Wide Dual Band MIMO Patch Antenna for Future 5G Applications

Gulzar Ahmad*, Amjad Ullah.

***Abstract*—The 5G Technology is being implemented in the developed countries and its employment in the developing countries will take time. This technology will support high speed data rate and require multiple input and multiple output (MIMO) Patch antenna having a very large bandwidth. The MIMO antennas are located in the close vicinity of each other and their mutual coupling degrades the performance of the antenna. Patch antennas are very popular antennas as they have been successfully applied in aircraft, space technology, mobile communication, biomedical and their demand in future wireless communication is increasing on daily basis. So the bandwidth expansion and the reduction of the mutual coupling of these MIMO patch antennas for its implementation in 5G technology have attracted the attention of the scientists working in the area of patch antenna and wireless communication systems. Procedures have been suggested in literature to improve the bandwidth and reduce the mutual coupling of the MIMO antennas. In this paper, some old techniques in combination with a new technique of augmented ground structure (AGS) are executed to enhance the bandwidth and reduce the mutual coupling between the two elements of the dual band MIMO antenna. Two rectangular patch structures with two parasitic elements are placed side by side.In order to investigate the performance of this MIMO antenna, 1.64 mm thick substrate of Preperm L450and a defected ground structure are used. The dielectric constant of this substrate is 4.5. The substrate of the MIMO antenna is 40mm long and 50mm wide. This dual band MIMO antenna has a large bandwidth of 18GHz in Band-1and a large bandwidth of 13GHz in Band-2.The mutual coupling was retained below the acceptable value of -16dB. The return loss, SWR with respect to voltage, efficiencies, gain, directivity and mutual coupling of both the antennas of this MIMO system has been investigated. It can be efficiently applied in the future 5G technology of wireless communication system.**

***Index Terms*—Return loss, Bandwidth, Gain, VSWR, Mutual Coupling, 5G Application, AGS**

I. INTRODUCTION

The demand for high speed data services initiated a huge research in the field of 5G technology. High data rate mobile communication system, multimedia, IoT, and Intelligent Transportation Systems require the GB/s rat. The 4G technology does not support applications with GB/s rate [1].

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The 5G technology that will support a higher data rate needs electromagnetic wave oscillating with very high frequency ranging from 20GHz to 60GHz. The researchers need to design MIMO antennas with high gain to encounter the losses in the mentioned higher frequency bands. The MIMO antenna at the transmitting and receiving end ensures the availability of the multipath signal at the receiver, increases the channel capacity, improves throughput and enhances the link channel reliability. The throughput of the channel improves by increasing the number of transmit and receive antennas in the MIMO system. Different methods have been elaborated in [2-4] to design patch antennas having high gain. As there are bandwidth constraints in the wireless communication systems, so the researchers are focusing on deployment of the idle spectrum in mm-wave more effectively.

The higher frequency bands have been recommended for 5G technology. The higher frequencies of 28GHz, 39GHz and 60GHz have been suggested for 5G applications [5]. It is expected that MIMO antenna will be used in the future 5G technology as it supports higher data rate and quality of service. In order to improve the range and capacity of any wireless communication system, MIMO antenna is used [6].MIMO antennas support the data rate in the range of gigabits per second in a wireless communication system[7]. The employment of MIMO antennas in the transmitter and receiver of a wireless system improves the channel capacity without increasing the signal to noise ratio. Small size cell networks [8-9], deployment of MIMO antennas [10] and huge bandwidth in mm-Wave bands[11] will support the higher data rates of the future 5G technology. When two or more than two antennas of a MIMO system are placed in proximity, the mutual coupling takes place due to electromagnetic interaction.

