Design and Development of Quad-Band H-Shaped Microstrip Patch Antenna for WiFi and LTE Applications

P.JOTHILAKSHMI[1], R.K.VIGNESHWARAN[2], R.NARASIMMAN[3], B.PRAVEEN[4]
[1]Assistant Professor
[2,3,4] UG Students
Department of Electronics and Communication Engineering
Sri Venkateswara College of Engineering, Chennai, Tamilnadu, India
Sriperumbudur, Chennai
INDIA
jothi@svce.ac.in

Abstract: - The increasing demand in portable devices with wireless connectivity provides a challenge to design a RF front antenna. Microstrip patch antennas are widely used because they are of light weight, compact, easy to integrate. However the serious problem of patch antenna is their narrow band due to surface losses and large size of patch for better performance. So for the antenna miniaturization and bandwidth improvement H-shaped microstrip patch antenna was used. In this paper proposed a design of small sized, low profile patch antenna for wireless applications. The antenna multiband capability could be achieved by introducing a slot in the rectangular patch portion of h shaped patch antenna. The proposed antenna structure operates at four frequency bands of 2.2 GHz, 2.4 GHz, 2.8 GHz, and 2.9 GHz for WiFi and LTE applications. The performance measures of antenna return loss, voltage standing wave ratio, radiation pattern, gain, directivity and power were measured and tabulated, which shows that the antenna performance was good and results obtained were optimum. The simulation tool used for this design was Advanced Design System (ADS).
Key-Words: - Microstrip patch, Multiband Antenna, Gain, Return loss, Directivity, Radiation pattern.

1 Introduction

An antenna is an essential part of a radio system, is defined as a device which can radiate and receive electromagnetic energy in an efficient and desired manner. Antenna is actually a transformer that transforms electrical signals into electromagnetic waves or vice versa. Requirements for conformal antennas for airborne systems, increased bandwidth requirements, and multi functionality have led to heavy exploitation of printed (patch) or other slot-type antennas and the use of powerful computational tools for designing such antenna. Needless to say, the commercial mobile communications industry has been the catalyst for the recent explosive growth in antenna design needs. Certainly, the past decade has seen an extensive use of antennas by the public for cellular, GPS, satellite, wireless LAN for computers Wi-Fi, Bluetooth technology, Radio Frequency ID devices, WiMAX, and so on. However, future needs will be even greater when a multitude of antennas are integrated into say automobiles for all sorts of communication needs and into a variety of portable devices and sensors for monitoring and information gathering.
The concept of microstrip radiators was first proposed by Deschamps in 1953. A patent was issued in France in 1955 in the names of Gutton and Baissinot. However, twenty years passed before practical antennas were fabricated. Development during the 1970 was accelerated by the availability of good substrates with low loss tangent and attractive thermal and mechanical properties, improved photolithographic techniques, and better theoretical models. The first practical antennas were developed by Howell and Munson. Since then, extensive research and development of microstrip antennas and arrays, aimed at exploiting their numerous advantages such as light weight, low volume, low cost, conformal configuration, compatibility with integrated circuits, and so on, have led to diversified applications and to the establishment of the topic as a separate entity within the broad field of microwave antennas. The importance of multiband antenna design was discussed in the literature [1-10]. Microstrip antennas have some distinct properties [11-12,21]

- The bandwidth is directly proportional to substrate thickness and width
- The resonant input resistance is almost independent of the substrate thickness
- The resonant input resistance is proportional to εr
- The directivity is fairly insensitive to the substrate thickness

- The radiation efficiency is less than 100% due to conductor loss, dielectric loss and surface wave power.

2 Structure and design equation of Microstrip patch antenna

A microstrip antenna in its simplest configuration consists of a radiating patch on one side of a dielectric substrate, which has a ground plane on the other side. The patch conductors, normally of copper or gold, can assume virtually any shape, but regular shapes are generally used to simplify analysis and performance prediction. Ideally, the dielectric constant of the substrate should be low to enhance the fringe fields that account for the radiation. However, other performance requirements may dictate the use of substrate materials whose dielectric constants can be greater than, say, and four. Various types of substrates having a large range of dielectric constant and loss tangent values have been developed. Some of these substrates are flexible in nature, which makes them suitable for conformal wraparound antennas. Microstrip antennas are widely used in the microwave frequency region because of their simplicity and compatibility with printed-circuit technology, making them easy to manufacture either as stand-alone elements or as elements of arrays. A Microstrip antenna consists of a planar radiating structure over a ground plane separated by an electrically thin layer of dielectric substrate. The rectangular and circular patches are the basic and most commonly used microstrip antennas. These patches can be used for the simplest and the most demanding applications. For an efficient radiator, a practical width that leads to good radiation efficiencies is given in equation 1. Equation 2 to Equation 9 are used to calculate the design parameters of microstrip patch antenna. These equations are used to calculate any shape of patch antenna.

$$W = \frac{C}{2 f_r \sqrt{\frac{\varepsilon_r + 1}{2}}} \tag{1}$$

Where c is the velocity of light, $3*10^8$m/s,

ε_r is the dielectric constant of the substrate.

f_r is the resonant frequency.

Effective Dielectric constant of the microstrip is determined as

$$\varepsilon_{reff} = \frac{(\varepsilon_r + 1)}{2} + \frac{(\varepsilon_r - 1)}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}} \tag{2}$$

Where ε_r is the dielectric constant of the substrate, 4.3mm,

h is the height of the substrate,

W is the width of the substrate.

Once width is found, Extension of the length ΔL can be determined and denoted as,

$$\Delta L = \frac{0.412 * h(\varepsilon_{reff} + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_{reff} - 0.258)(\frac{W}{h} + 0.8)} \tag{3}$$

Where, ε_{reff} is the effective dielectric constant.

Actual Length of the patch and also the substrate can now be determined by using effective length as,

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

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

Where, L_{eff} is the effective length.

