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Design and Analysis of E, L & U-slotted Patch Antenna for Multiband Operation

Kavita Rani[1], Shivani Malhotra[2]

[1,2]Department of Electronics and Electrical Engineering, Chitkara University, Chandigarh-Patiala National Highway (NH-64), Rajpura, India.

Abstract

In this paper, the design of two types of antenna, microstrip patch antenna and slot loaded patch antenna(SLPA) are discussed and further comparison have been done by considering the same dimensions of both the antenna designs. The slot loaded antenna design consists of the pair of symmetrical E, L and U-slots etched from the metallic patch. Both the antennas are printed on FR-4 material. The wide variations have analyzed in the simulation results of both the antenna in spite of having similar dimensions. It was inferred that bandwidth increases at an average by 70% when microstrip patch antenna converted into slotted antenna. It is additionally elucidated that slot antenna is more directive in comparison to microstrip patch antenna.

Keywords- Slot loaded patch antenna, Bandwidth, Gain, Return loss.

INTRODUCTION

The widespread requirement for mobile communication and information exchange through wireless devices has led to the achievements in designing antennas. Most of the researchers have been putting their efforts to design the compact, flexible and miniaturized antenna. On account of these necessities, designing a proficient antenna becomes a very exciting challenge [1]. There are different antennas which operate in the distinctive band of frequencies but the major concern now a day is flexibility, low cost, miniaturization, low return loss, high gain and high directivity, which led to the evolution of microstrip patch antenna.

Microstrip patch antenna was originated in the early 1950s. In 1960, radiations from the strip line discontinuity were investigated [2]. But there was little focus on the patch antenna because the patch antenna provides narrow bandwidth. In the 1970s, the patch antenna became quite popular because of the advantages like the low profile, conformal to the surface, low cost and ease of fabrication etc. was recognized by the researchers. In 1975, most of the researchers have worked on the microstrip patch elements [3-6]. The thought of the Microstrip patch antenna developed from the printed circuit technology, which was just for the transmission line and the electronic circuitry [7]. It fundamentally comprises the metallic patch situated on the thin grounded dielectric substrate material. Where, substrate material, patch and feed line are the significant parts of the patch antenna. Substrate material plays the vital task in the antenna design to attain the preferred electrical and physical characteristics. There are different shapes of metallic patch such as rectangular, circular, triangular, square and so on. But the rectangular patch gives the better outcome (in terms of return loss, radiation efficiency, and directivity) than other patch shapes [8]. Second significant part of the antenna design is the feed line as Feed line connects the feed antenna with the transmitting or receiving antenna. Different types of feeding methods (Coaxial, Microstrip line feeding, Aperture coupling, and Proximity coupling) have pros and cons [7]. There are numerous applications of the Microstrip patch antenna i.e. communication, biomedical, RFID, ISM band so forth, they can be utilized to enhance the bandwidth and Directivity [9].This antenna is more beneficial when contrasted with the conventional antennas. Some of its benefits are like Cost effective, Conformal to both planar and non-planar surface, lightweight and facile integration with microwave integrated circuits etc. Instead of these advantages, there are two noteworthy downsides of the patch antenna such as narrower bandwidth and low gain [9]. Keeping in mind the end goal to enhance the bandwidth of the patch antenna, few techniques have been proposed, for example, the thick substrate has been utilized with the low value of $\in_r$ [11-12]. For large bandwidth, the antenna with the different shapes of rectangular wide slots has been studied [10].

A few reports have shown up about the improvement of multiband antennas. Be that as it may, the vast majority of them are moderately substantial and additionally don't give desired bandwidth. Enhancement in bandwidth due to slots has been analyzed and also the dimensions of the antenna have been condensed. There are numerous antennas which are designed for wireless systems, for example, coplanar waveguide [11], meandered split-ring slots [12], and rectangular parasitic components [13].

Anyhow, the majority of the antennas exhibit either single or double band characteristics [11]-[13]. The slotted antennas are required to have broadband characteristics, higher gain and also low return loss. In [14-16], U-slot antenna design exhibits dual and multiband characteristics and provides desired bandwidth. In [17], V-slot antenna was designed using Ansoft Ensemble 8 software and furthermore fabricated. The improvement of v-slot antenna was contemplated. The bandwidth of the proposed antenna was dissected to be upgraded to 47% from the 40% bandwidth of the u-slot antenna design. The comparison was done between the single and dual layer v-slotted antenna. In [18], an antenna was designed with the pair of L- and U-slots for application of

WLAN (2.4GHz/ 5.2GHz/5.8GHz)/WI-MAX (2.5GHz/3.5GHz/5.5 GHz). The simulated outcome has analyzed through the software Ansoft HFSS. The simulated antenna results in the good multiband characteristics and Omni-directional. In the year 2015 [19], Multilayer microstrip patch antenna was specially designed for numerous wireless applications. The bandwidth has been enhanced with three layers of antenna design and it prompts the more scope of frequencies. The antenna was simulated by HFSS software. The antenna exhibits triple band operation.

