DUAL-/QUAD-ELEMENT 5G NR BAND (SUB 6GHz) MIMO ANTENNA FOR WLAN APPLICATIONS

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ABSTRACT

In this paper, the proposed antenna is a single band dual-/quad- element antenna consisting of microstrip lines placed one over another resembling T over T shape which are printed on the front side and the defected ground structure lies on the back side of an RT Rogers 5880 substrate. The antenna operates at 5190 to 5350 MHz (|S11| < −10 dB) covering the 5G NR band. Hence used for future 5G wireless applications at 5.2 GHz (WLAN). The isolation has been enhanced by an I-shaped ground slot and the mutual coupling reduction is facilitated by 10 mm neutralization line (NL) at both hands. Also, the proposed MIMO antenna exhibits excellent diversity performance (ECC < 0.2). The proposed antenna is designed, simulated and tested. Good agreement between measured and simulated results is achieved.

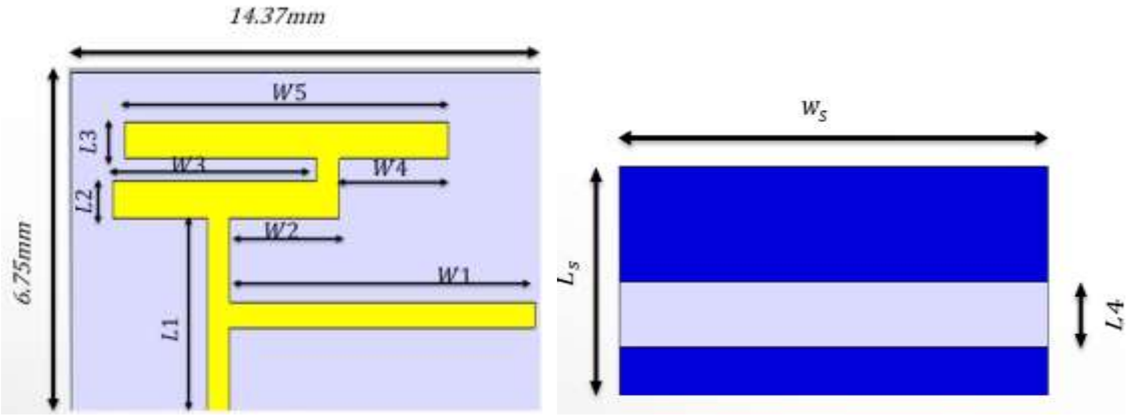
1. INTRODUCTION

The enhancement of the transmitting and receiving efficiencies of a wireless mobile communication network remains the biggest worry as the demand of intelligent services and high data rate increase day by day. In order to address the concern, various techniques have been introduced like implementation of multiple input multiple output (MIMO) antenna transmission technique. MIMO antenna effectively improves the spectral efficiency and channel capacity resulting in significant increase in LTE applications and will be one of the vital technologies in 5G communication [1]. The various constraints that need to be considered while designing an antenna like size, high isolation, ease of fabrication, ease of integration, and low profile must be overcome in order to qualify the design for MIMO antenna system for smartphones [2]. The 5G new radio (NR) frequency band is further divided into two sub frequency band, frequency range one (FR1) working in sub 6 GHz (or > 6 GHz band) and frequency range two (FR2) working in millimetre range (mm-Wave band) as per Technical Specification (TS) 38.101 of 3rd Generation Partnership project (3GPP) [3]. Various techniques and methods have been reported in recent times for 5G MIMO antenna arrays for smartphone handsets operating in sub-6 GHz band [4–9]. These MIMO antenna designs resonate at single frequency band at sub-6 GHz bands like 2.55–2.65 GHz, 3.3–3.6 GHz and are fit for mobile phones without metal frame, and some are suitable for mobile phone with metal frames [10–13]. The design of a MIMO system for 5G mobile terminals is a challenging task since the positioning of the antenna elements in a small space result in poor isolation, in turn altering the system performance characteristics. Various efficient methods have been proposed to reduce mutual coupling and enhance isolation such as defected ground structures (DGSs), lumped elements, neutralization line, and electromagnetic band gap structures. Reportedly, several studies and antenna element structures have been proposed in [14–20] consisting of slot antennas, loop antennas, ring antennas, planer antennas, etc.

