Antenna Design and Simulation for 2x2 MIMO System for IEEE-802.11a Application.

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Abstract- **The performance and advantages of multi-input multi-output (MIMO) antennas such as offering significant increase in data throughput and link range without additional bandwidth or increased transmitted power. Primary reason to use multiple antennas is to improve link quality and reliability. This is important especially for worst channel conditions like multipath fading, shadowing, etc. MIMO techniques are the most important advancements in recent wireless systems. They are a critical part of important standards such as IEEE 802.16, 802.11 and 4G LTE Technologies. The MIMO technology has attracted attention in wireless communications. In this paper, a compact (2x2) MIMO antenna system, The reduction of mutual coupling between the two antenna elements is achieved by using a simple defected ground structure (DGS) between them to limit the surface waves between them. The distance between the two antenna elements is only 0.3$\boldsymbol{\lambda}$ mm. The proposed antenna works at 5.8 GHz for wireless local area network (WLAN) applications. The proposed structure has a rectangular shape using FR-4 substrate with relative permittivity of 4.4. The resulted MIMO antenna is found to have a low mutual coupling of about -20.66 dB. The antenna also has a wide relative bandwidth of 18.75%, high total efficiency of 89.5% and acceptable realized gain of about 5.10 dB. The simulation of the proposed antenna has been carried out using Ansoft HFSS and MATLAB software.**

Keywords – Multi Input Multi Output (MIMO), Defected Ground Structure (DGS) , Return Loss (S).

I. INTRODUCTION.

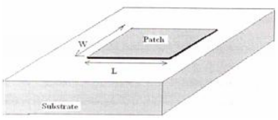
In the past years, wireless communications have grown very fast specially for WLAN communications, due to the different techniques which have been used to increase the channel capacity by increasing the data rate transform and to reduce the probability of error [1].One of the important techniques used for this purpose is the multiple-input multiple- output (MIMO) antenna systems, which utilize the advantages of multiplexing gain and diversity gain [2]. However, these systems have some disadvantages, especially the high mutual coupling that presents between the MIMO elements. The mutual coupling can be attributed to two reasons; the electromagnetic interaction of the elements or the surface current flowing from one element to the other or both [1]. Mutual coupling affects the MIMO antennas characteristics by degrading the impedance matching, reducing the efficiency, decreasing the capacity of the channel, increasing the correlation, increasing the coupling power and reducing the radiated power [3-4].

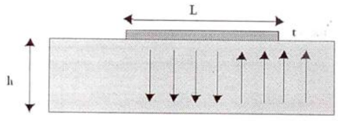
Wireless communication spectrum is a scarce resource and hence imposes a high cost on the high data rate transmission. Fortunately, the emergence of a multiple antenna system has opened another very resourceful dimension space, for information transmission in the air. It has been demonstrated that multiple antenna system provides very promising gain in capacity without increasing the use of spectrum, reliability, throughput, power consumption and less sensitivity to fading. Hence leading to a breakthrough in the data rate of wireless communication systems. Since then, MIMO system has become one of the major focuses in the research community of wireless communications and information theory as in [1].

Recently, microstrip antennas have been one of the most innovative topics in antenna theory and design and they increasingly found applications in a wide range of modern microwave systems [1]. This paper presents an overview of the basic characteristics of microstrip antennas in the array and MIMO forms. In addition, a new antenna configuration for improved performance is also discussed.

Microstrip antennas are mostly thin metallic patches of diverse shapes etched on dielectric substrates of height h Fig. 1, .The thickness of thin radiating patch ($t << \boldsymbol{\lambda}_0$, where $\boldsymbol{\lambda}_0$ is the free-space wavelength), the metallic strip (patch) occupied a small portion of a wavelength ($h << \boldsymbol{\lambda}_0$, usually $0.003\boldsymbol{\lambda}_0 \leq h \leq 0.05\ \boldsymbol{\lambda}_0$) above a ground plane. The microstrip antennas are suitable in the GHz range (f > 0.5 GHz). For frequencies lower than this, the problem of large dimensions will appear. The substrate with height h comes with various relative permittivity ε_o and the range is ($2.2 \leq \varepsilon_o \leq 12$). From Fig 1, it can be deduced that when the value ε_o increased, the resonant frequency decreased [2].