ΔL is the extension of length.

Feed line width can be modelled using the transmission characteristics and the impedance is given by,

$$Z_0 = \frac{120\Pi}{2\sqrt{2\Pi\sqrt{\varepsilon_r + 1}}} \ln\left\{\frac{4h}{W}\left\{\frac{14 + \frac{8}{\varepsilon_r}}{11} \times \frac{4}{W'} + A\right\}\right\} \tag{6}$$

$$A = \sqrt{\left(\frac{14 + \frac{8}{\varepsilon_r}}{11}\right)^2 \left(\frac{4h}{W'}\right) + \frac{1 + \frac{1}{\varepsilon_r}}{2} \times \Pi^2} \tag{7}$$

Where

$$W' = W + \Delta W' \tag{8}$$

$$\Delta W = W\left(\frac{1 + \frac{1}{\varepsilon_r}}{2}\right) \tag{9}$$

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3 Structure and design equation of Microstrip patch antenna

For designing H-shaped patch antenna first the basic rectangular patch has been designed. From that the L shaped patch has been developed and then combined four L shaped patch to form a h shaped patch antenna. For designing rectangular patch the following design values had been adopted. In the layout window of Advanced Design System the design of multiband antenna is made and then synthesised by giving a 50 Ω microstrip feed line. The antenna parameters can be calculated using the equation (1) to equation (9). The calculated design parameters for the rectangular patch was shown in Table1.

Table 1. Design Parameters of proposed patch antenna.

Parameter	Value
Relative permittivity	4.6
Height of the substrate	1.6 mm
Tan Delta	0.001
Conductivity	5.8e+7 S/m
Width of the patch	29.2 mm
Depth of the feed line	H = 0.822*L/2 , Y=W/5 X=Z=2W/5

Fig.1. to Fig.3. shows the design of rectangular patch antenna and its return loss and radiation pattern at single frequency of 2.4 GHz band.This design was the basic design for the design of h-shaped patched antenna. Further the rectangular patch antenna has been developed to from L-shaped patch antenna which is shown in Fig.4. This structure also can radiate for a single frequency of 2.4 GHz with minimum return loss and good radiation which is shown in Fig.5. The design of normal H-shpaed patch antenna is shown in Fig.6. Fig.7. and Fig.8 shows the return loss and radiation pattern of the general H-shaped patch antenna.for a single frequency band. It is a combination of four L-shpaed patch. Fig.9. shows the modified H-shaped patch antenna for multiband applications. Fig.10. to Fig.16. shows the return loss, voltage standing wave ratio and radiation pattern plot of modified H-patch antenna for multiband applications. The design parameters could be calculated using the equations (1) to equation (9). According to these design equation the width, legth extension, effective length and length of the H-shaped patch antenna can be calculated as, W= 29.3 mm, ΔL = 15 mm, L_{eff} = 64 mm and L= 34 mm. The modified H-shaped patch could be operates for multiple frequency bands which can be shown in Fig.10. The return loss and voltage standing wave ratios for all multiple frequency bands were optimum but efficiency got reduced in this design. So the improvement can be made to improve the efficiency.

The bandwidth and efficiency of H-shaped patch can be further improved by introducing a slot in the patch. Fig.17. shows the slotted H-shaped patch antenna. In this design four slots are introduced to obtain the desired bandwidth.Fig.18. and Fig.19. shows the return loss and voltage standing wave ratio plot of slotted H-shaped patch antenna, which shows that the proposed H-shpaed patch antenna radiates efficiently with minimum return loss and voltage standing wave ratio with desired bandwidth. Fig.20 to Fig.31 shows the radition pattern plot of proposed antenna for different parameteric observations, which is good and shows that the proposed structure can radiate for unidirectional with radiates efficiently for all frequency bands. The cost of the substrate material is a constraint and chosen dielctric material was FR4. The proposed antenna structure was fabricated using FR4 was shown in Fig.32. Fig.33. to Fig.35. shows the return loss and voltage standing wave ratio plot of proposed H-shaped patch antenna using Network Analyzer, which shows that the proposed antenna radiates for multiple frequency bands with minum retrun loss and optimum voltage standing wave ratio. The observed results are tabulated in table.2. These results shows that the performance of the antenna was good compared to previous literature results [1 -15].

