



# DESIGN AND ENHANCEMENT BANDWIDTH RECTANGULAR PATCH ANTENNA USING SINGLE TRAPEZOIDAL SLOT TECHNIQUE

Karim A. Hamad

Department of Electronics and Communications, College of Engineering, Al- Nahrain University, Iraq

E-Mail: [abdulakarim333@yahoo.com](mailto:abdulakarim333@yahoo.com)

## ABSTRACT

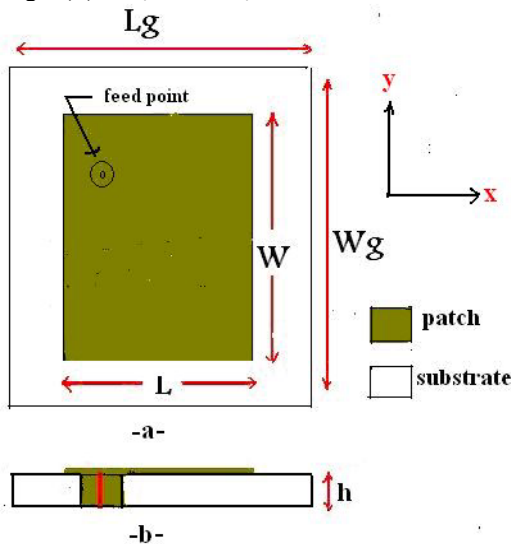
Microstrip patch antennas has some drawbacks of low efficiency, narrow bandwidth (3-6%) of the central frequency, its bandwidth is limited to a few percent which is not enough for most of the wireless communication systems nowadays. In this paper one of the efficient methods used for the enhancement of patch antenna bandwidth is the loading of microstrip patch antenna with a trapezoidal slot. Microstrip patch antenna that meets the requirement of operation at 2.4 GHZ, the proposed configurations is simulated and analyzed using (CST- 2010) software package. The VSWR, input impedance, radiation patterns and S11 performance are used for the analysis of the different configurations. The simulated results for trapezoidal slot give bandwidth of 287.2 MHZ (11.93% fractional bandwidth). Feed point on the patch that gives a good match of 50 ohm.

**Keywords:** bandwidth, RMPA, design, enhancement, trapezoidal, slot.

## 1. INTRODUCTION

Microstrip antennas are popular for their attractive features such as low profile, low weight, low cost, ease of fabrication and integration with RF devices. The major disadvantages of Microstrip antennas are lower gain and very narrow bandwidth [1, 2, 3]. This paper presents the use of transmission line method to analysis the rectangular microstrip antenna [4]. RMPA operating of resonance frequency (2.4 GHZ) for TM10 mode, with the coaxial probe feed used, the antenna is matched by choosing the proper feed position [5].

RMPA is characterized by its length (L), width (w) and thickness (h), as shown in Figure-1. It is of a very thin thickness,  $h \ll \lambda_0$ , usually  $0.003\lambda_0 \leq h \leq 0.05\lambda_0$ , where  $\lambda_0$  is free space wavelength above aground plan [6]. For rectangular patch, the length (L) of  $\lambda_0/3 < L < \lambda_0/2$ :



**Figure-1.** Designed rectangular patch antenna (a) front side (b) bottom side.

## 2. ANALYSIS AND MODELING OF RMPA

It is useful to model the microstrip antenna as a transmission line. This model is the simplest of all and it gives good physical insight but it is less accurate.

In this model the MSA can be represented by two slots of width (w) and height (h) separated by transmission line of length (L). The width of the patch can be calculated from the following equation [7].

$$W = \frac{c}{2f_0 \sqrt{\epsilon_r + 1}} \tag{1}$$

The effective dielectric constant ( $\epsilon_{eff}$ ) is less than ( $\epsilon_r$ ) because the fringing field around the periphery of the patch is not confined to the dielectric speared in the air also.

