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Design of Wideband Conformal Vivaldi Antenna Array

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Abstract

This paper presents a Vivaldi antenna designed for IEEE C-band applications from 4.3 to 9.8 GHz with the aim of achieving -10 dB bandwidth from 4-9 GHz with a gain of 5-9 dBi throughout the band. The designed Vivaldi antenna is fed through a microstrip line for smoother slot transition. The Vivaldi antenna was used to develop a conformal antenna array for wide-angle beam scanning mounted on the periphery of a sphere which provides 360^o beam scanning in the azimuthal plane and $\pm 30^o$ in the elevation angle. Vivaldi antenna provides a maximum realized gain of 8.32 dBi gain at 7 GHz at $\theta = 0^o$. Two different antenna arrays are presented. The first antenna array consists of 1×5 antenna elements and provides a beam scanning capability of $\theta = \pm 30^0$ in the $\phi = 90^o$ plane with a realized gain of 13.79 dBi, 12.56 dBi, and 12.00 dBi at the target scan angles of $\theta_t = 0^o, 15^o$, and $\theta_t = 30^o$ respectively. Finally, a 3-D conformal Vivaldi antenna array is presented with a maximum realized gain of 19.97 dBi gain at $\theta = 0^o$. ANSYS HFSS was used to verify the validity of the designs.

1. Introduction

Gibson introduced the Vivaldi antenna in 1979 as a broadband end-fire traveling wave antenna [1]. It is employed in satellite communications, weather radars, and some surveillance applications due to its end-fire radiation characteristic and broadband operation. In spite of this, the gain of a Vivaldi antenna element is far from optimal. As a result, array structures are employed to achieve maximum antenna gain. Traditional Vivaldi antennas were mostly utilized in planar arrays. The resonant frequency of Vivaldi radiating elements is dictated by the length, width, and taper profile that impact the radiation properties of a Vivaldi antenna [2]. To optimize and miniaturize Vivaldi antenna arrays, arc-shaped slots, regular slot edge structures, and dielectric lenses were used. These approaches have big sizes and complexity and are unattractive [3]-[4]. Conformal antenna arrays have gained popularity recently due to their decreased aerodynamic drag, smaller radar cross-sections, better angle coverage, and lower infrastructure costs.

In this paper, a wideband end-fire conformal Vivaldi antenna array with 5×5 elements that work from 4.38 to 9.88 GHz is proposed. Since conformal antennas are built on a surface, the Vivaldi antenna elements are mounted on a plane cut from a sphere. In section II of this work, the proposed antenna design is shown. In section III, the construction of a planar antenna array is discussed, followed by a 5×5 antenna array formed on the periphery of a sphere, followed by the conclusion of the work.

2. Design of Vivaldi Antenna

A Vivaldi antenna, designed using an FR-4 substrate with a dimension of $L_g \times W_g \times h$. Both the top layer and bottom layer of the antenna are printed on the FR-4 substrate and are fed using an SMA connector as shown in Figure 1. The detailed optimized structural dimensions of the antenna are given in Table 1. The top layer of the Vivaldi antenna is designed for a lower cut-off frequency of 5 GHz. To make it more compact and to achieve a wide band reflection, slots are introduced on both sides of the tapered top layer of the Vivaldi antenna with a slot width, S_w is placed at an equal distance, g, along the opening transition of the Vivaldi antenna. This gave a reflection magnitude of less than -10 dB from 4.3 to 9.8 GHz, as shown in Figure 2.

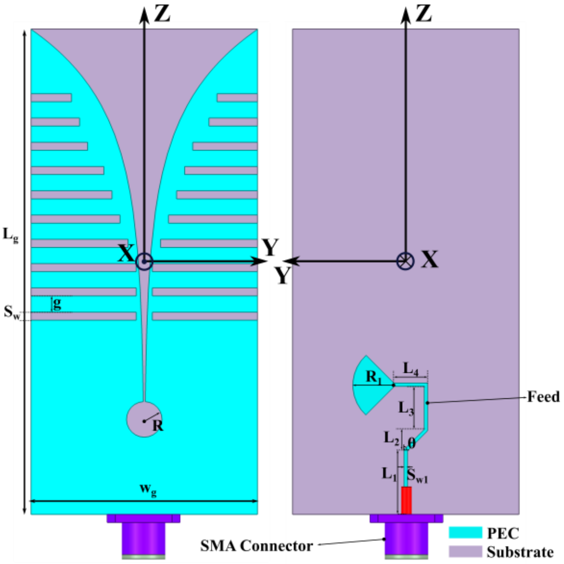

Figure 1. Vivaldi antenna top and bottom view with g=3 *mm*.

The total realized gain of the antenna at 7 GHz is 8.3 dBi at $\theta = 0^o$ as shown in Figure 3. The 3 dB beam width in both the E-plane and H-plane of the antenna is 77.42^o and 60.85^o respectively.

