Design and Simulation of Rectangular Microstrip Patch Antenna Arrays Operating at Ku-band For Satellite Communication Applications

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Abstract- Conventional microstrip patch antenna's has a small size, but it has low gain, therefore, it not convenient for long distance communication. For conventional applications that require high gain mostly depends on parabolic antennas and arrays antennas. The objective of this paper is to design, and simulation rectangular microstrip patch array antenna to improve the gain for satellite applications working at the operating frequency in Ku_band frequency range from 12 GHz to 18 GHz. Therefore, an analysis of the performance of a single and four planar array antennas are designed at resonant frequency 12GHz using high frequency structure simulator (HFSS) simulation tools. In our simulations, RT/duirod is used as dielectric material with low relative permittivity of 2.2 and loss tangent 0.0009. Moreover, in order to improve the gain of the proposed antenna, four-element (4x1) array antenna is exploited. The simulation results confirm that the return loss is -21.30dB, VSWR is 1.18, gain is 12.79dB, directivity is 12.89dBi, Bandwidth is 830 MHz (7.1%) at 12 GHz, efficiency 99% and beamwidth at 3dB is 32 at 0 °. As a result, these results can be used in Ku-band for satellite communication applications.

Keywords – micro strip patch antenna, ku-band, four-element array antenna, satellite communication.

I. INTRODUCTION

In modern wireless communication system, low profile, light weight, high gain, and simple structure antennas to guarantee reliability, mobility, and high efficiency characteristics are required [1]. Therefore, microstrip antenna satisfies such requirements. The microstrip antenna key features are ease of fabrication, light weight, low cost. Microstrip antenna provides all of the advantages of printed circuit technology. These advantages of microstrip antennas make them popular in many wireless communication applications such as satellite communications [2]. The limitations of microstrip antennas are narrow frequency band and low gain and disability to operate at high power levels of waveguide, coaxial line or even stripline. These limitations reduce radiation efficiency, therefore, the challenge in microstrip antenna design is to increase the gain and other parameters such as VSWR, return loss and bandwidth . The high gain is obtained using matrices with a number of elements and is the subject of our paper. In this paper, the design of rectangular patch antenna and four element (4x1) rectangular microstrip patch antenna arrays with microstrip line as feeding method is presented. Quarter-wave transformer is used to match the feeding line to the antenna. The center frequency is determined to operate at Ku band range frequency which is suitable for satellite communications application .

Papers [3], [4] and [5] have tried to increase the gain with the use of antenna arrays. However, such studies still lack to achieve an optimum array that provides high gain with minimal number of array elements for low cost and small size design. The optimum design proposed in this paper is attained through many stages, starting from the careful selection of single element with low cost substrate material (RT/duroid), selecting proper array geometry, and forming four of elements that achieve high gain and directivity with reduced side lobe level through optimized inter-element spacing. In its most basic form, a microstrip patch antenna is a single-layer design which consists of a metal patch on top of a grounded dielectric substrate, as shown in Figure 1.

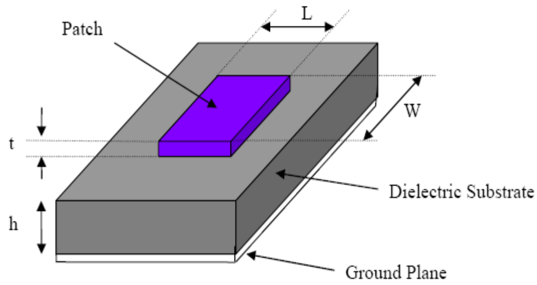

Fig. 1. Basic structure of Rectangular Microstrip antenna.

