An Electronically Switchable Leaky Wave Antenna

Limin Huang, *Member, IEEE*, Jung-Chih Chiao, and Michael P. De Lisio, *Member, IEEE*

***Abstract*—We report an electronically switchable dielectric leaky wave antenna. The main beam angle can be electronically steered using p-i-n diodes. The diodes are used as switches to control the radiation from two sets of gratings with different periods, thereby switching the main beam angle. Beam steering is achieved at a single fixed frequency; no frequency sweeping is necessary. A microwave prototype demonstrates a 35° change in beam direction at 3.5 GHz. Measured antenna patterns agree with theoretical predictions. This approach should be scalable to millimeter-wave frequencies using diodes monolithically integrated on a semiconductor waveguide.**

***Index Terms*—Electronic beam steering, leaky wave antenna.**

I. INTRODUCTION

LEAKY WAVE antennas based on a dielectric rod waveguide periodically loaded with perturbations have been investigated for some time [1]–[6]. These antennas are lightweight, easy to fabricate, and readily integrated into conventional millimeter-wave systems—properties that make leaky wave antennas the subject of continuing interest today. Another intriguing property of leaky wave antennas is the fact that the main beam direction can readily be scanned. The angle θ of the main beam measured from broadside will be given by the well-known expression

$$\sin\theta = \frac{\lambda_0}{\lambda_g} - m\,\frac{\lambda_0}{d} \tag{1}$$

where

- d perturbation spacing;
- λ_0 free-space wavelength;
- λ_g guided wavelength inside the dielectric rod;
- m integer most often equal to unity.

Many researchers achieve scanning by changing the operating frequency, thereby changing both the free-space and guided wavelengths λ_0 and λ_g in a prescribed manner [1], [4], [6]. Fralich and Litva [7] have reported a frequency scannable leaky wave antenna integrated with a voltage-controlled oscillator, effectively achieving an electronically controlled beam. For many applications, however, fixed-frequency operation would be preferable. Horn and co-workers [8] achieve electronic scanning by using p-i-n diodes to modulate the effective waveguide size. They demonstrate fixed-frequency electronic beam steering by effectively changing the guided wavelength λ_g. These researchers report a 10° change in beam angle as the diode bias is varied. Finally, Maheri and others [9] achieve fixed-frequency beam scanning by varying a static magnetic field in a corrugated ferrite slab. This approach also effectively varies the guided wavelength λ_g.

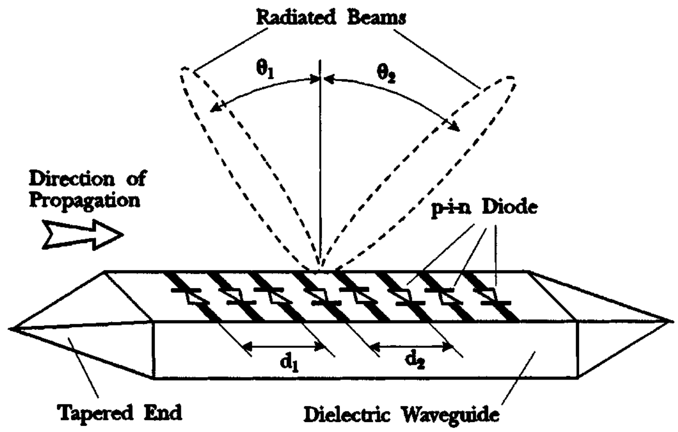

Fig. 1. Principle of antenna operation. Metal strips loaded on a dielectric waveguide radiate microwave energy. p-i-n diodes act as switches to change the strip spacing from d_1 to d_2, thereby switching the beam angle from θ_1 to θ_2.

We report fixed-frequency beam switching using a different approach: we electronically vary the perturbation spacing d. Fig. 1 illustrates the idea. A rectangular dielectric rod is loaded with a grating of metal-strip perturbations. p-i-n diodes are loaded in these metal strips. Two grating periods d_1 and d_2 are present. The p-i-n diodes act as switches, controlling the effective grating spacing. A dc bias voltage controls the state of the p-i-n diode switch, thereby controlling whether grating d_1 or d_2 primarily radiates. This, in turn, switches the main beam angle from θ_1 to θ_2. The beam could be switched among many possible angles by using several grating spacings. This approach has a number of advantages. Beam scanning is achieved without changing the operating frequency. Electronic control allows rapid variation of the scan angle. Finally, the approach is amenable to MMIC fabrication techniques by monolithically integrating the switch diodes on silicon, gallium arsenide, or indium phosphide waveguides. Our approach is similar to the work developed by several researchers who achieve beam steering using a photoinduced plasma grating in a semiconductor antenna [10]–[12].

