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Design of a 2GHz Microstrip Antenna for Wireless Application using Cross-Shaped Patch Aperture

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Abstract

In the few past years, wireless communication has employed microstrip patch antennas as common components in its systems. This paper presents a design of an inset-fed cross-shaped microstrip patch array to operate at dual band frequencies for wireless communication. A rectangular cut-out is done in the ground plane to obtain the dual band. A high gain is obtained by the use of a cross shaped patch aperture. It is shown that the cross shapes are more effective in suppressing surface wave thus resulting in a higher gain. Several antenna parameters such as radiation pattern and directivity for single and two elements are plotted and good results have been found. High-frequency structure simulator software (HFSS) has been used to obtain experimental results. As a substrate material, a Duroid 5887 has been used having a dielectric constant of 2.2.

Index Terms — *cross-shaped, patch modeling, Array, dual bands, wireless applications.*

I. INTRODUCTION

The huge demand of the modern wireless communication systems has led to the employment of microstrip patch antenna since they are compact, minimal weight and inexpensive. The advancement in printed circuit board technology has allowed the fabrication of microstrip patch antenna on a flat surface to be easy realized. The potential applications attracted the attention of many researchers and industry operators in the area of communication engineering to embrace the design and analysis of various shapes of microstrip patch antenna in order to improve several characteristics of the antenna. In general, Microstrip Antenna a has basically two main parts. It consists of a ground plane that supports the radiating part (patch and the substrate). The patch is generally made of copper or gold which are conducting materials. The radiating patch and the feed lines are photo-etched on the dielectric substrate [1]**.** The most common shapes that have been designed and studied so far are rectangular, square, and circular. Although they are satisfactory still there is need of increasing the gain for the antenna to cover a longer range distance and the diversity of shapes are needed. Several research works have been carried out in some ways in order to overcome the drawbacks of microstrip patch antennas in terms of their low gain and narrow bandwidth [2]**.** This implies the design of an inset - feed rectangular patch antenna using partial ground with an edge-cut method for bandwidth enhancement [3]

For many wireless communication systems, an antenna operating at multiple frequency bands (broadband or multiband) is desired. Microstrip patch antennas are able to exhibit dual resonant frequencies from a single antenna structure by inserting a cut-off on the ground plane structure and increasing their gain by mounting them in an array configuration. This can lead to improved antenna performance.

Some other methods of dual-band antenna design have been carried out so far. This implies studying the effect of loading different shapes of slots into a square Microstrip Antenna [4]**.** A dual frequency band that can be used in wireless Applications is achieved successfully.

A multi-band is achieved by introducing slots [5] and this has led to an achievement in high gain.

In this paper, we are proposing the design and simulation of dual-band smart antenna to be applied in wireless communication using an inset-fed cross shaped aperture and it has been successfully achieved. The need for enhancing some parameters such as gain and directivity has been achieved by inserting a cut-off in the ground plane structure. The rest of this paper is organized as follows: section 2 briefly presents the proposed microstrip patch antenna design, section 3 summarizes the antenna simulations and results and finally, section 4 validation procedure and section 5 concludes the proposed work.

II. PROPOSED ANTENNA DESIGN

In this paper, a thin medium dielectric substrate material Duroid 5887 substrate with dielectric constant, $\varepsilon_r = 2.2$ is used for this design in order to enhance the input impedance matching (inset feed) and the antenna gain. The thickness of the substrate is 1.5748mm. For the Microstrip Antenna design, a number of methods have been suggested. Among them, are the cavity model and the transmission line model. In this design, transmission line model is used to design first the rectangular patch, then edges of it are cut to form a cross-shaped patch antenna. Afterwards all an array configuration of two elements is mounted. The cross-shaped array is processed from a single rectangular by maintaining the same patch size. The antenna resonates at the design frequency of 2GHz with the dimension of L x W as (49.8 x 59.29) mm having an aspect ratio of 0.84mm. The dual-band frequency is achieved by inserting cutoffs on the ground plane structure having. Our design is measured and compared to a design and simulation of dual bands rectangular patch antenna design [6] resonating at the same frequency and having the same patch size.

High-Frequency Structure Simulator software (HFSS v13.0) is used for this design because it is more adapted while dealing with electromagnetic waves. It helps in calculating parameters such us return loss, VSWR, gain and bandwidth.

