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4 x 4 Massive MIMO Antennas for 39 GHz Millimeter-Wave Applications

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***Abstract*— This paper shows a compacted design of 4 × 4 Massive Multiple Input Multiple Output (mMIMO) antennas that will be used for future 39 GHz millimeter-wave (mm-Wave) effective communications required for 5th Generation (5G) networks. The 5G networks not only support a high data rate but also accommodates excessive internet traffic. The proposed single element antenna is designed on Rogers RT5880 (lossy) with a maximum dimension of 10 × 8.8 mm^2. The proposed design consists of 4 × 4 MIMO with defected ground structure, improves the isolation between MIMO antenna elements. The required band is covered by this proposed MIMO structure, which ranges from 38.26 GHz to 39.69 GHz, covering a bandwidth of around 1.43 GHz. Peak gain obtained in the required band is 6.38 dB. Moreover, the results of the Envelope Correlation Coefficient (ECC), Diversity Gain (DG), and the Mean Effective Gain (MEG) have also been discussed. The simple planar design and radiation qualities approve the proposed massive MIMO structure, exhibiting an appropriate contender for future mm-Wave 5G applications.**

Keywords—5G, 39GHz, MIMO, DG, mm-wave

I. INTRODUCTION

In the past few years, there has been tremendous progress in the field of wireless communication. With the advancement in technology, we need to cope with increased internet traffic. The considerable development of associated internet of things (IoT) gadgets is the primary consideration driving the remote business to outstretch the upcoming fifth-generation (5G) innovation [1]-[3]. In this way, the critical measure of underutilized range in the Wi-Fi band persuades administrators to consolidate the long-haul development for long-term evolution (LTE) with Wi-Fi innovations. The new LTE in the unlicensed band (LTE-U) has the physical layer topology to get a Wi-Fi range, explicitly the 5 GHz band [4],[5].

Wireless research activity emphasizes many technologies for future communication. The main objective for 5G is the demand for high data rates and low latency. The five crucial research areas that can significantly impact the future generation are M-MIMO, D2D, dense small cell development, M2M, and millimeter-wave [6]. 5G versatile systems are relied upon to accomplish higher limit builds contrasted with 4G systems, with significantly higher-speed data rates, to meet sensational traffic development throughout the following decade. This target can be practiced with dense small cell development, the millimeter-wave band, the massive MIMO network, and beamforming.

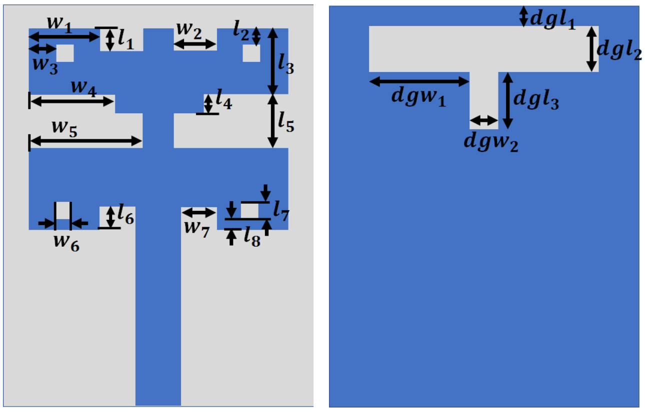
For the future 5G communication, we will require 8×8 MIMO antennas or more, which will bring high requirements as desired in 5G equipment [7]. Attenuation and absorption effects do play a key role when we move towards a higher frequency range. Therefore, the high gain antennas are essential to overcome increased atmospheric attenuations [8] - [10]. The current misuses and Future Prospects of MIMO antenna systems are discussed in [11]. Lately, several MIMO antennas have been proposed that operate at the band allocated by FCC for 5G communication. A T-shaped antenna is designed with a defected ground plane, and it covers the 5G band with a gain of 10.06 dBi and having a dimension of 12×50.8×0.8 mm^3 [12]. Furthermore, an 8×8 MIMO antenna was designed operating at 25.2 GHz, and a gain of 6 dBi was obtained with an inverted H-shaped patch [13],[14]. Another MIMO antenna array operating at 28 GHz with a maximum dimension of $12 \times 24 \times 0.38$ mm^3 is presented in [15], covering a bandwidth of 2.5 GHz. From the works proposed earlier, it can be seen that there is a tradeoff between gain and bandwidth. For covering a wide bandwidth, the gain is relatively low. Adding to it, the antenna does not radiate well, and mutual coupling rises between different MIMO elements. Therefore, it is necessary to keep the antenna size as small as possible, creating a real challenge for antenna designers.

This paper presents a compact 4×4 massive MIMO antenna array with the defected ground (DG) structure [16] for 5G devices. The antenna gives a stable radiation pattern making it suitable for future communication.

