Design and Analysis of Insetcut Feed & Aperture Coupled Feed Microstrip Patch Antennas

[1]P. Varun Kumar Reddy, [2]Dr.R.Sandhya

[1]M.E. (MRE), [2]Associate Professor
Department of ECE
UCEOU, Hyderabad, Telangana, India

***Abstract*: The Insetcut feed and aperture coupled feed antennas are used for Radar and Mobile applications, mainly for Long distance communications and Air traffic control. In the frequency range of 1GHz - 3GHz (L & S Bands), the Insetcut feed design can be used with good VSWR, Gain and Bandwidth. Adding aperture coupled feed to this design, an improvement in the performance parameters like Return loss, VSWR, Gain and Bandwidth can be achieved. The existing antenna design with Insetcut feed gives Return loss of -19dB, gain of 5.3dB, Directivity of 7.8 dB and Impedance Bandwidth improvement of 6%, whereas in the proposed design with aperture coupled feed with Insetcut gives return loss of -38dB, Gain of 10.5dB, Directivity of 12.2dB and Impedance Bandwidth increase of 19%. Aperture coupled feed provides good Impedance matching and more efficiency compared to other Insetcut feed.**

Keywords: Return loss, Voltage standing wave ratio (VSWR), Microstrip patch antenna (MPA), Gain, Directivity.

1. INTRODUCTION

Microstrip or patch antennas are becoming increasingly useful because they can be printed directly onto a circuit board. Microstrip antennas are becoming very widespread within the mobile phone market. Patch antennas are low cost, have a low profile and are easily fabricated.

In the wide range of interest in wireless and radar communication in recent years, the demand for low cost, thin profile, robustness, simplicity in manufacturing, wideband and easy integration with printed circuit board (PCB) has been increased significantly [1]. Nowadays it is easy to construct low profile antennas due to recent Printed Circuit Antenna (PCA) techniques which are extremely useful and such antennas are referred as Micro strip patch antennas (MPA). The low cost and reconfigurable antennas are more possible with PCA techniques and low frequency substrates. The MPA are used most widely in wireless communication due to less weight, reduced weight, high bandwidth, and low cost, appropriate size and easy to fabricate and the designing of MPA with simulation software becomes more popular in these years.

Micro strip patch antenna have few feeding techniques to be applicable, one such non-contacting technique is aperture coupled feeding. After analyzing various techniques to feed power, aperture coupling gives an improvement in the parameters like gain, efficiency, directivity and bandwidth with VSWR<2. Therefore, one of the better approaches to improve the parameters is to use aperture coupled feed.

This is a type of multilayer feeding mechanism that isolates radiating element and the feed. An aperture (slot) is placed in the ground plane which is common to the pair of dielectric substrate through which energy is coupled from one layer to the other layer.

2. SELECTION OF SUBSTRAT

The selection of substrate is an important factor for designing good and effective antenna. The technical properties like relative in permittivity Ɛr, substrate the thickness d and the dielectric loss tangent *tan* should be chosen carefully. Relative permittivity Ɛr and dielectric loss tangent decide the size of an antenna. In general, dielectric loss tangent should be low as 0.002 to ensure the high network performance and bandwidth. The substrate materials like FR4, Foam, Roger 4350 can be used to design the micro strip patch antenna (MPAs) with die electric constant of range 2.2 to 12. The design of an antenna with a thicker substrate and lower dielectric constant gives better efficiency and larger bandwidth. In this work, RT/Duroid 6010 communication antenna is used with three layers of different properties to avoid wave-based propagation method and to provide maximum size of coupling between the radiating element and feed. Also, this provides low dielectric loss tangent (0.0009) and better thermal conductivity. The RT/Duroid 6010 substrate offers the mechanical properties like mechanical resistance, stability, temperature, good adhesion between conductor and substrate during fabrication. This paper analyzes the design of aperture feed micro strip based patch antenna to operate at the resonant frequency of 2.4 GHz. Simulations were carried out in ADS (Advanced Digital Systems Software)

3. FEEDING TECHNIQUES OF ANTENNA

Feeding techniques plays major role with highly effective in the efficient operation of the antenna. This helps in improving gain, impedance mismatch, efficiency and directivity. The most commonly used techniques are contacted and non-contacted feeding.

3.a. **Contact feeding techniques** :- This type of feeding techniques makes the feed line contact direct with the substrate and ground plane. It is easy to make the contact with substrate but difficult in impedance matching.

