Effect of Feed Techniques and Substrate Material on Rectangular Patch Antenna

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Abstract

This paper investigates the performance of a rectangular patch antenna with regard to return loss, VSWR and total gain at 2.4GHz for WLAN applications. One of the deficient characteristics of a patch antenna is the impedance mismatch brought about mainly by the choice of substrate material of the antenna and the feeding technique. A patch antenna was designed with these feeding techniques; Edge Feed, Inset Feed and Probe Feed and three distinct substrate materials namely; FR4_epoxy, Rogers RT Duroid 5800™ and Rogers RO 3003™ to check on how to mitigate this mismatch. Simulation analysis shows that Inset Feed technique and Rogers RT Duroid 5800™ when used together are more superior to other feeding techniques and substrate materials in enhancing the performance of a rectangular patch antenna in term of return loss, VSWR and total gain.

Keywords

Patch Antenna, Return Loss, VSWR and Total Gain

I. Introduction

Microstrip patch (or simply patch) antenna consist of a radiating patch on one side of a dielectric substrate which has a ground plane on the other side as shown in fig. 1 [1]. The patch is usually made of a conducting material such as copper. Patch antennas are increasingly gaining popularity for use in wireless applications due to their low-profile nature. They are compatible in embedded system antennas in mobile wireless devices such as cell phones; access points (APs) etc.

Patch antenna are in demand being low-cost, light in weight, robust and easy to manufacture and can be fabricated using photolithographic technique [1-2]. The patch dimension can be rectangular, elliptic or circular. Rectangular patch is most preferred because of its ease of fabrication. Moreover the substrate material, patch dimension and feeding technique determine the overall performance of the patch antenna. Therefore, a careful selection of substrate material and feeding technique is required in the design an optimum patch antenna.

In this work we intend to compare the performance of patch antenna when different substrate materials and feed techniques are employed with regard to the following performance metrics: Return Loss, Total Gain and Voltage Wave Standing Ratio (VSWR). Return Lost measures the logarithmic ratio in dB of reflected power by antenna and the antenna power input. Hence this ratio should be as high as possible.VSWR on the other hand indicates the level of matching between the feed lines, transmission line and the patch antenna and its value should ideally be between1-2 while total Gain measures the relative performance of the antenna [3].

The rest of the paper is arranged such that section two highlights the feed techniques, section three gives the design equations for the antenna, the simulation set up and sessions. Results and discussions are given in section four and section five forms the concluding part of the paper.

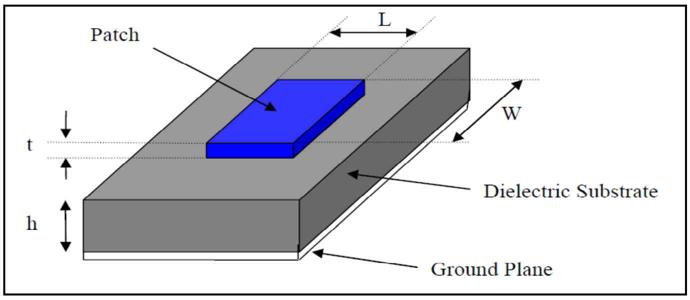

Fig. 1: Structure of a Patch antenna

II. Feeding Techniques

There are several ways patch antenna can be fed, either via contacting or non-contacting methods. In contacting methods, Radio Frequency (RF) power is fed directly to the radiating patch using a connecting element such as a strip line [4-5]. RF power on the other hand is transferred between the Microstrip line and the radiating patch via electromagnetic coupling in non-contacting methods [4]. In this work contacting methods are considered because they are easy to design and fabricated. These contacting methods are discussed below.

A. Edge Feed

In this method the conducting strip is directly connected to the edge of the radiating patch. The width of the strip is smaller compared to the patch. This type of feed has the advantage of providing a planar structure since the feed is etched on the same substrate material [4]. Fig. 2 shows this structure.

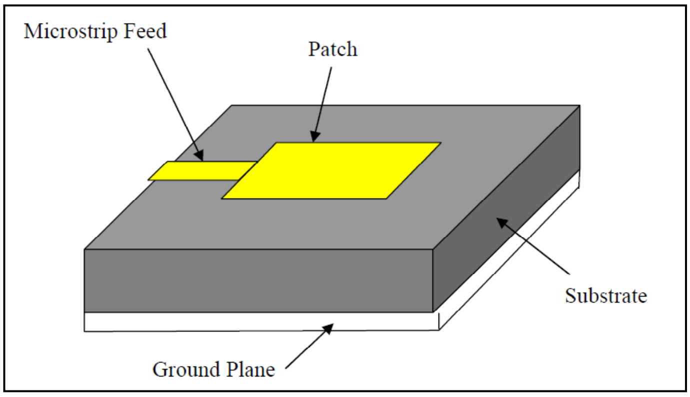

Fig. 2: Edge Feed Structure

B. Inset Feed

The main advantage of this feed technique, see fig. 3, is that it provides a planar structure as the edge feed and additionally allow for impedance matching between the feed line and the radiating patch [4-5].

