A MULTI-BAND RECTANGULAR PATCH ANTENNA FOR WIRELESS COMMUNICATIONS

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Abstract

In this paper, a multi-band microstrip antenna is designed and its measurement results in terms of S11 and radiation pattern are given. Microstrip design equations are introduced and validated by simulated and experimental results. A patch antenna is designed to support modes with resonance at 0.9, 2.4 and 5.2 GHz. By this design, it is also shown that triple band operation is possible with proper position of the coaxial feed and proper determination of inset size. This antenna is implemented on FR4 dielectric substrate with ε_r = 4.6 and h = 1.55 mm. Designed antenna is simulated by Advanced Design System (ADS) software.

Key words: microstrip antennas; rectangular patch antennas; multi-band

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1. Introduction

Microstrip antennas have attracted a lot of attention due to rapid growth in wireless communications area. Several patch designs with single-feed, dual-frequency operation have been proposed recently. Designed tri-band microstrip antenna can be used in various commercial systems such as; Digital Cellular System (DCS) at 900MHz, Automatic Toll Collection at 905 MHz and Wireless Local Area Networks around 2.4 GHz. In this paper, microstrip antenna is considered as a candidate for multi-band operation. After designing an antenna for 900 MHz it was seen that we can excite some modes with proper feeding of the antenna. Patch antenna is designed to support four modes at 0.9, 2.4, 5.2 GHz. Theoretical results are also introduced and compared with simulation results in the following sections.

2. 900 MHz Antenna

2.1. Theoretical Design of 900 MHz Antenna

Design process has started with the design of a microstrip patch antenna operating at 900 MHz. Width of the antenna is calculated using

$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{\vartheta_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \qquad (1)$$

where μ_0 is the permeability of free space, ε_0 is the relative permittivity of free space, f_r is the radiation frequency and ε_r is the permittivity of the substrate used in the antenna. In this design, FR4 which has a relative permittivity of 4.6 Farads/m^2 is used as the substrate. For the 900 Mhz case, the width is calculated using values $\mu_0 = 1.2566*10^{-6}\, Weber/(Amps*m)$, f_r = 900 MHz and $\varepsilon_0 = 8.8542*10^{-12}\, Farads/m$, and the result is found to be 9.96cm. Then the length of the antenna is calculated as

$$L = \frac{1}{2f_r\sqrt{\varepsilon_{reff}}\sqrt{\mu_0}\varepsilon_0} - 2\Delta L \qquad (2)$$

where

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

and

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2} \tag{4}$$

is the effective permittivity. In the effective permittivity calculation h is the thickness of the substrate and it is assumed to be much smaller than the thickness of the antenna. For the 900MHz design calculation, length of the antenna is found to be 7.76cm. After calculating the dimensions of the patch, design process continued with the matching of the radiation resistance of the antenna to $50\,\Omega$. For matching, inset feeding technique is used. Position of the inset feed point is calculated as follows:

$$y_0 = \frac{L}{\pi}\arccos\left(\frac{R_{in}}{R_{in0}}\right)^{1/2} \tag{5}$$

In the above formula, R_{in0} is the resonant input resistance of the antenna before the application of inset feeding and R_{in} is the required input resistance which is $50\,\Omega$ for this case. The result of the calculation on the position of the inset feed point came out to be y_0 = 3cm.

2.2. Simulation Results of 900 MHz Antenna

After the calculation of the above metrics of the antenna, the antenna is simulated in 'Agilent Advanced Design System' software and the S11 parameter of the antenna is given on the below plot within a frequency range of 500-2000MHZ:

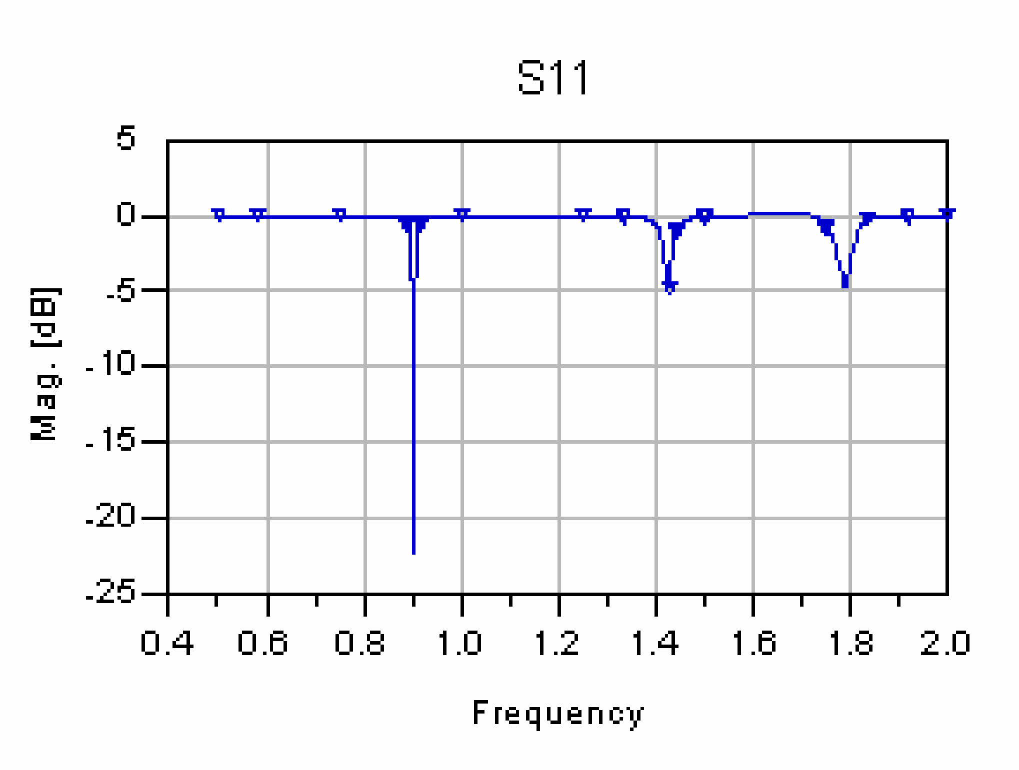


Fig. 1: S11 plot for simulation of 900 MHz patch

As seen on the plot, the antenna performs very well for 900MHz and there is radiation 1.42GHz and 1.8GHz due to other modes of operation. The current distribution at 900MHz is given below:

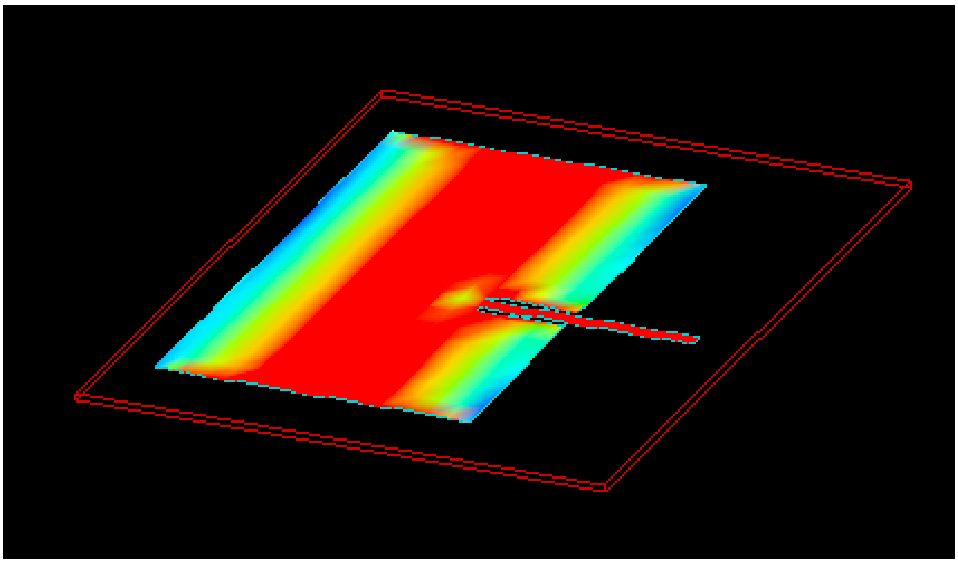


Fig. 2: Current distribution at 900 MHz

3. Antenna Modifications for Multi-Band Operation

3.1. Simulation Results for the Modified Antenna

In order to get multiple frequency of operation from this patch, our studies focused on exciting the other modes. For this purpose location of the inset feed was recalculated for providing matching at 1800MHz. The aim was to operate dual band operation at 900MHz and 1800MHz. This trial did not actually give the expected result, then another trial was proceeded with a shift of the position of the feed line to left by 1cm. The simulation results of the ending antenna are as given below:

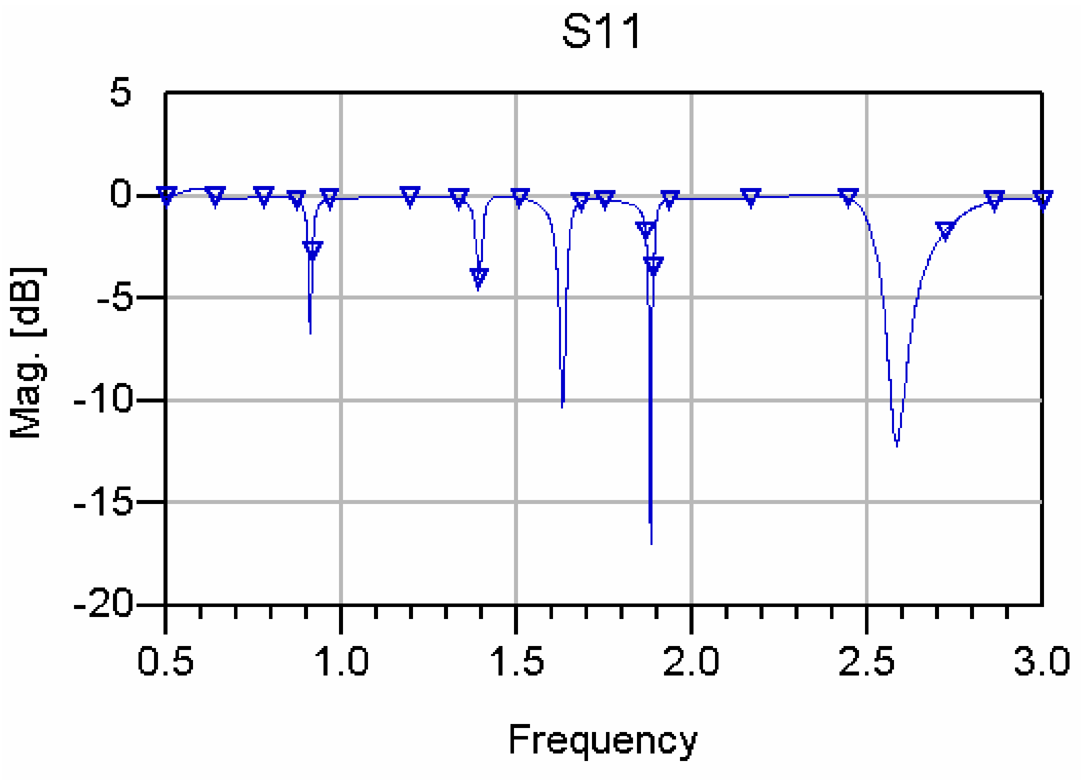


Fig. 3: S11 plot for modified (inset inserted and shifted) simulation

Above antenna operates at around 900MHz, 1650MHz, 1900MHz and 2600MHz. The current distribution for those frequencies is shown on the following plots:

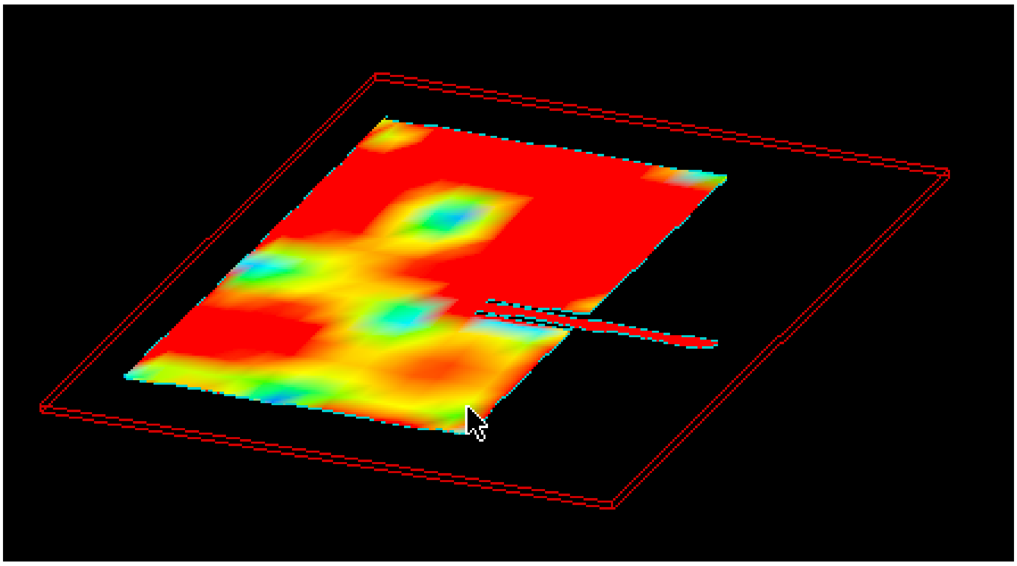


Fig. 4: Current distribution at 1650 MHz

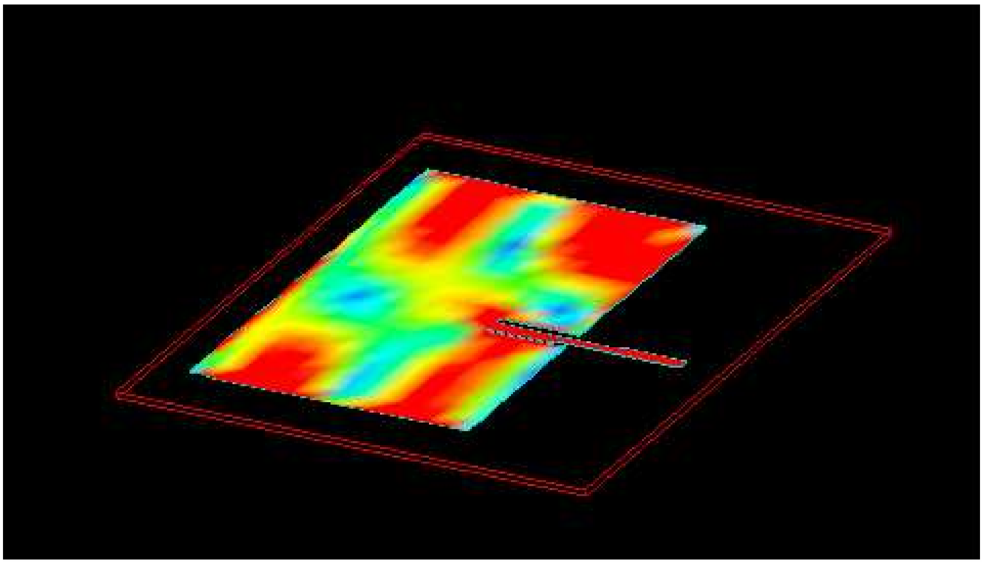


Fig. 5: Current distribution at 1900 MHz

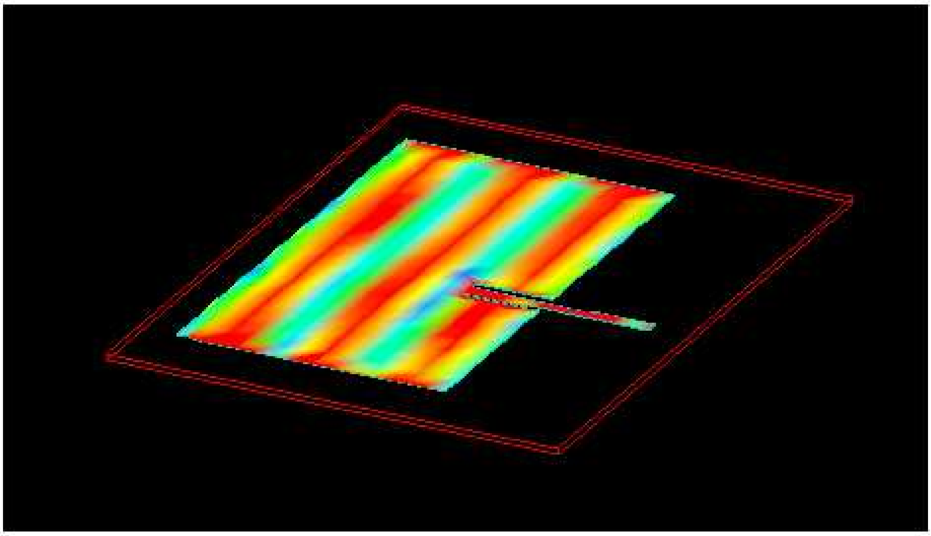


Fig. 6: Current distribution at 2600 MHz

As a conclusion due the above plots, the antenna seemed to operate at 2-2 mode in 1900 MHz and at 3-1 mode in 2600MHz. At this point, in order to compare the simulation results with the theoretical calculations, the possible modes of operation and the radiation frequencies for those modes are calculated using equation 6;

$$f_r(m,n) = \left(\frac{c}{2\pi\sqrt{\mu\varepsilon}}\right)\sqrt{\left(\frac{(m-1)\pi}{a}\right)^2 + \left(\frac{(n-1)\pi}{b}\right)^2} \tag{6}$$

Results can be seen in Table 1;

Modes	**0**	**1**	**2**	**3**	**4**
0	0	1.0098	2.0197	3.0295	4.0394
1	0.7777	1.2746	2.1642	3.1278	4.1135
2	1.5555	1.8545	2.5492	3.4055	4.3285
3	2.3332	2.5424	3.0859	3.8239	4.6648
4	3.1110	3.2708	3.7092	4.3424	5.0985

Table 1: Frequency modes of microstrip rectangular antenna

Above results are not actually consistent with the simulation results, but since ADS is a program that use numerical methods and since the simulation is performed at only a limited number of points, the calculated results are more reliable. On the other hand the simulation results provide necessary information in order to decide which modes of operation are excited with the current position of the inset feed point. According to simulation results it can be seen that the 1-0, 2-0, 2-2 and 3-1 modes are excited and according to the theoretical results when those modes are excited the resulting radiation frequencies should be around 800MHz, 1GHz, 1.5 GHz and 2.5GHz. With all of the above theoretical and simulation results, the shape of the antenna is chosen to be as shown below and building process of the antenna started.

