Design of Multi-band U-Slot Microstrip Patch Antenna for GSM /WLAN and WiMAX Applications

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***Abstract*—A simple, low-cost, and low-profile U-slotted microstrip patch antenna has been designed, fabricated, measured and implemented to operate at the three desired frequencies; 1.8GHz, 2.44GHz, 3.5GHz. In the design process, the effects of several parameters on the performance of the antenna have been studied, utilizing an international standard antenna software; CST Studio Suite. The antenna was first measured as far as return loss, using a network analyzer, provided by a national operator and the radiation patterns were measured in-house, utilizing an antenna measurement system. The fabricated antenna was installed on a networked WiFi access point, and the average received power over a distance range was tested.**

Index Terms—U-slot, microstrip antenna, multiple-band, GSM, WLAN, WiMAX, FR4, 802.11b/g/n.

I. Introduction

The basic U-slot antenna was first developed a couple of decades ago, as a linearly polarized, single layer, single patch antenna to become a simple to design, easy to manufacture robust antenna with wideband performance [1]. Although it was mainly used for bandwidth enhancement, it became realizable, that it can be used to design patch antennas with dual and multiband characteristics [2,3]. Design of U-slot antennas with multiple specified wireless bands and even with narrow bandwidths have proved to be very challenging. A combination of dual U-slot and multiple layers were reported to get multiple bands with wide bandwidth [4]. Tong and Wong [5] have shown that by cutting a U-slot with unequal arms in a rectangular patch, two degenerate orthogonal modes with equal amplitudes and 90° out of phase are excited, resulting in circular polarization.

As far as single layer, linearly polarized, single U-slot patch antennas, many articles in the literature addressed various designs and analysis with interesting measured performance . Khunead et al [6] compared the performance of equal sized rectangular patch antenna, with and without two incorporated L-shaped strips. With the L-shaped strip antenna, dual resonances were obtained at 2.4 and 5.38 GHz. The other antenna resonated at as single frequency of 2.36 GHz. Ansari et al [7] reported on a U-slot loaded patch with a coaxial feed point, using equivalent circuit concept and obtained two resonant frequencies. A close agreement was found between analysis and simulation results. Ghalibafan and Attari [8] reported on a new dual band microstrip antenna with U-shaped slot where a broadband electromagnetic coupling probe was used. Radiation characteristics were shown to be broadside with low cross-polarization level at both resonant frequencies. Lee et al [9] investigated single and double patch antenna with an air substrate and obtained double and triple resonant frequencies. Double resonant frequencies were obtained at 5.1 GHz and 6.6 GHz whereas triple resonant frequencies were obtained at 5.1 GHz, 5.8 GHz and 6.8 GHz. Dwivedi et al [10] designed a single slot antenna for various substrate heights using RT/Duroid 5880 substrate material. The obtained simulated bandwidth was 6% of the 2.5 GHz resonant frequency, for a 1.6 mm substrate height. Wang et al [11] used a 2x2 array of single U-slot patches and obtained an impedance bandwidth of 18%, ranging from 5.56 GHz to 6.78 GHz. More recently, Mittal et al [12] reported on a U-slot with incorporated electromagnetic band gaps and on substrate and defected ground structure in the ground plane. With this technique the authors were able to improve return loss and obtain impedance bandwidth of 202 MHz bandwidth at a resonance frequency, 6.1 GHz.

On the other hand, a compact dual band antenna with two U-slots were reported [13] to provide a broad impedance bandwidth between 2.15 to 3.72 GHz. A coplanar waveguide feeding line and an FR4 substrate were utilized. L-shaped slots that were employed in the ground plane helped in broadening the impedance bandwidth. Another compact microstrip patch antenna with two U-slots shape was reported [14]. The designed antenna generated three resonant modes at 2.7, 3.3 and 5.3 GHz and could, therefore, be used in WiMAX applications. Two bridge elements were added between the two slots to shift the frequencies down to the mentioned bands.

Our objectives of this work are threefold:

- To design a multi-band microstrip antenna using U–slot techniques for applications in GSM, WLAN and WiMAX.
- To improve bandwidth and return loss of the proposed antenna.
- To test this antenna on some applications such as WLAN.

