A Novel MIMO Patch Antenna for 5G Applications

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Abstract. In this paper, a new MIMO patch antenna is proposed, the proposed antenna consist of patch with certain dimensions in the top layer of FR-4 dielectric substrate, and ground plane in the bottom of it, this antenna is feeding by microstrip feed line with 50-ohm characteristic impedance. The dimensions of the proposed antenna are (50 × 50 × 1.6) mm3, the FR-4 epoxy substrate has relative dielectric constant \(\varepsilon_r = 4.3\), loss tangent \(\tan (\delta) = 0.025\). This antenna is realized a bandwidth of 4.337 GHz (24.22 – 28.557) GHZ and gain (3.68) dBi which is compatible with 5G applications. Some modifications were done in the ground plane and some of slots are etched on the patch to achieve the desired gain and bandwidth, all dimensions of these slots were chosen by using sweep parameter method to achieve the optimum value of them. The simulation results are obtained using CST software. And the proposed antenna is manufactured in the Electronic Manufacturing Center at the Ministry of Science and Technology, also the vital parameters are measured, a good agreement between simulation and measured results are achieved.

1. Introduction
The exponential increase in wireless data rate (up to 5,000 times by 2030[1]) and its unusual growth has led to efforts and development of 5G architecture requirements that are expected to include data rate increases over 4G systems[2] Which may reach 10 G bps plus reduce the latency to less than 1 ms, The high density of the network will transform the structure of the traditional network from a group of large cells covering large areas to a large number of small cells that provide higher capacity and better services to users and reduce transmission power as the transition to millimeter waves is another modern through which to benefit from High bandwidth and very high data rates but these high frequencies will impose conditions on this system due to signal blocking and attenuation. Therefore, multiple antennas such as MIMO antenna become a necessity in communication standards as they enable the transmitted signal parameters Adaptable to address the effects of the wave’s millimeter[3]. 5G (5th generation) is a modern wireless technology expected to be deployed by 2020, a key element of 5G technology is the MIMO antenna system to achieve 10-100 times of bandwidth compared to 4G and LTE communication systems[4]. In addition to the MIMO antenna, other techniques that reduce interference are multicell processing[5], and interference alignment[6].Using these techniques (multicell processing and interference alignment) the cell size is reduced by fixing fimto cells or small cells[7] but this will increase the cost of additional equipment in addition to increasing interference, therefore, the most...
appropriate option is to use MIMO technology this technique is also known as Full Dimension MIMO, Hyper MIMO, and ARGOS.

Multiple antennas are used for transmitting and receiving to achieve their desired objectives of increasing data rate and bandwidth and mitigating multipath effects[8].

On the other hand, the antenna used to increase the capacity of the MIMO channel is a microstrip antenna[9] which has several advantages including low profile, low weight, conformal to the surface of objects and easy production. A large number of microstrip patches to be used in wireless applications have been developed; various shapes such as square, rectangle, ring, disc, triangle, elliptic, pentagonal[10].

The proposed antenna is MIMO array printed patch antenna of dimensions (50×50×1.6) mm\(^3\); all antennas are printed on the front surface of FR-4 dielectric substrate (relative permittivity 4.3 and loss tangent 0.025.) and the ground plane is printed on the back surface of FR-4 dielectric substrate, the geometry of radiator is rhombus but by using parametric study it has unequal length. A 50 Ω microstrip feed line is connected at the lower edges of each radiators, to improve the isolation by making all ports orthogonal in 90 degrees, the proposed MIMO antenna was designed and simulated using CST Studio Suite.

2. MIMO theory
MIMO technology is a technology based on the presence of multiple antennas in the transmitter and receiver sides to send and receive many data simultaneously as shown in Figure 1.

![Figure 1. MIMO- multiple input multiple output.](image)

With MIMO technology, many benefits will be available[11]:
1- Increase the data rate because using multiple antennas enables the transmission of many data simultaneously and thus processing more than one user.
2- Enhanced Reliability because there were many antennas, there were many independent paths through which the radio signal could propagate.
3- Improve energy efficiency as the base station concentrates its emitted energy in the direction specified where the terminals is located.
4- Reduced interference because the base station can purposely avoid transmitting into directions where spreading interference would be harmful.

