Design of Miniaturized and Enhanced Gain Antipodal Vivaldi Antenna for 5G Applications

Kolipaka Pranith Kumar, Sumit Kumar, Amruta S. Dixit

Abstract: In this project, method of designing of high gain and mutual coupling reduction is proposed, which can be done by antipodal Vivaldi antenna (AVA) for 5G applications. For the reduction of isolation between the antenna elements, the antennas are not placed adjacent to each other because they have a chance of absorbing the energy which is to be transmitted. The proposed AVA comprises of 2 x 1 multiple input multiple output (MIMO) antenna elements. The antenna parameter enhancement techniques used in this design are corrugation and circular slots. The antenna dimensions are 50mm x 48mm x 0.8mm. Here, we use corrugation and circular slots method, as to increase the gain than previously designed antenna. The maximum isolation of antenna is achieved is 37dB and gain is improved in the desired range. The simulated gain is in the range of 7.1-14.4 dB in the frequency band of 20-30GHz.

Keywords: Antipodal Vivaldi Antenna (AVA), 5G, multiple input multiple output (MIMO), corrugation etc.

I. INTRODUCTION

Currently, 3G/4G support a limited number of users at high data rates and there are many problems like propagation loss, signal discontinuity, moderate data rates, etc. 4G LTE has various commercial services to achieve high data rates and offers high speed in connection. To overcome these problems, a new technology is needed i.e.,5G. 5G is Fifth Generation cellular network technology, which supports a billion devices, while 4G supports only up to million devices. 5G technology will boost the network speed in wireless systems. Due to the wider bandwidth and an advanced antenna, 5G increases the data transmission amount over wireless systems. To deliver faster connection and greater capacity, 5G will have a fast response time referred to as latency [1]. 5G provides connectivity which allows new generations of applications, services and opportunities that have not been seen till now. The 5G technologies includes the advanced techniques which makes 5G technology in huge demand in future. The term "MIMO" indicates the use of various antennas at the transmitter and the receiver simultaneously over the same radio channel by using multipath propagation. MIMO structure allows the providing of effective and consistent communications due to high data rates. The advanced requirements of 5G communication can be fulfilled by AVA with MIMO (AVA-M). Vivaldi Antenna was invented in 1979 by Gibson. Basically, Vivaldi's outer edge is tapered which becomes gradually narrower towards one end. After that, the tapered shape is modified to antipodal shape by Gazit in 1988 [2]. The AVA has one tapered shape on the upper side of the substrate and another tapered shape which is a mirror image at the bottom side of the substrate which acts as ground. The AVA has low input impedance, so it can match easily the distinctive impedance of 50Ω. AVA can also feed signal directly from microstrip line. Radar, micro imaging applications use AVA because of its wideband and symmetric E and H plane. Dual-polarization applications, and Ultra-wideband (UWB) applications. Corrugation is used at both ends of radiating elements to increase electrical length for better current distribution. Radiation in undesired direction causes increase in side lobe level and decrease in cross polarization. So, Current path is set to be in parallel and opposite in path for minimizing the radiation in unwanted direction. So, corrugation structure results in achieving high gain, low side lobe levels and cross polarization levels [3]. A rectangular guide is within the substrate, which is mounted on the metal over the ground plane and limits the structure of vias on the both side. SIW is easy in design and for fabrication process. SIW are also flexible and cost-effective [4]. The main objective is to achieve higher gain for 5G communication in the range of 20 to 30 GHz. In this paper, the designed AVA has size of 50 x 48 x 0.8mm³ and the maximum gain achieved is in the range of 7.1-14.4dB. The paper includes the proposed antenna design in section 2, simulated results in section 3 and conclusion in last section.

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II. ANTENNA DESIGN

The early AVA single antenna is shown in fig 1. The tapered slot is designed with the exponential equations,

$$y1 = a1 \times \exp(0.0756x) + 1\text{mm} \quad (0 \leq x \leq 35 \text{ mm})$$

$$y2 = a1 \times \exp(0.304x) + a2 \quad (0 \text{ mm} \leq x \leq 8.2 \text{ mm})$$

where a1 = 1 mm and a2 = 3 mm

Antipodal Vivaldi antenna (AVA) of single patch is implemented on Rogers RO4003 substrate of 0.8mm width having a relative permittivity of 3.55. The antenna is designed in XZ- plane. To understand the antipodal antenna structure, the top part of the substrate is mirror image at the bottom part of the substrate, which is 180° phase shifted. The dimensions of substrate are listed in table 1.