II. Conceptual Design

The U-slot technique is one of the popular microstrip techniques to obtain multi-band operation. In order to get more than two bands of frequencies such as a quad band, two

U-slots must be introduced in the radiating patch. Figure 1 shows a conceptual design of a U-slot loaded patch which is analyzed by considering it composed of two sections. The first section (upper one) is an E-shaped patch and the second section (lower one) as a microstrip bend line.

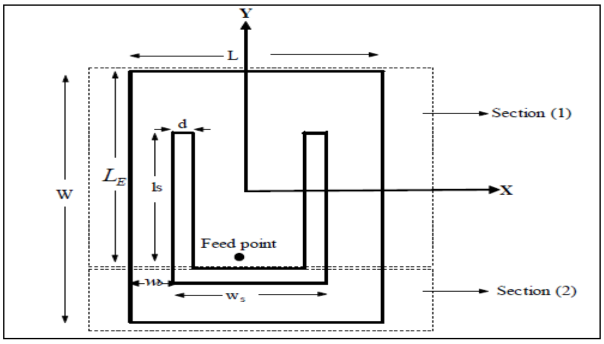

Fig. 1: U-Slot configuration

Section 1 is analyzed as a patch in which two parallel notches are incorporated. This perturbation in the patch changes the current length which is accounted for by an additional series inductance and a series capacitance to the parallel equivalent lumped resistance, capacitance and inductance components. Section 2 is considered as two microstrip bend lines and the equivalent impedance of this shape is given as an equivalent impedance of a series inductance with a parallel capacitance and inductance combination for each of the microstrip bent lines. The analysis of the equivalent transmission line circuit [7], shown in Fig. 2 and equation 1, resulted in a very good match between the theoretical and simulated results of the return loss curve and its two resonant frequencies.

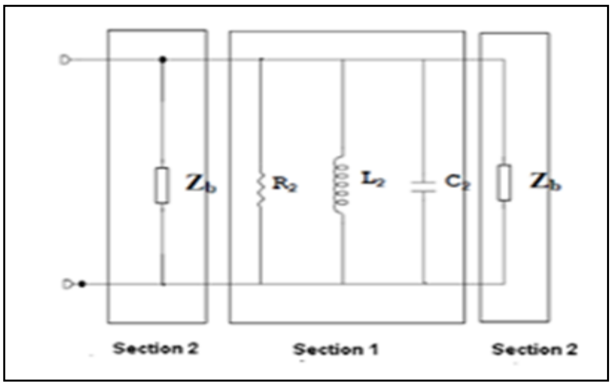

Fig. 2: Equivalent Circuit of U-slot patch antenna

Where

$$Z_b = jwL_b + \frac{1}{\frac{1}{jwL_b} + jwC_b} \quad (1)$$

Z_b is the complex impedance of the bent line
w is the radian frequency
L_b is the equivalent inductance of the bent line
C_b is the equivalent capacitance of the bent line

Our design incorporates two slots; one inside the area surrounded by an outer one. This would result into three or four resonant frequencies. The feed for the patch is a simple 50 Ω transmission line.

III. Double U-slot Antenna Design

There are various types of substrate material commercially available that provide considerable flexibility in the choice of a substrate for particular applications. For good antenna performance, a dielectric with low value but high thickness is required, as this would provide better radiation efficiency and larger bandwidth. However, such a design would lead to an antenna of relatively larger size. In order to reduce the size, a higher dielectric constant should be used, but this would compromise its efficiency and bandwidth. In our design the dielectric material is Flame Retardant (FR4) which is a composite material composed of woven fiberglass cloth with an epoxy resin binder that is flame resistant, with the dielectric constant equal to 4.4. This material is relatively low in cost for a satisfactory low loss tangent. The effective dielectric constant, ε_{eff}, can be calculated from the following equation:

The effective dielectric constant is given by equation 2 for W/h > 1[15].