3.a.(i) **Microstrip Line based feeding:-** In this type of feeding techniques to conduct feed strip is directly connected to the micro strip patch. The width and length of the strip are smaller as compared to the patch and this type of feed gives an advantage of feed etched on the same substrate to provide planar surface. This feeding is mainly used in MPA designs for WiMax applications [2].

3.a.(ii) **Inset feeding:-** In this type of micro strip feeding technique, the feeding strip is directly etched with the patch with an inset cut between patch and feed strip. This inset cut is to match the impedance without the need for any additional matching element of the feed strip. Impedance matching can be done by adjusting the position and dimension of feed strip.

3.b. **Non-contact feeding technique:-** In the non-contact feeding technique the link between the substrate and ground plane will be made through the slot. There will be no direct contact between the ground and patch. The main advantage of this technique is impedance match is easy compared to contacting feed. In this type of feeding techniques, three layers are used upper, ground and lower substrate as shown in Fig 1 where the feed line is shown.

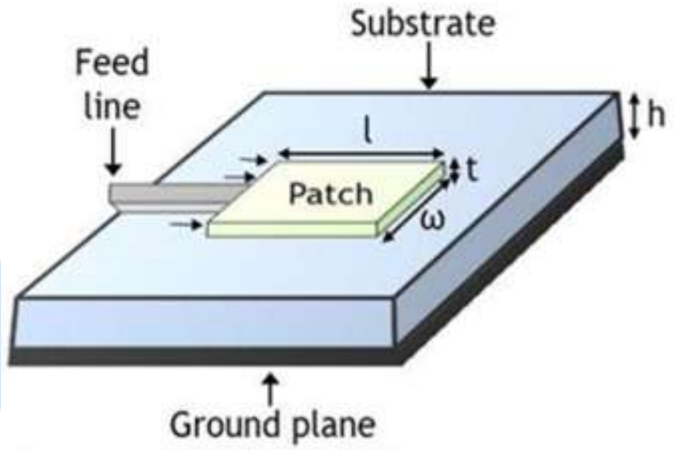

Fig. 1. Single patch Microstrip patch Antennas

Substrate and the coupling between patch and feed is made through theslot (or) aperture in the ground plane. In this type of feeding techniques, three layers are used upper, ground and lower substrate as shown in Fig 1. The feed line is given in lower substrate and the coupling between patch and feed is made through the slot (or) aperture in the ground plane.

4. ANTENNA DESIGN

The proposed design of single patch antenna element is shown in Fig. 1 The major objective of proposed work is to design the aperture coupled patch antenna technique which operates in the frequency range of 1 GHz–3 GHz. Design of Antenna with inset feed and aperture coupled feed is done here and the two designs are compared.

4.a. DESIGN OF SINGLE PATCH INSET FEED-BASED ANTENNA

The design of single patch with inset feeding technique is done with manual calculations. In both designs' air/foam (permittivity 1.07) shown and has been used as antenna substrate with a thickness of 17 mm. FR4 material (permittivity 4.4 and thickness 1.58 mm loss tangent 0.0023) is used for feed line substrate and material with permittivity 2.5, thickness 1.58 mm and loss tangent 0.0023 is used for the random (patch) substrate of the antenna. The below Fig 2 shows the current distribution of inset cut feed Microstrip Patch Antenna with length of 14.7 mm and width of 19 mm and 30 mm (Length, width 3mm) inset feed from the ground plane. FR4 material is used for the design. The inset feed is the easy and simplest feeding technique with compromise in return loss, gain, efficiency and directivity compared to aperture coupled technique. In this design single patch is designed with centre frequency of 2.4 GHz.

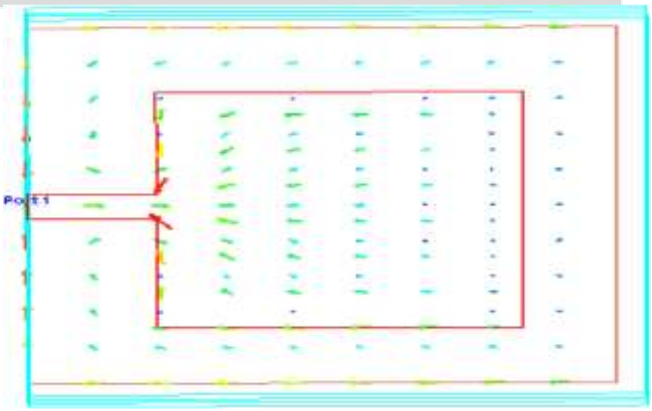

Fig 2. Current distribution of Single Microstrip Patch Antenna.

