T–Shape MIMO Antenna with Parasitic Element and DGS for 5G Applications

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***Abstract*— This paper presents the design of a 4×1 MIMO antenna useful for 5G Cellular applications. The proposed antenna design consists of four T-shaped MIMO structure radiating patches on the top layer of the substrate. To improve the bandwidth and return loss characteristics, defected ground structure (DGS) is incorporated on the bottom plane along with parasitic element on both sides of patches. A single element antenna is with the size of 12mm×12mm×0.8mm and a complete antenna is with the size of 12mm×50.7mm×0.8mm. The proposed antenna design is found to resonate at many adjacent frequencies, rendering a large bandwidth which makes it suitable for 5G applications. The simulated and measurement results show a wide bandwidth of 28 GHz – 44 GHz with a peak gain of 10.1 dB.**

***Index Terms*— Millimeter-Wave Antenna, Communication for 5G, defected ground structure, Parasitic Element, Microstrip Patch Antenna.**

I. Introduction

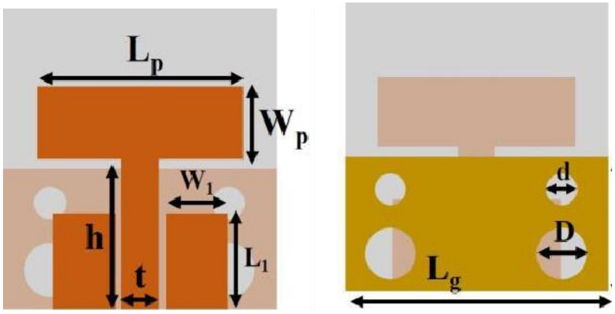
Rapid advancements in wireless communication has presented a need for usable communication bandwidth. This restricts further advancements in a number of simultaneous users and applications on their devices, while consuming the conventional limited spectrum of sub-3GHz [1-2]. The available spectrum above 3GHz is expected to be used for 5G demands in future. This band is also known as Millimeter Waves (MMWs). In this spectrum, the obvious challenges that require immediate resolution are atmospheric absorption, path loss attenuations, signal fading emerge [3-4-5], which are in the form of a complete RF link budget analysis and channel parameter analysis for radio wave propagation. Recent researchers have reported that MIMO (Multiple - input multiple-output) antenna systems have attained great attention because they support multiple functions simultaneously. MIMO systems enable efficient and reliable communication with multi-Gbps throughput and high data rates [6-7]. In order to satisfy the 5G cellular network requirements, the MIMO antenna in Millimetre-Wave spectrum, has become one of the most preferred devices. While designing such an antenna, the prime considerations include flexibility of the system architecture, its consistent performance and compatibility with MIMO systems, low multipath fading and high spectral efficiency. The antenna should offer high bandwidth and have high gain [8-9]. A high bandwidth is needed to support a broad range of system services to function simultaneously, and a high gain to get rid of the attenuation and atmospheric absorption [10]. Moreover, it should be capable of fitting in cellular devices; therefore, customized, compact size and cost-effective fabrication is essential to meet the wireless industry requirements for economic, portable communication devices.

Microstrip antennas has been widely used in cellular communications because of their low cost, light weight, planer geometry, compact size and application specific performance [11-12]. However, there are some major limitations, such as lower gain and lesser bandwidth, that needs to be overcome. Out of several techniques to overcome these limitations, the most suitable technique is the DGS, which is used for improving the antenna performance significantly by intentionally constructing a ‘defect’ in the ground plane. The continuity of the surface current and uniformity of the ground plane get obstructed by the induced derangement due to these defects. The symmetrical structure of DGS functions as resonant gaps, which are added directly on both sides of the microstrip line, enabling efficient coupling and producing changes in the inductive and capacitive response of transmission line. Considering the effect of shape as well size of the defect created in the ground plane, the distributed shield current in the ground plane also changes, which facilitates proper electromagnetic propagation across the substrate by enabling controlled excitation. In other words, the effect of creating a defect in the ground plane causes a net increase in the capacitance and inductance, resulting in multiple resonant frequencies to produce a multiband antenna or a filter. The designed antenna is capable of producing desired resonant frequency by constructing a suitable defect and locating its appropriate position in the ground plane. Based on the wideband and multiband antennas, a number of configurations have been reported by putting DGS as single/periodic, as well as symmetrical/asymmetrical structure [13–14], integrated as slots or radiating patch in the ground plane [15, 16]. The previously proposed antennas based on DGS are meant for single-band MMW operations or low frequency [17]; hence, some research works are still needed to utilize the DGS technique for MMW wideband operation.