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

As a result of the fringing fields, the dimensions of the patch look different from its physical dimensions. Along its length the patch looks longer by ΔL and it is given by[15]:

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

As the length of the patch is extended by ΔL, its effective length now is given by[15]:

$$L_{eff} = L + 2\Delta L \quad (4)$$

where the length, L, can be calculated from the following:

$$L = \frac{1}{2fr\sqrt{\varepsilon eff}\sqrt{\mu o \varepsilon o}} - 2\Delta L \quad (5)$$

and the width, W, can be calculated from the following:

$$W = \frac{1}{2 fr\sqrt{\mu o \varepsilon o}}\sqrt{\frac{2}{\varepsilon r+1}} \tag{6}$$

f_r is the resonant frequency, described as:

$$f_r = \frac{1}{2L\varepsilon r} \tag{7}$$

Equations 5 and 6 were utilized to calculate the rectangular patch dimensions at the required resonant frequency. The feeding structure was a simple 50 Ω transmission line feed, the width of which was found from a CST Studio simulation software [16]. The same software was used to build a rectangular patch structure. By constructing a single U slot in the patch the double resonant frequencies can be generated. In the design we initially used a single slot in the patch with the initial dimensions represented in Table 1.

TABLE 1. INITIAL VALUES OF THE INNER U-SLOT IN MM

L_1	W_1	T_2	W	L
32	4	4	30	40

where L, W are the length and width of the patch, respectively. L1, W1 are the length and width of the inner U-slot. T2 is the thickness of the U-slot.

The effect of adjusting the dimensions of the U-slot was studied for optimum resonant frequencies. Then another outer U-slot, for achieving multi-band characteristics, was added with initial values, as described in Table 2.

TABLE 2. INITIAL VALUES OF THE OUTER U-SLOT IN MM.

L_3	W_2	T_1
32	8	2

FR4_epoxy (dielectric constant = 4.4 and height = 1.6 mm) was used as a substrate material to design the proposed U-slot microstrip patch antenna. Positioning the double U-slots on the patch was a main challenge in the design, since in order to get a compatibility between the two slots and the desired operation frequency, optimized positioning of the two slots on the patch was required. The proposed design of the antenna is shown in Fig. 3. The dimensions of the antenna patch were 40 x 30 x 1.6 mm and the detailed dimensional parameters of the double U-slot are shown in Fig. 3.

Those parameters were initially calculated or simply estimated. The final design was found through optimization of selected parameters of the simulated design, using CST software.

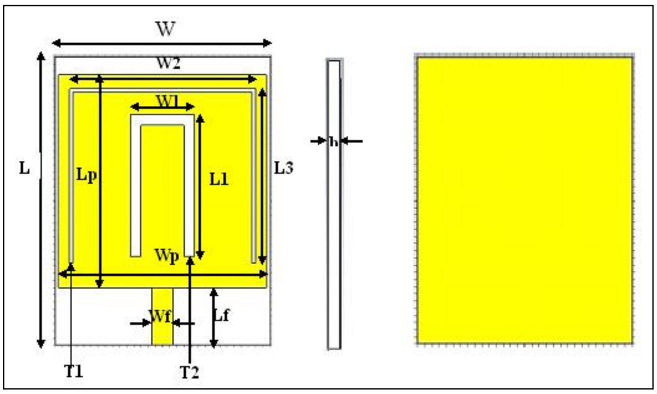

Fig. 3: U-slot patch antenna design (Left is top design, right is bottom design)

Table 3 shows the optimized values of the dimensional parameters of the double U-slot patch antenna (h= 1.6 mm).

TABLE 3 . OPTIMIZED DIMENSIONAL PARAMETERS

Parameter	**W**	**L**	**W2**	**L1**	**W1**	**L3**
Units (mm)	30	40	26	19.7	9	24.2
Parameter	**Wf**	**Wp**	**Lp**	**T1**	**T2**	**Lf**
Units (mm)	3	29	29.5	0.5	1.5	8

IV. Simulated Results

Results obtained from the CST simulation tool, mainly focused on the return loss curves and radiation patterns. Selected parameters are shown, in terms of their variation effect on desired frequency resonances. Fig. 4 shows an increase in L3 parameter by 2mm which affected a decreasing shift in the upper 3.5 GHz resonance frequency by more than 150 MHz. On the other hand, an increase in the L1 parameter affected a decreasing shift in the lower 1.8 GHz resonance frequency by more than 150 MHz, as shown in Fig. 5, whereas a decrease in W1 by a similar amount affected an increasing shift in the same resonance frequency by more than a 100 MHz, as shown in Fig. 6. On a third account a change in the patch length parameter, Lp, by 1.5 mm seemed to have the largest effect on shifting the middle 2.4 GHz resonance frequency, shown in Fig. 7, by less than 100 MHz, as compared to the other frequencies. A change in the other U-slot dimensions seemed to have a much less effect on all resonance frequencies.