The 2 x 1 MIMO (Multiple Input Multiple Output) AVA array is also designed on Rogers RO4003 substrate of width 0.8mm having a relative permittivity of 3.55. The antenna is designed in XZ- plane.

To understand the antipodal antenna, the structure on the top of the substrate is mirror image at the bottom of the substrate, which is 180º phase shifted. So, that return loss and gain is improved as compared to previous design single patch antenna design. Fig 2 shows 2 x 1 Antipodal Vivaldi Antenna (AVA) and dimensions are listed in table 2.

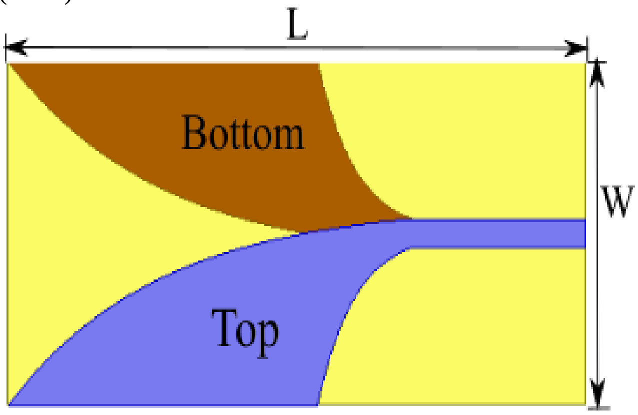


Fig. 1. Top and Bottom patch of designed AVA

Table. 1. Dimensions of designed AVA single antenna

Description	Parameters	Dimensions
Length	L	50mm
Height	H	0.8mm
Width	W	24.09mm

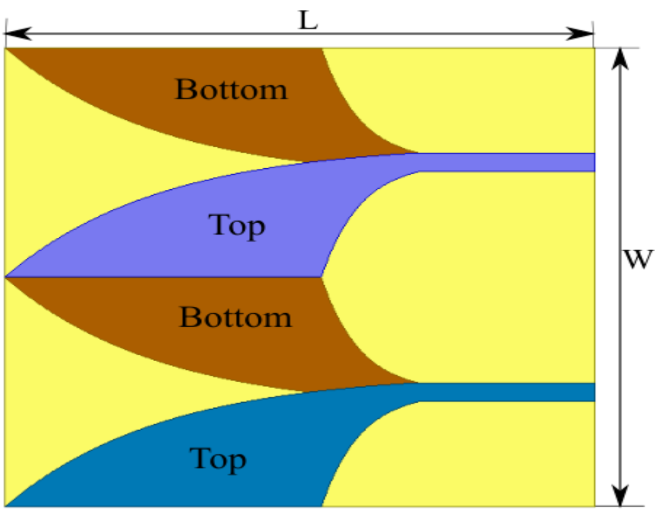


Fig. 2. 2 x 1 MIMO Top and Bottom patch of designed AVA antenna.

Table. 2. Dimensions of designed 2 x 1 MIMO antenna.

Description	Parameters	Dimensions
Length	L	50mm
Height	H	0.8mm
Width	W	48.3mm

In order to improve gain of antenna, now 2 x 1 MIMO AVA with corrugation and circulator slots is used. Here, rectangular slots are used i.e., corrugation is applied on top and bottom patches which are of equal distances between each of them. Corrugation is placed on the both sides of radiating elements to achieve high gain, low side and back lobes [5]. The return loss and radiation patterns are improved as compared to the previous design and circular slots are added to design for the current flow movement in between the top and bottom metals. These circular slots are arranged on microstrip line and these slots also known as 'Via' act as a waveguide [6]. SIW are integrated waveguide-like structures which connects the top and bottom ground planes of the substrate. SIW components are easy in design and fabrication process. SIW are advantageous because of flexibility and cost effective. Current leakage problem is occurred, if the design rules are not followed properly. By applying these Via slots, the return loss and gain is improved. Fig 3 shows 2 x 1 Antipodal Vivaldi Antenna (AVA) with corrugation and circulator slots and dimensions of slots and corrugation are listed in table 3 and 4.

