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Design and Performance Analysis of a 24 GHz Series-Fed 1×5 Antenna Array with Material Deformation for D2D Applications

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***Abstract*—This paper presents the design and simulation of a 24 GHz 1×5 series-fed microstrip patch antenna array and its performance analysis with structural deformation. The optimized design comprises of 5 antenna elements arranged in series, where the entire design is symmetric about the center antenna element. The parameters such as S_{11}, gain vs. theta plots are analyzed with and without the material deformation. The shape deformation analysis is indeed needed to determine the performance efficiency of the designed antenna when deployed on drones, where the antenna needs to be flexible enough to be aligned with the curvature of drone's body. The simulation results are analyzed to see how best can the proposed antenna array can perform with the structural deformation.**

I. Introduction

The 24 GHz industrial, Scientific, and Medical (ISM) band is becoming increasingly popular for communications between unmanned aerial vehicles (UAVs) which are otherwise commonly called drones. This ISM band of 24 GHz enables effective short-range aerial vehicle communication. Furthermore, as it facilitates higher data rates, the 24 GHz ISM band is increasingly being used in modern drone-to-drone communication technology for precrash detection, blind-spot detection, and many other D2D applications. The crucial part of effective aerial communication is an extremely robust antenna design that can achieve a high-gain radiating beam along the desired direction. Also, the antenna design should be highly compact and serve a variety of mass markets. Despite the fact that several recent prior works contributed antenna designs for various 24 GHz frequency band applications [1]–[4], only a few works have analyzed the performance of antenna with material deformation to estimate the robustness of the design and to achieve a high gain and low sidelobe magnitude [5].

In this work, we present an optimized 1×5 series-fed microstrip patch antenna array and its performance analysis with structural deformation. The novelty of our work lies in the performance analysis of the proposed optimal antenna array design with an aspect of material deformation.

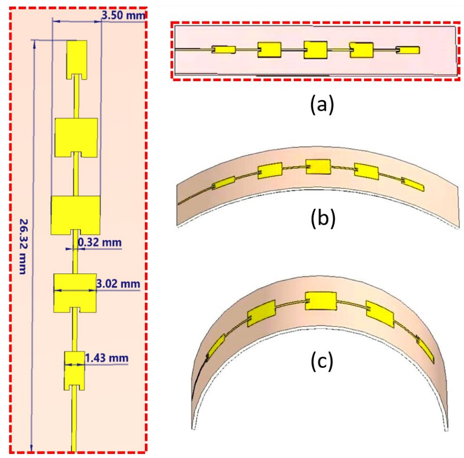

Figure 1: The proposed 1×5 series-fed antenna array (a) unbent case (b) $145°$ bend case (c) $95°$ bend case.

II. Antenna Design Methodology

The designed 1×5 series-fed array is symmetric with respect to the center antenna element. The center antenna element has the length and width values of 2.48 mm (5.03λ) and 3.50 mm (3.56λ) respectively. The proposed antenna array has dimensions of $26.32 \times 3.50 \times 0.16$ mm^3. The Rogers 5880 substrate utilized has a tangent loss of 0.001 and a dielectric constant of 2.2. The configuration of the designed antenna array is shown in Fig. 1. The thickness of the substrate used is 0.09 mm and the thickness for both the patch and the ground material individually are 0.035 mm. The edge-fed port is utilized to feed the array. The design and simulation of the proposed antenna array along with structural deformation analysis are performed using the computer simulation software (CST). The practical width and length values of the center antenna element that leads to good radiation efficiencies are estimated using equations 1 and 2.

$$W = \sqrt{\frac{2}{\epsilon_r + 1}} \times \frac{v_o}{2f_r} \tag{1}$$

$$L = \frac{1}{2f_r\sqrt{\mu_o\epsilon_o}\sqrt{\epsilon_{reff}}} - 2\Delta L \tag{2}$$

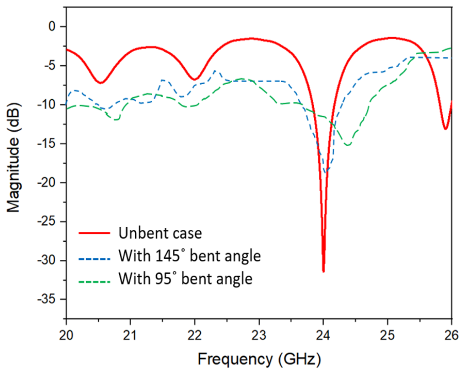

Figure 2: S_{11} parameter result.

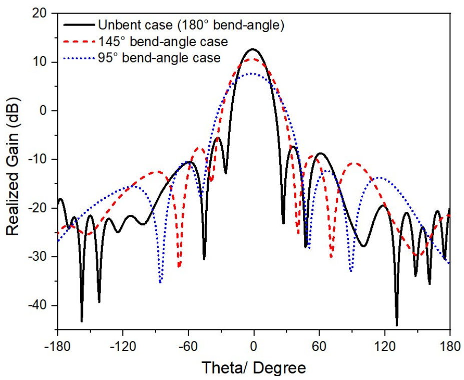

Figure 3: Gain versus Theta plots.

Where, f_r is the resonating frequency and v_o is the speed of light. The μ_o and ϵ_o are the relative permeability, ϵ_{reff} is the effective dielectric constant value, and ΔL is the extended incremental length of the patch.

Table I: Performance parameters of the antenna

Parameters	Scenarios of series-fed 1×5 antenna array		
	With 145° bend	With 95° bend	Unbent case
Gain (dBi)	10.2	7.9	12.7
Angular width (deg)	38.5	49.5	21.9
Side lobe magnitude (dB)	-19.2	-25.0	-18.1
S_{11} (dB) at 24 GHz	-19.6	-14.7	-34.25

III. Results and Discussion

The simulated S_{11} parameter results for the aforementioned cases are presented in Fig. 2. The designed antenna array has shown an operating bandwidth range from 23.7 GHz to 24.5 GHz, which is 0.8 GHz of operational bandwidth with fractional bandwidth (FBW) of 3.31%. The resonating frequency is 24 GHz. The S_{11} (in dB) at resonating frequency is obtained as -34.25 dB, which indicated good matching. The gain versus theta plots for the unbent and bent cases are presented in Fig. 3. It is observed that the angular beamwidth has been observed to increase with respect to the increased bend effect and as a result, the gain is attenuated. The respective antenna performance parameters are presented in Table I. This work is compared with prior works and is presented in Table II. The S_{11} parameters were significantly affected as a result of the bending effect. A better resonance was observed in the unbent case when compared to cases that involved the bending effect. It is observed that the designed antenna has maintained its resonating frequency nearly at 24 GHz with +0.2 GHz and +0.4 GHz of a shift in resonance frequency towards the right for 145° and 95° bend angles, respectively. The resonance shift is observed as a result of the bending effect.

Table II: Comparison with other works

	[1]	[2]	[3]	This Work*
Array factor	1×16	1×5	1×6	1×5
Gain (dBi)	14.4	12.3	9.5	12.7
Angular beamwidth	45°	29°	30°	21.9°
Sidelobe magnitude (dB)	-18.1	-10	-5	-12.3

* This work is based on simulation

IV. Conclusion

The 24 GHz 1×5 series-fed microstrip patch antenna array is designed and a material deformation-based performance analysis is carried out. The simulation results were in good agreement with the expected theoretical values. In contrast to the case where the bending effect is involved, the unbent case showed better resonance. In future work, we plan to fabricate the proposed array design to conduct a thorough analysis of simulated and measured results.

Acknowledgment

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