Design and Simulation of a Quarter Wavelength Gap Coupled Microstrip Patch Antenna

Sanjay M. Palhade[1], **S. P. Yawale**[2]

[1]Department of Physics, Shri Shivaji College, Akola, India

[2]Department of Physics, Govt. Vidharbha Institute of Science & Humanities, Amravati, India

Abstract: ***The bandwidth obtained from a conventional rectangular microstrip patch antenna is not sufficient for many purposes. The bandwidth of a rectangular microstrip patch antenna can be improved by gap coupling parasitic patches to it, along its radiating and or non radiating edges. However, the resulting antenna structure has larger patch area and overall size than the unmodified conventional rectangular microstrip patch antenna. The microstrip patch antenna design presented here employs gap coupling technique to improve its bandwidth and reducing patch size by 50%. The half wave length long patch, of the conventional rectangular microstrip patch antenna, is divided along its width, into two half parts which are quarter wave length long, for two different TM_{10} mode frequencies. These quarters wave length long patches are then gap coupled along their non radiating edges. One of these patches is probe fed. The simulation of the proposed design predicts nearly two fold bandwidth enhancement over the conventional half wavelength long microstrip patch antenna.***

Keywords: Microstrip Patch Antenna, Gap Coupling, EMCoS Simulation, Bandwidth, Parasitic Resonator

1. Introduction

Microstrip patch antennas are compact resonant structures of narrow bandwidth. A microstrip patch antenna consists of a radiating metallic patch printed on a grounded substrate. The radiating patch can assume any shape but rectangular shape is most often used. The rectangular patch has to be half wave length long at the resonant frequency [1].

The bandwidth of a microstrip patch antenna depends on the substrate dielectric constant, substrate thickness and the operating frequency. Thick substrate with low dielectric constant provides improved bandwidth. Bandwidth increases with operating frequency [2]. However, excitation of surface waves, puts limit on the use of thicker substrates and smaller patch size require substrates with higher dielectric constants [3] [4]. The probe inductance in thick substrate poses problem of matching transmission line to the antenna [5].

Bandwidth can be increased by incorporating additional coplanar or multilayer resonators in the antenna structure. Additional resonators in the form of coplanar parasitic patches gap coupled along the radiating edges of the driven patch, enhances the bandwidth considerably [6]. These parasitic patches may also be gap coupled along the non radiating edges of the driven patch [7].

The gap coupled rectangular microstrip patch antenna configuration consists of a driven patch and one or more parasitic patches. The driven and parasitic patches are half wavelength long rectangular patches, resonant at different TM_{10} mode frequencies. Therefore, the benefit of bandwidth enhancement due to addition of coplanar parasitic patches, to the antenna structure, is accompanied by increase in the overall patch size.

The proposed rectangular microstrip patch antenna employs quarter wavelength long driven and parasitic patches to offset the increase in the overall antenna size accompanied by gap coupling technique. The proposed antenna design reduces the patch size by 50% over the conventional one.

This paper is divided into three parts. The first part deals with design and simulation of conventional half wavelength long rectangular microstrip patch antenna, resonant at TM_{10} mode frequency 1950 MHz. The second part considers modifications to first design to obtain quarter wavelength gap coupled microstrip patch antenna design and its simulation. In the third part, the simulation results of the two designs are compared and discussed along with the conclusions drawn from the simulation study of the two designs and scope to extend the work.

2. Rectangular Microstrip Patch Antenna Design

This section presents the design and simulation of rectangular microstrip patch antenna, for resonant frequency of 1950 MHz, using EMCoS Antenna VirtualLab™ [8] electromagnetic simulation software, which is based on the Method of Moment (MOM) technique of solving electromagnetic problems [9]

2.1 Initial Design

The initial design parameters, patch length L, patch width W, feed position from the center of the patch (x_f, y_f), ground plane length L_g and ground plane width W_g, are estimated, using the Transmission Line model [10] and the Cavity model of microstrip patch antenna [11]. The design steps are detailed below

The first step is to select the width W of the patch radiator. The optimum value of W is given by,

$$W = \frac{\lambda_o}{2}\left(\frac{\varepsilon_r + 1}{2}\right)^{\frac{-1}{2}} \quad (1)$$

where,

λ_o is the free space wavelength, corresponding to the resonant frequency f_o and

ε_r is the dielectric constant of the substrate material.

