DUAL BAND RECTANGULAR MICROSTRIP ANTENNA ARRAY FOR WIRELESS COMMUNICATION

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ABSTRACT

Two dual band rectangular microstrip antenna arrays with improved gain performance using inset feeding technique suitable for wireless communication devices are presented in this paper. The elements of the arrays were designed using transmission line equations and analysis was done using full wave model equations with the aid of Computer Simulation Technology (CST) Studio software. The antenna was designed at frequencies of 2.4 and 5.2 GHz using Flame Resistant (FR-4) substrate with a dielectric constant of 4.4 and a substrate thickness of 1.6 mm. The first antenna array configuration of 1 x 2 employed a patch for each resonating frequency while the second array configuration of 2 x 2 employed two patches for each resonating frequency. A gain of 6.06 dB and 7.56 dB was achieved by the 1 x 2 antenna array at 2.4 GHz and 5.2 GHz while 2 x 2 array antenna achieved a gain of 9.25 dB and 8.66 dB at 2.4 GHz and 5.2 GHz, respectively.

Keywords: Rectangular, Microstrip, array, improved gain, communication.

INTRODUCTION

With the existence of different antenna types such as wire, aperture, lens and reflector antennas, specific field of application is strictly required-parameter dependent (Kumar and Ray, 2003). Among the requirements of contemporary communication devices given their miniaturized shapes, is the need for conformity to the mounting host as well as planar and compact physical characteristics. Worthy of note is that microstrip antennas (an example of aperture antenna) meets these requirements for modern communication devices.

Microstrip is a planar transmission line, similar to stripline, but devoid of a substrate at the top. The structure of microstrip transmission line consists of a copper trace separated from a ground plane by an insulating substrate (Pozar, 2012). Microstrip antennas (also known as patch antennas) have been known to be of low profile, planar, compact, easy to fabricate and easily conformable to the host (Balanis, 2005). These characteristics have endeared microstrip antennas to antenna designers world over for application in modern communication devices. A notable property of microstrip antennas is their rugged nature which is mostly desired in devices that are prone to vibration and excessive external pressure such as missile and rocket launchers (Kumar and Ray, 2003; Huang and Boyle, 2008).

Microstrip antenna array configuration is employed where specific properties or improvement on existing properties are desired (Khraisat, 2011). Properties such as to synthesize a required antenna pattern, scan beam of an antenna system, increase the antenna directivity among others. In this study, dual-frequency patch array configuration for improved gain performance is proposed for detailed study. A high-gain antenna (HGA) is an antenna with a narrow radio beam that is used to increase signal strength. High-gain antennas provide a more precise way of targeting radio signals and are therefore very essential to long-range wireless networks (Khraisat, 2011; Fathima and Rajini, no date). They even amplify weak signals used in satellite communication (Bhatnagar, Prakash and Dahiya, 2016).

LITERATURE REVIEW

Some authors like Khraisat, 2011; Sohail, 2016; Rao and Pradesh, 2017; Ali and Khawaja, 2013 and Asrokin and Rahim, 2005 previously worked on the rectangular antenna arrays with a few exploring the option of dual frequency resonation. The design of 4-element rectangular microstrip patch antenna with high gain for 2.4 GHz applications using basic transmission line equations and simulated using IE3D simulator by Zealand was worked on by Khraisat, 2011. The author reported that a gain of 13.2 dB at 2.4 GHz. Rectangular microstrip patch antenna array with a 4 x 4 configuration for near field focusing on an FR-4 substrate which achieved a bandwidth of 50 MHz at 2.4 GHz was presented by Sohail, 2016. However, the achieved gain was not stated. The design, modelling, simulation and performance analysis of a microstrip line quarter wave transformer-fed 4x4 circular patch phased array on an RT Duriod 5880 substrate material with a thickness of 1.588 mm and a relative permittivity (εr) of 2.2 was reported by Rao and Pradesh, 2017. The design frequency selected was 2 GHz and VSWR $\leq$ 2. The proposed 4x4 Circular Patch phased array was modelled and simulated in ANSOFT HFSS 15.0 achieving a gain of 16.963 dB and bandwidth of 31.9 MHz. The design, optimization and simulation of a dual-band coaxial-fed 2×2 rectangular U-slot microstrip patch antenna array for wireless sensor network applications with operating frequencies of 2.1 GHz and 3.5 GHz, respectively was published by Ali and Khawaja, 2013. A maximum gain of 11 dBi was achieved by the 2 × 2 U-slot rectangular patch antenna array proposed at 2.1 GHz. Also, dual band square and circular microstrip antenna array arranged in a log-periodic configuration designed at 2.4 GHz and 5.2 GHz was presented by Asrokin and Rahim, 2005. The square patch passive antenna at 2.44 GHz achieved a gain of 19 dB and 4 dB at 5.2 GHz while the circular patch achieved a gain of 21 dB and 4 dB at 2.44 GHz and 5.2 GHz respectively.