The mutual coupling needs to be reduced as it results in an extra power loss [12]. In mutual coupling a fraction of the power radiated by one antenna of the MIMO system is absorbed by another antenna which is an undesirable phenomenon. Each antenna should function efficiently, and it should not absorb the energy radiated by another antenna in its proximity. The parameter that is used to measure the mutual coupling between two antennas of a MIMO wireless system is represented by S_{12} and S_{21}.There are two ports in the proposed MIMO Antenna, so S_{12} stands for the power that is transferred from port 2 to port 1, while S_{21} stands for the power that is transferred from port 1 to port 2. The MIMO antennas work properly in its working band if the numerical value of this parameter is less than -16dB.The easiest way to minimize the mutual coupling is to increase the distance between antennas. This technique improves the isolation on one hand but increases the size of the MIMO antenna on the other hand, which is declared unsuitable for small portable devices.

The mutual coupling between the antennas can be minimized with the help of defected ground structure, addition of parasitic elements and employment of electromagnetic band gap (EBG) structures [13-15]. The EBG structure in the gap between the two antennas increases the complexity of the MIMO antenna and hence its fabrication becomes costly. It is need of the hour to design and analyze a MIMO patch antenna having high performance [16–18]. The reduction in the mutual coupling can be attained on the cost of narrow bandwidth, small gain and low efficiency. A MIMO antenna is designed in [19] for fifth generation technology that has a very low bandwidth of 450MHz as compared to the antenna described in this article.

The future 5G MIMO antennas need to have a wide bandwidth, large gain and high efficiency to cope with the demands of end users. In this paper 2×2 MIMO antenna is designed, using the traditional concept of parasitic elements, defected ground structure and a novel concept of augmented ground structure (AGS). The mutual coupling is reduced, the bandwidth and gain of the antenna is enhanced using the abovementioned techniques.

A. STRUCTURE OF SINGLE ANTENNA

The first step in the design of a MIMO patch antenna is to construct a single antenna and investigate its performance. So, initially a rectangular patch with two parasitic copper elements on the insulator substrate of Preperm L450 using a novel technique of AGS has been constructed. The pictorial view of the patch of this single unit is shown in Fig 1.

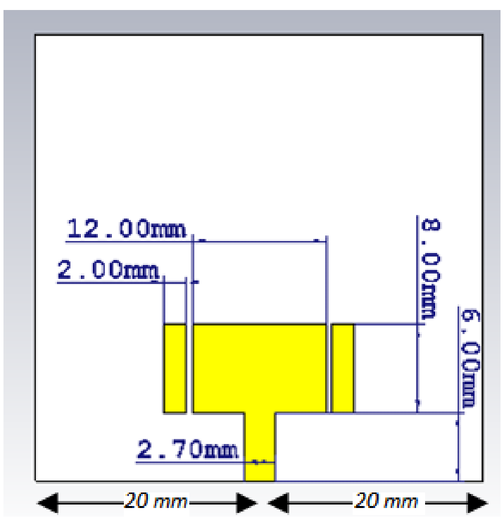

Fig 1: Pictorial View of the Patch of the Antenna

The size of the substrate/ground was 40×40mm². The optimized thickness of the insulator substrate was 1.5mm and the optimized thickness of the conductor of the single unit was 0.035mm. The size of the defect, created in the center of the ground plane of the antenna, was 24×4mm². The pictorial view of the ground of this single unit is shown in Fig 2.