Table 1. Optimized parameters of the Vivaldi antenna

Parameter	Value(mm)	Parameter	Value(mm)
L_g	60	L_1	8
W_g	28	L_2	3.7
h	0.8	L_3	5.5
S_w	1	L_4	0.6
R	2.5	S_{w1}	0.4
R_1	5	θ	45^o

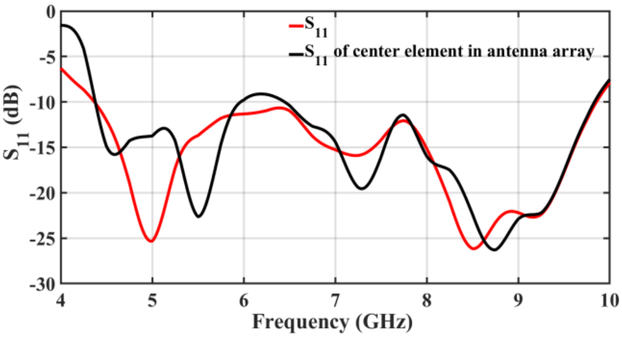

Figure 2. S-parameter of the Vivaldi antenna and array.

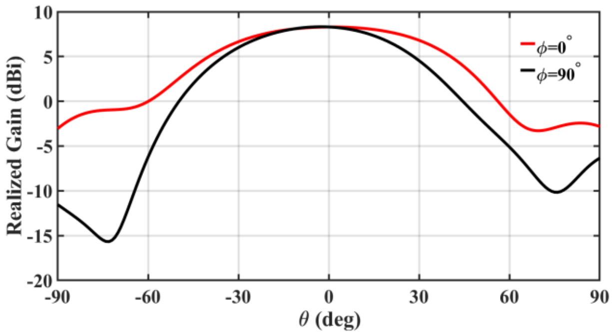

Figure 3. Gain of the Vivaldi antenna at $\theta = 0^o$

3. Planar Antenna Array

An Antenna array is formed as shown in Figure 4, in which the antenna elements are placed conformal to the plane, and each element is separated by $\lambda/2$ to ensure sound isolation between the antenna elements to minimize the grating lobes. Each antenna element C, C_{R1}, C_{R2}, C_{L1}, and C_{L2} are placed at the periphery of the circular plane cut from a hemisphere at angles of $\theta = 0^0$, $\pm 15^0$, and $\theta = \pm 30^0$ respectively. The antenna arrays are excited with identical SMA connectors with proper phase compensation calculated using the method mentioned in [5]. The array is simulated to direct the beam to a target scan angle of $\theta_t = 0^o, 15^o$, and $\theta_t = 30^o$ at $\phi = 90^0$ plane. The antenna array beam scanning performance parameters are presented in Table 2. From Table 2, it is observed that the array configuration illustrated in Figure 4, has low scan loss up to $\pm 30^0$ with a scan loss of ~1.79 dB. The array exhibits an approximately constant 3 dB beam width throughout the scanning angles confirming the fact that the higher the gain narrows the beam width. The simulated S-parameters of the single Vivaldi antenna and Vivaldi antenna array are presented in Figure 2, showing the nominal impact on the impedance bandwidth offered by an antenna array that of a single antenna element. The antenna array provides a realized gain of 13.79 dBi, 12.56 dBi, and 12.00 dBi at the target scan angles of $\theta_t = 0^o, 15^o$, and $\theta_t = 30^o$ respectively. The normalized radiation pattern of the antenna array is shown in Figure 5.

