IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
Volume 2, Issue 2, December 2022
Impact Factor: 6.252

Analytical Study of a Rectangular Microstrip Patch Antenna

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Abstract: *This work presents the analytical study of a rectangular microstrip patch antenna design which is developed on FR4 type substrate material. The resonant frequency of this rectangular microstrip patch antenna is first estimated using Transmission Line Model (TLM) and Cavity Model (CM) based Computer Aided Design (CAD) procedure. The dielectric constant of the FR4 type substrate is assumed to be 4.4 for these calculations. The estimated value of resonant frequency is 2472 MHz. The Return Loss (RL) and Voltage Standing Wave Ratio (VSWR) of the antenna are then measured around the estimated Resonant Frequency of antenna, using a Scalar Network Analyzer setup. The actual resonant frequency of the antenna is found to be 2380 MHz from Return Loss measurements of the antenna. The dielectric constant of substrate is then estimated from the geometry and Resonant Frequency of the antenna. The estimated value of the dielectric constant of substrate comes out to be 4.7545. The probe feed location is also calculated. The radiation pattern of the antenna is measured at the Resonant Frequency 2380 MHz.*

Keywords: Microstrip Patch Antenna, Maxwell's Equations, Finite Difference Time Domain algorithm, Cavity Model, Transmission Line Model

I. INTRODUCTION

Microstrip patch antenna is a planner and conformal type of antenna. It has a metallic patch on top of dielectric substrate and ground plane on its bottom [1] [2]. This structure is similar to a planner transmission line. The first model proposed to understand the working of microstrip patch antenna is Transmission Line Model [3]. Electromagnetic radiation from this antenna structure is explained by Cavity Model. The microstrip patch antenna structure behaves like an electromagnetic cavity with perfect electrical conductors at top and bottom, and magnetic boundaries on the sides of dielectric substrate. The cavity supports standing modes of electromagnetic field. The leaking of these fields at the edges of the patch causes their radiation into space [4].

Computer Aided Design (CAD) procedures are developed for rectangular, triangular, circular and other regular geometrical patch shapes [4]. A patch antenna design is first simulated by electromagnetic simulation software and optimized before its actual production. Electromagnetic simulation softwares numerically solve the Maxwell's equations in either frequency domain or in time domain. HFSS (High Frequency Structure Simulator), CST Studio(Computer Simulation Technology), FEKO, Xfdtd etc are commercial simulation softwares used for patch antenna design simulation and optimization [5]. On the other hand openEMS is a free and open source electromagnetic simulation software which is based on modified Finite Difference Time Domain algorithm [6].

The present work performs analysis of a rectangular microstrip patch antenna developed on FR4 type substrate. The analysis involves calculation of antenna parameters which are compared with their measured values. In the present work, the resonant frequency of a rectangular microstrip patch antenna design developed on FR4 type substrate is first estimated using TLM and CM based CAD procedure. The dielectric constant of FR4 type substrate is initially assumed to be 4.4 for these calculations. The Return Loss and Voltage Standing Wave Ratio of the antenna are then measured around this estimated resonant frequency of the antenna. These measurements are performed using a scalar network analyzer setup. The exact value of resonant frequency of the antenna is then determined from Return Loss measurements. The dielectric constant of the antenna substrate is calculated from the exact value of resonant frequency of the antenna using the procedure outlined in the works of [7, 8]. The resonant frequency of antenna is then calculated

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from this measured value of dielectric constant. The probe feed location is also calculated. The radiation pattern of the antenna is then measured at its resonant frequency.

II. METHODOLOGY

The first step in the analysis of rectangular microstrip patch antenna developed on FR4 type substrate is estimation of its resonant frequency. It is estimated using TLM and CM based CAD process. It requires the patch length Lp, patch width Wp, substrate thickness h, and substrate dielectric constant. The dielectric constant of FR4 type substrate is assumed to be 4.4 for these calculations. The estimated value of resonant frequency comes out to be 2472 MHz.

