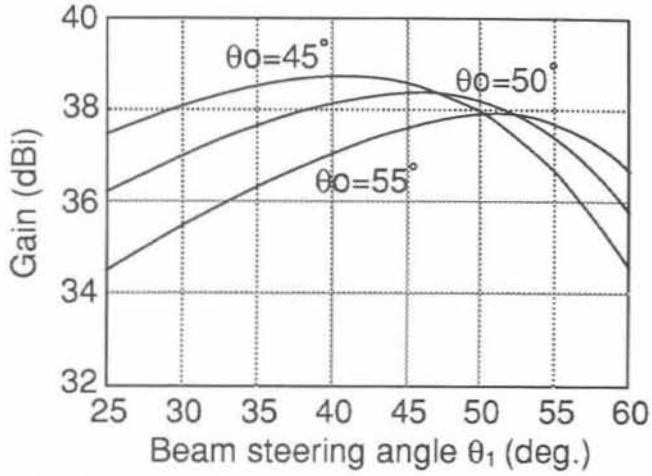

Fig.2. Maximized antenna gain vs. beam steering angle (calculated).

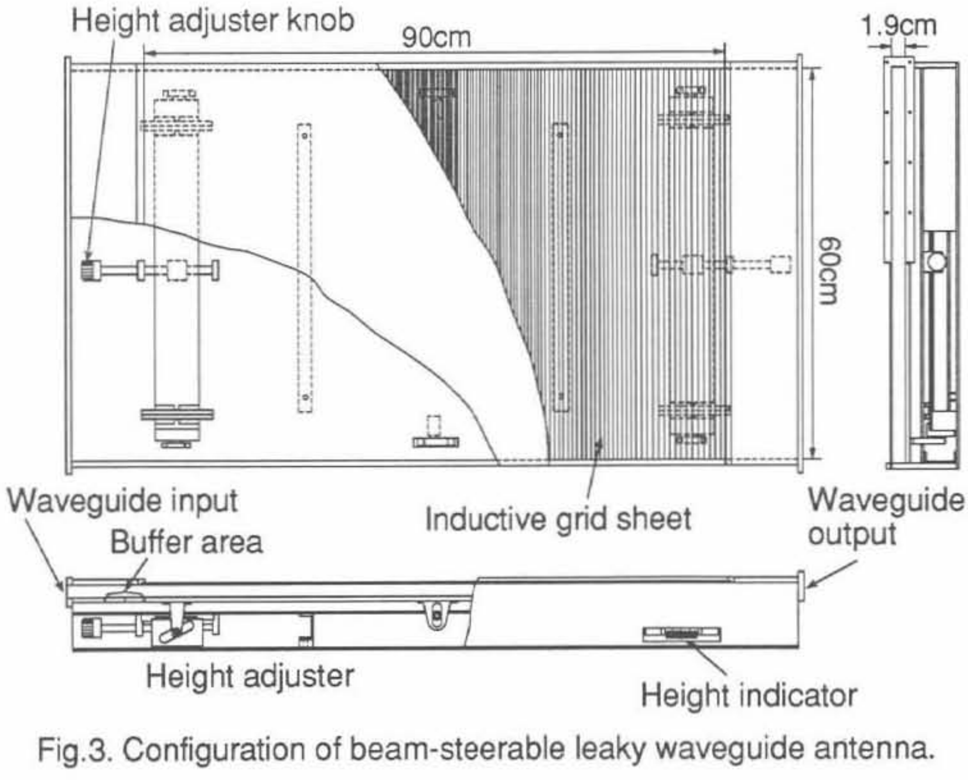

Fig.3. Configuration of beam-steerable leaky waveguide antenna.