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \sqrt{\frac{1}{1 + 12 \frac{h}{W}}} \tag{2}$$

In order to operate in the fundamental TM10 mode, the length of the patch must be slightly less than  $\lambda/2$  where  $\lambda$  is the wavelength in the dielectric medium. The difference in the length ( $\Delta L$ ) which is given empirically by [8, 9] is given below.

$$\Delta L = 0.412 h \frac{(\epsilon_{eff} + 0.3) \left(\frac{W}{h} + 0.264\right)}{(\epsilon_{eff} - 0.258) \left(\frac{W}{h} + 0.813\right)} \tag{3}$$

$$L_{eff} = \frac{c}{2f_r \sqrt{\epsilon_{eff}}} \tag{4}$$

Where  $c$  = speed of light,  $L_{eff}$  = effective length,  $f_r$  = resonance frequency,  $\epsilon_{eff}$  = effective dielectric constant.

$$L = L_{eff} - 2\Delta L \tag{5}$$



**3. DESIGN CONSIDERATION OF RMPA**

**Step-1: Substrate selection**

The first step in the design is to choose a suitable dielectric substrate of appropriate thickness (h) and loss tangent. A thicker substrate, besides being mechanically strong it will increase the radiated power, reduce the conductor loss and improve impedance bandwidth [9].

**Step-2: Width and length parameters**

A larger patch width increases the power radiated and thus gives decreased resonant resistance, increased BW and increased radiation efficiency. With proper excitation one may choose a patch width (W) greater than patch length. It has been suggested that  $1 < W/L < 2$  [10, 11]. In case of microstrip antenna, it is proportional to its quality factor Q and given by [12] as:

$$BW = \frac{VSWR - 1}{Q \sqrt{VSWR}} \dots \dots \dots (6)$$

The percentage bandwidth of the rectangular patch microstrip antenna in terms of patch dimensions and substrates parameters is given as follows [12].

$$BW \% = \frac{Ah}{\lambda_0} \sqrt{\frac{W}{L}} \dots \dots \dots (7)$$

Where

$$A = 180 \text{ for } \frac{h}{\lambda_0 \sqrt{\epsilon_r}} \leq 0.045$$

$$A = 200 \text{ For } 0.045 \leq \frac{h}{\lambda_0 \sqrt{\epsilon_r}} \leq 0.075$$

$$A = 220 \text{ For } \frac{h}{\lambda_0 \sqrt{\epsilon_r}} \geq 0.075$$

Where

- h = substrate thickness
- $\lambda_0$  = wavelength in the substrate
- $\epsilon_r$  = dielectric constant of the substrate
- w = width of patch dimension
- L = length of patch dimension

**4. DESIGN PARAMETERS OF RMPA**

The dielectric material selected for this design is duroid which has a dielectric constant of ( $\epsilon_r = 4.3$ ), loss tangent ( $\tan \delta$ ) = 0.019, the height of the dielectric substrate is (h = 5.8) mm. the resonant frequency of the antenna must be selected properly. The WIFI applications use the frequency range from (2-3) GHZ, ( $f_0$ ) selected for this design is 2.4 GHZ.

**4.1 Calculation of the width (w):** the width of the equation (1) gives at  $f_0 = 2.4 \text{ GHZ}$ ,  $\epsilon_r = 4.3$ ,  $w = 38 \text{ mm}$

**4.2 Calculation of effective dielectric constant  $\epsilon_{eff}$ :**

Equation (2) gives the effective dielectric constant as: for  $\epsilon_r = 4.3$  and  $f_0 = 2.4 \text{ GHZ}$ , it gives:  $\epsilon_{eff} = 3.632$

**4.3 Calculation of the length extension ( $\Delta L$ )**

Equation (3) gives the length extension as:  
 $\epsilon_{eff} = 3.632$ ,  $f_0 = 2.4 \text{ GHZ}$ ,  $w = 38 \text{ mm}$  and  $h = 5.8 \text{ mm}$

it gives:

$$\Delta L = 2.58$$

**4.4 Calculation of the effective length ( $L_{eff}$ ) as:** for

$\epsilon_{eff} = 3.632$ ,  $f_0 = 2.4 \text{ GHZ}$  it gives:  $L_{eff} = 32 \text{ mm}$

**4.5 Calculation of actual Length of patch (L)**

The actual Length is obtained by equations (5) as:  $L = 26.84 \text{ mm}$

**4.6 Calculation of ground plane dimensions ( $L_g$ ) and ( $w_g$ )** by [13] would be given as:

$$L_g = L + 6 h \dots \dots \dots (8) \text{ then}$$

$$L_g = 61.64 \text{ mm}$$

$$w_g = w + 6 h \dots \dots \dots (9) \text{ then}$$

$$w_g = 72.8 \text{ mm}$$

after going through with the optimization process, the final optimization process, the final optimum parameters for the rectangular microstrip patch antenna were obtained, where the width and length are found 37 mm and 25.29 mm, respectively.