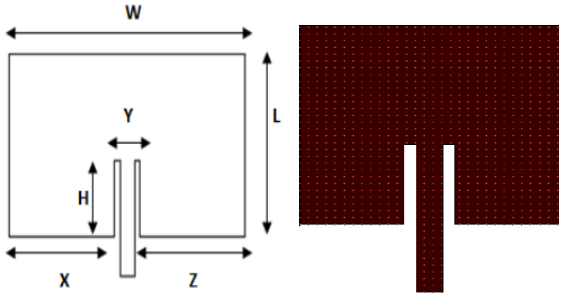

Fig.1. Structure of rectangular Microstrip patch antenna

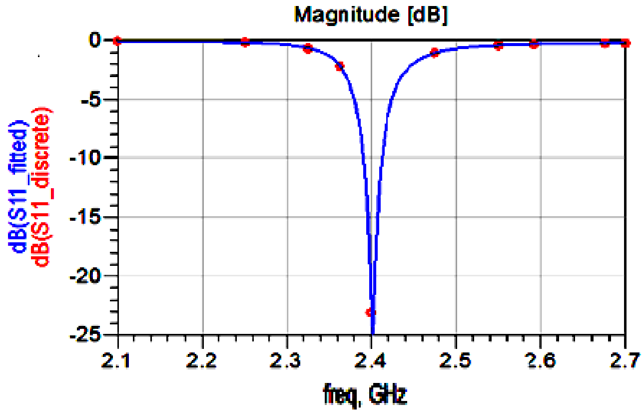

Fig.2. Return loss plot of rectangular patch antenna

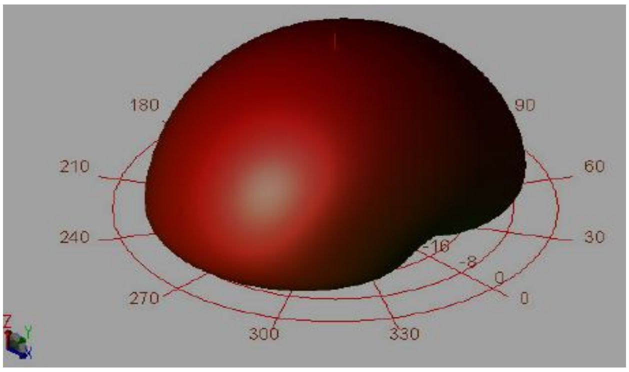

Fig.3. Three dimensional radiation pattern o rectangular patch antenna during ADS simulation

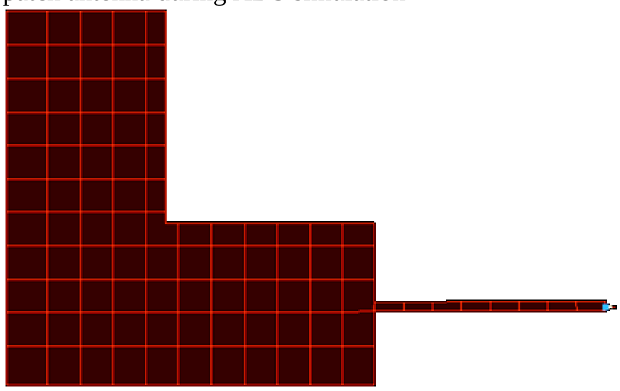

Fig.4. Structure of L-shaped patch antenna during ADS simulation

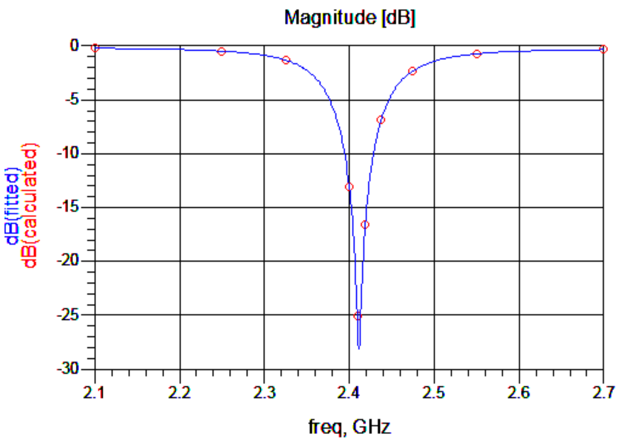

Fig.5. Return loss plot of L-shaped patch antenna

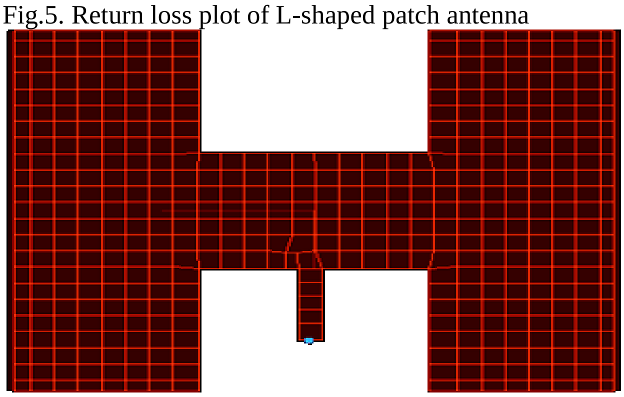

Fig.6. Structure of normal H-shaped patch antenna during ADS simulation

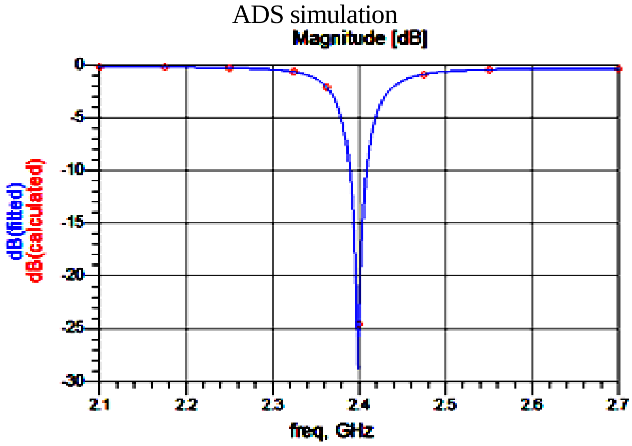

Fig.7. Return loss plot of normal H-shaped patch antenna during ADS simulation

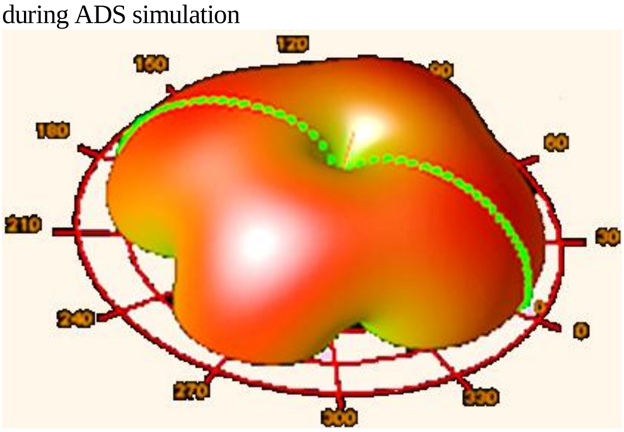

Fig.8. 3-D radiation pattern of normal H-shaped patch antenna during ADS simulation