The basic antenna element is a strip conductor of length (L) and width (W) on a dielectric substrate with constant ε_r , thickness or height of the patch being (h) with a height and thickness (t) is supported by a ground plane. The rectangular patch antenna is designed so as it can operate at the resonance frequency. The length that is for the patch does depend on the height, width of the patch and the dielectric substrate. In order to simplify dissection and execution prediction, the patch is generally circular, square, rectangular, and triangular. When designing a rectangular patch, the length of the patch is usually $0.3\lambda o < L < 0.5\lambda o$ [6], where λo is the free-space

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wavelength. The patch is selected to be very thin such that t << λ_0 (where *t* is the patch thickness). The height h of the dielectric substrate should be in the range $0.003\ \lambda o \leq h \leq 0.05\ \lambda o$. The range of the value of the dielectric of the substrate (ε_r) is normally in the range $2.2 \leq \varepsilon_r \leq 12$ [6]. The most desirable substrate for good antenna performance are normally thick substrate whereby the dielectric constant is at the lower end This is due to the fact that the this range provide better performance compared to thin substrate . RT Duroid 5880 was originally chosen as the substrate as it has a low loss tangent which will not reduce the antenna efficiency, and has a relatively low dielectric constant .

In this paper, we present analyzing and modeling an proposed 4x1 array rectangular microstrip patch antenna shape was designed and simulated by HFSS V13 (High Frequency Structure Simulator) software for improve antenna gain and other characteristics such return loss VSWR, directivity. Rectangular microstrip Patch Antenna configurations are simulated with the microstrip line with edge feed. The proposed antenna operates on wide band frequency range 12GHz that supports applications of satellite communications.

II- MICROSTRIP ANALYSIS BASED ON MATHEMATICAL TRANSMISSION LINE MODEL

In this paper will use the transmission line model to analyze the rectangular shape of the antenna [6]. Easy to analyze and more accurate .The Performance of the microstrip antenna depends on its dimension. Figure 2 shows the geometry of microstrip rectangular patch antenna.

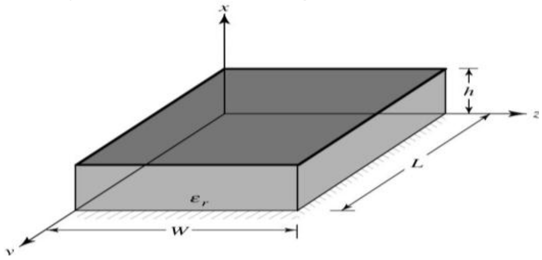

Fig.2. Geometry of microstrip rectangular patch**.**

Based on the transmission line model, the dimension of the rectangular patch antenna, of length L and W can be calculated using the following formulas:

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

Where, c is the speed of light in free space, ε_r is the dielectric constant of substrate and f_r is the resonant frequency. Then, The length of the antenna becomes

$$L = (L_{eff} - 2\Delta L), \quad (2)$$

where

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

and

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\ \frac{1}{\sqrt{1+12\frac{h}{W}}}, \quad (4)$$

where, h is the height of dielectric substrate and the resonant frequency f_r of the rectangular patch antenna ,it can be calculated using the following formula

$$f_r = \left(\frac{c}{2L\sqrt{\varepsilon_{eff}}}\right), \quad (5)$$

where, ε_{eff} is the effective dielectric constant. Then we can find the width of ground plane W_g and length L_g using equations :

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

$$L_g = 6h + L \quad (7)$$

III- DESIGEN OF SINGLE ELEMENT PATCH ANTENNA

The rectangular patch antenna applied on the dielectric material RT/ duirod with relative permittivity $\varepsilon r = 2.2$, tangent loss $\delta = 0.0009$ and thickness h = 1.56mm. The dimensions of the rectangular patch antenna slots are shown in the Table 1. The bandwidth of this antenna is between (12GHz - 18GHz) that supports the ku- band satellite commutations application. This section discusses such geometry and establishes some of the design parameters that directly apply to the final model. The antenna is shown in Figure 3, whose dimensions were calculated according to the transmission line model equations as mentioned in above section and by using mathematical calculation for patch dimensions. The specifications of the rectangle antenna are listed in Table 1.

Table 1. Design parameter specifications of the 12 GHz microstrip antenna

PARAMETERS	VALUES
Resonant frequency (f_r)	12GHz
Width of the patch (W_p)	9.88mm
Length of the patch (L_p)	7.36mm
Height of the dielectric substrate (h)	1.56mm
Substrate material	RT/Duirod5880
Dielectric constant (ε_r)	2.2
Effective dielectric constant (ε_{eff})	1.95
Length extension (ΔL)	0.808 mm
Width of the ground plane (W_g)	19.24mm
Length of the ground plane (L_g)	16.72mm
Feeding method	Microstrip line

We will feed the antenna across the edges, a microstrip line feeding at the edge. Figure 3 below shows a single microstrip patch antenna which consists of patch, quarter wave transformer and feedline 50omh .