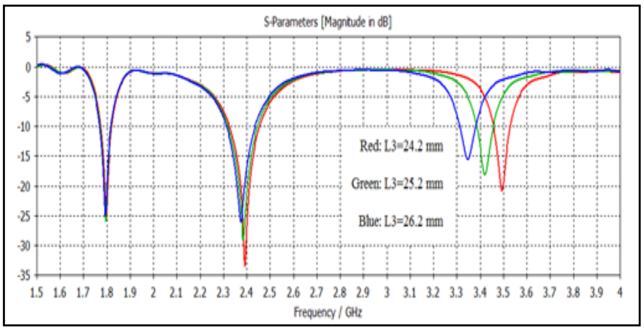

Fig. 4: Variation of the 3.5 GHz resonant frequency by changing L3

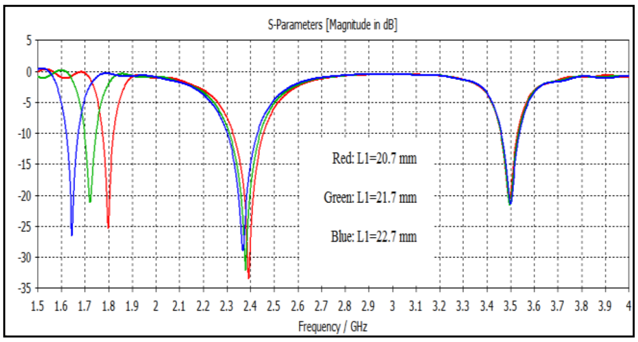

Fig. 5: Variation of the 1.8 GHz resonant frequency by changing L1

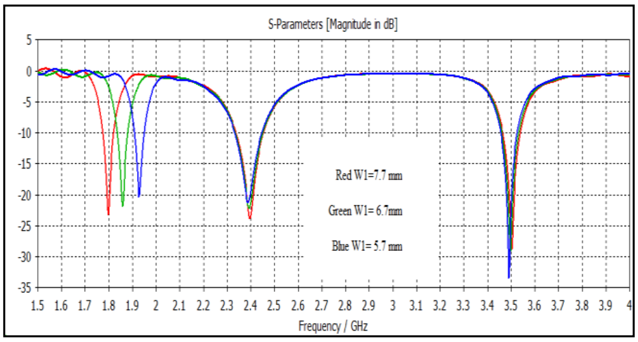

Fig. 6: Variation of the 1.8 GHz resonant frequency by changing W1

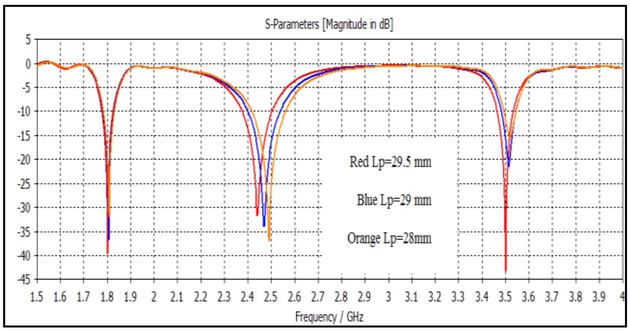

Fig. 7: Variation of the 2.44 GHz resonant frequency by changing Lp

V. Experimental Results

Two antennas were fabricated, in house, using an FR4 substrate material (h=1.6 mm) on a CNC machine, specialized for PCB board fabrication. Fig. 8 shows the fabricated antennas with 50 Ω SMS feed connectors.

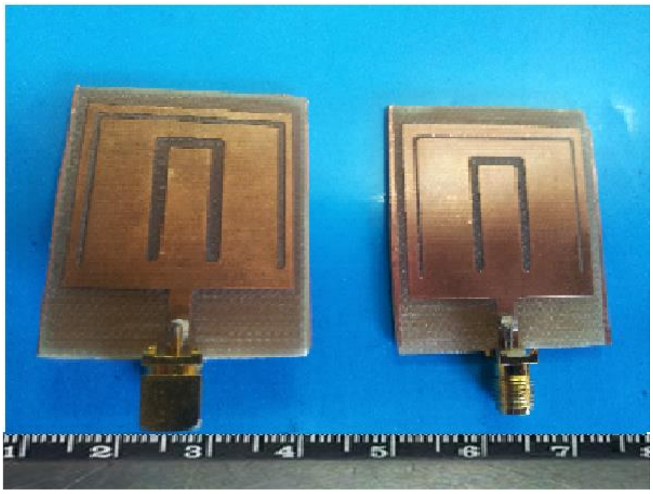

Fig. 8: Fabricated antennas with 50 Ω SMS feed connectors
(L x W x h= 40 mm x 30 mm x 1.6 mm)