The substrates that are most desirable for good antenna performance are thick ones, whose dielectric constant is in the lower end of the range because they provide better efficiency.





(a) Top view (b) Side view

Fig 1. Microstrip antenna, (a) top view (b) side view

In this paper, we presents the basic characteristics and structure of a microstrip antenna, modeling and analyzing the behavior of a two element rectangular microstrip patch antenna array then using to construction of MIMO antenna

Received July 2019, Received in received from August 2019, Accepted October 2019, and Published July 2020

for IEEE-802.11a. Configurations of a symmetrical 1×2 patch array have been analyzed and an optimum frequency range of the patch antenna array has been reached. The antenna provides frequency close to the designed operating frequency with an acceptable directivity and gain. When antenna structure is closely spaced, the return loss improves. It has been shown that with the increasing array spacing, the gain of the antenna reduces significantly.

II. Microstrip Antenna Analysis

There are many methods of microstrip antenna analysis. However, four famous methods are used widely. Their names are transmission line model, cavity model, generalized cavity model, and multiport network model. The transmission line model will be used because of the square and rectangular microstrip, patch antennas are simple in shape and structure, which means they are easy to be analyzed.

Transmission line method is the easiest method compared to the rest of the methods. This method represents the rectangular microstrip antenna as an array of two radiating slots separated by a low impedance transmission line of certain length as shown in Fig. 2, [2].

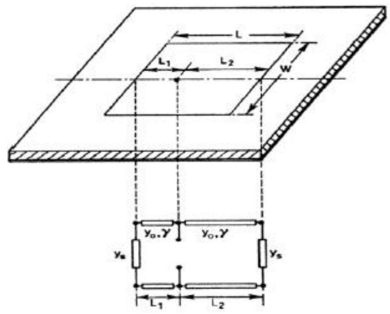


Fig 2. Equivalent circuits for typical feed transmission line model.

The Performance of the microstrip antenna depends on its dimensions. Depending on the dimensions, the operating frequency, radiation efficiency, directivity, return loss and other related parameters are also influenced. For an efficient radiation, the practical width of the patch can be written as [3].

$$W = \frac{c}{2f_r\sqrt{\frac{(\varepsilon r+1)}{2}}} \quad (1)$$

$$L = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L \quad (2)$$

Where

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-\frac{1}{2}} \quad (3)$$

$$\Delta L = 0.412h\frac{(\varepsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right))}{(\varepsilon_{reff}+0.258)\left(\frac{W}{h}+0.8\right)} \quad (4)$$

and the ground plane are:

$$W_g = 6.h + W \quad (5)$$

$$L_g = 6.h + L \quad (6)$$

where f_r is the resonant frequency, L and W are the length and width of the patch element respectively and ε_r is the dielectric constant.

III. Antenna for IEEE-208.11a Applications (5.8 GHz)

Based on the previous discussions and analysis of microstrip antenna, we will design a microstrip antenna to be used for IEEE802.11a technology applications. A preliminary model based on this type of antennas was proposed. This patch was designed on a stacked layer of FR4 material and fed by a microstrip line. The operating frequency of the IEEE802.11a band is 5.8 GHz. This section discusses such geometry and establishes some of the design parameters that directly apply to the final model. The patch is printed on top of the first FR4 substrate layer (ε_r=4.4, thickness=1.6mm).

The antenna is shown in Fig 3, whose dimensions were calculated according to the transmission line model equations as mentioned in above section and By using MATLAB for patch dimensions calculation. The antenna is designed on a low-cost FR4 substrate. It is fed by a microstrip line, which can be easily integrated on the same substrate. The dimensions of the single patch has been designed, and they length (L=15.73 mm) and width (W= x11.75 mm). The antenna can be easily fabricated at a very low cost. The simulation of the antenna is created by using HFSS software.

