A Bi-Directionally Steering Phased Array Antenna Controlled by Dual Piezoelectric Transducers*

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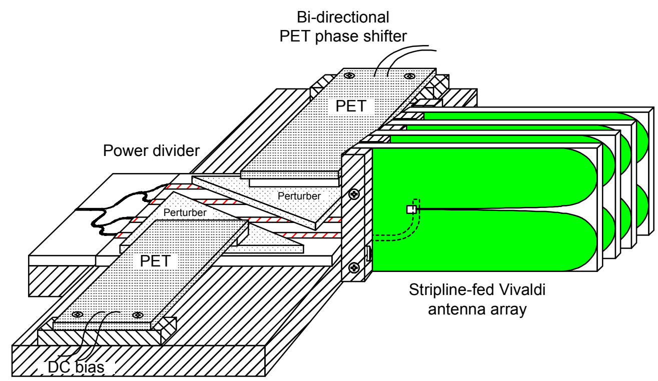
Abstract — **A new bi-directionally steering phased array antenna controlled by dual piezoelectric transducers (PET) is presented. This phased array antenna operates over the frequency range from 7.6 to 26.5 GHz with a maximum beam scanning of 60º from -34º to +26º. Both PET phase shifters are controlled by a single bias voltage that varies from 0 to 40 V. The PET controlled phase shifter is optimized with a parametric analysis, which results in a smaller control voltage and a better linearity of phase shift as a function of frequency, compared to the previously reported results. The proposed beam steering method should reduce the size and cost of phased array antenna systems.**

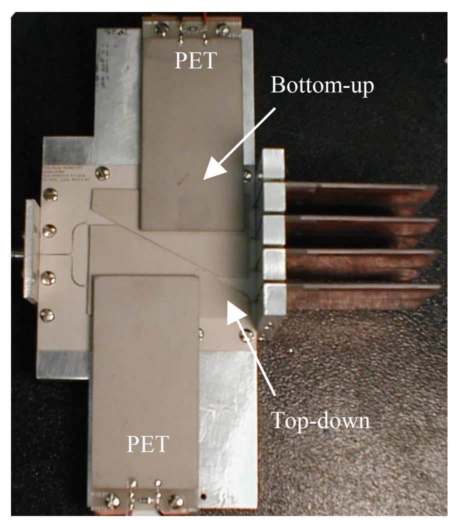
I. Introduction

For beam steering and beam forming in phased array antenna systems, as well as timing recovery circuits and phase equalizer for data channels, a wideband and low loss phase shifter is often required. Because phased array antennas typically consist of several thousand phase shifters which cost is about 45 % of the total system expense, low cost and low complexity phase shifter designs are very important issues [1]. The phased array reported here uniquely incorporates a multi-line configuration with progressive phase shifts [2]. The array does not contain traditional, individual PIN or ferrite phase shifters but includes a new phase shifter controlled by a piezoelectric transducer (PET) or piezoelectric actuator. The PET is a piezoelectric ceramic with a composition of Lead Zirconate Titanate, deflected by an applied voltage [3]. A dielectric perturber attached to the PET moves vertically above the microstrip lines with the DC bias voltage. The dielectric perturbation changes the propagation constant and phase [4].

In this paper, the phased array antenna consists of a power divider, two PET phase shifters with one control voltage, and one by four (1 x 4) H-plane antenna array, as shown in Fig. 1. An optimized PET phase shifter is obtained using a theoretical and parametric analysis. The dual PET-controlled phase shifting with the multi-line technique provides a cheap and simple method for multi-functional, multi-channel (i.e. broadband), and wide scanning phased array systems.



(a)



(b)

Fig. 1 A bi-directional H-plane phased array antenna using two differently aligned and one voltage-controlled PET phase shifters: (a) configuration with power divider, phase shifters, and strip-fed Vivaldi antennas and (b) a photograph.