3.2. Dimensions of the Multi-Band Patch

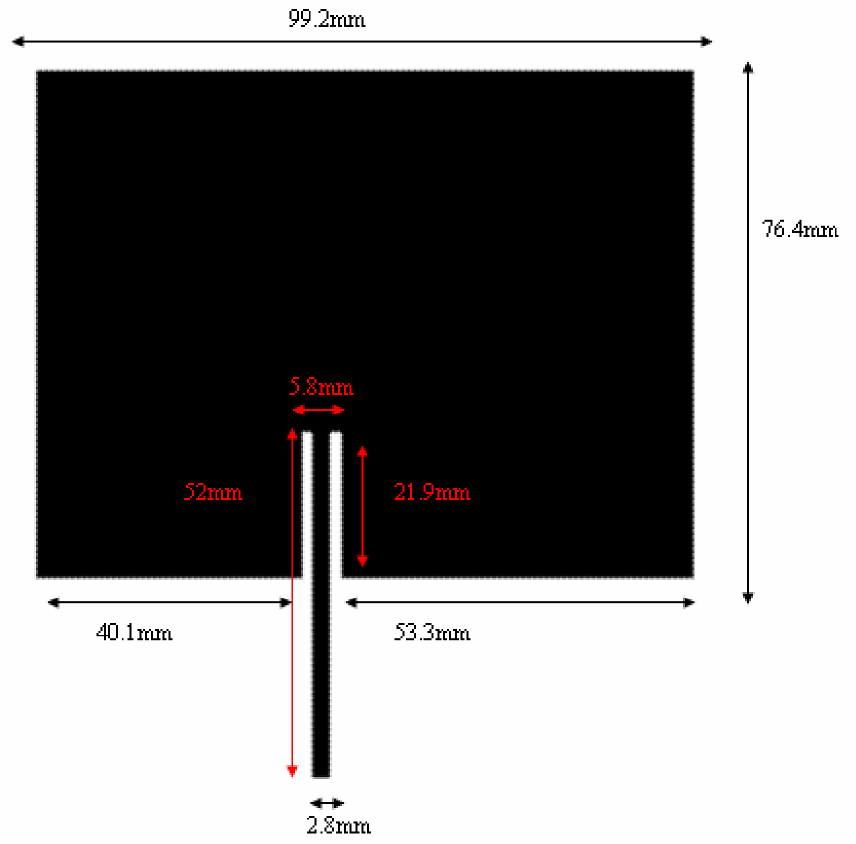


Fig. 7: Designed antenna dimensions

4. Building Process and Simulations of the Antenna

4.1. Steps of the Antenna Building Process

1. Shape of the antenna is printed (with 1:1 scale) on a copy transparency.
2. A plate of substrate with appropriate dimensions is provided and carefully cleaned.
3. One side of the plate is coated with a photo sensitive lacquer (Positiv 20).
4. It is allowed to dry (20^oC = 24hours, 70^oC = 15 min.) in a dark place. In this design coated plate is allowed for 2 hours to dry in room temperature.
5. The transparency carrying the mask is placed on the board and it is exposed to high UV light for 2 minutes.
6. Board is developed using 7gr NaOH in 1 liter water.
7. Opposite side of the board is covered using nail polish to prevent the ground layer from dissolving in next step.
8. As the last step, the antenna is developed in a solution consisting of 770ml H_2O, 200ml HCl and 30ml H_2O_2.
9. At the end of the process, both sides of the antenna are cleaned using acetone to remove the remains of the coating on the front side and the nail polish on the back.

4.2. Antenna Test Results

As the building process is complete, the antenna is tested using a network analyzer in order to get the S11 parameter of the antenna at different frequencies. The result between 0.5-5.5GHz is as shown below:

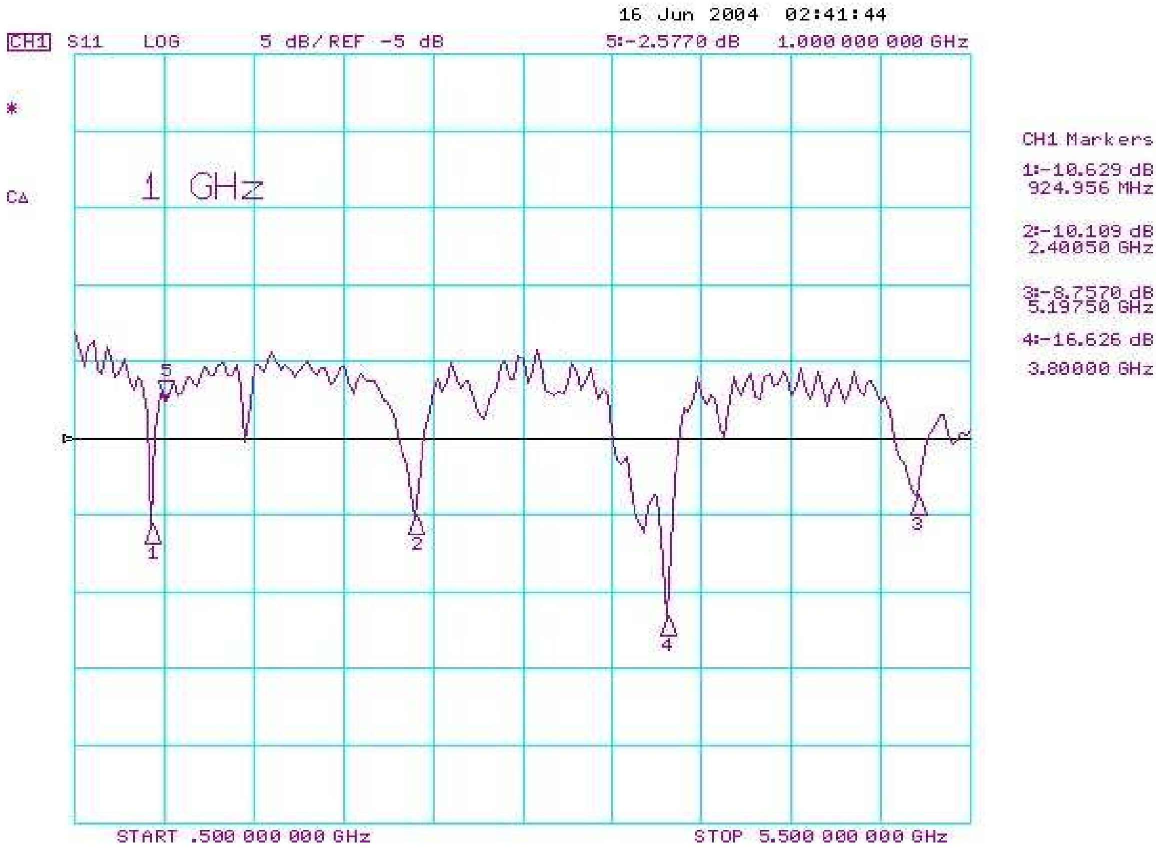


Fig. 8: S11 results for the built antenna

As seen above, the antenna operates at 924 MHz, 2.4GHz and 5.2GHz. Up to this point simulation results were given up to 3GHz. When testing the antenna 5.2GHz is observed as an additional radiation frequency. Simulation is performed for 5.2 GHz and the resulting current distribution is as given below:

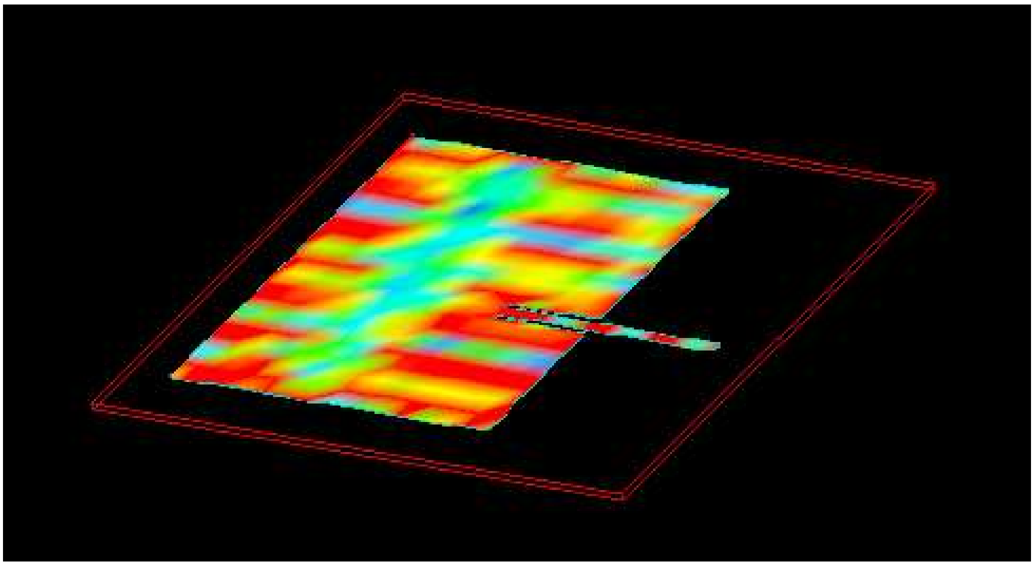


Fig. 9: Current distribution at 5200 MHz

Above current distribution tells that at 5.2 GHz of operation 2-5 mode of the antenna is excited. This result is consistent with the theoretical result obtained using equation (6).

5. Conclusion

The antenna for multiple band operation was designed according to simulation results. After achievement of the results which are reasonably close to the desired radiation frequencies, the antenna was built and tested. In the tests, some deviations from the simulation results were observed on the operation of the actual antenna. Despite those deviations, operating frequencies of the actual antenna, which are 900 MHz, 2.4 GHz and 5.2 GHz are the frequencies which are employed in currently used wireless systems. (The complete table of the results is given in Appendix1.)

One unique feature of this antenna implementation is that, in this design both inset feeding technique and offset feeding technique are used. The reason for the employment of the offset feeding technique was to be able to excite multiple modes on the same patch in order to provide multi-band operation. Amount of the shift was determined by simulation and according to the simulation results, the feed point has been shifted to the location which resulted in the excitation of the desired modes, and inset feed technique was also employed together with offset feed, in order to improve matching at the desired frequencies.

6. Appendices

6.1 Test results of the Antenna

Frequency	S11
924.956MHz	-10.629dB
2.40050GHz	-10.109dB
5.19750GHz	-8.7570dB
3.8GHz	-16.626dB

6.2 MATLAB code for determining radiation frequencies corresponding to the modes of the antenna

```
clear all
close all
c = 3*1e8;
mur = 1;
er = 3.78;
a = 0.0992; % original: 0.041
b = 0.0764; % original: 0.039
for m = 1:5;
   for n = 1:5;
f(m,n) = c/(2*pi*sqrt(mur*er))*sqrt( ((m-1)*pi/a)^2 + ((n-1)*pi/b)^2);
end
end
a,b
f/(10^9)
```

6.3 MATLAB Code for determining width and length of the antenna

```
clear all;
epsilon=input('enter epsilon');
rfreq1=input('enter radiation frequency');
rfreq=rfreq1*10^9;
h=input('enter the thickness of the substrate');
h=h/10;
c=3*10^10;
w=(1/(2*rfreq*c^(-1)))*(2/(epsilon+1))^0.5;
epsiloneff=((epsilon+1)/2)+((epsilon-1)/2)*((1+12*(h/w))^(-0.5));
deltaL=h*0.412*(epsiloneff+0.3)*((w/h)+0.264)*(epsiloneff-0.258)^(-
1)*((w/h)+0.8)^(-1);
L=(2*rfreq*(epsiloneff)^0.5*c^(-1))^(-1)-2*deltaL;
```