The second step determines the effective dielectric constant of air-substrate-air multilayer medium,

$$\varepsilon_e = \frac{1}{2}\left[(\varepsilon_r + 1) + (\varepsilon_r - 1)(1 + 12h/W)^{\frac{-1}{2}}\right] \quad (2)$$

where, h is the height or thickness of the substrate.

The third step calculates the electrical elongation of patch length,

$$\Delta l = 0.412h\left(\frac{\varepsilon_e + 0.3}{\varepsilon_e - 0.258}\right)\left(\frac{W/h + 0.264}{W/h + 0.8}\right) \quad (3)$$

The resonant frequency f_o of the TM_{10} mode is given by,

$$f_o = \frac{c}{2(L + 2\Delta l)\sqrt{\varepsilon_e}} \quad (4)$$

where, c is the speed of light in free space.

The fourth step obtains the physical length L of the patch resonating at frequency f_o,

$$L = \frac{c}{2f_o\sqrt{\varepsilon_e}} - 2\Delta l \quad (5)$$

The fifth step determines the feed position, relative to the origin, located at the center of the patch,

$$x_f = \frac{L}{\pi}\arcsin\sqrt{\frac{50}{R_{in}\left(x = \frac{L}{2}\right)}} \quad (6)$$

$$y_f = 0$$

The sixth step decides the ground plane length L_g and width W_g, which should be at least

$$L_g = 6h + L$$
$$W_g = 6h + W \quad (7)$$

The design parameters estimated using the above six steps, for a rectangular microstrip patch antenna, resonant at 1950 MHz, which uses RT5880™ copper clad substrate from Rogers, USA, are shown in the Table 1. The table also shows RT5880™ copper clad substrate parameters [12]. The half wavelength rectangular microstrip patch antenna is illustrated in the Fig 1.

Table 1: Initial Design Parameters

Parameter	Value in mm	RT5880™	
L	50.129560	h	3.175 mm
W	60.813032	ε_r	2.2
L_g	69.179560	$\tan(\delta)$	0.0009
W_g	79.863032	d	1.3 mm
x_f	10.316876		
y_f	0		

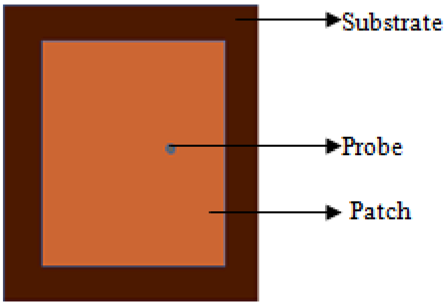

Figure 1: Rectangular Microstrip Patch Antenna on RT5880™

2.2 Simulation and Final Design

The initial antenna design obtained using the Transmission Line model and the Cavity model, is simply a rough estimate. It needs further refinements, to achieve the design specifications. The initial design is refined using computer simulation. The electromagnetic simulation software EMCoS Antenna VirtualLab™, developed by Georgia based company EMCoS Ltd., is used for simulation and corrections.

The EMCoS Antenna VirtualLab™ simulation involves three steps. In the first step, geometrical model of the microstrip patch antenna is created. The microstrip patch and the gound plane, are represented by rectangles, of the dimensions mentioned in the Table 1. The substrate is represented by rectangular box of size LxWxh. The connector and its connections to the patch and ground are represented two lines with gap. The electrical and physical properties are assigned to these geometrical entities, in the second step. The rectangles for the microstrip patch and ground plane are assigned properties of perfect electrical conductor (PEC) and the rectangular box is assigned dielectric properties of RT5880™ substrate. The lines are assigned properties of electrical wires of diameter d = 1.3 mm. A delta gap voltage generator is placed in the gap between these two wires. The third step converts the physical model into mathematical model. The physical model is converted into mathematical mesh. The mathematical mesh consists of triangular elements with edge size determined by the operating frequency. The meshed model is simulated and the obtained results are processed to determine the antenna parameters S_{11}, Z_{11}, VSWR and Smith chart.

The initial antenna model is created from the dimension values shown in the Table 1. The model is simulated and obtained results for the antenna parameters, S_{11}, Z_{11}, VSWR and Smith chart, are compared with those required for the design specifications. In the first run, the simulation results for the antenna parameters do not match well with the antenna parameters required, to satisfy the design specifications. Therefore, the antenna model is improved by changing any one of antenna model parameters, the patch dimensions or ground dimensions or the feed location and the resulting model is simulated and obtained results are compared again with the antenna parameters required. The process of changing antenna model, simulating it and comparing results with the antenna parameters, required to satisfy design specifications, is repeated until a good match between simulation results and required antenna parameters is obtained.