In this paper, a two-/quad- element MIMO antenna array structure is presented which covers the sub-6 GHz frequency band (from 5190 to 5350 MHz) with little intricacy. The proposed MIMO antenna is investigated by loading two antennas into a low-cost material with the partial ground. A thin substrate made of Rogers 5880 RT material is used in designing the antenna. Isolation is enhanced using the I-shaped defected ground structure. Hence the maximum isolation achieved between the radiating elements is -21 dB. Monopole antennas having dimensions of 14.37 × 6.75 mm2 each are placed orthogonally one over another resembling a T over T shape with a 10 mm neutral line. It is composed of a 50 Ω microstrip feed line which is directly attached to an SMA connector placed on the edge of the structure, thus reducing required ground clearance.

2. DESIGN AND ANALYSIS OF UNIT ELEMENT ANTENNA

The basic antenna element design uses Rogers 5880 RT substrate material with a thickness (hs) of 0.254mm, relative permittivity (εr) of 2.2 and loss tangent (tan δ) of 0.0009. Figure 1(a) illustrates the design geometry of the single-element antenna. On the back side, an I-shaped defected ground structure is used with the length being Ls and the width being Ws. It is provided with a matching line with a 50 Ω microstrip whose width is of 0.77mm.



(a) front view (b) back view

Figure 1 Configuration of single element

The dimensions (in mm) of the prototype are optimized as:

L1	4	L2	0.77	L3	0.77	L4	2
Ls	7	W1	10.40	W2	3.73	W3	6.93
W4	3.70	W5	11	Ws	16		

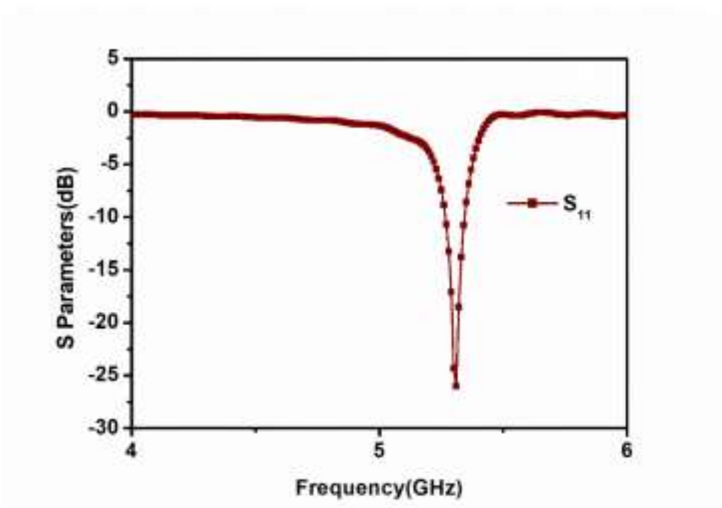
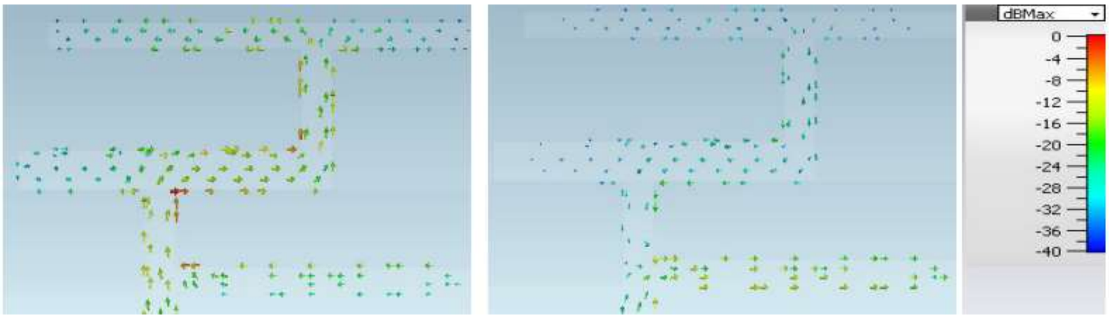


Figure 2 Simulated S11 parameter

The simulated S11 parameter of the corresponding antenna is shown in Figure 2. A single band resonant response is obtained at 5.2 GHz with −10 dB return loss bandwidth. The objective of designing this antenna is to attain resonance at 5.2GHz so as to cover the 5G NR band for WLAN applications. Here we achieved a bandwidth of 160MHz which is higher than the minimum value (100 MHz) set for the sub 6 GHz design by ITU-R Report ITU-R M.2410-0 (11-2017), and for higher frequencies it is 1 GHz [23].



(a) (b)

Figure 3 Simulated surface current distributions at (a) 5.2 GHz and (b) 5.3 GHz.