**4.7 Determination of feed point location ( $x_f, y_f$ ):**

Using the equation provided in Bah1/ Bhartia [14].

Feed point location where the input impedance is nearly 50 ohm is

$$y_f = w/2 \dots \dots \dots (10)$$

$$x_f = L / (2 \sqrt{\epsilon_{eff}}) \dots \dots \dots (11)$$

When trial and error are used, it was found the best impedance match at feed position ( $x_f = -6.62$ ,  $y_f = 11.4$ ), at input impedance of (50 + j 0.46) ohm. The software used to model and simulate the RMPA is the (CST - 2010) package, Mesh cells = 263, 004

**5. BANDWIDTH ENHANCEMENT TECHNIQUE.**

Larger bandwidth can be achieved by loading slots within the patch of the antenna and with different shapes, arrangements and sizes the effect of this techniques on increasing the bandwidth is more than using the other techniques [15] to realize compact MSAS there are several techniques, such as higher dielectric constant



substrate, a slot cut inside the patch [16] for broader BW, thicker and lower dielectric constant substrates and single slot cut. A single trapezoidal slot cut in probe feed rectangular patch with dimensions  $(L \times W)(25.29 \times 37)mm$  operating at resonance frequency 2.4 GHz the patch is excited by (50) ohm, coaxial cable at feed position  $(x_f = -6.159, y_f = 10.31)$ , which gives the best matching result in this work. A dielectric substrate of  $\epsilon_r = 4.3$ , with loss tangent = 0.019 has been used, the substrate thickness  $(h) = 5.8$  mm, and mesh cells = 314, 608, by using single trapezoidal slot with dimensions  $(L_s \times W_s)(20.1 \times 2.024)mm$  cut the left radiating edge  $(Z = 22$  mm) from the bottom edge. Figure-2, show the configuration of the probe feed microstrip patch antenna with single trapezoidal slot. Single trapezoidal slot with different dimensions and locations were tested in this work. The performance (BW, radiation patterns) was studied and analyzed for the simulated configurations.

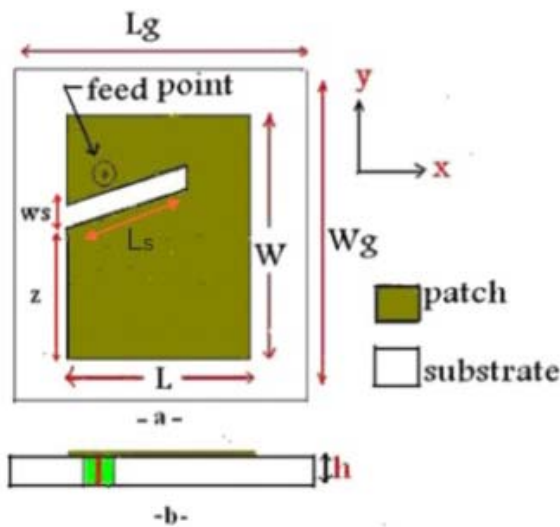


Figure-2. Rectangular patch antenna with trapezoidal slot (a) front side (b) bottom side.

6. SIMULATION RESULTS

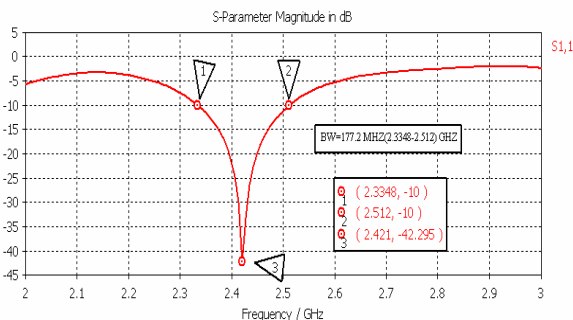
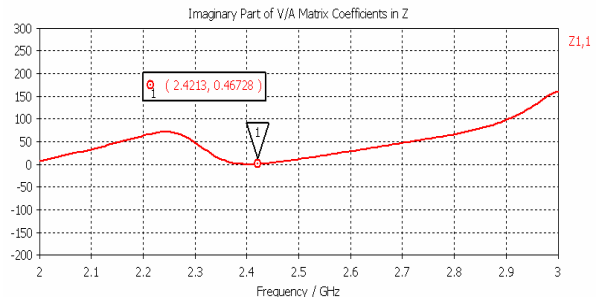
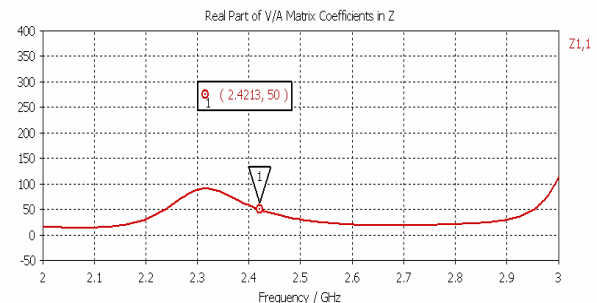


