Computational Analysis Of 2.25ghz Rectangular Patch Antenna

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Abstract

Finite Element Method (FEM), Method of Moments (MoM) and Finite Difference Time Domain (FDTD) are the most commonly used EM simulation technologies for analyzing RF circuits, microwave devices and high frequency structures. In this paper, a comparative study is made on the performance of FEM, MoM and FDTD considering the design of a planar patch antenna as a metric. The antenna operates at a center frequency of 2.25GHz with RT-Duroid as a substrate. The antenna is given a probe feed and has as a partial ground plane. After simulation, the antenna characteristics such as VSWR, return loss and current density are observed in each case. This comparative analysis aims at bringing out an effective and accurate method of modelling an antenna that is to be used in missiles for defence applications.

1. Introduction

Simulation of electromagnetic devices involves the process of modelling the EM fields with physical objects and environment. This can be done either by an analytical method or by a numerical approach. Analytical methods are very good at analyzing certain problems with a high degree of symmetry and they can provide a great deal of insight into the behaviour of many configurations. But an accurate evaluation of most electromagnetic configurations requires a numerical approach. The most commonly used numerical modelling techniques are Finite Element Method (FEM), Method of Moments (MoM) and Finite Difference Time Domain (FDTD). These techniques aim at providing computationally efficient approximations to Maxwell's equations and are referred to as solvers [1].

In the literature, only one of the numerical techniques is applied to solve electromagnetic engineering problems depending on the application, ease of usage and availability. In this paper, a computer aided design of a high frequency rectangular antenna is proposed using all the three EM modelling techniques and choosing the best results to develop the hardware of the antenna that makes it an accurate and reliable system for missile in defence.

The rest of the paper is organized as follows. In Section 2, the mathematics of the patch antenna is presented along with the design equations in each of the simulator cases. Section 3 contains the corresponding results obtained upon simulating the antenna.

2. Design of the Antenna

The structure of the proposed antenna is shown in Fig.1.

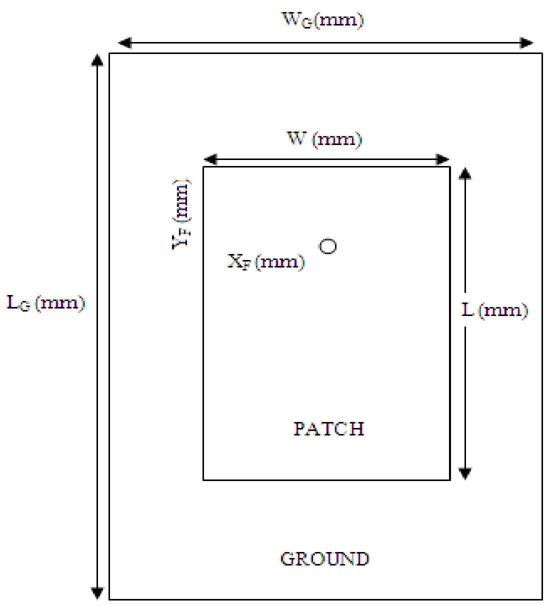

Fig.1. Proposed design of the rectangular patch antenna

The antenna is designed to operate in the 2-2.5GHz band with a center frequency of 2.25GHz to meet the defence specifications. The substrate of the antenna is chosen to be RT-Duroid with a dielectric constant (ε_r) of 2.2 with 1.6mm thickness and the ground plane made of copper is located on the other side of the substrate. The antenna is fed by a standard coaxial of 50Ω and this type of feeding is to be placed at the point on the patch so as to match with the desired input impedance and reduce spurious radiations.