Multiband antenna covers diverse applications in wireless communication systems, however, in this paper; a microstrip patch antenna is designed without slotting and with the combination of E, L and U-shaped slots to cover the immense part of the wireless such as Bluetooth, WLAN and WI-MAX. CST (Computer Simulation Technology) software was used to design these antennas and furthermore resultant antenna parameters for both the antenna designs have been calculated. Slot loaded patch antenna (SLPA) is designed for multiband applications. Multiband characteristics of the given antenna design are accomplished by the combination of E, L, and U-slots on the patch with a well-ordered outline methodology. Comparison of the antenna without slotting and with slots is also given.

ANTENNA DESIGN

This section comprises two parts. Where, first part depicts the Rectangular patch antenna without slotting and second section describes the slot loaded patch antenna. Both the antennas shown in fig 1 and 3 are simulated by utilizing CST microwave studio software. To design the antenna, dimensions are needed by the software which is calculated through some standard equations [20] such as:

Width of the patch antenna (W):

$$W = \frac{v_0}{2f_r}\sqrt{\frac{2}{\epsilon_r+1}} \quad (1)$$

Where, v_0 - velocity of light, which is 3×10^8m/s and f_r - resonance frequency.

Effective dielectric constant (ϵ_{reff}):

$$\epsilon_{reff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2}\left[1+\frac{12h}{W}\right]^{-\frac{1}{2}} \quad (2)$$

Where, ϵ_r - dielectric constant of the substrate,

h- Thickness of substrate,

W- Patch width.

The extension length ΔL of the patch:

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

The effective length of the patch:

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

Using the given equations, dimensions of the antenna have been calculated as shown in table no.1.

Table 1. Dimensions for the design of microstrip patch antenna

Sr.No.	Antenna Parameters		Dimensions (mm)
1.	Substrate length	L	28
2.	Substrate width	W	29.5
3.	Feed line length	L_f	26
4.	Feed line width	W_f	4
5.	Gap between patch and feed line	GPF	1
6.	Inset feed length	Fi	12
7.	Substrate thickness	h	1.6
8.	Patch thickness	Mt	0.1

A. *Rectangular Patch Antenna Without Slotting*

Equations (1)-(4) have been used to design the antenna. The proposed antenna is designed by using FR-4 material having dielectric constant (ϵ_r) =4.4, and thickness, h=1.6mm. All the specifications of the designed antenna are represented by table no. 1.

All the dimensions i.e. substrate length and substrate width, feed line width, inset feed length, patch thickness and substrate thickness of the designed antenna with their corresponding values are represented by table no. 1. In order to design the antenna, CST microwave studio was utilized.

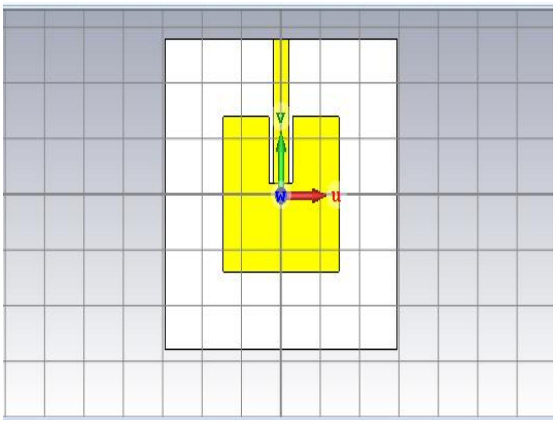


Figure 1: Rectangular Patch Antenna without Slotting

a. *Simulation results of the rectangular patch antenna without slotting*

The simulation results of the patch antenna design without slotting include return loss (RL), Voltage Standing Wave Ratio (VSWR), gain, directivity and bandwidth.

Return loss (RL)

The curve between RL and frequency is shown in figure 2(a). Basically, the RL should be less than -10dB [20]. It is observed that RL of rectangular patch antenna without slotting is -11.752 dB at resonating frequency 2.5GHz.

VSWR

Figure 2(b) shows the VSWR of the patch antenna design without slotting. Its value should be less than 2[20]. It is observed that VSWR is 1.6983 at resonating frequency 2.5GHz.