In this paper, a design of a compact Microstrip MIMO antenna has been presented. This design offers high gain and wide bandwidth at MMW frequencies. In order to achieve large bandwidth, a partial ground concept is incorporated in the antenna design. The proposed antenna is able to resonate at multiple frequencies (beyond 3GHz) which fulfils the requirement of 5G application. The antenna is simulated using Ansoft HFSS. The simulated results and measured data are presented along with the design procedure.

II. Antenna Configuration

Beginning with the composite design of our MIMO antenna structure, single T-shape radiating patch is designed over the top layer of the substrate along with two parasitic patches on the either side of the micro-strip feedline as shown in Figure 1(a).



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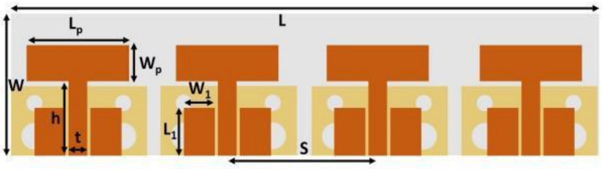

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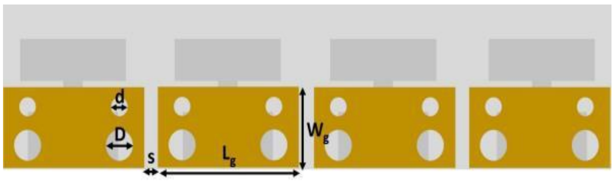

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(d)

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Figure 1: (a) Layout of single antenna element, Proposed MIMO antenna layout (b) Front view (c) Back view, Fabricated MIMO antenna (d) Front view. (e) Back view

Roger RT Duroid 5880 (relative permittivity Ɛr = 2.2 and loss tangent = 9×10^{-4}) was used as substrate material of dimension 12mm×12mm. The proposed single T-shape antenna with defected ground structure was able to resonate at single frequency. To improve the bandwidth; bottom ground plane of the antenna was modelled to partial ground with defected ground structure. Circular slots of diameter 2 mm and 4 mm were cut from the ground plane metal.

The next step is to place the antenna design into a four-element MIMO configuration to integrate. In order to place all the four antennas on a single substrate, the minimum required spacing between the patches should be of the order of λ/2(i.e.in order to minimize coupling effects).

Figure 1(d) and Figure 1(e) present the original view of the proposed MIMO antenna array. The optimized dimensions of proposed antenna designs shown in Figure.1 (a), Figure. 1(b) and Figure. 1(c) are tabulated in Table 1.

Table 1
Design Parameters of the Proposed Antenna

Parameters	Symbol	Size (mm)
Length of the overall antenna array	L	50.7
Width of the overall antenna array	W	12
Separation between two antenna elements	S	12.6
Length of the radiating patch	Lp	8
Width of the radiating patch	Wp	3.1
Height of the microstrip feedline	H	6
Width of the microstrip feedline	T	1.4
Height of the parasitic element	L1	4.35
Width of the parasitic element	W1	5.1
Length of the ground plane	Lg	12
Width of the ground plane	Wg	6
Separation between two ground planes	S	0.9
Diameter of smaller circular slots	d	2
Diameter of bigger circular slots	D	4

