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A V-band Phased-Array Antenna for Millimeter-Wave-Based 3D Beam Steering Applications

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***Abstract*—This paper presents a compact phased-array antenna for efficient and high-gain millimeter-wave-based 3D beam steering applications. The proposed antenna array consists of 2×2 unit cells and each unit cell is a sub-array comprising of 2×2 patch elements connected to microstrip lines that are co-fed by a single coaxial cable. Two 45° phase shifting lines are incorporated in each sub-array to facilitate the wide beamsteering range. The dimensions of the proposed phased array antenna are $24 \times 24 \times 0.324\ mm^3$. Simulation results show that the proposed phased-array antenna has a resonating frequency at 58.4 GHz with an operational bandwidth from 50.1 GHz to 77.5 GHz along with a high gain of 26.8 dBi. The array exhibits a maximum beam steering range of 105° in the elevation plane and 195° in the azimuth plane with a gain variation less than 0.9 dBi.**

I. Introduction

Wireless communication at Millimeter Wave (mmW) operating frequencies represents the most recent game-changing development for wireless systems. The use of millimeter-wave (mm-Wave) frequency spectrum for UAV communications is a promising direction, as massive antenna arrays could be packed within a compact space on the UAV to perform three-dimensional (3D) beamforming and beamsteering. Beam steering operation is especially needed to maintain LOS communication links when a mmW antenna system is placed on a mobile platform such as in UAV (Unmanned Aerial Vehicle) communications, where the communication can be enhanced further by using antennas with wide beamsteering capability. Even though several prior works which contributed antenna designs for different high frequency applications [1], [2], there are a few works that optimized the antenna design parameters for miniaturizing the antenna array design, simultaneously maintaining the high gain of the antenna with wide bandwidth and beam steering capability.

In this work, we present a four-port phased array antenna for mmW applications. The novelty of our work is that the conventional microstrip antenna array is modified by incorporating phase-shifting lines, which provides a 45° phase shift at 60 GHz to the feeding paths to enhance the wide beamsteering capability. The proposed phased array is designed to operate in the V-band (40 GHz to 75 GHz) and have dimensions of $24 \times 24 \times 0.324\ mm^3$. Each element of the array consists of four microstrip antennas that share a single coaxial feed.

The remaining of the paper is organized as follows: Section II presents the antenna design methodology. In Section III, the simulation results of the proposed phased array antenna are discussed. Section IV comprises of the concluding remarks and future works.

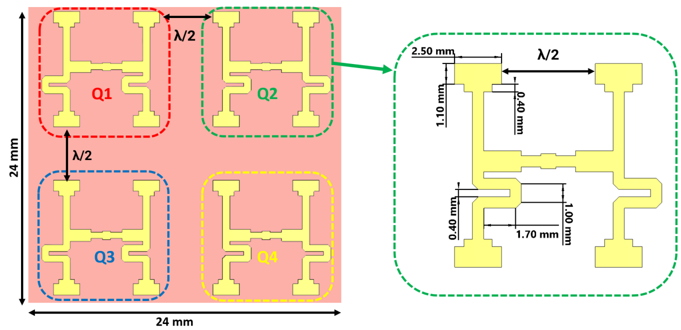

Fig. 1. The configuration of beam steering antenna array design.

II. Antenna Design

The single unit of the proposed phased array antenna has the length and width values of 2.25 mm and 1.1 mm respectively, with feed line width of 0.6 mm. The antenna's substrate material is chosen as Rogers 5880 as it has a low dielectric loss. The di-electric constant and the tangent loss of the substrate are 2.2 and 0.0004, respectively. Copper is used as a radiating patch and the ground material due to its high conductivity and good performance with respect to the gain of the antenna. The configuration of the beam-steering array is shown in Fig. 1. The thickness of the Rogers substrate used is 0.254 mm and the thickness for both the patch and the ground material individually are 0.035 mm. The design and simulation of the antenna array are performed using the CST (computer simulated technology) studio suite. The whole design is divided into four quadrants (Q_1, Q_2, Q_3 and Q_4), where each 2×2 array is considered as a quadrant, and it is co-axially fed. Each quadrant is placed $\lambda/2$ distance apart from other adjacent quadrants which ensured narrow beamwidth. The resonating frequency considering 60 GHz, using the formula $\lambda = v/f$, where v is the speed of light ($3 \times 10^8\ m/sec$), the corresponding λ value is 5 mm and that of $\lambda/2$ is 2.5 mm. The shape of the feeding lines in the antenna array design is modified by introducing a 45° phase shifter loop strip with 0.3 mm loop gap to boost the gain and to attain a wide beam steering capability in the high frequency region. The two 45° phase shifting lines incorporated in the each sub-array facilitate the wide beamsteering range through their phase shifting capability. Coaxial feeding is used for all four ports of the antenna array in order to improve directivity and gain.