6.4 MATLAB Code for determining inset-feed position

```
clear all;
rin=input('enter the required resistance');
L=input('enter length');
w=input('enter width');
c=3*10^10;
freq=input('enter frequency');
freq=freq*10^9;
lambda0=c/freq;
if w < lambda0
   G1=(1/90)*(w/lambda0)^2;
else
   G1=(1/120)*(w/lambda0);
end
rin0=(2*G1)^(-1);
y01=(L/pi)*acos((rin/rin0)^0.5);
y02=(L/pi)*acos(-(rin/rin0)^0.5);
```

6.5 Radiation Patterns of the Antenna for 924MHz, 2.4GHz and 5.2GHz

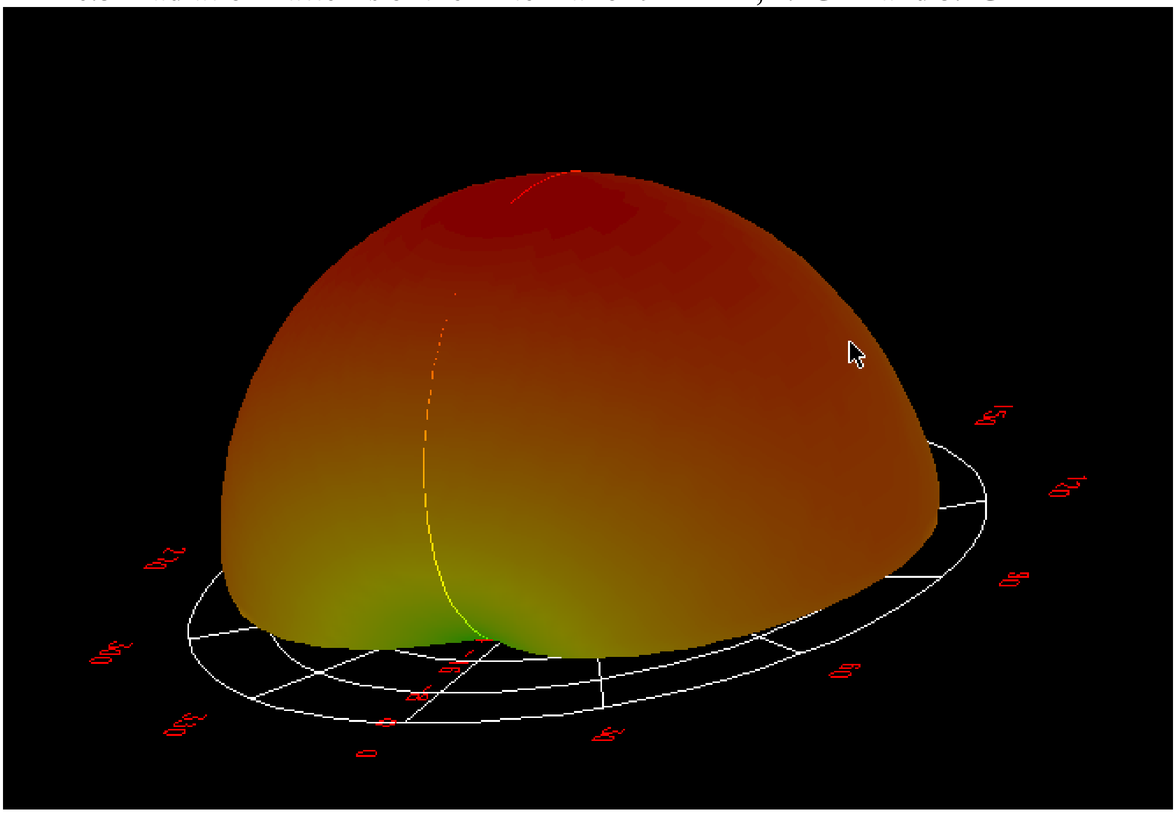


Fig. 10: Radiation pattern at 924 MHz

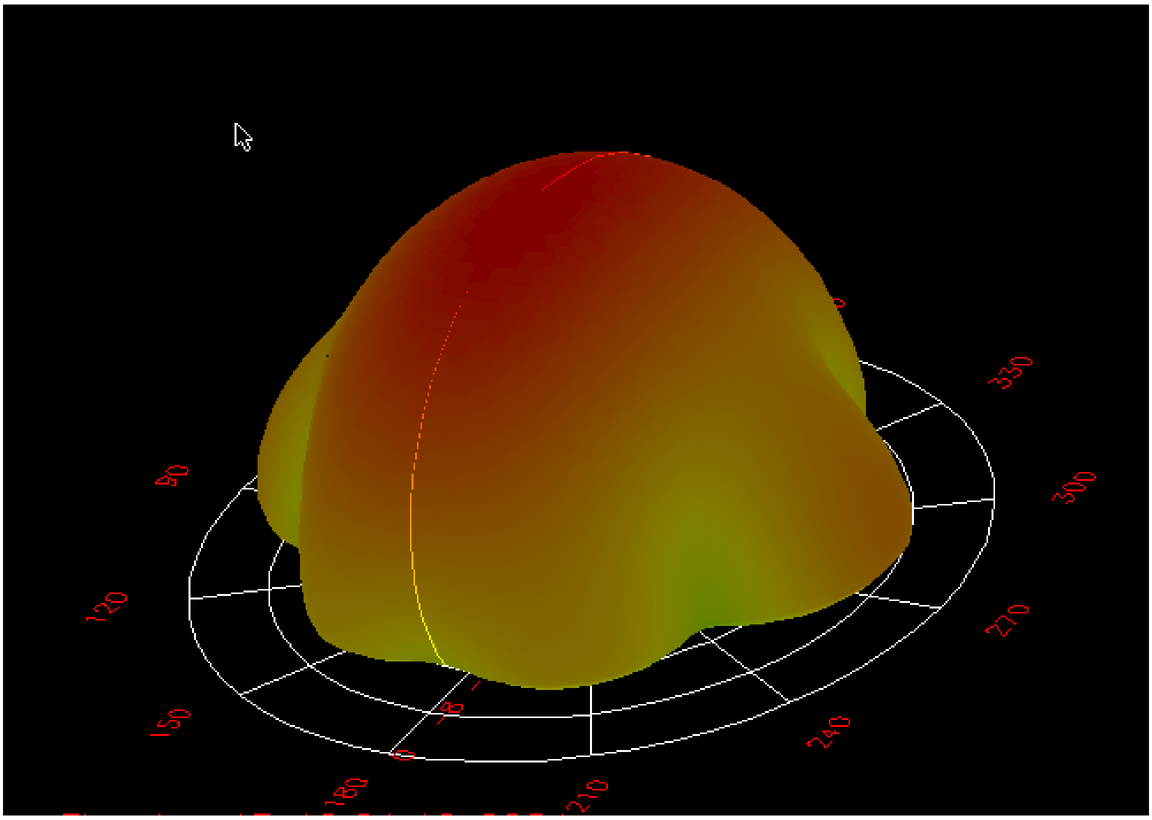
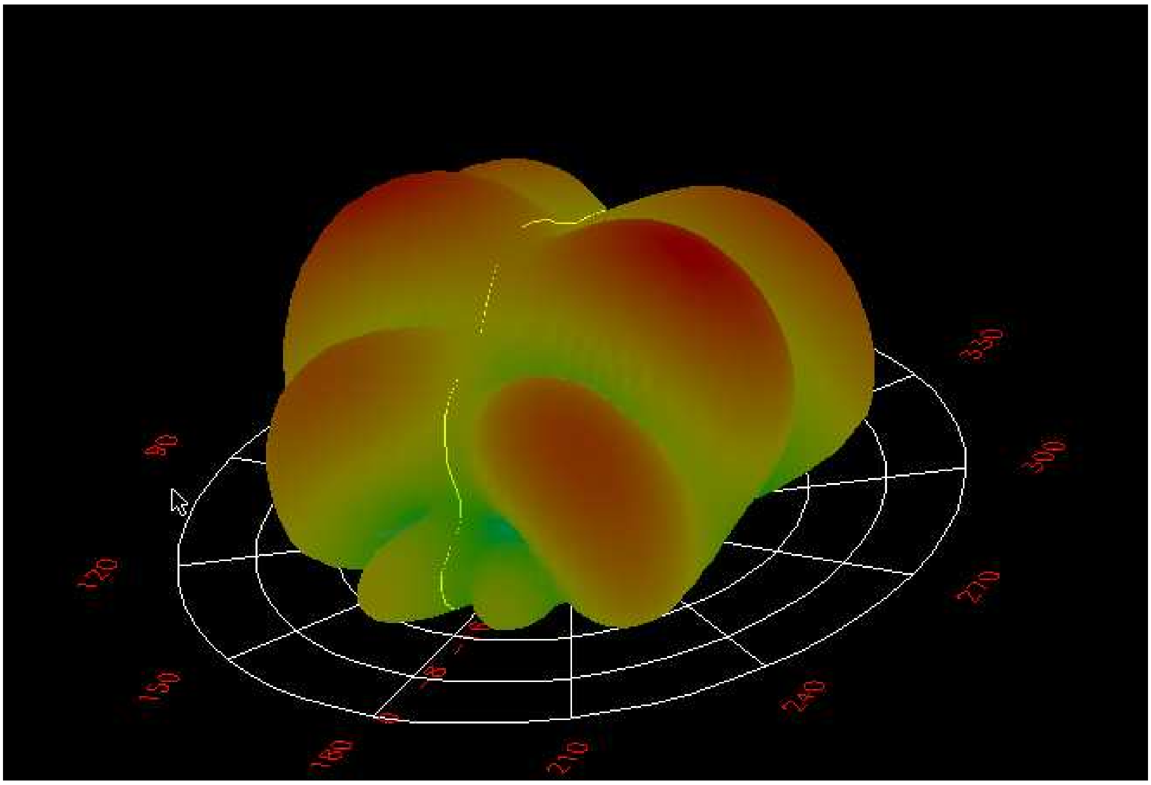


Fig. 11: Radiation patterns at 2.4 GHz (above) and 5.2 GHz (below)



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