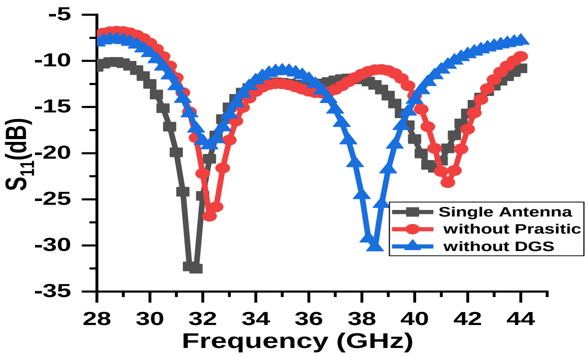
III. Results and Discussion

The simulated and measured results of T-shaped MIMO antenna are discussed in this section. Firstly, the simulated and measured results of single antenna element are presented followed by the simulated and measured results of MIMO antenna structure. The proposed structure has distinctive features, such as high efficiency, good isolation characteristic between the adjacent antennas' patches, and large bandwidth with sufficient high gain. All these characteristics further validate the capability of the proposed antenna for 5G applications.

A. Single T-shape Antenna Element

a) Return Loss

The proposed antenna reports the bandwidth of 28-44 GHz. Effects of DGS and parasitic element on antenna bandwidth are shown in Figure 2(a). It presents the composite result of the return loss of single antenna, MIMO antenna without parasitic with DGS MIMO antenna without DGS with parasitic.



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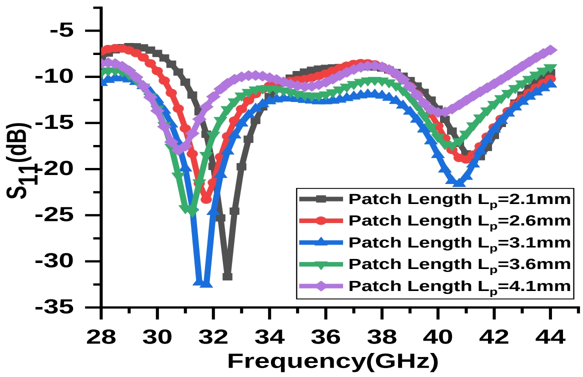

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Figure 2: (a) S11 plot of the proposed single antenna element, without DGS and without parasitic element (b) Antenna parametric analyses on variation of the length of the radiating patch

The design parameters are thoroughly analysed and optimized, while simulation was conducted in the software. The S11 values of the proposed MIMO antenna with respect to variations in the patch length "Lp" was high, when Lp = 3.1mm compared to other values. The antenna S11 is presented in Figure 2(b).

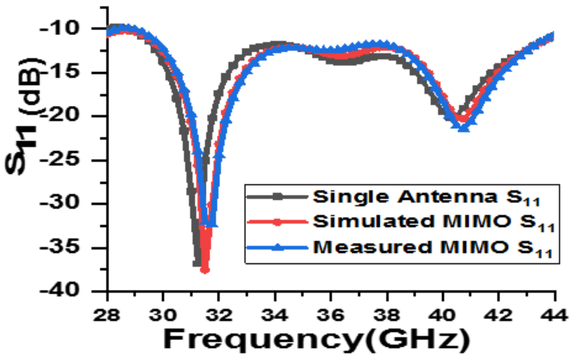
B. MIMO Antenna

a) Return Loss

Figure 3 (a) illustrates the measured, simulated and single antenna reflection coefficient (S11). The proposed antenna has a large operating bandwidth of 16 GHz ranging from 28 GHz to 44 GHz. The slight variation, in negligible amount, between simulated and measured results are due to the different dielectric properties of the substrate at different frequencies. Analysis of effects of variation of position and radius of the circular slots was performed to achieve the required return loss characteristics. The position and radius of the circular slots incorporated in ground plane was also optimized. Figure 3 (b) illustrates the measured transmission coefficient (S12) of the MIMO antenna. We see that the two adjacent antenna elements are well isolated and mutual coupling between them is very low. Transmission below -21 dB indicates significant low mutual coupling and good isolation.

b) Peak Gain

The effects of DGS and parasitic element on antenna bandwidth are presented in Figure 3 (c). It presents the variations in gain of the MIMI antenna with DGS and parasitic, MIMI antenna without DGS and with parasitic and MIMI antenna with DGS and without parasitic.