After simulation and optimization using HFFS Software, the final dimensions identified as shown in the Fig. 3,.

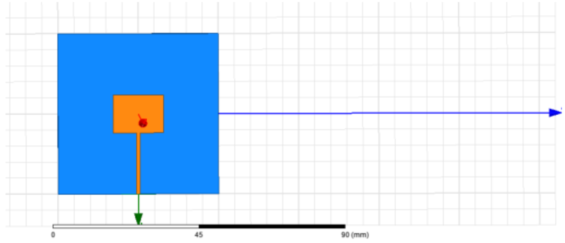


Fig 3. 3D Geometry of a 5.8 GHz microstrip antenna.

The published structure is carried out in HFSS. The necessary simulations are carried out to obtain the scattering parameters.

Simulation results for return loss S11 values and 3D gain and directivity pattern are illustrated in Fig. 4 and Fig. 5, respectively. The geometry of antenna designed simulation is performed. At the resonant frequency of 5.8 GHz the design is simulated in the frequency range of 5.69 to 5.83 GHz (under -10 dB) with -10.9 dB, as shown Fig. 4, it is quite clear that this operating band meet the design requirements of IEEE802.11a standard operating frequency.

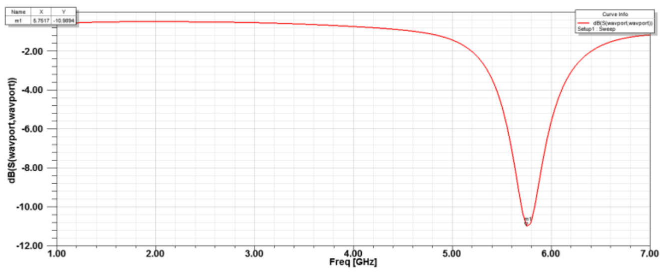


Fig 4. Return loss Vs. Frequency plot of microstrip patch antenna.

A single element microstrip patch antenna is a structure usually designed for low power applications. It

Received July 2019, Received in received from August 2019, Accepted October 2019, and Published July 2020

also has the limitation of low gain, narrow bandwidth and loss directive as shown simulation results. For applications where the requirements are high gain and high directivity in compact and conformal devices, to increase the bandwidth, directivity and gain, the most common method is using multi-elements which are known as array. Cost is one of the key factors in choosing microstrip patch antenna as the array element, because it is cheap and easily available. Microstrip patch antenna arrays are highly popular for their significance in beam scanning and radiation field focusing. This antenna is designed, discussed and analysis in the next section.

IV. DESIGN 1X2 MICROSTRIP ANTENNA ARRAY FOR IEEE802.11A

One of challenge in designing a antenna is to design compact, low-cost, small size antennas and increase gain. The microstrip antenna has been widely applied because of its several advantages over conventional microwave antennas. Microstrip antenna array is widely used due to its several advantages, such as low profile, light weight, and low cost, etc. However, microstrip antenna suffers from low gain, low efficiency, and low power handling capability. Various broadband techniques have been reported using multilayer or stacking the patches. High-gain antenna is usually realized by using either parabolic reflectors or line fed antenna arrays. In this section, the high gain antenna array using 1x2 elements and excited with fed network is proposed.

A- Antenna Design

The design of the proposed array starts with a design of a conventional antenna used to operate in IEEE802.11a band (centered at 5.8 GHz). The optimization geometry used was a rectangular patch with inset microstrip fed line, as shown in Fig. 5,. The microstrip fed line is used to improve the impedance matching between the element and the feed line. The dimensions of the one patch are L = 14.7mm, W =11.3 mm. The an inset feed is obtained through a microstrip line with 13.8 mm x 1.7. The two elements of antenna are combined together with small distance between them as shown Fig. 5,. The distance between the center of two elements has been achieved to be only 0.3 $\boldsymbol{\lambda}$., since it facilitates the integration of the array with other RF circuits. The substrate used was the FR4 with ε_r= 4.4, and h = 1.6 mm, Fig. 6,illustrates the geometry of the array with all dimensions used and the discontinuities in feed network.

