Volume 6, Issue 4, April 2016 ISSN: 2277 128X
International Journal of Advanced Research in Computer Science and Software Engineering
Research Paper
Available online at: www.ijarcsse.com

Design and Development of Microstrip Rectangular Patch Antenna with Different Feed Techniques at 4GHz

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Abstract— This paper provides detail description about design and development of microstrip rectangular patch antenna for wireless applications. There are various feeding techniques for patch antenna, in this paper we designed for two well-known and widely used feeding techniques such as Co-axial probe feed technique and microstrip feed line technique. The proposed antenna has resonance frequency (f_0) at 4 GHz. This antenna is designed and fabricated using dielectric substrate known as Rogers RT/duroid 5870 with ε_r = 2.33. This antenna is simulated using HFSS tool at resonance frequency of 4 GHz. This proposed antenna is fabricated using Photolithographic technique and it is tested with Vector Network analyzer. This antenna has better return loss, gain and radiation properties. Measured results are well matched with simulated results.

Keywords— In Design and Development of Microstrip Patch antenna, Co-axial Probe Feed, Microstrip Line, HFSS Tool.

I. INTRODUCTION

Antenna constitutes as the major component in communication system. An antenna can be used to concentrate radiation in particular frequency or range and it is suppressed in other frequencies. So the antenna can be tuned to particular frequency for required application.

The microstrip antenna are low profile antenna usually operates at frequency greater than 100MHz. It is widely used because of its ease of integration with MIC's and for its microwave frequency range. The microstrip patch antenna consists of radiating patch which is etched on the one of the surface of the dielectric substrate and ground plane on the other side of the substrate. The patch is usually a conducting material whereas the dielectric substrate used should be in the range of $2.2 < \varepsilon_r < 12$. The suitable metal layer forms the ground plane. The patch may take up any configuration such as square, rectangle, circular, elliptical etc. but out of these rectangular and circular are majorly used.

The dielectric substrate and the dielectric constant place an important part in determining the characteristics of MSA. Low dielectric constant and thick dielectric substrate is used to get good performance of antenna and also yields better radiation, return loss, efficiency, gain and bandwidth. There are various feeding techniques for patch antenna. The proposed antenna has resonance frequency (f_0) at 4 GHz.

II. FEED TECHNIQUES

There are various feed technique for microstrip patch antenna. The feed techniques are majorly categorized as:

I. Contacting Feeds.
II. Non-contacting Feed.

In contacting feed, the RF power transfer is done to the patch directly by using connecting element such as microstrip or line. It includes co-axial feed and microstrip feed.

In non-contacting feed, the RF power transfer between the feed line and the patch is done by using electromagnetic coupling. This includes aperture coupled feed and proximity coupled feed.

A. Co-axial Feed

The coaxial probe feed technique is majorly used technique for feeding. In this the main thing is to design the coaxial probe and to position it correctly for impendence matching to get maximum radiation. The coaxial probe contains one inner conductor and one outer conductor which is separated by a dielectric medium. The outer conductor is designed such that it touches till the ground. The dielectric layer passes through the ground till substrate. The inner conductor passes through the dielectric and it extended till the patch end and it is soldered. The input impedance is controlled by the position of the feed. This method has the advantage of easy fabrication, easy matching and low spurious radiation. But it suffer from narrow bandwidth and difficult to drill the hole in substrate and sometimes the connector comes out of the ground plane. A model of Co-axial feed is given in fig. 2.1.

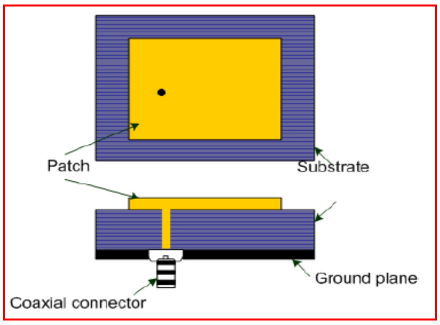

Fig. 2.1. A Model of Co-axial Feed

B. Microstrip Feed

To design rectangular patch antenna with microstrip line, the conducting strip is connected at the edge of the patch directly. There are various configuration of microstrip line feed. They are

- Centre feed
- Offset feed
- Inset feed
- Quarter wave line feed

Here we make use of microstrip line feed with quarter wave transformer. This quarter wave matching section with characteristic impedance Z1is used to match the patch antenna with the characteristic impedance Z0 of the transmission line. The impedance of the antenna is ZA, then the input impedance of the quarter wave section is given by

$$Z_{IN} = Z_0 = \frac{Z_1^{\ 2}}{Z_A} \qquad (2.1)$$

By varying the input impedance Z_{in}, proper selection of Z1 is made so that Z_{in} = Z0 and also when using 50 ohm connector the characteristics impedance is given as

$$Z_0 = \sqrt{Z_1 * 50} \qquad (2.2)$$

The width of the feed must be less than the width of the patch for effective etching of the patch on the substrate. The length of the section is quarter wave of the guide wavelength.