A. Design specifications

The dielectric constant (ε_r) of the material ranges from 2.2 to 10 i.e. $2.2 \leq \varepsilon_r \leq 10$

The Operating frequency f_r for a wireless application design ranges between 1 to 2.4 GHz

The thickness of the substrate material (h) is in the range of $\lambda_o \leq h \leq 0.05\ \lambda_o$

Where λ_o is the wavelength in vacuum

For an efficient radiator, the practical patch width that leads to good radiation efficiencies is calculated using [7]

$$\mathbf{W} = \frac{\mathbf{1}}{\mathbf{2f_r\sqrt{\mu_o\varepsilon_o}}}\sqrt{\frac{\mathbf{2}}{\boldsymbol{\varepsilon}_\mathbf{r}+\mathbf{1}}} = \frac{\mathbf{v_o}}{\mathbf{2f_r}}\sqrt{\frac{\mathbf{2}}{\boldsymbol{\varepsilon}_\mathbf{r}+\mathbf{1}}}\,. \qquad (1)$$

Where:

v_o = the speed of light

f_r = Design frequency

ε_r = dielectric constant of the substrate material (Duroid 5887)

The initial values (at low frequencies) of the effective dielectric constant are referred to as the *static values,* and they were calculated as [7]

$W/h > 1$

$$\varepsilon_{reff=}\frac{\epsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}[1+12\frac{h}{W}]^{-\frac{1}{2}}. \qquad (2)$$

The extension length is calculated as [7]:

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{W}{h}+0.8)}\,. \qquad (3)$$

The actual length of the patch is determined by solving L as [7]:

$$L = \frac{1}{2f_r\sqrt{\varepsilon_{reff}}\sqrt{\mu_o\varepsilon_o}} - 2\Delta L. \qquad (4)$$

B. Design calculations

Let the operating frequency of the proposed antenna be

f_r = 2 GHz

The substrate material is rogers duroid 5887

The dielectric constant of the material is 2.2 (the lowest)

The thickness/height of the substrate to be 1.5748 mm

By using the above equations we can determine the antenna geometry as follow:

From equations (1):

The patch width **W**

$$W = \frac{v_o}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}}$$

$\mathrm{W} = 59.29\ \mathrm{mm}$

From equations (2): we calculate the effective dielectric constant as:

$$\varepsilon_{reff=}\frac{\epsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}[1+12\frac{h}{W}]^{-\frac{1}{2}}$$

$\varepsilon_{\text{reff}=2.288\text{mm}}$

From equation (3): we find the normalized extension of the length as:

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

$\Delta L = \mathbf{0.728\ mm}$

From equation (4): we can obtain the actual length of the patch

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

$\boldsymbol{L = 49.82\ mm}$

After getting the width and the length of the patch we can easily calculate the ground plane dimension as follow:

Lg=6h+L = **59.29 mm**

Wg=6h+W = **68.71mm**

Matlab code is used for the calculation of the required dimensions of the following parameters when 50 ohms is used as the input impedance:

Inset distance: **15.215 mm**, Inset gap: **2.426 mm**, Feed Width: **4.852 mm**, Feed Length: **25.69 mm**

And the design and simulation of 1x1 and 2x1 inset fed conventional and modified patch antennas was carried out using HFSS software are as shown in the figure 1.

The rectangular patch in Fig.1 (a) is selected as the basis of the modeling using the patch dimensions as calculated earlier in section II. The rectangular patch is designed then modified to obtain a cross shaped patch as show in Fig.1 (b). This modification implies subtracting the edges of the rectangular from Fig.1 (a). in order to increase the gain, reduce side lobe radiation, and increase directivity, the patch antenna in Fig.1 (b) was then expanded to two (02) elements array as shown in Fig.1 (c). Two elements array are used, separated by λ/2. The patch length and width for each element is the same as the single cross-shaped patch described earlier.

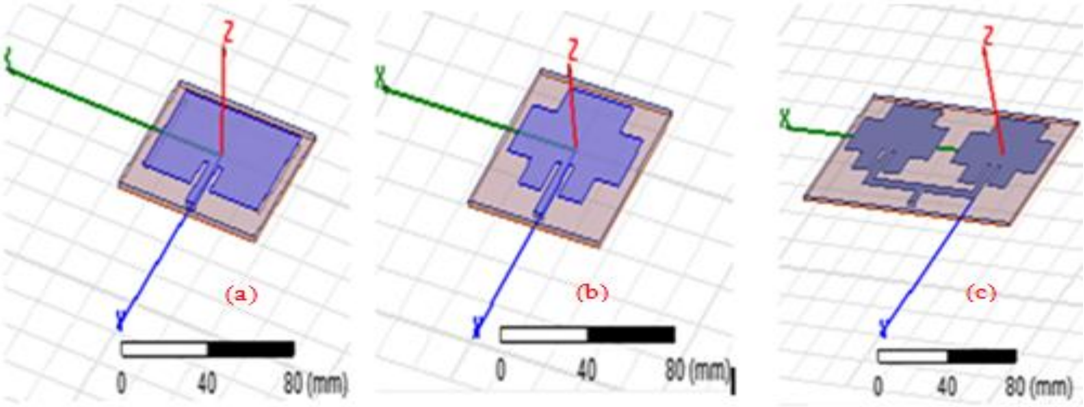


Fig.1: Patch modeling.