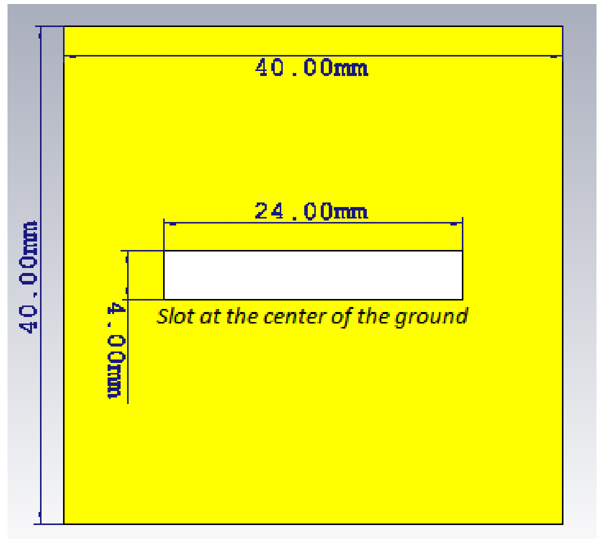

Fig 2: Pictorial View of the Ground of the Antenna

It is evident from Fig 1 that the area of the patch was 12×8mm² and the area of each parasitic element was 2×8mm². A separation of 0.5mm was maintained between each parasitic element and the patch. Microstrip feed line having dimensions of 2.7mm×6mm was deployed to energize this unit. The creation of the two parasitical copper elements, erection of a slot in the center of the ground plane and parametric optimization of antenna's dimensions along with the deployment of a novel method of AGS converted this antenna to dual operation wide band antenna. All the dimensions to reproduce the single unit antenna are illustrated in Table I.

TABLE I
Dimensions of the Single Unit

Parameters	Values
Overall area of the Antenna	40×40mm²
Substrate's Depth	1.5mm
Area of the Copper Patch	12×8mm²
Area of the Parasitical Copper elements	2×8mm²
Distance between Parasitical Copper elements and Copper Patch	0.5mm
Feed's Area	2.7×6mm²
Defect in the Ground	24×4mm²

III RESULTS OF THE SINGLE UNIT

The objective was to design a MIMO antenna having a huge bandwidth in the mm-Wave band. The bandwidth of this single unit is exhibited in Fig 3. It is evident from the figure that this single unit works effectively in two different bands isolated by a narrow frequency gap. A bandwidth of 19GHz and a bandwidth of 11.6GHz were attained by this single unit. The single unit covers the dual bands, 20.55GHz-39.75GHzand 40.32GHz-50GHz. Reflection coefficient (S_{11} dB) is less than -10dB in both bands and a value of -39.61 dB and a minimum value of -41.8dB were observed in this graph. The abovementioned minimum values of the reflection coefficients were recorded at frequencies of 20.89GHz and 47.9GHz respectively. The bandwidths observed in both bands of this single unit are declared huge bandwidths as compared to those mentioned in [20-22].

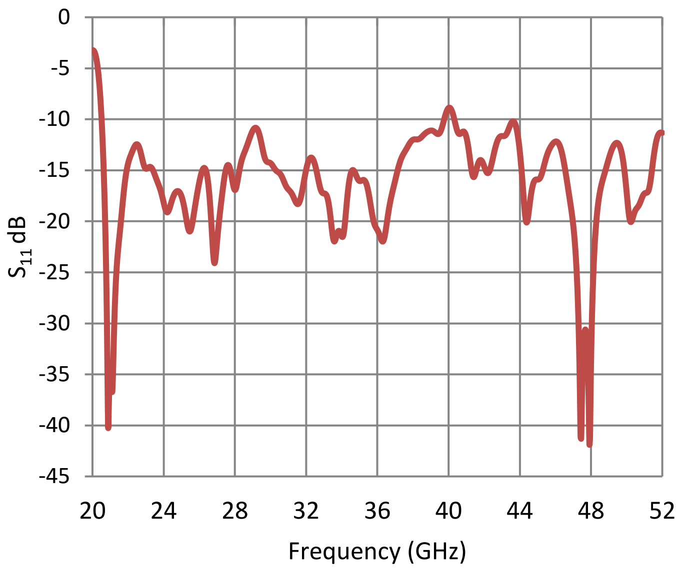

Fig 3: S_{11} dB of the Single Unit

The total efficiency of the single unit is exhibited in Fig 4. The maximum values of 90.9% and 84.1% were observed in Band-1 and Band-2 respectively. The minimum value of 73.6% was recorded in Band -2. Usually, the efficiency of the antenna constructed for the higher frequency bands is low, but this single unit has demonstrated high efficiency in its dual band operation.

