Microstrip Patch Antenna Design, Simulation, and Optimization at X-Band

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I. Abstract

The purpose of this project is to design a coaxially fed microstrip patch antenna with a wide operating bandwidth by increasing the thickness of the patch and cutting a U-shaped slot on patch. By doing this, it can provide impedance bandwidths of up to 42%. The reflection coefficient is less than -10dB for a frequency range of 7.02 GHz to 10.80 GHz with the resonant frequency of 8 GHz. The proposed microstrip patch antenna has been devised using Rogers RT/duroid 5880 with dielectric constant (ϵ_r) equals to 2.2. The various parameters of the antenna such as the gain, the directivity, the reflection coefficient, and the front-to-back ratio are obtained from Full-wave EM solver, High Frequency Structural Simulator (HFSS).

II. Overview

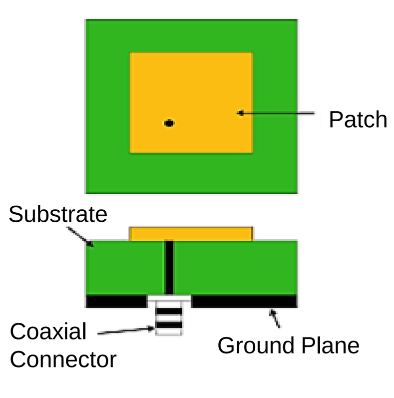

Fig 1. *A microstrip patch antenna with coaxial probe fed.*

A microstrip patch antenna is a metallic strip or patch of conductive material that mounted on a grounded dielectric substrate. Microstrip patch antennas are popular because they are low profile, lightweight, mechanically robust, very versatile in terms of resonant frequency, polarization, pattern, and impedance. While microstrip patches have become popular and used in many diverse applications, their natural bandwidth is very narrow. As applications require increased bandwidth we need to look for ways to increase bandwidth for ever increasing data transmission. By increasing the thickness of the patch and cutting a U-shaped slot on patch, we can increase the bandwidth.

III. Design Procedure

We assumed thickness of substrate (h) = 1.52 mm, relative permittivity (ϵ_r)= 2.2, resonant frequency (f)= 8GHz, and R=50Ω. Using the following design equations for a rectangular microstrip patch antenna for infinite ground we can find our projected dimensions:

- Step 1 : Calculation of the Effective length (L_{eff})

$$L_{eff} = \frac{\lambda}{2\sqrt{\epsilon_{eff}}} \quad \& \quad L_{eff} = L + 2\Delta L$$

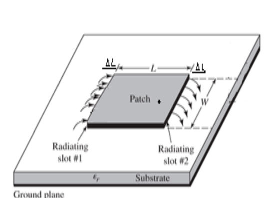

Fig 2. *Fringing effect along the width causes the physical length shorter than the effective length by 2ΔL*

- Step 2 : Calculation of the width of the patch (W)

$$W = 1.5L$$

- Step 3: Calculation of the length of the patch (L)

$$L = L_{eff} - 2\left[0.412h\frac{(\epsilon_{eff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\epsilon_{eff}-0.258)\left(\frac{W}{h}+0.8\right)}\right]$$

- Step 4 : Calculation of the conductance (Gb)

$$G_b = \frac{1}{3\pi\mu}\left[\frac{(k_0W)^2}{1-\frac{(k_0W)^2}{60}}\right][1.32 + 0.63\cos(0.77k_0L_{eff})]$$

- Step 5 : Calculation of the location of the probe (Lf)

$$Lf = \frac{L}{2} + \frac{L_{eff}}{\pi}\sin^{-1}\left(\sqrt{2G_bR}\right)$$

Where: $k_0 = \frac{2\pi}{\lambda}$ & $\epsilon_{eff} = \frac{\epsilon_r+1}{2} + \frac{\frac{\epsilon_r+1}{2}}{\sqrt{1+\frac{10h}{W}}}$

We designed a rectangular microstrip patch antenna in HFSS using the results from the design equations but truncated the ground plane. We used a 40 x 40 mm grounded substrate, 1.45 mm outer diameter and 0.635 mm inner diameter coax for our design. We optimized the rectangular microstrip patch antenna for impedance radiation pattern and frequency. Once we optimize the rectangular microstrip patch antenna, we increase the thickness of the substrate from 1.52 mm to 3.175 mm, which is a standard size. We then cut three rectangles to make a U-shaped slot on the microstrip patch as shown in Fig 3, then continued we optimize it again.