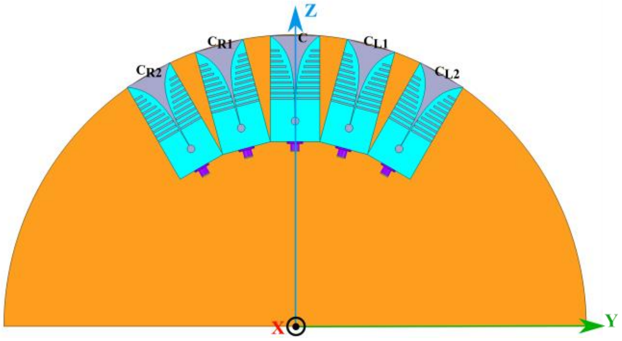

Figure 4. Planar antenna array along $\phi = 90^0$ plane

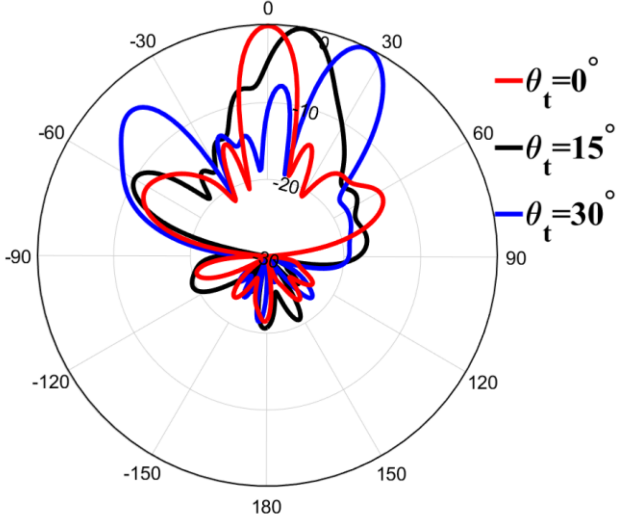

Figure 5. Beam steering performance of the antenna array at $\phi = 90^o$ plane

Table 2. Beam scanning parameters of the antenna array

Scan Angle (deg)	Position of the Main Lobe (deg)	Magnitude of the Main Lobe (dBi)	Sidelobe Level (dB)	3 dB beam-width (deg)
0^0	0^0	13.79	14.23	14.33
15^0	14^0	12.56	12.92	13.38
30^0	26^0	12.00	10.8	14.65

4. 3-D Conformal Antenna Array

A 5×5 antenna array is formed on the surface of a hemispherical surface with a radius r of 165 *mm.* The antenna elements are placed at the periphery of the hemisphere separated by $\lambda/2$ distance along X and Y directions of the coordinate system. The antenna elements, C, C_{R1}, C_{R2}, C_{L1}, C_{L2}, C1, $C1_{R1}$, $C1_{R2}$, $C1_{L1}$, $C1_{L2}$, C2, $C2_{R1}$, $C2_{R2}$, $C2_{L1}$, $C2_{L2}$, C3, $C3_{R1}$, $C3_{R2}$, $C3_{L1}$, $C3_{L2}$, C4, $C4_{R1}$, $C4_{R2}$, $C4_{L1}$, and $C4_{L2}$, are placed along angles $\theta = 0^o, \pm 15^o$, and $\theta = \pm 30^o$, respectively with respect to X and Y axis as shown in Figure 6. Forming an antenna array is as essential as providing the proper phase compensation to each individual antenna element to yield the maximum gain in the desired direction. The maximum simulated realized gain of the antenna array consisting of 5X5 elements is 19.97 dBi at $\theta = 0^o$.

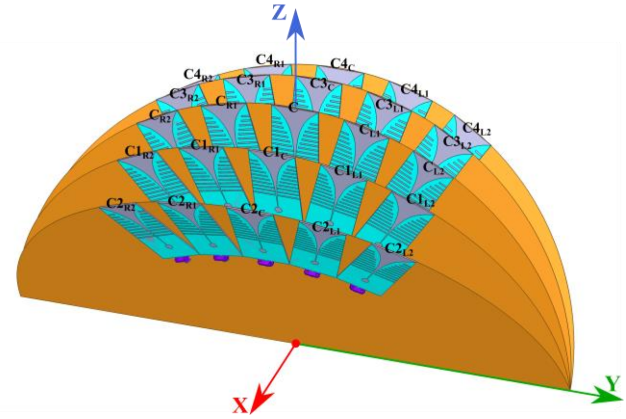

Figure 6. A 3-D conformal antenna array

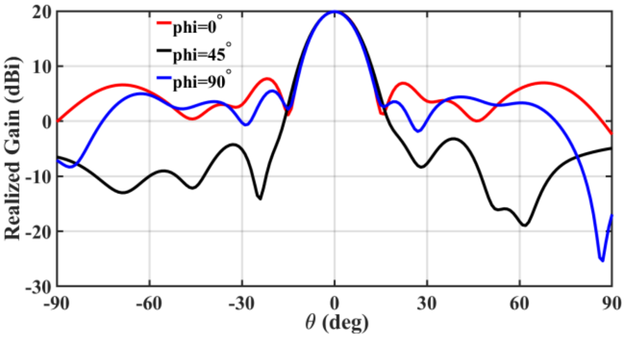

Figure 7. Realized gain of the antenna array at $\theta = 0^o$.

The antenna arrays presented in the previous two sections are compared with the literature presented in [6]-[8] shows a good performance in terms of impedance bandwidth, complexity, overall gain, and beam steering capabilities.

4. Conclusion

The antenna presented in this paper has an impedance bandwidth of ($|S_{11} < -10\, dB|$) 4.3-9.8 GHz and has fractional bandwidth of 78.57%. The antenna has a realized gain of 8.32 dBi at 7 GHz at $\theta = 0^o$. Two types of antenna arrays are presented. The scan performance of the 1×5 antenna array is demonstrated with a low scan loss of ~1.79 dB and has a maximum realized gain of 13.79 dBi, 12.56 dBi, and 12.00 dBi at the target scan angles of $\theta_t = 0^o, 15^o$, and $\theta_t = 30^o$ respectively. Later a 3-D conformal antenna array with 5×5 antenna elements is demonstrated and has a maximum realized gain of 19.97 dBi at $\theta = 0^o$. The 3-D antenna array presented covers 360^o beam steering capability in the azimuthal plane. Due to their low profile and robust nature, these antenna arrays find applications in IEEE C-band, satellite communications, and surveillance applications.

5. Acknowledgements

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6. References

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