Fig 9 shows the return loss performance of the U-slot antenna, as measured by a portable vector network analyzer [17]. It shows resonance frequencies, close at 1.8, 2.4 and 3.45 GHz which were close to the simulated values. Return loss respective values measured in the 11-14 dB range.

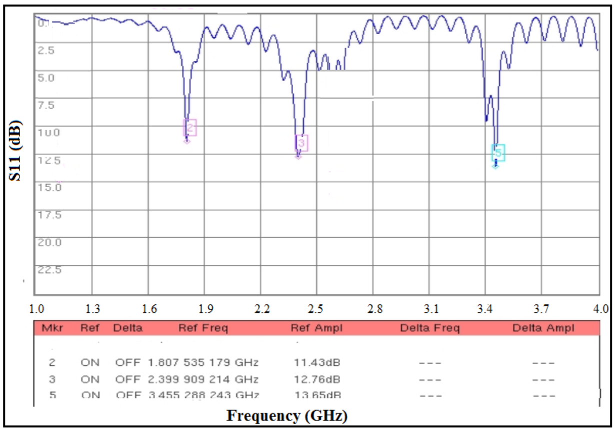

Fig. 9: Return Loss of the U-slot antenna with the three distinct resonant frequency bands

Fig 10 shows the return loss performance of the 2.4 GHz frequency band with a resonant bandwidth of 43 MHz. It is interesting to note that Channel 1 in 802.11b/g/n WLAN standard fits within measured available resonance bandwidth. The antenna will be tested on an indoor WiFi access point.

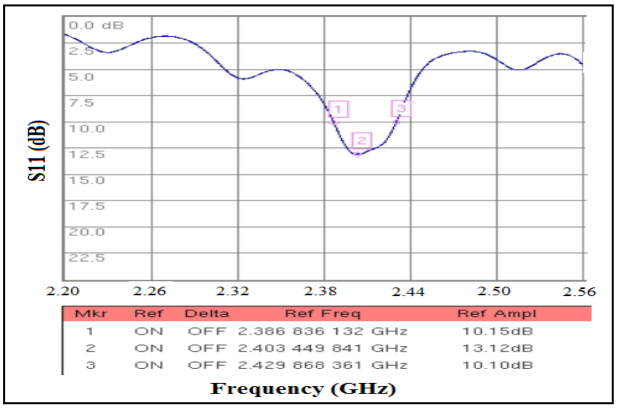

Fig. 10: Return Loss of the U-slot antenna with the 2.4 GHz resonant frequency band

As far as radiation pattern measurement, an in house antenna measurement system was utilized and the obtained E-plane patterns were compared with those simulated by the CST tool. Fig. 11-13 show the compared radiation patterns at 2.4, 1.8 and 3.5 GHz frequencies. The measurements were not run in an anechoic chamber and hence reflections from surroundings, antenna fabrication tolerances and misalignment of the measured antenna from the exact center of rotation may have not resulted in an exact but fair comparison of the simulated and measured patterns. The correlation seems as relatively highest at the 3.5 GHz frequency.

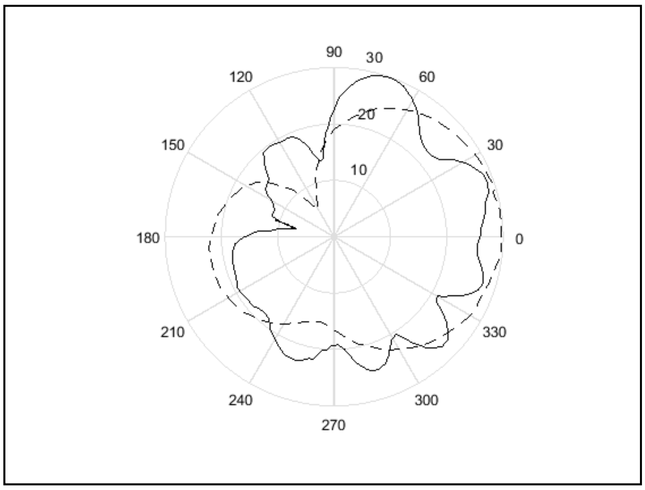

Fig. 11: Radiation Pattern at 2.4 GHz
Simulated (dashed line), experimental (solid line)

