

Ka-Band True Time Delay E-plane Beam Scanning and Broadening Phased Array System Using Antipodal Elliptically-Tapered Slot Antennas

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Introduction

Endfire tapered slot antennas (ETSA) fabricated on dielectric substrates hold particularly great potential to reduce the cost and weight of antennas and consequently have been applied in phased antenna array (PAA) and focal-plane imaging systems. In addition, the explosion in communications and the overcrowding of lower frequency bands have provided impetus for designing phased array antenna systems in Ka-Band. Many of these applications require wide bandwidth operation necessitating the use of true time delay based PAAs rather than phase shifter implementations to avoid beam squinting [3].

The piezoelectric transducer (PET)-controlled phased shifter developed by Kim and Chang [1] offers such true time delay capability over a wide frequency range [3], which also possesses the advantage of low cost and simplicity, albeit at the expense of slow speed. An 8-40 GHz 1×4 H-plane array using antipodal exponentially-tapered slot antennas [1] demonstrated a 30° beam steering range. However, for E-plane beam steering, there are more limitations on the design of single antenna element because the distance between each element, which should be around $\lambda_0/2$ to avoid grating lobes, is restricted by the aperture width of each element. On the other hand, as the number of antenna elements increases, more phase shift is needed to generate wider scanning angles for a given element spacing. In addition to beam steering, beam shaping also has potential applications in radar and communication systems [6]. On the longer term, there exists an electronically controlled “lens” application for plasma radar reflectometric imaging diagnostics, where one electronically generates and controls a concave (focusing) or convex (defocusing) wavefront from a PAA to monitor plasma cutoff surfaces [4].

In this paper, the design and testing of an 8-element E-plane array of antipodal elliptically-tapered slot antennas designed in Ka-Band is described. A low-cost E-plane beam scanning and beam broadening capability is realized using a true time delay PET-controlled phase shifter. The beam is steered from -21° to $+24^\circ$ and the 3 dB beamwidth is widened by about 10° , the latter being the requirement for the plasma radar reflectometric imaging application [4].

1 by 8 E-plane array of antipodal elliptically-tapered slot antennas

Figure 1 shows the antipodal elliptically-tapered slot antenna designed for the present application. The antenna is fed using a microstrip line through a parallel-strip transition. An experimentally determined approximate optimum range is about 0.005 to 0.03 for the effective dielectric thickness of the substrate (normalized to the free-space wavelength λ_0), t_{eff} , which is defined by,

$$t_{eff} / \lambda_0 = (\sqrt{\epsilon_r} - 1)t / \lambda_0$$

where, t is the actual thickness of the antenna substrate [5]. However, for the Vivaldi antenna, a somewhat thicker substrate can be utilized [5].

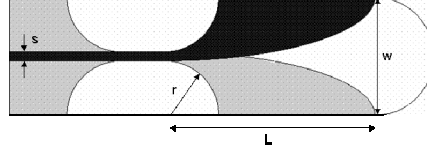


Fig.1 Antipodal elliptically-tapered slot antenna design.

(details: substrate thickness = 10 mil, $\epsilon_r = 6.15$; radiating flare length $L = 353$ mil, width at aperture $w = 196.8$ mil, radius of transition $r = 91$ mil, width of the microstrip feed line $s = 15$ mil; elliptical flare shape, major to minor axis ratio = 3.33)

The semicircular extension of at the end of the substrate is employed for improved return loss response [2]. A conventional 8-way Wilkinson power divider is used for feeding the network. The entire structure is fabricated on a single substrate (RO3006) with thickness 10 mil (Figure 2). The width of the perturbed microstrip line is 15 mil.

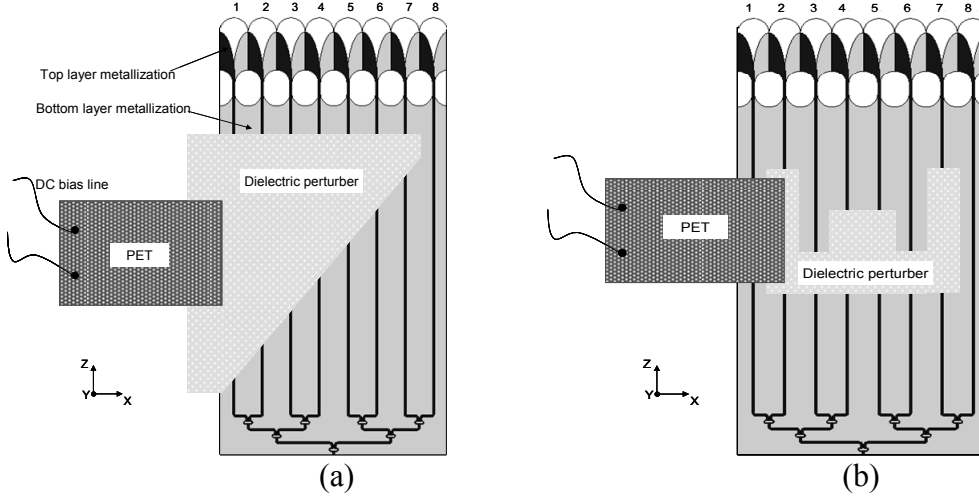


Fig.2 Structure of the antipodal elliptically-tapered slot antenna array controlled by PET:
(a) Beam steering (b) Beam broadening