Figure-3. Return loss for designed antenna.



(a)



(b)

Figure-4. The input impedance of the designed antenna (a) imaginary part (b) real part

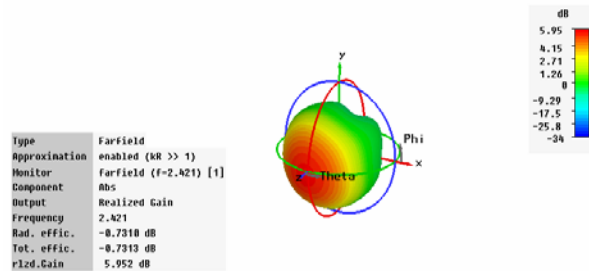
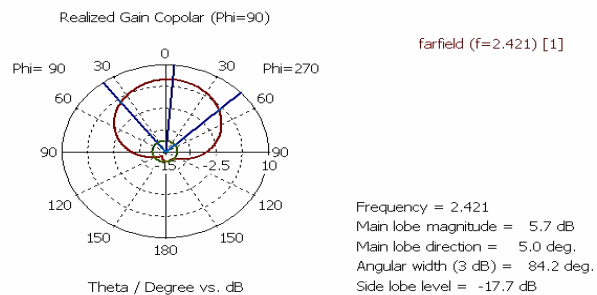


Figure-5. 3D radiation patterns of designed antenna



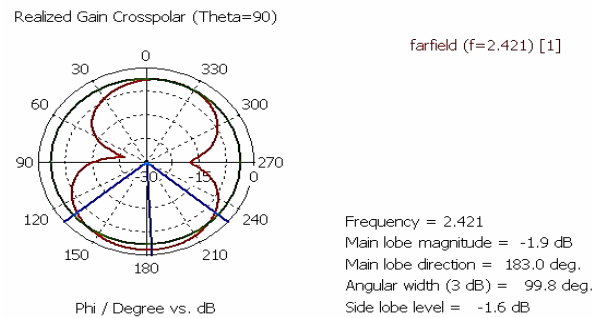
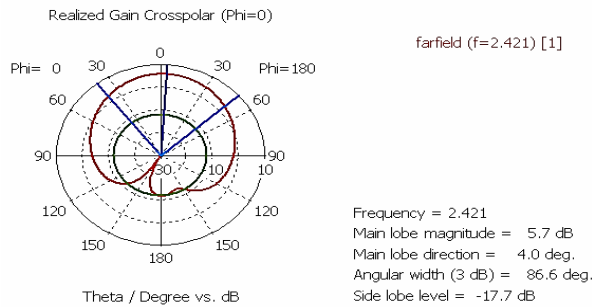
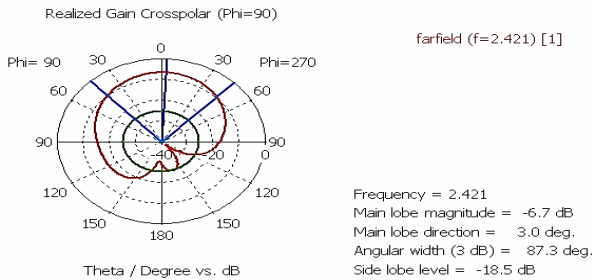
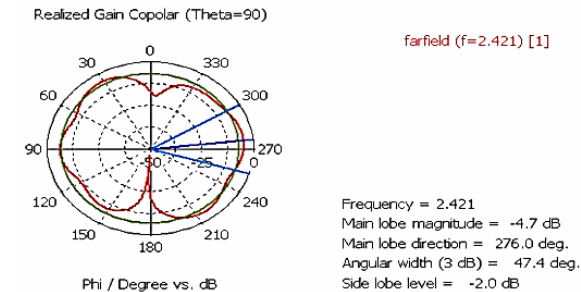
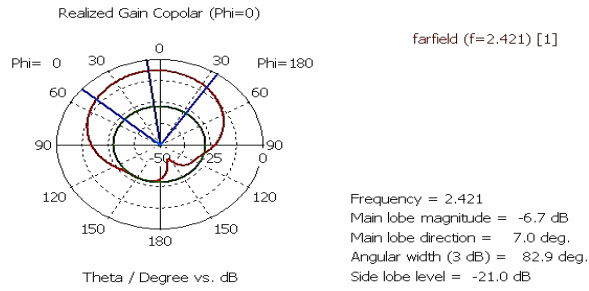