Figure 1 represents the process of modeling the patch from the rectangular to cross-shaped patch using inset feed technique. This is done by dividing equally the length and the width into three parts; only the middle parts are consider while the edges at each corner are subtracted to obtain the cross-shape as proposed earlier in section 2. These values are optimized to achieve the performance of the antenna as needed

III. VALIDATION PROCEDURES

The proposed antenna is designed and simulated using the High-Frequency Simulator Software (HFSS) and parameters such as gain, return loss; bandwidth are measured as shown in figures 2, 3 and 4. The bandwidth of the antenna is measured by the return loss curve**.** We modeled a rectangular patch antenna at the same resonating frequency and having the same size as our proposed antenna for validation purpose. The results from the rectangular are close to the reference antenna data.

A. Return loss: reference vs. proposed rectangular patch antenna

The return loss represents the amount of the power reflected back from a device. That happens when there is a mismatch with the load hence maximum power is not delivered. A return loss of at least -9.5dB is sufficient to ensure the transmission of the power and an increase in gain. A single cross shaped patch antenna resonating at the frequencies of 1.9 GHz and 2.64 GHz has a return loss of -10.5 dB and -12.33dB respectively. The 2x1 elements giving a return loss of -17.9dB at 2.14GHz and -18.82 dB at 2.9GHz were measured as shown in figure 5. The dual-band of the reference antenna **[6]** has a return loss of -9.56dB and -12.32dB at 1.90 GHz and 2.62 GHz respectively as shown in figure 2. The simulated impedance bandwidth for the dual band is obtained as follows: 34MHz (2.1587- 2.1233 GHz) and 24 MHz (2.9179-2.8936 GHz) were achieved at -9.5 dB. Our proposed rectangular patch antenna has given a return loss of -10.2dB.

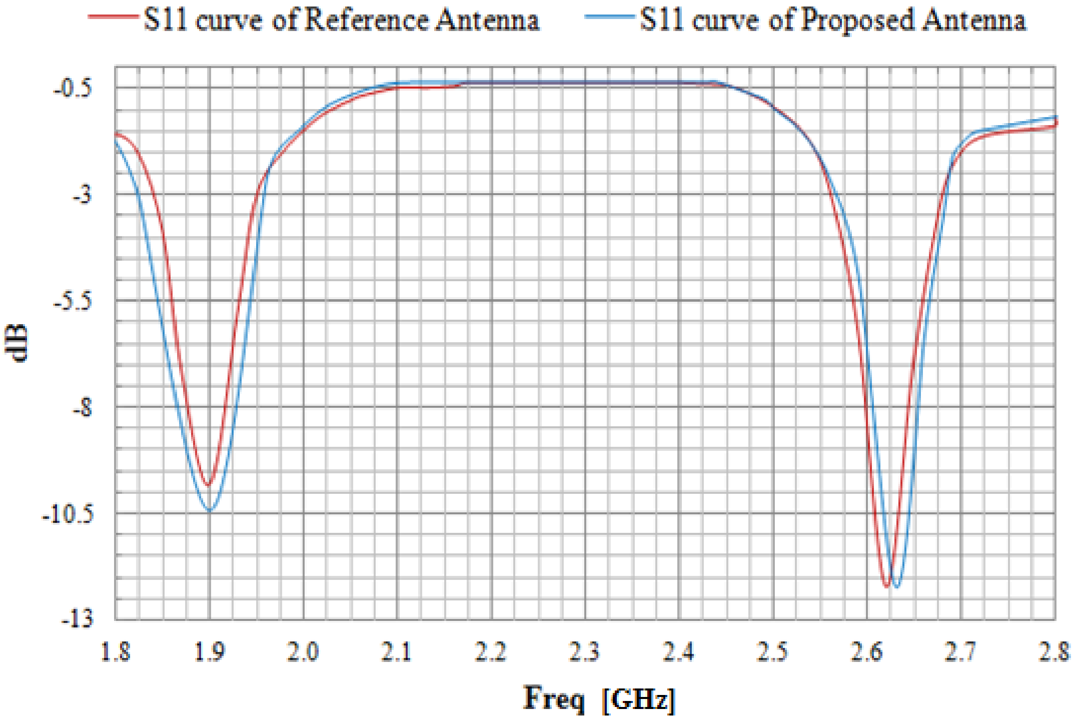


Fig 2: return loss of reference antenna vs. proposed antenna.

B. Directivity: reference vs. proposed rectangular patch antenna

Directivity is one of the fundamental parameters of an antenna. It is a measure of how “directional” an antenna’s radiation pattern is. For the case of directional antennas, the directivity is usually 1dB or 0dB because the power is radiated in all direction. The Microstrip antenna is a directional antenna since it radiates its energy towards a given direction. Our proposed antenna shows in **figure 3** how it radiates its power towards one direction and numerically recorded as **7.1 dB** has been recorded while in the other side the reference antenna has given **7.04dB** of directivity [6]