METHODOLOGY

The design of the proposed antennas follows the transmission line equations for designing rectangular antennas from (Balanis, 2005). The basic parameters of the microstrip such as the width, length and the dimensions of the transmission line are determined as follows.

The width of the patch W_p is determine from Equation 1:

$$W_p = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \qquad (1)$$

where c, f_r and ε_r are the speed of light, design frequency and relative permittivity.

The patch length can be calculated using Equation 4 however, the length's extension, ΔL and the effective permittivity, ε_{reff} are first calculated from Equations 2 and 3 before the length of the microstrip patch. The substrate thickness, h of 1.6 mm is maintained all through the design.

The effective dielectric constant and length extension are calculated thus:

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

$$\Delta L = 0.412h\,\frac{(\varepsilon_{reff} + 0.3)\left[\frac{W_p}{h} + 0.264\right]}{(\varepsilon_{reff} - 0.258)\left[\frac{W_p}{h} + 0.8\right]} \quad (3)$$

The patch length is calculated from Equation 4 thus:

$$L = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L \quad (4)$$

As earlier stated, inset feeding technique was used in order to offset the feeding location to the point where impedance match can be achieved. The inset feed parameters are determined using the following equations.

To calculate the notch width, g equation from (Ramil, Ali and Tan, 2013) is employed as given in Equation 5.

$$g = \frac{c\, f_r \times 10^{-9} \times 4.65 \times 10^{-9}}{\sqrt{2\varepsilon_{reff}}} \quad (5)$$

The resonant input resistance R_{in} is calculated from Equation 6;

$$R_{in}(y = y_o) = \frac{1}{2(G_1 + G_{12})}\cos^2\left(\frac{\pi y_o}{L_p}\right) \quad (6)$$

The equation for the characteristic impedance Z_o is given in Equation 7;

$$Z_0 \begin{cases} \frac{60}{\sqrt{\varepsilon_{reff}}}\ \ln\left[\frac{8h}{W_f} + \frac{W_f}{4h}\right] & \frac{W_f}{h} \leq 1 \\ \frac{120\pi}{\sqrt{\varepsilon_{reff}}}\left[\frac{W_f}{h} + 1.393 + 0.667\ln\left(\frac{W_f}{h} + 1.444\right)\right] & \frac{W_f}{h} \geq 1 \end{cases} \quad (7)$$

In this design, the ratio, $\frac{W_f}{h} = \frac{2.98}{1.6} = 1.863 > 1$, so the second expression in Equation 7 applies.

Edge impedance, $R_{in(edge)}$ is computed from Equation 8:

$$R_{in(edge)} = \frac{1}{2(G_1 \mp G_{12})} \quad (8)$$

As reported by Balanis (2005), the plus (+) sign is used for modes with odd (antisymmetric) resonance voltage distribution beneath the patch and between the slots while minus (-) sign is used for modes with even symmetric resonant voltage distribution. In order to evaluate the input resistance, other parameters such as wave number k, input current I_1, input conductance G_1 and mutual conductance G_{12} have to be known first. The equations for computing the various parameters highlighted are given in Equations 9 to 13.

$$k = \frac{2\pi}{\lambda_{air}} \quad (9)$$

$$I_1 = -2 + \cos(X) + XS_i(X) + \frac{\sin(X)}{X} \quad (10)$$

$$X = kW_p \quad (11)$$

$$G_1 = \frac{I_1}{120\pi^2} \quad (12)$$

$$G_{12} = \frac{1}{120\pi^2}\int_0^{\pi}\left[\frac{\sin\left(\frac{kW_p}{2}\cos\theta\right)}{\cos\theta}\right]^2 J_o(kL_p\sin\theta)\sin^3\theta\, d\theta \quad (13)$$

where J_o is the Bessel function of the first kind of order zero. G_{12} is resolved using MATLAB-based program developed for the calculation of rectangular microstrip antenna parameters.