Figure-6. Radiation pattern for designed antenna (a) copolar (b) cross polar

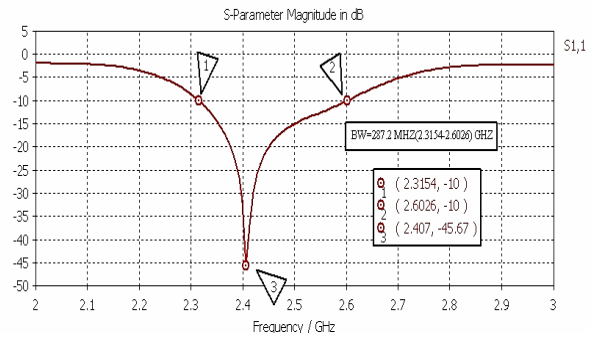


Figure 7. Return loss for Antenna with single trapezoidal slot.

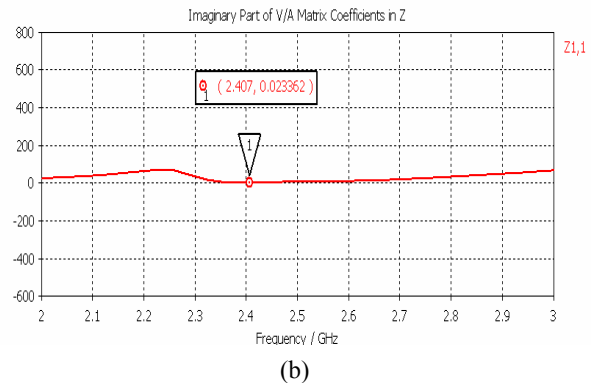
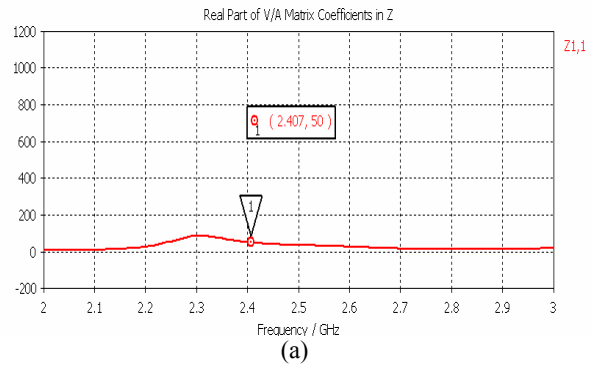


Figure-8. The input impedance of the antenna with single trapezoidal slot (a) real part (b) imaginary part.