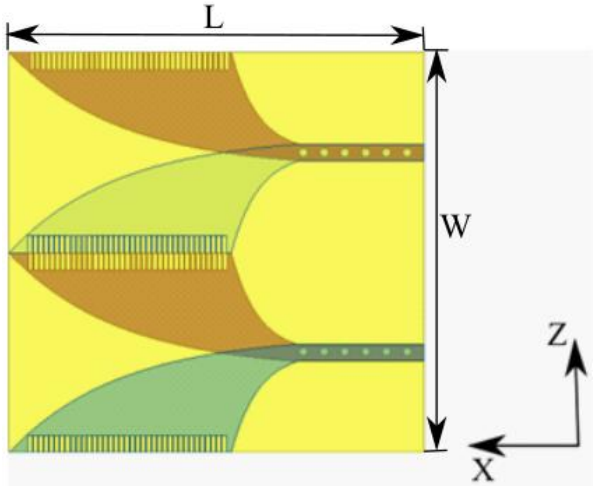


Fig. 3. MIMO AVA with Corrugation and Circular slots.

Table. 3. Dimensions of corrugation slots

Description	Parameters	Dimensions
Length	L	2.1mm
Width	W	0.5mm

Table. 4. Dimensions of Circular slots

Description	Parameters	Dimensions
Radius	R	0.5mm
Height	H	0.8mm

III. SIMULATED AND EXPERIMENTAL RESULTS

The simulated return loss S_{11} of AVA is less than -10dB with an isolation of -30.5dB in the operating frequency of 20 to 30 GHz, which covers the 5G communications frequency band. Smith chart of AVA antenna where the impedance is equal to 1 in angle between 0º and 90º which indicates the good performance of AVA antenna. Next, 2 x 1 MIMO AVA antenna has improvement in return loss S_{11} than the previous single patch AVA antenna with an isolation of -34dB in the desired range and impedance matching, and gain is also better than previous design. Next, 2 x 1 MIMO AVA with corrugation and circular slots is improved than previous two design with isolation of -37dB in the operating range and impedance matching, and gain is also improved, and the gain occurred in this 2 x 1 MIMO with corrugation and circular slots is the required gain i.e., 7.1-14.4dB.

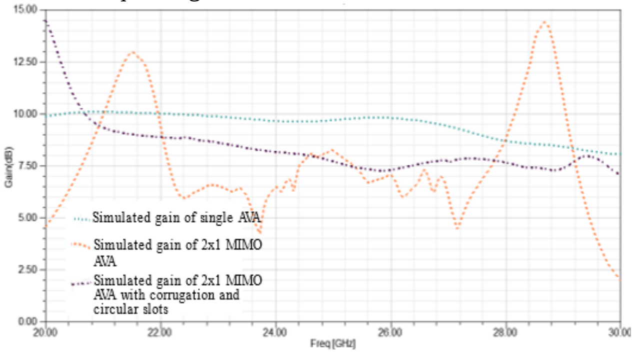
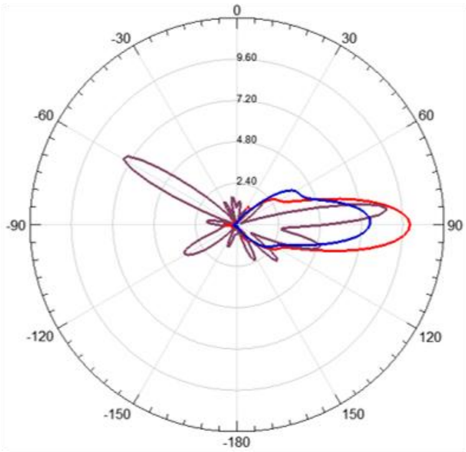
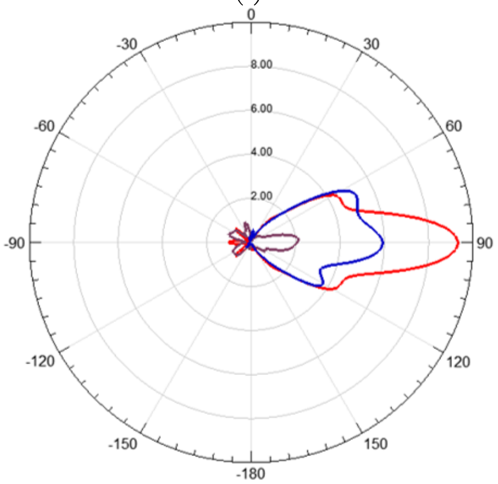