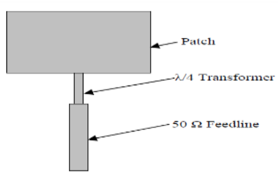

Fig. 3. Patch antenna with quarter-wave transformer.

The feedline will be fed to the patch through a quarter-wave transformer matching network. Table 2. below shows all the dimensions of microstrip line impedance edge fed.

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Table 2. Shows the edge feed line dimensions for a single rectangular patch antenna.

PARAMETERS	VALUE
Edge feed width (W_q)	1.987mm
Edge feed length (L_q)	4.324mm
Width of the 50Ω feed line (W_f)	4.89 mm
Length of the 50Ω feed line (L_f)	4.324mm
Quarter Wave transformer impedance (Z_q)	86Ω
Input edge impedance of the patch (R_{in})	150Ω
characteristics Input impedance (Z_{in})	50Ω

After simulation and analysis using HFSS Software, the final dimensions are shown in the Figure 4

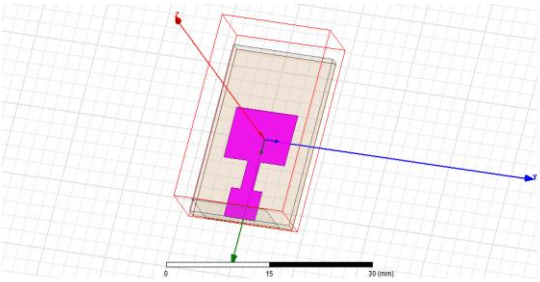
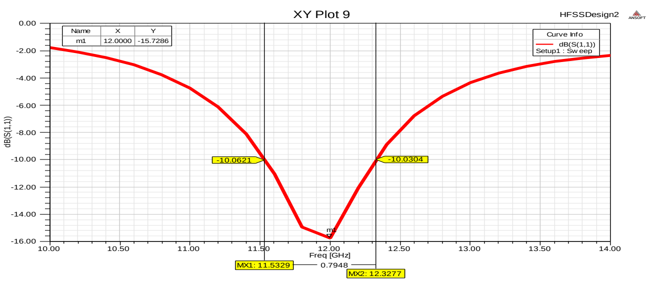


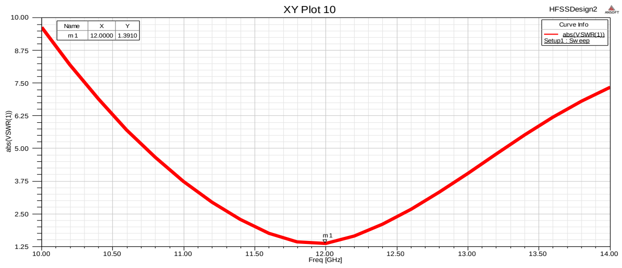
Fig 4. Shows the geometry of the proposed rectangular microstrip patch antenna at 12GHz.

IV-SIMULATION RESULTS OF SINGLE PATCH ANTENNA

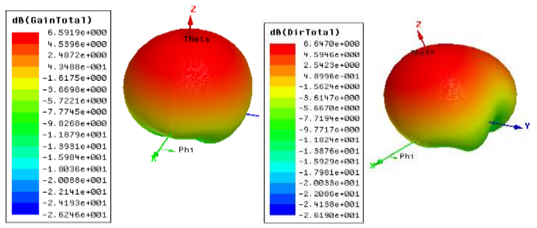
Figure 5 (a), it denotes the reflection coefficient of the transmitted power in the antenna. The minimum return loss (S11) is -15.72dB at 12GHz. Also, at -10dB return loss the bandwidth is between 11.53 GHz to12.32GHz. Hence, the antenna has the fractional impedance bandwidth 6.5%. Ideally, the value of VSWR for operating frequency must be less than 2 (VSWR≤2). Figure 5 (b) shows the value of minimum VSWR of the rectangular single antenna is 1.39. There are two important parameters gain and directivity that are effected on the performance of the antenna have been obtained 6.59dB and 6.64dBi, respectively, as in Figure 5(c). From these result we can say that proposed antenna don't exploit well the ku band satellite communication applications. Here, the color red denoted the maximum value for gain and directivity. Figure 5 (d) shows, maximum gain in 2D plots at the resonant frequency 12 GHz and beamwidth is about 78° at 0deg.