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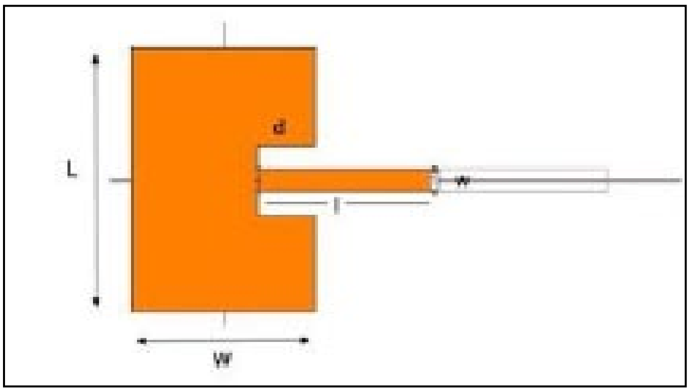


Fig. 3: Inset Feed Structure

C. Probe Feed (Co-axial Feed)

This method being very common in Microstrip antenna has the advantages of improving the gain, providing narrow bandwidth and impedance matching. Another unique advantage of this technique is that the feed can be placed anywhere on the radiating patch for impedance matching between the co-axial cable and the antenna. The inner conductor of the connector extending through the substrate is soldered to the patch while the outer conductor is connected to the ground as shown in fig. 4 [4].

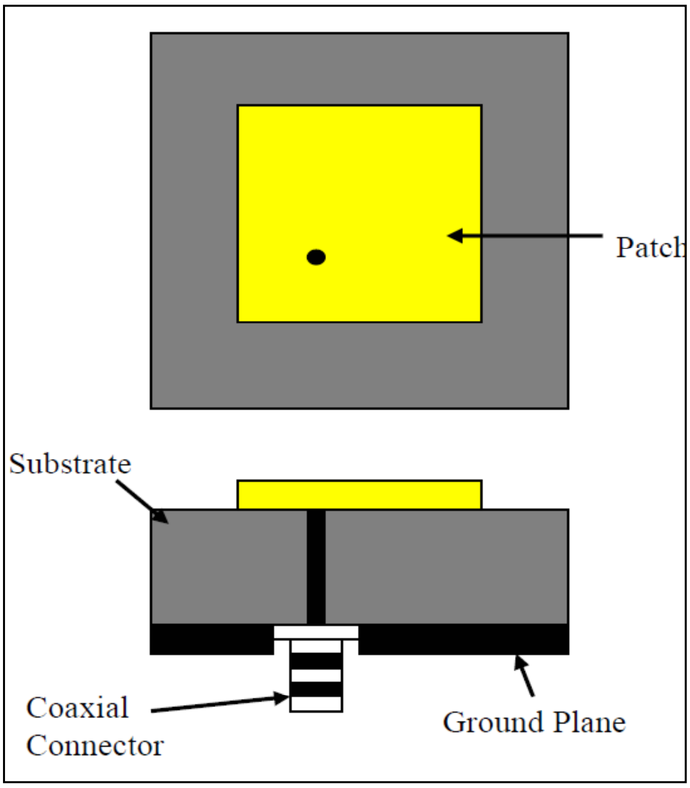


Fig. 4: Probe Feed Structure

III. Design Equations

The following parameters are needed to design an effective patch antenna; ε_{eff} = effective dielectric constant, ε_{r} = dielectric constant, h = height of dielectric substrate, W = width of the patch and L = length of the patch.

For an enhanced performance of the antenna, careful selection of a substrate material of a given dielectric constant is required as it affects bandwidth, gain, operating frequency and return loss of the patch antenna. So given the dielectric constant, ε_r, of a substrate material, the effective dielectric constant, ε_{eff}, is calculated using equation (1) [6].

$$\varepsilon_{\mathrm{eff}} = \frac{\varepsilon_r+1}{2}\frac{\varepsilon_r-1}{2}\frac{1}{\sqrt{\left[1+12\frac{h}{W}\right]}} \qquad (1)$$

The height, h, of the substrate material controls bandwidth and surface waves and at the same time is responsible for inductive matching;

$$h = \frac{0.3c_0}{2\pi f_0\sqrt{\varepsilon_r}} \qquad (2)$$

Where, c_0 and f_0 are speed of light and the resonant frequency respectively.

The width, W, of the patch usually determines the radiation efficiency of the patch antenna and is given by

$$W = \frac{c_0}{2f_0}\sqrt{\frac{2}{\varepsilon_r+1}} \qquad (3)$$

The resonant frequency f_0 is determined by the length L of the patch thus is very important for narrow band patch. But due to fringing effects [6], we have to find the effective length L_eff of the patch as follows;

$$L = \frac{c_0}{2f_0\sqrt{\varepsilon_{eff}}} - 2\Delta L \qquad (4)$$

Where $\Delta L = 0.412h\left[\frac{(\varepsilon_{eff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{eff}-0.258)(\frac{W}{h}+0.8)}\right]$

A. Simulation Set Up

Nine (9) simulation sessions were designed and run. High Frequency Structured Simulator (HFSS) [7] version 13.0 was used for the simulations. The resonant frequency was chosen to be 2.4GHz for all sessions for suitability to Wireless Local Area Networks (WLAN). Patch dimensions were calculated using the specifications for dielectric materials given in Table 1 below.