The width (W) of the patch antenna can be determined by [2] :

$$W = \frac{c}{2f\left(\sqrt{((\varepsilon r+1)/2)}\right)} \quad (1)$$

The effective dielectric constant is defined before calculating the length of the antenna:

$$\varepsilon reff = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}\left[1+\frac{12h}{w}\right]^{-0.5} \quad (2)$$

h, here is the height of the substrate and w is the value as obtained in (1). The dimensions of the patch along its length have been extended on each end by a distance of ΔL which is given empirically by:

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

The actual length L of the patch is given by:

$$L = \frac{\lambda}{2} - \Delta L \quad (4)$$

λ_0 in (4) is the free space wavelength at center frequency. The ground plane dimensions are greater than the patch dimensions by approximately six times and are given as:

$$L_G = 6h+L \quad (5)$$

$$W_G = 6h+W \quad (6)$$

The co-ordinates for the position of the coaxial feed point can be obtained by using:

$$X_F = \frac{L}{\sqrt{\varepsilon_{reff}}} \quad (7)$$

$$Y_F = \frac{W}{2} \quad (8)$$

The following table summarizes the antenna parameters on substituting the design values through (1) – (8).

TABLE I DIMENSIONS OF THE PATCH ANTENNA

L	44.1676 mm
W	52.7046 mm
L_G	53.7 mm
W_G	63 mm
X_F	26.3523 mm
Y_F	10.8mm

A) Antenna design using FEM

The basis of the technique is to have a discrete view of the problem region by dividing the design into finite number of elements. Each such element is to be modelled individually. The entire volume of the patch antenna is meshed and each mesh will have different material properties than its neighbourhood. This is called volume meshing. The simulator tool used for the design is High Frequency Structure Simulator (HFSS). Major steps in building the antenna using HFSS –

(i) Create rectangles with the dimensions as shown in Table I for designing the substrate, ground and the patch.

(ii) Create two cylinders, subtract them and join the resultant to a circle of radius 1.6mm to construct a coaxial cable.

(iii) Excite the antenna via the feed by assigning a wave port.

(iv) Select the solution type to be a driven terminal and analyse the antenna for a solution frequency of 2.25GHz.

The antenna developed is as shown in fig.2 and the corresponding results are displayed in section 3.

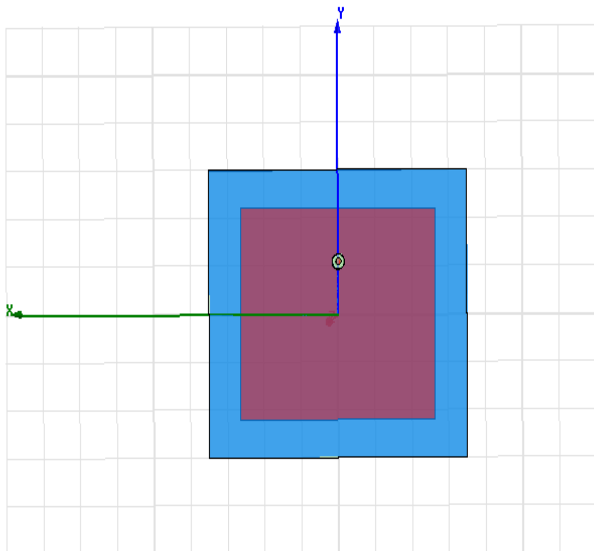

Fig.2. Patch antenna designed in HFSS

In this method, the numbers of unknowns increase with the linear meshing density (LMD) .For these methods the memory and solution time scale depends greatly on implementation of the type of the problem [3]. The mesh edge length is chosen to be less than one-tenth of the wavelength so as to decrease the number of computations required in analysing the antenna. The system of equations to be solved for the potentials and fields of the antenna are assembled after obtaining the partial differential equations of the problem. The memory and time are O (LMD^3), for an antenna problem. FEM has an advantage as the simulator adopts matrix method to solve the configuration and reducing computations at higher frequencies. FEM is therefore suitable for high frequency structures.

B) Antenna design using MoM

The basis of this technique is to solve the integral form of the Maxwell's Equations by introducing a potential mesh around the structure. It is based on the method of weighted residuals called the moments. This method can analyze low frequency structures with high accuracy [4]. Sonnet is the simulator tool used in this paper to analyze the antenna under MoM. Major steps in building the antenna using Sonnet –

(i) Create rectangles with the dimensions as shown in Table I for designing the substrate, ground and the patch. Also, specify the cell size and box size such that the substrate is meshed into cells and can be made to sit in a six sided metal box.

(ii) Add the port at the required co-ordinates of the patch.