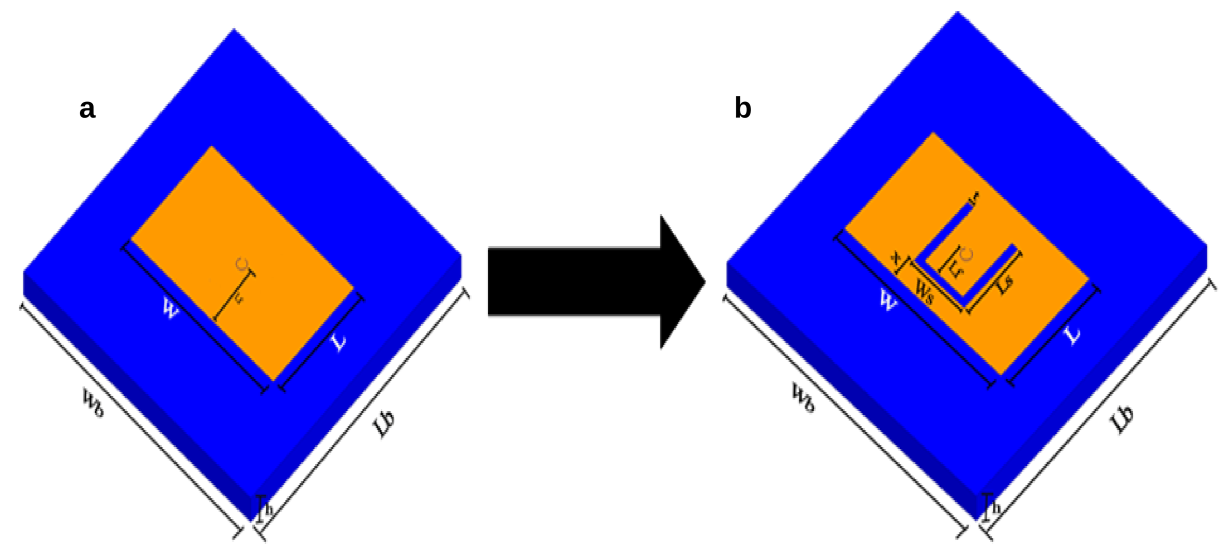

Fig 3. *A transition from rectangular to U-slot microstrip patch antenna. (a) Geometry of rectangular microstrip patch antenna (b) Geometry of U-slot microstrip patch antenna.*

IV. Results

The design and simulation are done by using HFSS. The rectangular and U-slot patch antennas are shown in Fig. 3 (a) and (b). Its design parameters listed in Table 1. Furthermore, the simulation results are shown in Table 2.

Table 1 *The dimension of a rectangular and U-slot microstrip patch antenna (all dimensions in mm)*

	W	L	h	Lf	t	Ls	Ws	x
Rec-tangular	17.5	11.26	1.52	3.08	-	-	-	-
U-slot	18.4	10	3.175	0.8	0.625	6.15	7.45	2.125

Table 2. *The simulation results*

Rectangular	U-slot

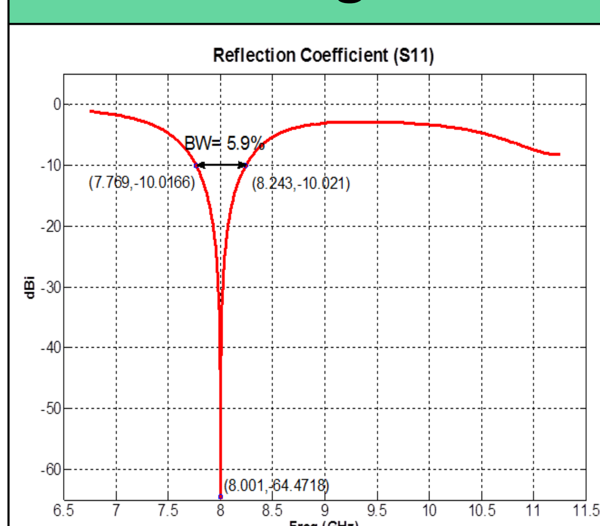

Fig 4. *The return loss of rectangular patch antenna shows it operates at 8GHz, and the impedance bandwidth at |S11| = -10 dB is 5.9%*