Inset feed technique is used with a chosen characteristic impedance of 50 Ω.

To calculate the inset feed recessed distance, y_0 and the width of the transmission line, W_f Equations 15 and 16 are used;

$$Z_0 = R_{in(edge)} \cos^2\left(\frac{\pi}{L_p} y_0\right) \tag{14}$$

$$y_0 = \frac{L_p}{\pi} \cos^{-1}\left[\sqrt{\frac{Z_0}{R_{in(edge)}}}\right] \tag{15}$$

According to Pozar, (2012), the width of the transmission line is calculated thus;

For $\frac{W_f}{h} > 2$;

$$W_f = \left(\frac{2h}{\pi}\right) \times \left[\frac{60\pi^2}{Z_o\sqrt{\varepsilon_r}} - 1 - \ln\left[2\times\left[\frac{60\pi^2}{Z_o\sqrt{\varepsilon_r}}\right] - 1\right] + \left(\frac{\varepsilon_r - 1}{2\varepsilon_r}\right) \ldots \\ \ldots \times \left(\ln\left[\left[\frac{60\pi^2}{Z_o\sqrt{\varepsilon_r}}\right] - 1\right] + 0.39 - \frac{0.61}{\varepsilon_r}\right)\right] \tag{16}$$

Ideally, an infinite ground plane is desired for patch antennas but for want of space and reduced size, the minimum ground plane dimensions for optimal performance was calculated using (17) and (18) thus;

The length of the ground plane (Lg) is:

$$L_g = 6h + L_p \tag{17}$$

The width of the ground plane is:

$$W_g = 6h + W_p \tag{18}$$

Having known the physical dimensions of the patch, the feed network parameters were selected by ensuring that the input to the patch are matched to the $Z_1 = 50\ \Omega$ feed line which then splits into two $Z_2 = 100\ \Omega$. However, a quarter-wave transformer $Z_q = \sqrt{Z_1 \times Z_2} = 70.7\ \Omega$ is then used to couple signal from the source to match with the 50 Ω line feed of the patch.

The various impedances are then used to compute the width of their consecutive feed lines. As stated by Subramanian and Prabbu, 2015, to have in-phase array elements and radiation in normal direction, the distance between array elements is taken to be about half wavelength $\left(\frac{\lambda_{air}}{2}\right)$.

RESULTS

A summary of the computed design parameters is presented in Table 1.

Table 1. Dual band antenna array design parameters

Parameter	**Value (mm)**
Patch dimensions:	
Length of 2.4 GHz patch, L_p	27.44
Width of 2.4 GHz patch, W_p	38.04
Length of 5.2 GHz patch, L_p	13.20
Width of 5.2 GHz patch, W_p	17.56
Dielectric constant, ε_r	4.4
Height of substrate, h	1.60
Feed dimensions:	
Width of 50 Ω transmission line, W_f	2.98
Width of 70.7 Ω transmission line, W_3	1.62
Width of 100 Ω transmission line, W_2	0.71
Inset distance (2.4 GHz), y_o	10.9
Inset distance (5.2 GHz), y_o	4.86
Inset gap (2.4 GHz), g	1.17

Inset gap (5.2 GHz), g	2.61
Length of transmission line, L_f	4.80
Ground plain dimensions:	70
Length of ground plain, L_g	160
Width of ground plan, W_g	170
Mitred bend dimensions:	
A_m	0.86
X	2.41
D	4.21
Distance between Patches, d	62.50

The designed antennas in CST studio are presented in Figures 1 and 2. The first antenna array of 1 x 2 configuration is presented in Figure 1 while the 2 x 2 configuration is given in Figure 2.