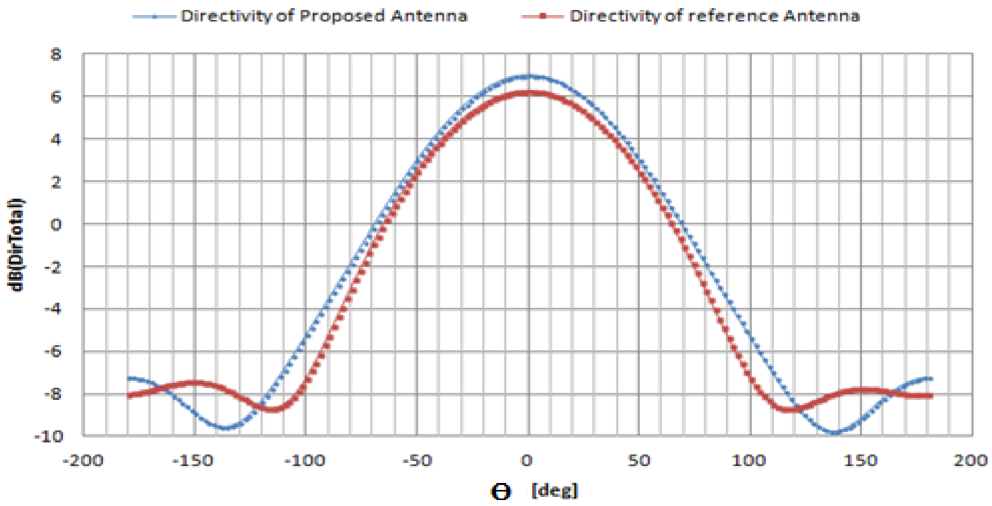


Fig 3: directivity of proposed antenna vs. reference antenna.

C. Gain: reference vs. proposed rectangular patch antenna

The gain of an antenna represents the capability of that antenna to concentrate energy towards a direction. It is taken as a quantity which describes the performance of the antenna or in another way it is the direction in which the power is radiated the most (maximum radiation). In this design, the maximum achievable gain of our proposed antenna is **6.3dB**. The gain of the reference antenna is found to be **6.03dB.** The cross-shaped patch antenna has given a gain of 6.59 dB and 8.95 dB respectively for the single and the array of 2 elements as shown in **figure 5**. An increment in gain is observed when the rectangular patch is modeled to a cross shaped patch and then mounted in an array configuration. The overall size of the proposed and the reference antenna is (49.82 x 59.29 x 1.6) mm^3 at the resonant frequency of 2 GHz.

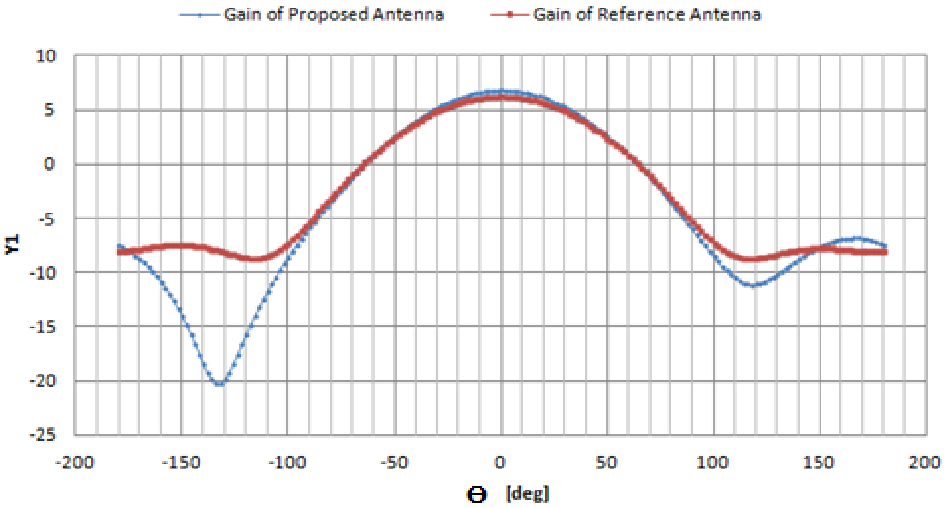


Fig. 4: gain of proposed ant vs. reference antenna.

IV. SIMULATED RESULTS AND DISCUSSION

A cross-shaped patch antenna is designed in a single patch. The results such as return loss, gain, directivity, and radiation pattern are obtained to evaluate the antenna performance. The simulation is carried out using high frequency simulator structure software.