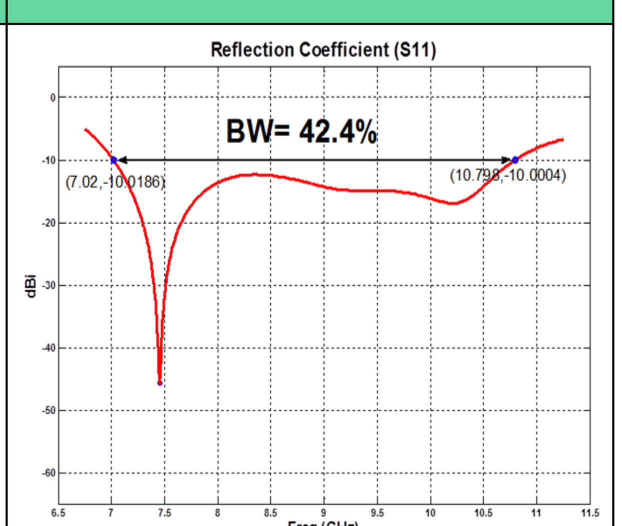

Fig 5. *The return loss of U-slot patch antenna shows the impedance bandwidth (|S11|< -10 dB) is about 42.4 % from 7.0 GHz to 10.8 GHz.*

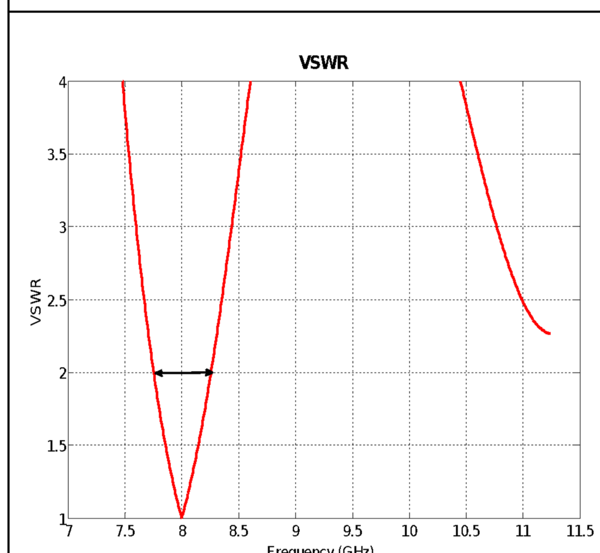

Fig 6. *The voltage standing wave ratio (VSWR) of rectangular patch microstrip antenna shows it operates at 8GHz, and the bandwidth at VSWR = 2dB is 5.9% .*

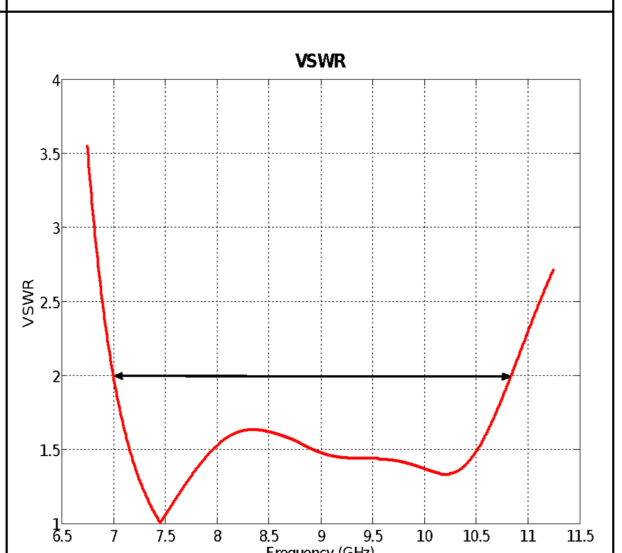

Fig 7. *The VSWR of U-slot patch microstrip antenna shows the impedance bandwidth (VSWR = 2dB) is about 42.4 % from 7.0 GHz to 10.8 GHz.*