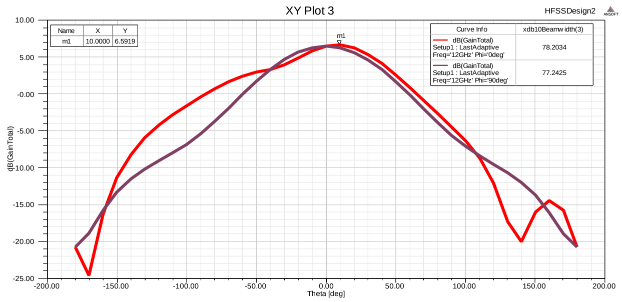
(a)



(b)



(c)



(d)

Fig 5. Return Loss (S11) (a) VSWR vs Frequency (b) 3_D Gain and directivity (c) 2_D gain antenna at12GHz.

Current distribution *J* is an important property of microstrip antennas. The current distribution for simulated rectangular micro strip patch antenna at 12GHz is as shown in figure 6 , which shows that the maximum value of current is 56 A/m, at the resonant frequency. The red color refers to the current intensity at the edges of the patch.

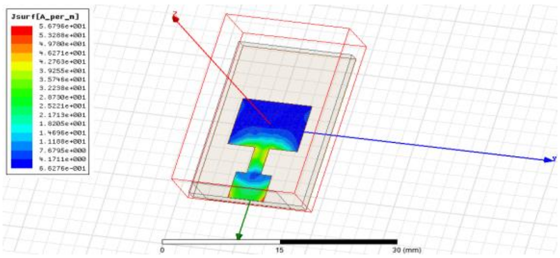


Fig.6. Current distribution on patch antenna at 12GHz.

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The single element rectangular microstrip patch antenna cannot satisfy the gain and other characteristics for many wireless communication systems. Furthermore, single microstrip patch antennas are not suitable for applications which need high gain, beam scanning and large bandwidth. Therefore, the performance of the single microstrip patch antenna in terms of low gain is improved in this paper by implementation of single patch antenna in array configurations. This Array have relatively simple structure, light weight, small lateral dimensions, wideband, high efficiency, and provide increase signal-to-noise ratio (SNR) and high gain characteristics[1]. They are excellent candidates for array applications. In this work the elements of an array may be spatially distributed to form a planar array and feeding method (microstrip line fed), that are employed to feed microstrip array are parallel and quarter-wave transformer methods . The microstrip lines are split the power by using symmetrical T-junction power dividers .

V. DESIGEN OF 4X1 MICROSTRIP ANTENNA ARRAY FOR SATELLITE COMMUNCATION APPLICATIONS

In this section, the high gain antenna array using four element (4x1) and motivated with edge-feeding is proposed and applied for ku-band satellite commutation applications to increase directivity, gain, and efficiency and have better radiation patterns using 4x1 linear microstrip arrays.

a)- proposed antenna description

This proposed paper a 4X1 array of rectangular micro strip patch antenna is designed to achieve higher gain, better directivity , and improved bandwidth of the antenna array. Because single antenna is not enough to achieve high gain, directivity and it has limited bandwidth. This antenna has been designed to operate at 12GHz with input impedance of 50Ω, using the same values of height of the dielectric substrate (h=1.56mm) and the same dielectric material (RT/duirod). With use of the same patch dimensions (9.88 mm x 7.36 mm) at the same frequency with microstrip line feed. The power divider technique is used for feeding 4x1 antenna array to equal power in every antenna element.