II. ANTENNA FABRICATION

We designed, fabricated, and tested a microwave scale model as a proof of the concept. A microwave system has the advantage of being easy to fabricate and test, while the approach should be scalable to millimeter wavelengths. Fig. 2 shows a photograph of the antenna. The dielectric rod waveguide is constructed out of lucite, with a relative dielectric constant of 2.56. The cross

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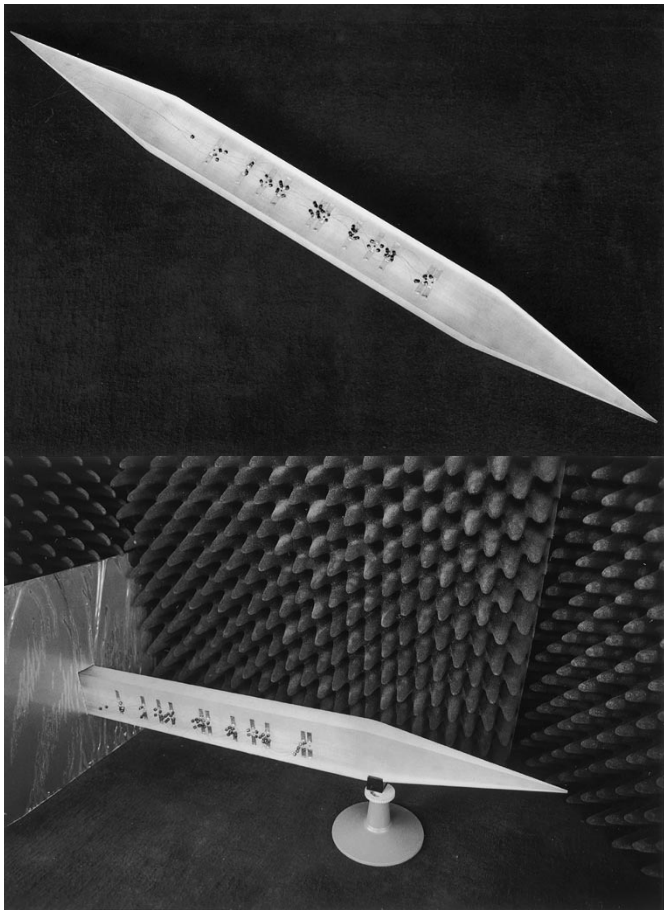


Fig. 2. Photographs of the leaky wave antenna. The dielectric waveguide cross section is 2.75 × 1.25 inches. The antenna is 36 inches long.

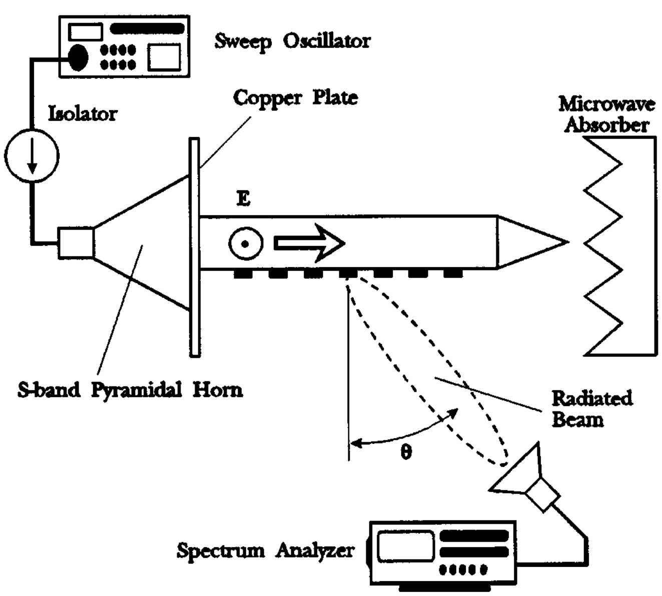
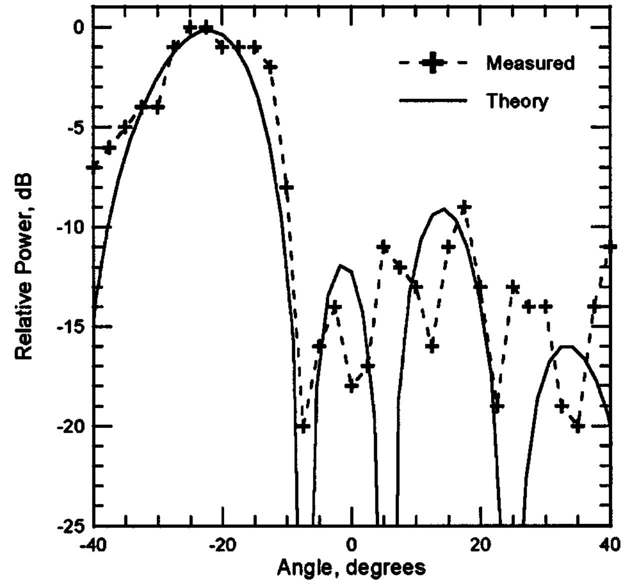
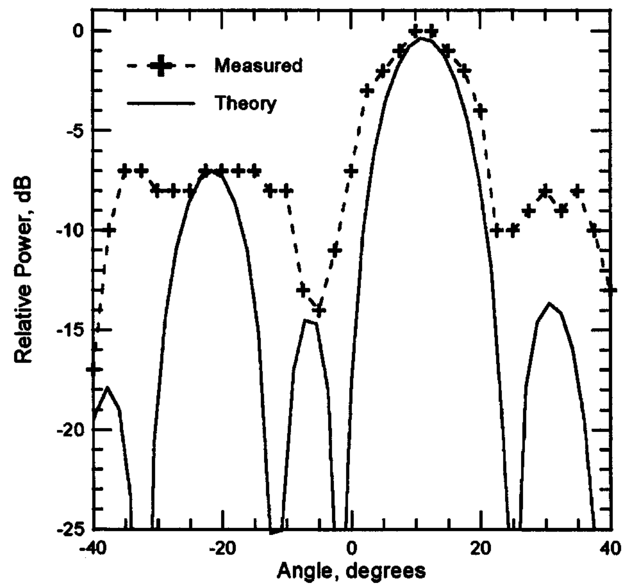