Far field Results

The far field results of the designed antenna have also been observed which includes gain and directivity of the antenna.

It has been observed that gain and directivity of the rectangular patch antenna without slotting is 3.79dB and 6.53dBi at resonating frequency 2.5GHz shown in figure 2(c) and 2(d).

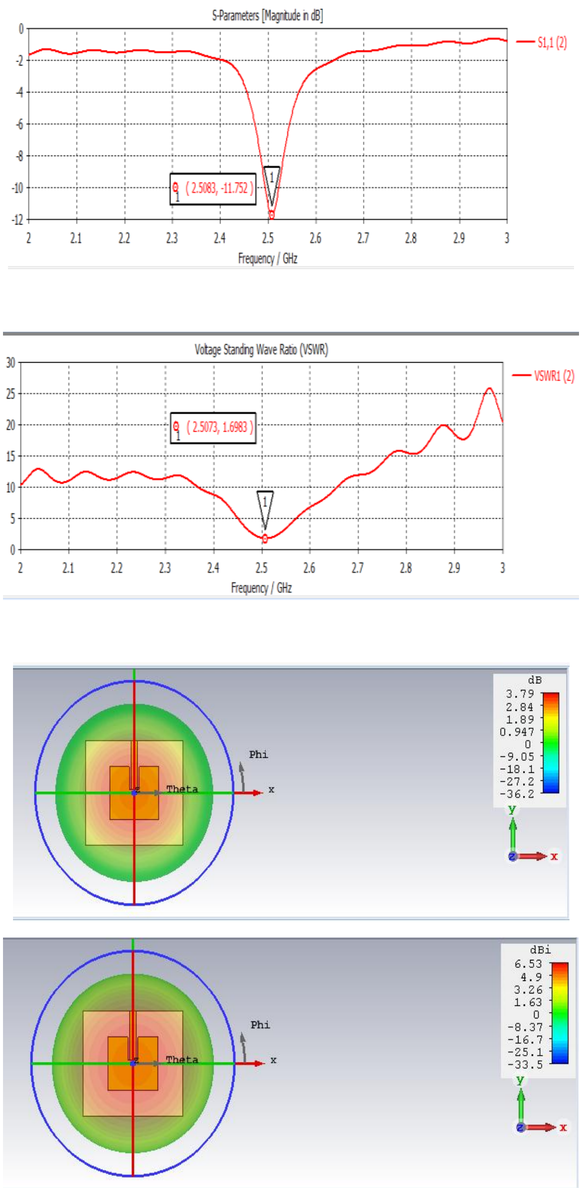


Figure 2 (a) RL, (b) VSWR, (c) Gain and (d) Directivity of rectangular patch antenna without slotting

B. Slot Loaded Rectangular Patch Antenna(SLPA)

Figure 3 shows the combination of three slots E, Land U which has been designed to accomplish the multiband characteristics. Dimensions of all the slots are shown in figure 4.

The pair of E- slots is of same dimensions, likewise pair of L-slots and pair of U-slots is of same dimensions

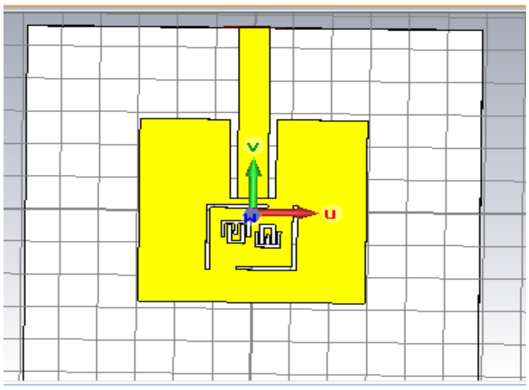


Figure 3. SLPA design

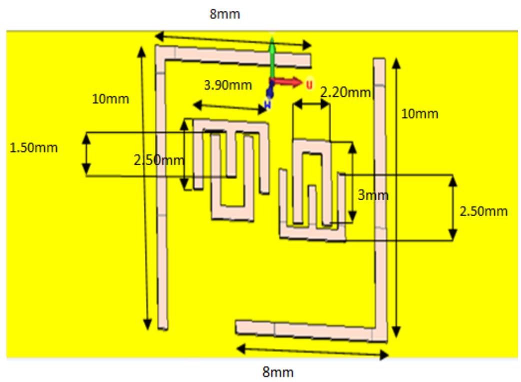


Figure 4. Dimensions of SLPA design

a. Simulation results of SLPA

In this part, simulations results for RL, VSWR, gain and directivity of the slot loaded patch antenna are presented.