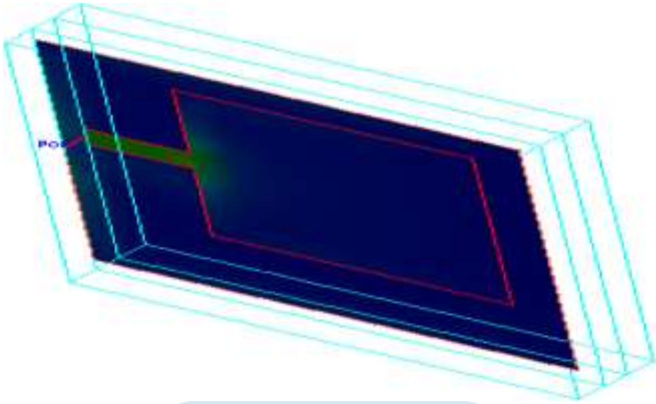

Fig.3. 3D view of Single Microstrip patch with insetcut feed.

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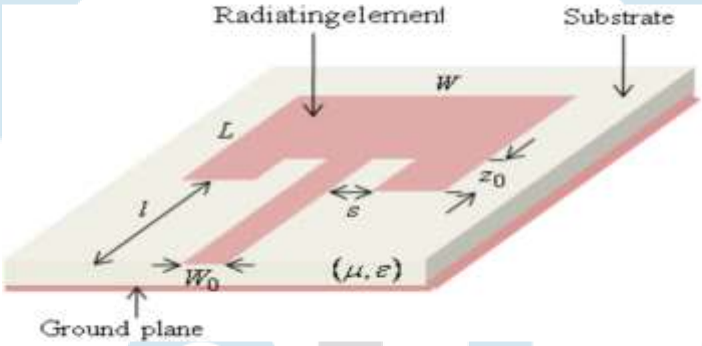

Fig 4. Insetcut Microstrip Patch Antenna

The fig 4 shows insetcut feed design provides good impedance matching when compared with single patch Microstrip Antenna shown in Fig.1

4.b Return Loss

The loss due return of the power is called return loss this is the easy, best and most commonly used method to analyze performance of the designed antenna. When the load is not matched the whole power will not be delivered to the load and possibility of return of the power. This is called loss, and the loss due to return of the power is called the return loss. The Fig.5 shows the S11 parameter which has impedance with bandwidth of 18% (1 GHz–3GHz), return loss of nearly-20dB, VSWR<2.

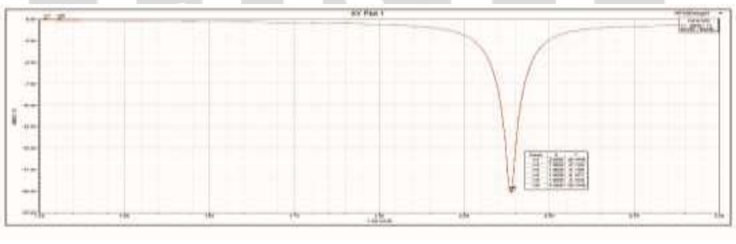

Fig.5 Return loss Plot of the inset cut design

4.c VSWR

The Fig. 6 shows the VSWR vs frequency plot. The antenna will perform efficiently only if maximum power transmission occurs between the antenna and the transmitter. This occurs only when the impedance matches with the transmitter impedance. This process is characterized as Voltage Standing Wave Ratio (VSWR). The proposed Antenna design gives the VSWR is less than < 2 for 2.4 GHz. Finally, as the reflection coefficient varies from 0 to 1, the VSWR ranges from 1 to ∞. Fig 7 provides graph between Gain Vs frequency and Fig 8 gives graph between Directivity w.r.t Frequency