The final microstrip patch antenna model dimensions and feed location, obtained using the technique of iteratively improving antenna model, described previously, is shown in the Table 2.

Table 2: Final Design Parameters

Parameter	Value in mm	RT5880™	
L	47.132799	h	3.175 mm
W	60.813032	ε_r	2.2
L_g	79.863032	$\tan(\delta)$	0.0009
W_g	79.863032		
x_f	11.864407		
y_f	0		
d	1.30		

The antenna characteristics for S_{11} and Z_{11} are presented in Fig 2 and Fig 3, respectively. The VSWR and Smith chart for
the antenna design, are presented in Fig 4 and Fig 5 respectively.

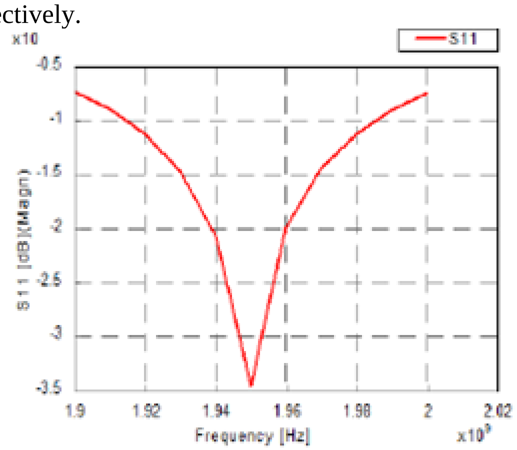

Figure 2: S_{11} Characteristics

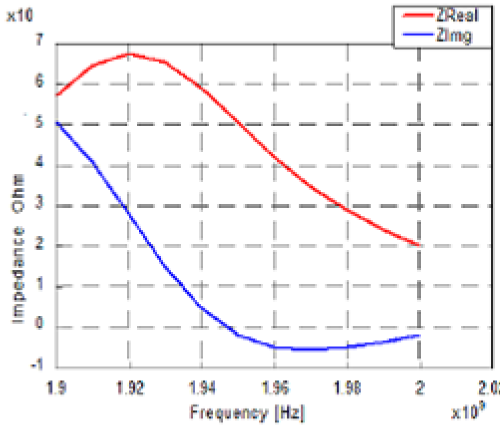

Figure 3: Z_{11} Characteristics

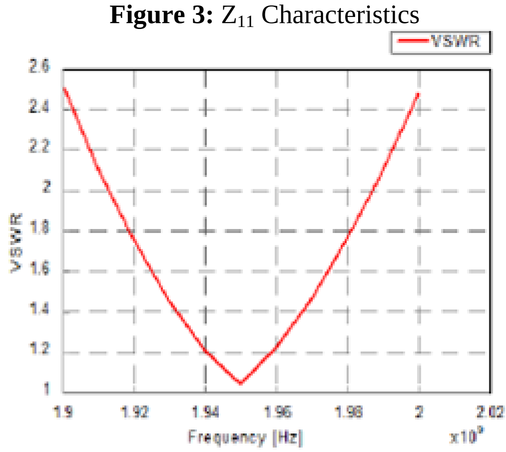

Figure 4: VSWR

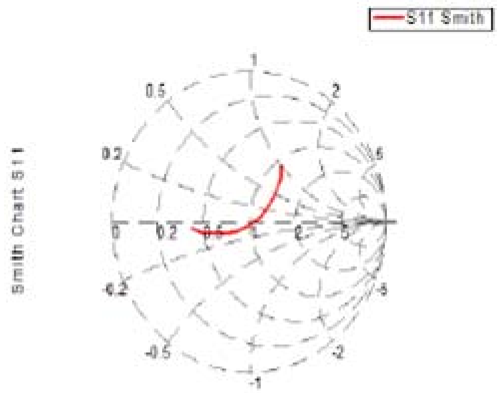

Figure 5: Smith Chart

The results for some important antenna parameters are given in the Table 3

Table 3: Rectangular Microstrip Patch Antenna

Antenna Parameter	Value	Unit
f_o	1950	MHz
S_{11} Minimum	-34.5935	dB
VSWR Bandwidth	60	MHz
S_{11} Bandwidth	60	MHz
Z_{11} at resonance	50.4816-j1.80978	Ohm

3. Quarter Wave Gap Coupled Rectangular Microstrip Patch Antenna Design

The gap or capacitively coupled rectangular microstrip patch antenna designs offer broader bandwidths than the conventional ones. The gap coupled design consists of a driven half wavelength patch gap coupled to parasitic patches. The parasitic patches have resonant frequencies close to the resonant frequency of the driven patch. The parasitic patches may be gap coupled to either the radiating edges and or to the non radiating edges, of the driven patch.