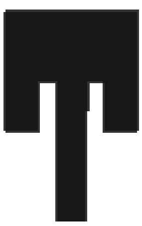


Fig 5. Optimization of single patch antenna geometry used in the array.

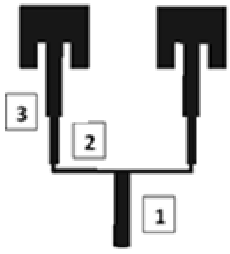


Fig 6. Proposed 1x2 array geometry microstrip antenna.

B- The feed network

The feed network of the array was designed for the signal can reach the antennas in a same way. For the distribution of the equalized signal to both elements of the array, some discontinuities have been incorporated in feed lines that make up the network. The discontinuity with the number (1) is called T-junction and it is, perhaps, one of the most important discontinuities of devices used in microstrip. The T-junction is designed to divide equally the signal to both elements of the array. The (2) known as impedance transformer is intended to obtain an impedance matching of the microstrip lines with different impedances.

Table 1. Dimensions parameters of designed fed network

Connection	Parameters Value	Parameters Value (mm)
(1)	impedance 50$\boldsymbol{\Omega}$	13.85x3.11
(2)	impedance 100$\boldsymbol{\Omega}$	1x0.7
(3)	impedance 70$\boldsymbol{\Omega}$	7.13x1.67

Finally, the discontinuity (3) is used to feed the antenna. The dimensions of the feed network were calculated from formulas found in traditional literature. The power divider of 1x2 microstrip patch antenna designed are given in table 1. [5].

After simulation and optimization using HFFS Software, the final dimensions are shown in the Fig. 7,.

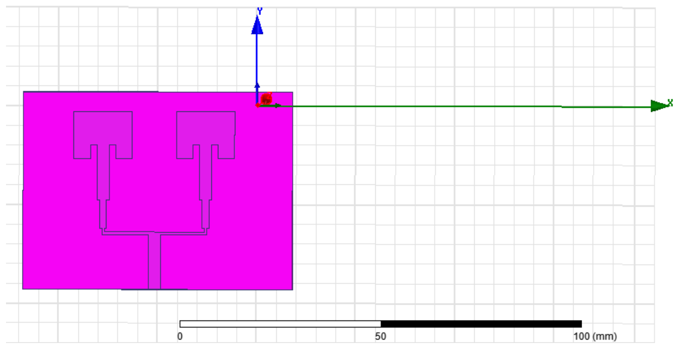


Fig 7. View of microstrip antenna array 1x2.

V. SIMULATION RESULTS

A- Antenna Return Loss

The simulated reflection coefficient of the 1x2 microstrip patch antenna is shown in Fig. 8,. It is obvious that the reported antenna can operate in IEE802.11a WiFi band. The operating band is centered at 5.8 GHz (under -10 dB) with -16.28 dB, the bandwidth which extends from 5.6 GHz to 5.99 GHz (FBW 6.7%). So, it is quite clear that this operating band meets the design requirements of IEEE802.11a standard operating frequency.

Received July 2019, Received in received from August 2019, Accepted October 2019, and Published July 2020

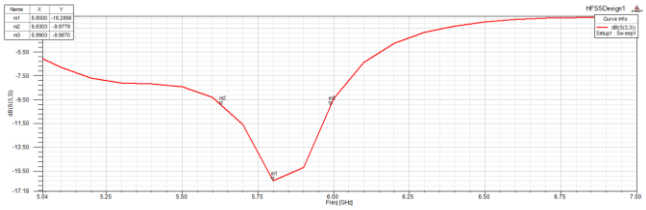


Fig 8. Return loss Vs. Frequency plot of propsed antenna.

B- Radiation Pattern

The radiation patterns for the design 1x2 microstrip patch antenna for IEEE802.11a is shown in Fig. 9, the antenna design has directional shaped radiation patterns in the phi=0 deg (x-y plane) and phi=90 deg (y-z plane) planes as expected since the antenna has a directional pattern.