The design of the proposed antenna consists of folded monopole arms to achieve quarter wavelength of operation. It is observed that it resonates at single frequency and this resonance mechanism gets introduced because of the arms W2 and W3 as can be seen from surface current distribution, and in Figure 3(a) due to higher resonant frequency the current is mostly confined in these arms and minimum current flows in the neutral line resulting in greater isolation. The high surface current in the folded antenna arms depicts the quarter wavelength resonance of the design. The surface current distribution confirms the claim that all the meander lines in the antenna yield the resonance frequency in S11 curve. The relation between the resonance frequency and antenna parameters/physical characteristics is given as:

$$F_r = \frac{c}{2L}\sqrt{\frac{2}{\varepsilon_r + 1}}$$

where Fr is the resonant frequency, L is the total electrical length of the antenna structure, c is the velocity of light, and εr is the permittivity. Desired resonating frequency is produced through fine tuning and appropriate placing of meander line conductive elements.

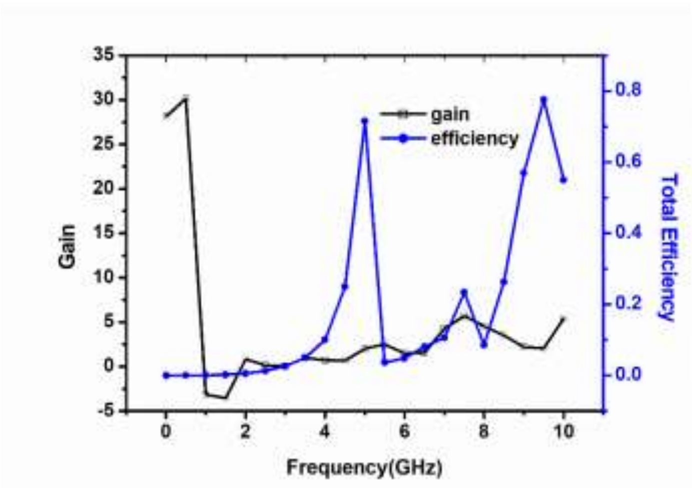
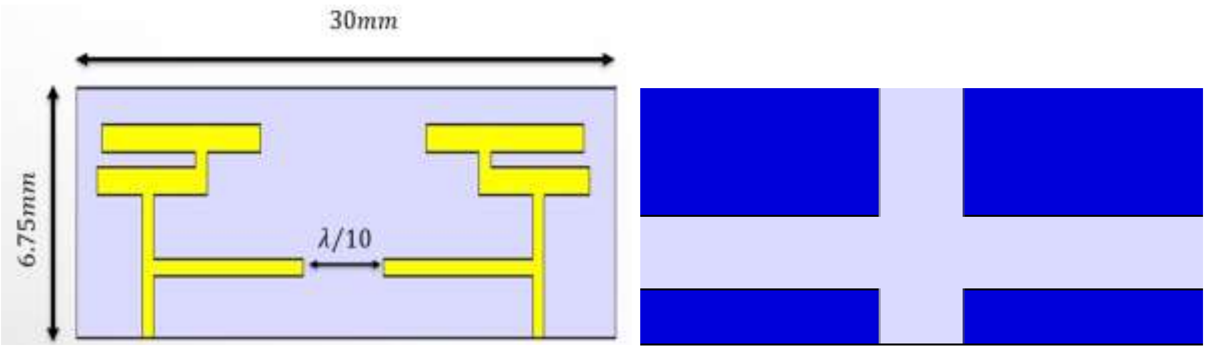


Figure 4 Gain and Efficiency of single element antenna

The gain and total efficiency are shown in Figure 4 at the frequency operating band NR n79 for the proposed prototype. As evident from the figure, the maximum gain of 1.95 dB and total maximum efficiency of 72.50% are attained at 5.2 GHz i.e., at desired resonating frequency.

3. Design and analysis of dual-element MIMO antenna

The designed dual-element monopole MIMO antenna has a configuration of 30×6.75×0.32 mm3 typically designed for mobile handsets. The substrate used is Rogers 5880 RT substrate with thickness of 0.254 mm, εr = 2.2, and tan δ = 0.0009. It is shown in Figures 5 (a) and (b)



(a) front view (b) back view

Figure 5 Antenna configuration of 2-element

It is designed by placing $\lambda|10 = 5 \cdot 64$mm inter-element gap and it is symmetrical in shape so is placed on the edges at corners of the mobile handset. Here, the monopole antenna is folded and is placed orthogonally with each other. Fed by a 50 Ω line directly connected with an SMA connector. As the SMA connector is connected on the edge of the prototype, no ground clearance is needed.