The broader bandwidth half wavelength gap coupled rectangular microstrip patch antenna design is accompanied by the disadvantage of larger total patch size than the conventional design. The quarter wavelength gap coupled rectangular microstrip patch antenna design , on the other hand, provides broader bandwidth and 50% size reduction over conventional rectangular microstrip patch antenna.

This type of design, consists of, non radiating edge gap coupled, quarter wavelength driven and parasitic patches. These patches are obtained by halving the half wavelength patch of half wavelength rectangular microstrip patch antenna design along its length and width. They are shorted to ground along their one radiating edge. The quarter wavelength gap coupled rectangular microstrip patch antenna design is illustrated in Fig 6.

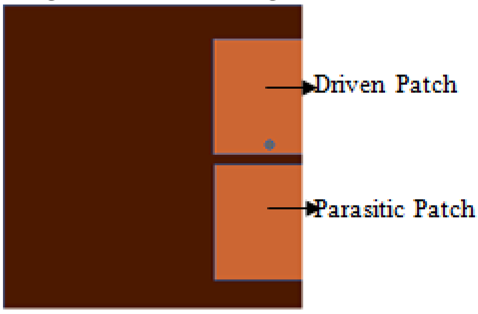

Figure 6: Quarter Wavelength Gap Coupled Rectangular Microstrip Patch Antenna

3.1 Initial Design

The initial estimates for the dimensions of quarter wavelength driven and parasitic patches are obtained by halving the patch dimensions shown in Table 2 for the final design of conventional rectangular microstrip patch antenna. The initial estimates of the design parameters for quarter wavelength gap coupled rectangular microstrip patch antenna are shown in the Table 4. The new design parameters are, length of the driven patch $L_{d,}$, length of the parasitic patch $L_{p,}$ the width of driven patch $W_{d,}$, the width of parasitic patch W_p and the gap between the driven and the parasitic patch *g*.

Table 4: Initial Design Parameters

Parameter	*Value in mm*	*RT5880^{TM}*	
L_d, L_p	23.5663995	h	3.175 mm
W_d, W_p	30.406516	ε_r	2.2
L_g	79.863032	$\tan(\delta)$	0.0009
W_g	79.863032		
x_f	35.4308065		
y_f	0		
g	1.5		
d	1.30		

3.2 Simulation and Final Design

The design specifications for the quarter wavelength gap coupled rectangular microstrip patch antenna are, the resonant frequency of driven patch f_d =1950 MHz and the resonant frequency of parasitic patch fp =1980 MHz. The bandwidth of driven as well as parasitic patch should be 50 MHz. The total bandwidth should be 100 MHz. The initial antenna model created using the design parameters shown in the Table 3 is improved using iterative process of simulation, comparison of simulation results with the design specifications and changing design parameters.

The final design parameters obtained for the quarter wavelength gap coupled rectangular microstrip patch antenna, are shown in the Table 5.

Table 5: Final Design Parameters

Parameter	Value in mm	Parameter	Value in mm
L_d	23.758518	x_f	32.790992
L_p	23.482393	y_f	5.5
W_d	30.406516	g	1.5
W_p	30.406516	d	1.30
L_g	79.863032		
W_g	79.863032		

The simulation results for S_{11}, Z_{11}, VSWR and Smith chart are presented in Figs 7 to 10.