Table 1: Patch Dimension with Different Substrate Materials at 2.4GHz

Dielectric Material	Height (cm)	Width (cm)	Effective Permittivity	Effective Length (cm)
FR4_epoxy	0.28	3.80	3.94	2.84
Roger RO3003™	0.35	3.10	2.6	3.39
Rogers RT Duroid 5880™	0.40	4.94	2.03	3.95

Table 2: Properties of Chosen Substrate Materials

Dielectric Material	Relative Permittivity,	Relative Permeability,	Dielectric Loss Tangent,
FR4_epoxy	4.4	1	0.02
Roger RO3003™	3	1	0.0013
Rogers RT Duroid 5880™	2.2	1	0.0009

1. Sessions

In the first three sessions inset feed technique was employed for the simulation. Dielectric material FR4_epoxy was used in the first session, see Table 2, for the properties of the substrate materials. In the second session, Roger RO3003™ material was used as the substrate material while Rogers RT Duroid 5880™ was utilized in the third session.

Same simulation sessions were repeated with edge-feed and probe-feed methods to investigate whether change of feed technique has any effect on the performance of the patch antenna. The dielectric materials were substituted in turn to check their advantage or otherwise on the overall performance of the antenna.

IV. Results and Discussion

In this section the results of the simulation session highlighted in the previous section is presented and discussed based on the influence of dielectric material using the three contacting methods and lastly the performance of the antenna was compared using Rogers RT Duroid 5888™ as common substrate material.

A. Influence of Substrate Materials on Edge Fed Rectangular Patch Antenna

Fig. 5 shows that the edge feed with Rogers RT Duroid 5880™ material performs better as the return loss at 3.39GHz is -2.95dB. This seems low but using other materials caused the operating frequency to be shifted from the desired resonant frequency. Fig. 6 confirms that for this feeding technique the patch antenna performs best with Rogers RT Duroid 5880™ as substrate material since the VSWR achieved is around 5.96 at 2.39GHz even though there is a mismatch between the antenna elements. The VSWR for FR4_epoxy and Rogers RT 3003™ stand at 18.11 and 100.11 respectively.

The total gain surprisingly is highest with Rogers RT 3003™ at 7.69dB while it stand at 6.9 and -.68dB for Rogers RT Duroid 5880™ and FR4_epoxy respectively. This is shown in fig. 7.

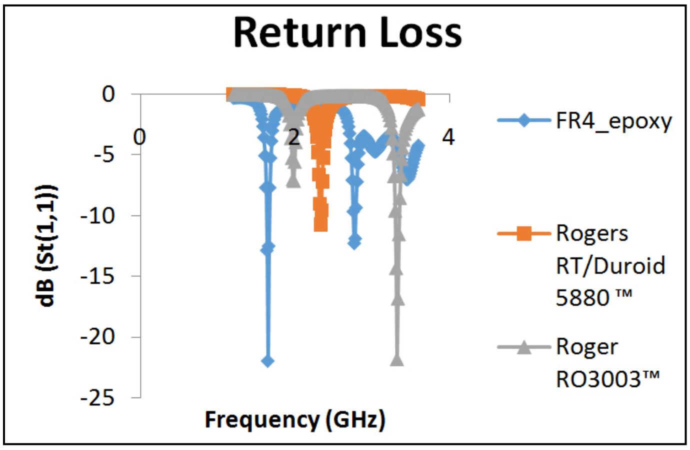


Fig. 5: Return Loss for Edge Fed with Different Substrate Materials

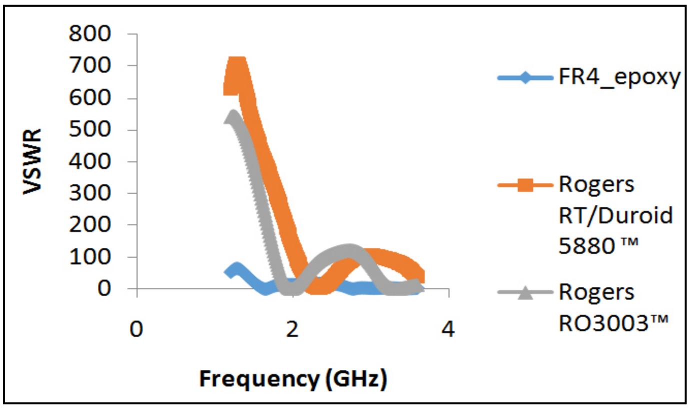
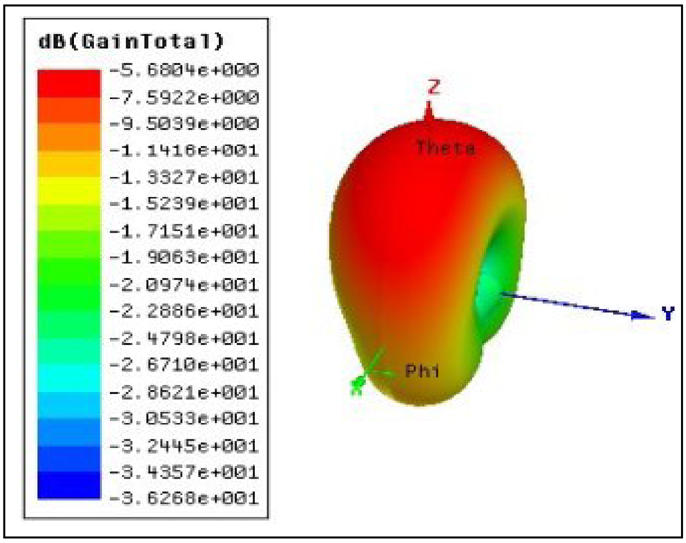
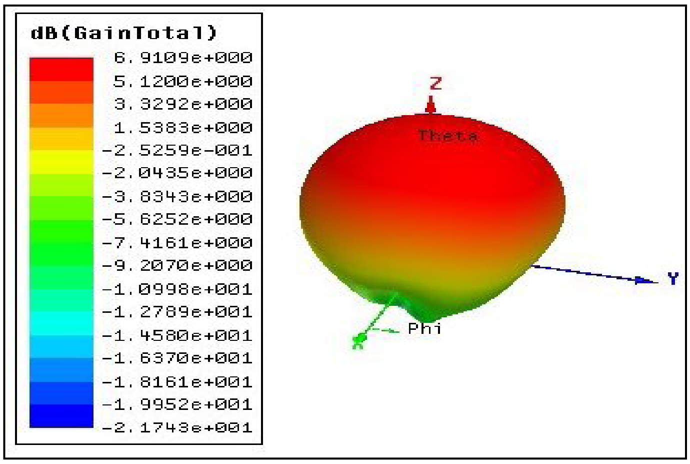