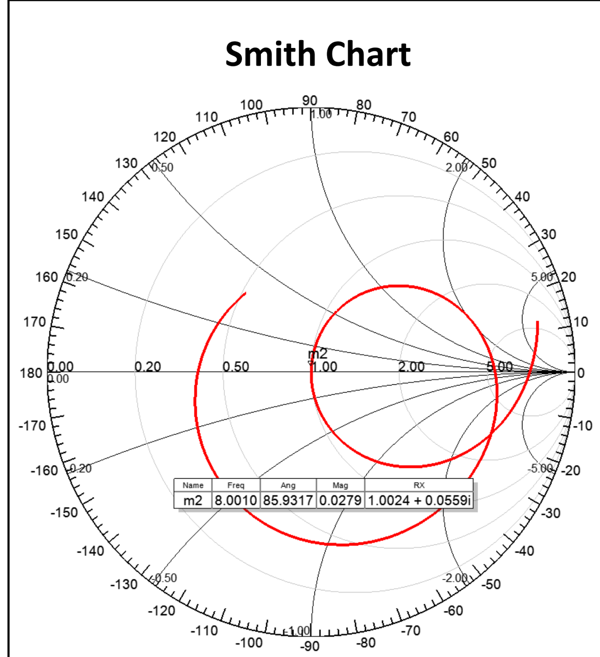

Fig 8. *The Smith chart of rectangular microstrip patch antenna shows the real part of Z-parameter of frequency 8 GHz is 1.0029 which means it is close to 50 ohm.*

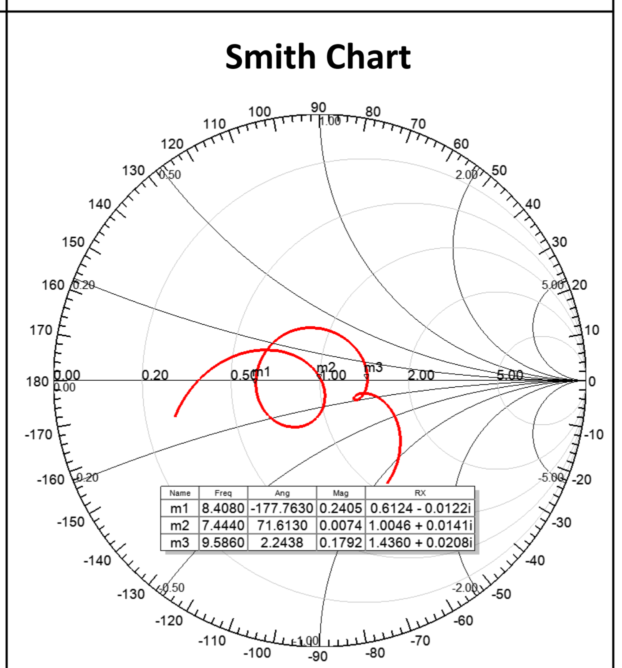

Fig 9. *The Smith chart of U-slot microstrip patch antenna shows there are three resonant frequencies that located in the range of re(Z)= 0.5 to 1.5, which give the result a wider bandwidth.*

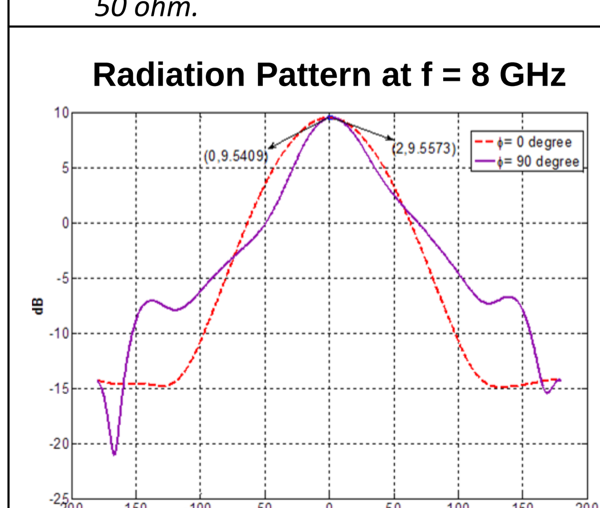

Fig 10. *The 2D radiation pattern of rectangular microstrip patch antenna shows a symmetric radiation pattern at φ= 90° and φ= 0°.*