The determination of exact resonance frequency of the antenna requires measurement of its Return Loss. Therefore, the next step is to measure Return Loss and VSWR of the antenna using a scalar network analyzer setup so as to cover the estimated antenna resonant frequency 2472 MHz. The scalar network analyzer setup used in this work consists of RF generator capable of providing RF signal from 35MHz to 3000MHz, RF detector to detect rf signal and Directional Coupler [9]. The exact resonant frequency of the antenna is found to be 2380 MHz from Return Loss measurements. The dielectric constant of the antenna substrate can be then calculated using this value of resonant frequency. The dielectric constant of the antenna substrate is found to be 4.7545. The feed location can be calculated from the geometrical parameters of the antenna and the dielectric constant of its substrate. It comes out to be 5 mm from the centre along the downward x direction towards the patch width. Its measured value is 6.5 mm.

The final step is to obtain the radiation pattern of the antenna using the radiation pattern measurement setup. The radiation pattern measurement setup consists of RF generator capable of providing RF signal from 100MHz to 4000MHz, RF detector to detect RF signal, transmitter antenna to radiate at 2380 MHz, a 360 degree computer controlled rotatable platform with fixture to mount test antenna [10].

Initial estimate of antenna resonant frequency, calculation of the actual dielectric constant and calculation of feed location and verification antenna design are performed using GNU Octave software. The geometrical parameters of antenna structure, dielectric constant of its substrate and resonant frequency of antenna are used to build GNU Octave script files for these calculations. GNU Octave is open source and free interpreted programming language which is similar to MATLAB programming language [11].

III. RESULTS AND DISCUSSION

The measured geometrical parameters of the antenna structure are shown in the Table 1. The CAD calculations of antenna parameters and estimation of the resonant frequency of antenna is presented in the Table 2.

Table I: Antenna Parameters

Antenna Parameter	Symbol	Value
Patch Length	L_P	2.86 cm
Patch Width	W_P	3.71 cm
Ground Plane Length	L_g	9 cm
Ground Plane Width	W_g	9 cm
Substrate Height	h	1.5 mm
Feed Position	X_f	6.5 mm

Table 2: Estimation Of Resonant Frequency

Antenna Parameter	Symbol	Value	
Substrate Dielectric Constant	ε_r	4.4	Assumed
Substrate Height	h	1.5 mm	Measured
Patch Width	W_P	3.71 cm	Measured
Effective Dielectric Constant	ε_{re}	4.094955	Calculated
Patch Length Elongation	dL	0.693015 mm	Calculated
Patch Length	L_P	2.86 cm	Measured
Electrical Patch Length	L_e	2.9986 cm	Calculated
Resonant Frequency Estimated	f_{re}	2472 MHz	Calculated

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The return loss measurements for the rectangular microstrip patch antenna is performed around the estimated resonant frequency 2472 MHz using scalar network analyzer setup described earlier. The return loss measurements is graphically presented in Figure 1. The frequency where return loss is minimum is the resonant frequency of antenna. The resonant frequency of antenna from return loss measurement graph is found to be 2380 MHz.

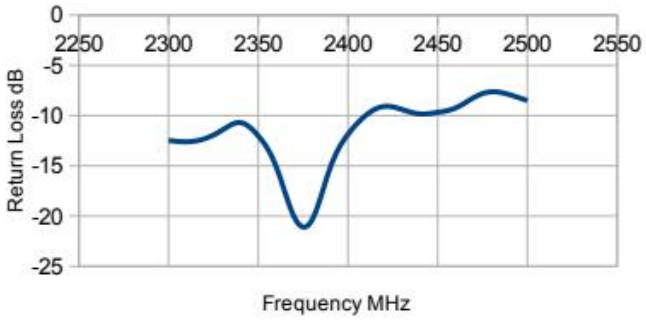

Figure 1: Return Loss Measurement

The CAD calculations of the substrate dielectric constant based on [7,8] is presented in the Table 3.