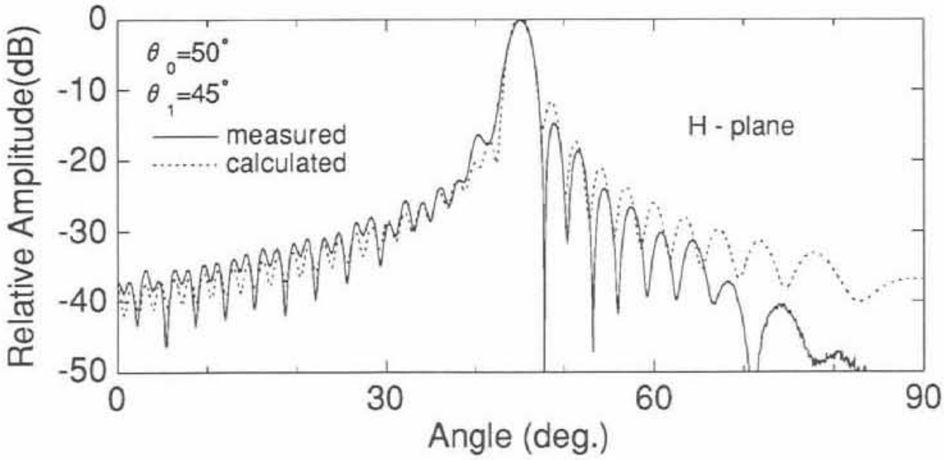

Fig. 4. Radiation pattern measured in Fresnel region (d=8.58m).

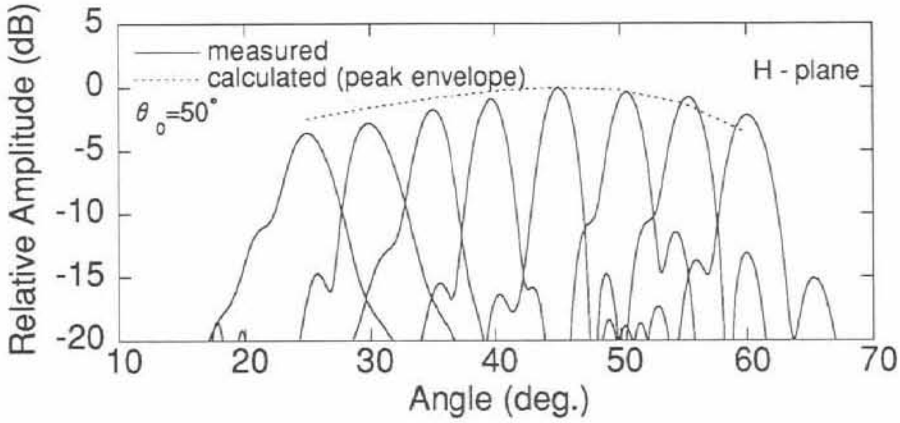

Fig.5. Beam-steering characteristics measured in Fresnel region (d=8.58m).

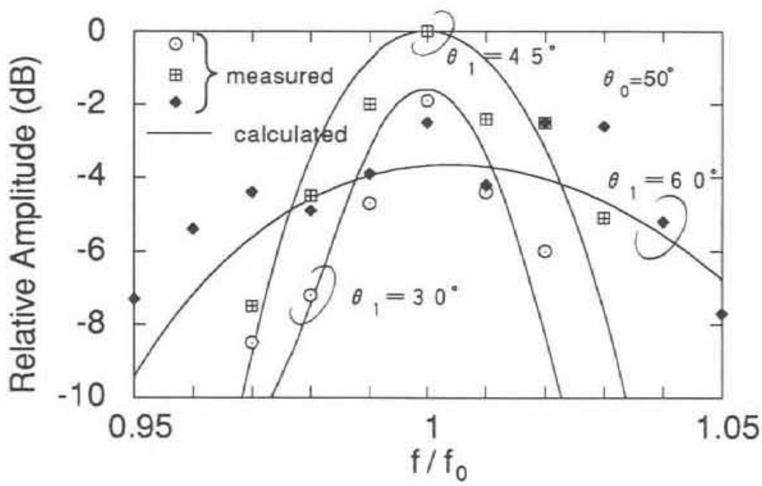

Fig.6. Frequency characteristics of radiation level measured in Fresnel region.