It is very easy to design and fabricate, simple to model, and match with characteristic impedance of 50 or 75 ohm. But here if the substrate thickness increases the surface wave and spurious radiation increases so it affects the bandwidth. A model of Microstrip Feed is given in fig. 2.2

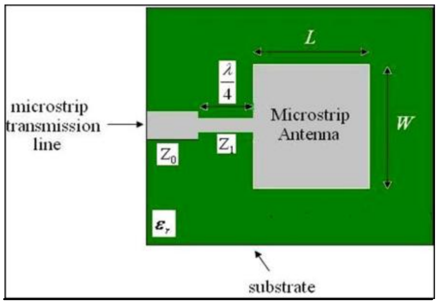

Fig. 2.2. A model of Microstrip Feed

C. Aperture Coupled Feed

It is known as electromagnetic coupling scheme. There are two dielectric substrate one is a thin high dielectric material is used for bottom substrate and another thick and low dielectric constant material for the top substrate. Patch is on the top of upper substrate and feed is in between the two substrate. Main advantage is that it eliminates spurious feed radiation and gives high BW. Disadvantage is that this is more complex and difficult to fabricate. A model of Aperture Coupled Feed is given in fig. 2.3.

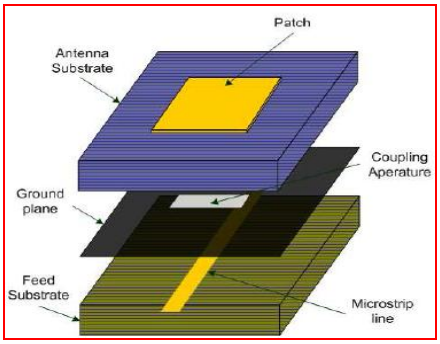

Fig. 2.3. A model of Aperture Coupled Feed

D. Proximity Coupled Feed

This feed is similar to inset feed and if that feed is stopped before the patch or if the probe is trimmed as such it does not protrude inside till the patch. This type of feed is called proximity coupled feed or indirect feed. Proximity coupling has the advantage that it adds extra degree of freedom in designing and it has largest bandwidth and low spurious radiation. But it is not easy as other feed techniques and fabrication is complex. A model of Proximity Coupled Feed is given in fig. 2.4.

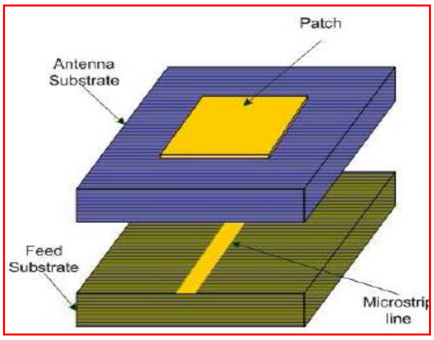

Fig. 2.4. A model of Proximity Coupled Feed

In this paper we designed for two well-known and widely used feeding techniques such as Co-axial probe feed technique and microstrip feed line technique.

III. DESIGN OF RECTANGULAR MICORSTRIP PATCH ANTENNA

The important parameters that are required to design are a resonant frequency, dielectric constant and thickness of the dielectric substrate material. The other parameters are width & length of material and patch and ground plane dimensions. This proposed rectangular microstrip patch antenna is designed with a return loss less than -10dB. The specification of important parameters are:

- Resonant Frequency = 4GHz
- Dielectric constant $\varepsilon_r = 2.23$
- Substrate thickness h = 1.575 mm
- Thickness of patch t = 0.035 mm
- Thickness of ground plane = 0.035 mm

A. General Design Calculation of Patch Parameters

In designing rectangular microstrip patch antenna, the first is to calculate all the parameters with antenna specifications such as:

Microstrip patch antenna width (W):

$$W = \frac{c}{2f_0\sqrt{\frac{(\varepsilon_r + 1)}{2}}} \tag{3.1}$$

Effective Dielectric constant:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}} \tag{3.2}$$

Effective Length:

$$L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_{reff}}} \tag{3.3}$$

Length Extension:

$$\Delta L = 0.412h\,\frac{(\varepsilon_{reff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{W}{h} + 0.8\right)} \tag{3.4}$$

Actual length of Patch:

$$L = L_{eff} - 2\Delta L \tag{3.5}$$

B. Co-axial Probe Feed Technique Design

In co-axial probe feed technique, the patch parameters of rectangular microstrip patch antenna are calculated using the general patch parameters formulas. And other parameters that are required to complete this design are calculated using the following formulas:

Location of the Feed:

$$X_F = \frac{L}{2\sqrt{\varepsilon_{reff}}}$$

$$Y_F = \frac{w}{2} \tag{3.6}$$

Dimension of Ground Plane & Substrate:

$$W_g = 6h + w$$

$$L_g = 6h + L \tag{3.7}$$

The Calculated parameters are:

Table 1 Dimensional Parameters of a Rectangular microstrip Patch Antenna for Co-axial Probe Feed Technique

Parameters	**Values**
Microstrip patch antenna width (W):	29.062 mm
Effective Dielectric constant:	2.1826 mm
Effective Length:	25.383 mm
Length Extension:	0.813 mm
Actual length of Patch:	23.757 mm
Location of the Feed (XF)	8.04 mm
Location of the Feed (YF)	14.53 mm
Ground plane Width	38.512 mm
Ground plane Length	33.207 mm
Substrate Width	38.512 mm
Substrate Length	33.207 mm

In co-axial probe technique design, the dimension of conductors are:

Table 2 Dimensional of Conductors of a Rectangular microstrip Patch Antenna

	Radius	**Height**
Outer Conductor	2.5 mm	5 mm
Inner Conductor	0.65 mm	5+0.035+1.575 mm
Teflon	2.05 mm	5+0.035 mm

C. Microstrip Line Feed Technique Design

In microstrip line feed technique, the patch parameters of rectangular microstrip patch antenna are calculated using the general patch parameters formulas. And other parameters that are required to complete this design are calculated using the following formulas:

Guide Wavelength:

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{reff}}} \tag{3.8}$$

Quarter wave section length:

$$l_{quarter} = \frac{\lambda_g}{4} \tag{3.9}$$

Quarter wave section width:

$$W = \frac{7.48\,H}{e^{\frac{Z_0}{87}\sqrt{(\varepsilon_r+1.41)}}} - 1.25T \tag{3.10}$$

For 50 ohm Termination Line:

$$Length\ l_{50} = \frac{\lambda_g}{4}$$

$$Width\ W_{50} = \frac{10H}{1+\varepsilon_r} \tag{3.11}$$

Dimension of Substrate and ground:

$$L_G = W_G = L_S = W_S \tag{3.12}$$

L_G = 2 x (half-length of path + length of quarter wave section + length of 50 ohm line)

Input Impedance of Quarter wave section:

$$Z_{IN} = Z_0 = \frac{{Z_1}^2}{Z_A} \tag{3.13}$$

The Calculated parameters are:

Table 3 Dimensional Parameters of a Rectangular microstrip Patch Antenna for Microstrip Line Feed Technique

Parameters	**Values**
Microstrip patch antenna width (W):	29.062 mm
Effective Dielectric constant:	2.1826 mm
Effective Length:	25.383 mm
Length Extension:	0.813 mm
Actual length of Patch:	23.757 mm
Guide Wavelength	50.766 mm
Quarter wave section Length	12.6915 mm
Quarter wave section Width	1.164 mm
Length for 50 ohm Termination Line	12.6915 mm
Width for or 50 ohm Termination Line	4.73 mm
Length & Width of Substrate and Ground	72.6302 mm
Input Impedance of Patch	210 ohm

IV. SIMULATION AND RESULTS

A. Co-axial Probe Feed Technique Design

This antenna is designed using dielectric substrate known as Rogers RT/duroid 5870 with ε_r = 2.33. This antenna is simulated using HFSS tool at resonance frequency of 4 GHz and final patch obtained in shown in fig. 4.1 & 4.2.

