TRIANGULAR MIRCOSTRIP PATCH ANTENNA FOR 2100 MHZ

S. M. Palhade* & S. G. Shende
smpalhade65@gmail.com
Department of Physics
Shri Shivaji College of Arts, Comerce & Science
Akola 444001 (India)

Abstract: Triangular microstrip patch antenna has advantage of smaller size compared to rectangular microstrip patch antenna for the chosen resonanant frequency. Its mode structure is richer than the rectangular geometry. This paper describes the design and simulation of a triangular microstrip patch antenna on RO3003 substrate for 2100 MHz using openEMS electromagnetic field solver. openEMS is a free and open source electromagnetic field solver and simulator available on Linux and Windows platforms. It is based on the EC-FDTD algorithm which extends the Yee's FDTD algorithm. This paper first describes the EC-FDTD algorithm and the openEMS electromagnetic field solver. Finally, TLM and cavity model based design and openEMS simulation of a triangular microstrip patch antenna on RO3003 substrate for 2100 MHz is detailed. The results for the resonanant frequency, bandwidth and directivity of the designed antenna are provided.

Keywords: Electromagnetics, Computational Electromagnetics, FDTD, EC-FDTD, MOM, TLM , Microstrip Patch Antenna

I. INTRODUCTION

Antenna plays prime role in the wireless technology. Modern wireless devices demand low profile and conformal antennas.. Microstrip patch antenna (MPA) composed of metallic patch on a grounded substrate can fulfil the requirements of modern handheld and portable wireless devices [1].

The microstrip patch antennas are planner electromagnetic radiating structures. They are half wavelength long, have a high Q and low bandwidth [2]. A microstrip patch antenna on thick substrate of low dielectric constant provides good operating bandwidth and radiation efficiency [3]. The resonant frequency of microstrip patch antenna is determined by the geometrical shape and dimensions of the patch and ground. There are approximate models for the prediction of its resonant frequency and bandwidth. The two models used to create a starting design of microstrip patch antenna are the transmission line model (TLM) and the cavity model [4], [5]. These models consider that the antenna structure has infinite or very large ground plane which in practice is small for the modern wireless handheld and portable devices. The initial design, therefore, needs testing and refinements before actual antenna is fabricated. The testing of and refinement to the initial design is done using computer simulation and its geometrical parameters are adjusted to get the desired resonant frequency and bandwidth.

The microstrip patch antenna can be modelled and simulated using commercial and licensed simulators like HFSS, XFdtd, EMCoS, FEKO, CST MWS etc [6]. These simulators are electromagnetic solvers that employ one of the numerical methods from the finite element method (FEM), Yee's finite difference time domain (FDTD) algorithm, and the method of moments (MOM) [7], [8]. These softwares have graphical user interface (GUI) and good technical support. On the other hand, free electromagnetic field solvers like MEEP, gprMax, Angora, emGine, openEMS available on the internet are mostly text based, without any dedicated support and demand self learning [9].

openEMS is EC-FDTD (equivalent circuit FDTD) based free and open source electromagnetic field solver developed by Thorsten Liebig *et al* [10]. It is available for both Linux and Windows platforms. In this work, the EC-FDTD algorithm is first desribed briefly and then the design of a triangular microstrip patch antenna for 2100MHz on RO3003 substrate is outlined. Finally, the antenna simulation using openEMS to arrive at a final antenna design suitable for actual fabrication is detailed.

EC-FDTD and openEMS

Many complex electromagnetic field problems have been solved using the Yee finite-difference time-domain (FDTD) algorithm [10]. The Yee algorithm translates the electromagnetic equations into a direct and explicit numerical method to solve electromagnetic problems. It considers both the electric and magnetic field components. The equivalent circuit (EC-FDTD) approach, on the other hand, considers

circuit variables like voltages and currents instead of fields. The EC-FDTD scheme is derived from Maxwell's equations in integral form by discretizing them using the Yee algorithm [11]. The EC-FDTD scheme can be summarized using two update equations

$$v_x^{n_t} = \frac{2C_x - \triangle_t G_x}{2C_x + \triangle_t G_x} v_x^{n_t - 1} + \frac{2\triangle_t}{2C_x + \triangle_t G_x}\left(i_y^{n_t - 0.5} - i_y^{n_t - 0.5}(n_z - 1) - i_z^{n_t - 0.5} + i_z^{n_t - 0.5}(n_y - 1)\right) \quad (1)$$

$$i_y^{n_t + 0.5} = \frac{2L_y - \triangle_t R_y}{2L_y + \triangle_t R_y} i_y^{n_t - 0.5} - \frac{2\triangle_t}{2L_x + \triangle_t R_y}\left(v_z^{n_t} - v_z^{n_t}(n_x + 1) - v_x^{n_t} + v_x^{n_t}(n_z + 1)\right) \quad (2)$$

where,

$v_x = E_x \triangle_x, v_y = E_y \triangle_y, v_z = E_z \triangle_z$ and $i_x = H_x \tilde{\triangle}_x, i_y = H_y \tilde{\triangle}_y, i_z = H_z \tilde{\triangle}_z$

$C_x = \frac{\varepsilon \tilde{A}_x}{\triangle_x}$, $G_x = \frac{\sigma \tilde{A}_x}{\triangle_x}$, $L_y = \frac{\mu A_y}{\tilde{\triangle}_y}$ and $R_y = \frac{\rho A_y}{\tilde{\triangle}_y}$

where, $\triangle_x, \triangle_y$ and $\triangle_z$ are the edges of the Yee computational cell.