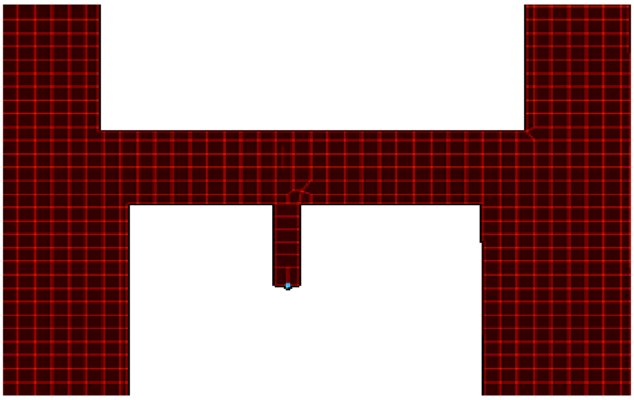

Fig.9. Structure of modified H-shaped patch antenna during ADS simulation

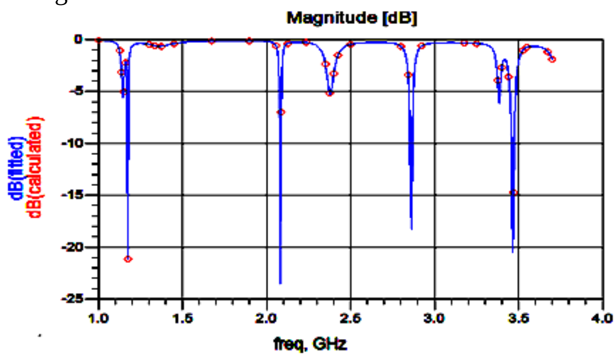

Fig.10. Return loss plot of modified H-shaped patch antenna during ADS simulation

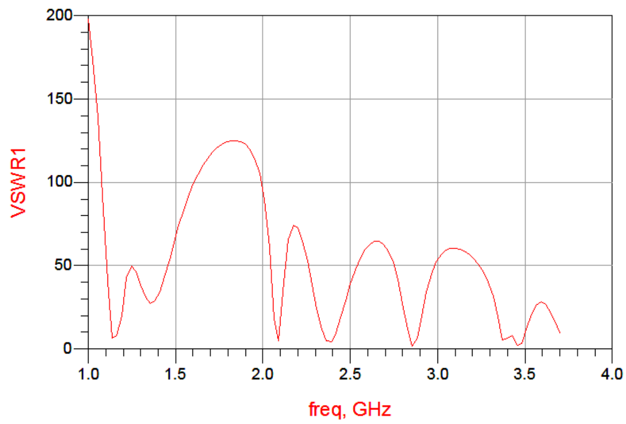

Fig.11. Voltage Standing Wave Ratio (VSWR) plot of modified H-shaped patch antenna during ADS simulation

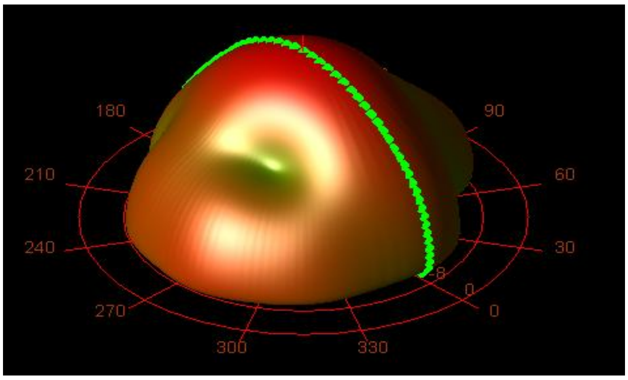

Fig.12. 3-D radiation pattern of modified H-shaped patch antenna during ADS simulation

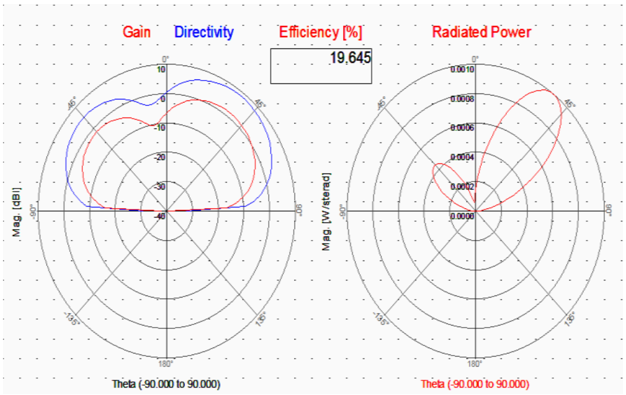

Fig.13. Polar plots of Gain, radiated power of a modified H patch antenna at 1.38 GHz.

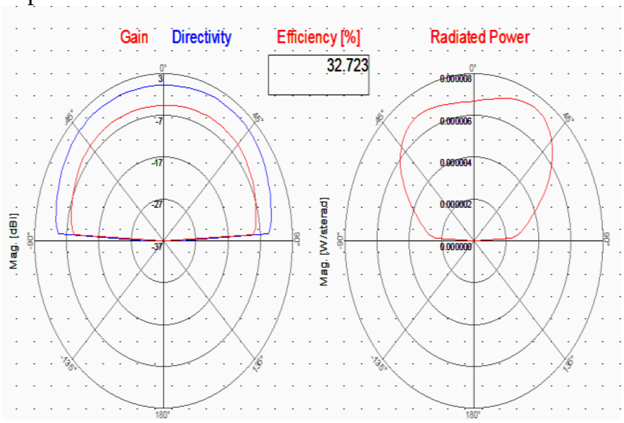

Fig.14. Polar plots of Gain, radiated power of a modified H patch antenna at 2.18 GHz.