The Figure 5 below represents the back power reflection of the single patch antenna which is known as a return loss. Here a value of -10.40 dB is recorded at the frequency of 2.18 GHz as shown in the figure 5

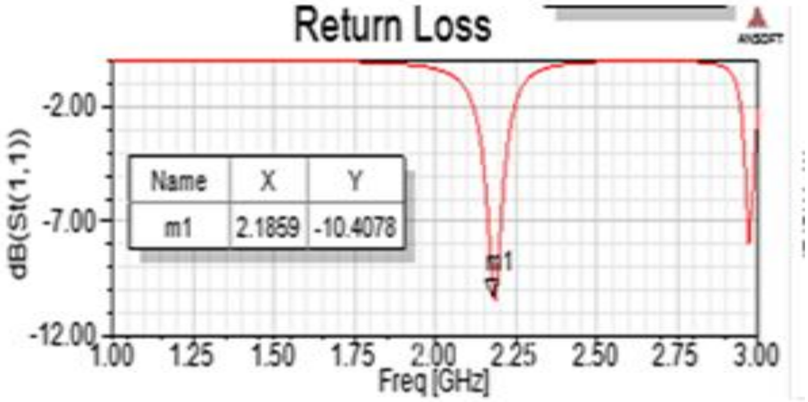


Fig. 5: Return Loss for a Single Patch Element

The cross-shaped patch antenna for a single patch exhibits a high gain as shown in figure 6 below. A pick gain of 6.59dB is recorded shows how strong the energy is concentrated towards one direction. As compared to the gain of rectangular patch which has been recorded as 6.3 dB, we can here notice the benefits of using the cross-shaped antenna over the rectangular in term of power radiated at its maximal. In Figure 6 below, the gain of single patch element is represented in 3D using hfss software

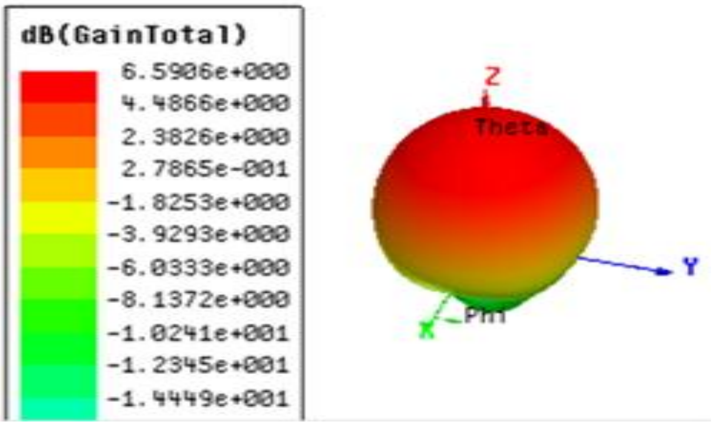


Fig. 6: Gain for Single Patch Element

A directivity plotted against Theta Ɵ [degree] gave **7.04 dB** from the simulation of a single cross shaped patch antenna as shown in figure 7 below. The directivity shows that the antenna is very directive.

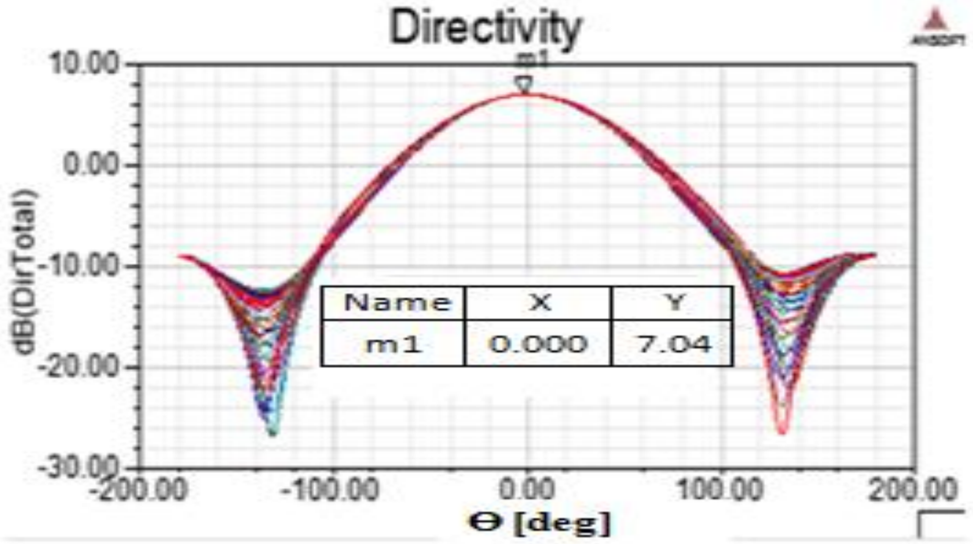


Fig. 7: Directivity for a Single Patch Element

The bandwidth of an antenna that is able to transmit a signal is recorded at the return loss that is not greater than -9.5 dB. In this case the single cross shaped patch antenna provides a frequency band of 20 MHz (2.19 GHz – 2.17 GHz) as shown in figure 8 below