b)- Feed Networks

A corporate feed is most widely used parallel feed configuration. For a uniform aperture distribution, the power is equally split at each junction [7]. In our design of the proposed 4x1 array it is feed by a symmetrical one dimensional parallel (corporate) feeding arrangement with proper impedance matched network. In this design, all the patches are connected to 100Ω lines each. The equivalent at the junctions of each pair is 50Ω. A quarter wave transformer is placed between a 50Ω equivalent point and 100Ω line whose resultant impedance is calculated as $Z_q = \sqrt{50 * Z_0} = \sqrt{50 * 100}$ = 70.7Ω [7]. Finally two pairs of 100Ω lines from each side result in an equivalent of 50Ω where the edge feeding is considered. The distance between the two elements equal to $0.57\lambda_0$ from the center between two patches and it was calculated accurately, to avoid mutual coupling between patches elements. The following Table 3 displays the dimensions of the power division and the feeding elements after they have been calculated. They will be entered into the HFSS simulation program for the design. Figure 7 below presents the impedance for individual lines in the four element rectangular array antenna.

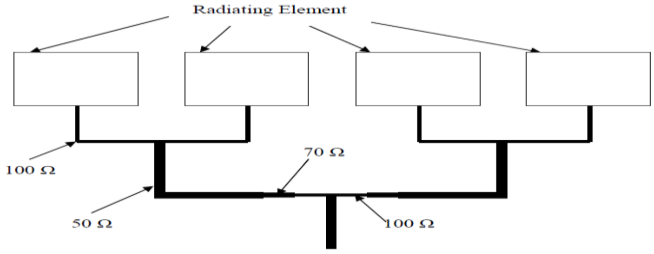

Fig.7. Four elements array line impedance design layout.

Table 3. power divider dimensions for the 4x1 array antenna.

PARAMETERS	VALUE
Width of the ground plane (W_g)	55.12mm
Length of the ground plane (L_g)	30.76mm
Width of the 70.7Ω feed line	4.47mm
Length of the 70.7Ω feed line	2.63mm
Width of the 100Ω feed line	1.32mm
Length of the 100Ω feed line	4.47mm
Width of the 50Ω feed line (W_f)	4.8mm
Length of the 50Ω feed line (L_f)	4.47mm
Impedance of garter wave transform	70.7Ω
Inter-element spacing (S)	0.57λo

At the end of the design, the dimensions that were calculated are entered into the simulation program for the proposed antenna design with the corporate –feeding. We obtain a good design of four elements. Figure 8 depicts the configuration of 4x1 rectangular microstrip patch antenna arrays.

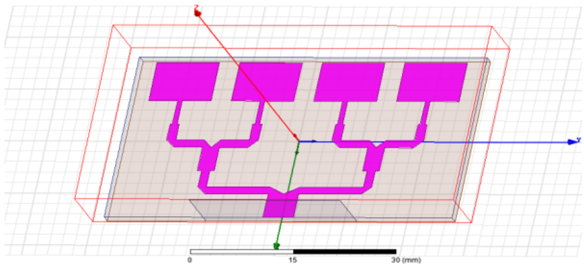
Fig .8. Proposed 4x1 Element array antenna at 12GHz.

VI. SIMULATION RESULTS OF 4X1 ARRAY

From the return loss graph as shown in Figure 9 (a), is appear that the minimum return loss is -21.30 dB at 12GHz, we note, the reflection coefficient is best in 4x1 array which means good matching obtained in this case. Also, at below -10dB return loss the bandwidth is between 11.47GHz to12.32GHz. Hence, the antenna has bandwidth 830MHz and fractional bandwidth (FBW= 7.1%) at 12GHz. This shows that the array antenna has increase the bandwidth of the