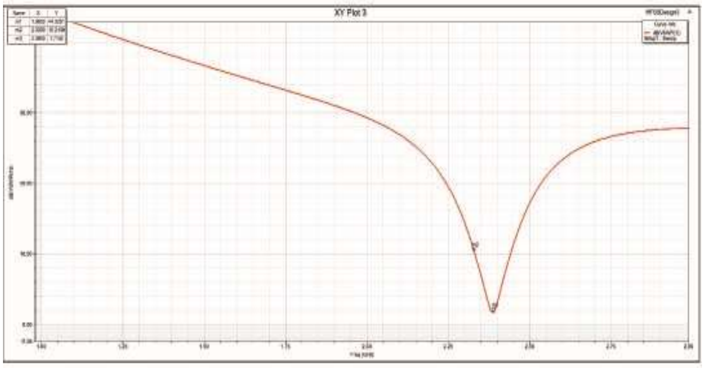

Fig 6. VSWR Vs Frequency Plot

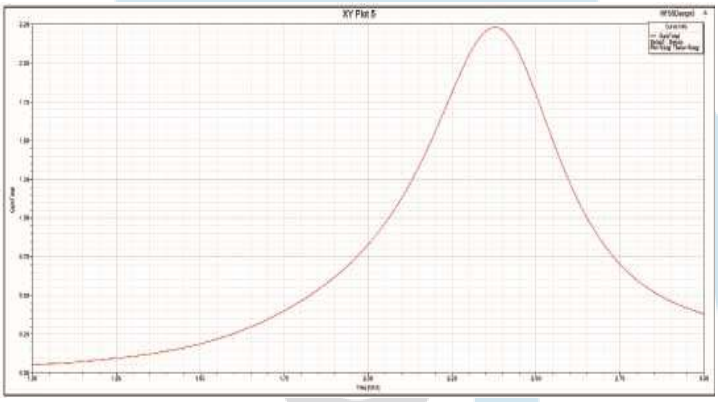

Fig 7. Gain Vs Frequency Plot

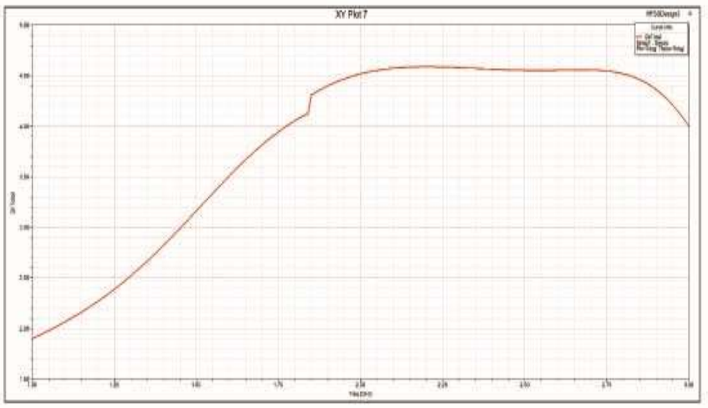

Fig 8. Directivity Vs Frequency Plot

4.2 Design of Aperture coupled feed antenna

The Fig 9 indicates that the design of MPA which gives the efficiency of more than 90% and gain of 10 dB. This frequency band (1GHz–3 GHz) is most preferred for long-range air surveillance radars (of about 390 km). In this design, there are three layers viz., the upper substrate, ground plane and lower substrate. The radiating patch of height H1is etched on the upper substrate, aperture (slot) of height H2 is etched on the ground plane and feed line of height H3 is etched on the lower substrate. This type of arrangement of substrate layer feed the mechanism to the radiating element. Many shapes like square, rectangular, circular and elliptical have been adopted for the radiating element. Here, half wavelength rectangular patch is used. In the ground plane, the aperture is placed at the centre, so the distribution of energy is uniform.

The aperture in the ground plane will reduce the interference and avoids impedance mismatch due to multiple layers. Aperture design has to be taken into consideration in order to avoid impedance mismatch and to obtain more return loss. Therefore, the ratio slot length (L) to a width (W) is taken as 1/10. Resonant length of the slot determines the resonant frequency.

The patch and feed line is placed at the centre, right angle over the slot to attain maximum coupling, lower back radiation, less spurious radiation and good efficiency. The ground Plane and the feed line is connected with 50Ω impedance. The Azimuth angles for XY-plane are 90^0 and YZ-plane also 90^0. The dimension for the design through theoretical calculations are derived and tabulated in Table 1.