Fig. 3. Simplified schematic of the measurement setup.

section of the rod is rectangular, machined to be 2.75 × 1.25 inches. These dimensions were chosen to be comparable to the cross section of S-band waveguide as well as a standard size for easy fabrication. The entire rod is 36 inches long, with both ends tapered to a point to improve the input and output matching.



(a)



(b)

Fig. 4. Measured and theoretical H-plane radiation patterns. (a) Corresponds to the 5.1-cm strip spacing. (b) Corresponds to the 7.8-cm strip spacing.

Metal-strip radiators are positioned along the length of the antenna. Six strips are spaced 5.1 cm apart (d_1) and five strips are spaced at 7.8-cm intervals (d_2). All strips are identical, with the length and width determined experimentally. M-Pulse packaged p-i-n diodes are located midway along the strips. Thin magnet wires loaded with ferrite-bead chokes provide dc bias to the switch diodes.

Fig. 3 shows a simplified schematic of the measurement setup. A sweep oscillator connected to a S-band pyramidal horn is used to excite the dielectric waveguide. The isolator helps to maintain the frequency stability of the generator. A copper plate at the mouth of the horn is used as a screen to block any direct radiation from the horn itself. The dielectric rod is excited through an aperture in the plate. The copper screen can

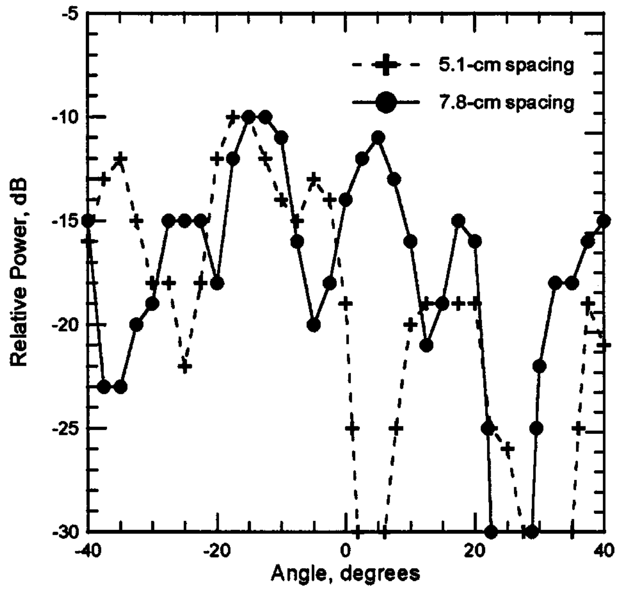


Fig. 5. Measured cross-polarized H-plane radiation pattern.

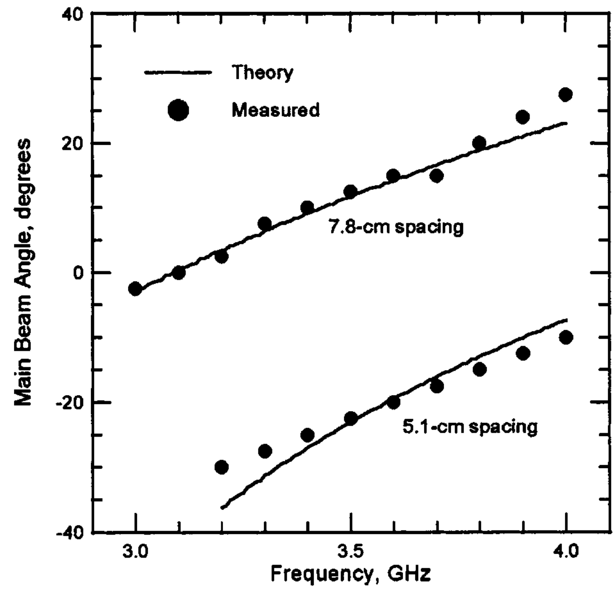


Fig. 6. Measured and theoretical main beam angle for both strip spacings as a function of frequency.

