Rectangular Microstrip Patch Antenna with Double L-Shaped Slots for Enhanced Bandwidth

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***Abstract*—Rectangular microstrip patch antennas, although having many advantages, usually suffer from having narrow bandwidth. Changing the feed point, or adding slots to the patch or to the ground plane or the addition of resonant circuits to the structure are different methods that can be applied for enhancing the bandwidth. Slots are usually added for creating multiple band operations. In this work, design and implementation of a rectangular microstrip patch antenna with double L-Shaped slots is proposed for enhanced bandwidth. Design is done with simulation verification of the problem and testing of two prototype circuits. Simulated and measured responses for both of the antenna circuits are demonstrated. One circuit indicated about 600MHz bandwidth at 2.6GHz center frequency and the other one about 1GHz bandwith with center frequency being around 2.4GHz.**

***Index Terms*—microstrip antennas, patch antennas, slot, enhanced bandwidth, perturbations in structure**

I. Introduction

The microstrip antennas received attention starting in 1970s although the idea of microstrip antennas was first introduced in 1950s. Many advantages of microstrip antennas make them preferable such as their low cost and low weight as well as the fabrication ease. The main disadvantage of microstrip antennas is their narrow bandwidth and enhancing the bandwidth of microstrip antennas is always a means of research. The performance can be increased by using different techniques such as changing feed points or adding slots. Wong and Hsu suggested adding wide slits at one of the radiating edges of rectangular patch on an air substrate [1], [2]. The impedance bandwidth of 408MHz corresponding to 25% of the fractional bandwidth was reported. Wideband shorted rectangular microstrip patch antenna was proposed by Nashaat *et al.* [3] using a U shaped slotted patch antenna to increase the bandwidth. By adjusting the position of the slot wideband characteristic was observed with 23% fractional bandwidth at 2.48GHz and 24% at 4.95GHz. Haaij *et al.* increased the bandwidth of microstrip patch antenna by adding a parallel LC resonator circuit in the form of an open and short circuited stubs [4]. About 7% bandwidth was obtained at 1.8 GHz which was a good improvement in bandwidth since the theoretical value was about 3.2%. For dual band operation, Liu and Chen proposed a different CPW fed compact meandered patch [5]. With the design, different ground structure was proposed with L-shaped nature with a meandering slit on the patch which yielded two resonances at 2.0GHz and 5.32GHz with 260MHz and 710MHz bandwidths respectively. Inserting L-type slits into the edge of the patch was proposed by Sung *et al.* [6]. The aim was for obtaining polarization diversity. Sekra *et al.* used the orthogonal crossed slits in the patch [7]. About 7.6% bandwidth was observed at 3.56GHz. Also, Munir *et al.* used a series of 13 parallel slots to enhance the bandwidth [8]. In terms of simulation about 98% enhancement was observed, in terms of measurement, 70.8% improvement corresponding to about 53.3MHz was observed at 1.6GHz. For convential patch antenna bandwidth of about 31.2MHz could be obtained.

In this work addition of two L shaped slits on the main patch and addition of a slit at the feedline is done. The slot use in the surface of the patch naturally affects the radiation characteristics of the antenna. Normally this kind of addition also produces wider bandwidth at the expense of creating worse return loss.

A. Circuit Dimension Calculations

The microstrip patch antenna consists of a radiating patch on one side of the dielectric susbtrate and a ground plane on the other side. Simple three dimensional view of a microstrip patch antenna circuit with microstrip feed is shown in Fig. 1.