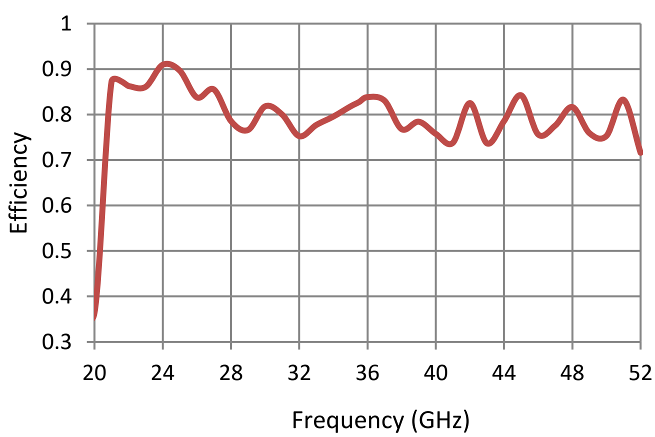

Fig 4: Efficiency of the Single Unit

The graph for the gain of the single unit is displayed in Fig 5. The maximum value of 9.99dB was recorded at the frequency of 29GHz. This maximum value of the gain occurred in Band-1. The minimum value of 6.15dB was recorded at the frequency of 27GHz and this minimum value of the gain took place in Band-1as well.

IV STRUCTREOF MIMO ANTENNA

As it can be seen from Fig 6 that the MIMO antenna presented in this article consists of two units. Adjustments were made in a few dimensions of the antenna to improve its performance in both the bands. The width of the copper ground and insulator substrate was magnified to 50mm and thickness of the insulator substrate was increased from 1.5mm to 1.64mm. It is evident from Fig 6 that the separation between the left edge of the substrate and the left parasitic copper element of the first unit is 4mm. The separation between the right parasitic copper element of the first unit and the left parasitic copper element of the second unit is 7mm. The separation between the left edge of the substrate and the microstrip feed line of the first unit is 11.15mm. The separation between the right edge of the substrate and the microstrip feed line of the second unit is 12.15mm. Finally, the separation between the right edge of the substrate and the right parasitic copper element of the second unit is 5mm. The remaining dimensions of the antenna remain the same as discussed in the preceding section of the antenna. All the dimensions to reproduce the MIMO antenna are illustrated in Table II.

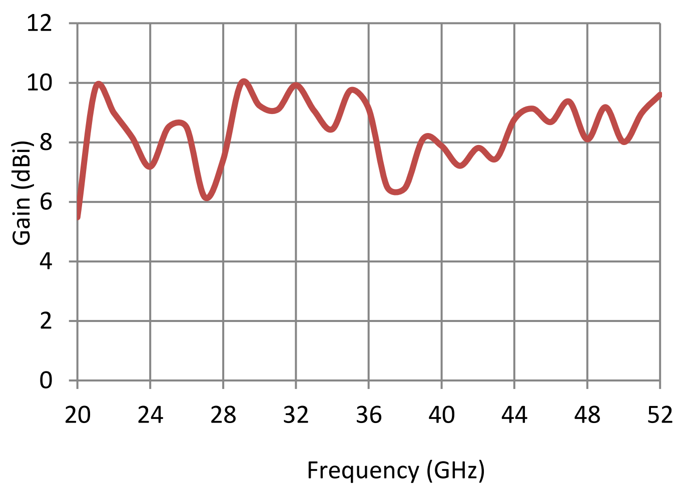

Fig 5: Gain of the Single Unit

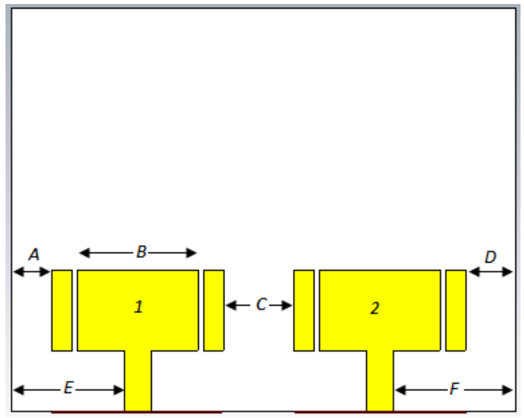

Fig 6: Patch View of MIMO Antenna

The ground view of the MIMO antenna is shown in Fig 7. There is no difference between the ground of the single unit and the MIMO antenna.