TABLE I
Beamsteering and gain values along elevation plane and azimuth plane for different input phases at 58.4 GHz.

Q_1	Q_2	Q_3	Q_4	Elevation plane (EP)		Gain (dBi)	Azimuth plane (AP)		Gain (dBi)
				Beam Direction	HPBW		Beam Direction	HPBW	
0°	-30°	-60°	-90°	-60°	24.1°	26.5	-75°	34.5°	26.3
0°	-45°	45°	0°	0°	24.8°	26.2	15°	34.8°	26.1
0°	20°	40°	60°	45°	23.8°	26.4	120°	34.6°	26.8

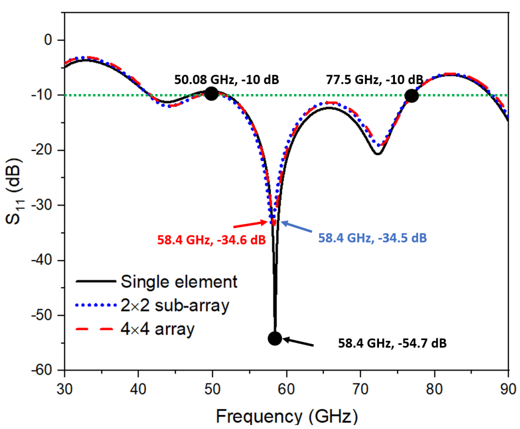

Fig. 2. S_{11} parameter result.

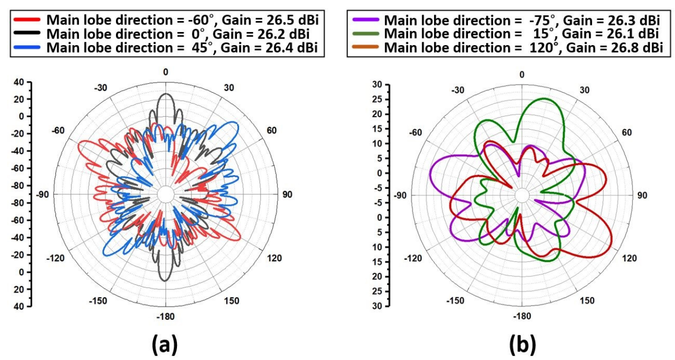

Fig. 3. Far-field directivity of the combined antenna array (a) In elevation plane (b) In azimuth plane for different input signal phase at 58.4 GHz.

TABLE II
COMPARISON WITH OTHER WORKS

	[3]	[4]	[5]	This Work*
Array factor	1 × 16	5 × 5	1 × 8	4 × 4
Operating frequency (in GHz)	60	60	60	58.4
Array Gain (in dBi)	24.6	19.7	22.3	26.8
Beam Steering range	45°	100°	100°	EP:105°, AP:195°
Size mm^2	22 × 35	12.5 × 12.5	45 × 22	24×24
Beam-angle	57°	45°	30°	24°

* This work is based on simulation

III. Results and Discussion

The simulated S_{11} parameter result for the single antenna element, 2 × 2 sub-array and 4 × 4 array are shown in the Fig.2. The magnitude value of the S_{11} (in dB) for each antenna element at resonating frequency is -54.7 dB. Simulation results of the proposed antenna array demonstrate a wide scanning range of -60° to 45° along the elevation plane and -75° to 120° in azimuth plane as shown in the Fig.3(a) and Fig.3(b) respectively. The antenna provides a highest gain of 26.8 dBi and a wide operating bandwidth of 50.1 GHz to 77.5 GHz. The beamwidth value of the proposed phased array antenna is 24.1° in the elevation plane. The beam steering and gain values for different input phases are tabulated in Table I. The comparision of the proposed work with prior published works is presented in Table II. The proposed antenna array is highly compact and has high gain value of 26.8 dBi along with having wide beam steering capability.

IV. Conclusion

A compact four port co-axially fed antenna array is presented that is suitable for millimeter wave based 3D beamsteering applications. The high gain value of 26.8 dBi, ultra-wide operational bandwidth ranging from 50.08 GHz to 77.5 GHz along with a wide beamsteering capability of 105° along the elevation plane and 195° along the azimuth plane portray the good performance capability of the proposed antenna. As a future work, we plan to design the butler matrix network to feed the proposed antenna array and fabricate the proposed design to analyze the measured and simulation performance results.

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