II. ANTENNA DESIGN AND DIMENSIONS

The complete antenna design development is discussed in this section, and the antenna simulation optimization is carried out using CST Microwave Studio. The overall dimension of the proposed 4×4 massive MIMO antennas is 35.2×43 mm^2, and the dimension of a single element antenna is 8.8×10 mm^2. The proposed antenna is etched on Rogers RT5880 (lossy) dielectric with a thickness of 0.508 mm as substrate material. The patch (radiator) and ground layers are packed by copper (annealed), having a thickness of 0.035 mm. Fig. 1 illustrates an antenna's top and back view, and the dimension of a patch (radiator) is 7×5 mm^2. The width and length of the 50 Ω feedline are 1.565 mm and 4.4 mm respectively.

The designed antenna consists of three back-to-back layers: patch, substrate, and a defected ground. The slots on both sides of the patch and ground are responsible for the antenna to resonate at the desired frequency. Table I gives the detailed dimensions of a single element antenna, where all the values are in millimeters (mm). The single element antenna design is later converted into a 4×4 massive MIMO antenna array. The resonance will be shifted from lower to a higher frequency by incorporating the T-shaped defected ground structure. The proposed sixteen-element MIMO antenna's geometry is presented in Fig. 2.



(a) Patch top view (b) Patch back view

Fig. 1. The proposed single element antenna design (Copper layer is in blue color).

TABLE I. ANTENNA DIMENSIONS

Length	Value (*mm*)	Length	Value (*mm*)
w_1	1.90	l_1	0.60
w_2	1.00	l_2	0.40
w_3	0.70	l_3	1.50
w_4	1.90	l_4	0.50
w_5	2.90	l_5	1.50
w_6	0.50	l_6	0.60
w_7	0.85	l_7	0.50
dgl_1	0.88	l_8	0.25
dgl_2	1.45	dgw_1	2.00
dgl_3	2.00	dgw_2	1.00

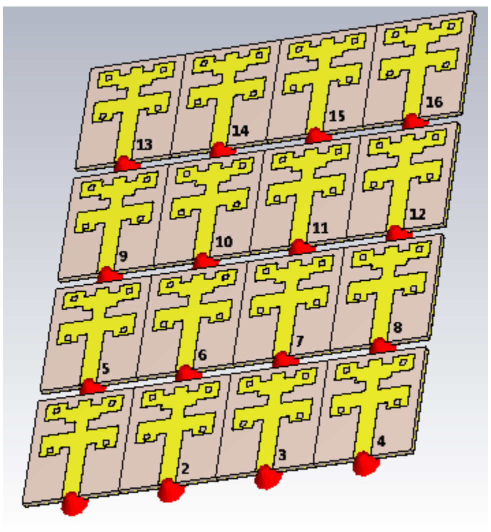


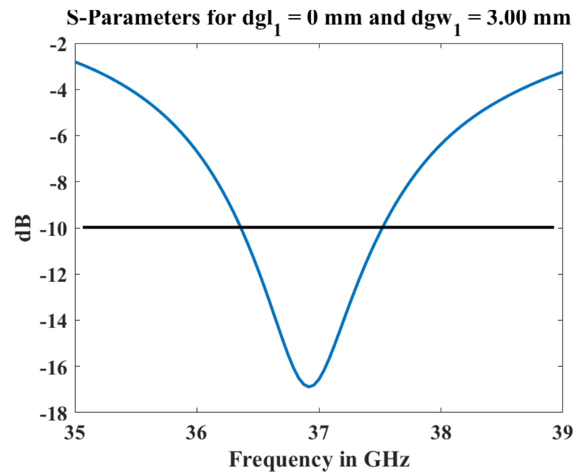
Fig. 2. Proposed geometry of sixteen elements MIMO.

III. SIMULATED RESULTS AND DISCUSSION

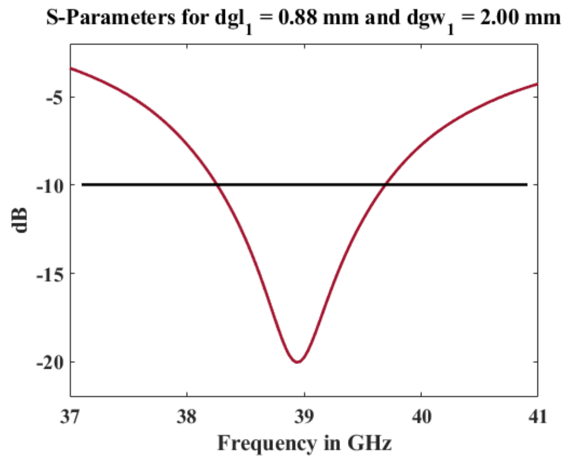
As per the parameters in Table I, the proposed antenna is designed for a resonant frequency of 39 GHz band. By changing the two parameters of defected ground structure, the resonance frequency is shifted to a lower frequency of 37 GHz, and we obtained a resonance at 36 GHz without adding a T-shaped defected ground structure. Following results are obtained after simulation: reflection coefficient, realized gain, directivity, efficiency, etc.