V RESULTS OF THE MIMO ANTENNA

To explore its possibility of implementation in the future 5^{th} generation technology the MIMO antenna was simulated using the CST software. The bandwidth of the 2×2 MIMO is exhibited in Fig 8. It is evident from the figure that this structure works efficiently in two different bands isolated by a narrow frequency gap. It has demonstrated better results than the single unit.

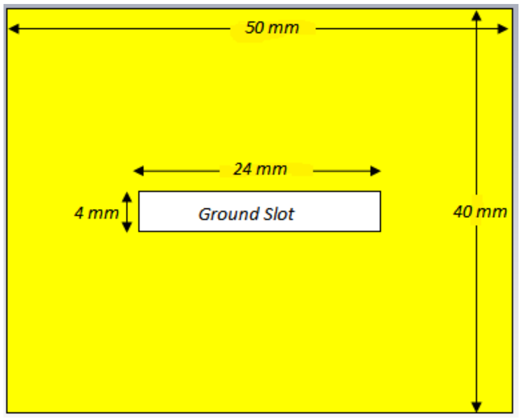

Fig 7: Ground View of MIMO Antenna

TABLE II
Dimensions of the MIMO Antenna

Parameters	**Values**
Overall area of the Antenna	40×40mm^2
Substrate's Depth	1.65mm
Area of the Copper Patch	12×8mm^2
Area of the Parasitical Copper elements	2×8mm^2
Distance between Parasitical Copper elements and Copper Patch	0.5mm
Feed's Area	2.7×6mm^2
Defect in the Ground	24×4mm^2
A	4.00mm
B	12.00mm
C	7.00mm
D	5.00mm
E	11.15mm
F	12.15mm

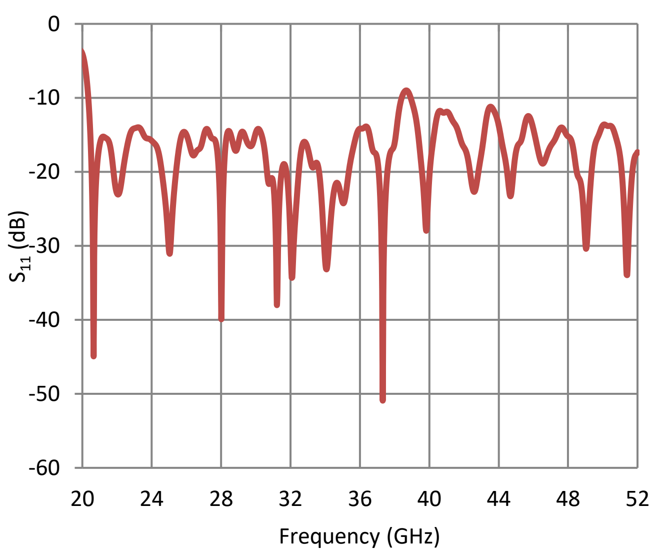

Fig 8: S_{11} dB of the 1st Unit of MIMO Antenna

A bandwidth of 18GHz and a bandwidth of 13GHz were attained by this MIMO structure. It covers both the huge bands, 20.34GHz-38.40GHz and 38.98GHz-52GHz. S_{11} dB is less than -10dB in both bands. The minimum values of -44.91 dB, -31dB, -39.8dB, -37.9dB, -34.2dB, -33.14dB and -50.9 can be observed in Band-1. The abovementioned minimum values of the reflection coefficients were recorded at frequencies of 20.65GHz, 25,02GHz, 28GHz, 31.21GHz, 32.1GHz, 34GHz and 37.31GHz respectively. Minimum value of -27.9dB at the frequency of 39.8GHz, -30.38dB at 49GHz and -33.93dB at 51.4GHz were observed in Band-2. All these values justify the best matching of the antenna in both the bands.