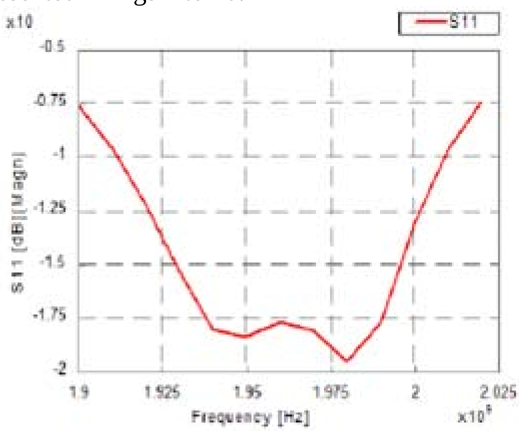

Figure 7: S_{11} Characteristics

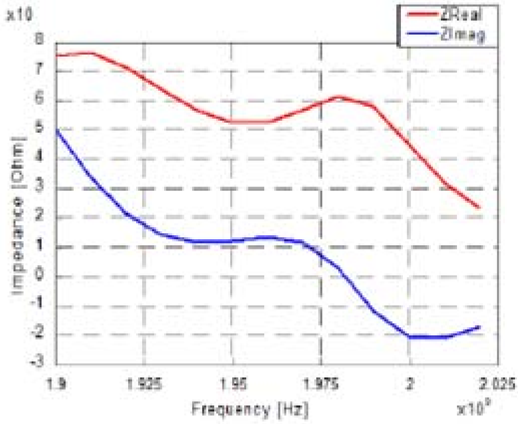

Figure 8: Z_{11} Characteristics

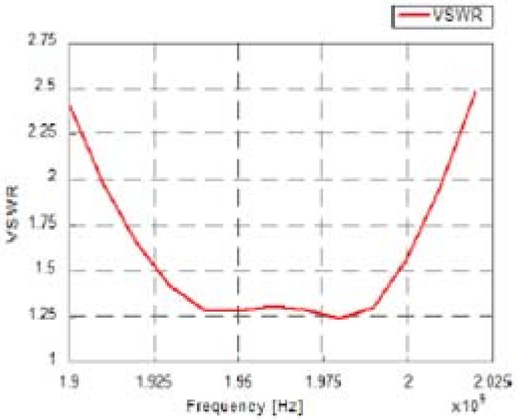

Figure 9: VSWR

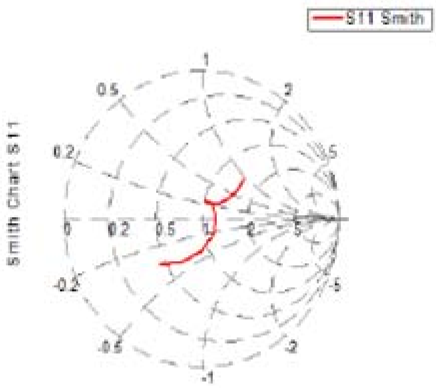

Figure 10: Smith Chart

The simulation results show the presence of two resonant frequencies, corresponding to the driven and the parasitic patches. The presence of these frequencies is confirmed by the Smith chart. The bandwidth of 98 MHz is obtained for this design.

4. Conclusions and Discussions

The half wavelength rectangular microstrip patch antenna design is resonant at frequency f_o = 1950 MHz. The -10dB bandwidth is 60 MHz. The lower and upper cutoff frequencies are f_L = 1920 MHz and f_U = 1980 MHz. The impedance characteristic shows that the antenna is slightly capacitive at resonance. The patch size is about 2866.2884 mm^2. The ground plane size is 6378.1039 mm^2.

The quarter wavelength gap coupled rectangular microstrip patch antenna design shows excitation of two TM10 resonant modes of frequencies, f_d = 1950 MHz and f_p = 1980 MHz, corresponding to the driven quarter wavelength patch and parasitically coupled quarter wavelength patch. The presence of these resonant modes is confirmed by Smith chart. The –10dB bandwidth is 98 MHz. The lower and upper cutoff frequencies are f_L = 1911 MHz and f_U = 2009 MHz. The

antenna design is not perfectly matched to the transmission line at the resonant mode frequencies, the input impedance is inductive at f_d = 1950 MHz and f_p = 1980 MHz. The overall patch size is about 1444.8275 mm^2 while the ground plane size remains 6378.1039 mm^2.

The quarter wavelength gap coupled rectangular microstrip patch antenna design, enhances bandwidth from 60 MHz of conventional design to 98 MHz. The proposed design has patch size which is 50% smaller than the conventional design. However, more simulation study is needed to reduce the inductive reactance of this design. The comparison of conventional microstrip patch antenna design and the proposed quarter wavelength gap coupled rectangular microstrip patch antenna design is presented in the Table 6.

Table 6: Comparison of Designs

Conventional Design		Proposed Design	
Parameter	Value	Parameter	Value
f_o	1950 MHz	f_d	1950 MHz
		f_p	1980 MHz
Bandwidth	60 MHz		98 MHz
Z_{11}	50.4816-j1.80978 Ohm	f_d	52.6065+ j12.1723 Ohm
		f_p	61.437+ j2.82774 Ohm
Patch Area	2866.2884 mm^2		1444.8275 mm^2
Ground Plane	6378.1039 mm^2		6378.1039 mm^2

5. Acknowledgements

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