The microstrip patch antenna circuit dimensions can be calculated with the basic formulas to start with. Then, they can be optimized using a microwave or structure simulation software. In this work, we choose the circuit board substrate with properties similar to Rogers Theta. The dielectric constant for Rogers Theta is 4.01 and the thickness of the substrate used is 2.00mm. The frequency

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of operation is chosen to be 2.4GHz and the patch width (*Width*) is calculated using the equation below:

$$Width = \frac{c}{2f\sqrt{\frac{\varepsilon_r + 1}{2}}} \quad (1)$$

where c is the speed of light, f is the frequency of operation and ε_r is the dielectric constant of the material used. The patch width turns out to be 39.5mm. When the calculations for patch length needs to be done, two regions need to be considered; air and dielectric. As a result effective dielectric constant (ε_{eff}) is used while finding the length for the patch antenna [9]:

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{h}{Width}\right)^{-1/2} \quad (2)$$

$$L_{eff} = \frac{c}{2f\sqrt{\varepsilon_{eff}}} \quad (3)$$

where h is the thickness of the substrate. After calculating the effective length, one more modification to the patch length should be included, this correction is due to the fact that there are fringing fields at both edges of the patch and these should be taken into account in order to use the correct length [10], [11].

$$\Delta L = 0.412h\frac{(\varepsilon_{eff} + 0.3)\left(\frac{Width}{h} + 0.264\right)}{(\varepsilon_{eff} - 0.258)\left(\frac{Width}{h} + 0.8\right)} \quad (4)$$

$$L = L_{eff} - 2\Delta L \quad (5)$$

The length (L) is found to be 30.7mm. These values are used as our starting values for the design.

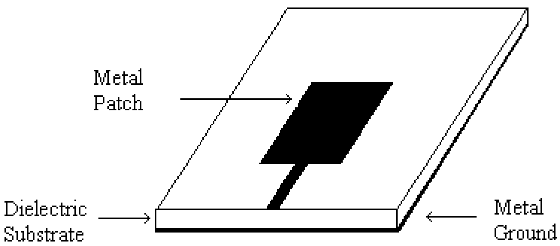

Figure 1. Three dimensional view of microstrip patch antenna.

II. SIMULATION

The simulations are done to optimize and finalize the design. A feed with width 2mm (which corresponds to an impedance of about 73.5Ω) and length 18mm is used. The design is done for 2.4GHz and simulated in Sonnet Software [12]. The drawing of simulated patch antenna in top view is shown below in Fig. 2.

The simulation parameters are as follows: patch length is set to 30.7mm and the width is set to 39.5mm. In the simulations, Rogers Theta with properties ε_r = 4.01, dielectric loss tangent = 0.0118 is chosen, the thickness of the substrate is 2mm (about 0.032λ), and the simulations take place inside the box with a height of 20mm. Bottom part of the box is grounded. From the simulation result, as it can be observed in Fig. 3, the simulation indicated the resonant frequency to be at 2.42GHz and about -5.469dB resonance. This value for return loss is not optimum, this is probably due to the reason that a proper matching circuit is not included in the structure. If we consider the -3dB bandwidth, the bandwidth of the antenna is about 130MHz. From the previous studies, it was observed that addition of slits [1]-[3] creates additional resonances and enhances the bandwidth of antennas.

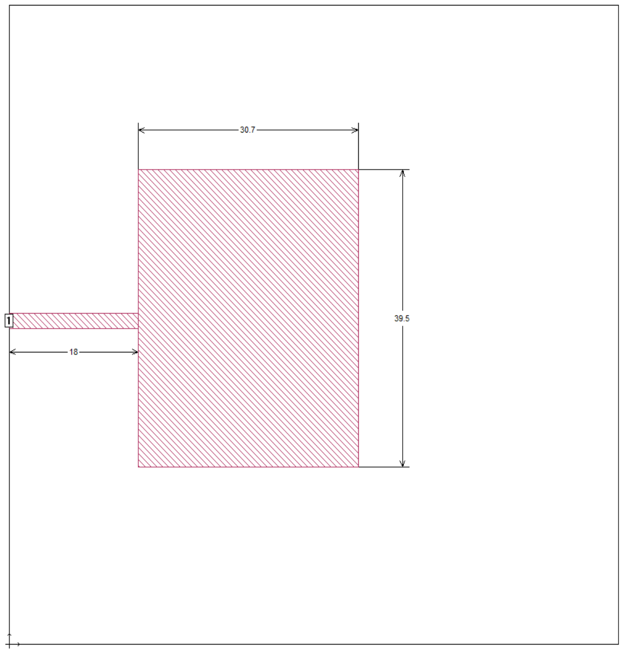

Figure 2. Simulated patch antenna.

