A Novel Multibeam Grating Antenna with Applications to Low-Cost Millimeter-Wave Beam-Steering

Christopher T. Rodenbeck, Ming-yi Li, and Kai Chang

Texas A&M University, Electrical Engineering Dept., College Station, TX 77843-3128, USA

Abstract — **This paper introduces a low-cost millimeter-wave dual-beam scanning antenna that uses a dielectric image line fed grating film designed for bidirectional excitation. An excellent radiation pattern is maintained for both beams across wide scan angles over the 35 to 40 GHz frequency range, with over ±50° scanning reported at each frequency. Theoretical calculations closely predict the observed scan angle across the entire range of measurement.**

I. Introduction

In recent years, several researchers have reported multiple-beam frequency-scannable antennas based on bidirectionally-excited microstrip, CPW, and slotline leaky-wave antennas [1]-[4]. In these approaches, forward and backward traveling waves share the aperture of a single antenna. Unfortunately, due to their large electrical length, microstrip leaky-wave antennas become prohibitively lossy at high microwave and millimeter-wave frequencies.

Our investigation extends these multiple-beam approaches to millimeter-wave frequencies by introducing a novel dual-beam grating antenna with a distribution of element widths designed for bidirectional excitation. Fixed-frequency beam steering is demonstrated across a wide range of frequencies by etching continuous grating strips with variable element-to-element spacings onto a moveable dielectric film. Experimental results indicate that this technique provides over ±50° beam steering across the 35 to 40 GHz band, with low side lobes and good gain flatness across the scans.

II. Concept & Design

A general class of leaky-wave antenna may be constructed by placing dielectric or conducting strips periodically along a dielectric waveguide. These strips form a grating that perturbs the energy traveling along the guide, exciting leaky modes above the surface that determine the nature of the far-field pattern. The radiated beam is fan-shaped, being highly directive in the array-effect dimension. Assuming the grating strips themselves have a negligible effect on the propagation constant along the perturbed guide, the angle of radiation in the direction forward from broadside can be calculated at any given frequency of excitation as a simple function of the guide wavelength λ_g and strip spacing d [5]:

$$\theta_n = \arcsin\left(\frac{\lambda_o}{\lambda_g} + \frac{n\lambda_o}{d}\right), \quad \left|\frac{\lambda_o}{\lambda_g} + \frac{n\lambda_o}{d}\right| \leq 1 \qquad (1)$$

where λ_o is the free space wavelength and n, the space harmonic $(0, \pm1, \pm2, \cdots)$, is conventionally chosen as -1.

Earlier beam-scanning studies using this class of antenna have focused on scanning θ_n by varying the operating frequency, which is inconvenient in many system applications, or by modulating the propagation constant along the dielectric waveguide feed, which typically results in narrow bandwidth, significant loss, or limited scanning at millimeter wave frequencies.

A new beam-steering technique, however, has recently been invented that overcomes these disadvantages [6]-[7]. The idea behind the technique is to scan θ_n by directly varying the inter-element spacing d. In this study, we modify this technique, extending its capabilities to wide-scan dual-beam operation.

Figure 1 illustrates the configuration of the dual-beam scanning antenna. A thin, moveable dielectric film is extended across a stationary dielectric image line. Two *Ka*-band waveguide transitions bidirectionally feed the image line. Other transitions, including microstrip transitions [8], may also be used. Continuous metal grating strips (depicted as visible in the figure) are etched on the underside of the film. The separation distance between the grating strips varies linearly from d_{max} to d_{min} along the length of the film. The number of grating strips increases as the spacing between strips decreases in order to enhance antenna's scanning efficiency. The widths of the strips themselves increase linearly away from the input ports to the antenna in order to gradually perturb the electromagnetic signals as they propagate along the image line.

The signal injected from Port 1 radiates a beam in the $+\theta$ direction, while the signal injected from Port 2 radiates

0-7803-7239-5/02/$10.00 © 2002 IEEE

a beam in the $-\theta$ direction. Both beams are E-polarized in the z-direction. Shifting the grating layer in the $\pm x$-direction varies the spacing between the grating strips, scanning the radiated beam along θ in the y-z plane.

The design featured in this study uses a dielectric image line 1.7 mm high, 6.4 mm wide, and 140 mm long. The moveable grating film is 0.13 mm thick and 140 mm long in the y-direction of Figure 1. The grating film is 258 mm long in the x-direction, with the spacing between strips varying from d_{max} = 6.36 mm to d_{min} = 3.69 mm along the film's length. A second section of film, used to extend the scanning range at 35 GHz, is 54 mm long in the x-direction, with the spacing varying along its length from d_{max} = 6.66 mm to d_{min} = 5.52 mm. Both the image line and dielectric film are fabricated using RT-Duroid 5880, with relative dielectric constant $\varepsilon_r = 2.2$.

III. Measured Performance

The scanning antenna of Figure 1 is tested using a *Ka*-band magic tee to combine received CW power from the two input ports of the dielectric image line. Since the relative phase between the two input signals is not controlled in this experiment, the dual beams are not scanned to within ±5° of broadside.