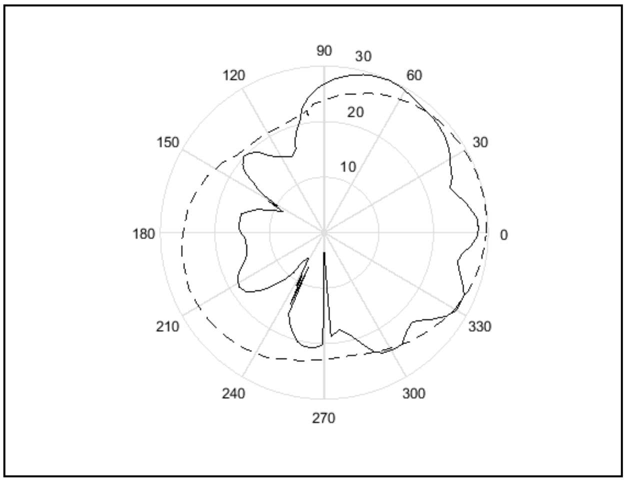

Fig. 12: Radiation Pattern at 1.8 GHz
Simulated (dashed line), experimental (solid line)

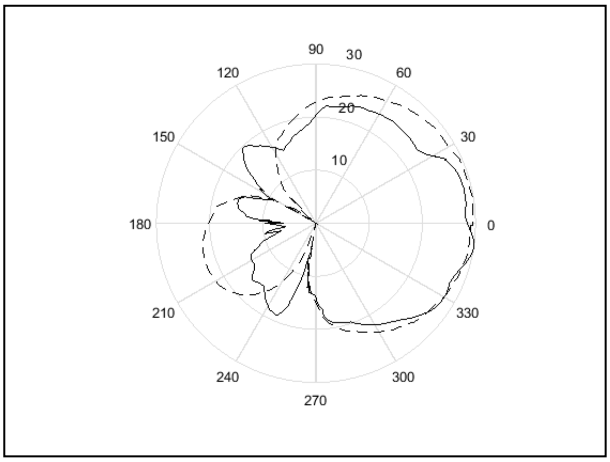

Fig. 13: Radiation Pattern at 3.5 GHz
Simulated (dashed line), experimental (solid line)

VI. WLAN Experiment

The average received power versus distance was tested for an indoor access point with the U-slot antenna installed instead of the reference dipole antenna. The WiFi access point operated in the 2.4 GHz frequency band (802.11b/g/n WLAN standard). The performance of both antennas were compared. Fig. 14 shows an average 10 dB relative improvement, over distance, when using the U-slot antenna.

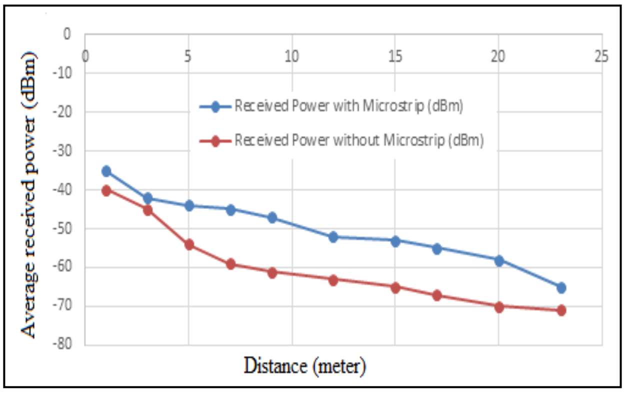

Fig. 14: Average received power versus distance of the WiFi access point with and without the U-slot antenna installed

VII. Conclusion

A simple, low-cost, low-profile U-slotted microstrip patch antenna was designed, fabricated and measured to operate at the three desired resonant bands; 1.8GHz, 2.4GHz and 3.5GHz. Measured return loss and radiation pattern compared fairly well with the simulated patterns. The average received power versus distance, when tested using a WiFi access point operating in the 2.4 GHz band, showed a relative 10 dB improvement, when a U-slot antenna was installed. The size of the antenna could be further decreased by using a substrate with a higher dielectric constant. Further U-slots could be added to the patch, if more resonant bands are desired but efforts for further optimization and fabrication precision may become more challenging.

