Extra Wide Band MIMO Antenna with High Isolation and Low Correlation at 38 GHz mm-Wave Frequency Band for 5G Applications

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Abstract. A compact wide-band Multiple Input Multiple Output (MIMO) antenna having highest isolation and least correlation for millimeter-wave 5G communications is proposed in this paper. Firstly, a single antenna was designed and simulated to be working at 38 GHz, a potential target band for 5G applications. It consists of a 5-shaped radiating patch, with partial ground plane. Its length is adjusted and a wide bandwidth is obtained. Then, the two antenna elements are closely positioned with edge-to-edge spacing of 1 mm (0.55 λ, with λ is the free space wavelength at resonance). Thanks to the technique of spatial diversity, a high degree of isolation is attained; more than 25 dB in the whole bandwidth. Moreover, correlation value is under 0.0002 in the working band. The prototype antennas are fabricated and measured. The result indicates that this antenna shows a reflection coefficient under -10 dB over a range of frequencies from 32.3 to 54.6 GHz (BW=22.3 GHz, 58.68% fractional bandwidth). The antenna presents a high realized gain of 7.12 dBi and radiation efficiency of about 82.46% at the desired frequency. Due to these results, our antenna may be regarded a suitable candidate for mm-wave 5G MIMO applications.

1 Introduction

As demand for mobile high-speed and data traffic increases rapidly, the conflict for both capability needs as well as spectrum scarcity is becoming more and more important, and bandwidth congestion is becoming a major problem for 5G mobile networks. Furthermore, because of the enormous frequencies ranges from 30 GHz to 300 GHz in mm-wave bands, they are considered as essential aspect in 5G cellular network in order to deliver multiple gigabit. Therefore, the usage of millimeter bands is one of the disruptive technologies of 5G.

The Federal Communication Commission (FCC) allocated the licensed frequency spectrum 28 GHz (27.5 – 28.35), 37 GHz (37 – 38.6), 39 GHz (38.6 – 40) and unlicensed frequency band 64 – 71 GHz for 5G wireless communication. The frequency bands around 28 GHz and 38 GHz are the powerful candidate band and the advantageous for 5G networks [1].

Added to the advantage of wide bandwidth, millimeter waves are characterized by shorter wavelengths, which means that the occupied size of the radiating elements is smaller. Despite these benefits, mm-wave suffer from high attenuation and interference [2]. In addition, shorter range and higher sensitivity to obstacles are the main difficulties facing 5G [3]. To address these, the use of Multiple Input Multiple Output MIMO antenna technology is primordial [4].

This kind of antenna is also employed to enhance SNR, improving channel capacity and multipath propagation, increasing data rate and upgrading Quality of Service (QoS) [5]. Therefore, MIMO technology is among the core technologies in the fifth generation of mobile communication. In this context, the main focus of our work consists in designing compact MIMO antenna functioning in mm-wave range having a wide bandwidth.

In this paper, a compact wide bandwidth millimeter wave MIMO antenna for 5G communication is presented. The suggested MIMO antenna is composed of two radiating elements, placed next to each other using spatial diversity technique, spacing by a distance of 0.55 λ (λ: is free space wavelength at the resonant frequency 38 GHz) and partial ground plane. The global dimension of the proposed single and MIMO antennas is 13x12.8 mm^2 and 26x12.8 mm^2, respectively. The proposed antenna achieves the impedance bandwidth (at -10 dB) of 22.3 GHz from 32.3 to 54.6 GHz, this band covers well the licensed spectrum from 37 to 40 GHz allocated by the FCC and also other frequency 5G bands: 32, 42, 47, 50 GHz. The MIMO antenna performance include envelope correlation coefficient (ECC), diversity gain (DG), realized gain and radiation efficiency are studied. The suggested antennas are conceived and simulated by CST MS software and then the results are verified using the HFSS 3D simulation tool. The simulation results have been validated by comparisons with experimental results; a good accordance is achieved

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between simulations and measurement. The advantages such as: very wide bandwidth, small size, higher isolation, lower envelope correlation coefficient and simpler design, made this suggested antenna a great candidate for millimeter wave MIMO 5G communications.

