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RESEARCH ARTICLE

A Super Wideband Dual-Polarized Vivaldi Antenna for 5G mmWave Applications

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ABSTRACT Millimeter wave (mmWave) is a key band for fifth-generation (5G) mobile communication that features large available bandwidth and high data rates. Antenna elements are recommended to be dual-polarized, compact, wideband, and high gain to be utilized for 5G array antenna systems. In this paper, a miniaturized gain-enhanced Vivaldi antenna element in an evolutional-oriented process is designed, simulated, and successfully measured for 5G mmWave applications. The size of the antenna is as compact as 5.5mm × 12mm. The measured operational bandwidth of the antenna element is between 22.5 – 45 GHz covering 5G *n257*, *n258*, *n259*, *n260*, and *n261* frequency bands even though the simulation results reveal the extension of the bandwidth to 70 GHz. The results show a nearly constant end-fire radiation pattern with a measured gain of more than 5dBi across the whole bandwidth. The comparison of the proposed antenna with the most recent related works justifies the novelties and advantages of the antenna in terms of 5G requirements, bandwidth, and compactness properties. The proposed antenna element is a suitable candidate for large antenna arrays and 5G MIMO applications.

INDEX TERMS 5G antenna, advanced antenna system, vivaldi antenna, 5G array, mmWave antenna, MIMO antenna.

I. INTRODUCTION

With the advancement of wireless technologies especially the fifth generation of mobile communication (5G), millimeter wave (mmWave) frequencies are required to provide wider bandwidth and higher data rates. One of the most important components of 5G wireless systems is the advanced/active antenna system (AAS). AAS employs novel techniques to improve the performance and spectral efficiency of 5G systems. AAS requirements for 5G applications for frequency bands, antenna element properties, array configurations, and beamforming characteristics can be found in [1]. More specifically, antenna elements need to have certain characteristics to meet AAS requirements from the latest standards. The 3rd Generation Partnership Project (3GPP) mmWave frequency bands for 5G systems are [1]:

$$n257 : 26.5\ \text{GHz} - 29.5\ \text{GHz}$$

$$n258 : 24.25\ \text{GHz} - 27.5\ \text{GHz}$$

$$n259 : 39.5\ \text{GHz} - 43.5\ \text{GHz}$$

$$n260 : 37\ \text{GHz} - 40\ \text{GHz}$$

$$n261 : 27.5\ \text{GHz} - 28.35\ \text{GHz}\ (\text{subset of } n257)$$

The single antenna element is recommended to be dual-polarized with the half-power beam width of at least 65°. Therefore, the proposed 5G antennas need to be dual-polarized and in line with 3GPP mmWave frequency bands, *n257, n258, n259*, *n260,* and *n261* ranging from 24.25 GHz to 43.5 GHz [1].

The Antipodal Vivaldi Antenna (AVA) invented by Gazit [2] is an end-fire traveling wave antenna that features wideband, high-frequency operation, nearly-constant radiation pattern, low profile, and easy fabrication which can be a good candidate for mmWave 5G applications [3].

A variety of techniques have been applied to AVA to enhance the bandwidth, miniaturization, and radiation such as notched tapered slot [4], exponential slot edge [5], and

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elliptical corrugations [6]. However, small size and close element distance lead to degradation in antenna gain and mutual coupling. Hence, radiation enhancement and coupling reduction along with extension of the bandwidth and miniaturization is a key challenge for AVA design.

In recent years, one-dimensional electromagnetic bandgap (EBG) and split ring resonator (SRR) structures have been proposed to improve the radiation characteristics and mutual coupling between the antenna elements [7]. In [8], a metamaterial-inspired structure is employed on AVA to improve the gain. However, due to the complexity of the designs, there are no significant works dealing with the coupling reduction of the Vivaldi antenna using EBG, SRR, and metasurface.

The use of dielectric lenses [9] and metal director [10] are also investigated to improve the radiation directivity. The dielectric lens or director in the aperture of the AVA can concentrate the energy in the end-fire direction. The dielectric lens acts as a guiding structure to obtain a more directive radiation pattern. Elliptical shaping of the dielectric can reduce the mismatch between the dielectric and air. Also, the metal director provides a different propagation environment on the antenna aperture leading to the enchantment of the field coupling between two arms of the antenna and consequently delivers closer radiation to the plane wave.

In this paper, a novel super wideband antipodal Vivaldi antenna with compact size and high gain is developed to meet the AAS requirements for 5G applications. The design starts with the traditional AVA geometry for a target frequency of above 20 GHz. Novel slots are applied to the AVA to improve the performance at lower frequencies. In order to reduce the mutual coupling and enhance the radiation gain at lower frequencies, a novel metasurface (MS) is loaded into the antenna. An elliptical dielectric lens is also applied to the antenna to enhance the radiation by focusing the energy in the end-fire direction without changing the impedance performance. The antenna performances at each evolutional stage are analyzed and compared.