The EC FDTD algorithm iteratively updates both sets of equations (1) and (2) until there is a complete dissipation of energy from the simulation domain.

openEMS is a free and open source electromagnetic field solver based on the EC-FDTD algorithm. It supports 3D cartesian as well as cylindrical coordinates. It uses CSXCAD C++ library to describe geometrical objects and their physical or non-physical properties [12]. It provides MUR and PML absorbing boundary conditions (ABCs). MATLAB™ and GNU Octave interface is provided for easy scripting. The electromagnetic problem to be solved is described in a MATLAB/Octave script file which includes the geometry and physical properties of computational domain, meshing of the computational domain, the excitation and port, calculations and post processing instructions.

Antenna Design

The initial design of triangular microstrip patch antenna for 2100 MHz on RO3003 substrate with dielectric constant 3.0 and thickness 1.524 mm using the transmission line model (TLM) and the cavity model is described here. The design steps are detailed in the Table 1 below [13].

Table 1 Design Steps

	Parameter	Formula	Value
1	Free Space Wavelength	$\lambda_o = \frac{c}{f_{res}}$	142.86 mm
2	Triangle Side Initial	$a = \frac{2c}{3f_r\sqrt{\varepsilon_r}}$	54.96 mm
3	Effective Dielectric Constant	$\varepsilon_{eff} = \frac{1}{2}(\varepsilon_r + 1) + \frac{1}{2}(\varepsilon_r - 1)\left(1 + 12\frac{h}{a}\right)^{\frac{-1}{2}}$	2.99
4	Effective Patch Length	$a_{eff} = a + \frac{h}{\sqrt{\varepsilon_r}}$	55.83 mm
5	Design Equation	$a_{eff}\sqrt{\varepsilon_{eff}} = \frac{2c}{3f_{res}}$	
6	Triangle Side Final		55 mm

The initial design using the parameter values from the Table 1 was simulated using openEMS with GNU Octave script which gave 1727 MHz resonant frequency with -20 dB reflection coefficient and 63 Ω input resistance. Therefore, the triangular patch side length *a* was reduced from the initial 55 mm in steps of 1mm to obtain the resonant frequency of 2065 MHz at *a* = 50 mm. In the next step, the feed position was varied from the initial value 0.0 in steps of 1 mm to obtain a reflection coefficient -35 dB and input resistance 50.2 Ω at feed position -12.00 mm from the center of the patch. The openEMS simulation predicts max directivity of Dmax = 4.7951 (6.808 dBi) and radiation efficiency η_{rad} = 89.94 % for the final antenna design. The final design is summarized in the Table 2.

Table 2 Final Design Summary

1	Substrate Dielectric Constant	3.0
2	Substrate Thickness	1.524 mm
3	Triangle Side	50 mm
4	Resonant Frequency (TM_{10})	2065 MHz
5	Feed Position	(-12.00 mm, 0.00 mm)
6	Ground	70 mm X 70 mm
7	Dmax and Efficiency	4.7951 (6.808 dBi) & 89.94 %

Results and Discussion

The openEMS simulation results for reflection coefficient S11, input impedance Zin and radiation pattern of the microstrip patch antenna are presented here. The S11 graph clearly shows that the antenna is resonant at 2065 MHz and the minimum value of the reflection coefficient is -35 dB. The -10 dB bandwidth is about 20 MHz only as the antenna is a simple equiilateral triangular patch on the substrate of dielectric constant 3 with thickness 1.524 mm.

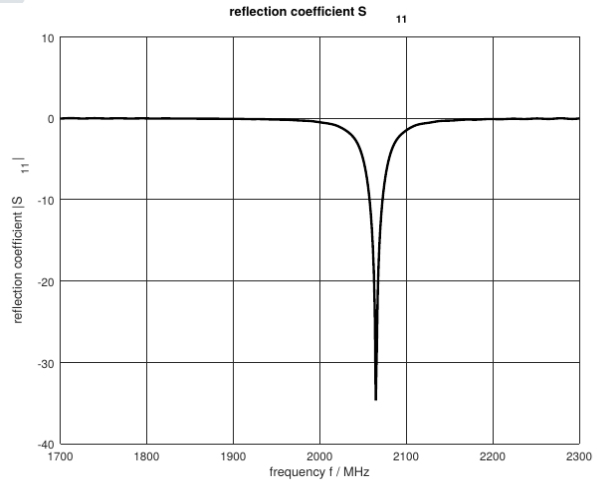


Figure 1. S11 versus Frequency

The Smith chart clearly shows that the antenna input impedance is purely resistive at 2065 MHz. The complete single loop on the chart indicates that the antenna design has only one resonant frequency in the frequency range from 1 GHz to 3 Ghz.