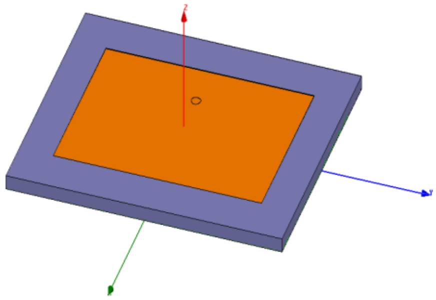

Fig. 4.1. Top View of a Rectangular Microstrip Patch Antenna for a Co-axial Probe feed Technique

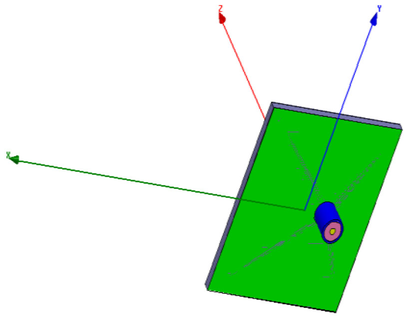

Fig. 4.2. Bottom View of a Rectangular Microstrip Patch Antenna for a Co-axial Probe feed Technique

The simulated return loss of rectangular microstrip patch antenna at resonance frequency of 4 GHz has return loss of -27.6752 dB, BW of 12.7 %, gain of 6.88 dB and directivity of 7.091 dB as given in fig. 4.3 – 4.5. Simulated LHCP & RHCP of a rectangular microstrip patch antenna are given in fig. 4.6 & 4.7.

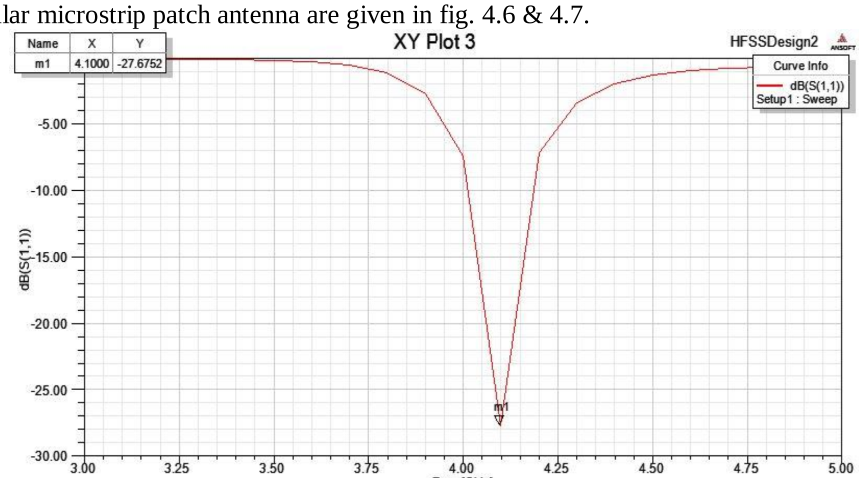

Fig. 4.3. Simulated Return Loss of a Rectangular Microstrip Patch Antenna for a Co-axial Probe feed Technique

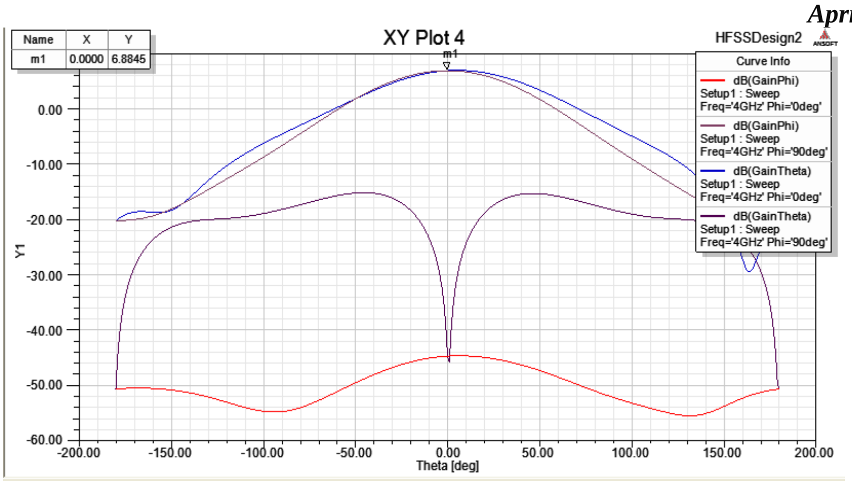

Fig. 4.4. Simulated Gain Plot of a Rectangular Microstrip Patch Antenna for a Co-axial Probe feed Technique