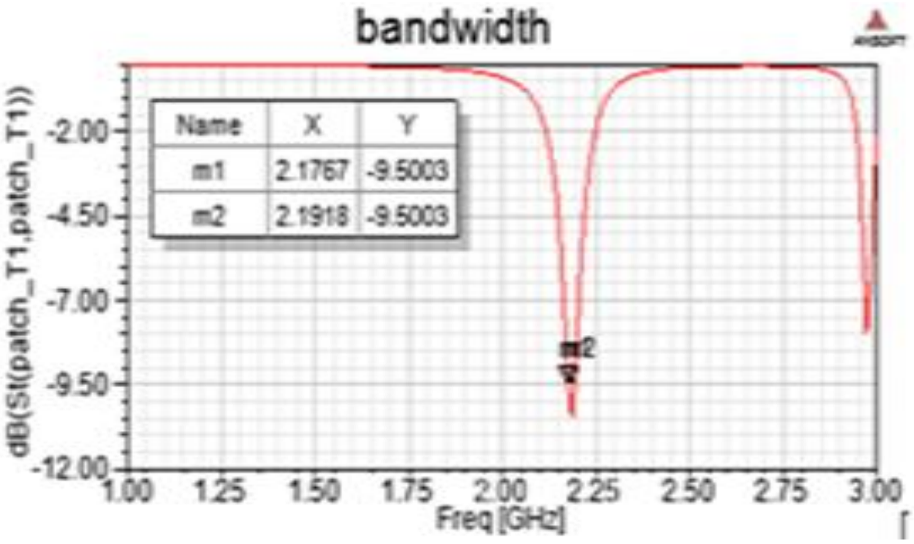


Fig.8: Bandwidth of Single Patch Element

The single cross-shape patch antenna is expanded here to an array of two (02) elements in order to obtain an increased in antenna characteristics as compare to the single element patch. Below are following parameters obtained from the array configuration

The Figure 9 below shows the return loss of the array two elements patch antenna. A dual band is also obtained by inserting a cut off in the ground plane system and it has been recorded as -17dB and -18dB respectively at the frequency of 2.14 GHz and 2.9GHz. as compared to the single patch elements, the array of two elements performed much more better with less power back propagation for both bands.

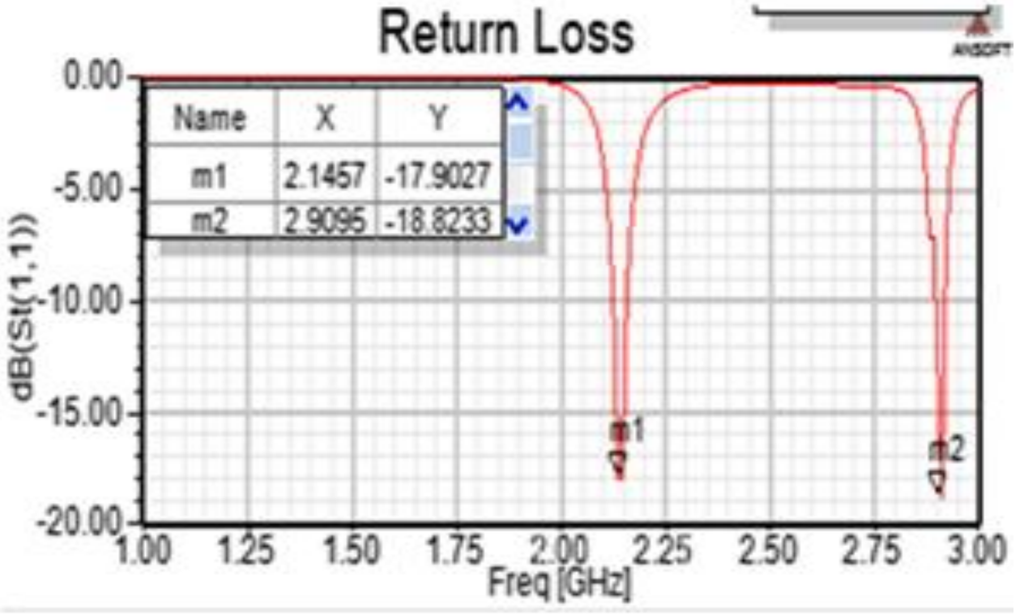


Fig. 9: Return Loss of 1 x 2 Patch Element

The main advantage of array element configuration is to increase the performance of the antenna. The gain of the two elements cross-shaped patch antenna recorded in figure 10 gives a pick gain of 8.9 dB while the single elements with same patch size gives a pick gain of 6.95dB as shown earlier in figure 6. We can here notice an increment of at least 2dB gain while using same patch size.