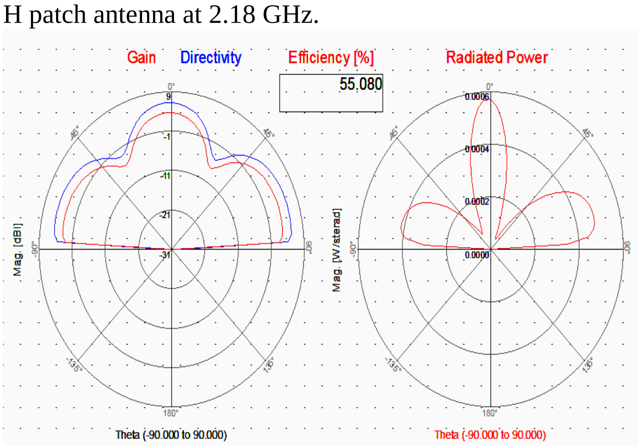

Fig.15. Polar plots of Gain, radiated power of a modified H patch antenna at 2.78 GHz.

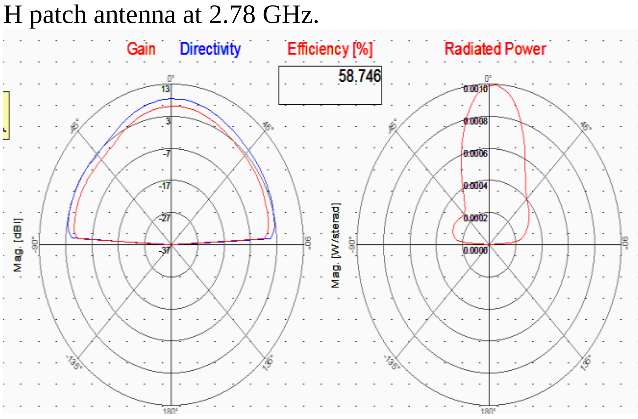

Fig.16. Polar plots of Gain, radiated power of a modified H patch antenna at 3.48 GHz.

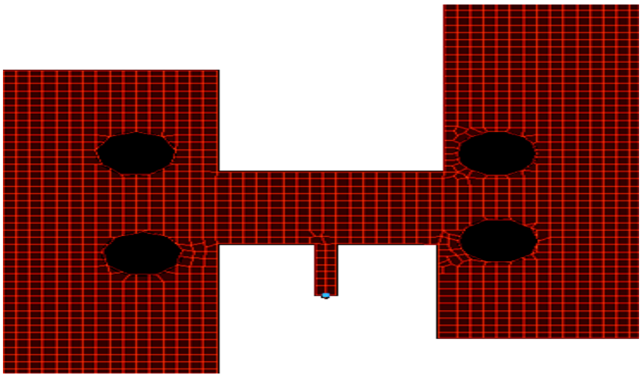

Fig.17. Structure of slotted H-shaped patch antenna during ADS simulation

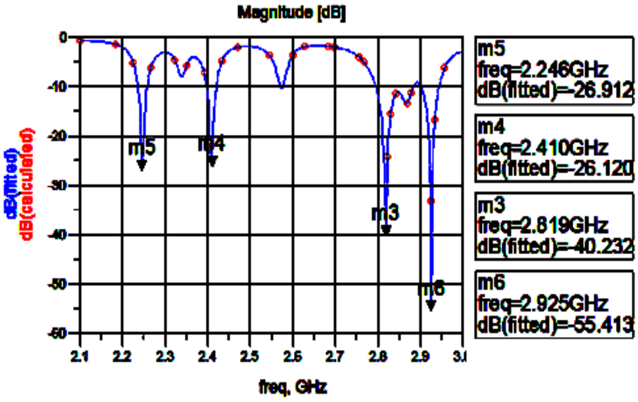

Fig.18. Return loss plot of slotted H-shaped patch antenna during ADS simulation

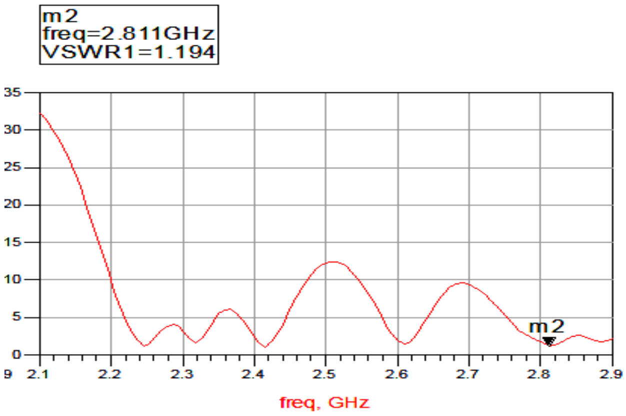

Fig.19. Voltage Standing Wave Ratio plot of slotted H-shaped patch antenna during ADS simulation.

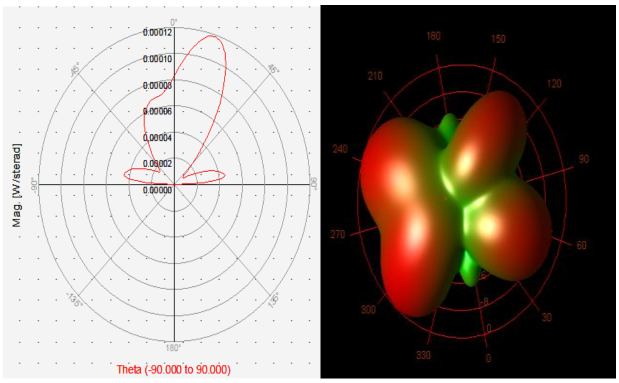

Fig.20. Polar and 3-D radiation pattern of H –shaped slotted microstrip patch for 2.2GHz operating frequency.