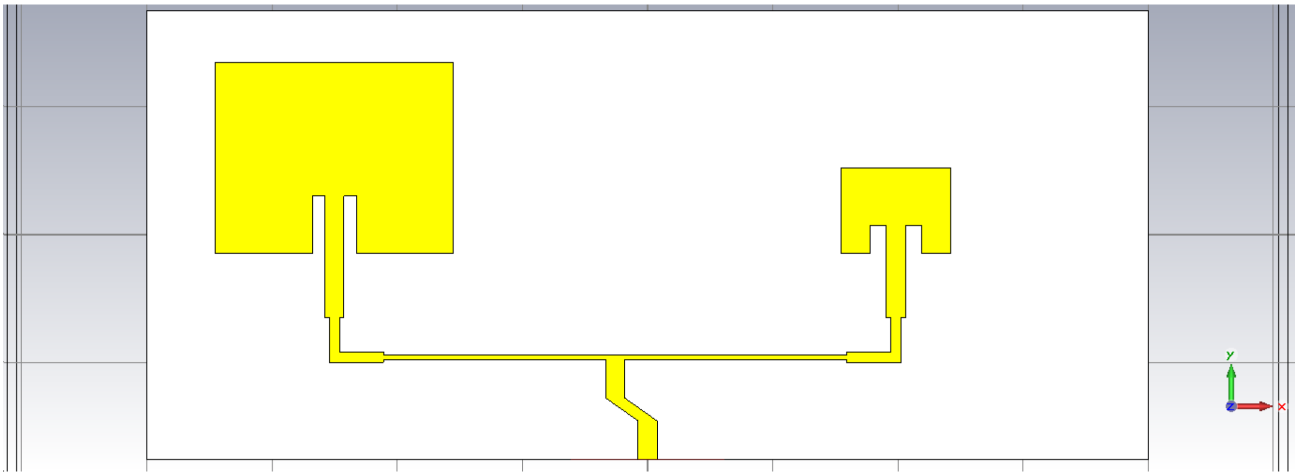

Figure 1. 1 x 2 array antenna

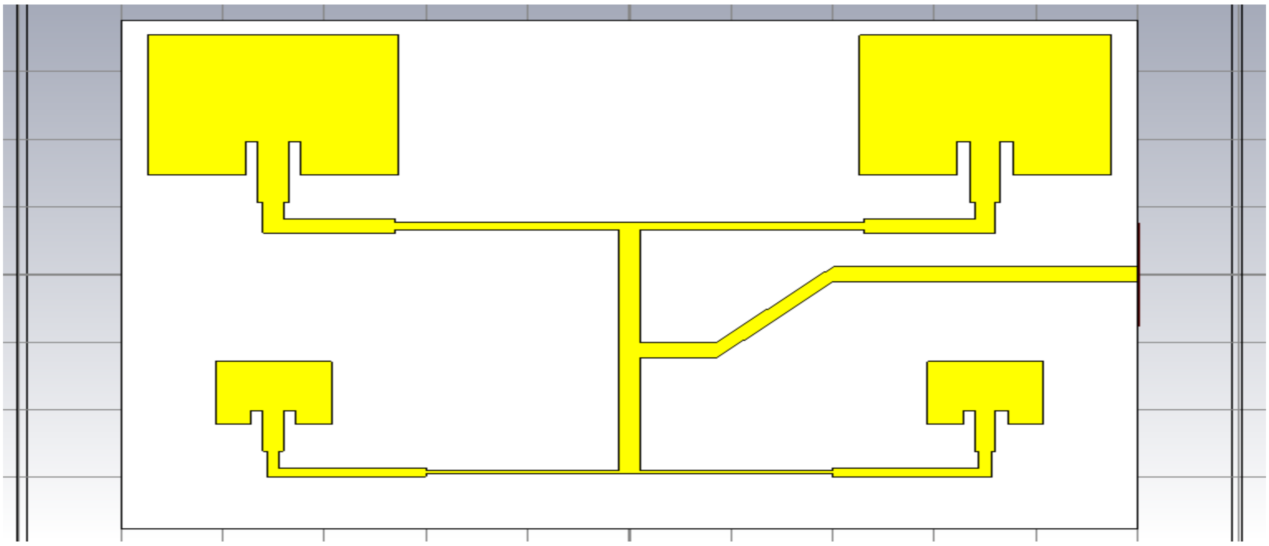

Figure 2. 2 x 2 array antenna

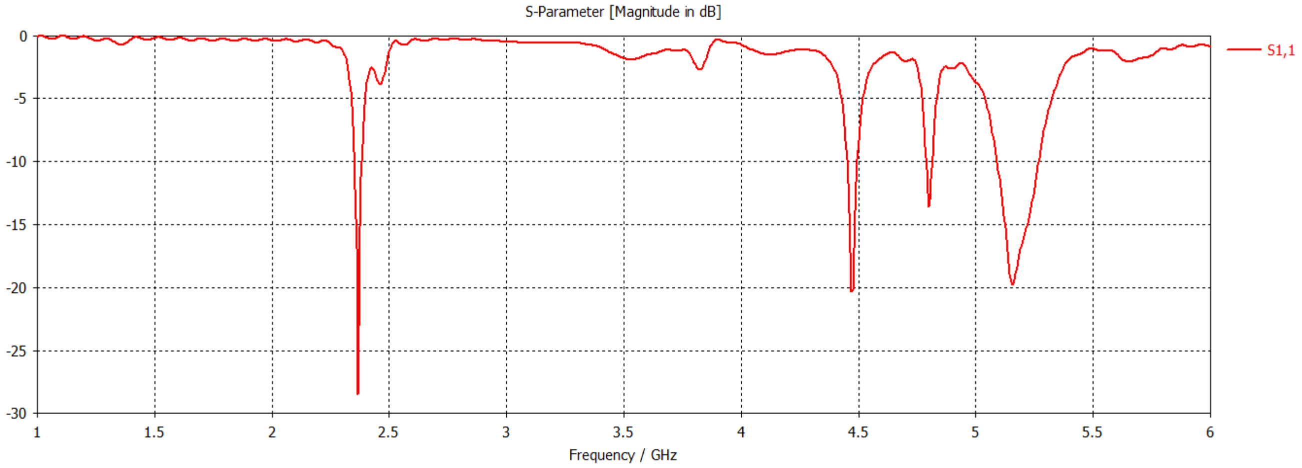

Fig 3: Return loss of 1 x 2 array antenna

The return loss plots of the two proposed dual band RMSA arrays are given in Figures 3 and 4. It is observed that a maximum return loss of -22.923 dB and -24.569 dB yielding a bandwidth of 42.4 MHz and 144.19 MHz at 2.4 GHz and 5.2 GHz, respectively by the proposed 1 x 2 array antenna was achieved. Also, a return loss of -26.2992 dB and -11.5756 dB was achieved at 2.4 GHz and 5.2 GHz respectively by the 2 x 2 array antenna and a bandwidth of 35.1 MHz and 412.3 MHz at 2.4 GHz and 5.2 GHz, respectively were achieved.