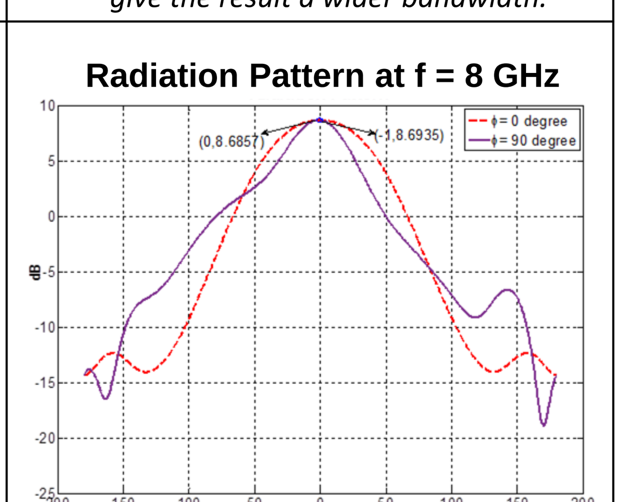

Fig 11. *The 2D radiation pattern of U-slot microstrip patch antenna shows a quite symmetric radiation pattern at φ= 90° and φ= 0°.*

Rectangular	U-slot

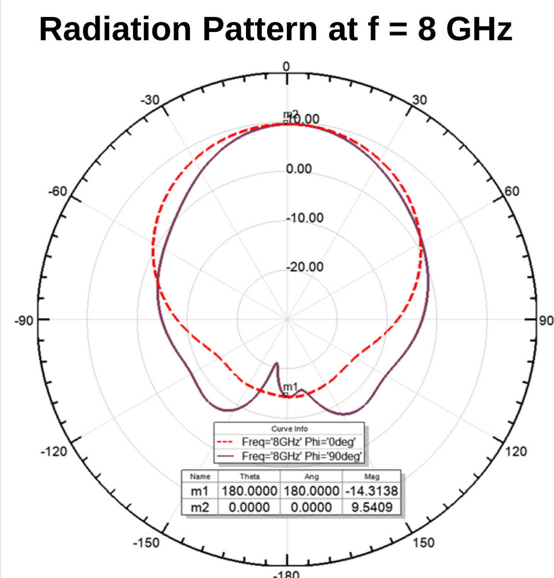

Fig 12. *The polar radiation pattern of rectangular microstrip patch antenna shows the maximum gain of 9. 54dB and the front-to-back ratio of 23.8 dB*

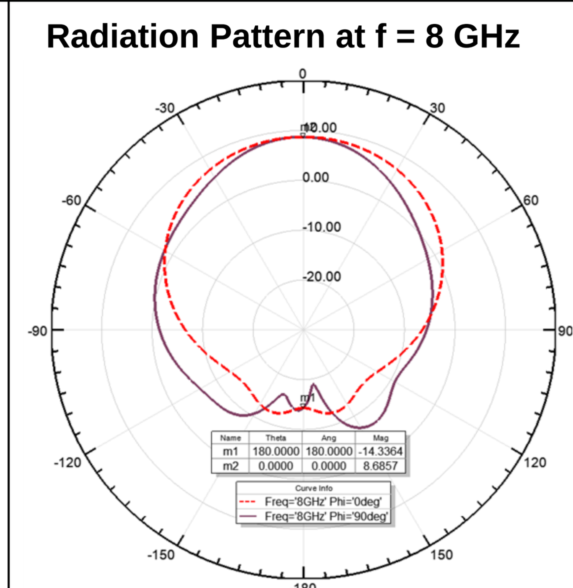

Fig 13. *The polar radiation pattern of U-slot microstrip patch shows the maximum gain of 8.69dB and the front-to-back ratio of 23 db.*