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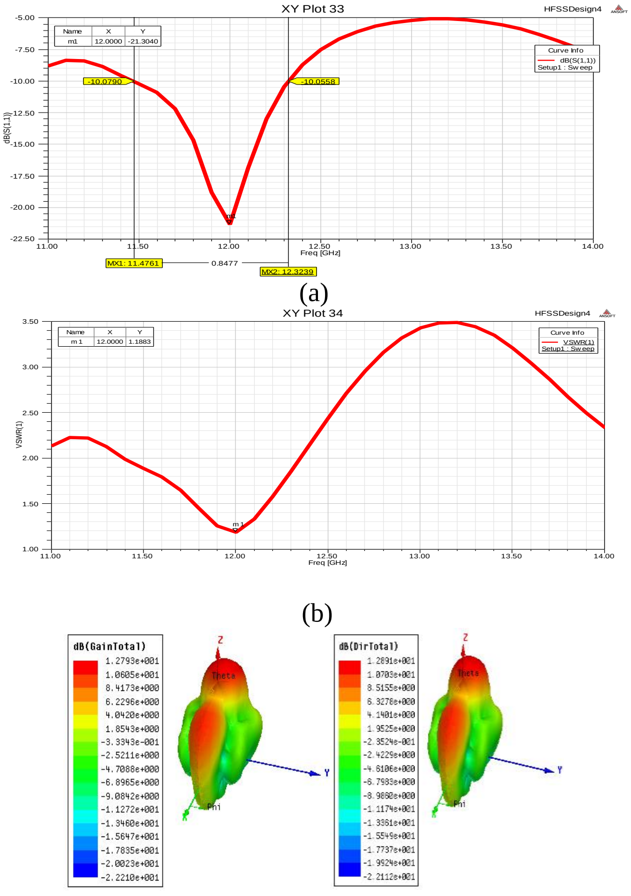
antenna as compared to the single rectangle antenna. It is observed from the VSWR curve in Figure 9 (b) that, the value of minimum VSWR is 1.18 which means a good matching and the value clearly meets the antenna design requirements for ku band satellite communication applications. The Figure 9 (c), demonstration the gain and directivity that are obtained from array antenna, 12.79dB and 12.89dBi, respectively. High gain and directivity values indicates that the antenna's efficiency is high up to 99%. Both gain and directivity for the 4x1 rectangular shape are increasing as the number of array elements is increased, hence, the gain and directivity are significantly increased compared to the single element patch antenna.



(a) (b) (c)

Fig. 9. (a) Return Loss (b) VSWR (c) 3D Gain and directivity

Figure 10 depicts the simulated radiation pattern with peak gain of 12.79 dB for proposed antenna configuration at 12GHz.

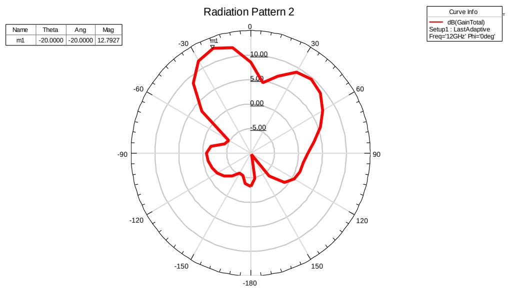


Fig.10. Radiation pattern for 4x1 antenna array at Phi = 0.

From Figure 11, the maximum gain value represented by the 2_D curve is 12.79dB at maximum point m1. Equal to the maximum gain value in 3D plot represented in Figure 9 (c) and Half power Beamwidth (HPBW) (32° at ϕ = 0) at 12GHz. Radiation pattern E and H -plane for 4x1 array at phi = 0 & 90 degree give peak gain at φ=0. It can be concluded that the array design antenna generates more intensity or focus at the center of the radiation. The beamwidth for patch array antenna obtained was 22 degrees in E-plane and 32 degrees in H-plane.

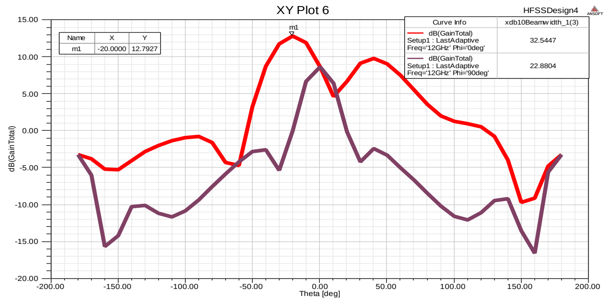


Fig.11. 2_D gain for antenna array at Phi = 0 & 90 degree.

The following Figure 12 represents radiation pattern in both directions E , H plane, which represents the maximum gain value.

