A New Millimeter-Wave Printed Dipole Phased Array Antenna Using Microstrip-Fed Coplanar Stripline Tee Junctions

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***Abstract* — A new millimeter-wave printed twin dipole phased array antenna is developed at Ka-band using a microstrip-fed CPS Tee junction. To accomplish a progressive phase shift, a tunable phase shifter controlled by piezoelectric transducer (PET) is used. Measured return loss of better than 15 dB is achieved from 30 to 31.5 GHz for a 1 x 8 array. The phased array antenna has a measured antenna gain of 14.4 dBi with 42° beam steering and more than 11 dB side lobe suppression across the scan.**

I. Introduction

A printed dipole antenna has the benefits of low profile, light weight, low cost and compact size. To construct a printed dipole array, several configurations have been proposed. Nesic *et al.* [1] reported a one-dimensional printed dipole antenna array fed by microstrip at 5.2 GHz. Scott [2] introduced a microstrip-fed printed dipole array using a microstrip-to-coplanar stripline (CPS) balun. In [1] and [2], the balun designs were not easy to match the impedance and the structures were too big and complicated. In 1998, a wideband microstrip-fed twin dipole antenna was introduced with double-sided structure operating at the frequency range from 0.61 to 0.96 GHz [3]. Zhu and Wu [4] developed a 3.5 GHz twin dipole antenna fed by a hybrid finite ground coplanar waveguide (FGCPW)/coplanar stripline (CPS) Tee-junction. An X-band monolithic integrated twin dipole antenna mixer was reported in [5] with devices directly integrated to the antenna, so no feeding network was necessary.

The demands for low cost, low profile, small size, light weight, less complicated phased array antenna systems are increasing nowadays for applications in wireless and satellite communications, radar, and military systems. Recently, a piezoelectric transducer (PET) controlled phase shifter was developed for the low cost phased array antenna systems [6-7]. In this structure, a dielectric perturber controlled by PET is used to introduce a differential phase shift. The deflection takes place at the PET when the proper voltages are applied. Using this property of the PET, a dielectric perturber can have upward and downward movement according to the applied voltages. Consequently, if a transmission line is perturbed by a PET actuated dielectric perturber, its propagation constant will be changed. This phenomenon induces a variable phase shift along the transmission line controlled by PET. In [6] and [7], an end-fire Vivaldi antenna was used for covering a wide bandwidth, and a transition was required to feed antennas. Consequently, the system was large and bulky.

In this paper, a new planar printed dipole phased array antenna using a tunable phase shifter controlled by PET is presented at 30 GHz. The phased array antenna uses a new twin dipole antenna excited by a microstrip-fed CPS Tee junction [8]. The PET controlled phase shifter does not require any solid-state devices and their driving circuits. The 1 x 8 twin dipole phased array antenna has compact size, low loss, low cost, light weight and reduced complexity as well as good beam steering with low side lobe levels.

II. Twin Dipole Antenna Using Microstrip-Fed Coplanar Stripline (CPS) Tee Junction

The structure of the twin dipole antenna is illustrated in Fig.1. For the antenna design, IE3D software [9], which uses the method of moment, is employed for full wave electromagnetic simulation. A 31 mil RT/Duroid 5870 substrate with a dielectric constant of 2.33 is used for the antenna fabrication.

The twin dipole antenna utilizes the microstrip-fed coplanar stripline (CPS) Tee junction reported in [8]. In [8], a coupled CPS (CCPS) is used to have a physical discontinuity of CPS while fields are continuous all over the transmission line. The antenna array is placed in front of a reflector for uni-directional radiation. The reflector is spaced from the antenna at the distance of 1.5 mm (60 mil), which is about 0.15 λ_0. The length of dipole is 5.3 mm or 0.53 λ_0 and the distance between dipoles is optimized to 3.6 mm or 0.36 λ_0, which is less than one half wavelength in order to have low side lobe and grating lobe levels as well as low loss incurred from the CPS Tee junction.

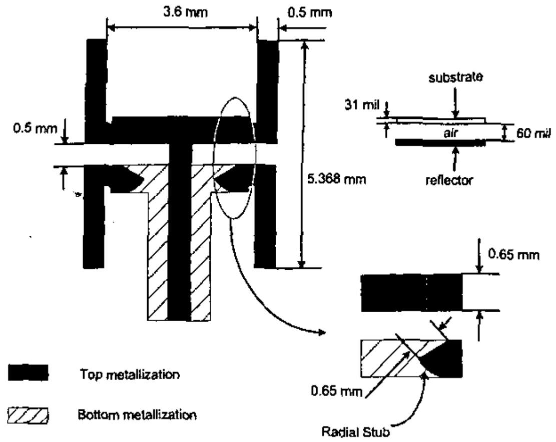

Fig. 1. The structure of printed twin dipole antenna using a microstrip-fed CPS Tee junction.