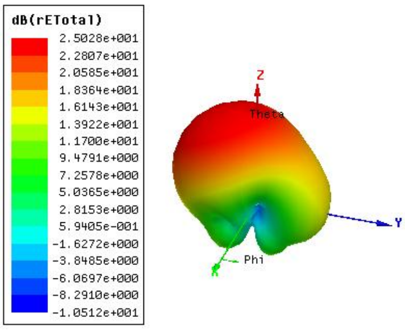
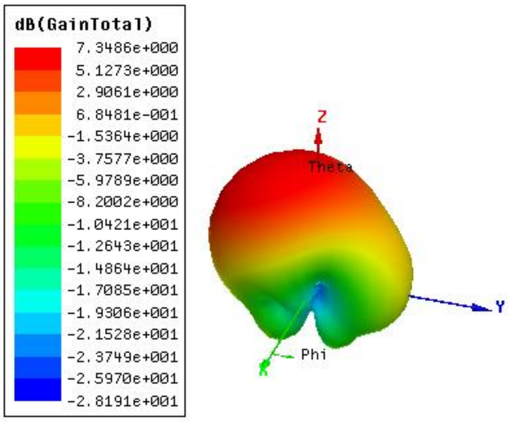


Fig 9. 3D Radiation pattern of the microstrip antenna array 1x2.

C- Gain and Directivity

Fig. 10, gives the view of gain and directivity in 3D far-field polar plot. It is observed from far-field that the value of gain is 7.34 dB and the directivity is directional with 9.81 dB. By improved the design by increase patches, the gain and directivity have consequently increased.



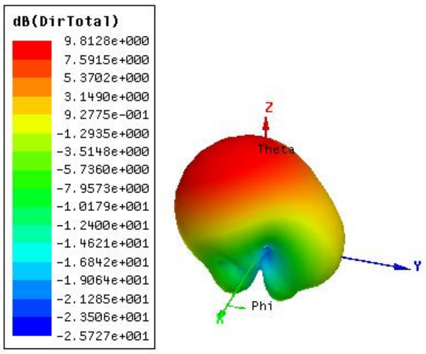


Fig 10. 3D Gain and directivity of the 1x2 microstrip antenna array.

D- Current distribution

Fig. 11, illustrates the current distribution of 1x2 elements. It is clear from the Fig that the amount of current declines at the edge of elements. Figure shows the current distribution pattern at 5.8 GHz, from Figure the current doesn't distribute for patch to another this means good isolation coupling between them. The red arrows show the strongest current distributed in patch of antenna.

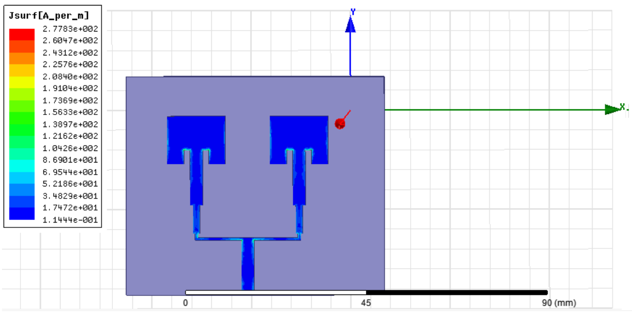


Fig 11. Average current distribution of the microstrip antenna array 1x2.

VI. 2x2 MIMO Antenna Design

A 1x2 array microstrip antenna is introduced in a two element compact space MIMO antenna system [8]. The optimization geometry of the MIMO antenna system is shown in Fig. 12,.

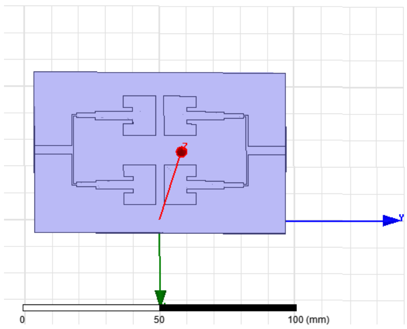


Fig 12: Geometry of MIMO microstrip antenna at 5.8 GHz.

