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Design and Photo-Lithographic Fabrication of Microstrip Patch Antenna

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Abstract: ***Microstrip patch antennas are generally fabricated by photo-lithographic method. Photo-lithographic method produces highly accurate etched pattern for the microstrip patch. Fabrication accuracy is very critical as the microstrip patch antennas are narrow band resonant structures that usually operate in the microwave bands. Fabrication errors in the patch dimensions will shift its resonant frequency. Photo-lithographic method is a chemical etching process which removes the unwanted metal regions of the metallic layer. This paper describes the design, simulation and the step by step fabrication process for a rectangular microstrip patch antenna .***

Keywords: Microstrip Patch Antenna, EMCoS Simulation, Photo-lithography, Fabrication, UV light

1. Introduction

Microstrip patch antennas (MSPAs) consist of a metallic patch printed on a grounded and electrically thin dielectric substrate. The radiating metallic patch can assume any shape but regular geometrical shapes are generally employed. Regular geometrical shapes simplify analysis and provide performance prediction. Rectangular and circular geometries are common. The rectangular patch has to be half wave length long at the resonant frequency [1]. Thick substrates with a low value of dielectric constant ε_r are generally used to enhance the fringing fields, which account for the radiation from microstrip patch antenna [2], [3].

This paper describes the designing and fabrication of a rectangular microstrip patch antenna. The microstrip patch antenna is designed and simulated using EMCoS Antenna VirtualLab™ [4] electromagnetic simulation software, which is based on the Method of Moment (MOM) technique of solving electromagnetic problems [5]. The designed microstrip patch antenna is fabricated by photo-lithographic method. Photo-lithographic method is a chemical etching process which removes the unwanted metal regions of the metallic layer. Photo-lithographic method produces highly accurate etched pattern for the microstrip patch. Fabrication accuracy is very critical as the microstrip patch antennas are narrow band resonant structures that usually operate in the microwave bands. Fabrication errors in the patch dimensions will shift its resonant frequency [6].

This paper is divided into two 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 describes the photo-lithographic fabrication of the microstrip patch antenna designed in the first part.

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™ electromagnetic simulation software.

2.1 Initial Design

The initial microstrip patch antenna design parameters, patch length *L*, patch width *W*, feed position (x_f, y_f) from the center of the patch, ground plane length L_g and ground plane width W_g, are estimated, using the Transmission Line model [7] and the Cavity model of microstrip patch antenna [8]. 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,

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

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,

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

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

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

The third step calculates the electrical elongation of patch length,

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

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

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

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

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

$$y_f=0$$

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

$$L_g=6h+L \qquad (7)$$

$$W_g=6h+W$$

The design parameters estimated using the above six steps, for a rectangular microstrip patch antenna, resonant at 1950 MHz, which uses RO3003^{TM} copper clad substrate from Rogers, USA, are shown in the Table 1. The table also shows RO3003^{TM} copper clad substrate parameters [10]. The half wavelength rectangular microstrip patch antenna is illustrated in the Fig 1.

Table 1: Initial Design Parameters

Parameter	Value in mm	RO3003^{TM}	
L	43.942995	h	1.524 mm
W	54.392829	ε_r	3
L_g	53.086995	$\tan(\delta)$	0.0013
W_g	63.536829	d	1.3 mm
x_f	8.247373	Colour	White
y_f	0		

Figure 1: Rectangular Microstrip Patch Antenna on RO3003^{TM}

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^{TM} is used for simulation and corrections. The details of simulation of microstrip patch type antenna using EMCoS Antenna VirtualLab^{TM} are given in [9].

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 of 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 of the design specifications, is repeated until a good match between simulation results and the design specified 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	RO3003^{TM}	
L	42.215513	h	1.524 mm
W	54.392829	ε_r	3
L_g	65	$\tan(\delta)$	0.0012
W_g	65	Colour	White
x_f	8.907163		
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.