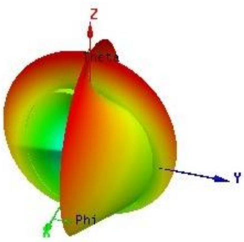

Fig. 4.5. Simulated Directivity of a Rectangular Microstrip Patch Antenna for a Co-axial Probe feed Technique

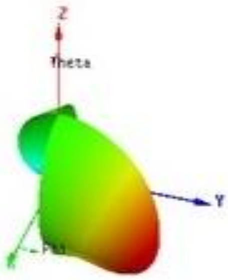

Fig. 4.6. Simulated LHCP of a Rectangular Microstrip Patch Antenna for a Co-axial Probe feed Technique

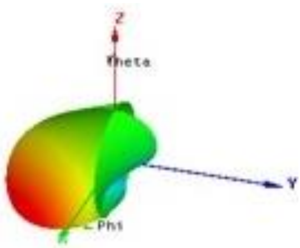

Fig. 4.7. Simulated RHCP of a Rectangular Microstrip Patch Antenna for a Co-axial Probe feed Technique

B. Microstrip Line Feed technique Design

This antenna is designed using dielectric substrate known as Rogers RT/duroid 5870 with ε_r = 2.33. This antenna is simulated using HFSS tool at resonance frequency of 4 GHz and final patch obtained in shown in fig. 4.8 & 4.9.

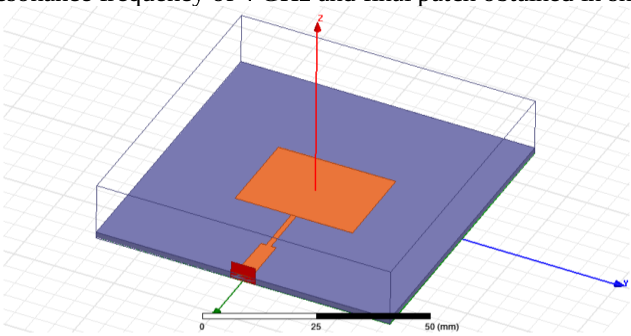

Fig. 4.8. Top View of a Rectangular Microstrip Patch Antenna for a Microstrip Line feed Technique

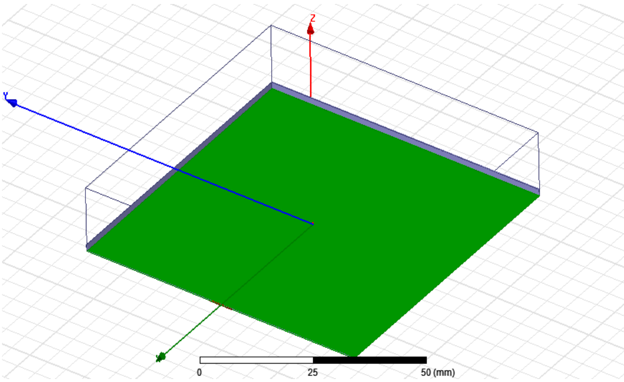

Fig. 4.9. Bottom View of a Rectangular Microstrip Patch Antenna for a Microstrip Line feed Technique

The simulated return loss of rectangular microstrip patch antenna at resonance frequency of 4 GHz has return loss of -29.1597 dB, BW of 15.2 %, gain of 6.9194 dB and directivity of 7.12 dB as given in fig. 4.10 – 4.12. Simulated LHCP RHCP of a rectangular microstrip patch antenna are given in fig. 4.13 & 4.14.