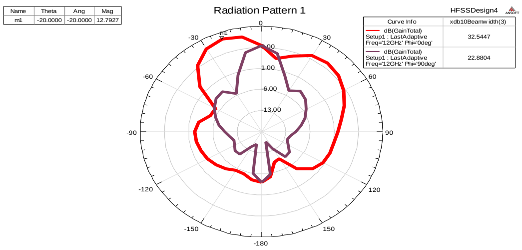


Fig.12. Radiation pattern E and H-plane for 4x1 array at phi = 0&90 degree.

Using the HFSS simulator we displayed the input impedance of the designed antenna which is shown in Figure 13, the input impedance of the antenna at the resonant frequency 12GHz is 50.8Ω. The system is perfectly and very less power reflected and the antenna is well matched to 50Ω at12 GHz. Simulated results satisfy the requirements of ku_band satellite communication applications.

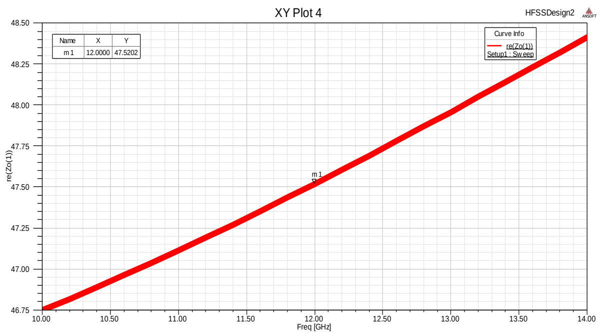


Fig13. Impedance matching of 4x1 antenna array at 12GHz..

Figure 14 , illustrates the current distribution of four elements. It is clear from the figure that the amount of current

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declines at the patch of elements. Also, the current distribution pattern at 12GHz is 88 (A/m).

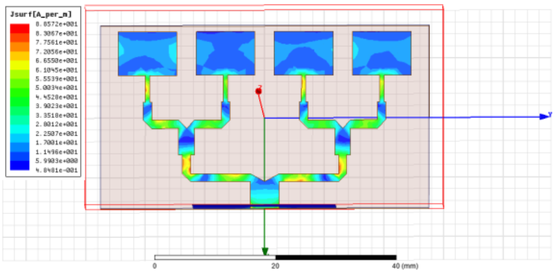

Fig.14 Current distribution of four elements using simulation model.

IV- COMPARTION BETWEEN SINGLE AND FOUR ARRAY.

From the simulation results, we can summarize the results as a comparison table between the single antenna and the antenna of four elements

Table 4. Parameter comparison between arrays & single element of rectangular patch

PARANETRES	SINGLE PATCH	4X1 ARRAY ELEMENS
Gain dB	6.59dB	12.79dB
Directivity dBi	6.64dBi	12.89dBi
Return loss dB	-15.72dB	-21.30dB
VSWR	1.39	1.18
FBW	6.5%	7.1%
HPBW	78°	22°

From the Table 4, the comparison between the single element and four elements array antenna with corporate feed , we have clearly seen, that the four elements array antenna has the better gain and improved directivity over the single element antenna. Also, four elements array antenna shows the best return loss, VSWR, directivity, bandwidth and beamwidth. For example, in this proposed 4x1 array antenna has optimal gain which about 12.79dB, which means approximately 6dB improvement. Moreover, the directivity of 4x1 array improved by about 6dBi. Also, four elements array antenna has minimum return loss which about -21.3dB, this means less reflected power. Furthermore, 4X1 antenna has bandwidth 830MHz and fractional bandwidth (FBW= 7.1%). The improvement in these parameters lead to effective performance of four elements antenna. This antenna can therefore meet the various requirements for ku band satellite communication applications.

VII. CONCLUSION

Microstrip patch antenna arrays of rectangular shaped radiating elements were successfully designed and implemented using the RT/duirod substrate material. The result confirmed that the gain of the 4x1 microstrip patch antenna arrays increased the gain compared to single rectangular patch antennas over Ku_band of frequencies. The problem of low gain by single element rectangular antenna has had resolved by the proposed rectangular micro strip patch antenna array. The gain obtained by array method was much higher than single element antenna. The gain was achieved approximately 6 dB higher than the single element antenna. This concluded that the gain value increased when the number of patch elements was increased. This antenna can therefore meet the various requirements successfully for ku_band satellite communication applications .

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