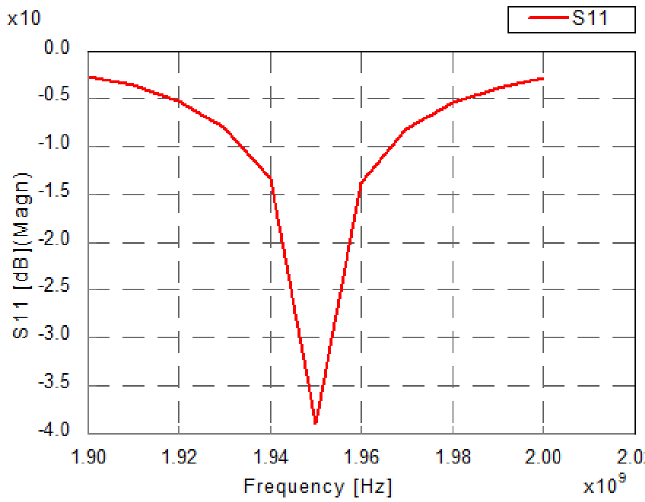


Figure 2: S_{11} Characteristics

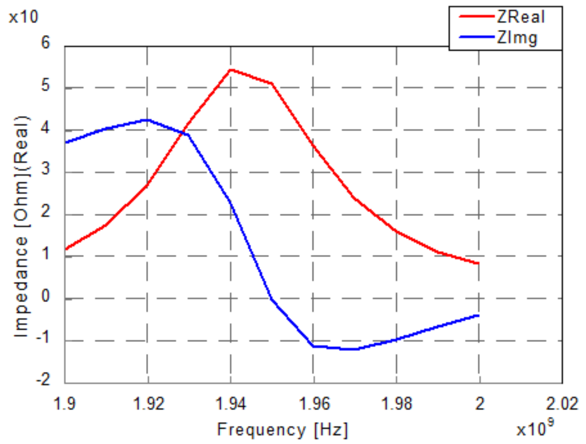


Figure 3: Z_{11} Characteristics

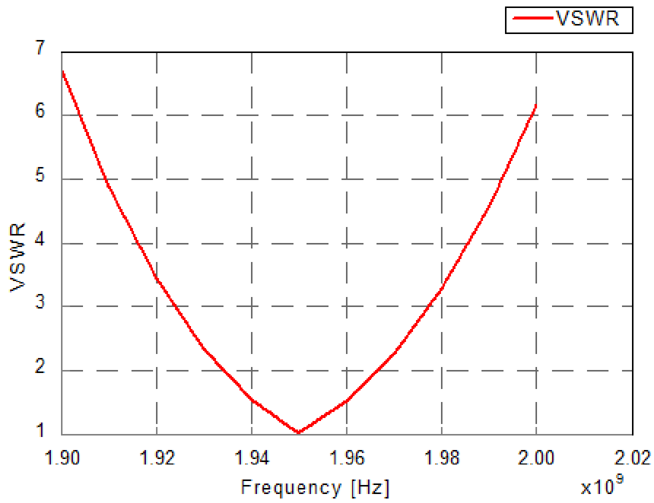


Figure 4: VSWR

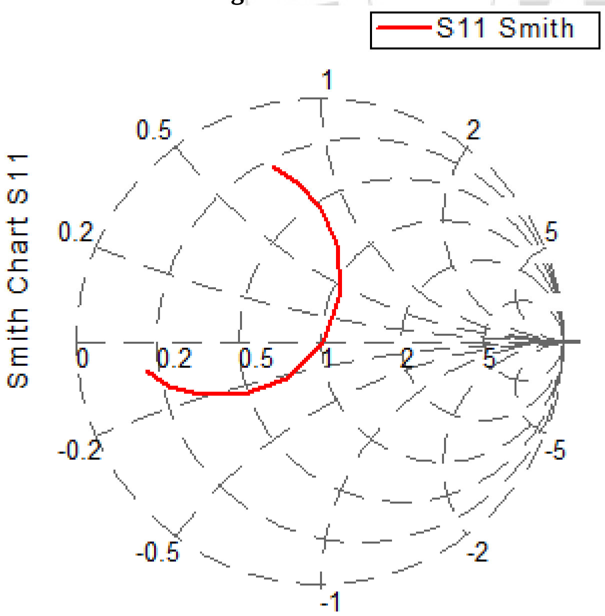


Figure 5: Smith Chart

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

Table 3: Rectangular Microstrip Patch Antenna Parameters

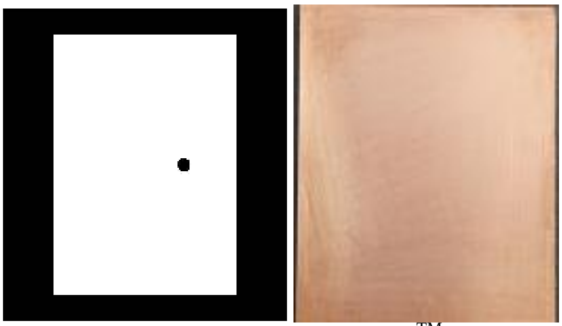
Antenna Parameter	Value	Unit
f_o	1950	MHz
$S_{11\ Minimum}$	-39.0398	dB
VSWR Bandwidth	32	MHz
S_{11} Bandwidth	34	MHz
Z_{11} at resonance	51.1144-*j*0.183245	Ohm

[1] Fabrication of Rectangular Microstrip Patch Antenna

This section describes the photo-lithographic fabrication of rectangular microstrip patch antenna designed and simulated in the earlier section. The dimensions of designed rectangular microstrip patch antenna are given in the Table 2.