The designed AVA has a compact dimension of 12 × 5.5 × 0.254 mm^3. The simulated results are performed between 20 – 70 GHz, while due to the restriction with the supported connector frequency, the measurement is carried out till 45 GHz. Impedance and Radiation performances are studied over the target operating frequency band. A comparison between the proposed antenna relative to the recent work reported in the literature is also provided.

II. DUAL-POLARIZED VIVALDI ANTENNA DESIGN

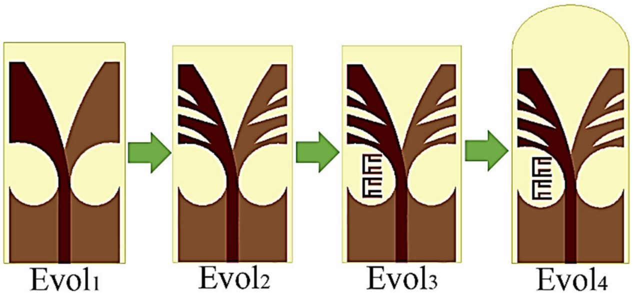


FIGURE 1. Evolutions of the Vivaldi antenna element.

TABLE 1. MS unit cell parameters.

Parameter	w6	w7	a	b	c
Size (mm)	0.9	0.1	0.18	0.23	0.56

The proposed antenna design is based on the conventional antipodal Vivaldi antenna (AVA). The geometry in the design process is shown in Figure 1. The basic geometry structure can be divided into three layers: a radiation patch, a dielectric substrate, and a ground plane. The used dielectric substrate is Rogers 4350B (εr=3.48) with a thickness of 0.254 mm. Two radiation arms are printed on the top and bottom sides of a dielectric substrate. Both the radiator and ground patches are mirror images of each other as illustrated in the first evolution (Figure 1). The design parameter begins with the microstrip width (w) of the radiating arm as [11]:

$$w = \frac{7.48 \times h}{e^{\left(Z_0 \frac{\sqrt{\varepsilon r+1.41}}{87}\right)}} - 1.25 \times t \sim 0.55mm \qquad (1)$$

where $Z0$ is the characteristic impedance, h, and t are the substrate and track thicknesses respectively. Considering the 50Ω characteristic impedance and proposed substrate parameters, w=∼ 0.55 mm.

The proposed patch width of the arms and tapered slots (Y) can be calculated as:

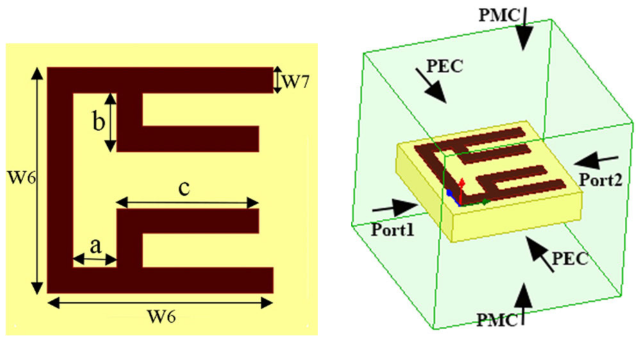
$$PatchWidth = \frac{\lambda}{2 \times \sqrt[4]{\varepsilon_{eff}}} \sim 5.5mm \qquad (2)$$

$$Y = \pm\left(-0.0068e^{600x} - 0.0012\right)$$
$$(-1.83mm \leq x \leq 0.265mm) \qquad (3)$$

where λ is the wavelength of the minimum frequency and εeff is the effective permittivity (∼2.7). The length and width (W) of the basic antenna geometry are 10 mm and 5.5 mm respectively. In order to improve the impedance bandwidth and radiation properties, three slots are applied as a corrugation on the edges, which defines the antipodal tapered slot antenna as indicated in the second evolution (Figure 1). In the third evolution, a four-branch metasurface (MS) structure is loaded to the antenna to reduce the mutual coupling and enhance the gain in the lower frequencies of the bandwidth. To further improve the radiation performance, the top of the dielectric substrate is shaped as a half elliptical dielectric lens as shown in the fourth evolution (Figure 1).

The Vivaldi antenna is modeled and simulated using the Ansys HFSS EM simulator package.

The schematic of the MS unit cell is depicted in Figure 2 (a) and its parameters are given in Table 1. The transmission



(a) (b)

FIGURE 2. (a) MS unit cell schematic. (b) MS simulated model.

properties of the proposed MS are investigated via the model shown in Figure 2 (b) using full-wave numerical analysis.

The simulation results of the MS unit cell are presented in Figure 3. Figures 3(a) and (b) show the magnitude and phase of S-parameters of the proposed MS. The electric permittivity ε and the magnetic permeability μ are calculated from the scattering (S) parameters using retrieval processes [12] and depicted in Figures 3(c) and (d). The results ensure the artificial medium and show that most of the radiation power can be transmitted through the proposed MS within a wide frequency band leading to an increase in the gain at the end-fire direction.

The proposed Vivaldi antenna element and its dual-polarized structure are presented in Figure 4. The Vivaldi antenna parameters have been also summarized in Table 2.