The antenna system consists of two radiating elements of similar closed spaced geometry elements with edge-to-edge separation of 3λ printed on a common FR4

Received July 2019, Received in received from August 2019, Accepted October 2019, and Published July 2020

substrate of thickness 1.6 mm and a compact size of 60× 93 mm. The relative permittivity of the substrate is 4.4. fed through a 50 Ω microstrip line.

The DGS is designed to introduce a stop band at 5.8 GHz, which is the desired antenna operating frequency. The DGS resonator was designed using a slot of width and length 56.5x2.2 mm as shown Fig. 13,. [7].

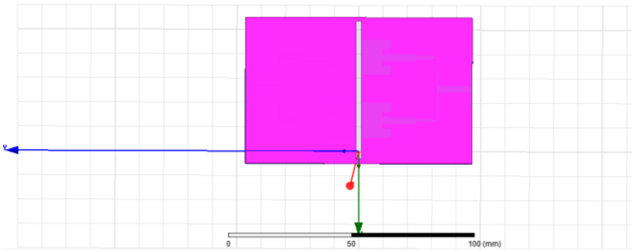


Fig 13: DGS microstrip resonator.

VII. SIMULATION RESULTS OF MIMO ANTENNA

The results for the 5.8 GHz Band microstrip MIMO antenna will be discussed in this section in order to validate the simulated results obtained from HFSS software.

A- Antenna Return Loss and mutual coupling

A final result of MIMO microstrip patch antenna has optimized for return loss. From Fig. 14, it can be observed that the return loss value has met the desired value less than -10 dB which is centered at 5.8 GHz with -16.83 dB and the coupling (S12) value is -20.66 dB as shown Fig. 15.

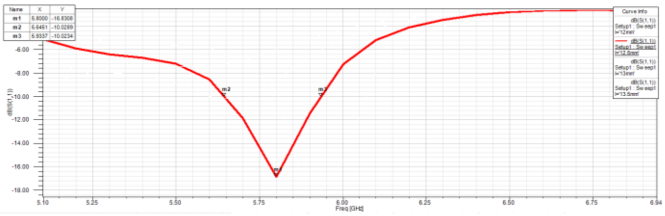


Fig 14. The return loss and (S11) of the MIMO microstrip antenna at 5.8 GHz.

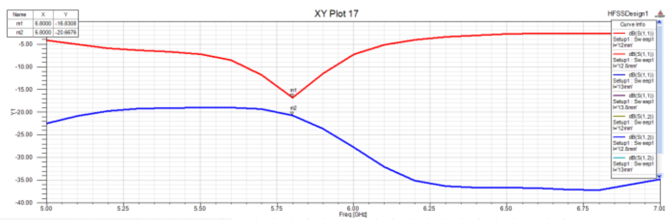


Fig 15. The return loss and mutual coupling (S11-S12) of the MIMO microstrip antenna at 5.8 GHz.

B- Radiation Pattern

Fig. 16, shows the simulated xz-plane and yz-plane radiation pattern of the proposed antenna at 5.8 GHz. The designed antenna radiates relatively to directional pattern.

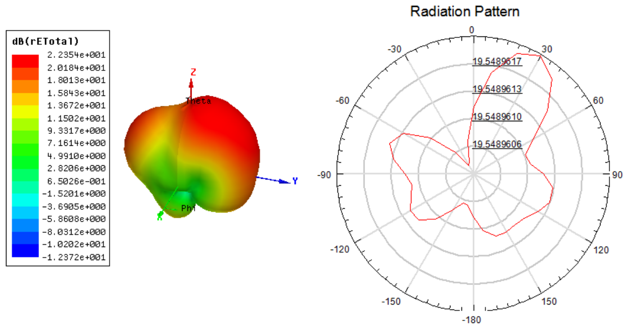


Fig 16. 3D radiation pattern of the MIMO antenna.