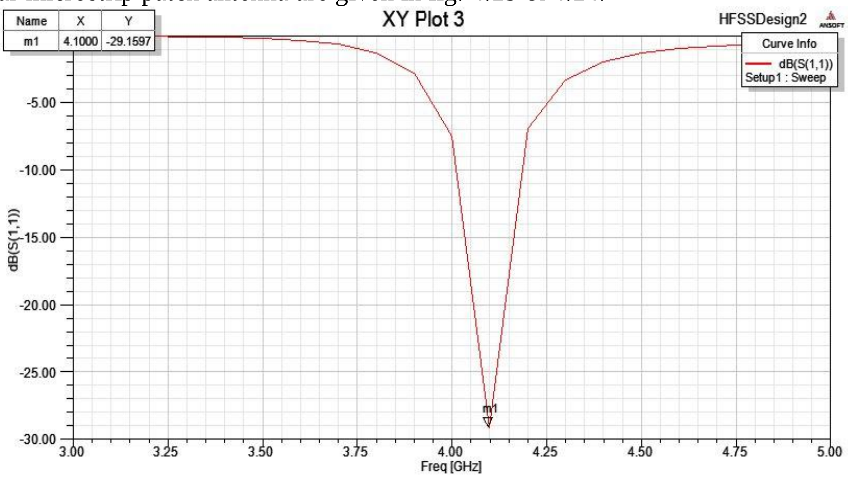

Fig. 4.10. Simulated Return Loss of a Rectangular Microstrip Patch Antenna for a Microstrip Line feed Technique

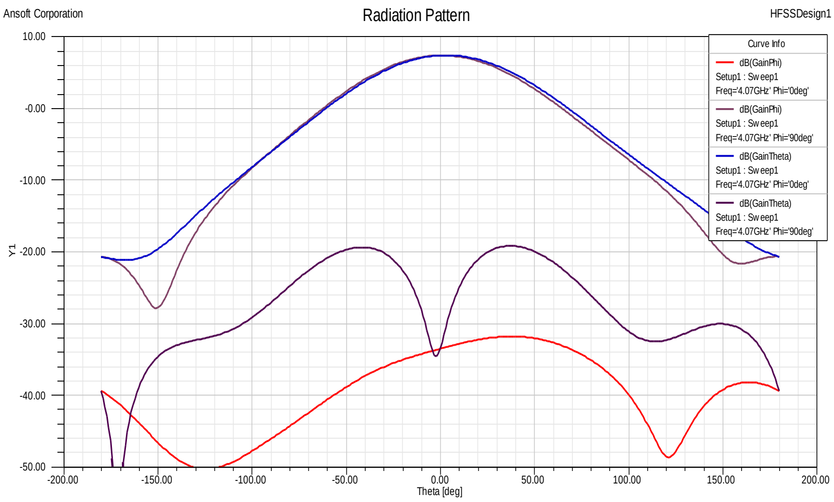

Fig. 4.11. Simulated Gain Plot of a Rectangular Microstrip Patch Antenna for a Microstrip Line feed Technique

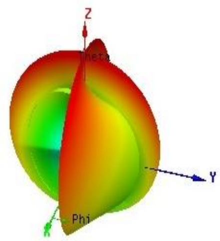

Fig. 4.12. Simulated Directivity of a Rectangular Microstrip Patch Antenna for a Microstrip Line feed Technique

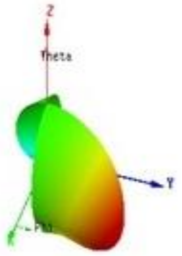

Fig. 4.13. Simulated LHCP of a Rectangular Microstrip Patch Antenna for a Microstrip Line feed Technique

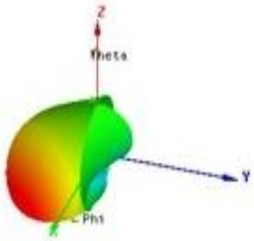

Fig. 4.14. Simulated RHCP of a Rectangular Microstrip Patch Antenna for a Microstrip Line feed Technique

V. FABRICATION AND RESULTS

A. Co-axial Probe Feed Technique Design

This antenna is fabricated using Photolithographic technique with dielectric substrate known as Rogers RT/duroid 5870 which as εr = 2.33. The fabricated antenna is tested using Vector Network analyzer at resonance frequency of 4 GHz and fabricated antenna in shown in fig. 5.1 & 5.2.

Fig. 5.1. Fabricated Top View of a Rectangular Microstrip Patch Antenna for a Co-axial Probe feed Technique

Fig. 5.2. Fabricated Bottom View of a Rectangular Microstrip Patch Antenna for a Co-axial Probe feed Technique

The measured return loss of rectangular microstrip patch antenna at resonance frequency of 4 GHz has return loss of -26.8511 dB and BW of 12.5% as given in fig. 5.3.