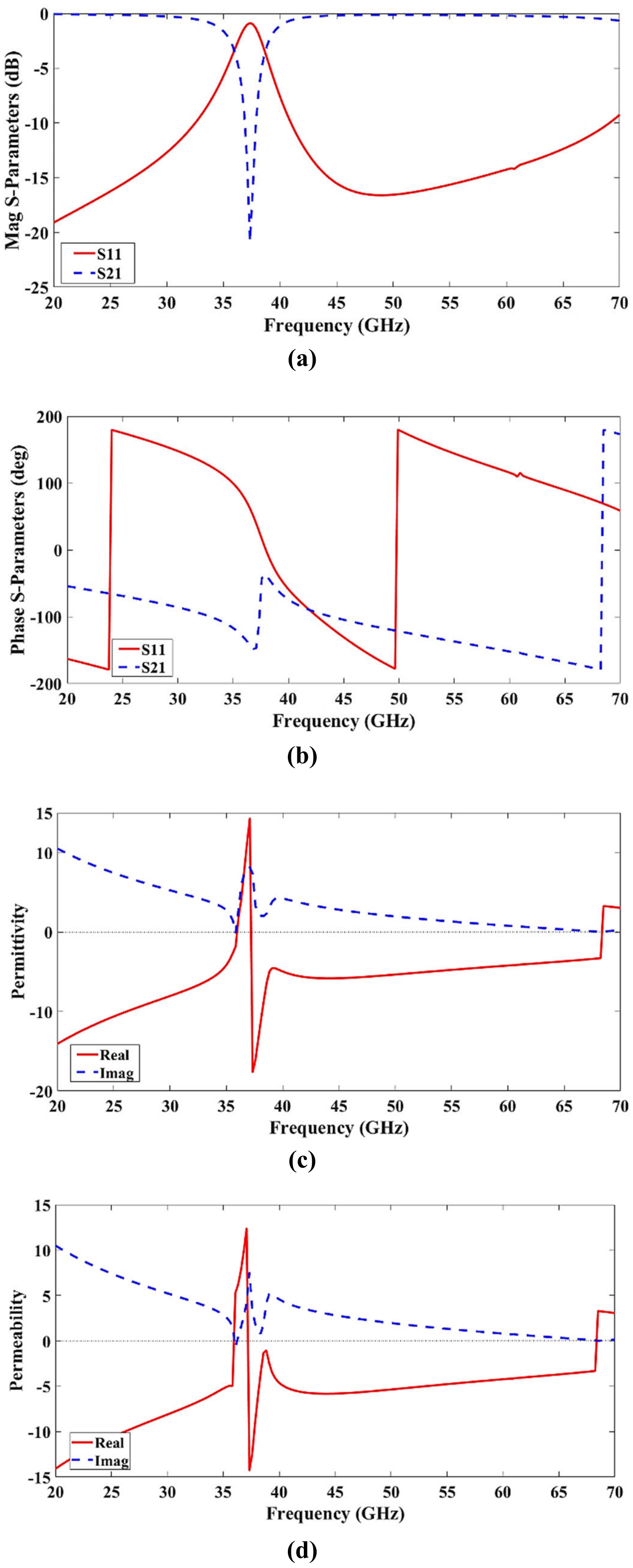
To study and analyze the evolutions of Vivaldi antenna performance, the surface current distributions of the evolutions of the Vivaldi antenna at the lower frequency are shown in Figure 5.

It is clear that the surface current density of the first evolution is weak in the arms. The excited surface currents in the second evolution are obviously improved leading to the extended current path for a fixed dimension and accordingly provides the extension of lower bandwidth. More intensive surface currents can be observed in the third and fourth evolutions.

The 5G AAS needs to be dual-polarized with ±45° linearly polarized element pair [1]. The dual-polarization feature is achieved by incorporating two orthogonally arranged elements taking into account two distinct ports.

The S-parameters and gain of the dual-polarized configuration of the first to fourth evolutions of the antenna (Figure 1) are simulated and presented in Figure 6 and Figure 7.

The surface current distribution for dual-polarized configuration is also shown with/without MS in Figure 8.



(a)

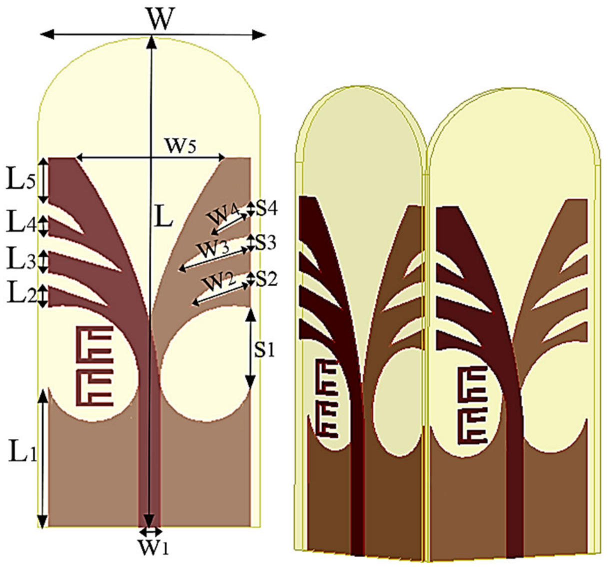
(b)

(c)

(d)

FIGURE 3. Simulated MS unit cell. (a) S-Parameter Magnitude, (b) S-Parameter Phase, (c) Permittivity, (d) Permeability.