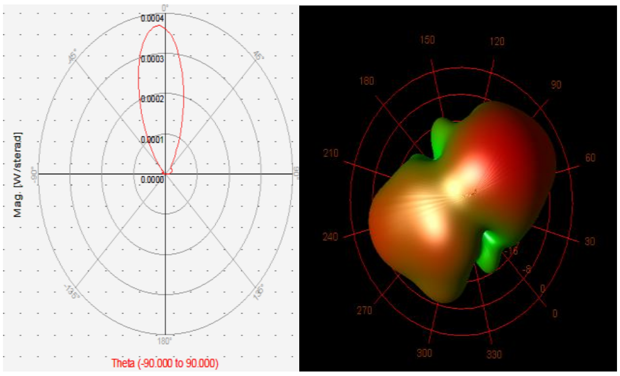

Fig.21. Polar and 3-D radiation pattern of H –shaped slotted microstrip patch for 2.4 GHz operating frequency.

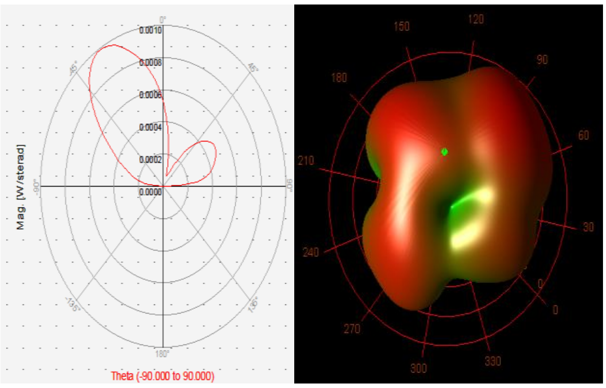

Fig. 22. Polar and 3-D radiation pattern of H –shaped slotted microstrip patch for 2.6 GHz operating frequency

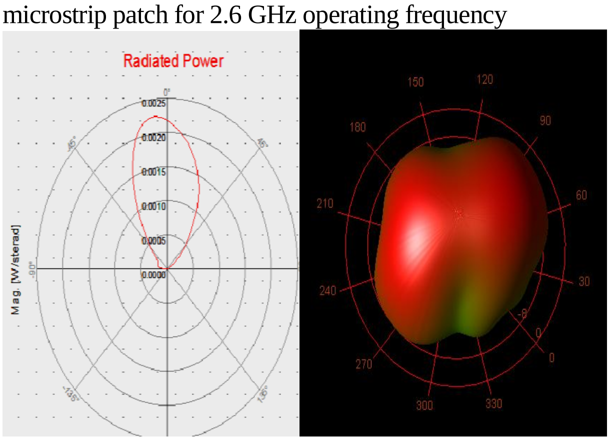

Fig.23. Polar and 3-D radiation pattern of H –shaped slotted microstrip patch for 2.8 GHz operating frequency

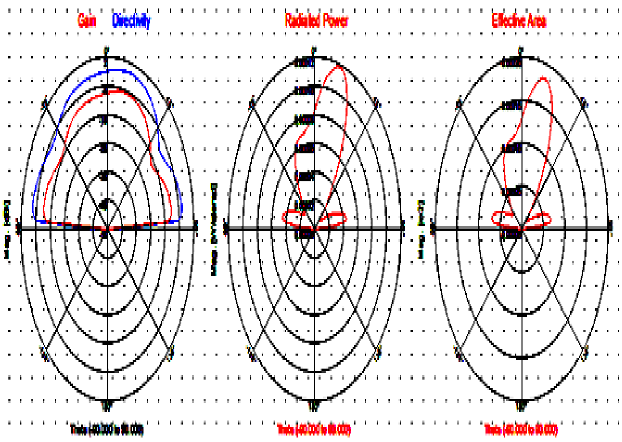

Fig.24. Polar plots of Gain, radiated power and effective area of a slotted H patch antenna at 2.2 GHz

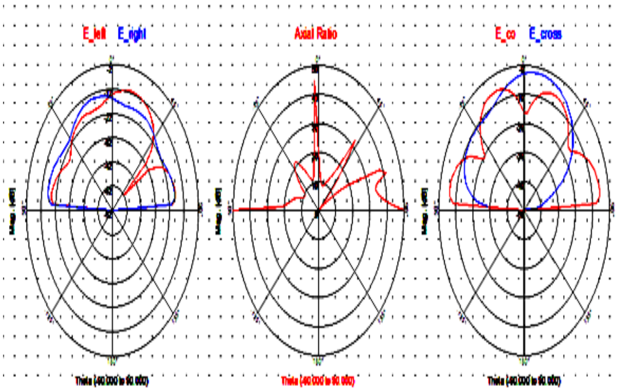

Fig.25. Polar plots of circular polarization, linear polarization and axial ratio of a slotted H patch antenna at 2.2 GHz.

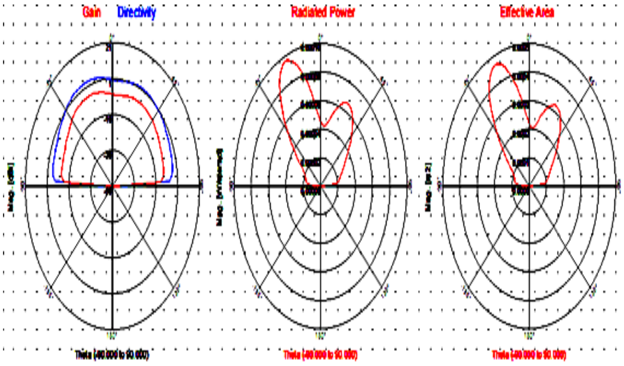

Fig. 26. Polar plots of Gain radiated power and effective area of a slotted H patch antenna at 2.4 GHz.