2 Antenna design

2.1. Wide-band single antenna

The configuration of the proposed wide-band antenna at mm-wave band for the fifth generation applications with detailed dimensions is illustrated in Fig.1. The suggested antenna is fabricated on a FR4 substrate with a relative permittivity of 4.4 and thickness of 1.6 mm and loss tangent of 0.02. Total dimensions of the single wide-band antenna are 13x12.8 mm^2. The substrate has a partially ground plane on the underside. The 5-shaped radiating element is fed using 50 Ω micro-strip line. The antenna is conceived and simulated with Computer Simulation Technology (CST) Microwave Studio Software.

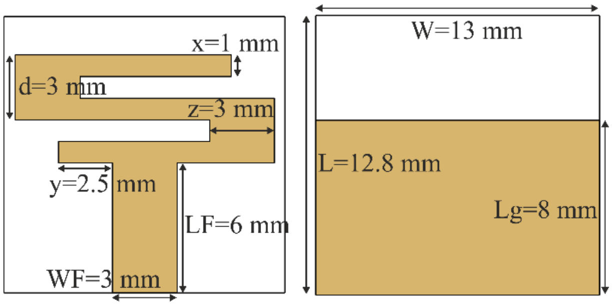


Fig. 1. Configuration of the proposed wide-band antenna.

2.2 Design evolution

The development steps of the suggested wide-band antenna and the corresponding simulated reflection coefficients (S_{11}) are shown in Fig.2.

We have based on the antenna [6], which operates at 28 GHz frequency band, by optimizing the geometry of the ground plane and the dimensions of certain parameters in the radiating element of that antenna to get a wideband antenna operating at 38 GHz, hence the purpose of this paper.

In the first step, a basic antenna [6] (Antenna (1)) has been simulated in the frequency range between 30 and 60 GHz, as shown in Fig.2. It resonates around 39 GHz with a narrow bandwidth that is why in the second step, a partial ground plane is utilized to improve the antenna bandwidth. As we can see in Fig.2, the curve corresponding to (Antenna (2)) clearly shows that a very large bandwidth is achieved while the resonating frequency is 38 GHz with a reflection coefficient S_{11}=-25.33 dB. In the third step, to further improve the reflection coefficient, both parameters y and z have been adjusted, and their optimal values are z=3 mm and y=2.5 mm. Therefore, as seen in Fig.2, the curve corresponding to the suggested antenna (Antenna (3)) illustrates a return loss greater than 37 dB at 38 GHz mm-wave frequency band and the -10 dB simulation bandwidth of impedance is (31.5 – 54.5 GHz).

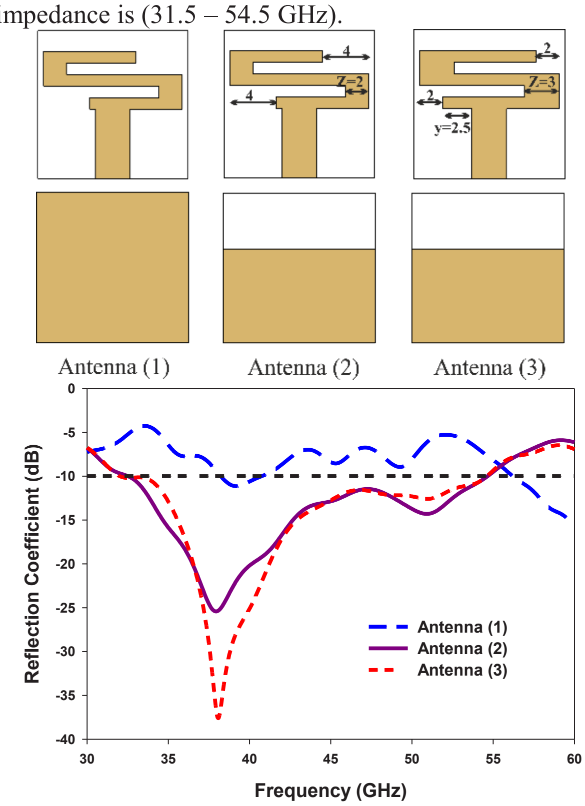


Fig. 2. Three antennas configurations and their corresponding S11 parameter.