It is clear that applying the slots to the basic Vivaldi geometry (Evol2) extends the lower cutoff frequency and improves the impedance bandwidth significantly based on the reflection coefficient results (S11 & S22) for dual-polarized configuration. According to Figure 5, significant current can be observed in region A along the slot edges revealing the extension of the effective length of the current path on the



(a) (b)

FIGURE 4. (a) Proposed Vivaldi antenna. (b) Dual-Polarized structure.

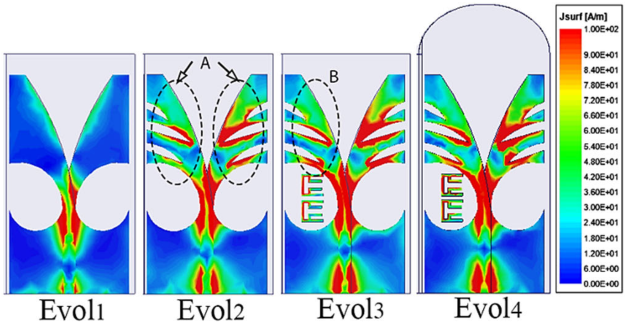
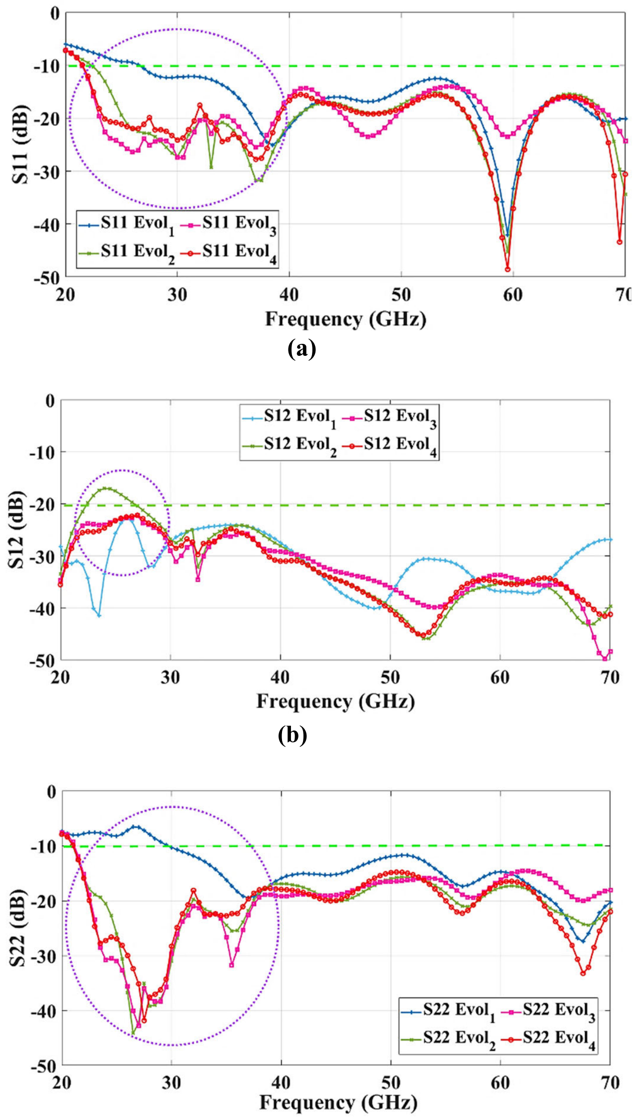


FIGURE 5. Surface current distribution at 24 GHz.



(a)

(b)

(c)

FIGURE 6. Simulated S-parameters of the evolutions of the Vivaldi antenna.

antenna. This leads to extending the lower-end bandwidth and enhances the gain (Figure 7) remarkably at lower frequencies of the bandwidth. Loading the MS split ring resonator to the antenna (Evol3) enhances further the surface current distribution in region B (Figure 5) and accordingly decreases the cutoff frequency from 22.5 GHz to 21.5 GHz. This contributes to minimizing the antenna size and improves the gain between 0.5 – 2dBi at lower frequencies of the bandwidth as demonstrated in Figure 7. Furthermore, loading MS to the antenna improves the mutual coupling, especially at lower bandwidth frequencies. While the mutual coupling for the second evolution in 22 – 28 GHz is more than -20dB, loading MS in the third evolution can improve the coupling up to 10 dB (Figure 6b).

As can be seen from Figure 8a, due to coupling, a significant current is induced on the left arm, and by loading the MS, a great amount of surface current circulates around the MS. This behavior contributes to the reduction of mutual coupling.