The bandwidths of the 2nd unit is displayed in Fig 9. The 2nd unit has attained the same bandwidths. A minor difference can be found between S_{11} dB and S_{22} dB. The MIMO antenna has attained huge bandwidths in both the bands. The bandwidths observed in both bands of this antenna are declared huge bandwidths as compared to those mentioned in [20-22]. VSWR of 1.005 and 1.008 were attained by both the units. The mutual coupling was decreased by the optimizations of the parameters of the antenna, creation of two parasitic elements and creation of the slot in the ground. The mutual coupling was retained below the acceptable value of -16dB as shown in Fig 10. The total efficiency of the MIMO structure is exhibited in Fig 11. The maximum values of 86.55% and 63.96% were observed in Band-1 and Band-2 respectively. As discussed earlier, the efficiency of the antenna constructed for the higher frequency bands is low, but this MIMO antenna has achieved remarkable efficiency in its dual band operation. The graph for the gain and directivity of the structure is displayed in Fig 12. The maximum value of 9.32dB was recorded at the frequency of25GHz. This maximum value of the gain occurred in Band-1.

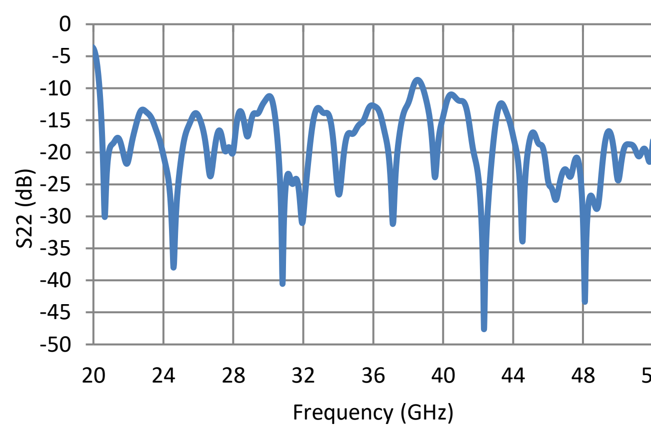

Fig 9: S_{22} of the 2nd Unit of MIMO Antenna

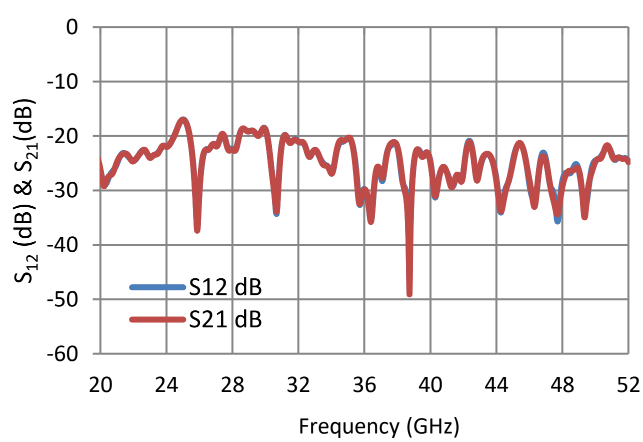

Fig 10: S_{12} dB and S_{21} dB of MIMO Antenna

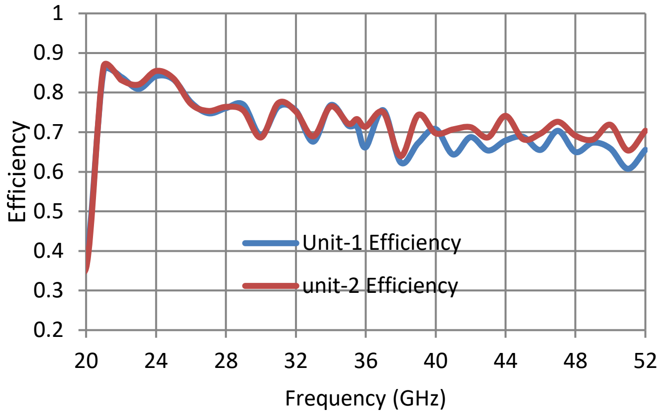

Fig 11: Efficiency of the MIMO Antenna

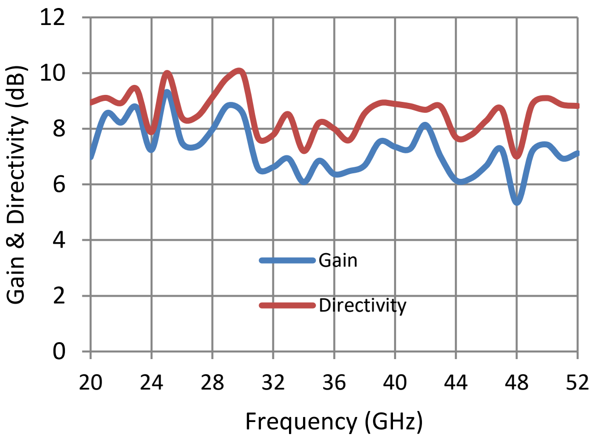

Fig 12: Gain and Directivity of the MIMO Antenna

The minimum value of 5.89dB was recorded at the frequency of 44GHz and this minimum value of the gain took place in Band-2.

TABLE III
Comparison with Previous Work

Article	Bandwidth	Mutual Coupling	Design Complexity
[23]	5.1GHz	-24dB	Very Complex
[24]	1GHz	-19dB	Very Complex
[25]	5.37 GHz	-20d**B**	Very Complex
[26]	6GHz	-45dB	Very Complex
[27]	2.6GHz	-----	Complex
[28]	5GHz	----	Complex
[29]	2.65GHz	-34dB	Complex
This Work	18GHz and 13GHz	-48dB	Very Low

VI COMPARISON WITH PREVIOUS WORK