The differential phase shift $\Delta\phi$ caused by the perturbation of the PET is given by

$$\Delta\phi = L_p \cdot \Delta\beta$$

where L_p is the perturber length along the transmission line and $\Delta\beta$ is the difference between the unperturbed and perturbed propagation constants along the microstrip line. The amount of phase shift of the PET-controlled microstrip line is calculated using spectral domain analysis of the moment method, simulated in Zeland IE3D, and measured using an HP 8510 network analyzer. The antenna array was designed and simulated in Ansoft HFSS. The antenna element spacing is 197 mil, which is 0.44λ at 26.5 GHz and 0.66λ at 40 GHz.

Phased array measurements

Both beam steering and beam broadening of the antenna array were measured in an anechoic chamber. To steer the beam, the dielectric perturber is cut linearly from

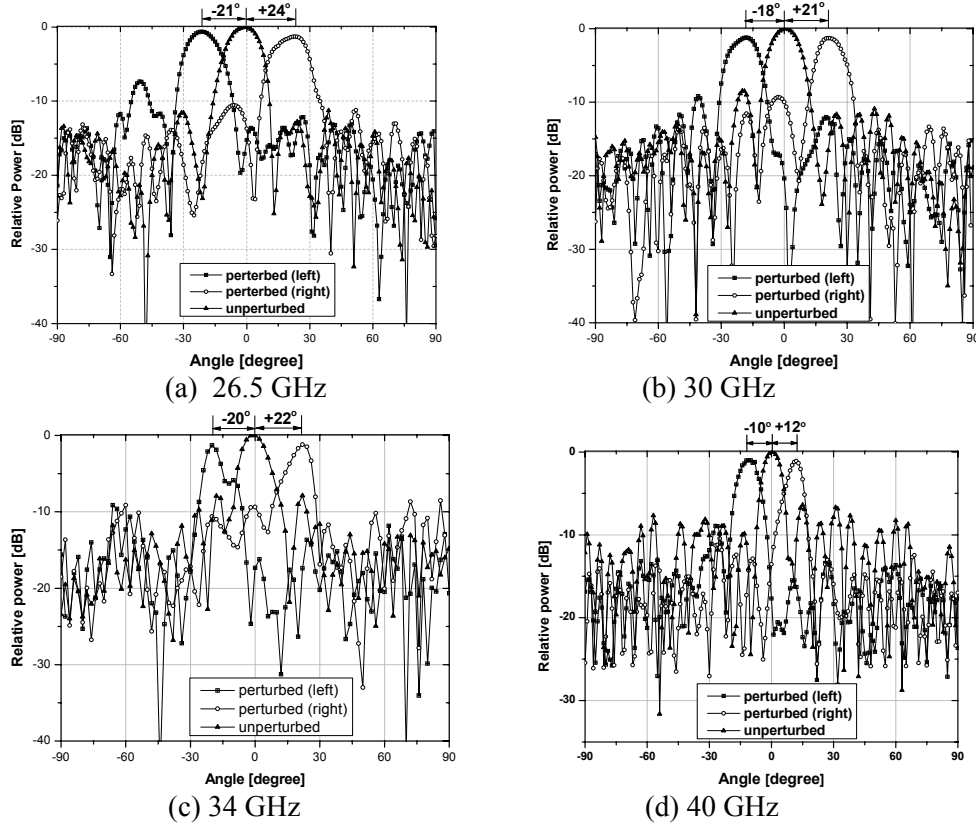


Fig. 3 Beam steering radiation patterns for E-plane array at:

(a) 26.5 GHz; (b) 30 GHz; (c) 34 GHz; (d) 40 GHz

2.1 in to 0.3 in to cover the microstrip lines (Fig. 2(a)). To broaden the beam, the concept of interleaved subarrays is applied [6]. The perturber lengths are 1.8 in, 0.6 in, 1.2 in, 1.2 in, 0.6 in, and 1.8 in covering the 2nd to 7th microstrip lines (Fig. 2(b)). To ameliorate the effects of strong leaky waves and higher sidelobes which can occur at high frequencies, RO3010 and RO3006 substrates with dielectric constants of 10.2 and 6.15 are chosen as the perturbers below and above 35 GHz for beam steering, at the expense of reduced scanning range at higher frequencies. Because beam broadening does not require as much phase shift as beam steering, RO3006 is used through the Ka-band. Figures 3 and 4 show the E-plane steered and broadened beam patterns measured at 26.5 GHz, 30 GHz, 34 GHz, and 40 GHz. The unperturbed and perturbed patterns are measured with 50V and 0V DC control voltages applied to the PET.