The input impedance of a single dipole antenna is around 202 Ω. Hence, the CPS strip width (*W*) and gap (*s*) are configured as 0.65 and 0.5 mm, respectively, to have a characteristic impedance of 202 Ω for the input impedance matching of a single antenna. The input impedance to the microstrip feed is about 101 Ω, which is half of 202 Ω. Radial stubs effectively rotate the electric fields from parallel to the normal to the substrate to have a good coupling to the bottom metallization, which provides the ground of microstrip line. The Tee junction is simulated with IE3D to verify the performance at 30 GHz. The simulated performance shows that the Tee junction equally splits the power to each CPS port with 1.2 dB insertion loss at 30 GHz. Measured return loss of the twin dipole antenna is better than 20 dB at 30 GHz. Measured E and H-plane gains are about 7.6 and 7.7 dBi with the 3 dB beamwidths of 32° and 34°, respectively.

III. Phased Array Antenna with PET Controlled Phase Shifter

The structure of the 1 x 8 printed twin dipole phased array antenna is shown in Fig. 2. A conventional microstrip power divider with binominal impedance transformers is used to cover the wide bandwidth. The bottom metallization provides good ground plane for the microstrip.

For phase shift, a 101Ω microstrip line, which has the same input impedance as the twin dipole antenna, is perturbed with a dielectric perturber actuated by PET. The length of dielectric perturber varies linearly from 5 to 35 mm. The PET is configured to have no deflection (no perturbation) when 0 V DC voltage is applied, and full deflection (full perturbation) when 50 V DC voltage is applied. A 50 mil RT/duroid 6010.2 with a dielectric constant of 10.2, is used as the dielectric perturber. With a dielectric perturber of 5 mm, Fig. 3 shows a differential phase shift of 88.8° takes place with a 2 dB insertion loss. Narrower microstrip line generates larger phase shift but the insertion loss is increased. Hence, a proper microstrip line's width should be chosen for having a good phase shift as well as low insertion loss.

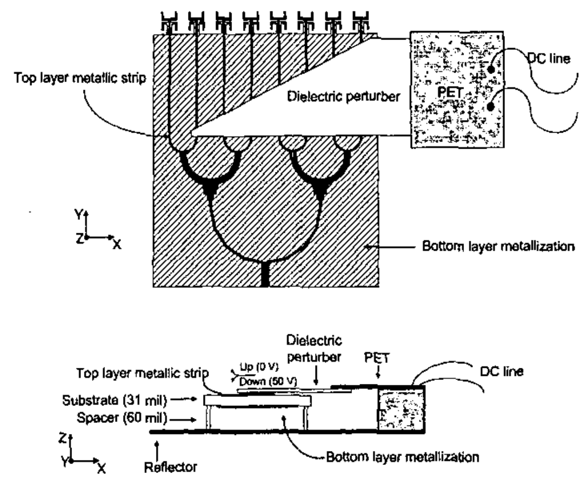

Fig. 2. The structure of printed dipole phased array antenna controlled by PET.

The amount of phase shift is linearly proportional to the length of perturber [7], which is expressed as

$$\Delta\Phi_n = L_{perturber,n} \bullet \Delta\beta_n \qquad (1)$$

where, $L_{perturber,n}$ is the perturber length along the nth transmission line. $\Delta\beta_n$ represents the differential propagation constant expressed as

$$\Delta\beta_n = \beta_{unperturbed} - \beta_{perturbed,n} \qquad (2)$$

where $\beta_{perturbed,n}$ represents the propagation constant of the nth perturbed transmission line, which is microstrip in this case.

According to (1) and (2), the perturber's length can be determined for a desired phase shift. IE3D analysis shows that an 88.8° progressive phase shift in each microstrip feed for the twin dipole phased array antenna can have around ± 20° beam steering with low side lobe levels. The minimum perturber length ($L_{perturber,1st}$) to have an 88.8° phase shift ($\Delta\Phi_1$) is about 5 mm. Hence the length of each neighboring perturbed line is increased in 5 mm steps. The length of perturber for the final microstrip

($L_{perturber,7th}$) is about 35 mm, which gives a differential phase shift of 621.6°.