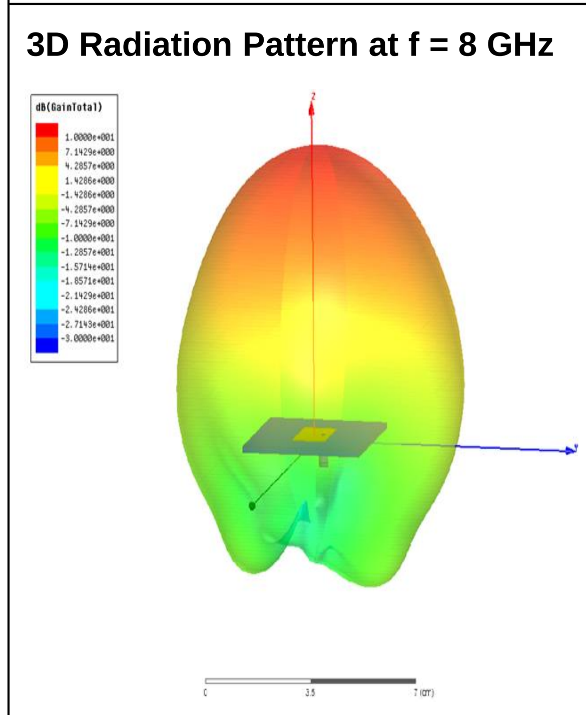

Fig 14. *3D radiation pattern of rectangular microstrip patch antenna shows the spatial distribution of radiation intensity*

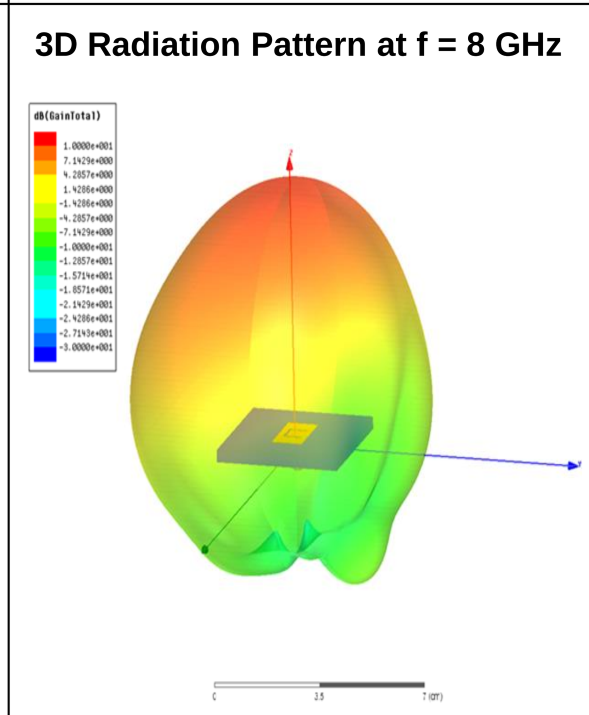

Fig 15. *3D radiation pattern of U-slot microstrip patch antenna shows the spatial distribution of radiation intensity*

Table 3. *Comparison parameters of patch antenna with and without U-slot with the standard patch antenna.*

Parameters	Without U-slot	With U-slot	Standard
Bandwidth	5.9%	42.4 %	1-5%
Gain	9.5 dB	8.6 dB	6-9 dB
Directivity	9.5 dB	8.6 dB	6-9 dB
Front-to-back ratio	23.8 dB	23 dB	-

V. Conclusions

By increasing the thickness of the substrate and cutting U-shaped slot on a rectangular patch, we can increases the impedance bandwidth up to 42%. Using Full-wave EM solver, we were able to numerically confirm this the frequency bandwidth of U-slot microstrip patch antenna was broadened from 5.9 % to 42.3 % in term of the return loss, VSWR, and the radiation patterns.

VI. Acknowledgements

Dr. Maria Pour and Mr. Hite

VII. References

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