C. Gain and directivity of the MIMO antenna

From Figs Fig. 17, it can be observed that the gain and directivity values are 5.10 dB and 7.99 dB respectively.

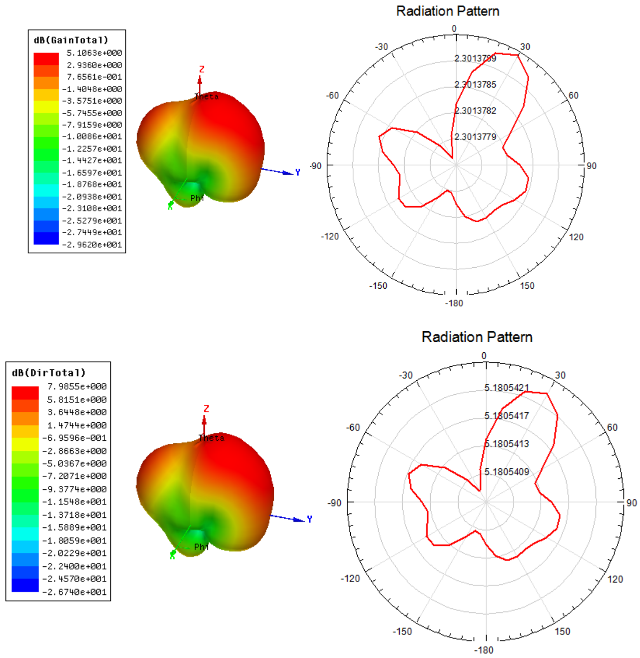


Fig 17. 3D Gain and directivity of the MIMO microstrip antenna at 5.8 GHz.

D. Current Distribution on the MIMO Antenna

The Current distribution is described as current distribution between the patch and the ground plane, which is used as the indicator of the radiation from microstrip patches. Fig. 18, shows the current distribution pattern at 5.8 GHz, we notice that the DGS could isolate the antennas and prevent flowing the current between them.

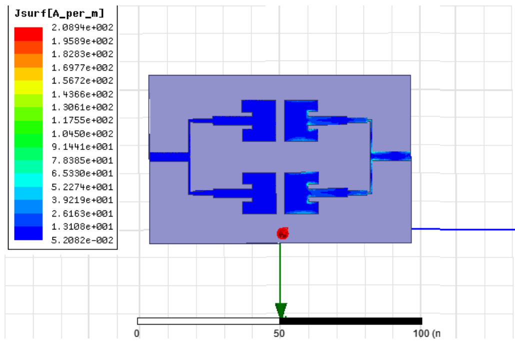


Fig 18. Average current distribution of the MIMO microstrip antenna.

Received July 2019, Received in received from August 2019, Accepted October 2019, and Published July 2020

VIII. CONCLUSION

Microstrip patch antenna configured in 2x2 MIMO and an array format with 1x2 number of patch elements have been analyzed for IEEE802.11a applications. These designed antennas are very simple, low cost and high efficiency for the 5.8 GHz frequency band. Since the operating band is centered at 5.8 GHz and the return loss is under -10 dB, this indicates that the 1x2 arrays and 2x2 MIMO operate at the required frequency. we have noticed that the bandwidth, and the radiated power improve by increasing the number of patch elements in the arrays.

A closely spaced 2x2 element MIMO antenna with small size, and high coupling isolation using DGS has been designed and analyzed. The two antenna elements have been designed on a substrate of FR4 with $\varepsilon_r = 4.4$. The designed antenna has provided coupling isolation with a value of 20.66 dB between the two ports at the operating frequency 5.8 GHz, with a very close distance separation. Also, the gain and directivity values have been good, directional radiation pattern, and with values of 5.10 dB and 7.99 dB respectively. Due to its small size, light weight and conformal properties, these analyzed microstrip patch antenna arrays are useful for IEEE802.11a WiFi and 4G LTE Technologies.

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