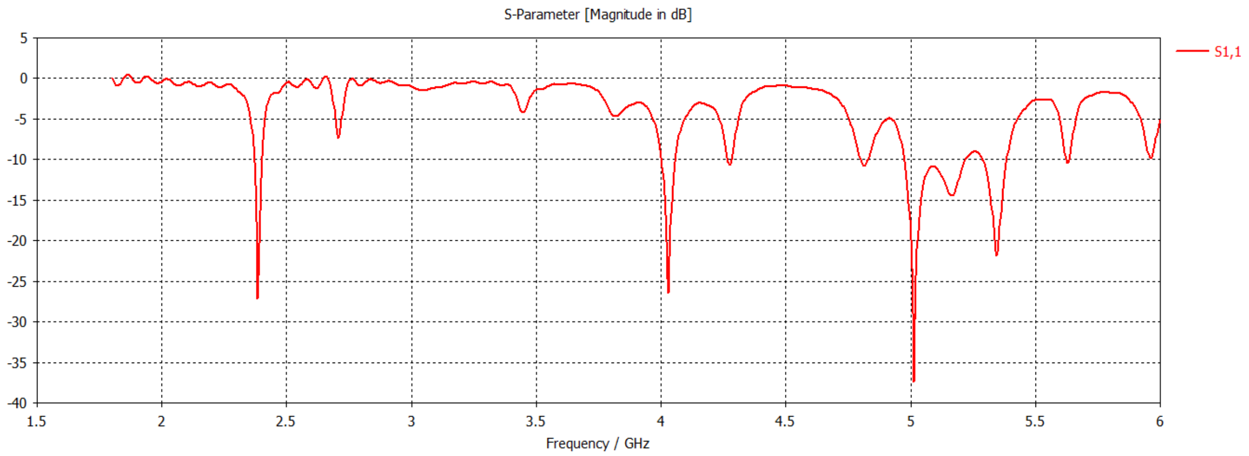

Figure 4. Return loss of 2 x 2 array antenna

The gain of the 1 x 2 dual band RMSA array is shown in Figures 5 and 6. A gain of 6.06 dB and 7.56 dB was achieved at 2.4 GHz and 5.2 GHz, respectively. Figures 7 and 8 show the gain of the designed 2 x 2 antenna array. From the figures, an increase in gain is noticeable in comparison with the 1 x 2 array antenna. A gain of 9.25 dB and 8.66 dB at 2.4 GHz and 5.2 GHz, respectively.

