Design of a Compact 24 GHz Antenna Array for Unmanned Aerial Vehicle-to-Vehicle (V2V) Communication

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Abstract— This paper presents the design of a compact 4 × 4 antenna array suitable for unmanned aerial vehicle-to-vehicle (V2V) communication applications. The proposed antenna array can offer a narrow beamwidth, high gain, wide beam steering capability and is highly compact. The substrate material used is Rogers 5880 with a thickness of 0.2 mm, and copper is used for the patch and ground material with 0.14 mm thickness. The di-electric constant and the tangent loss of the Rogers substrate are 2.2 and 0.0004, respectively. 45° phase shifters are incorporated in the feeding paths to facilitate the beamsteering. The dimensions of the proposed antenna array are $32 \times 32 \times 0.48$ mm³. The designed antenna array has the resonating frequency at 24 GHz and has a bandwidth of 0.83 GHz (3.5% fractional bandwidth). The measured far field gain of the designed antenna array is 16.7 dBi. The beamwidth derived from the array's far-field radiation pattern is 14.6°, and the maximum beam steering range of the array is 102° along the θ axis.

Keywords— Unmanned aerial vehicles, phased array, planar antenna, millimeter wave antenna array, miniaturized.

I. Introduction

The recent advancements in wireless communications systems necessitate the effective design of compact antenna arrays capable to exhibit the high gain and wide beam steering range. The antenna arrays should be designed in such a way that they can be adopted on a worldwide scale in order for technology trends to develop in industry [1]. The idea that phased antenna arrays can have high gain and a large beam steering range is the driving force behind this work, and these are the primary parameters considered for millimeter-wave based UAV communication systems [2,3]. Even though there are few prior works which contributed antenna designs for different radar applications [4], there are very few which actually worked on miniaturizing the antenna array design, simultaneously maintaining the high gain of the antenna with narrow beamwidth. In this research, we present a four-port antenna array for unmanned aerial vehicle radar applications. The quadrant-based approach has been implemented to facilitate the wide beam steering range. The novelty of our work is that the conventional microstrip antenna array is modified by incorporating 45° phase shifters to the feeding paths to attain wide beam steering capability. The incorporated phase-shifting lines, provide 45° phase shift at 24 GHz to the feeding paths to enhance the wide beam steering capability. Each element of the array consists of four microstrip antennas that share a single coaxial feed. The coaxial-feed approach has been chosen as it produces minimal spurious radiation and reduces the system's complexity and enhances the directivity and gain. Also, suitable materials are chosen to achieve the high gain, making it apt for unmanned aerial vehicle radar applications.

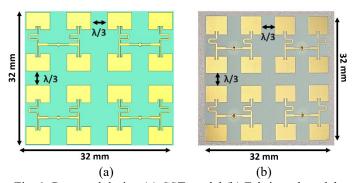


Fig. 1. Proposed design (a) CST model (b) Fabricated model

II. ANTENNA DESIGN

The length and width of single unit antenna are $5.4 \text{ mm} \times 3.9 \text{ mm}$, with feed line width of 0.3 mm. The antenna's substrate material is chosen as Rogers 5880 as it has a low dielectric loss. 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 dimension of the designed antenna array is $32 \times 32 \times 0.48 \text{ mm}^3$. The proposed antenna array design is shown in Fig. 1, where Fig. 1(a) is the designed model and Fig. 1(b) is the fabricated version of the designed compact antenna array. The thickness of the Rogers substrate used is 0.2 mm and the thickness for both the patch and the ground material individually is 0.14 mm.

The design and simulation of the antenna array are performed using the CST (computer simulated technology) studio suite. The whole 4 × 4 antenna array is divided into four quadrants where each 2 × 2 array is considered as a quadrant, and it is coaxially fed. Each quadrant is placed at $\lambda/3$ apart from other adjacent quadrants which ensured narrow beamwidth. The resonating frequency is 24 GHz, using the formula $\lambda = c/f$, where c is the speed of light (3 × 10⁸ m/sec), the corresponding λ value is 12.49 mm and that of $\lambda/3$ is 4.16 mm.

The shape of the feeding lines in the antenna array design is modified by introducing a 45° phase shifter loop strip with 2.4 mm loop gap to boost the gain and to attain a wide beam steering capability in the high frequency region. Coaxial feeding is used for all four ports of the antenna array in order to improve the directivity. This feed mechanism is simple to construct and produces minimal spurious radiation and reduces the system's complexity, size, cost, and weight significantly and is suitable for UAV based V2V communication applications.

Table 1. Beamsteering and gain values along θ axis and Φ axis for different input phases.

Q1	Q2	Q3	Q4	Theta (θ)		C-i (ID)	Phi (φ)		
				Beam Direction	HPBW	Gain (dBi)	Beam Direction	HPBW	Gain (dBi)
0°	-30°	-65°	-90°	-57°	26.5°	16.4	47°	19.8°	16.1
0°	-45°	45°	0°	00	24.3°	16.7	52°	18.7°	16.6
0°	45°	65°	90°	48°	24.1°	16.6	58°	14.6°	16.2

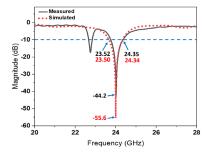


Fig. 2. S_{II} parameter results.

III. RESULTS AND DISCUSSION

The measured and simulated S_{II} -parameters were compared, and the results are presented in Fig. 2. All of the four ports have shown identical measurement results, i.e., The measured S_{II} , S_{22} , S_{33} and S_{44} were all identical. The proposed antenna-array has a maximum beamsteering angle of 102° , i.e., from the -54° to 48° along the θ -axis, as shown in Fig. 3(a), and the beam steering range along the Φ -axis is from 47° to 58° as shown in the Fig. 3(b). The beam steering angle and gain values along the θ and Φ axises for different input phases are presented in Table 1.

The highest gain of the proposed compact phased antenna array is 16.7 dBi. The comparison among similar prior works is presented in Table 2. The proposed antenna array has shown a better performance with high gain and wide beam steering capability compared to the other works.

Table 2. Comparison among prior works.

Parameters	[1]	[2]	[3]	[6]	This work
Array	1 × 16	1 × 8	1 × 10	1 × 8	4 × 4
Operating frequency (GHz)	24	24	28	24	24
Array Gain (dBi)	14.43	11.1	16.3	13.5	16.7
Dimensions L×W (mm ²)	104 × 7	37 × 71	60 ×100	38 × 3	32 × 32
Beam- steering range	± 10°	166°	60°	125°	102°

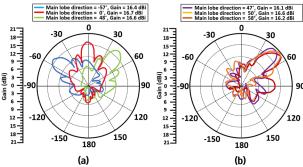


Fig. 3. Far-field directivity of designed antenna array (a) along θ axis (b) along Φ axis for different input signal phase.

IV. CONCLUSION

A compact four port coaxially fed antenna array is presented, which has the high gain value of 16.7 dBi, a bandwidth of 0.83 GHz at 24 GHz operating frequency and has a narrow beamwidth of 14.6°, and a wide beamsteering capability of 102° along the θ -axis. The simulated and measurement results are in good agreement. As a future work, we plan to design the 24 GHz butler matrix network to feed the proposed antenna array and analyze its performance results

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