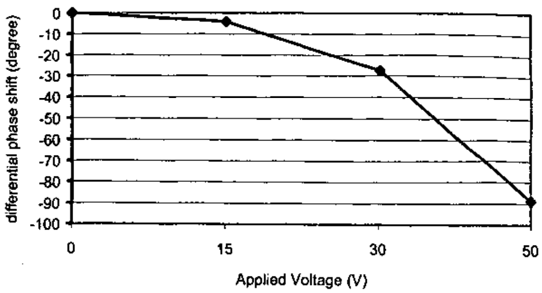

Fig. 3. Differential phase shift for 5 mm dielectric perturber controlled by PET.

Measured return loss of the 1 x 8 twin dipole array is plotted in Fig. 4. The measured return loss is about 41.9 dB at 30.3 GHz for the unperturbed twin dipole phased array antenna. With perturbation by the dielectric perturber, the return loss is about 31.8 dB at 30.7 GHz, which shows a 0.4 GHz frequency shift compared with the unperturbed result. For a bandwidth from 30 to 31.5 GHz, a measured return loss is better than 15 dB.

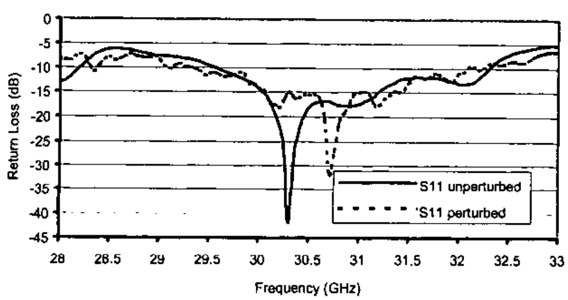

Fig. 4. Measured return loss of the printed twin dipole phased array antenna.

IV. PHASED ARRAY MEASUREMENTS

The phased array is measured in an anechoic chamber. As shown in Fig. 2, the antenna is arrayed for the H-plane beam steering. To accomplish bi-directional scan, two triangular perturbers are used side by side [7]. PET actuation for the dielectric perturber is configured as 0 V for no perturbation (no PET deflection) and 50 V for full perturbation (full PET deflection). The measured twin dipole phased array antenna gain without perturbation (0 V for PET) is about 14.4 dB with a 3 dB beam width of 6° as shown in Fig. 5. The fully perturbed antenna with a dielectric perturber controlled by PET shows about 42° (-20° ~ +22°) beam steering with the gain of 12.2 dBi. Side lobe levels of the steered beam are more than 11 dB down compared with main beam.

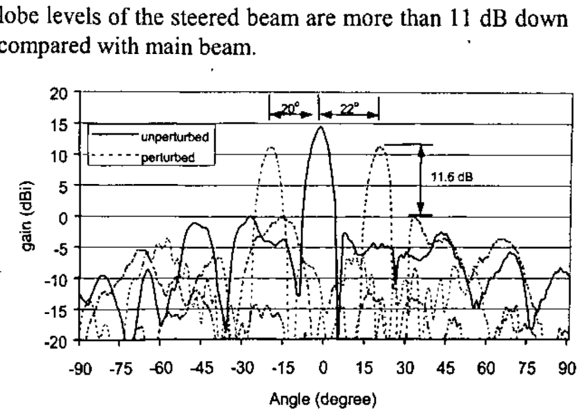

Fig. 5. Measured H-plane radiation pattern for twin dipole phased array antenna at 30 GHz. Measured beam steering is from −20° to +22° with full perturbation.

The gains of steered beams are about 2.2 dB down due to the insertion loss incurred by dielectric perturbation. The beam can be dynamically steered depending on the voltages applied to PET because the amount of phase shift changes according to the applied voltages on PET as shown in Fig. 3.

V. CONCLUSIONS

A new printed twin dipole phased array antenna is developed at 30 GHz using a tunable phase shifter controlled by a piezoelectric transducer (PET). The new twin dipole antenna is designed using a microstrip-fed CPS Tee junction. The PET actuated phase shifter requires only one (one-directional beam steering) or two (bi-directional beam steering) applied voltages to produce the progressive phase shift. A PET controlled phase shifter is tested and optimized for the proper phase shift with minimal insertion loss. The twin dipole phased array antenna shows a 42° (-20° ~ +22°) beam steering with more than 11 dB side lobe suppression across the scan. The antenna should find many applications in wireless communications and radar systems.

ACKNOWLEDGEMENT

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