Conclusions

A Ka-Band 8-element E-plane array of antipodal elliptically-tapered slot antennas was designed and measured. The beam has 45° (−21° to +24°) and 22° (−10° to +12°) scanning ranges below and above 35 GHz and the 3 dB beamwidth is widened by about 10° using the PET-controlled phase shifter. The measured beam scanning range is about 6° less than simulation result. This is attributed to the bender tile producing an uneven air gap between the dielectric perturber and antenna board, the eight outputs of the power divider not being exactly the same causing unequal amplitude excitation to each antenna element, the individual antenna element being imperfectly flat and also because of the mutual couplings between antenna elements.

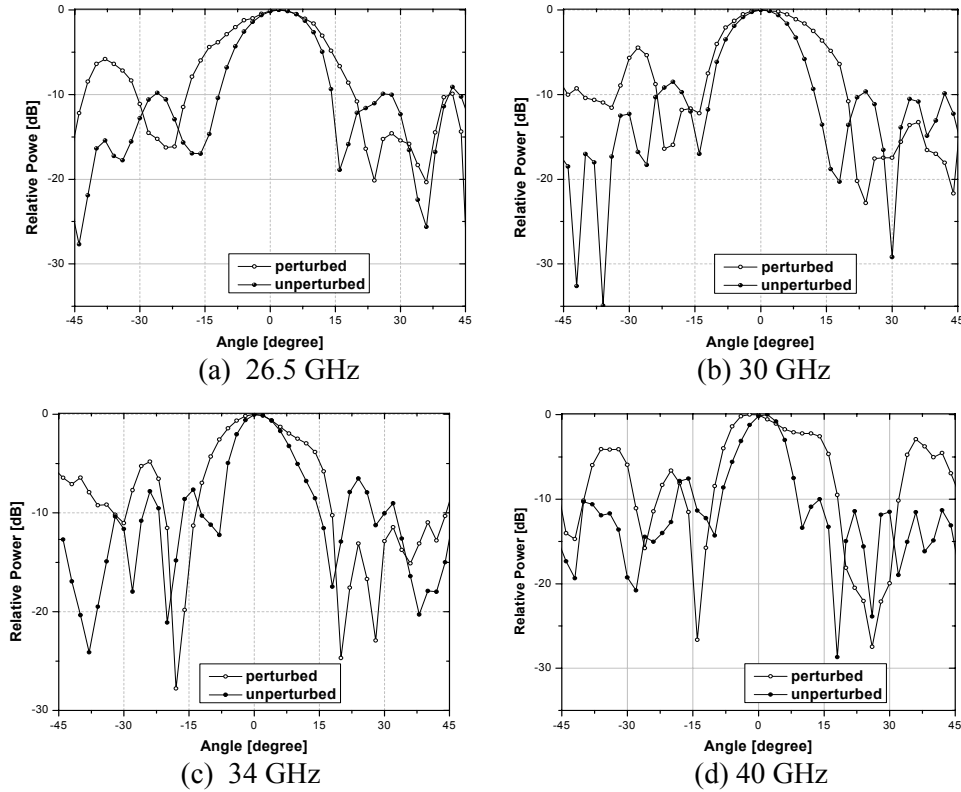


Fig. 4 Beam broadening patterns at: (a) 26.5 GHz; (b) 30 GHz; (c) 34 GHz; (d) 40 GHz

Acknowledgments

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References

- [1]. Sang-Gyu Kim and Kai Chang, "Ultra wideband 8 to 40GHz beam scanning phased array using antipodal exponentially-tapered slot antennas," *IEEE MTT-S Digest.*, vol.3, pp.1757-1760, June 2004.
- [2]. J.D.S. Langley, et al., "Balanced antipodal Vivaldi antenna for wide bandwidth phased arrays," *IEE Proceedings Microwave, Antenna and Propagat.*, vol. 143, pp. 97-102, April 1996.
- [3]. Christopher T. Rodenbeck, et al., "Ultra-wideband low-cost phased-array radars," *IEEE Trans. Microw. Theory Tech.*, vol. 53, pp. 3697-3703, Dec. 2005.
- [4]. Chia-chan Chang, et al., "True time phased antenna array systems based on nonlinear delay line technology," *APMC 2001*, pp. 795-800, Dec. 2001.
- [5]. K.Sigfrid Yngvesson, et al., "The tapered slot antenna-A new integrated element for millimeter-wave application", *IEEE Trans. Microw. Theory Tech.*, vol. 37, pp. 365-374, Feb. 1989.
- [6]. G.M.Shaw, et al., "Beam broadening for active aperture antennas", *IEEE Antenna Propagat. Society International Symposium*, vol.1, pp. 26-30, June 1989.