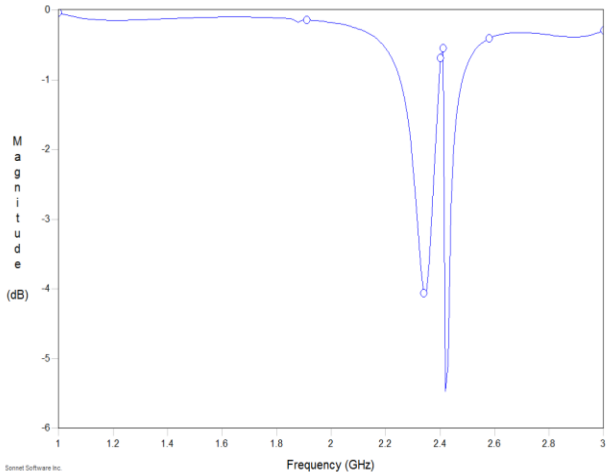

Figure 3. Return loss vs. frequency.

In this work two L shaped slits on the main patch and a slit at the feedline is placed. The Fig. 4 shows the design circuit with the lengths indicated. The design values for width and length as well as slits are all optimized for having multiple resonances around 2.4GHz.

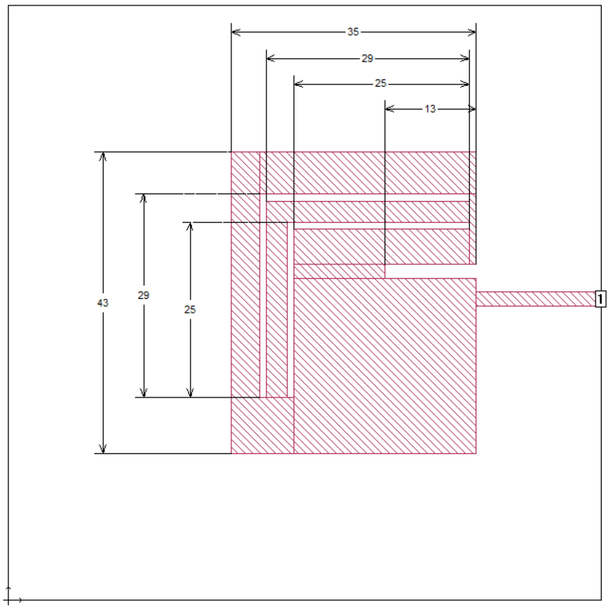

Figure 4. Simulated patch antenna with L shaped slots.

The patch length is set to 35mm and the width is set to 43mm. The L shaped slots have thickness of 1mm and the slit at the feedline has an opening of width 2mm. The first L shaped structure has a length of 25mm and the second L shaped structure has a length of 29mm. The simulations again are carried out in a box with a dielectric material Rogers Theta of thickness 2.00mm, a grounded layer at the bottom of the box. Fig. 5 shows the simulation response of the optimized design. Multiple Resonances occurs and these are recorded for convenience in Table I below.