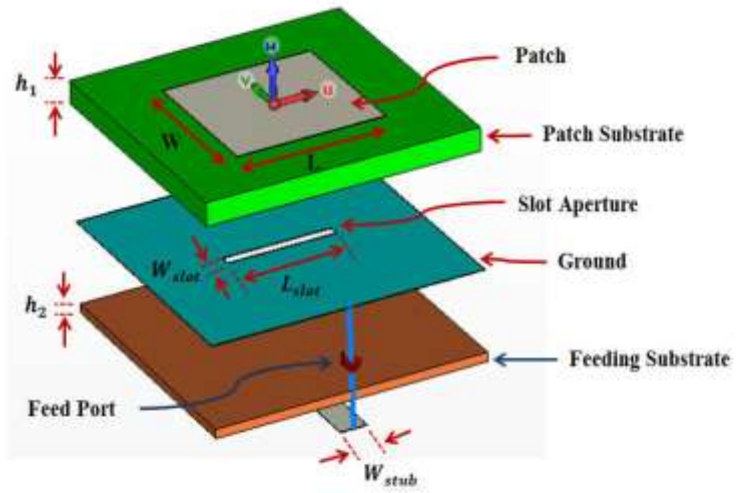

Fig 9. Aperture couple Microstrip patch antenna design

Table 1

Slot, Ground Plane and conducting patch dimensions

Patch lenth	38.2(mm)
Patch width	28.22(mm)
Slot Length	13 (mm)
Slot Width	1.3 (mm)
Substrate Thickness(upper layer)	1.6 (mm)
Substrate Thickness (lower layer)	1.6(mm)
Feed Lenth	28.6(mm)
Feed width	2.66 (mm)

4.2.a Current distribution:-

In the below Fig.10 discuss the current distribution method of the aperture feed antenna. As discussed in the previous method the current flow is maximum in centre of the patch which shows the effectiveness of the aperture feed MPA compared to inset feed MPA. This improvises the gain, efficiency, and directivity of the antenna

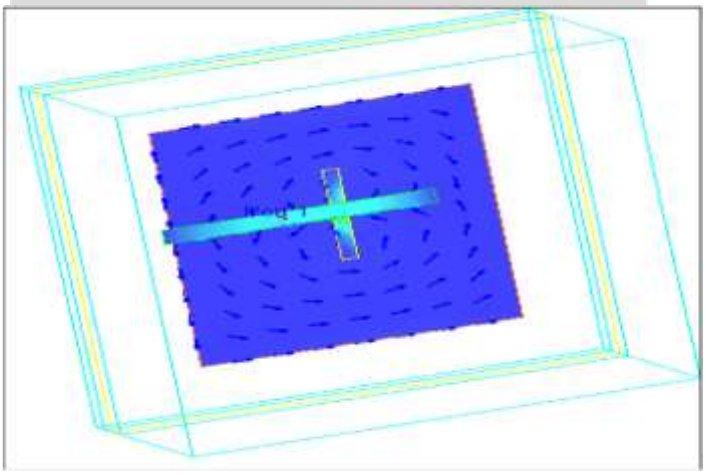

Fig.10 Current distribution of Aperture coupled microstrip patch antenna

4.2.b Return Loss

Fig.11 gives Return Loss of -38dB over inset cut feed technique (Return loss of -19dB).The current distribution is high at the centre of the patch which shows low loss in power compared to inset feed. This improvises the return loss of nearly -19dB with impedance bandwidth of 40% improvement which is almost double the bandwidth compared to inset feed at 2.23 GHz frequency.

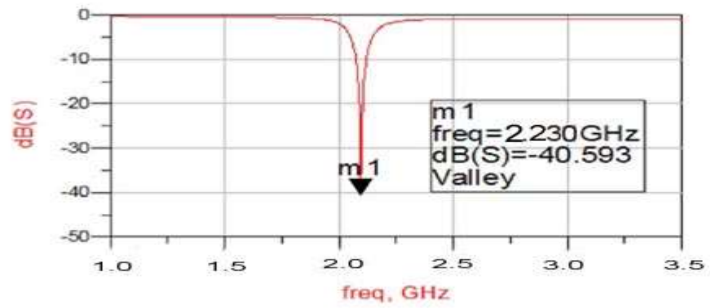

Fig 11 Return Loss of the aperture coupled design plot

4.2.c VSWR

If VSWR is high, the return will get even worse and unstable. It is said that for practical cases VSWR is accepted up to 2 as the return loss would be around -10 dB. The Fig.12 shows the VSWR< 2 at 2.4 GHz frequency.