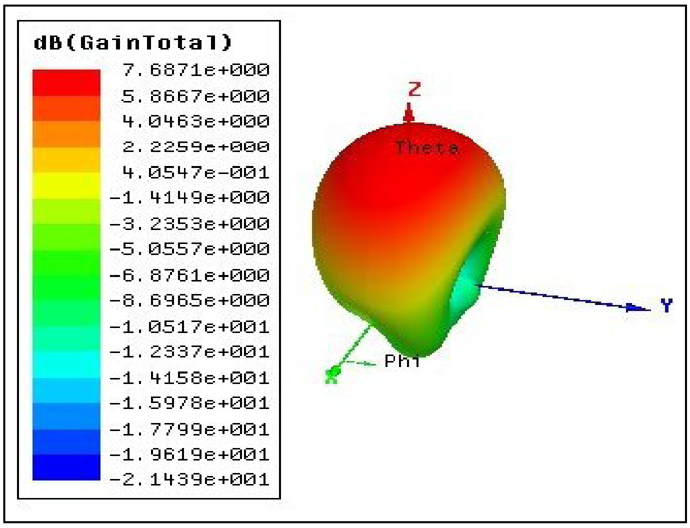
Fig. 6: VSWR for Edge Fed with Different Substrate Materials



(a). FR4_epoxy



(b). Rogers RT Duroid 5800™



(c). Rogers RO 3003™

Fig. 7: Total Gain for Edge Fed with Different Substrate Materials

B. Influence of Substrate Materials on Inset Fed Rectangular Patch Antenna

For Inset Feed, Fig. 8, shows that the antenna resonates well at 2.39GHz with Rogers RT Duroid 5800™ achieving a return loss as high as -22.36dB while same antenna with same technique has its operating frequency shifted using FR4_epoxy and Rogers RO 3003™ are used. Fig. 8 agrees with this as the VSWR stand at

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1.16 indicating good matching when Rogers RT Duroid 5800™ is used as the substrate material. The VSWR achieved by the antenna with FR4_epoxy and Rogers RO 3003™ being utilized is found to be 17.93 and 1991.08 respectively. This shows a great mismatch when these two substrate material are used with inset feed technique. Fig. 9 support this as the antenna achieve a total gain of 7.81dB with Rogers RT Duroid 5800™ while gaining only -2.63 and 4.52dB when FR4_epoxy and Rogers RO 3003™ are employed respectively.