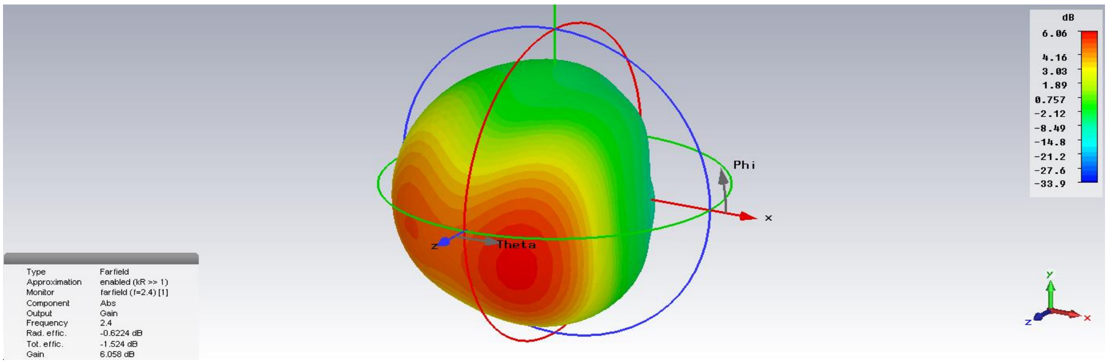

Figure 5. Gain of proposed 1 x 2 array antenna at 2.4 GHz

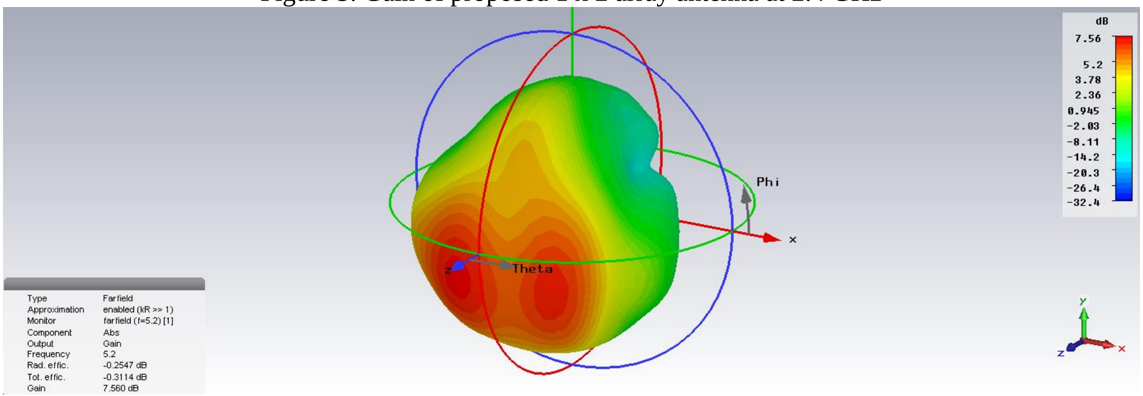

Figure 6. Gain of proposed 1 x 2 antenna array at 5.2 GHz

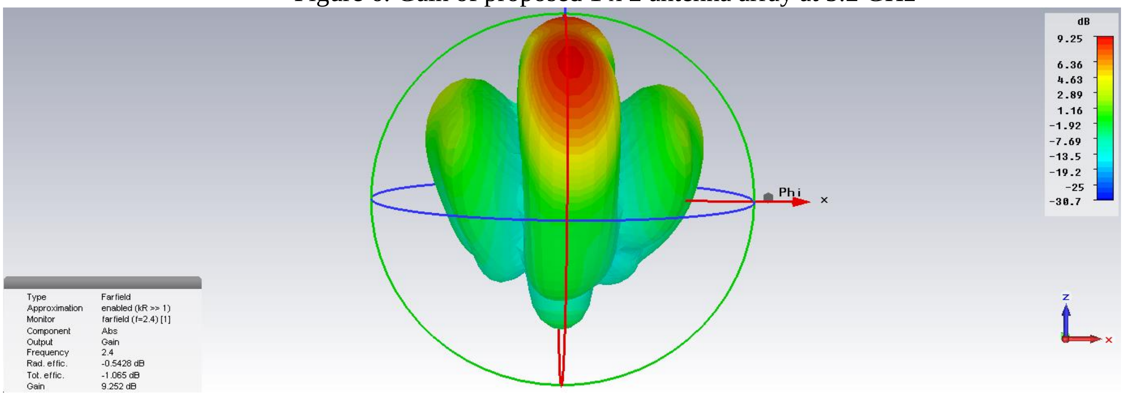

Figure 7. Gain of proposed 2 x 2 array antenna at 2.4 GHz

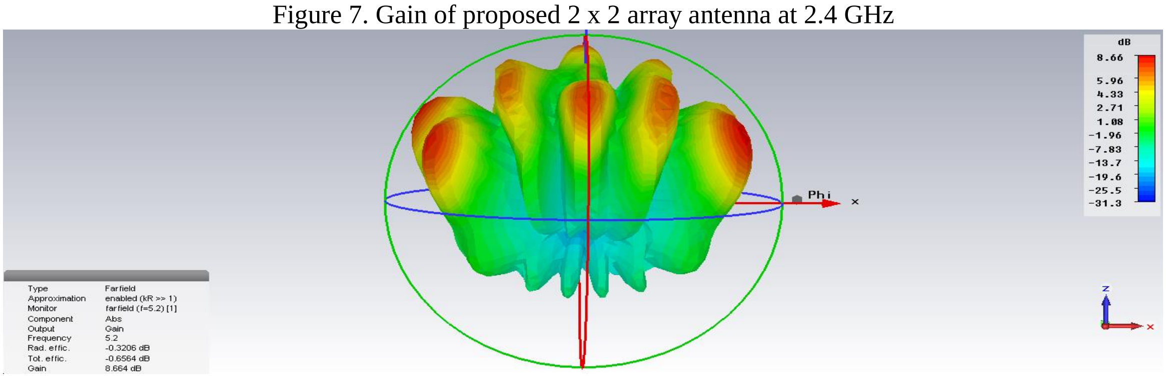

Fig 8: Gain of proposed 2 x 2 array antenna at 5.2 GHz

DISCUSSION

The performance of both antennas designed shows that the higher the number of microstrip elements, the higher the gain of the antenna as illustrated in Figure 5 to Figure 8.

CONCLUSIONS

The design and simulation of two dual band microstrip antenna arrays has been presented. The array antennas showed a superior gain performance in comparison to single patch antennas with typical gain of between 1 – 5 dB. From the return loss plot shown it was shown that the antennas proposed also has the capacity to operate with addition frequency band when incorporated into it.

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