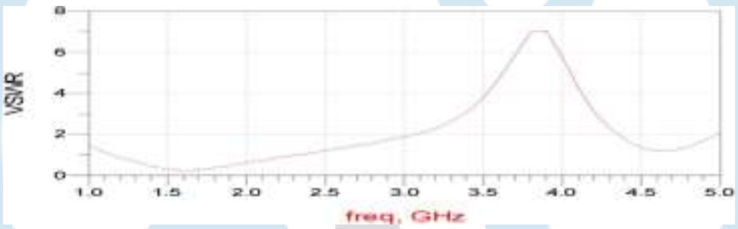

Fig 12. VSWR Plot of Aperture coupled design

4.2.d Impedance Circle

The Fig13 shows the impedance circle for the same. The impedance matching is good compared to inset feed technique.

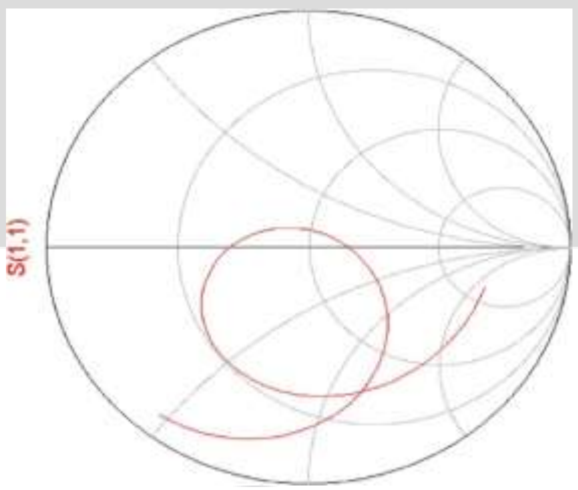

Fig 13 Impedance Circle Aperture coupled design plot

4.2.e Gain and Directivity

The Fig.14 shows the gain and directivity of the design. The gain is defined as the quantity used to describe the capability to concentrate energy in proper direction to give good radiation performance. The gain is 10 dB and the directivity is nearly 12 dB. The gain is 6 dB high compared to inset feed technique.

The gain is the product of efficiency and directivity of the antenna. It is recommended to maximize the radiation pattern in particular direction in order to receive or transmit the power. The directivity is defined as the ratio of radiation intensity in particular direction from the antenna to average radiation intensity in all the directions. The directivity is mainly depends on the shape of the radiation pattern.

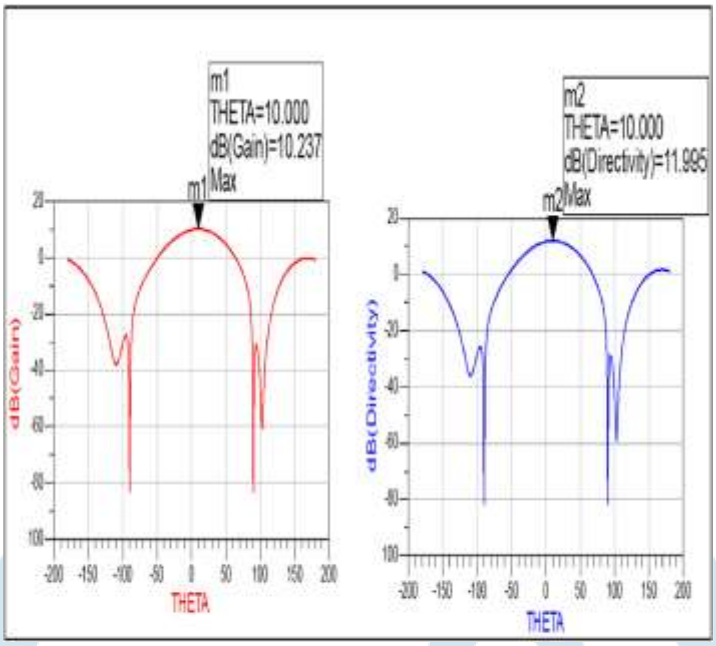

Fig. 14 Gain and Directivity

Table 2

Finalized parameters for single patch antenna

Parameters	Obtained Values	Tuned values
Patch Length(mm)	10.55	9.50
Patch width(mm)	10.55	9.50
Strip line length(mm)	10.30	10.60
Strip line width(mm)	10.30	10.60
Slot length(mm)	0.6	0.85
Slot width(mm)	5.485	5.6