Shaping the top of the substrate as an elliptical lens obviously improves the antenna gain while not adversely affecting the S-parameters (Figures 6 & 7) given the fact that the dielectric lens like a dielectric waveguide directs the radiating wave to the aperture center and leads to the plane-like wave propagation. A gain improvement of at least 0.5 dB can be achieved for the fourth evolution as indicated in Figure 7.

A prototype of the antenna with dimension sizes shown in Table 2 and in Figure 4b was fabricated as shown in Figure 9. SMPM connectors are attached to the antenna based on the transition design methodology proposed in [13].

The simulated and measured S-parameters are presented in Figure 10 for the frequency range 20 – 45 GHz as the connector supports frequencies up to around 40 GHz.

The measured results present a good impedance performance with return loss > 14 dB and mutual coupling > 20dB for 5G mmWave frequencies ranging from 24 to 43.5 GHz.

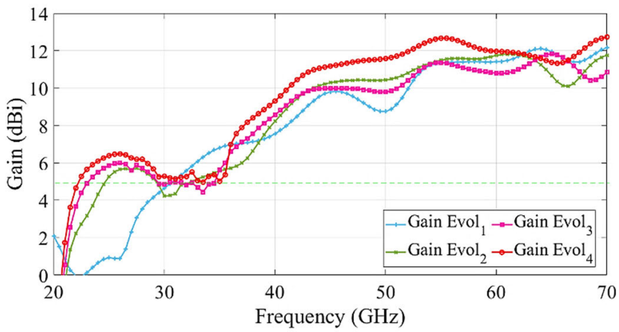
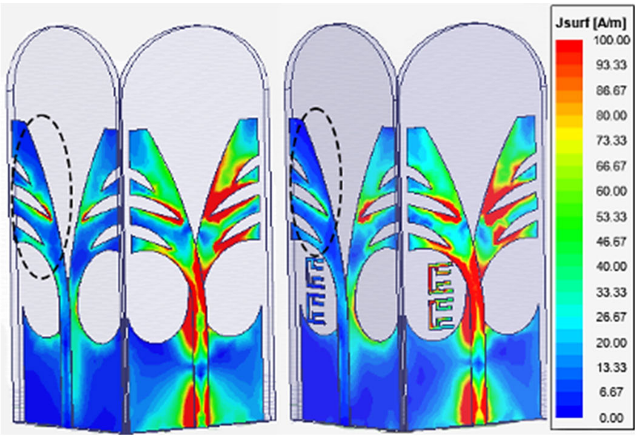


FIGURE 7. **Simulated gain of the evolutions of the Vivaldi antenna.**



(a) (b)

FIGURE 8. **Surface current distribution at 24 GHz: (a) without MS, (b) with MS.**

TABLE 2. **Vivaldi antenna parameters.**

Parameter	W	L	w1	w2	w3	w4
Size (mm)	5.5	12	0.53	1.6	1.93	1.03
Parameter	w5	L1	L2	L3	L4	L5
Size (mm)	3.68	3.48	0.53	0.53	0.48	1.12
Parameter	S1	S2	S3	S4		
Size (mm)	1.97	0.33	0.38	0.32		

The difference between the simulation and measurement might be due to the mini-SMP connector installation as the precision of the connector mounting can affect significantly the antenna performance, particularly the impedance characteristics.

In order to study the radiation performance, Figure 11 shows the simulated and measured radiation pattern in E and H plane for both co and cross-polarization for the selected frequencies across the bandwidth. The simulated and measured antenna gain which is almost identical for both polarization has been demonstrated in Figure 12.

FIGURE 9. **Fabricated prototype of the dual-polarized Vivaldi antenna.**

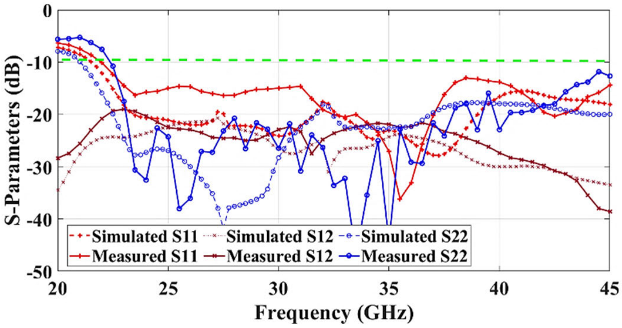


FIGURE 10. **S-parameters for dual-polarized Vivaldi antenna.**

It can be found that the antenna has end-fire radiation directed to the symmetrical axis of the slot aperture with a half-power beam width of at least 65° for both E/H planes which meets the AAS single-element requirements. The measured cross-polarization is better than 15dB for all frequencies. The antenna gain is also more than 5dBi across the whole bandwidth and specifically more than 5.5dBi for 5G bands.