(iii) Specify the solution frequency as 2.25GHz and analyse the antenna.

The antenna developed is as shown in fig.3 and the corresponding results are displayed in section 3.

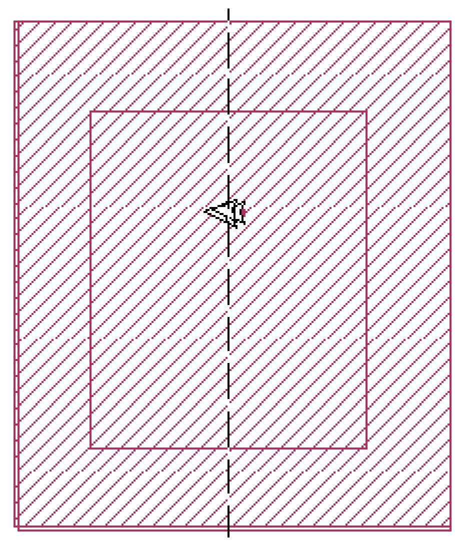

Fig.3. 2-D view of the patch antenna designed in Sonnet

As seen in Fig.3, the patch is meshed along its surface and this technique is called surface meshing. The meshing parameter is determined by mentioning the cell size and box size onto which the patch and the substrate are likely to be divided and analyzed. In this method, the numbers of unknowns increase with the linear meshing density. Surface meshing of the antenna is to be done for both substrate and patch separately. For these methods the memory and solution time scale varies as the fourth power of the linear meshing density given by O (LMD^4). MoM is suitable and efficient for low frequency structures [5].

C) Antenna design using FDTD

The basis of this technique is to solve the differential form of the Maxwell's Equations [6]. It is a time domain method and can cover a wide range of frequencies over a single time period. A code is written in MATLAB determine the performance of the antenna in FDTD. The mesh as applied to the antenna with initialized nodes is shown in Fig.4. The Maxwell's Equations in differential form can be solved using the PDE toolbox in MATLAB.

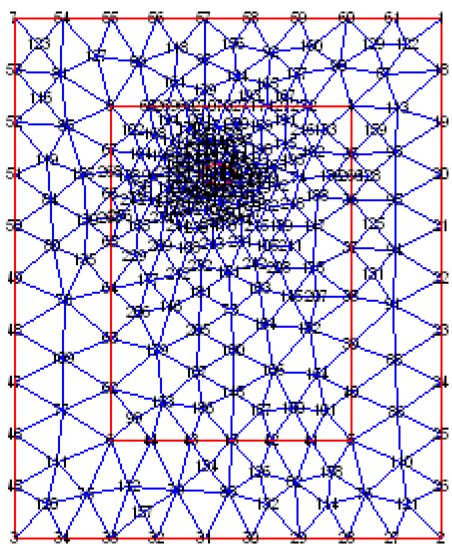

Fig.4. Patch antenna design in MATLAB

The memory and time scale are proportional to the 3rd power of the linear meshing density [7] and the computations are O (LMD^3) [8]. The computations are proportional to the design structure and the number of nodes initialised for meshing the antenna. From Fig.4 it is seen that the mesh concentration is more at the probe feed point of the antenna than at the edges of the patch indicating the operational strength nearby the probe co-ordinates.

3. Results and Comparisons

The results obtained upon simulating the antenna in all the three methods are presented in this section. A comparative study is then made on the efficiency and ease of computation in analysing the antenna set-up. The impedance and radiation characteristics of the antenna are observed in each of the three cases. Fig.5, Fig.6 and Fig.7 are the results obtained using HFSS tool.