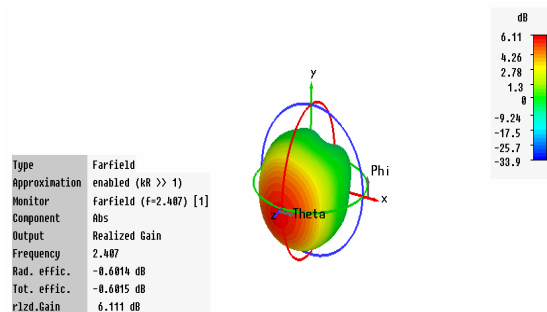
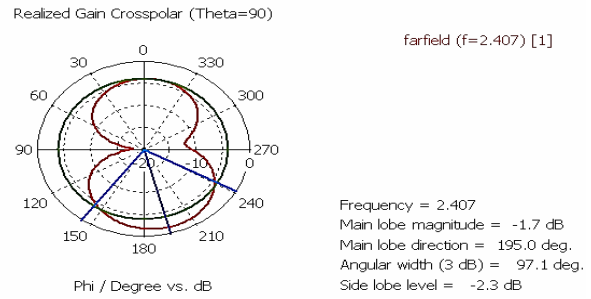
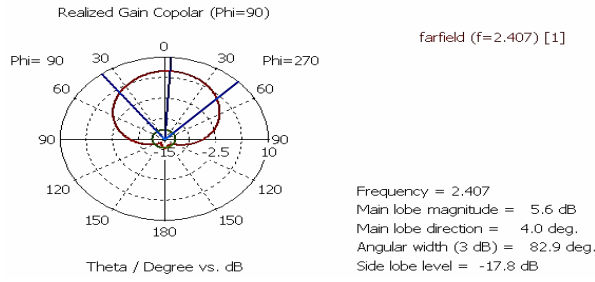


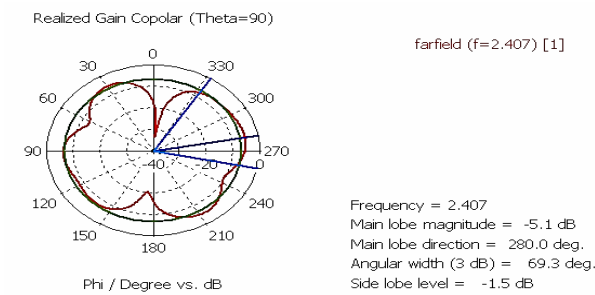
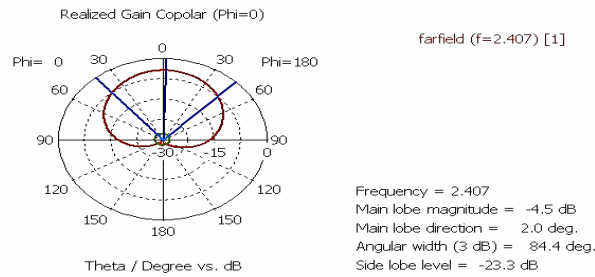
Figure-9. 3D radiation pattern of antenna with single trapezoidal slot.



(b)

**Figure-10.** Radiation pattern for antenna with single trapezoidal slot (a) copolar (b) cross polar.

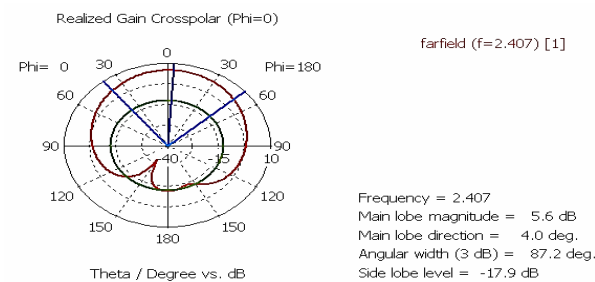
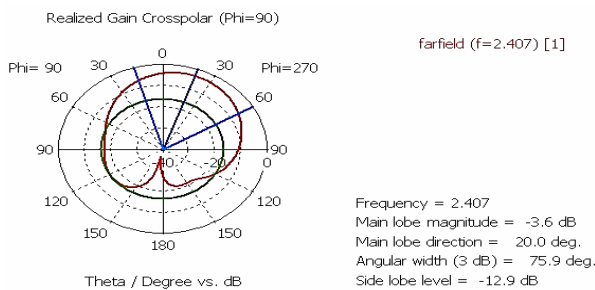
The bandwidth can be calculated from the return loss (RL) plot with Figure-3. The simulated impedance bandwidth of (177.2 MHz, 7.31%) from (2.3348) GHZ to (2.512) GHZ is achieved at (-10 dB) return loss ( $VSWR \leq 2$ ), shown in Figure-7. The simulated impedance bandwidth of (287.2 MHz 11.86 %) from (2.3154) GHZ to (2.6026) GHZ is achieved at (-10dB) return loss ( $VSWR \leq 2$ ).