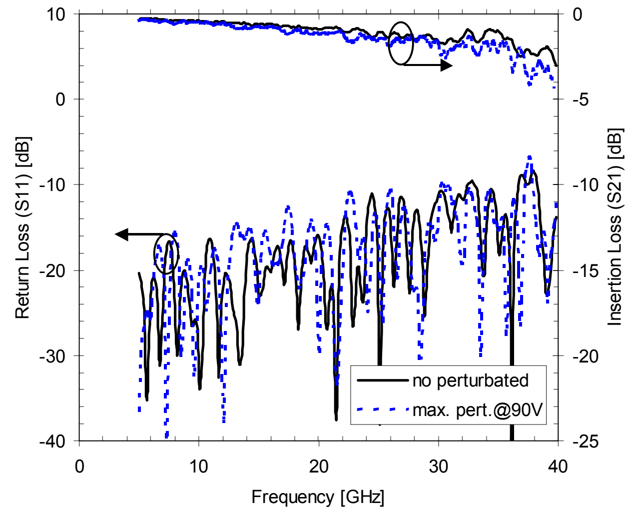
* Patent pending.

II. DESIGN AND EXPERIMENTS

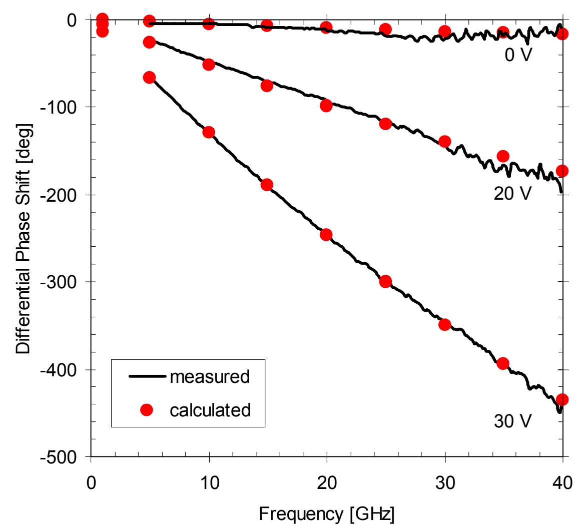
The phased array antenna is designed to operate over the X, Ku, K bands from 8 to 26 GHz. A low loss and broadband 1 x 4 power divider is designed using the Chebyshev 4^{th} order transformations to operate from 2 to 29 GHz with a small phase difference of less than 4^o. To demonstrate the feasibility of the multi-line dual PET phase shifters for the phased array antenna application, a 1 x 4 H-plane antenna array is built. Exponentially tapered slot antennas or "Vivaldi" antennas are used to achieve the wide bandwidth performance.

As shown in Fig. 1, two multi-line PET phase shifters are oppositely aligned and controlled by only one voltage. One is aligned for top-down perturbation and the other for bottom-up way. Twin bias wires of both PETs are oppositely connected together. Thus if one PET phase shifter is going down, the other one is going up simultaneously, and vice versa, by one control voltage. From a parametric analysis based on a theoretical calculation using the single layer reduction technique [5] and method of moment [6], the differential phase shift can be maximized with a higher permittivity substrate and perturber, thicker perturber, narrower strip width, and thinner substrate. The optimization results in a reduction of the control voltage and an improvement of the linearity of the phase shifting vs. frequency, in comparison to the previously reported results [2, 4]. The PET phase shifter is designed with a perturber of dielectric constant of 10.8, thickness of 50 mil, and perturbation length of 1.2 in on a substrate dielectric constant of 10.8, thickness of 10 mil, and line width of 5 mil. The magnitude of S-parameters for the phase shifter is measured with and without the perturbation, as shown in Fig. 2 (a). Up to 40 GHz, the maximum perturbation added loss is about 2 dB, and the total insertion loss (S_{21}) is about 4 dB for the phase shifting of 450^o given in Fig. 2 (b). The return loss (S_{11}) is less than -15 dB over most of the frequency range and about -10 dB near 40 GHz. The magnitude of the S-parameters is not greatly affected by the dielectric perturbation. Fig. 2 (b) shows very linearly controlled phase shift curves vs. control voltages and frequencies.

An antenna element spacing of 10 mm is chosen by considering grating lobes, scanning blindness, and the size of a coaxial K-connector®. To achieve 30^o of beam steering, the progressive phase shift of each line is designed to be 60^o at 10 GHz. To obtain the maximum phase shift of 180^o (=3 x 60^o), the chosen perturbation length of the perturber is 1.8 in. The length of triangular dielectric perturber is varied linearly (0.6, 1.2, and 1.8 in)



(a)



(b)

Fig. 2 An optimized PET controlled phase shifter: (a) frequency responses and (b) differential phase shift vs. frequency at different PET voltages.