The simulated reflection coefficient of the two element MIMO antenna is given in Figure 6

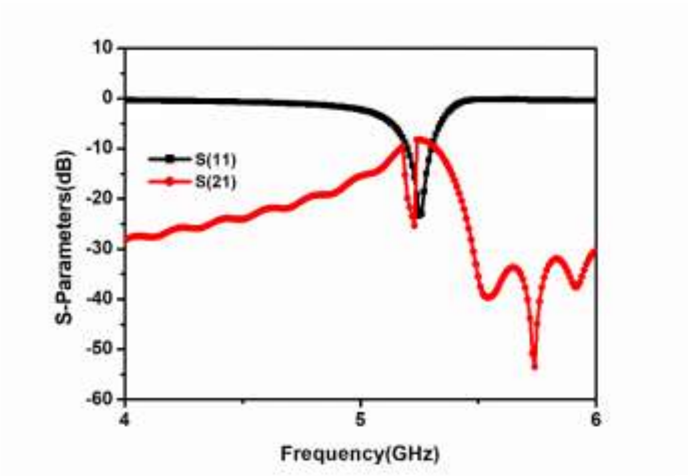


Figure 6 Simulated S parameters

The reflection coefficients curve is below −10 dB at resonating frequency, and the maximum isolation obtained is less than −20 dB (−21 dB). The substrate used in this design is very thin and cannot let surface waves to travel via substrate. Hence, good isolation is achieved by mitigating the mutual coupling caused due to surface waves.

In order to characterize MIMO antenna performance, the analysis of parameters, such as Envelope Correlation coefficient (ECC) and Diversity Gain (DG) is a necessity. The ECC is an important primary constraint which explores how the radiating elements interfere with other elements of the system during port excitation. The ECC is calculated using Equation (2)

$$\rho_e(i,j,N) = \left| \frac{\sum_{n=1}^{N} s_{i,n}^{*} s_{n,j}}{\left| \prod_{k=i,j} \left(1 - \sum_{n=1}^{N} s_{k,n}^{*} s_{n,k}\right) \right|^{1/2}} \right|^{2}$$

where ρe is the correlation between two antenna elements, and N is the number of antenna elements. The diversity gain (DG) of a MIMO antenna system is an important parameter that discusses the increase in signal to interference ratio in a MIMO antenna while incorporating different diversity schemes and is dependent on correlation coefficient ρe. Diversity gain can be calculated by using Equation (3).

$$DG = 10 \times \sqrt{1 - |\rho e|}$$

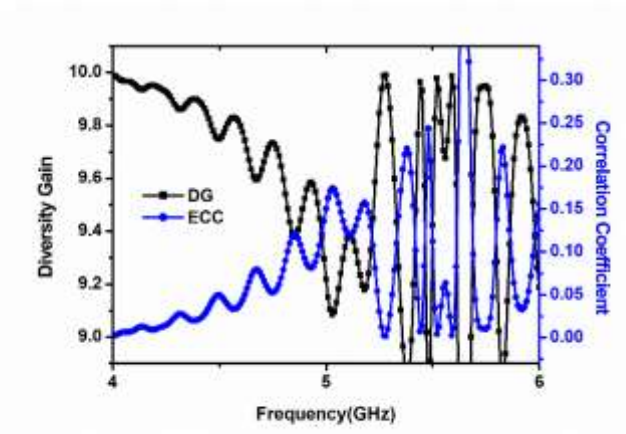


Figure 7 ECC and Diversity gain

The ECC and DG parameters of the two port MIMO antenna are depicted in Figure 7. The proposed antenna has shown good ECC and DG values at the desired frequency. The ECC, as per radiation pattern method, is < 0.5 and is found to be quite satisfactory [20]. In our proposed MIMO antenna, the value of the ECC is near about < 0.2 dB meaning that the isolation is good between the antenna elements. The value of DG is touching 10 dB in the operating band. Therefore, the proposed MIMO antenna system has acceptable performance in diversity.

4. Design and analysis of quad-element MIMO antenna

The design configuration of the proposed MIMO 4-element antenna is arranged in such a way that four monopoles are orthogonal to each other, as given in Figure 8.