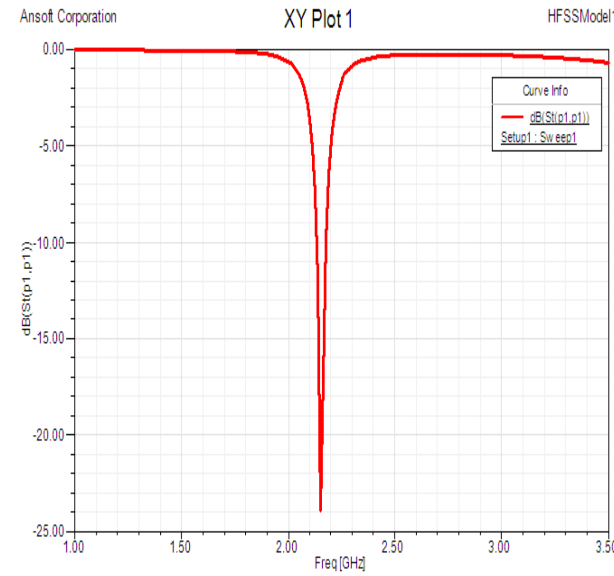

Fig.5. Return Loss of the antenna in HFSS (-22dB)

The return loss of the antenna at center frequency is around -22 dB. This corresponds to a VSWR of nearly 1.13:1 which a very good response is given the specification and application of the antenna. A Voltage standing wave ratio of less than 2 (VSWR<2) is always acceptable. HFSS could thus provide good impedance characteristics for the antenna under simulation.

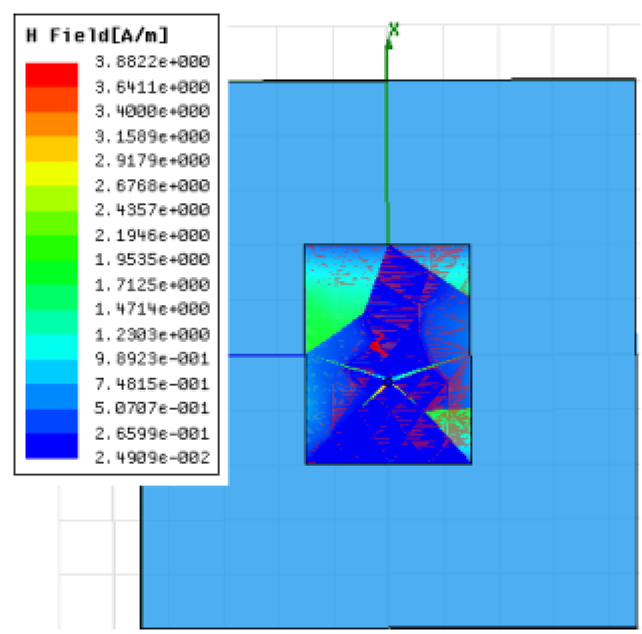

Fig.6. H-Field of the antenna in HFSS (3 A/m)

This implies that the maximum H-field lies along the outer edges of the patch and are supposed to be radiating edges. The non radiating edges on the opposite side do not carry any current and filed there is always zero.

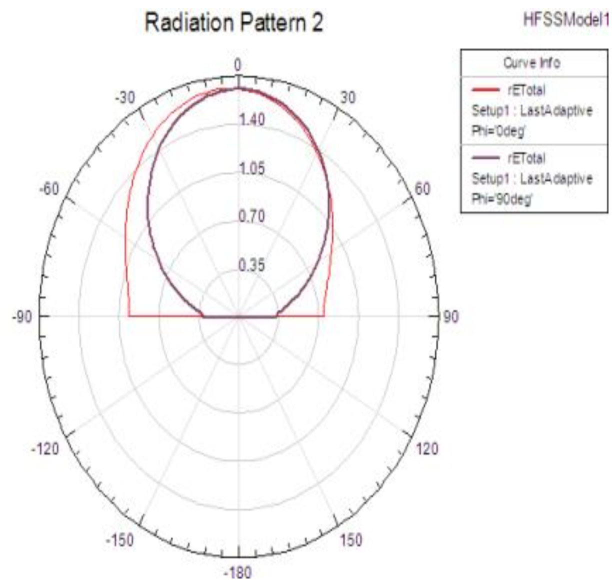

Fig.7. Radiation Pattern of the antenna

The directive gain of the antenna is found to be 2dB.The E and H field patterns are observed from Fig.7 and are verified with the plots obtained under Sonnet tool as shown in Fig.8 and Fig. 9. The results obtained using MATLAB are displayed in Fig.10 and Fig.11