at each line. The Vivaldi antenna operates from 8 to 26.5 GHz. A round-end Vivaldi antenna results in an improved return loss response. The stripline-fed structure gives a better cross-polarization characteristic than the microstrip line-fed one [2] due to the symmetry. The substrate used is RT/duroid® 5870 with a dielectric constant of 2.33, thickness (*t*) of 40 mil, and the stripline width of 29.4 mil. The length of antenna is 1.47 in (=1.25 λ_o at 10 GHz). The round-end design is based on experiments; its radius is about 0.35 in and the height is 1.5 in. The total size of the system is 4 x 6 in^2. A smaller size can be realized if a smaller PET is available. The four microstrip-lines of the

PET phase shifter are directly, perpendicularly connected to stripline-fed antennas so that extra connectors are unnecessary, and the system size and cost is thus reduced. The performance of the perpendicular transition is confirmed by a good return loss.

As shown in Fig. 3, the bi-directional beam steering is demonstrated at 7.6 and 26.5 GHz. A maximum beam scanning range from -34° to +26° and the side lobe level (SLL) of better than -10 dB are achieved over the entire frequency range except at 26.5 GHz. Cross-polarization is about -30 and –15 dB at 7.6 and 26.5 GHz, respectively. The performance of relative gain and SLL worsens as the steering angle is increased because of the scan loss and the presence of amplitude and phase errors among antenna elements.

III. CONCLUSIONS

A new bi-directionally steering phased array antenna controlled by dual piezoelectric transducers (PET) has been demonstrated from 7.6 to 26.5 GHz. A total beam scanning angle of 60° has been demonstrated. Both PET phase shifters were controlled by a single bias voltage of less than 40 V. The PET controlled phase shifter was optimized with a parametric analysis so that the control voltage and a linearity of phase shifting vs. frequency were improved over the previously reported data. The proposed new phased array antenna should be a useful method to reduce the cost of the system.

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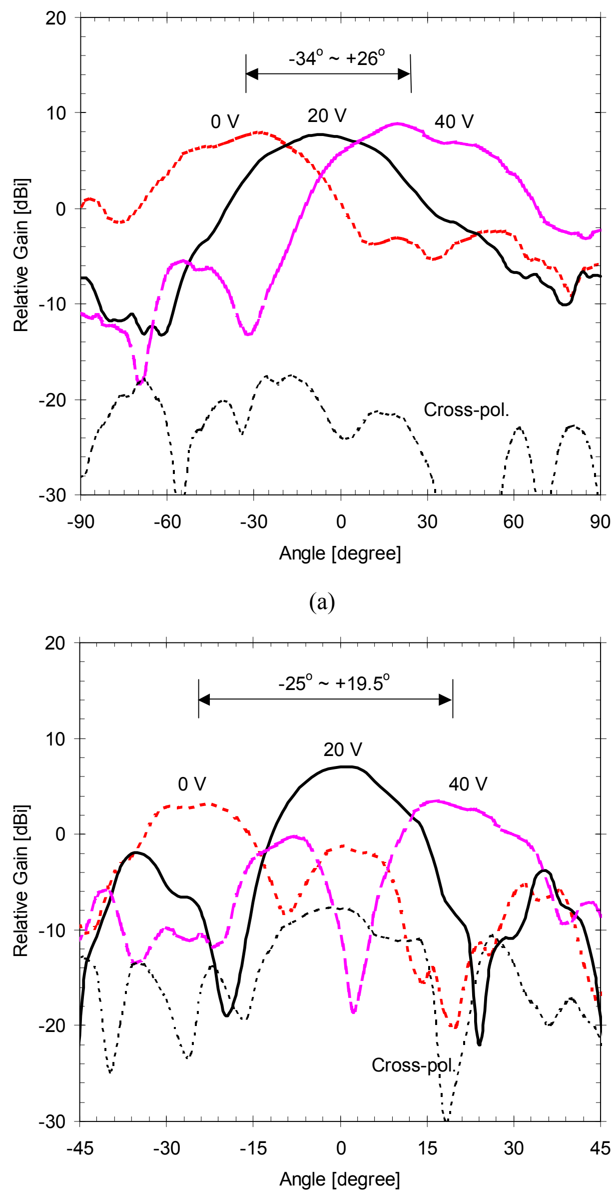

(a)

(b)

Fig. 3 Measured radiation patterns at: (a) 7.6 GHz and (b) 26.5 GHz.