As discussed earlier a MIMO antenna designed in [19] for fifth generation technology has a very low bandwidth of 450MHz as compared to the antenna described in this article. Similarly, single element antennas have been elaborated in [20-22] and all of them have lower bandwidth and gains than the presented antenna. The comparison with other works [23-29] is presented in Table III, which justifies the better performance of this antenna and secondly the design is very simple so its fabrication will be easy and economical. The mutual coupling has been reduced using augmented ground/substrate structure.

VII CONCLUSIONS

MIMO antennas will be deployed in the future 5G technology. The performance improvement of these antennas to cope with the requirements of the mentioned technology is still in the research phase. Bandwidth enhancement and the reduction of the mutual couplings between the antennas are the two major challenges for the scientists. Various methods have been recommended in the literature to enhance its bandwidth and reduce its mutual coupling. To avoid the complexity and extra cost of the design, the EBG structure is not used in the antenna presented in this article. The implementation of the traditional techniques of DGS and parasitic elements in combination with a novel technique of the deployment of larger size ground/ substrate (AGS) as compared to the size of the patch has achieved novel bandwidths of 18 and 13GHz in two operating bands. Thus, an overall bandwidth of 31GHz has not been claimed in the literature. Other parameters of the antenna such as gain, and efficiency have been improved as well. The mutual coupling between the two antennas has also been reduced. A 2×2 MIMO structure was successfully made on an insulator substrate of Preperm L450 with relative permittivity of 4.5. The mutual coupling between the units was maintained well below the level of -16dB without deploying any complicated structures of EBG. The total efficiency of 86.55% and 63.96% were observed in Band-1 and Band -2 respectively. The maximum value of gain is 9.32dB the frequency of 25GHz and it occurred in Band-1. The minimum value of gain is 5.89dB at the frequency of 44GHz and this minimum value of the gain took place in Band-2. This antenna can be deployed in future 5G technology.

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