A. *Reflection Co-efficient (S-Parameter)*

The simulated return loss (S-Parameter) plot of a single element antenna is represented in Fig. 3. Figure 3 (a) shows the resonance at 37.0 GHz, and figure 3 (b) shows the resonance at 39 GHz, respectively, which are the recommended frequency bands by the federal communication commission (FCC) for future mm-Wave 5G applications. From the Fig. 3 (a) and (b), it is clear that the frequency can be shifted by varying the defected ground parameters $dgl_1$and dgw_1.



(a) Resonance at 37 GHz



(b) Resonance at 39 GHz

Fig. 3. The reflection coefficient at the resonance frequency of 37 GHz.

B. *Realized Gain, Directivity, and Total efficiency*

The realized gain of a proposed single element antenna at 37 GHz is 5.1 dBi, and 6.4 dBi at 39 GHz, respectively, as depicted in Fig. 4. The figure shows that the realized gain is greater than 4.5 dBi for the 37 GHz frequency band and greater than 6 dBi for 39 GHz frequency bands. The directivity is 4.80 dBi and 6.49 dBi, and the total efficiency is 88% and 92% for 37 GHz and 39 GHz frequency bands, respectively. The relation between gain, efficiency, and directivity is given by equation (1).

$$Gain = efficiency \times directivity \quad (1)$$

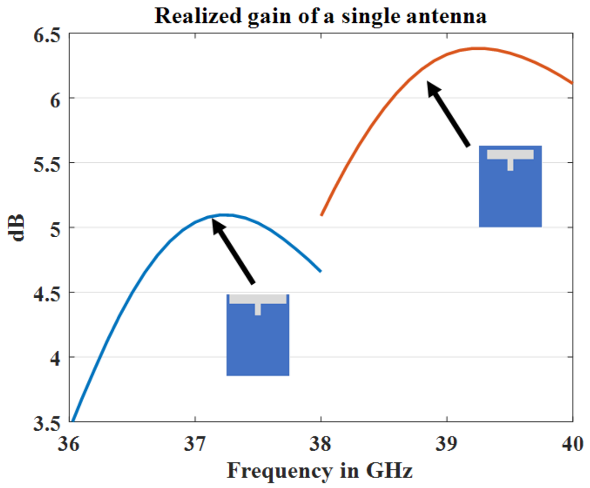


Fig. 4. The realized gain of a proposed antenna for mm-Wave applications.

IV. MIMO Performance Parameters

The performance parameters of the proposed sixteen elements MIMO structure are also obtained from CST Microwave studio by post-processing which will be discussed in the subsequent subsections.

A. Transmission Coefficients (Isolation)

From Fig. 5, it can be seen that the transmission coefficients (isolation) between all the MIMO antenna elements is less than -23 dB at a resonance frequency of 39 GHz. Therefore, the proposed MIMO antenna structure is appropriately isolated.

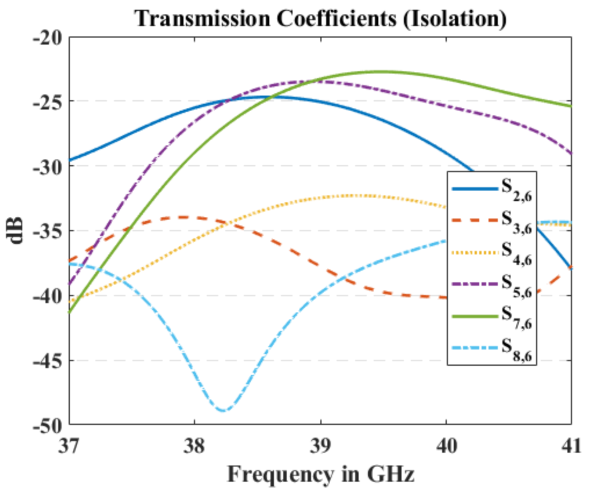


Fig. 5. The reflection coefficient of eight elements MIMO structure.