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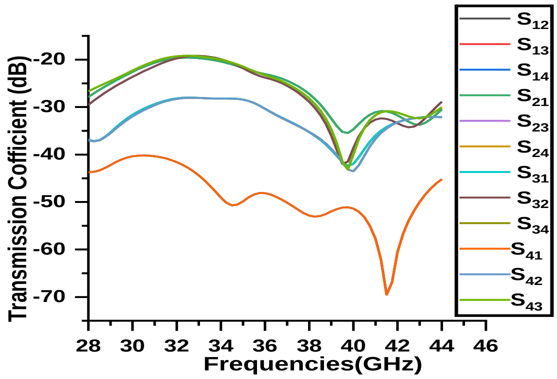

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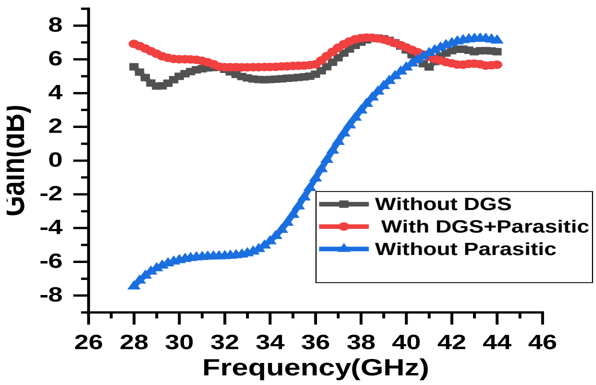

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Figure 3: (a) Comparison of simulated and measured return loss (b) Measured Transmission coefficient of the proposed MIMO antenna (c) Gain of single antenna element, without DGS and without parasitic element

c) Current Density

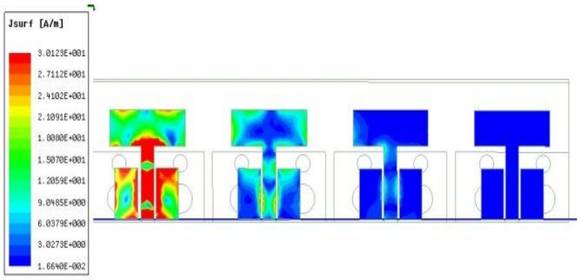
To get an insight of the surface current distribution and the effects of mutual coupling amongst the antenna elements, the current density of antenna was obtained and analysed. Only the first antenna element of the four MIMO was excited, and its current density plot is shown in Figure 4 (a) and Figure 4 (b).

d) Radiation Pattern and Gain

The E and H plane distributed radiation patterns at frequencies 30.5 GHz and 40.1 GHz are shown in Figure 4(c) and Figure 4 (d). Looking at the radiation plot, we see that nearly Omni-directional radiation pattern was obtained in E and H plane. The plot of measured and simulated values of gain shows that for the complete range of frequency the gain is ranging from 7 to 10.1 dB, having a peak gain of 10.1 dB at 38.5 GHz. The measured values of gain matches with the simulated plot are presented in Figure 4(e).

e) Envelope Correlation Coefficient

The independency of any two antenna elements in a MIMO configuration in terms of their performance is determined by the envelope correlation coefficient (ρe). It is computed based on the radiation patterns, antenna polarization, S- parameter and relative phase across any two antenna element in a MIMO configuration. For a set of antenna ports, some numerically estimated values of ρe are depicted in Figure 4(f), where we can observe low values of ρe along with the operating range. It indicates that the antenna elements are well isolated for simultaneous operation.