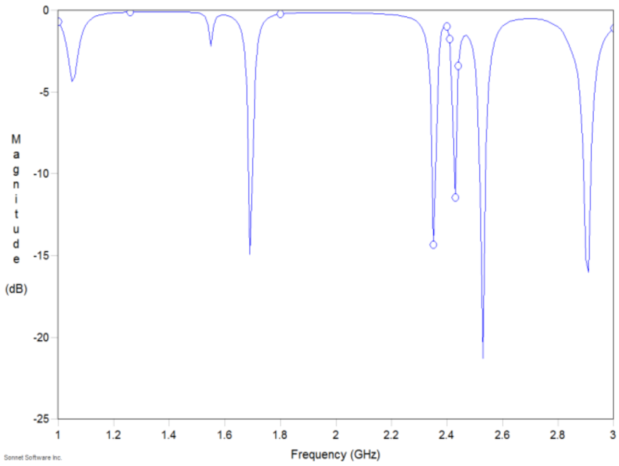

Figure 5. Return loss vs. frequency with L-shaped slots.

TABLE I. RESONANT FREQUENCIES AND RESPECTIVE RETURN LOSS VALUES

Frequency (GHz)	Return Loss (dB)
1.69	-14.9390
2.35	-14.3552
2.43	-11.4489
2.53	-21.2828
2.91	-16.0274

Resonance that occurs at 1.69GHz is far from the design values. This is also true for the resonance that occurs at 2.91GHz. The other three resonances however are close to each other between 2.35GHz and 2.53GHz, and this can be used to create some enhanced bandwidth. Therefore these simulated results are used as basis and the circuits are built with this design considered.

III. MEASUREMENTS

Two prototype circuits with the double L shaped slots are fabricated using the wet etching technique. The fabricated circuits are shown in Fig. 6 and Fig. 7. Copper layered circuits suffered from oxidation and color discoloration. Gold layer could not be deposited through electrolysis because of non-availability of proper equipment to do so. The circuits are measured using ANRITSU Vector Network Analyzer MS4642A [13]. For both of the circuits the response is plotted with the simulation result for comparison. This is shown in Fig. 8.

Figure 6. Fabricated circuit I with L-shaped slots.

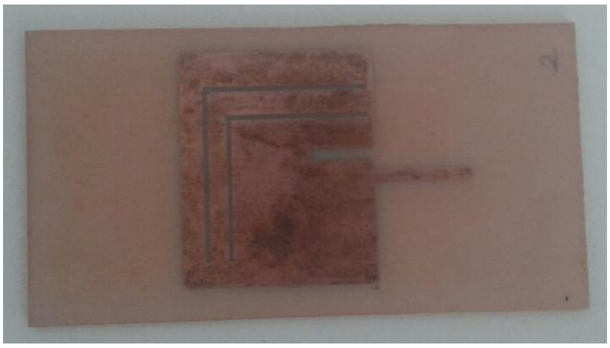

Figure 7. Fabricated circuit II with L-shaped slots.

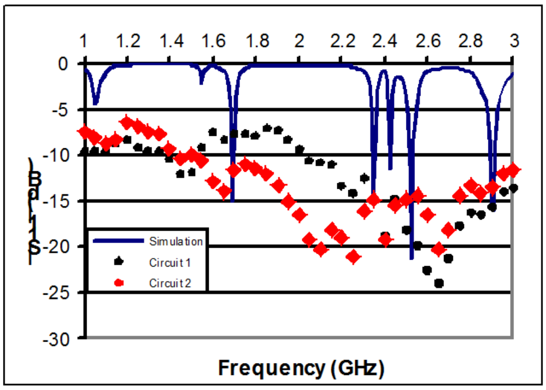

Figure 8. Measured and simulated response for circuits.

When we consider the responses of both of the circuits, first it is noticeable that although the deviations from simulation exist, resonances for both of the circuits can be observed with wide bandwidth. If we consider the first circuit, as we can see from the graph at about 1.4GHz about 200MHz bandwidth can be observed if we consider –10dB as the bandwidth limit. The real resonance occurs around 2.65GHz, the minimum value extending to –24dB if we consider the bandwidth values to be below -15dB, from about 2.35GHz to 2.90GHz resonance is observed. This corresponds to a bandwidth of 550MHz. With these added slits and the feedline slot, resonant frequency is shifted to about 2.65GHz and produces about 21.1% fractional bandwidth.