The proposed antenna element can be used in large antenna arrays. The study of antenna element performance in the array configuration is useful to show the embedded characteristics of the element. To this effect, a 3-element array using the proposed Vivaldi element has been fabricated as shown in Figure 13. The inter-element spacing is as small as 5.5 mm which is 0.44 λ at 24 GHz. The array has been measured in terms of return loss and mutual coupling. A termination load developed according to [14] is utilized to terminate the free port. The simulated and measured S-parameters of the one side element and center element of the array are presented in Figure 14.

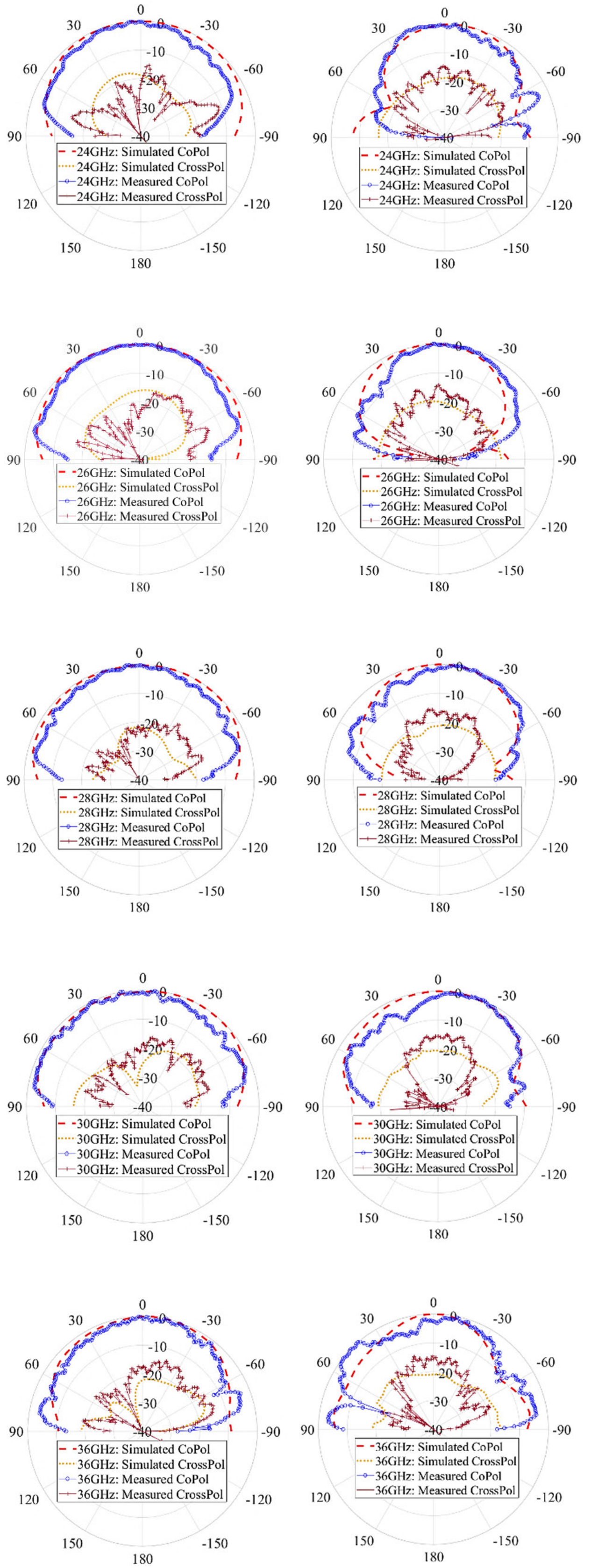
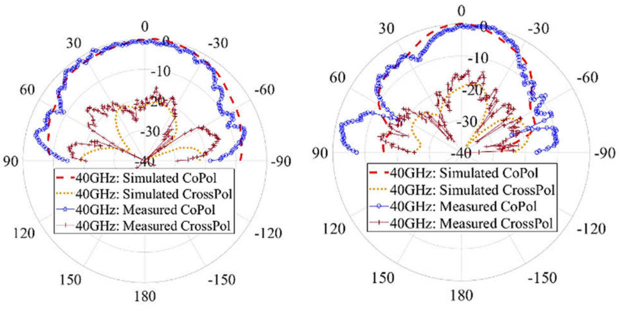


FIGURE 11. Simulated and measured radiation patterns. (a) E-plane. (b) H-plane.



(a) (b)

FIGURE 11. *(Continued.)* Simulated and measured radiation patterns. (a) E-plane. (b) H-plane.

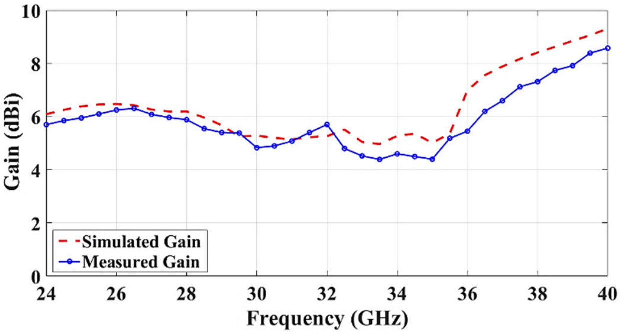


FIGURE 12. Simulated and measured Vivaldi antenna gain.