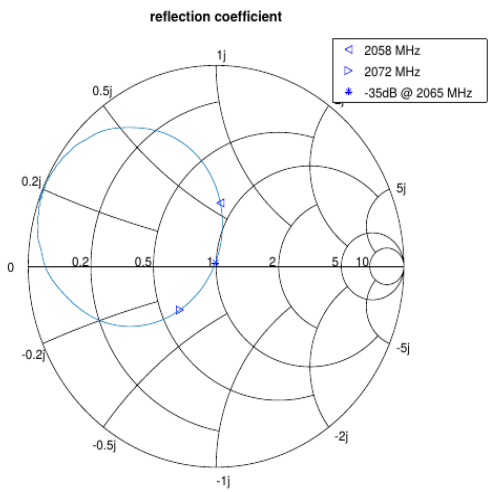


Figure 2. Smith Chart

The input impedance graph indicates that at 2065 MHz, the antenna input impedance is purely resistive, the reactive part being zero. The antenna input impedance is 50.2 Ω.

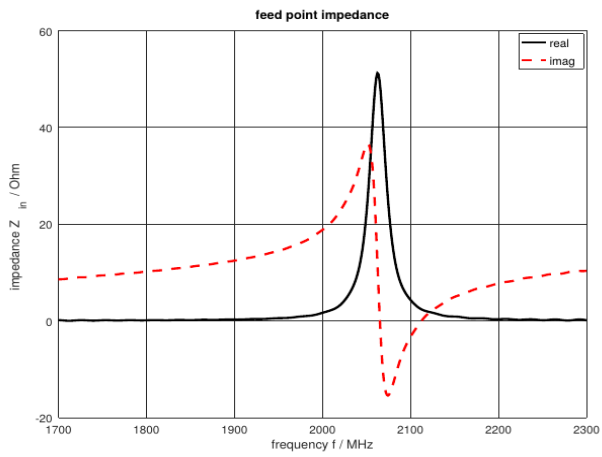
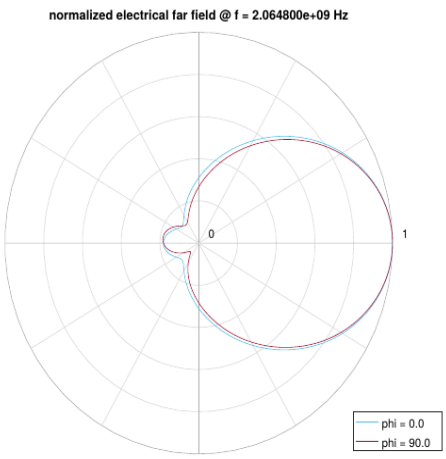


Figure 3. Input Impedance Z_{in}

The radiation pattern is broadside and back lobe of radiation is very small in both the E and H planes.. The simulation predicts that the directivity will have a maximum value of D_{MAX} = 4.7951 (6.808 dBi) and radiation efficiency will be 89.94 %



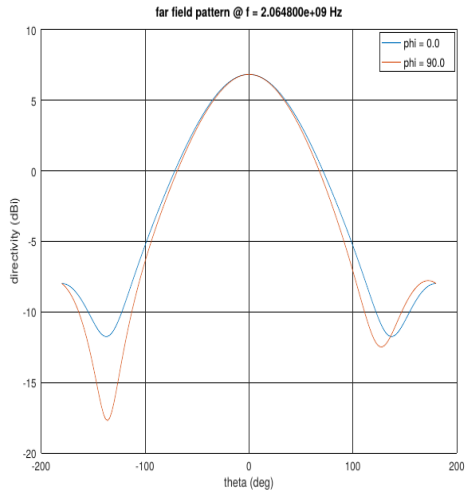


Figure 4. Radiation Pattern (polar) **Figure 5. Radiation Pattern (cartesian)**

Conclusion

A probe fed type simple equiilateral triangular patch microstrip patch antenna for the frequency 2100 MHz on RO3003 substrate has been successfully simulated using a free and open source EC-FDTD based electromagnetic field solver openEMS. The patch is equiilateral triangular with side length 50 mm and the substrate dimensions are 70mm X 70mm. The simulation results predict a resonant frequency of 2065 MHz with reflection coefficient of -35 dB and -10 dB bandwidth of 20 MHz. The radiation pattern simulation predicts a maximum directivity of 4.7951 (6.808 dBi) and radiation efficiency of 89.94 %. This work employs free and open source softwares like openEMS, GNU Octave and Linux operating system.

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