Channel capacity can be expressed in accordance with Shannon's law

\[
C = B \log_2 \left(1 + \frac{S}{N}\right)
\]

(1)

The bandwidth is directly proportional to the channel capacity so it is the key factor in achieving the maximum required data rate, SNR is the determining factor for the quality of the transmission, i.e. the
speed of data transfer in the cell, Thus, MIMO systems can increase channel capacity without having to increase bandwidth[12]. MIMO capacity increases linearly by increasing the number of antennas while Single-Input Single-Output (SISO), Single-Input Multiple-Output (SIMO) and Multiple-Input Single-Output (MISO) systems all increase only logarithmically[13]. A single path is providing between each pair of transmitter and receiver, these pair send the same information in different paths, that's mean a multiple independent replicas of data can be achieved at the receiver side, that give more reliable communication[14].

3. Antenna Design
The microstrip patch antenna is a single layer design which consists generally of four parts (patch, ground plane, substrate, and the feeding part)[15], the patch is a very thin radiating metal strip (or array of strips) which are placed on one side of the insulating substrate, the metallic patch is normally made of thin copper foil. The ground plane is the same metal located on the other side of the substrate, the substrate is used for the spacing between the patch and the ground plane, the front and back view of proposed antenna are shown in Figure 2, the FR-4 is chosen to the substrate of proposed antenna with height of 1.6 mm, 4.3 dielectric constant and 0.025 tangent loss, The CST microwave studio tool was used. A metal patch of different length and width (to achieve matching) was connected to 50Ω feed line. With dimensions of feed line were Li=8 mm and Wi =4 mm, as shown in Figure 2.

![Figure 2. Single antenna (a) front view (b) back view](image)

4. Simulation Result
The most important parameter to be considered is the maximum transfer of power (matching of the feed line with the input impedance of the antenna), Where S11 represent the amount of energy sent to the amount of energy reflected Therefore, a graph of S11 of an antenna versus frequency is called its input reflection coefficient curve as shown in Figure 3, Gain of an antenna is defined as its ability to concentrate the radiated power in a given direction or conversely to absorb effectively the incident power from that direction (which is around (2.31 dbi) for single patch antenna).
Figure 3. Simulated S11 of the single patch antenna resonating at 26GHZ. Radiation pattern is one of the important parameters which distinguishes each antenna from another. From simulated result it is obvious that the proposed antenna array has omnidirectional patterns and dips, and it’s acceptable throughout the operating bandwidth. As shown in Figure 4.

Figure 4. Single patch antenna radiation pattern at 26 GHz, $\varphi=90^\circ$

The Figure below show that gain characteristic for single patch antenna.

Figure 5. Gain of single element antenna

Since the array method improves the behavior of the microstrip patch antenna, it will increase the array elements to four to demonstrate how much the excess number of elements will enhance the
resulting antenna's performance, it is important to be compliant for the next generation of mobile communication (5G) in the proposed design of 4 elements. The proposed antenna consists of four microstrip antennas, as shown in the Figure 6 front and back view, the table (1) shows the geometric dimensions for the suggested antenna and as shown in Figure 7.

In the proposed MIMO antenna, four antennas are rotated to reduce the distance and maintain the small size of the antenna, the increase in the number of antennas resulting from an increase in gain and bandwidth, the distance between each antenna is 5 mm according to \( \frac{\lambda}{2} \) to reduce the interference and fading effect.