2.3 Influence of ground plane length "Lg"

The purpose of this paragraph is to study the effect of Lg parameter, which play a key role to obtain a wide-band. We will adjust the length of ground plane by changing the distance "Lg" from 6 mm to 10 mm and keeping the other parameters constant.

Fig.3 displays the simulated reflection coefficient of the suggested wide-band antenna at several values of "Lg" parameter. It is evident in this figure that changing the size of Lg has an influence on the bandwidth of the proposed antenna. For Lg=8 mm a wide bandwidth is achieved (BW=23 GHz) and the resonating frequency is 38 GHz with a good adaptation, so the optimal value is Lg=8 mm.

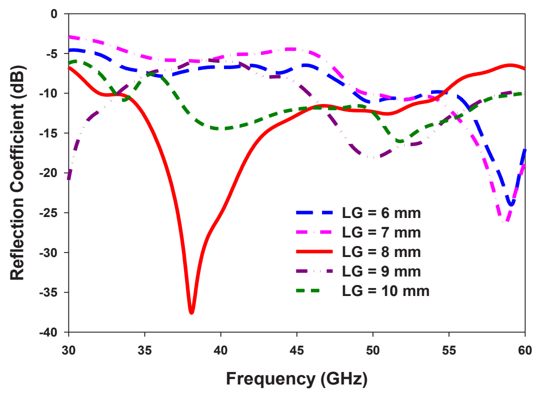


Fig. 3. Simulated reflection coefficient for different values of Lg.

2.4 Wide-band MIMO antenna

Once the single wide-band antenna has been completed, the arrangement of the two elements of this antenna will be done using the spatial diversity technique to obtain the desired MIMO antenna, that operates at 38 GHz for mm-wave applications. The configuration of the suggested wide-band MIMO antenna is shown in Fig.4.

Both radiating elements are placed adjacent to each other, and they are separated by a distance of $s = 1\text{ mm} = 0.55\,\lambda$, where λ: is free space wavelength at the resonant frequency (38 GHz).

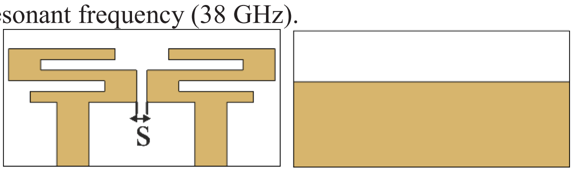
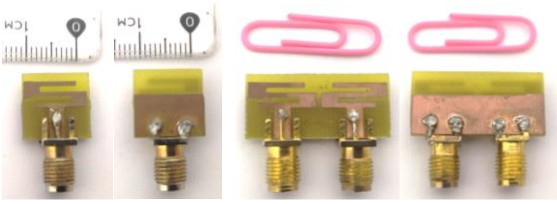


Fig. 4. Design of the suggested wide-band MIMO antenna.

3 Fabrication and measurements results

Based on the obtained designs in section 2, manufacturing of the proposed single element wide-band antenna and dual element wide-band MIMO antenna is done with a printed circuit board (PCB) milling machine: the LPKF Proto Mat E33. Next, the S-parameter measurement is performed with the PNA-L Network Analyzer N5234A (10 MHz-43.5 GHz). Manufactured prototype picture of single and MIMO antennas is given in Fig.5.



(a) (b)

Fig. 5. Photo of the manufactured prototype (a) single, (b) MIMO wide-band antenna.

Fig.6 represents measured and simulated reflection coefficient of our suggested wide-band antenna. The limit of the Network Analyzed used is 43.5 GHz, this is why the measured results are stopped to the maximum frequency 43.5 GHz. From this figure, the measured resonant frequency is 37.995 GHz with a return loss of -27.477 dB and the simulated one is 38.01 GHz, 38.4 GHz with a return loss of -37.31 dB, -39.82 dB for CST and HFSS respectively; so, close accord is reached regarding measured and simulated results. Based on CST simulator the simulated bandwidth is 23 GHz (from 31.5 GHz to 54.5 GHz). In order to verify this result we used High Frequency Structure Simulator (HFSS) Software, the bandwidth is from 31.5 GHz to 52.6 GHz, good agreement between HFSS and CST simulator is achieved.