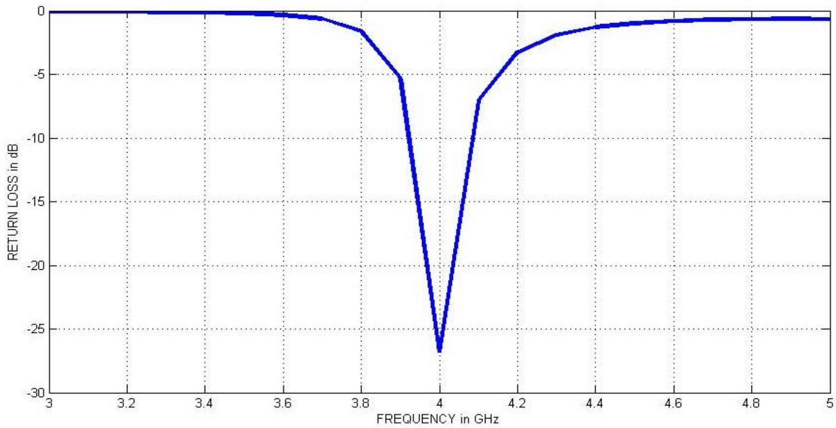

Fig. 5.3. Measured Return Loss of a Rectangular Microstrip Patch Antenna for a Co-axial Probe feed Technique

The comparison between measured & simulated return loss of rectangular microstrip patch antenna are given in fig. 5.4.

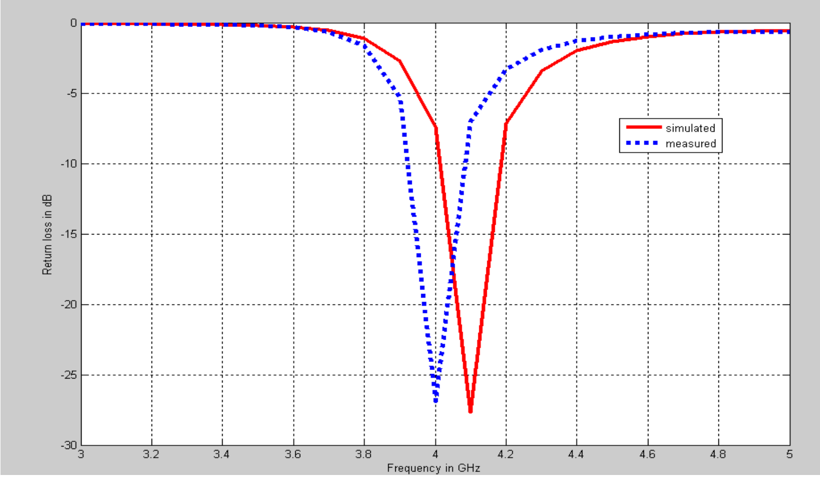

Fig. 5.4. Comparison between Simulated and Measured Return Loss of a Rectangular Microstrip Patch Antenna for a Co-axial Probe feed Technique

B. Microstrip Line feed Technique Design

This antenna is fabricated using Photolithographic technique with dielectric substrate known as Rogers RT/duroid 5870 which as $\varepsilon r = 2.33$. The fabricated antenna is tested using Vector Network analyzer at resonance frequency of 4 GHz and fabricated antenna as shown in fig. 5.5.

Fig. 5.5. Fabricated View of a Rectangular Microstrip Patch Antenna for Microstrip Line feed Technique

The measured return loss of rectangular microstrip patch antenna at resonance frequency of 4 GHz has return loss of -28.5353 dB and BW of 15% as given in fig. 5.6.

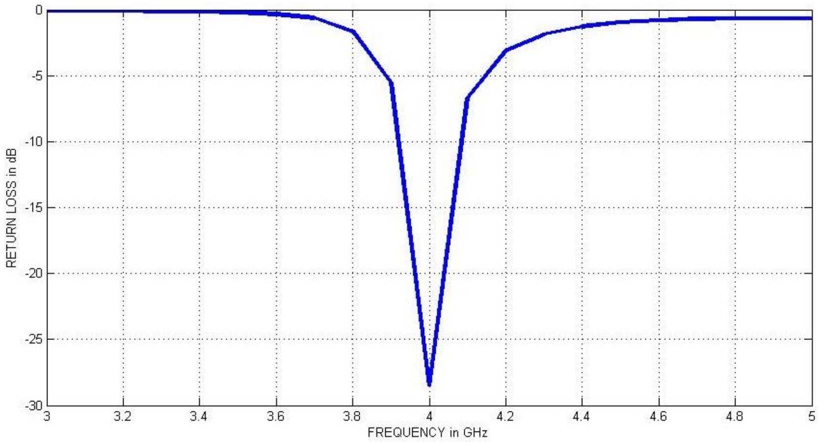

Fig. 5.6. Measured Return Loss of a Rectangular Microstrip Patch Antenna for a Microstrip Line feed Technique

The comparison between measured & simulated return loss of rectangular microstrip patch antenna are given in fig. 5.7.