![Figure 6. Proposed four array element (a): front view (b): back view](image)

**Table 1. Proposed dimension for MIMO array antenna**

| Parameter | Value in (mm) | Parameter | Value in (mm) | Parameter | Value in (mm) |
|-----------|---------------|-----------|---------------|-----------|---------------|
| L         | 50            | W         | 50            | H         | 1.6           |
| Lg        | 12            | Wg        | 17            | Wf        | 4             |
| Lf        | 8             | Ws        | 3             | Ls        | 4             |
| Xfp       | 19            | Yfp       | 18            | Yg        | 3             |

![Figures 7. The proposed antenna (a) single (b) MIMO array](image)

Whereas, Figure 8 shows the target bandwidth required in 5G applications
Figure 8. Simulated S11 of the MIMO array patch antenna resonating at 26GHz

Figure 9. MIMO array antenna radiation pattern at φ=90°

Figure 10. 3D radiation pattern for proposed MIMO array antenna.
From the results of simulation, the gain of proposed antenna with four elements increased by 1.37 dBi as compared with the single element antenna, where the reference antenna resonates at 26 GHz and its gain is 2.31 dBi, it is clear that the gain is enhanced to 3.68 dBi at the same frequency.

The performance of the antenna is influenced by several factors, including the geometry of the antenna and electrical parameters, the most important, dimensions of the antenna and the dimensions of the slots in each of the ground plan and patch plan.

The parameter optimized for the desired band is $y_3$, which represents the length of copper found on the ground as shown in Figure 11 a, b. it will get the band shown in the Figure 12.

![Figure 11. Ground before and after optimized.](image)

![Figure 12. Simulated s-parameter of the patch antenna with different values of $y_3$.](image)

In the Figure above, the value of the $y_3$ parameter has been changed for several values to obtain the target bandwidth required for 5G applications. Initially the value of the parameter $y_3 = 16$, but after adjustments using the sweep parameter it is found that the best value is 20 mm because the other values don’t satisfy the desired bandwidth.

The other improved parameter is $y_{10}$ which represents the patch with feeder connection point as shown in Figure 13, the band obtained from changing this parameter is shown in the Figure 14. Therefore the best value obtained is when $y_{10} = 18$ mm i.e. when obtaining the largest possible matching.
Figure 13. The location of the patch connection to the feed line (a) $y_{10}=18$ (b) $y_{10}=25$

Figure 14. Simulated s-parameter of the patch antenna with different values of $y_{10}$

As for the length of the substrate is simulated at two different length 25 mm and 17 mm but there was little improvement in the s-parameter and the best value was chosen as shown in Figure 15a, b.

Figure 15. Simulated s-parameter of patch antenna for different length of substrate

Therefore, the optimum parameters used to design the antenna are shown in Table 2 below:
Table 2. Optimal design parameters of patch antenna

| Parameter | Value in mm | Parameter | Value in mm |
|-----------|-------------|-----------|-------------|
| L         | 25          | W         | 25          |
| Y3        | 20          | Y10       | 18          |

The main purpose is to increase the band so that it suits the frequencies of the fifth generation and also increase user capacity.

The Co-reflection Coefficients (S41, S42, S43, S31, S32, S34, S21, S23, S24, S12, S13, S14) \( \leq -20\) dB and that represent amount of isolation between each ports and must be greater than or equal to -20 dB in order to prevent that each port affects the other as shown in Figure 16.

Figure 16. The co-reflection coefficient of MIMO Array Antenna

The gain from the single antenna is around (2.31) dBi and MIMO array antenna is (3.68) dBi, the proposed antenna is manufactured as shown in Figure 7a,b and the results of the practically manufactured antenna are shown in Figure 18, the sensible reflection coefficient versus frequency is 20GHz, due to the reality that there is no vector network analyzer extra than 20 GHz on hand in the lab, a slight difference in process results and simulation has been found, due to the feeder soldering as well as the connections of the vector network analyzer.

Figure 17. The practical proposed MIMO array antenna (a) front view (b) back view
The group time delay of the proposed antenna is evaluated and it has approaches to zero for the required band (24.25 – 27.5) GHz as shown in Figure below.