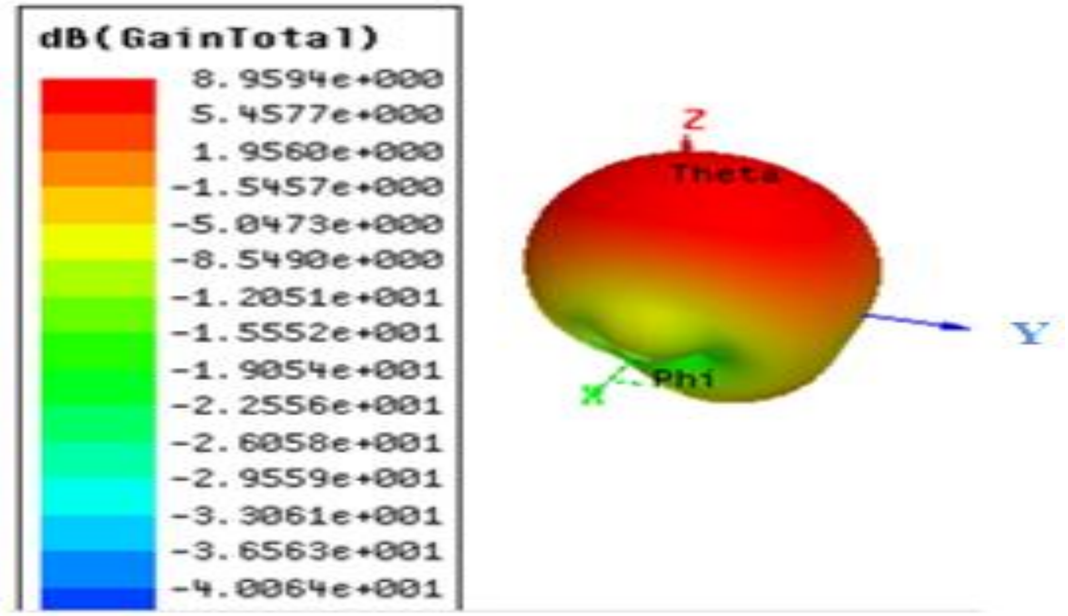


Fig.10: 3D gain of 1 x 2 Patch Element

For the array of two (02) cross-shaped patch antenna, the directivity plotted against Theta Ɵ [degree] gave 9.26 dB as shown in figure 11 below. Compare to the directivity of single patch element, the array one perform way better since an increased in directivity is shown.

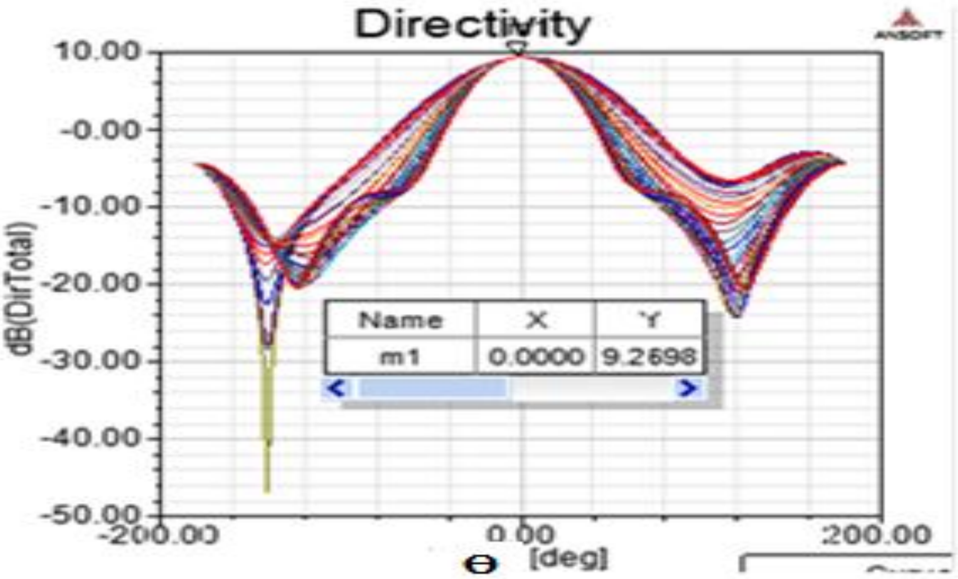
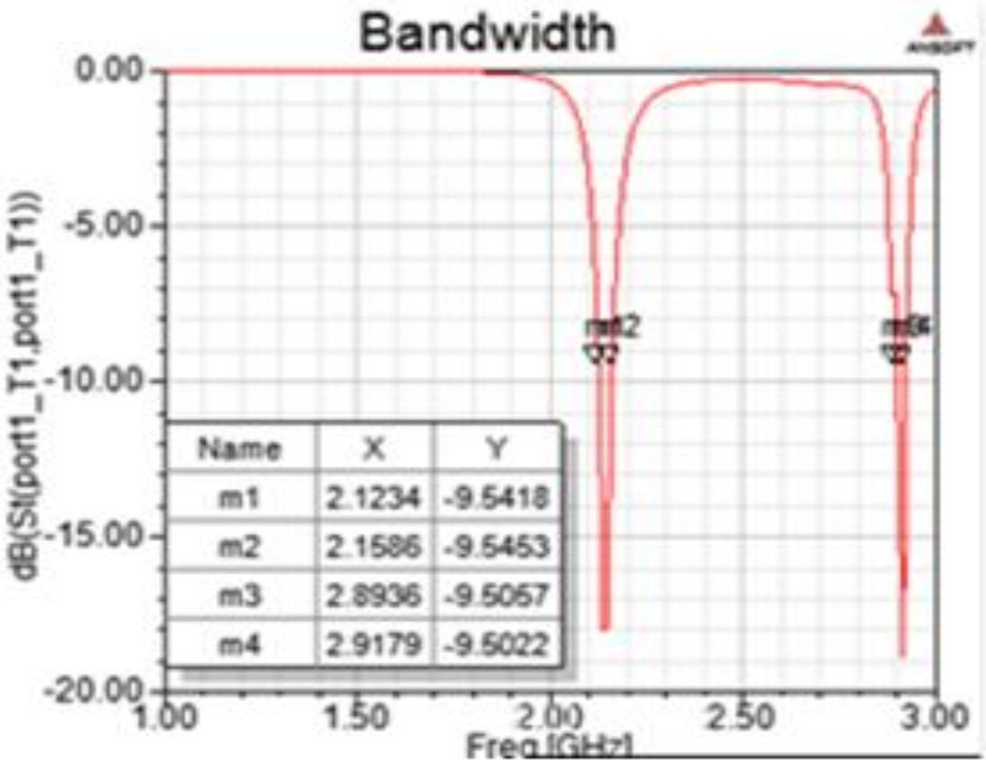