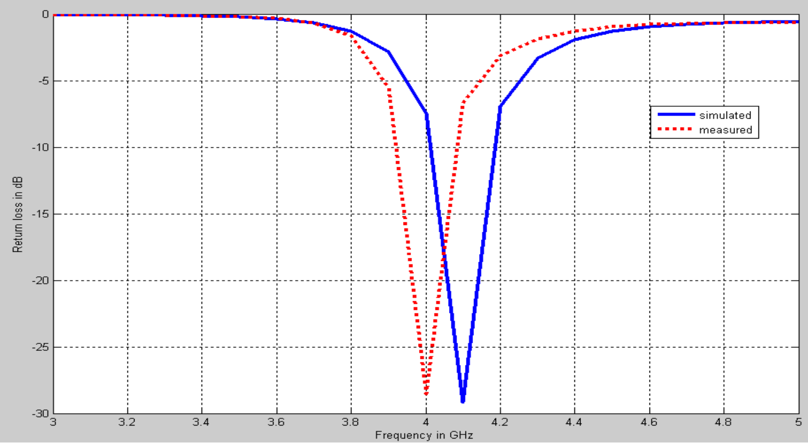

Fig. 5.7. Comparison between Simulated and Measured Return Loss of a Rectangular Microstrip Patch Antenna for a Microstrip Line feed Technique

VI. COMPARISON BETWEEN TWO FEEDING TECHNIQUES

The comparison between Return loss and bandwidth of co-axial probe and microstrip line feeding techniques for rectangular microstrip patch antenna are given in table 4. From the return loss value, we can observe that the return loss and bandwidth in microstrip line feeding technique is more compared with co-axial probe feeding technique. The gain and directivity are also more in microstrip line feeding technique. Other parameters for both feeding technique are given in table. 4.

Table 4 D Comparison of Simulation Results Between Both Feeding Techniques a Rectangular microstrip Patch Antenna

Parameters	**Co-axial Probe**	**Microstrip Line**
Return Loss (Simulated)	-27.6752 dB	-29.1597 dB
Return loss (Measured)	-26.8511 dB	-28.5353 dB
Gain	6.88 dB	6.9194 dB
Bandwidth	12.5 %	15 %
Directivity	7.091 dB	7.12 dB
Peak Directivity	7.1625 dB	7.1995 dB
Polarization Ration Circular RHCP	6.899 dB	6.5201 dB
Polarization Ration Circular LHCP	7.254 dB	7.0865 dB
Beam Area	3.9396 dB	3.9021 dB
Radiation Efficiency	0.9751	0.97354
Incident Power	1.0100 W	1.0350 W
Radiated Power	0.825 W	0.83633 W
Accepted Power	0.8547 W	0.86764 W

VII. CONCLUSIONS AND FUTURE SCOPE

This paper presents design and development of rectangular microstrip patch antenna using co-axial probe and microstrip line feeding techniques at resonance frequency of 4GHz and return loss less than -10dB. This antenna is designed and fabricated using dielectric substrate known as Rogers RT/duroid 5870 with dielectric constant = 2.33. This antenna is simulated using HFSS tool and fabricated antenna is tested using vector network analyzer at resonance frequency of 4 GHz and has return loss less than -10dB.

The design procedure for rectangular microstrip patch antenna are simple. All the required parameter of rectangular microstrip patch antenna for both feeding techniques are easily calculated using above given formulas. It is observed that the simulated and measured results are better match with each other. The results may vary due to fabrication error and dielectric constant varies a lot from batch to batch. And also the connection of the cables and connectors to the device also affects the results.

By comparing parameters of Co-axial probe and microstrip line feeding techniques, it proves that the Microstip Line feeding technique has better Return loss, Bandwidth, Gain and Directivity than Co-axial Probe feeding technique.
Other optimization techniques can be carried out for getting better results. The important parameters of rectangular microstrip patch antenna such as bandwidth, gain and directivity can be enhanced by designing rectangular microstrip patch antenna array by placing same rectangular microstrip patch antenna in series and using power divider circuits.

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