Photo-lithographic method requires ultra violet (UV) light of suitable wavelength and photo-resist sensitive to this wavelength. The photo-resist materials are of two types, positive and negative. The exposed portion of positive photo-resist dissolves in the photo-resist developer and that of negative photo-resist hardens. Photo-resist material in the form of dry negative photo-resist film, to be applied as lamination to the copper clad substrate and UV A type light, obtained from insect killer Philips^{TM} fluorescent tube lamp, are used in the present work. This UV light is centered around the wavelength of 370 nm [11].

The step by step process for the microstrip patch antenna fabrication, used in the present work, is illustrated in the Fig. 6 and 7. The first step is computer aided design of the antenna geometry. A negative of this geometry printed on transparent sheet serves as the mask. A double sided copper clad substrate RO3003^{TM}of dimension 65 mm X 65 mm is thoroughly cleaned using acetone and dried. Dust particles or impurities present on the copper clad surface introduce discontinuity in the etched pattern that alters the resonant frequency. In the second step, a negative photo-resist film is laminated to the cleaned and dried copper clad substrate. The negative mask prepared in the first step is firmly placed on the photo-resist laminated copper clad substrate. The masked and photo-resist laminated copper clad substrate is exposed to ultra violet (UV) light. The third step is to develop the UV exposed photo-resist laminated copper clad substrate. The photo-resist exposed to UV light becomes hard and dark blue in colour while unexposed photo-resist remains light blue and dissolves in the developer solution. Sodium Carbonate is used as the developer. Finally, the developed copper clad substrate is chemically etched by Ferric Chloride $FeCl_3$ solution. The copper parts except underneath the hardened photo resist dissolve in $FeCl_3$. The etched substrate is rinsed in running water to remove any etchant and then dried. The hardened photo-resist is removed using Sodium Hydroxide. The photo-lithographically fabricated rectangular microstrip patch antenna is shown in the Fig. 8. The UV Exposure unit is shown in Fig. 9.



Mask Copper Clad RO3003™

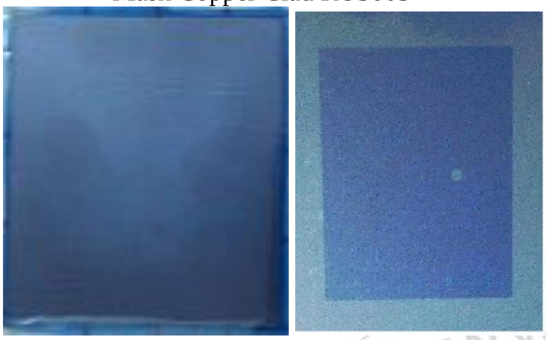
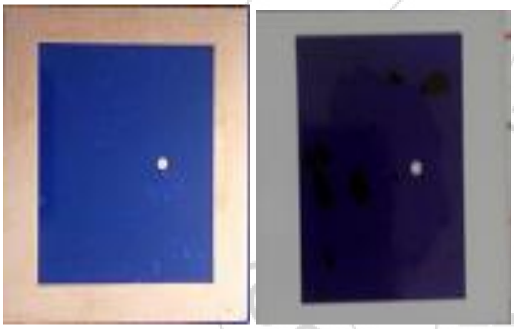


Photo-resist Laminated UV Exposed Laminated Copper Clad RO3003™ Copper Clad RO3003™

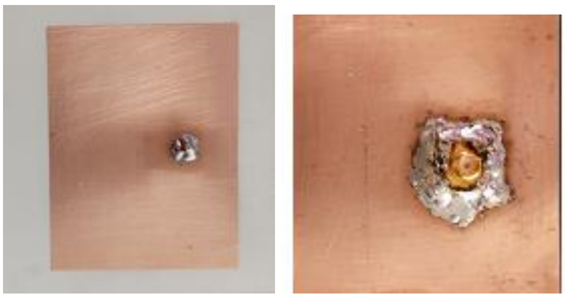
Figure 6: Photo-lithographic Fabrication Initial Steps



Developed Etched

Final photo-resist removed

Figure 7: Photo-lithographic Fabrication Final Steps



Patch Ground

Figure 8: Rectangular Microstrip Patch Antenna

Figure 9: UV Exposure Unit

3. Conclusions and Discussions

A half wavelength rectangular microstrip patch antenna, resonant at frequency f_o = 1950 MHz, is designed and simulated on RO3003™ copper clad substrate. The microstrip patch antenna dimensions obtained from the simulation are used to fabricate the antenna. The antenna is fabricated using photo-lithography technique. The photo-lithographic fabrication of microstrip patch antenna is described.

4. Acknowledgements

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