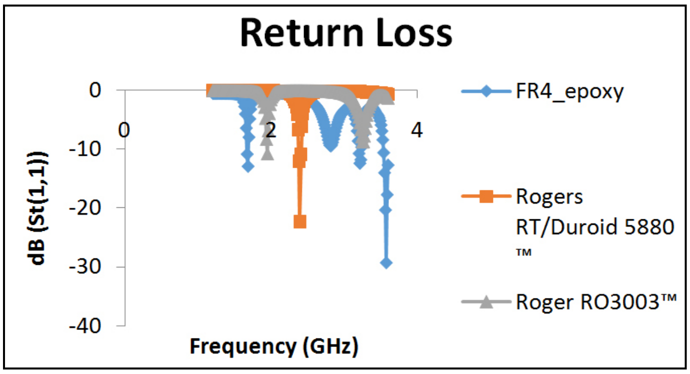


Fig. 8: Return Loss for Inset Fed with Different Substrate Materials

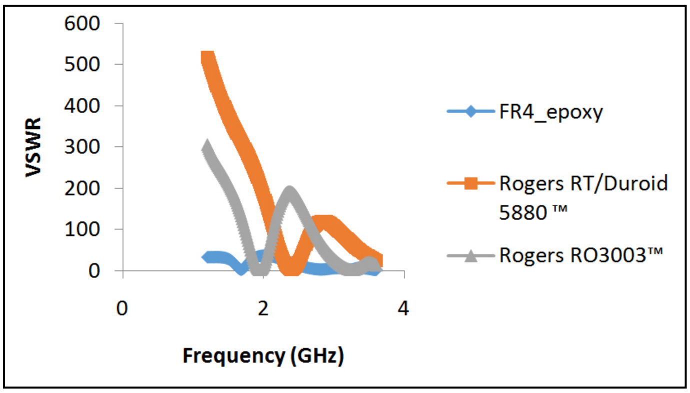
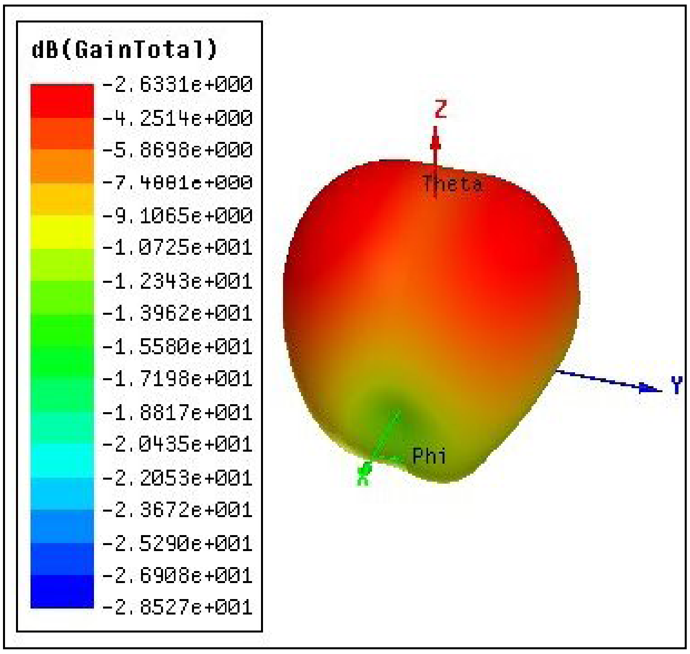
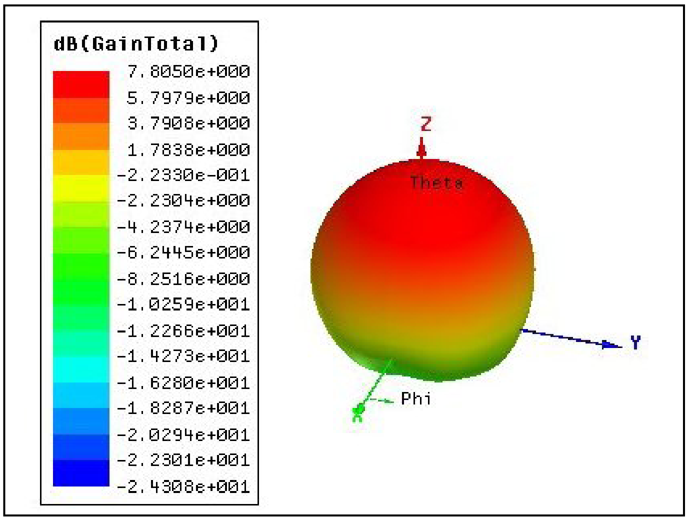


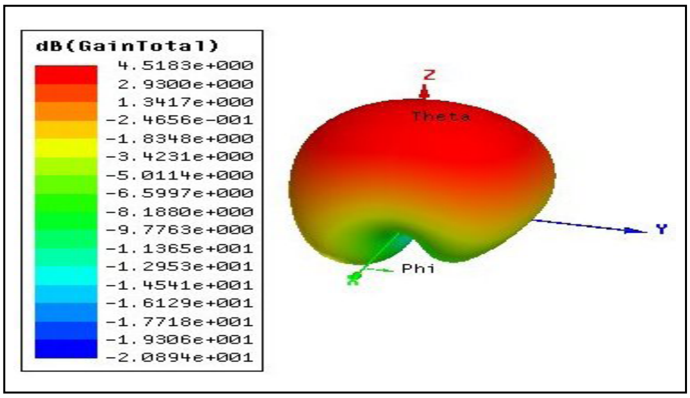
Fig. 9: VSWR for Inset Fed with Different Substrate Materials



(a). FR4_epoxy



(b). Rogers RT Duroid 5800™



(c). Rogers RO 3003™

Fig. 10: Total Gain for Inset Fed with Different Substrate Materials

C. Influence of Substrate Materials on Probe Fed Rectangular Patch Antenna

For the probe feed (fig. 11) the return losses at 2.39GHz for the three materials, that is, FR4_epoxy, Rogers RT Duroid 5800™ and Rogers RO 3003™ were -0.19, -2.18 and -0.08 respectively. The VSWR stood at 90.49, 8.06 and 195.48 for the three substrate materials in that order. The total gain, fig. 12, shows that the antenna has the highest gain with Rogers RT Duroid 5800™ at 7.72dB, -2.29 and 5.2 with FR4_epoxy and Rogers RO 3003™ respectively. These results show that for a single patch antenna to resonate at 2.4GHz, Rogers RT Duroid 5800™ substrate material or better should be used regardless of the feeding technique.