Table 3

Design parameters for inset feed patch antenna

S.No.	Parameters	Designed values
1	Dielectric constant, Ɛr	4.4
2	Resonant frequency, fr	2.4 GHz
3	Loss tangent, δ	0.0009
4	Thickness of substrate, L	1.66 mm
5	Patch length, LP	-14.7 mm
6	Patch width, WP	-19 mm
7	Feed width, WF	3 mm
8	Feed length, LF	30 mm
9	X coordinates, X	-30
10	Y coordinates, Y	-30

Table 4

Design parameters aperture coupled patch antenna

S.No.	Parameters		Upper layer		Goundlayer	Lower layer
1	Dielectric constant, Ɛr		2.5	1.07	4.4	
2	Resonant frequency, fr		2.23 GHz		2.23 GHz	2.23 GHz
3	Loss tangent, δ	0.0023	0.0009	0.0009		
4	Thickness of substrate, L		1.66 mm	18 mm	1.66 mm	
5	Patch length, LP	50 mm	38 mm	5.2 mm		
6	Patch width, WP	63 mm	9 mm	3.3 mm		
7	Feed width, WF - -			2.6 mm		
8	Feed length, LF - -			28.6 mm		
9	Slot length, Ls -		17 mm			
10	Slot width, Ws -		1.6 mm			
11	X coordinates, X	9.230	9.230	9.230		
12	Y coordinates, Y	12.45	12.45	12.45		

Table 5

Comparison for inset feed and aperture coupled feed performance parameters.

Parameters	Inset feed	Apertured coupled feed
Frequency Range (Ghz)	1-3 GHz	1-3 GHz
Return Loss	-19.494dB	-38dB
Gain	3.2 dB	10.5 dB
Directivity	4.6 dB	12.2 dB
Efficiency (%)	64%	92%
Impedance Bandwidth (%)	6%	19%

5. CONCLUSION

The research investigates the design of aperture coupled micro strip patch antenna for long range air surveillance radar applications is designed with 1 GHz–3 GHz frequency range. As aperture coupled design is crucial in designing and the same is proposed with good impedance matching and wide bandwidth. The Proposed aperture coupled Microstrip patch is designed, simulated, and compared with inset feed patch antenna. It is observed from the theoretical and simulation results that aperture coupling is preferred over other feeding techniques to increase efficiency (above 92%), Gain (10.5 dB), Return Loss (-38dB) and Directivity (12.2 dB). The proposed design gives high performance compared to inset feed as the return loss is nearly -20 dB, gain of ~3.4 dB, directivity of 4.4 dB. It is observed from results that good impedance matching is obtained at 2.4 GHz centre frequency. These parameters are crucial to know the fidelity of an antenna. This result shows promising increase in gain, directivity and if the same element is designed as an array of 16x16 would give better results and can be used for radar, surveillance applications. In an array, to couple patches, T joint power divider [3] can be used to reduce antenna size and losses. In array design, more side lobes are desired but this can be mitigated by using Taylor's distribution. The fabrication of 16x16 array stack has been carried out as future work. Finally it is concluded that, the aperture coupled feeding technique will increase the antenna performance by reducing the reflections and increasing front- to- back ratio. The return loss, radiation pattern, gain, efficiency, VSWR and directivity are observed and compared with inset feed to identify the best feeding technique for micro strip patch antenna. Therefore the proposed antenna can be used for long range radar applications and can be easily integrated with WLAN Circuits [4].

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Ponnala Varun Kumar Reddy has completed his B-Tech in Electronics and Communication Engineering in Kakatiya Institute of Technology and science, Warangal, Telangana. He is persuing M.E in Microwave and Radar Engineering in University College of engineering, Osmania University, Hyderabad, Telangana State, India.

Dr. Sandhya Rachamalla
Associate Professor

Dr. R. Sandhya has completed her B-Tech in Electronics and Communication Engineering from Jawaharlal Nehru Technological University at Hyderabad. She Completed M-Tech in Digital Systems and computer electronics from Jawaharlal Nehru Technological University. She completed her Ph.D in the area of Wireless Sensor Networks from Jawaharlal Nehru Technological University, now she is currently working as Associate professor in department of Electronics and Communication Engineering at UCE OU, Hyderabad, Telangana, India.