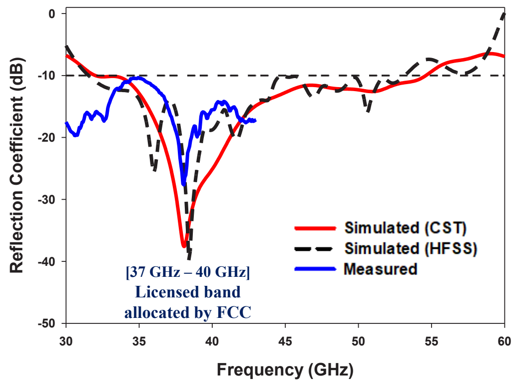


Fig. 6. Simulated and measured reflection coefficient of the suggested wide-band antenna.

Due to symmetry of suggested MIMO antenna (S_{11}=S_{22} and S_{12}=S_{21}), just the S_{11} and S_{12} will be analyzed. Fig.7 shown the measured and simulated S_{11} and S_{12} of the suggested wide-band MIMO antenna. From Fig.7, we remark an acceptable agreement between measured and simulated resonant frequencies 38.12, 38.37, 37.7 and corresponding reflection coefficients -24.4, -33, -33.12 for measured, CST and HFSS respectively. The simulated bandwidth is from 32.3 GHz to 54.6 GHz and from 33 GHz to 54 GHz for CST and HFSS respectively, which means a good accord between the two simulator CST and HFSS.

The isolation between both antenna elements is over 25 dB at the working bandwidth, additionally the value of simulated transmission coefficient S_{12} is 33.86 dB at the resonant frequency 38.37 GHz, signifying the independence of both antennas from one another. Furthermore, we can say that the suggested MIMO antenna is well performing.

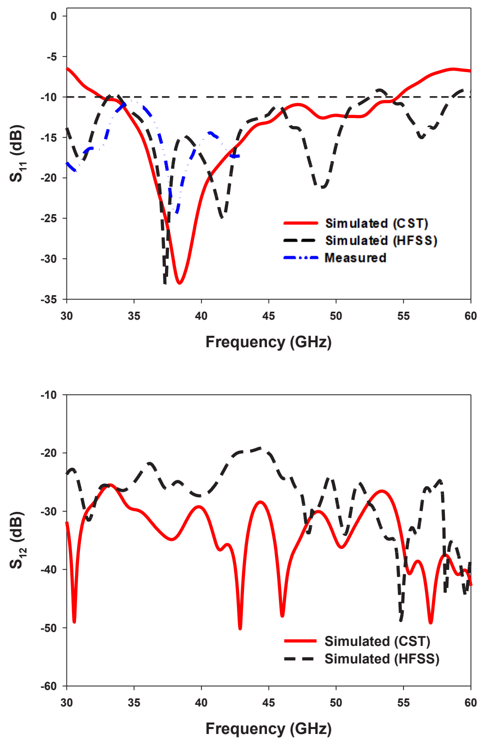


Fig. 7. Measured and simulated S-parameters of the suggested wide-band MIMO antenna.

4 MIMO antenna performances

The main goal of this section is to determine some metrics, which are important to evaluate the proposed wide-band MIMO antenna. These parameters are as follows: envelope correlation coefficient "ECC", diversity gain "DG", radiation efficiency and realized gain.

The Envelope Correlation Coefficient is a parameter with great importance, which indicates the correlation between radiating elements. This parameter can be calculated based on two approaches: far-field radiation pattern [7] and S-parameters [8]. Note that, for good MIMO operation this coefficient must be lower than 0.5. Ideally, diversity systems require a correlation coefficient of zero. For two elements MIMO antenna, the ECC is calculated from S-parameters by equation (1):

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

Diversity gain is associated with the correlation coefficient. The relation between DG and ECC can be given approximately with the equation (2) below:

$$DG = 10\sqrt{1-\rho_e} \quad (2)$$

Envelope correlation coefficient and diversity gain derived from far-field and S-parameters of the suggested wide-band MIMO antenna, are shown in Fig.8. According to this figure, we can observe that the ECC value is less than 0.003 and DG is more than 9.993 in the whole wide operating bandwidth. Which means a good diversity performance of the suggested wide-band MIMO antenna.