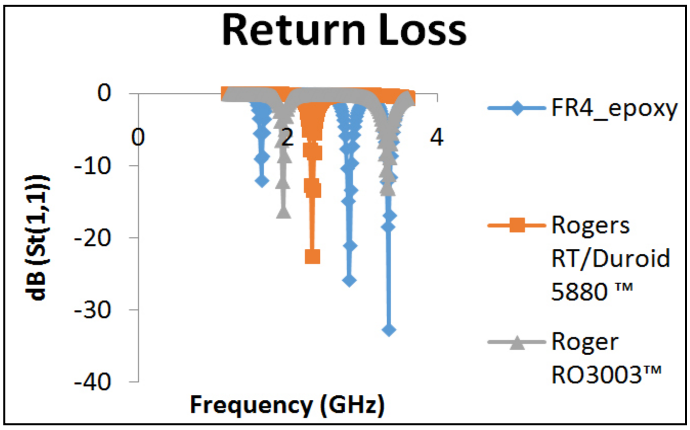


Fig. 11: Return Loss for Probe Fed with Different Substrate Materials

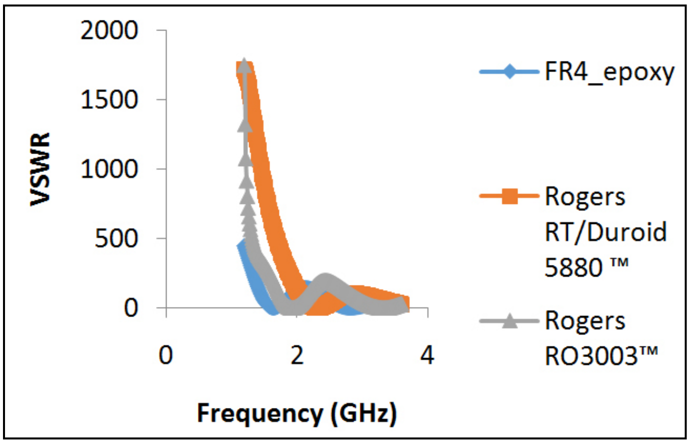
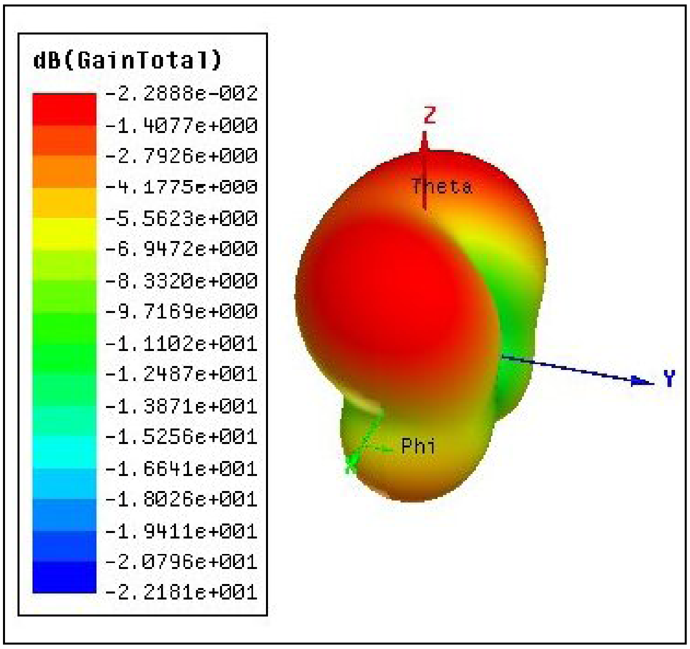
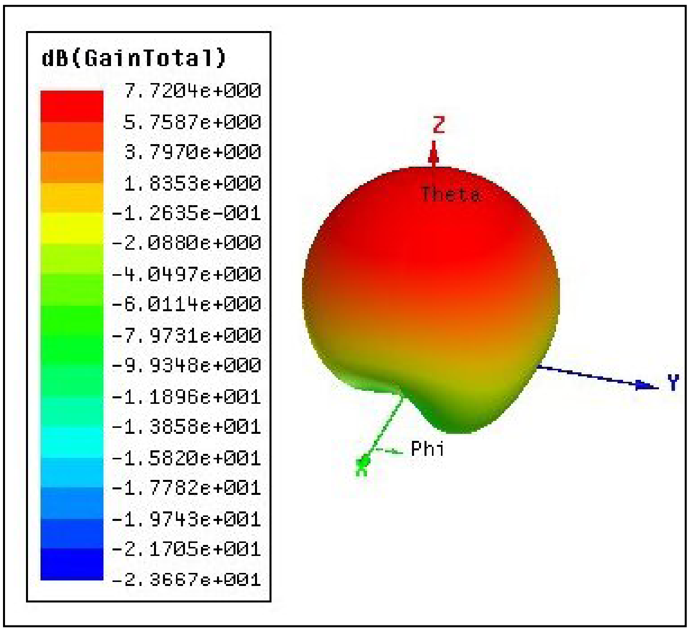