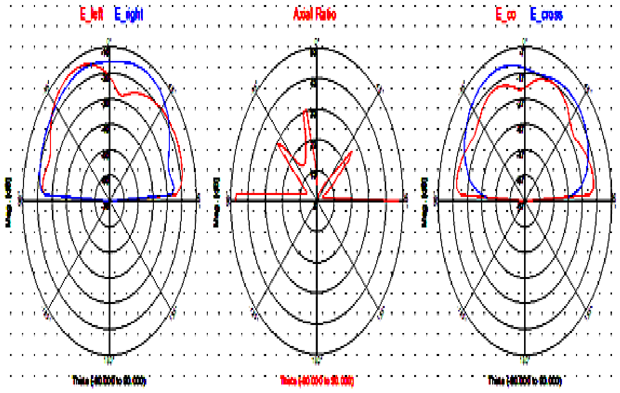

Fig.27.Polar plots of circular polarization, linear polarization and axial ratio of a slotted H patch antenna at 2.4 GHz

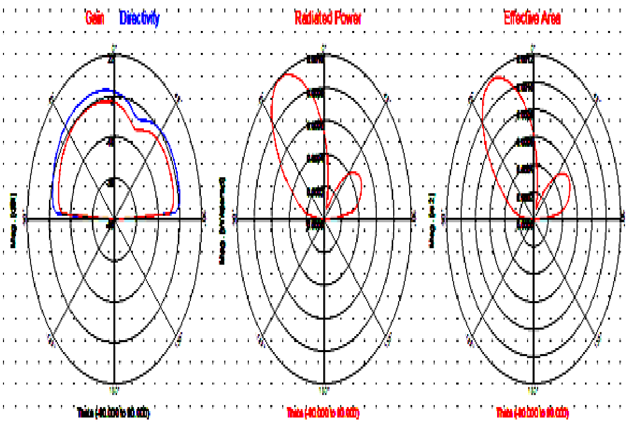

Fig.28. Polar plots of Gain radiated power and effective area of a slotted H patch antenna at 2.8 GHz.

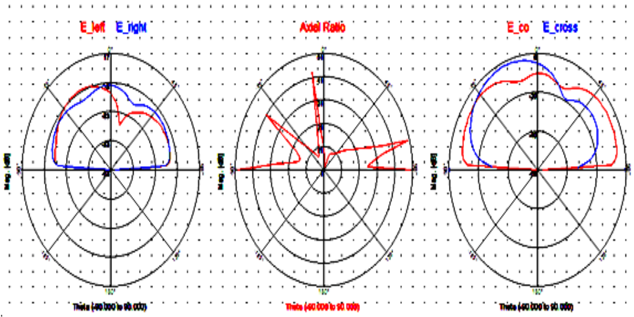

Fig.29. Polar plots of circular polarization, linear polarization and axial ratio of a slotted H-shaped patch antenna at 2.8 GHz.

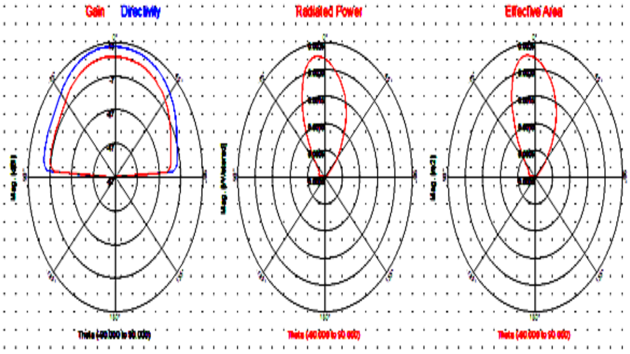

Fig. 30. Polar plots of Gain radiated power and effective area of a slotted H-shaped patch antenna at 2.9 GHz.

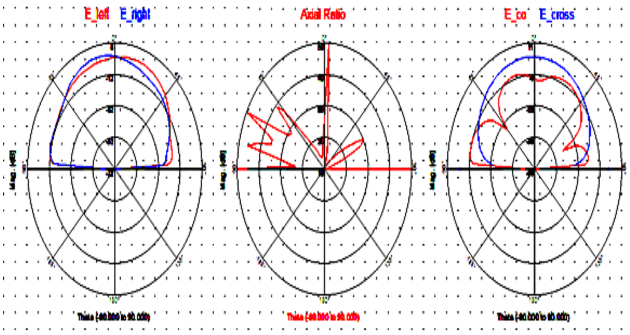

Fig.31. Polar plots of circular polarization, linear polarization and axial ratio of a slotted H-shaped patch antenna at 2.9 GHz.

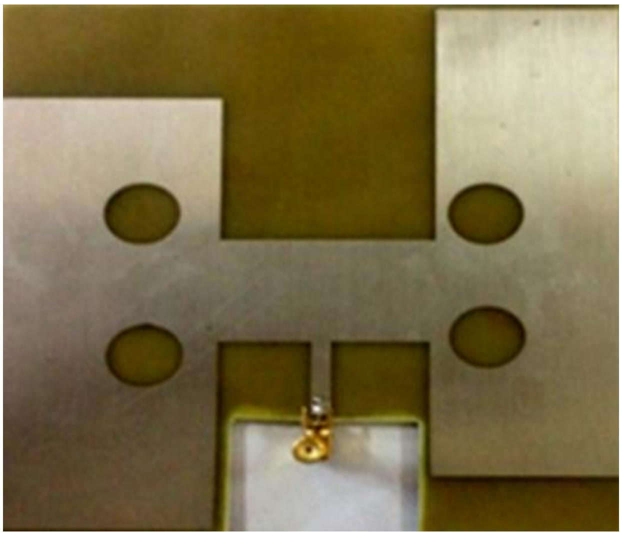

Fig.32. Fabricated multiband slotted H-shaped patch antenna.