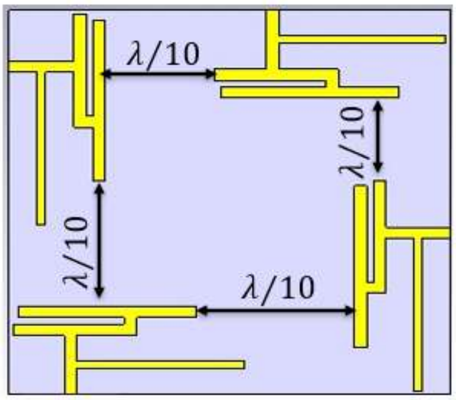


Figure 8 Quad-element antenna design

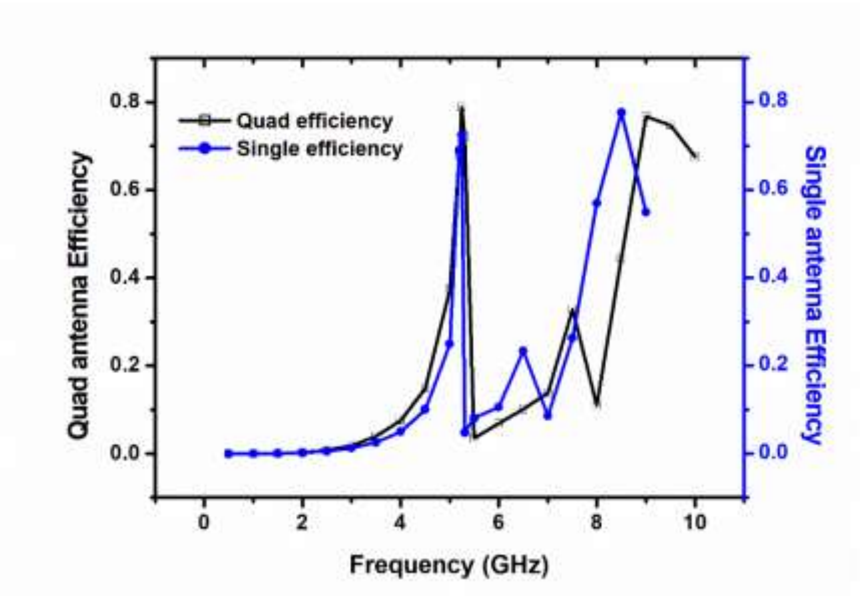
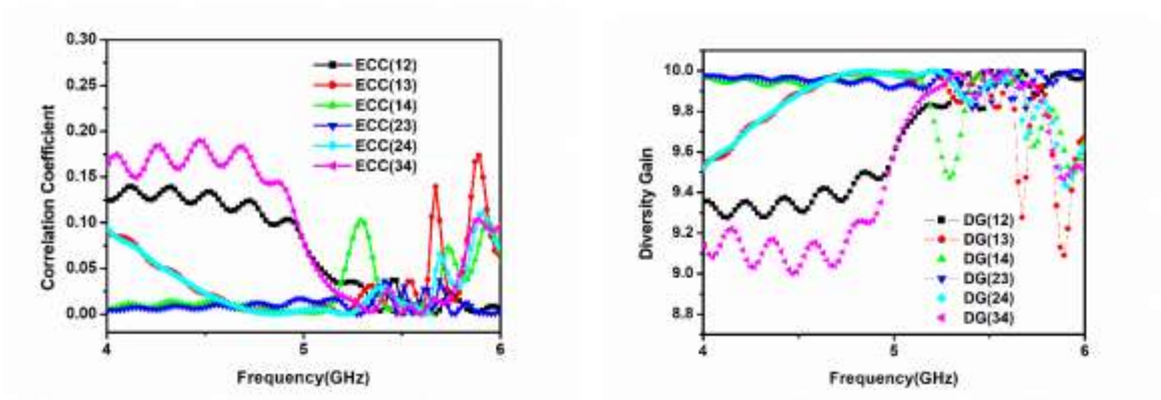


Figure 9 Comparison between efficiencies of single and quad element

From the graph plotted between the efficiencies of a single element antenna and quad-element antenna, we can clearly observe that the efficiency of the latter has increased to78.8%. So, the orthogonal 4-element MIMO antenna performs better efficiency than the single-element antenna.



(a) ECC (b) Diversity gain

Figure 10 (a)Simulated ECC and Diversity gain for 4-element MIMO antennas

The proposed MIMO 4-element antenna simulated ECC and DG as shown in Fig.10(a) and (b), respectively. From the graph, it is observed that four elements, improve both ECC and DG, which validates the application of this antenna.

5. CONCLUSION

This paper presents a dual-/quad- element sub-6 GHz MIMO antenna for future 5G WLAN applications. Miniaturized meander microstrip lines used as the antenna elements provide the flexibility to incorporate the structure on the edges of the smartphone reducing the add-on space. Compared with the other similar 5G antennas, the antenna has obvious low-profile characteristics. In addition, a neutralization line is used to reduce mutual coupling in the structure. To check the performance of the MIMO antenna, different performances are examined and are within an acceptable limit. The isolation of better than −20 dB and envelope correlation of < 0.3 dB are achieved making it a suitable candidate for MIMO applications

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