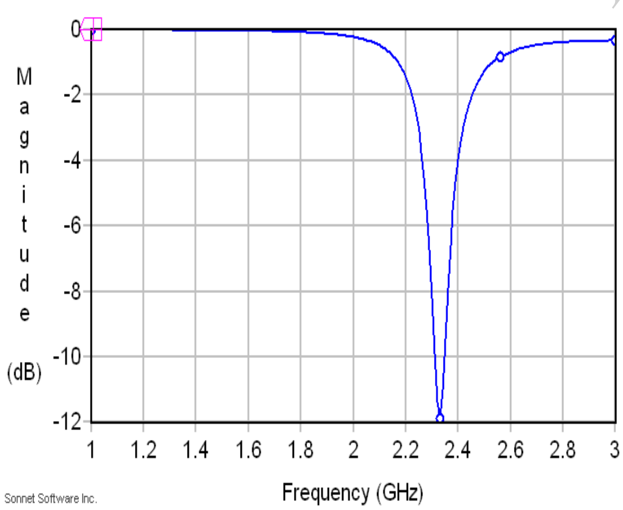

Fig.8. Return Loss of the antenna in Sonnet (-16dB)

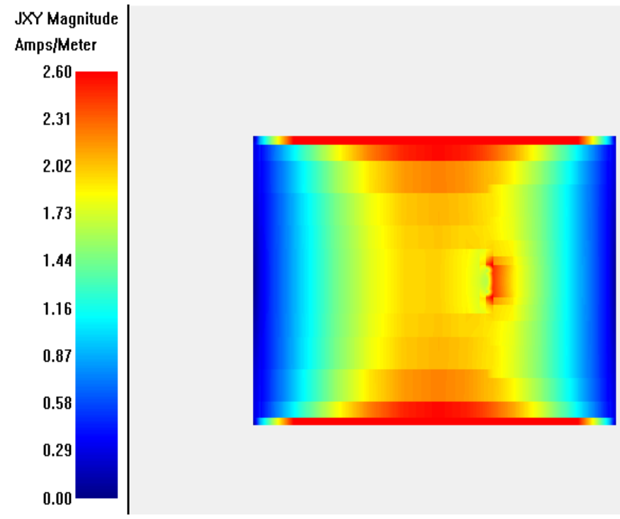

Fig.9. H-Field of the antenna in Sonnet (2.60 A/m)

The figure shows that two horizontal edges of the patch are radiating (2.6 A/m) and two vertical edges of the patch are non radiating (0 A/m). The maximum field strength is 2.6 A/m distributed from the feed to theouter edge.

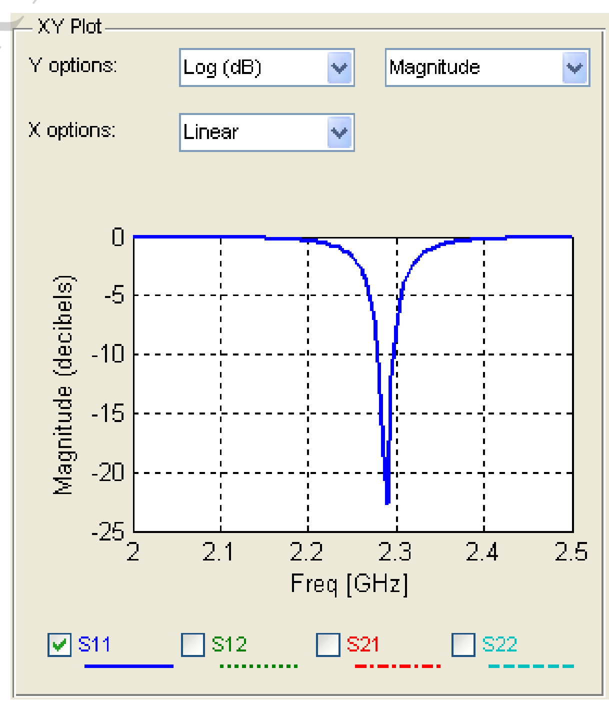

Fig 10. Return Loss of the antenna (-22dB)