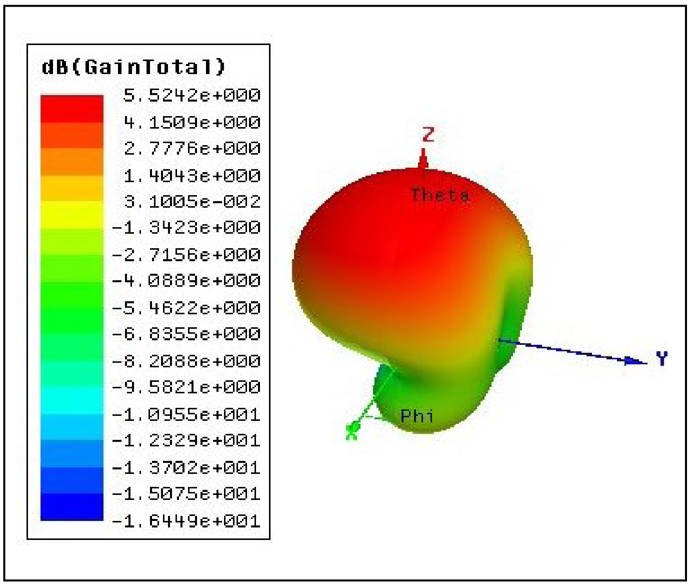
Fig. 12: VSWR for Probe Fed with Different Substrate Materials



(a). FR4_epoxy



(b). Rogers RT Duroid 5800™



(c). Rogers RO 3003™

Fig. 13: Total Gain for Probe Fed with Different Substrate Materials

Having established that Rogers RT Duroid 5800™ substrate material is more suitable for the operation of a single patch antenna at 2.4GHz, we would now compare the performance of the antenna using the above three feeding techniques while maintaining Rogers RT Duroid 5800™ as the substrate material throughout. This would enable designers to choose most appropriate feeding technique considering a patch antenna at 2.4GHz.

D. Comparison of Edge Feed, Inset Feed and Probe Feed Rectangular Patch Antenna Performance using Rogers RT Duroid 5880™ as Substrate Material

Fig. 14 shows that the return losses for inset-feed, probe-feed and edge-feed at 2.39GHz were22.36dB, -2.17dB and -2.94dB. Hence the inset-feed outperforms the other two feed techniques. Fig. 15 also confirms this conclusion as the value of VSWR for the feeding techniques were 1.16, 8.06 and 5.96 respectively. Fig. 1 further shows that inset feed technique is more suited for a patch antenna operating at 2.4GHz recording a total gain of 7.80dB while edge-feed and probe-feed gain 6.91 and 7.72 respectively.