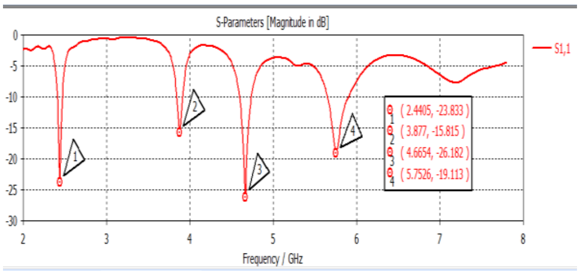
Return Loss (RL)

RL of the SLPA is -23.833dB, -15.815dB, -26.182dB, -19.113dB at resonating frequencies 2.4GHz, 3.8GHz, 4.6GHz, 5.7GHz respectively as shown in figure 5(a). It has observed that the slotted antenna exhibits multiband characteristics.

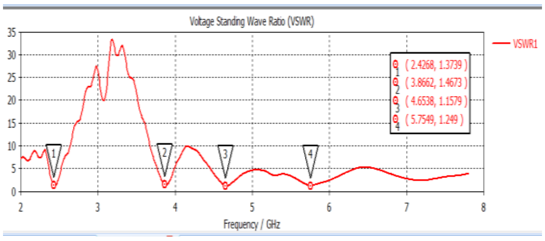
The first resonance frequency occurs because of without slotting antenna and rest of the resonances are just because of E, L and U-shaped slots.

VSWR

Figure 5(b) shows the values of VSWR are 1.37dB, 1.46dB, 1.15dB, 1.24dB at resonating frequencies 2.4GHz, 3.8GHz. 4.6GHz, 5.7GHz respectively.



(a)



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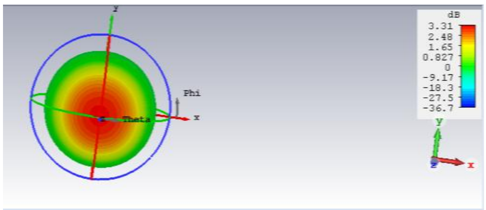
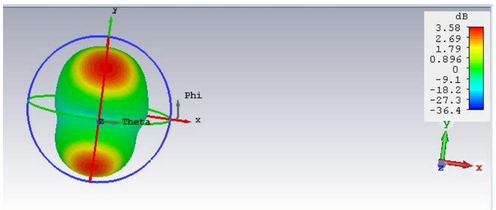
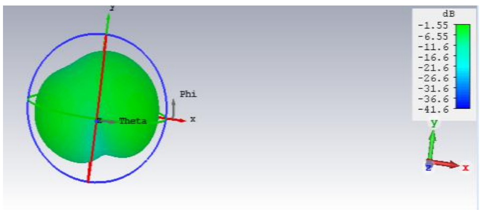


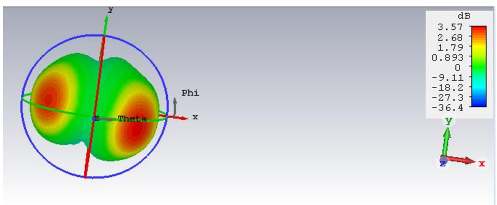
(c)



(d)



(e)



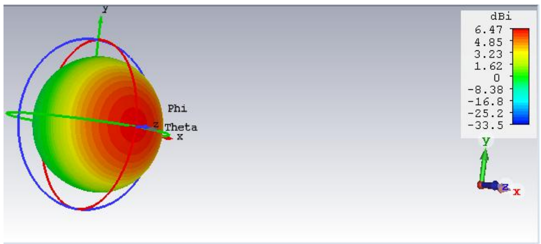
(f)

Figure 5. Slot loading patch antenna results: (a) RL, (b) VSWR, (c) Gain at 2.4GHz (d) Gain at 4.6GHz, (e) Gain at 3.8GHz, (f) Gain at 5.7GHz

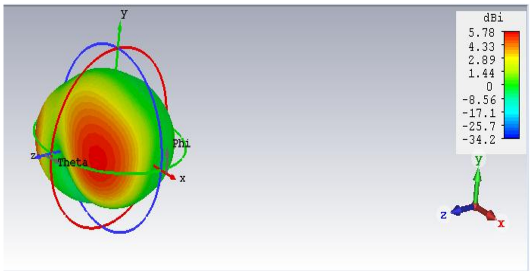
Far Field Results

The far field results of the designed antenna have also observed which includes gain and directivity of the antenna. Figure 5 (c)- 5(f) shows the gain of 3.31dB, -15.5dB, 3.58dB and 3.57dB at their respective resonance frequencies 2.4GHz, 3.8GHz, 4.6GHz and 5.7GHz.