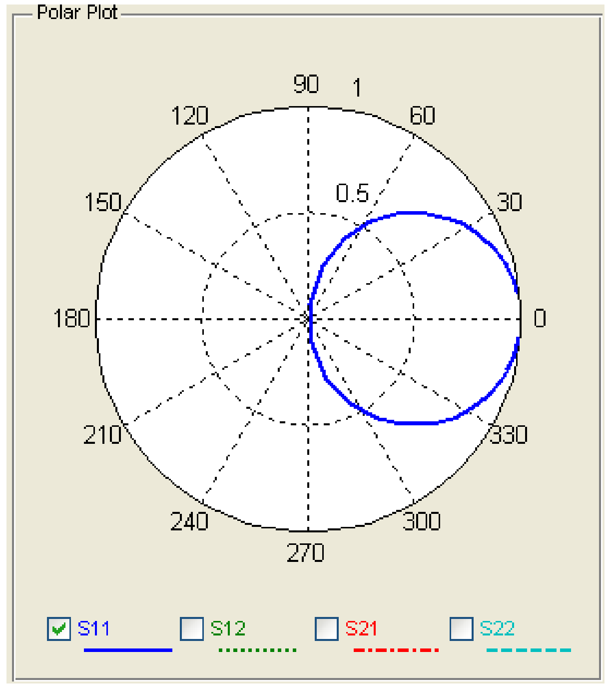

Fig.11. Radiation Pattern of the antenna as a polar plot

TABLE 2 COMPARISION OF THE EM SIMULATOR TECHNOLOGIES

PARAMETER	FEM	MoM	FDTD
MODE OF DDESIGN	Schematic	Schematic	Scripting
EASE OF DESIGN	Simple	Moderate	Difficult
ACCURACY	High	Moderate	Unpredictable
Type of Meshing	Volume	Surface	Node Type
NUMBER OF COMPUTATIONS	O (LMD^3)	O (LMD^4)	O (LMD^3)
COMPUTATIONAL SPEED	Fast	Slow	Moderate
VSWR	Nearly 1.1:1	1.66:1	1.3:1
H FIELD INTENSITY	3.05 A/m	2.59 A/m	Maximum
MAXIMUM GAIN	2dB	2dB	Maximum

4. Conclusion

As seen from Table 2 FDTD provides ideal results in few cases but is subject to critical design procedures. MoM, on the other hand is very inefficient for a high frequency design of 2.25GHz. FEM stands out as the best simulation technology within the scope of this paper and provides excellent results at the resonance period of the antenna. It can be seen from the results that Finite Element Method best suits for the design of a 2.25GHz patch antenna where design accuracy and speed are of paramount importance. The antenna hardware can be realized from the FEM generated results and the physical antenna is given a conformal shape depending on the radius of missile.

References

[1] A. Taflove and S. Hagness, *Computational Electrodynamics :* 3rd Edition, Artech House, Inc., 2005.

[2] Balanis C.A. (2005) Antenna Theory: Analysis and Design, John Wiley & Sons

[3] R.F. Harrington, "Matrix methods for Field Problems," *Proc. IEEE*, Vol. 55, pp. 136-49, Feb. 1967.

[4] R.F. Harrington, *Field Computation by Moment Methods*,Wiley IEEE Press, 1993.

[5] [www.sonnetsoftware.com]: "Electromagnetic Simulation Software".

[6] C. Wu, K. Wu, Z. Bi and J. Litva, "Accurate Characterization of Planar Printed Antennas using Finite – Difference Time – Domain method, " *IEEE Transactions on Antennas and Propagation,* vol. 40, May 1992.

[7] D. M. Sheen, S. M. Ali, M. D. Abouzahra and J. A. Kong, "Application of the Three – Dimensional Finite – Difference Time – Domain Method to the Analysis of Planar Microstrip Circuits", *IEEE Transactions on Microwave Theory and Techniques,* vol. 38, No. 7, July 1990

[8] M. Zweki, R. A. Abd – Alhameed, M. A. Mangoud, P. S. Excell, and J. A. Vaul, " Broadband Analysis of Finite Microstrip Patch Antenna Structure using FDTD ", *11th International Conference on Antennas and Propagation*, UMIST, Manchester, UK, April 2001.

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