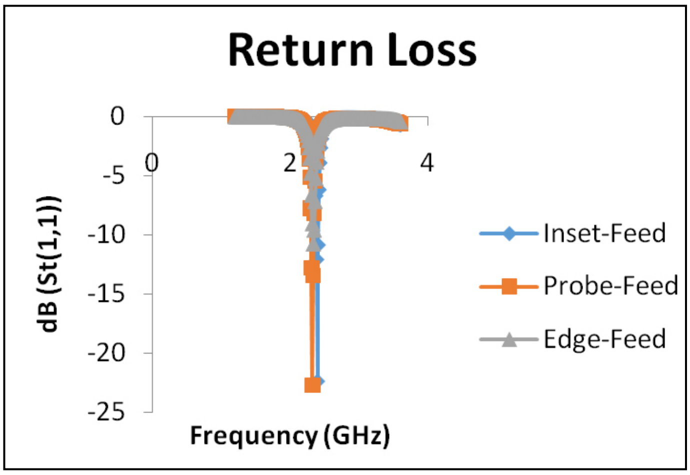


Fig. 14: Return Loss for Different Feed Technique with Rogers RT Duroid 5880™

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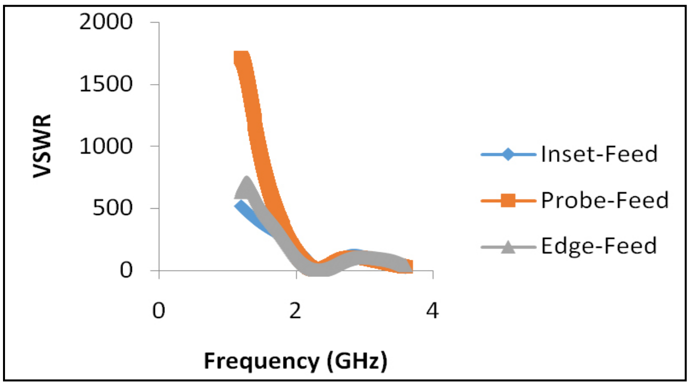
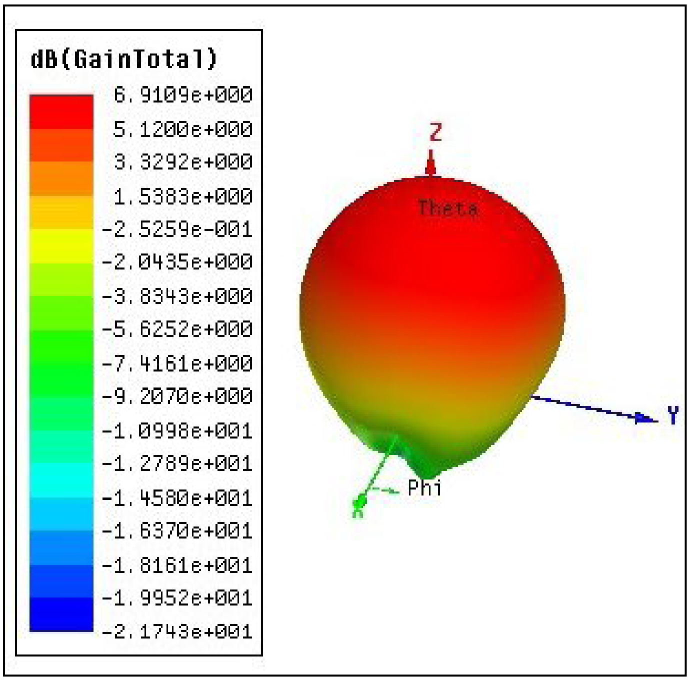
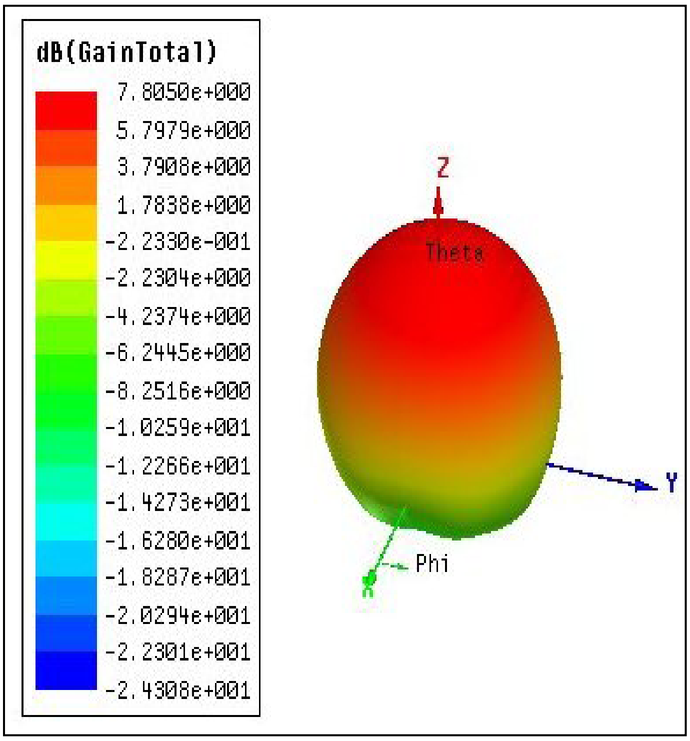


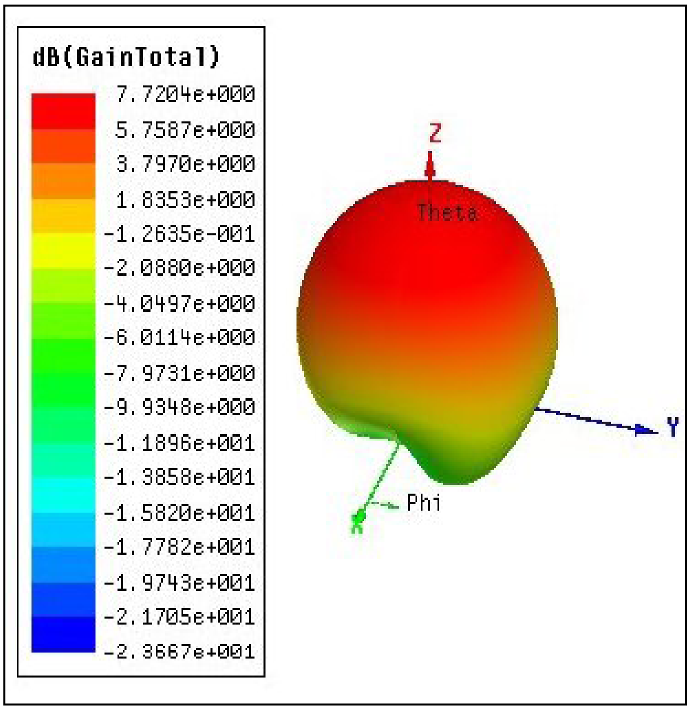
Fig. 15: VSWR for Different Feed Techniques with Rogers RT Duroid 5880™



(a). Edge Feed



(b). Inset Feed



(c). Probe Feed

Fig. 16: Total Gain for the Three Techniques with Materials

V. Conclusion

We have designed, simulated and analyzed the performance of a single rectangular patch antenna for different feed techniques and substrate materials of given dielectric constants. The metric used for the performance measure were return loss, voltage standing wave ratio (VSWR) and total gain. We found that the patch antenna achieves better return loss, total gain and VSWR with Rogers RT Duroid 5880™ as the substrate material regardless of the feeding techniques utilized at 2.4GHz. Furthermore, among the three feeding techniques, inset-feed stand best when compared with other techniques. Based on the foregoing, we recommend that for WLAN applications at 2.4GHz employing a rectangular patch antenna, inset-feed technique and Rogers RT Duroid 5880™ should be given priority for optimum patch antenna.

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