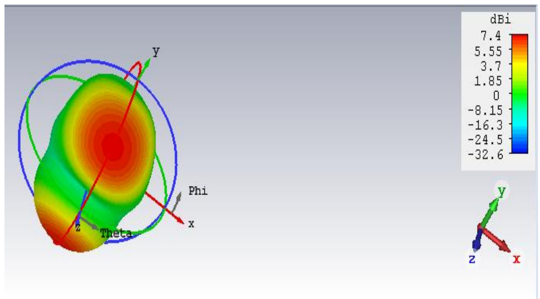
Figure 6(a)- 6(d) shows the directivity of 6.47dBi, 5.78dBi, 7.4dBi and 6.54dBi at their respective frequencies 2.4GHz, 3.8GHz, 4.6GHz and 5.7GHz



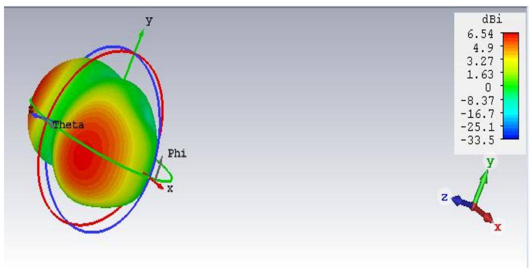
(a)



(b)



(c)



(d)

Figure 6. Directivity of SLPA at (a) 2.4GHz, (b) 3.8GHz, (c) 4.6GHz and (d) 5.7GHz

From the results received after summarization, the highlights are tabulated in the form of the table 2. RL, VSWR, Antenna gain, directivity, and bandwidth are the prime parameters while designing an antenna. So with the perspective of these parameters comparison of rectangular patch antenna without slotting and slot loaded rectangular patch antenna has been done. Rectangular patch antenna without slotting resonates at 2.5GHz covers 28.9MHz bandwidth. Whereas slot loaded antenna resonates at multiple frequencies of 2.4GHz, 3.8GHz, 4.6GHz and 5.7GHz covering a bandwidth of 57.91MHz, 77.93MHz, 158MHz and 264.81MHz respectively. M. Moosazadeh et al. [18] in his findings clarified that gain, bandwidth, and radiation patterns are the crucial factors while working for slotted antennas. Therefore, the comparison has been done for these parameters for both the antenna design as shown in table 2. The result of the two designs quoted in table 2 signifies that there is an appreciable increase in bandwidth of slotted antenna in comparison to the microstrip patch design. Also the region of applications extends from WIMAX at 2.5GHz (Microstrip patch design) to WIMAX, WIFI, satellite communication and so forth. In addition to it, an increase in directivity was also observed in later case.

Table 2. Comparison between rectangular patch antenna without slotting and slot loaded rectangular patch antenna

Parameters	Frequencies				
	Rectangular Patch Antenna Without Slotting	SLPA design			
	2.5GHz	2.4GHz	3.8GHz	4.6GHz	5.7GHz
RL (dB)	-11.75	-23.83	-15.81	-26.183	-19.113
VSWR	1.6983	1.37	1.46	1.15	1.24
Gain (dB)	3.79	3.31	-1.55	3.58	3.57
Directivity (dBi)	6.53	6.47	5.78	7.4	6.54
Bandwidth (MHz)	28.9	57.91	77.93	158	264.81

CONCLUSION

Design of microstrip patch antenna and SLPA is introduced in this paper. Similar dimensions have taken for both the designs. FR-4 material is used as substrate material. Symmetrical pair of E, L and U-slots was etched from the metallic patch while converting the microstrip patch antenna into slot loaded antenna design. Simulation results of both the antenna design have been done by taking similar dimensions. It was inferred that microstrip patch antenna resonates at 2.5GHz frequency called single band, whereas after addition of slots , antenna gets resonating at four frequencies 2.4GHz, 3.8GHz, 4.6GHzand 5.7GHz. RL of microstrip patch antenna is -11.75dB, which is appreciably improved by the slotted antenna i.e. -23.83dB, -15.81dB, -26.183dB and -19.11dB at their respected resonance frequencies. Furthermore, the bandwidth increases at an average by 70%, when microstrip patch antenna converted into slotted antenna. Additionally, slot antenna is more directive in comparison to microstrip patch antenna.

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