FIGURE 13. Fabricated prototype of the 3-element Vivaldi antenna array.

The measured results show that the return loss and mutual coupling are better than 14 dB and 22 dB respectively across the bandwidth (24 – 43.5 GHz) which offers a promising performance for large antenna arrays employing the proposed Vivaldi antenna element.

A comparison between the proposed and recently recognized reported Vivaldi antennas for 5G mmWave application

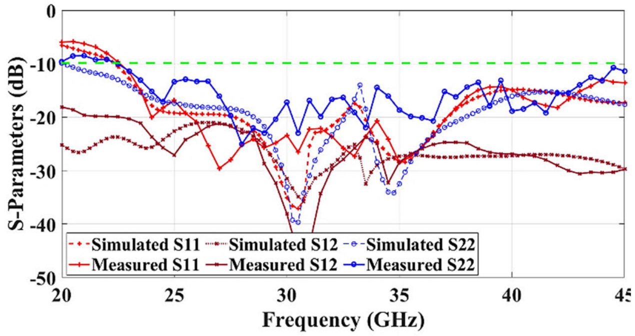


FIGURE 14. S-parameters for 3-element Vivaldi antenna array.

TABLE 3. Performance comparison of the proposed vivaldi antenna.

Ref.	Polarization	Freq. Band (GHz)	Gain (dBi)	Size (mm²)
[3]	Single	24.19 – 29.15, 30.28 – 40.5	4.2-4.5	$1.61\lambda_g \times 0.48\lambda_g$
[10]	Single	24.75 - 27.5	>5.5	$1.11\lambda_g \times 0.56\lambda_g$
[15]	Single	24.1 – 28.5	-	$1.08\ \lambda_g \times 0.48\ \lambda_g$
[16]	Single	21.77 – 30.3	6.5-8.8	$3.19\ \lambda_g \times 1.59\ \lambda_g$
[17]	Dual	18 - 30	-	$1.11\ \lambda_g \times 0.3\lambda_g$
This work	**Dual**	**22.5 – 45**	**5.5 -8.5**	$\mathbf{0.9\ \lambda_g \times 0.41\lambda_g}$

is summarized in Table 3. Most of the designed antenna elements are not entirely compatible with the 5G AAS requirements. The performance of the Vivaldi single element has been considered in terms of polarization configuration, frequency band, gain, and size. The antenna size is reported concerning λg as the wavelength of the lower cutoff frequency.

The main advantage of the proposed antenna element is to meet the performance requirements demanded for the single antenna elements in order to be used for 5G antenna arrays as known as AAS. The fabricated antenna in this work presents dual- polarization capability with more bandwidth between 22.5 – 45 GHz covering 5G *n257*, *n258*, *n259*, *n260*, and *n261* frequency bands and more compactness compared to the other works.

III. CONCLUSION

Recent mobile communication technologies have made advanced antenna system (AAS) an essential solution for 5G at mmWave frequency ranges. AAS single antenna element for inclusion in 5G large arrays is recommended to be dual-polarized, compact, wideband and operational in 3GPP harmonized frequency bands, and high gain with the half power beam width of at least 65°. In this paper, a novel design of an evolutional-oriented Vivaldi antenna is presented to meet the AAS requirements for 5G applications. A combination of novel corrugated slots, meta surface loading, and dielectric lens techniques are utilized to miniaturize the antenna size and enhance the bandwidth and radiation. The proposed antenna can operate in 22.5 – 45 GHz covering 5G *n257, n258, n259, n260,*and *n261* frequency bands with the compact size of $12 \times 5.5 \times 0.254\ \text{mm}^3$ ($0.9\lambda g \times 0.41\lambda g$ concerning the lower cutoff frequency) even though the simulation results show the extension of the bandwidth to 70 GHz. The dual polarization configuration of the antenna presents a good impedance performance with the measured return loss > 14 dB and mutual coupling > 20dB across the bandwidth. The end-fire radiation patterns are nearly stable over the operating frequency band with the measured gain ranging from 5.5 to 8.5 dBi in 5G bands and also half power beam width of more than 65°. The significance of the proposed antenna is proved by comparing it with the most recent AVAs in the mmWave band. The promising performance of this antenna element paves the way for developing large antenna arrays using this element to meet 5G massive MIMO applications.

REFERENCES

[1] A. Azari and H. Aliakbarian, "Requirements for 5G applications; a strategic approach," *Microw. J.*, vol. 65, Sep. 2022. [Online]. Available: https://www.microwavejournal.com/articles/38759-requirements-for-5g-applications-a-strategic-approach

[2] E. Gazit, "Improved design of the Vivaldi antenna," *IEE Proc. H, Microw. Antennas Propag.*, vol. 135, pp. 89–92, Apr. 1988.

[3] A. S. Dixit, S. Kumar, S. Urooj, and A. Malibari, "A highly compact antipodal Vivaldi antenna array for 5G millimeter wave applications," *Sensors*, vol. 21, no. 7, p. 2360, Mar. 2021, doi: 10.3390/s21072360.