For the second antenna circuit design shown again in Fig. 7, similar observations can be obtained. The first resonance occurs around 1.65GHz with the resonance value being –14dB and about 200MHz bandwidth considering the –11dB as the bandwidth limit. The second resonance is observed for about 300 MHz extending from 2GHz to 2.3GHz and the third resonance of about 200MHz extending from 2.55GHz to 2.75GHz. In fact since all the values are below –13 dB between the frequencies 1.9GHz to 2.9GHz, we can even say that the resonance has about 1GHz bandwidth with 41.6% fractional bandwidth.

IV. CONCLUSION

In this work our target was to observe the improvement that slots can perform in the bandwidth of patch antennas. As a result simulations were carried out to see the effect and then the fabricated circuits were measured for verification. A microstrip patch antenna with operation frequency of around 2.4GHz is designed and two L shaped slots and a feedline slit were added to see the effect of these variations. With simulations it was observed that the inset improved the design resonant frequency and addition of L shaped slots into the structure enhanced the bandwidth.

Measured circuits had some problems in terms of getting good response due to mismatch in connections and most probably not having exactly the same substrate used in the simulations. However, still the measured response for the circuits showed improved bandwidth with one of the circuits having 21.1% fractional bandwith at about 2.65GHz, and the second circuit having 41.6% fractional bandwidth at about 2.4GHz center frequency.

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REFERENCES

[1] K. L. Wong and W. H. Hsu, "A broadband patch antenna with wide slits," in *Proc. Antennas and Propagation Society International Symposium*, 2000, pp. 1414-1417.

[2] K. L. Wong and W. H. Hsu, "A broad-band rectangular patch antenna with a pair of wide slits," *IEEE Transactions on Antennas and Propagation*, vol. 49, no. 9, pp. 1345-1347, September 2001.

[3] D. Nashaat, H. Elsadek, and H. Ghali, "A wide band compact shorted rectangular microstrip patch antenna with U-shaped slot," in *Proc. Antennas and Propagation Society International Symposium*, 2003, pp. 296-299.

[4] D. D. Haaij, J. W. Odendaal, and J. Joubert, "Increasing the bandwidth of a microstrip patch antenna with a single parallel resonant circuit," in *Proc. IEEE 6th Africon Confrence*, 2002, vol. 2, pp. 527-529.

[5] W. C. Liu and W. R. Chen, "CPW-fed compact meandered patch antenna for dual-band operation," *Electronics Letters*, vol. 40, no. 18, 2004.

[6] Y. J. Sung, "Reconfigurable patch antenna for polarization diversity," *IEEE Transactions on Antennas and Propagation*, vol. 56, no. 9, pp. 3053-3054, September 2008.

[7] P. Sekra, S. Shekhawat, D. Bhantagar, V. K. Saxena, and J. S. Saini, "Rectangular patch antenna with orthogonal crossed slits," in *Proc. Applied Electromagnetics Conference*, 2009, pp. 1-4.

[8] A. Munir, G. Petrus, and H. Nusantara, "Multiple slots technique for bandwidth enhancement of microstrip rectangular patch antenna," in *Proc. International Conference on Quality in Research*, 2013, pp. 150-154.

[9] D. Pozar, *Microwave Engineering*, 3rd ed., John Wiley, 2005, p. 144.

[10] E. O. Hammerstad, "Equations for microstrip circuit design," in *Proc. Fifth European Microwave Conference*, September 1975, pp. 268-272.

[11] C. A. Balanis, *Antenna Theory: Analysis and Design*, 3rd ed., John Wiley, 2005, pp. 818-819.

[12] Sonnet High Frequency Electromagnetic Software. [Online]. Available: http://www.sonnetsoftware.com/products/lite/download.html

[13] Anritsu Cooperation. [Online]. Available: http://www.anritsu.com/en-US/Downloads/Brochures-Datasheets-andCatalogs/Datasheet/DWL3510.aspx

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