B. Envelope Correlation Coefficient (ECC)

Envelope Correlation Coefficient (ECC) is referred to as the independence of two antenna's radiation patterns. The ECC considers the antenna's radiation design shape and the relative phase between the neighboring antenna elements. It is calculated using the S-parameters method from the simulation tool. From Fig. 6, the maximum estimated value of ECC is 0.014, which is acceptable for future MIMO networks in [16]. Also, the formula for ECC ($\rho_{X,Y}$) by S-parameters is given in equation (2).

$$\rho_{X,Y} = \frac{|S_{11}^{*}S_{12}+S_{21}^{*}S_{22}|^{2}}{(1-|S_{11}|^{2}-|S_{21}|^{2})(1-|S_{22}|^{2}-|S_{12}|^{2})} \quad (2)$$

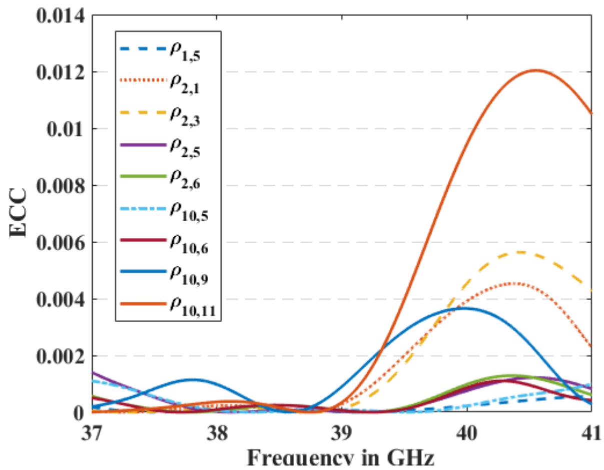


Fig. 6. The ECC of all the ports of the MIMO structure.

C. Diversity Gain (DG)

The most responsible antenna diversity evaluating parameter is the diversity gain. The range for a diversity gain varies from 9.97 dB to 10 dB, throughout the frequency band, with an average value of 9.998 dB. The diversity gain is presented in Fig. 7, and the value of 9.97 dB diversity gain is only at the upper high frequency, but at the resonance, it is almost 10 dB.

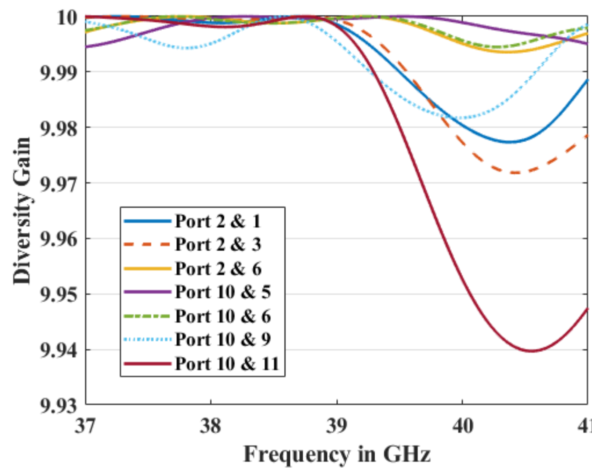


Fig. 8. The ED gain at the resonance frequency of 37 GHz.

D. Mean Effective Gain(MEG)

MEG is the ability of an antenna to receive electromagnetic power in a multipath environment, and it is the ratio of mean received power to mean incident power. MEG can be evaluated by the efficiency of an antenna, by an equation (3) given below,

$$MEG = \frac{\eta}{2} \quad (3)$$

TABLE II. COMPARISON WITH PUBLISHED WORK

References	[17]	[18]	[19]	[20]	Proposed
No. of ports	2	1	7	8	16
Size	20 × 20	60 × 40	56 × 34	158 × 77.8	35.2 × 43
Resonance frequency (GHz)	39	38.5	37	39	38.95
Bandwidth (GHz)	1.4	98.26	1.11	2.4	1.01
Gain (dBi)	2.1	6.6	7.7	7.2	5.002
Transmission Coefficient (Isolation)	-32.4	N/A	-23	-17	-23
MEG (-dB)	Not given	N/A	3.01	4.5	3.0103

If the antennas are 100% efficient (η), the MEG value comes out to be -3 dB. The MEG is calculated at each antenna element in a massive MIMO structure, which is -3.0103 dB for all the antennas. The comparison of a proposed sixteen-element massive MIMO antenna structure with recently published work is evaluated in table II.

V. CONCLUSION

The 5G sixteen-element massive MIMO antenna structure is proposed for future 5G applications, and the antenna has a packed geometry with required MIMO parameters. The proposed antenna has been designed on Rogers (RT5880), which gives us the required resonance and a gain of 5.002 dBi. In addition, the proposed sixteen-element massive MIMO antenna structure demonstrates better diversity characteristics. Consequently, the compactness of a proposed design, required bandwidth, good gain, and the excellent isolation of MIMO configuration due to defected ground structure shows the appropriateness of the proposed MIMO network for the future 39 GHz 5G mm-Wave applications.

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