Figure 2 illustrates the measured and calculated angles for both radiated beams as the element-to-element spacing of the perturbing grating is varied along the image line. The theoretical curves are generated using Equation (1) together with an effective dielectric constant technique [9] for calculating the guided wavelength λ_g along the dielectric image line. The calculations closely predict the observed scan angle for both beams.

Over the entire range shown in Figure 2, maximum side-lobe levels are at least 10 dB below the main beam. Using this conservative criterion to define the scanning range, the maximum achievable scan angle is ±52° at 35 GHz and ±51° at 40 GHz. In addition, the return loss at each port is well below −15 dB across the recorded scanning range. The isolation between Port 1 and Port 2 varies from 92 to 97 percent across the 35 GHz scan and from 88 to 94 percent across 40 GHz scan.

Figures 3 and 4 illustrate the E-plane variation in the dual-beam radiation pattern at 35 and 40 GHz, respectively. As the separation between grating elements decreases, the dual beams steer forward from broadside. A highly directive dual-beam radiation pattern is maintained across the scanning range, with low side lobes and excellent symmetry between the beams. Isotropic gains of 18.37 ± 0.75 dB and 18.29 ± 1.12 dB are observed across the 35 and 40 GHz scans, respectively.

IV. Conclusions & Discussion

This paper has introduced a novel millimeter-wave dual-beam scanning antenna. The antenna used a moveable grating film extended across a bidirectionally excited dielectric image line to achieve wide-angle dual-beam scanning across the 35 to 40 GHz frequency range. Measured and calculated results for the variation in the scan angle were in good agreement. The results should have many applications in broadband multibeam millimeter-wave beam-control techniques.

Acknowledgement

This work was supported in part by the National Science Foundation.

References

[1] C.J. Wang, "Active dual-beam leaky-wave antenna with asymmetrically scanning capability," *Electron. Lett.*, vol. 37, no. 11, May. 2001, pp. 672-673.

[2] C. C. Lin and C. K. C. Tzuang, "A dual-beam micro-CPW leaky-mode antenna," *IEEE Trans. Antennas Propagat.*, vol. 48, no. 2, Feb. 2000, pp. 310-316.

[3] C.C. Hu, C.F. Jou, and J.J. Wu, "A novel two-beam scanning active leaky-wave antenna," *IEEE Trans. Antennas Propagat.*, vol. 47, no. 8, Aug. 1999, pp. 1314-1317.

[4] G. W. Slade, L. Carin, Q. Xu, S. E. Borchardt, and K. J. Webb, "A study of slotline leaky-wave antennas," *IEEE Trans. Antennas Propagat.*, vol. 38, no. 3, Mar. 1990, pp. 411-413.

[5] P. Bhartia and I.J. Bahl, *Millimeter Wave Engineering and Applications*, Wiley: New York, 1984, pp. 591-592.

[6] C.T. Rodenbeck, M..Y. Li, and K. Chang, "System and method for millimeter-wave beam-steering using a grating film fed by dielectric integrated guide," Provisional Patent Application No. 60/292369, U.S. Patent and Trademark Office, May 2001.

[7] C.T. Rodenbeck, M.Y. Li, and K. Chang, "A novel millimeter-wave beam-steering technique using a dielectric-image-line-fed grating film," in *2001 IEEE MTT-S Int. Microwave Symp. Dig.*, Phoenix, AZ, May 2001, pp. 267-270.

[8] H. Tehrani, M.Y. Li, and K. Chang, "Broadband microstrip to dielectric image line transitions," *IEEE Microwave Guided Wave Lett.*, vol. 10, no. 10, Oct. 2000, pp. 409-411.

[9] R.M. Knox and P.P. Toulios, "Integrated circuits for the millimeter through optical frequency range," *Proc. of the Symposium on Submillimeter Waves*, New York, NY, pp. 497-516, March 1970.

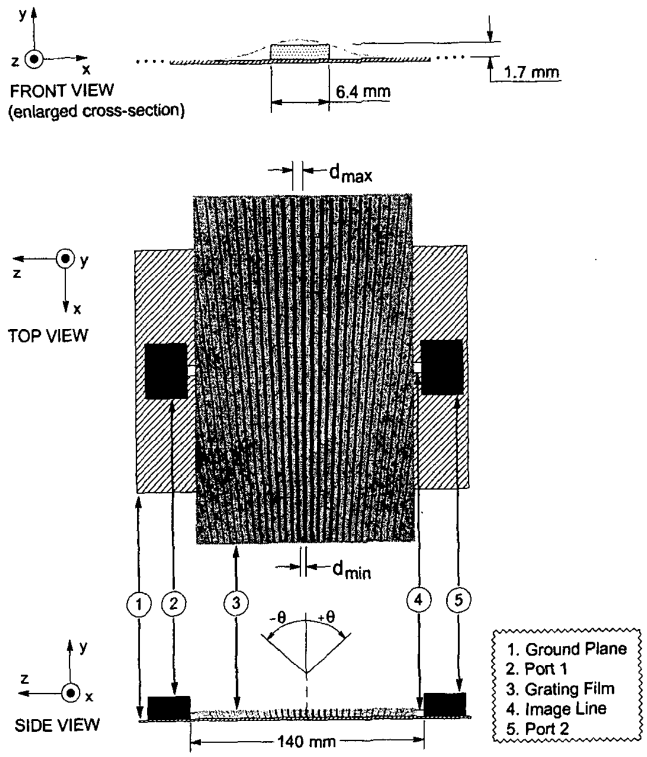

Fig. 1. Configuration of the novel dual-beam scanning antenna.