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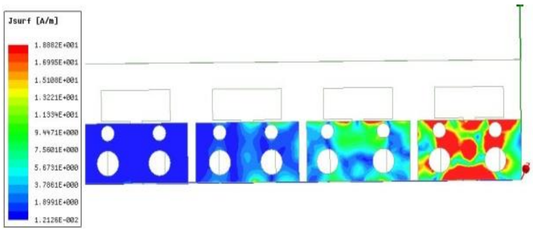

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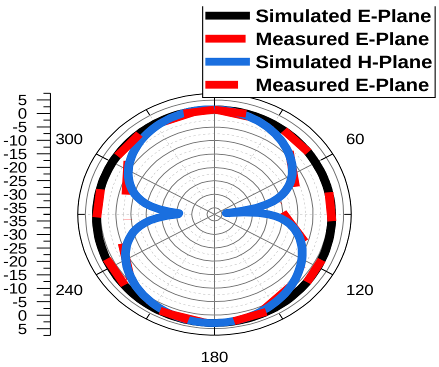

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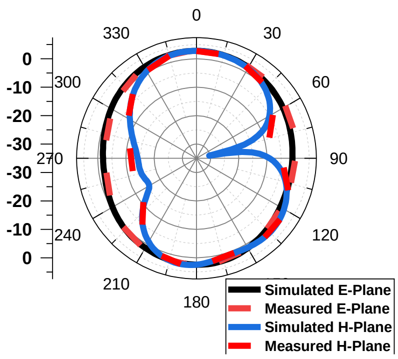

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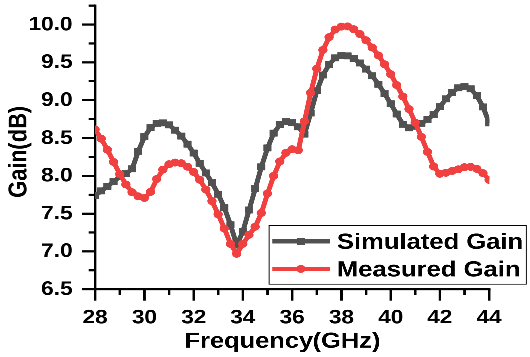

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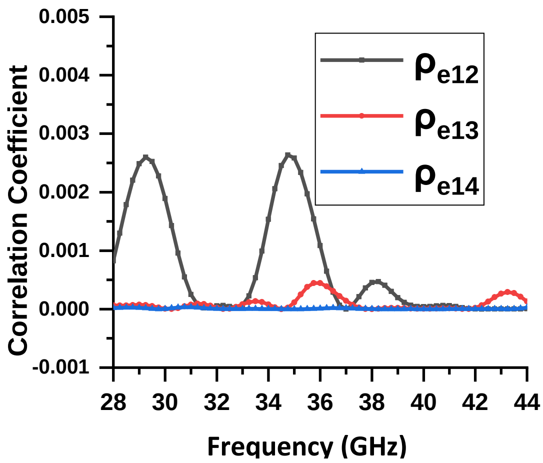

(f)

Figure 4: Current Density of the proposed MIMO antenna at 30.5GHz(a) top (b) ground, (c) Radiation pattern at 30.5GHz (d) Radiation pattern at 40.0 GHz,(e) Gain of MIMO antenna (f) Simulated envelope correlation coefficient of MIMO antenna

IV. CONCLUSION

The proposed MIMO antenna provides a large bandwidth of 16GHz, which is suitable for 5G MIMO applications. The partial ground concept is used in this antenna together along with DGS. The top plane metal has a T-shaped geometry of a single radiating patch along with two parasitic patches on either side of the microstrip feedline. Four T-shaped slots placed together complete the design of proposed antenna. The symmetrical circular slots in the bottom plane metal act as resonating defects and produce multiple resonances. The measured and simulation result shows a bandwidth of 28 - 44 GHz and a peak gain of 10.1 dB at 38.5 GHz having isolation more than 21dB.For validation of simulated design, the performance of the proposed four element MIMO antenna is fabricated and tested, which confirms the lower mutual coupling between the adjacent antennas. The simulated and measured results match with each other.

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