The values of the real part of the impedance in the ideal antenna should be 50Ω and the imaginary part must be zero to get the best matching. The real part of the manufacturing antenna is around (62.1Ω) and imaginary part is around (5.6Ω) These are acceptable values and are close to ideal state as shown in Figures. 20 and 21 respectively.
When designing MIMO antennas the main parameter is envelope correlation coefficient (ECC), recognize the correlation between every two ports MIMO antennas should have low ECC to indicate that channels are independent. The value ECC should be very low and it varies from 0 to 1\(^{[16]}\), as shown in Figure 22 for the manufacturing antenna.

5. Conclusion
A new design of MIMO patch antenna was proposed to be used in 5G applications, the dimensions of this antenna are \((50 \times 50 \times 1.6)\) mm\(^3\), the substrate material which is used is FR4 with \(\varepsilon_r=4.3\), loss tangent \(\tan(\delta)=0.025\), the proposed antenna is achieved a good bandwidth of 4.337 GHz and gain of 3.68 dBi, and these results are compatible with 5G requirements. Some slots are etched in patch to satisfy these requirements, also the ground plane is modified for the same goal. The designed antenna is manufactured in the Electronic Manufacturing Center at the Ministry of Science and Technology,
Baghdad, Iraq. the manufactured antenna shows a good agreement between measured and simulation results.

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6. References
[1] 2015 5G Vision. (USA: Samsung Electronics Co., Ltd.)
[2] 2014 Evolutionary & disruptive visions towards ultra-high capacity networks. In: IWPC International Wireless Industry Consortium, (USA)
[3] Misilmani H M E and El-Hajj A M 2017 Massive MIMO Design for 5G Networks: An Overview on Alternative Antenna Configurations and Channel Model Challenges. In: 2017 International Conference on High Performance Computing & Simulation (HPCS), pp 288-94
[4] Tong W and Peiying Z 2016 Huawei - 5G: A Technology Vision Huawei Technical Publications
[5] Gesbert D, Hanly S, Huang H, Shitz S S, Simeone O and Yu W 2010 Multi-Cell MIMO Cooperative Networks: A New Look at Interference IEEE Journal on Selected Areas in Communications 28 1380-408
[6] Maddah-Ali M A, Motahari A S and Khandani A K 2008 Communication Over MIMO X Channels: Interference Alignment, Decomposition, and Performance Analysis IEEE Transactions on Information Theory 54 3457-70
[7] Hoydis J, Kobayashi M and Debbah M 2011 Green Small-Cell Networks IEEE Vehicular Technology Magazine 6 37-43
[8] Saad A A R and Mohamed H A 2019 Printed millimeter-wave MIMO-based slot antenna arrays for 5G networks AEU - International Journal of Electronics and Communications 99 59-69
[9] Rao A, Ankaiah N and Cheruku D 2016 Antenna Performance Improvement in Elliptical Array Using RMI Method of Mutual Coupling Compensation Journal of Electromagnetic Analysis and Applications 08 8-21
[10] Sabri H and Atlasbaf Z 2008 Two Novel Compact Triple Band Microstrip AnnularRing Slot Antenna for PCS- 1900 and WLAN Applications 5 87-98
[11] Larsson E G, Edfors O, Tufvesson F and Marzetta T L 2014 Massive MIMO for next generation wireless systems IEEE Communications Magazine 52 186-95
[12] Foschini G J and Gans M J 1998 On Limits of Wireless Communications in a Fading Environment when Using Multiple Antennas Wireless Personal Communications 6 311-35
[13] Langton C and Sklar B 2011 Tutorial 27 - Finding MIMO
[14] Lzhong Z and Tse D N C 2003 Diversity and multiplexing: a fundamental tradeoff in multiple-antenna channels IEEE Transactions on Information Theory 49 1073-96
[15] Aboshosha A, El-Mashade M and Hegazy E 2018 Design and Analysis of Rectangular Microstrip Patch Array Antenna WSEAS Transactions on Communications 17
[16] Kurekar P R and Khade S S 2017 Design and implementation of MIMO antenna for WLAN application. In: 2017 International Conference on Communication and Signal Processing (ICCSP), pp 0477-80