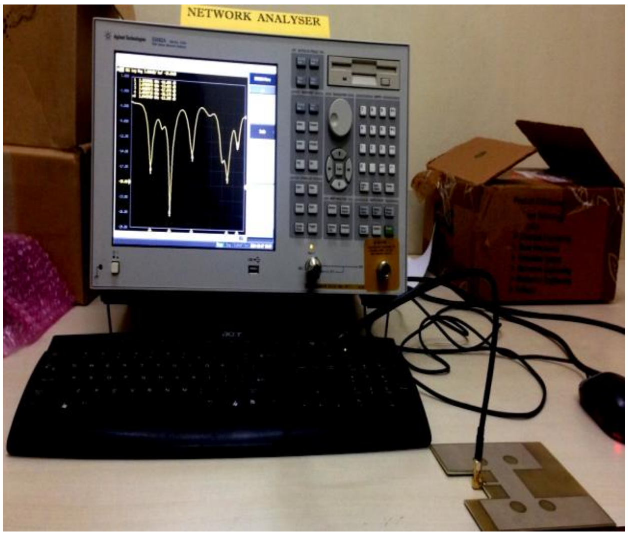

Fig.33. Fabricated multiband slotted H-shaped patch antenna tested using network analyser

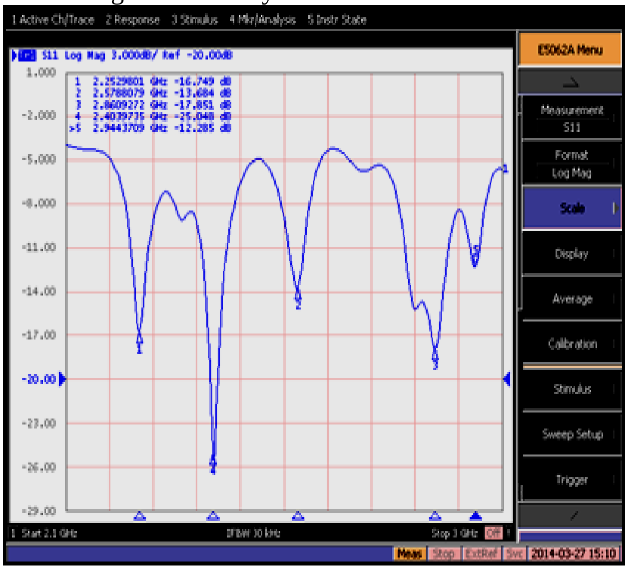

Fig.34. Return loss VBA file of H-shaped patch antenn tested using network analyser.

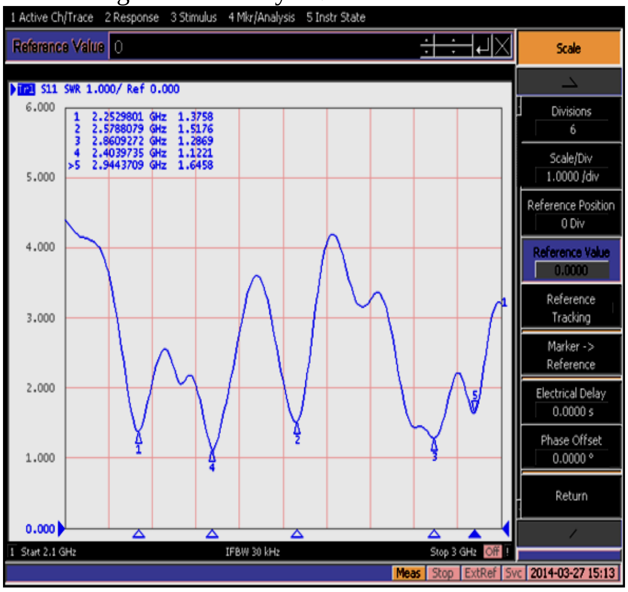

Fig.35. Voltage standing wave ratio (VSWR) VBA file of H-shaped patch antenna tested using net analyser.

Table.2. Observed Parameters of proposed slotted H-shaped patch antenna.

Parameters	Frequency in GHz			
	2.2	**2.4**	**2.8**	**2.9**
Return loss (below zero dB scale) Simulated	26.12	26.912	40.232	55.41
Return loss (below zero dB scale) Measured	15.1	22	17.70	11.9
Voltage Standing Wave Ratio (Simulated)	1:2	1:1.22	1:1.194	1:1:12
Voltage Standing Wave Ratio (Measured)	1:1.38	1:1.122	1:1.287	1:1.65
Power radiated (Watts)	0.002	0.0005	0.00269	0.0026
Directivity (dBi)	8.4	10.765	8.43216	10.590
Gain(dBi)	1	2.6716	2.88665	4.3345
Maximum intensity (Watts/steradian)	0.001	0.0005	0.00149	0.0022

Table.2 shows the observed return loss, VSWR power, directivity and intensity observed during simulation and measurement. The measured and simulated and measured return loss and VSWR shows that the proposed antenna structure radiates efficiently for entire frequency band.

4 Conclusion

The simulated and fabricated antenna results show that the proposed antenna structure can be used for WiFi and LTE applications. The H-shaped patch antenna can also be used for higher bandwidth and efficiency applications. The performance of the proposed antenna structure can be further improvised using Rogers substrate material. The structure can be further miniaturized to perform for UWB applications.

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Mrs.P.Jothilakshmi has received her B.E. degree in Electronics and Communication Engineering from Thanthai Periyar Govt. Institute of Technology,Vellore, India in 1996 and M.E degree from Mepco Schlenk Engineering College, Sivakasi, India in 2000. Currently working as an Assistant Professor in Electronics and Communication Engineering Department at Sri Venkateswara College of Engineering, Chennai, India. She has been a teacher for the past 15 years and has guided more than thirty five B.E and M.E Students projects. She has published more than thirty seven conference and Journal papers both National and International level. Pursuing Ph.D in the area wireless antenna under the supervision of Dr.Mrs (S).Raju, Professor and Head of the Department, Electronics and Communication Engineering, Thiagarajar College of Engineering, Madurai, India. She is a member in professional societies ISTE , IETE and IAENG.