(a)

**Table-1.** Design specification of designed rectangular patch antenna.

Parameters	Value
Operating frequency	2.4 GHZ
Dielectric constant	FR4 with $\epsilon_r = 4.3$
The thickness of the substrate	$h = 5.8$ mm
Loss tangent ( $\tan \delta$ )	0.019
Length of the patch	$L = 25.29$ mm
Width of the patch	$w = 37$ mm
Location of feed point ( $x_f, y_f$ )	(-6.62 , 11.4)



**Table-2.** Parameters rectangular patch antenna with single trapezoidal slot.

Parameters	Value
Operating frequency	2.4 GHZ
Slot length	$L_s = 20.1$ mm
Slot width	$W_s = 2.024$ mm
Slot distance of the bottom edge	$Z = 22$ mm
Location of feed point ( $x_f, y_f$ )	(-6.159 , 10.31)

**Table-3.** Comparison of designed antenna and antenna with single trapezoidal slot.

Parameters	Designed rectangular patch antenna	Rectangular patch antenna with single trapezoidal slot
Frequency (GHZ)	2.421 GHZ	2.407 GHZ
$S_{11}$ (dB)	-42.295 dB	-45.67 dB
Gain (dB)	5.95 dB	6.11 dB
Bandwidth MHZ	177.2 MHZ	287.2 MHZ
BW%	7.31 %	11.93 %
Input impedance	(50+ j 0.46) ohm	(50+ j0.023) ohm

## 7. CONCLUSIONS

In this paper the rectangular patch Antenna with (50) ohm coaxial feed has been designed. The impedance bandwidth of the designed antenna is 177.2 MHZ (7.31% fractional bandwidth).

Whereas the impedance bandwidth of the antenna with single trapezoidal slot is 287.2 MHZ (11.93 % fractional bandwidth). That means, the bandwidth enhancement is approximately (110 MHZ) higher than that of original case (patch without slot, Bandwidth 177.2 MHZ, 7.31%).

## REFERENCES

- [1] Thomas A. Milligan. 2<sup>nd</sup> Ed. Modern antenna design. pp. 318-354.
- [2] A.K Bhattacharjee, S.R Bhadra, D.R. Pooddar and S.K. Chowdhury. 1989. Equivalence of impedance and radiation properties of square and circular microstrip patches antennas. IEE Proc. 136 (Pt, H, no. 4): 338-342.
- [3] R. G. Voughan. 1988. Two-port higher mode circular microstrip antennas. IEEE, Trans. Antennas Propagat. 36(3): 309-321.
- [4] V. Zachou. 2004. Transmission line model Design Formula for Microstrip Antenna with Slots. IEEE.
- [5] Prabhakar H.V. and U.K. 2007. Electronics Letters. 2<sup>nd</sup> August. 43(16).
- [6] Pozar David M. 1998. Microwave Engineering. John Wiley, New York, NY, USA, 2<sup>nd</sup> Ed.
- [7] Bahl I.J. and Bharatia P. 1980. Microstrip Antennas, Artech House.
- [8] E.O. Hammerstad. 1975. Equations for microstrip Circuit Design. Proceeding of 5<sup>th</sup> European Microwave Conference. pp. 268-272.
- [9] Robinson and Y. Rahmat-Samii. 2004. Particle Swarm Optimization in Electromagnetic. IEEE Transaction on antennas and propagation. 52(2): 397-407.
- [10] A.A. Deshmukh and G. Kumar. 2005. Compact broadband E-shaped microstrip. Electronics Letters 1<sup>st</sup> September. 41(18).
- [11] Komsan Kanjanasit. Novel Design of a Widband Improved U-Slot on Rectangular Patch Using Additional Loading Slots.
- [12] Kumar G and Ray K.P. 2003. Broadband Microstrip antennas. (Artech House, USA).
- [13] C. A. Balanis. 1997. Antenna Theory, Analysis and Design. John Wiley and Sons, New York, USA.
- [14] I. J. bahl and P. Bhartia. 1982. Microstrip Antennas. Artech House Inc. India.
- [15] Ramesh Garg, Prakash Bhartia, Inder Bahl and Apisak Ittipiboon. 2001. Microstrip Antenna Design Handbook. Artech-House Inc. India.
- [16] J. R. James and P. S. Hall. 1989. Handbook of Microstrip Antennas. London, peregrinus.