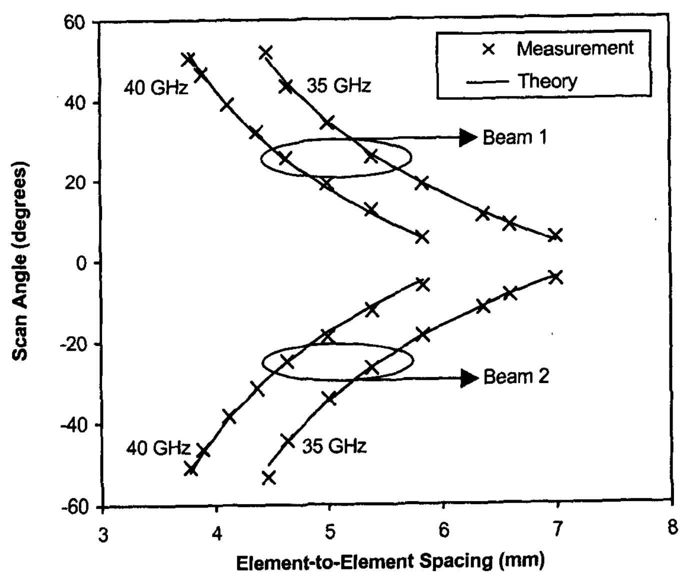

Fig. 2. Measured and calculated scanning angles for both beams.

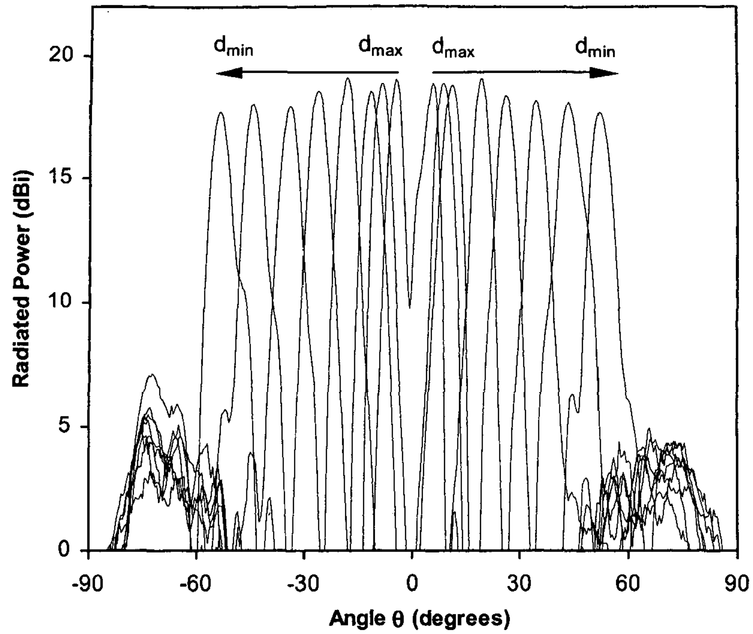

Fig. 3. Beam steering for the dual-beam radiation pattern at 35 GHz.

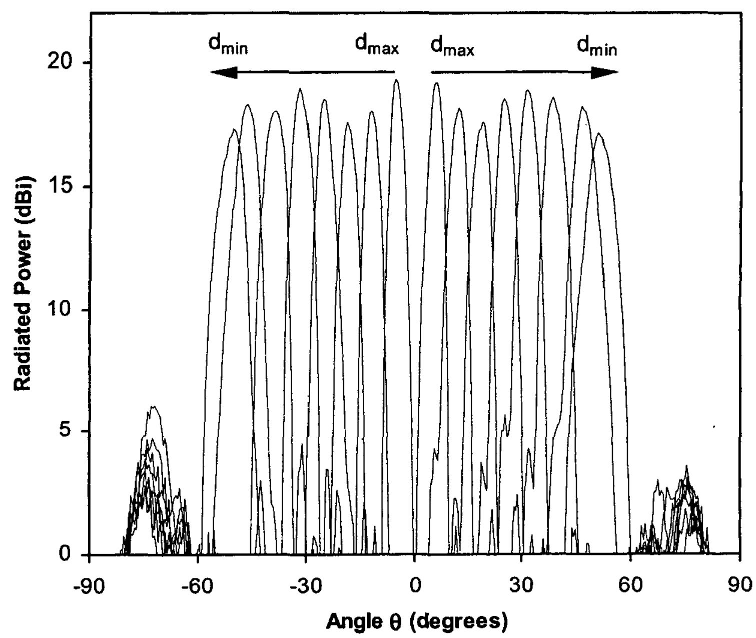

Fig. 4. Beam steering for the dual-beam radiation pattern at 40 GHz.