References

[1] T. Huynh and K. F. Lee, "Single-Layer Single-Patch Wideband Microstrip Antenna," Electronics Letters, vol. 31, no. 16, 1995, pp. 1310-1312.

[2] Y. X. Guo, K. M. Luk, K. F. Lee and Y. L. Chow, "Double VSlot Rectangular Patch Antenna," Electronics Letters, vol. 34, 1998, pp. 1805-1806.

[3] K. F. Lee, S. L. Steven Yang, A. A. Kishk, "Dual and Multi Band U-Slot Patch Antennas," IEEE Antenna and Wireless Propagation Letters, 7, 2008, pp. 645-647.

[4] N.K. Darimireddy, R.R. Reddy, A.M. Prasad, "Design of Triple-layer Double U-slot Patch Antenna for Wireless Applications," Journal of Applied Research and Technology, vol. 13, no. 5, Oct 2015, pp. 526-534.

[5] K. F. Tong and T. P. Wong, "Circularly Polarized V-Slot Antenna," IEEE Transactions on Antennas and Propagation, AP55, 8, Aug 2007, pp. 2382-2385.

[6] G. Khunead, J. Nakasuwan, N. Songthanapitak, N. Anantrasirichai, "Investigate Rectangular Slot Antenna with L-shape Strip," Piers Online, vol. 3, no. 7, 2007, pp.1076-1079.

[7] J.A. Ansari, S.K. Dubey, P. Singh, R.U. Khan, B.R. Vishvakarma, " Analysis of U-slot Loaded Patch for Dual Band Operation," International Journal of Microwave and Optical Technology, vol. 3, no. 2, Apr 2008, pp.80-84.

[8] J. Ghalibafan, A.R. Attari, F. Hojjat-Kashani,"A New Dual-band Microstrip Antenna with U-shaped Slot," Progress in Electromagnetics Research, vol. 12, 2010, pp. 215-223.

[9] K.F. Lee, S.L.S. Yang, A. Kishk, "The versatile U-slot Patch Antenna," In Antennas and Propagation (EuCAP), IEEE 3rd European Conference, Mar 2009, pp. 3312-3314.

[10] S. Dwivedi, A. Rawat, R.N. Yadav, " Design of U-shape Microstrip Patch Antenna for WiMAX Applications at 2.5 GHz," In Wireless and Optical Communications Networks (WOCN), IEEE 10th International Conference, July 2013, pp. 1-5.

[11] H. Wang, X.B. Huang, D.G. Fang, "A Single Layer Wideband U-slot Microstrip Patch Antenna Array," IEEE Antennas and Wireless Propagation Letters, vol. 7, 2008, pp.9-12.

[12] N. Mittal, R. Khanna, J. Kaur, " Performance Improvement of U-Slot Microstrip Patch Antenna for RF Portable Devices using Electromagnetic Band Gap and Defected Ground Structure," International Journal of Wireless and Microwave Technologies (IJWMT), vol. 3, May 2016, pp. 20-28.

[13] Z. Yang, H. Zhang, N. Zhou, B. Wu, 2014, " A Dual Band U-shaped Slot Antenna for WLAN and WiMAX Applications," In PIERS Proceedings, Progress In Electromagnetics Research Symposium, Guangzhou, China, Aug 2014, pp. 1486-1489.

[14] H.F. Abu Tarboush, R. Nilavalan, D. Budimir, H.S. Al-Raweshidy, " Double U-slots Patch Antenna for Tri-band Wireless Systems," International Journal of RF and Microwave Computer-Aided Engineering, vol. 20, no. 3, May 2010, pp.279-285.

[15] A. B. Constantine, "Antenna Theory: Analysis and design," MICROSTRIP ANTENNAS, third edition, John Wiley & Sons, 2005.

[16] CST - Computer Simulation Technology AG, "CST Microwave Studio," Darmstadt, Germany. http://www.cst.com/products/cstmws

[17] ANRITSU, "Vector Network Analyzer (VNA Master + Spectrum Analyzer MS2034B), " CA, USA. https://www.anritsu.com/en-US/test-measurement/products/ms2034b