Fig.11: Directivity of 1 x2 Patch Elements

The configuration of the 1 x 2 patch element provides greater bandwidth at two different bands as shown in figure 12 below. After simulation, we recorded a bandwidth of 30 MHz from (2.15 GHz – 2.12 GHz) x 1000 and 700MHz from (2.89 GHz – 2. 19 GHz) x 1000.



Name	X	Y
m1	2.1234	-9.5418
m2	2.1586	-9.5453
m3	2.8936	-9.5067
m4	2.9179	-9.5022

Fig. 12: Bandwidth of 1 x 2 Patch Element

The radiation pattern of the microstrip patch antenna is the power radiated or received by the antenna. It is the function angular position and radial distribution from the antenna

The 3D radiation pattern plot of the Cross-shaped Microstrip Patch Antenna for the single patch and the associated 2 patch elements are shown in figure 13 (a) and 13 (b) below.

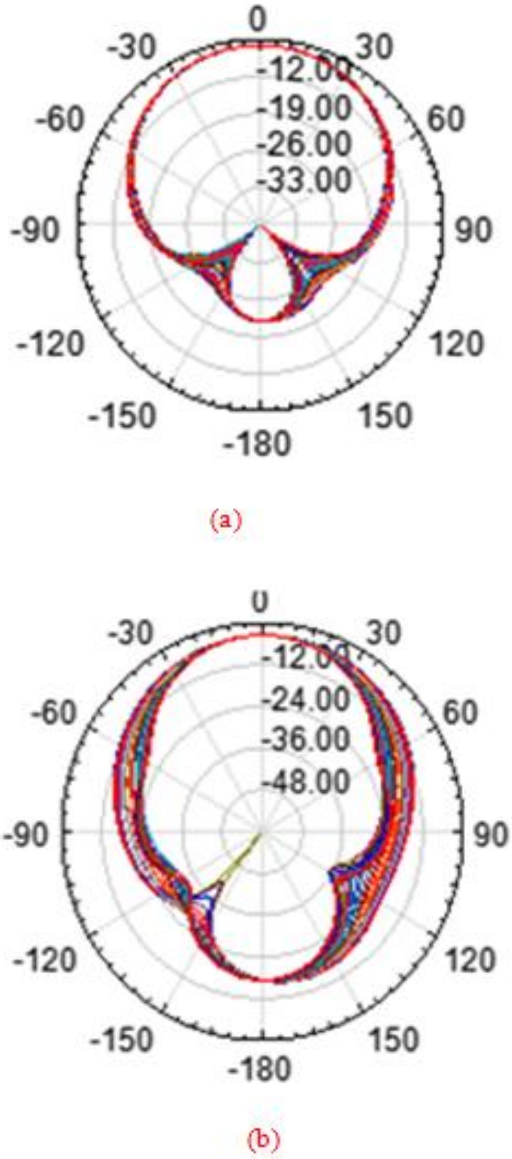


Fig. 13: 3D Radiation Pattern

(a) Single Patch Element (b) 1 x 2 patch element

V. CONCLUSION

In this paper, we have proposed a design of a cross-shaped microstrip patch antenna at the operating frequency of 2 GHz to address the drawback of microstrip antennas using a cross shaped aperture in terms of low gain. A dual-band has been exhibited by inserting a cut-off in the ground plane structure and results were plotted out. From the analysis of results obtained for different parameters of the antenna, it has been noted that the cross shaped patch antenna exhibits good performance in term of gain, directivity and radiation efficiency. However, this is obtained at the expense of higher return loss as compared to the reference antenna. And we must note that many aspects affect the performance of a microstrip patch antenna such as the dimensions, the choice of the substrate, the feeding techniques and also the operating frequency can be a major factor on the antenna’s output.

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