Table 3: Substrate Dielectric Constant Calculation

Parameter	Symbol	Value	
Substrate Dielectric Constant	ε_{r1}	4.4	Assumed
Resonant Frequency Estimated	f_{re}	2472 MHz	Calculated
Resonant Frequency Measured	f_{rm}	2380 MHz	Measured
Substrate Height	h	1.5 mm	Measured
Patch Width	W_P	3.71 cm	Measured
Effective Dielectric Constant	ε_{r1e}	4.094955	Calculated from Assumed
Patch Length Elongation	dL	0.693015 mm	Calculated from Assumed
Patch Length	L_P	2.86 cm	Measured
Electrical Patch Length	L_e	2.9986 cm	Calculated
Effective Dielectric Constant	ε_{r2e}	4.4177	Calculated
Substrate Dielectric Constant	ε_{r2}	4.7545	Calculated

Table 4: Antenna Design Process

Parameter	Symbol	Value	
		Calculated	Measured
Substrate Dielectric Constant	ε_{r2}	4.7545	
Resonant Frequency	f_{rm}		2380 MHz
Substrate Height	h		1.5 mm
Patch Width	W_P	3.716 cm	3.71 cm
Effective Dielectric Constant	ε_{r2e}	4.418026	
Patch Length Elongation	dL	0.686203 mm	
Patch Length	L_P	2.861 cm	2.86 cm
Electrical Patch Length	L_e	2.9985 cm	
Feed Location	X_f	4.928988 mm	6.5 mm

The CAD calculations of antenna geometry for substrate dielectric constant 4.7545 and resonant frequency 2380 MHz is presented in the Table 4. This process provides cross verification of antenna parameters after determining its substrate dielectric constant. The calculated and measured values for patch width W_P, patch length L_P and feed location are found to be very close. The measured radiation pattern of the antenna at 2380 MHz is shown in the Figure 2.

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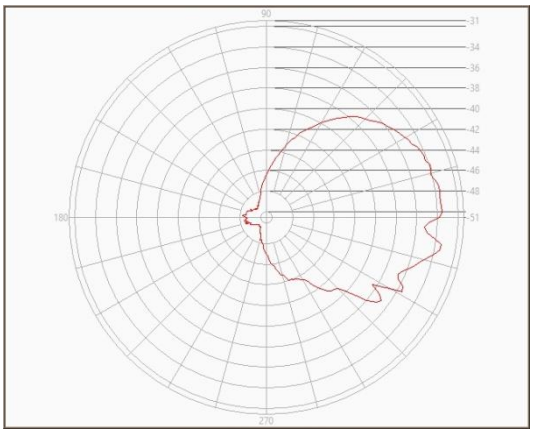

Figure 2: Radiation Pattern Measurement

IV. CONCLUSION

In this work a rectangular microstrip patch antenna developed on FR4 type substrate material is studied. Its geometrical parameters are measured. The resonant frequency of antenna is estimated assuming the dielectric constant of its substrate to be 4.4 using TLM and CM based CAD procedure. The estimated value of resonant frequency is found to be 2472 MHz. The Return Loss (RL) and Voltage Standing Wave Ratio (VSWR) of the antenna are measured around this frequency using a Scalar Network Analyzer setup. The actual resonant frequency of the antenna is then found to be 2380 MHz from Return Loss measurements of the antenna. The dielectric constant of antenna substrate is then calculated from the geometry and resonant frequency of the antenna which comes out to be 4.7545 Finally, a rectangular microstrip patch antenna design is computed for the frequency 2380 MHz and substrate with dielectric constant equal to 4.7545. The patch lengths, patch widths and probe feed locations of the actual antenna and computed antenna design are compared. Lastly, the radiation pattern of the antenna is measured at the resonant frequency 2380 MHz.

ACKNOWLEDGMENT

The author expresses his sincere thanks to the principal of Shri Shivaji College of Arts, Commerce and Science, Akola for his encouragement to undertake this research work. The author is grateful to the Research Development Committee of college for providing access to instrumentation and facilities of the Central Instrumentation Cell (CIC) established in the college under the DST-FIST Level 0 support to complete the work presented here. The author is also grateful to the Department of Science and Technology (DST), Govt. of India. The author gratefully acknowledges the help and assistance provided by the members of CIC.

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