Fig.8 shows also the simulated radiation efficiency and realized gain of the suggested wide-band MIMO antenna. From this figure, the suggested wide-band MIMO antenna clearly provides a gain of 7.12 dBi and the radiation efficiency is found to be 82.46 % at the resonance frequency of 38.37 GHz.

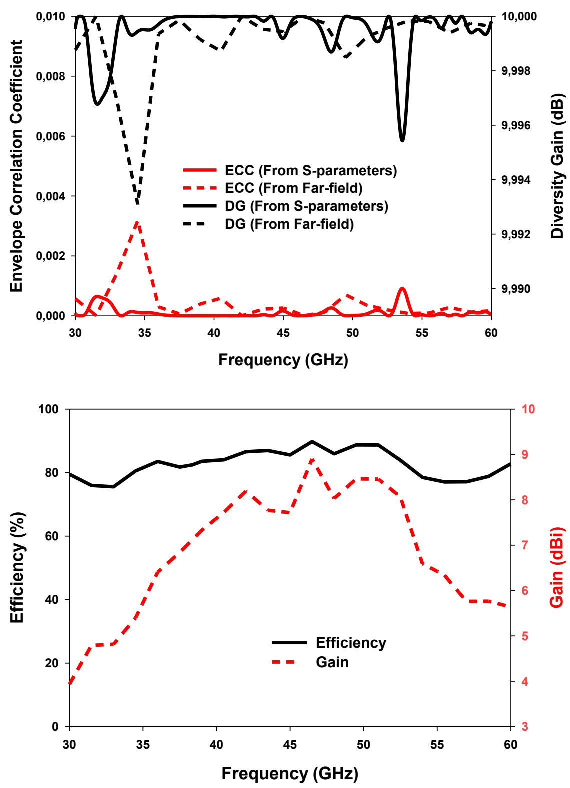


Fig. 8. ECC, DG, efficiency and gain of the suggested wide-band MIMO antenna.

5 Performance comparison

The comparison of the suggested wide-band MIMO antenna among other antennas is represented in Table 1. From this table, we remark that our antenna has high isolation, low correlation, and wide bandwidth compared to all the listed referenced antennas. Thus, our antenna is a good candidate for millimeter wave 5G MIMO applications.

Table 1. Performance comparisons between our proposed wide-band MIMO antenna and other antennas.

Ref	Size (mm^2)	N° Ports	Fr (GHz)	BW (GHz)	S_{ij} (dB)	ECC	Gain (dB)
This paper	12.8x26	2	38	22.3	-33	7.59×10^{-7}	7.12
[9]	30x25	4	38	13.68	-20	0.002	5.28
[10]	12.8x31	1	36	8.7	-20	--	6.5
[11]	14.5x15.5	1	38	--	--	--	2.46
[12]	80x80	4	38	17	-20	0.0014	11.45
[13]	48x21	2	30	1	-25	0.002	7
[14]	55x110	4	28/38	1.43	-26	7.65×10^{-5}	7.95

6 Conclusion

In this paper, a wide bandwidth MIMO antenna, working at 38 GHz mm-wave band for fifth generation applications has been presented. The suggested MIMO antenna is designed on a low cost FR4 substrate; it consists of two elements and the occupied volume was 26x12.8x1.6 mm^3. By optimizing the length of partial ground plane, wide bandwidth is achieved (58.68% fractional bandwidth). For obtaining a highest isolation of the two antenna elements, spatial diversity technique is utilized. The coupling between ports is less than -25 dB in the whole bandwidth. Moreover, the ECC value is below 0.0002, DG is greater than 9.99 and the antenna provided a gain of 7.12 dBi at the resonant frequency. A prototype of both suggested single and MIMO antennas has been manufactured and measured, an acceptable accord is achieved between the measurements and simulations. In addition, HFSS software was used to verify the results obtained by CST MS software, a good agreement was achieved. Based on the achieved results, we found that our suggested antenna was appropriate for millimeter wave 5G MIMO communications.

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