[4] N.-N. Wang, M. Fang, H.-T. Chou, J.-R. Qi, and L.-Y. Xiao, "Balanced antipodal Vivaldi antenna with asymmetric substrate cutout and dual-scale slotted edges for ultrawideband operation at millimeter-wave frequencies," *IEEE Trans. Antennas Propag.*, vol. 66, no. 7, pp. 3724–3729, Jul. 2018, doi: 10.1109/TAP.2018.2820422.

[5] J. Eichenberger, E. Yetisir, and N. Ghalichechian, "High-gain antipodal Vivaldi antenna with pseudoelement and notched tapered slot operating at (2.5 to 57) GHz," *IEEE Trans. Antennas Propag.*, vol. 67, no. 7, pp. 4357–4366, Jul. 2019, doi: 10.1109/TAP.2019.2906008.

[6] A. M. De Oliveira, M. B. Perotoni, S. T. Kofuji, and J. F. Justo, "A palm tree antipodal Vivaldi antenna with exponential slot edge for improved radiation pattern," *IEEE Antennas Wireless Propag. Lett.*, vol. 14, pp. 1334–1337, 2015.

[7] S.-A. Malakooti, M. Moosazadeh, D. C. Ranasinghe, and C. Fumeaux, "Antipodal Vivaldi antenna for sum and difference radiation patterns with reduced grating lobes," *IEEE Antennas Wireless Propag. Lett.*, vol. 16, pp. 3139–3142, 2017.

[8] J.-Y. Lee, S.-H. Kim, and J.-H. Jang, "Reduction of mutual coupling in planar multiple antenna by using 1-D EBG and SRR structures," *IEEE Trans. Antennas Propag.*, vol. 63, no. 9, pp. 4194–4198, Sep. 2015.

[9] X. Shi, Y. Cao, Y. Hu, X. Luo, H. Yang, and L. H. Ye, "A high-gain antipodal Vivaldi antenna with director and metamaterial at 1–28 GHz," *IEEE Antennas Wireless Propag. Lett.*, vol. 20, no. 12, pp. 2432–2436, Dec. 2021, doi: 10.1109/LAWP.2021.3114061.

[10] A. Molaei, M. Kaboli, S. A. Mirtaheri, and M. S. Abrishamian, "Dielectric lens balanced antipodal Vivaldi antenna with low cross-polarisation for ultra-wideband applications," *IET Microw., Antennas Propag.*, vol. 8, no. 14, pp. 1137–1142, Nov. 2014.

[11] H. Liu, W. Yang, A. Zhang, S. Zhu, Z. Wang, and T. Huang, "A miniaturized gain-enhanced antipodal Vivaldi antenna and its array for 5G communication applications," *IEEE Access*, vol. 6, pp. 76282–76288, 2018, doi: 10.1109/ACCESS.2018.2882914.

[12] D. M. Pozar, *Microwave Engineering*, vol. 8, 2nd ed. Hoboken, NJ, USA: Wiley, 1998, pp. 90–94.
[13] D. R. Smith, D. C. Vier, T. Koschny, and C. M. Soukoulis, "Electromagnetic parameter retrieval from inhomogeneous metamaterials," *Phys. Rev. E, Stat. Phys. Plasmas Fluids Relat. Interdiscip. Top.*, vol. 71, no. 3, Mar. 2005, Art. no. 036617.
[14] A. Azari, A. K. Skrivervik, H. Aliakbarian, and R. A. Sadeghzadeh, "High performance low cost transition connectors for 5G mmWave applications," in *Proc. 6th Int. Conf. Millim.-Wave THz Technol. (MMWaTT)*, Tehran, Iran, Dec. 2022, pp. 1–4, doi: 10.1109/MMWaTT58022.2022.10172110.
[15] A. Azari, A. K. Skrivervik, and H. Aliakbarian, "High performance low cost microstrip termination load for mmWave applications," *Electron. Lett.*, vol. 59, no. 20, 2023, doi: 10.1049/ell2.13017.
[16] S. Zhu, H. Liu, and P. Wen, "A new method for achieving miniaturization and gain enhancement of Vivaldi antenna array based on anisotropic metasurface," *IEEE Trans. Antennas Propag.*, vol. 67, no. 3, pp. 1952–1956, Mar. 2019, doi: 10.1109/TAP.2019.2891220.
[17] L. Zhou, M. Tang, J. Qian, Y.-P. Zhang, and J. Mao, "Vivaldi antenna array with heat dissipation enhancement for millimeter-wave applications," *IEEE Trans. Antennas Propag.*, vol. 70, no. 1, pp. 288–295, Jan. 2022, doi: 10.1109/TAP.2021.3091625.
[18] H. Kähkönen, J. Ala-Laurinaho, and V. Viikari, "A modular dual-polarized Ka-band Vivaldi antenna array," *IEEE Access*, vol. 10, pp. 36362–36372, 2022, doi: 10.1109/ACCESS.2022.3164201.

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