also be noted in Fig. 2. Microwave absorbing material placed at the tapered end of the rod acts as a termination. The antenna pattern is measured with a small wideband horn antenna and a spectrum analyzer.

III. Measured Results

To test the beam switching, we excite our dielectric leaky wave antenna with a 3.5-GHz signal. One set of p-i-n diodes is forward biased (+1 V) and the other set is reverse biased (−25 V). Fig. 4 plots the antenna's measured H-plane radiation patterns. Fig. 4(a) shows the pattern with the diodes biased such that the 5.1-cm grating is the primary source of radiation. Fig. 4(b) shows the pattern with most of the radiation emitting from the 7.8-cm grating. Negative angles correspond to a beam radiated in the backward direction. The main beam shifts by 35° when the diode bias is switched. We note that the absolute peak radiated power for the two cases are within 1 dB of each other. We suspect that the broad flat sidelobe centered at −25° in Fig. 4(b) may be the result of reflections from the copper end plate. The measured cross-polarized power is low—more than 10 dB below the power in the main beam, as shown in Fig. 5.

The theoretical curves in Fig. 4 are generated using Marcatilli's method to determine the wavelength in the dielectric rod [13]. We also assume that the currents in the radiating strips have identical magnitudes. Ideally, the nonradiating strips would carry zero RF current. Practically, however, the diode switch cannot completely prevent these strips from radiating. It is this spurious radiation that causes the rather high side-lobe level. A good fit between theory and experiment is achieved when we assume the spurious power radiated by a single nonradiating strip is 12 dB less than the power radiated from a single radiating element. It may be possible to improve the agreement between theory and experiment by assuming a more complicated nonuniform radiating strip illumination.

It is also possible to scan the main beam for both grating spacings d_1 and d_2 by varying the operating frequency. This is illustrated in Fig. 6. The operating frequency is varied from 3.0 to 4.0 GHz. The theoretical curves are generated using (1), with λ_g determined using Marcatilli's approach [13]. The agreement for both strip spacings is very good. With frequency scanning, the main beam angle can be swept over a considerable angular range.

IV. Conclusion

We have demonstrated an electronically switchable leaky wave antenna using p-i-n diode switches. The angle of the main beam changes by 35° when the bias on the diodes is varied. Measured radiation patterns agree very well with theoretical predictions. Although these measurements were conducted on a 3.5-GHz microwave model, the approach should be extendable to millimeter wavelengths using monolithic fabrication techniques.

At very high millimeter-wave frequencies, parasitic losses in the diodes will ultimately limit the antenna efficiency. An intriguing alternative is to use microelectromechanical switches (MEMS) to control the beam direction [14], [15]. These tiny switches have very low series losses well into the millimeter-wave regime. The idea is proposed in Fig. 7. A cantilever-beam switch is formed by depositing a thin layer of dielectric material with evaporated metal patterns on sacrificial layers. The cantilever beam is supported by a thicker layer of electroplated metal. The dielectric layer serves two functions: it provides dc bias isolation for an electrostatic force to close the switch and it provides the required stress to separate the contact when the bias is off. Another interesting possibility is to use photosensitive devices as switches, controlling the beam direction optically.

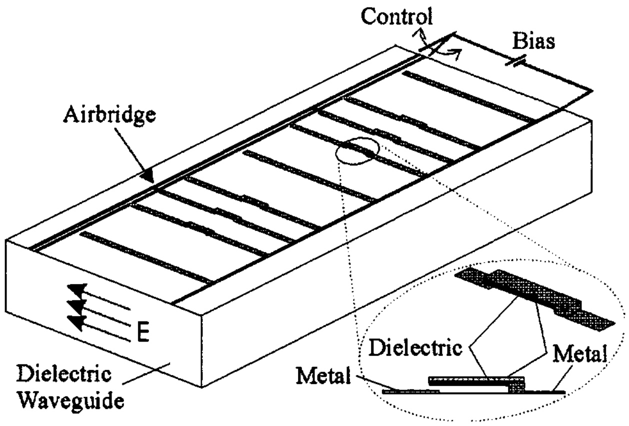


Fig. 7. Proposed MEMS switch for millimeter-wave applications. The state of the switch is controlled by the bias lines.

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