Fig. 4. Gain vs Frequency plot



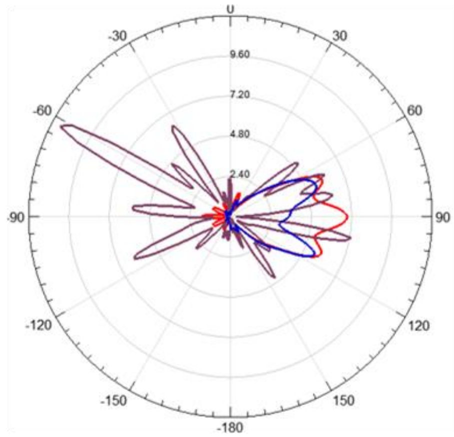
22GHz

(a)



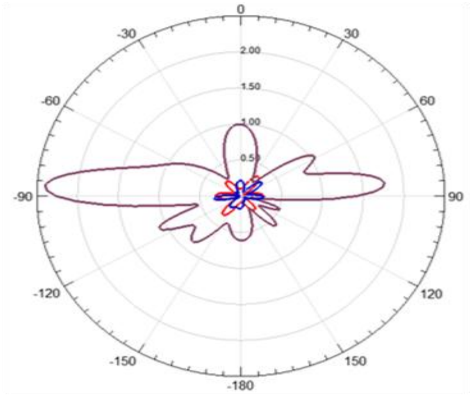
25GHz

(b)



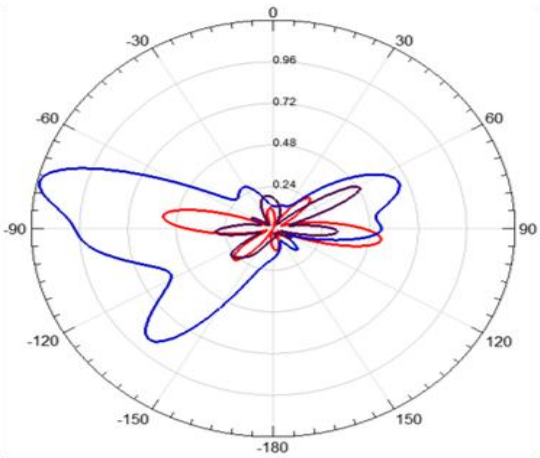
29GHz

(c)



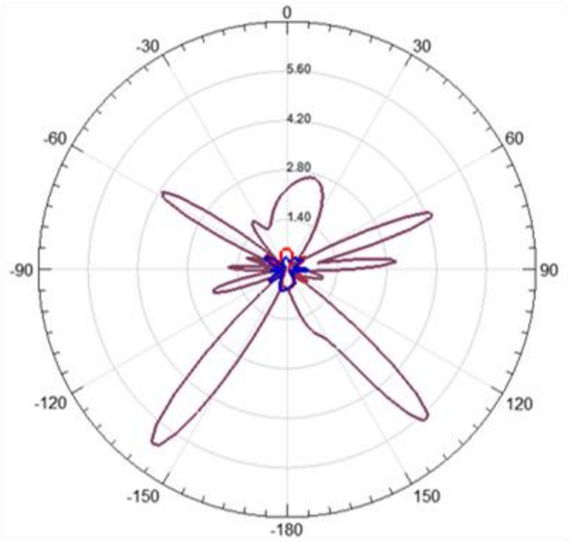
22GHz

(d)



25GHz

(e)



29GHz

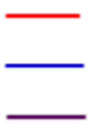


Fig 5: Simulated radiation patterns of designed MIMO antenna

(a), (b), (c): Elevation pattern at 22GHz, 25GHz, and 29GHz for MIMO configuration.
(d), (e), (f): Azimuthal pattern at 22GHz, 25GHz, and 29GHz for MIMO configuration.

Table 5: Comparison of array papers and proposed MIMO antenna

Ref No.	Size of Antenna (mm)	S11 (dB)	Gain (dB)	Frequency range (GHz)
[07]	40 x 24	-40	3-12	4-50
[08]	100 x 100	NG	4.8-6.8	1-35
[09]	33.8 x 16	-27	6.4-7.5	0-40
[10]	30 x 55	NG	7.5-11	5-50
[This work]	50 x 48.3	-37	7.1-14.4	20-30

*NG: Not Given
*S11: Return Loss

IV. CONCLUSION

The designed AVA has improved return loss and improvement of gain in the required range of 20 to 30 GHz. The MIMO size is compact in size. For the improvement of the gain of antenna, corrugation and circular slots are introduced onto AVA without the use of any extra space on substrate. Hence, MIMO gives a maximum gain of 7.1-14.4dB than previous antenna designs in the 5G communication range.

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