International Journal of Innovation and Applied Studies
ISSN 2028-9324 Vol. 3 No. 3 July 2013, pp. 727-731

http://www.issr-journals.org/ijias/

Modification in Formula of Resonating Frequency of Equilateral TMPA for Improved Accuracy and Analysis

Tajeswita Gupta, P. K. Singhal, and Vandana Vikas Thakre

Department of electronics and communication MITS Gwalior
Gwalior, M.P. 474005, India

ABSTRACT: In the present work, an equation has been developed to calculate the side length of the equilateral triangular patch for given resonant frequency. With the previously existing equation poor accuracy has been achieved for the performance parameters of the triangular microstrip patch antenna. Modified formula enhances the accuracy of the performance parameters of the triangular microstrip patch antenna. Proposed formulae provide a nonlinear relationship between the resonating frequency and the dimensions of the equilateral triangular patch antenna i.e. the required performance parameters and the design parameters used in the simulation and fabrication process. With the help of calculated dimension, performance of triangular patch antenna has been analyzed for particular resonating frequency. Simulated results of proposed equation have been compared with the existing equation, and better accuracy in the results has been achieved with the improved formula. Proposed equation has been verified by simulating and fabricating various antennas, and measured results are found satisfactory.

KEYWORDS: Triangular microstrip patch antenna, resonant frequency, Curve fitting procedure, Impedance Bandwidth, Return Loss.

1 INTRODUCTION

Literature reveals, a lot of work has already been done on the resonant frequencies of the Equilateral Triangular Microstrip Patch Antenna [1-6], based on cavity model analysis. The whole reported work was unanimous with the various correction factors applied to the existing formula obtained from the cavity model analysis and the same values were compared with the measurements of Dahele & Lee [4]. The resonant frequency of equilateral triangular microstrip patch antenna was grounded on the effective side length and an effective relative permittivity [4]. On the contrary, Garg and Long [5], proposed an alternative expression with effective side length and the actual substrate permittivity was used for the calculation of resonating frequency. However Gang [6] also argued that the effective values of both side length and relative permittivity should be considered for calculations. Triangular shape for printed microstrip patch antenna comes as a good option due to its small surface area as compared to the other printed shapes like rectangular and circular patches. The advantage of such structure is the ability of building compact antennas with low manufacturing cost and high reliability. However, it is in practice difficult to accomplish this while at the same time achieving high bandwidth and efficiency. Nevertheless, improvements in the properties of the dielectric materials and in design techniques have led to enormous growth in the popularity of microstrip patch antennas, and there are now a large number of commercial applications.

To compute the dimensions of radiating triangular patch an improved formula has been developed in this paper. The prime objective of the research is to present a simplified formula with enhanced accuracy. Proposed formula provides a relation between the side length and its corresponding resonant frequency, by considering the effective value of side length and the actual substrate permittivity. Proposed equation yields better accuracy when the calculated design parameter has been simulated as compared to the simulated result of the design parameters provided by Dahele & Lee and Garg & Long [4]-[5]. Authenticity of the equation has been verified by various aspects viz. by simulating a number of antennas in CST

Corresponding Author: Tajeswita Gupta (tajeswitagupta@gmail.com)

simulation software [7-9] using various dielectric materials as substrate and by fabricating few antennas to verify the practicability of the proposed equation.

2 DEVELOPMENT OF EQUATION

For the development of the proposed equation a wide range of data has been generated by simulating a large number of Equilateral Triangular Microstrip Patch Antennas of different side lengths varying from 15-135 mm, in CST microwave studio [7-9], and the resonating frequencies corresponding to them have been noted. With the obtained data a smooth curve has been fitted using curve fitting procedure, among the side length corresponding to their resonating frequencies. In the procedure, a best fitted equation having least root mean square error has been chosen among the various options. In the process of determination of data, the height of the substrate is kept constant at 1.6 mm. Geometry of Equilateral Triangular Patch Antenna has been pictured in figure 1.

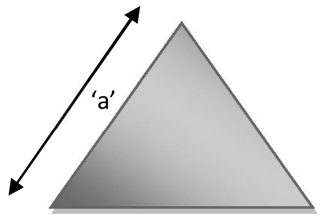


Fig. 1. Geometry of Equilateral Triangular Microstrip Patch Antenna

Let 'a' be the side length of the Equilateral Triangular Microstrip Patch Antenna, and 'f' is the designing resonating frequency. Curve fitting procedure has been used to develop the equation among the data. Curve fitting is the process of constructing a curve, or mathematical function that has the best fit to a series of data points, possibly subject to constraints. Curve fitting can involve either interpolation, where an exact fit to the data is required, or smoothing, in which a "smooth" function is constructed that approximately fits the data. The proposed formulated equation using curve fitting mathematical procedure is given as in equation (1).

$$a = \frac{343.4 * f^{-1.009}}{\sqrt{\epsilon_r}} \tag{1}$$

' ϵ_r' is the relative substrate permittivity ranges between $2.2 \leq \epsilon_r \leq 12$.

3 DETERMINATION OF PATCH DIMENSION USING PROPOSED EQUATION

The side length of equilateral triangular microstrip patch antenna is calculated using proposed formula mentioned in equation (1) for specified parameters viz.

Relative dielectric constant ϵ_r = 3.75

Thickness of substrate h = 1.58 mm

Designing frequency = 5 GHz

Thus, the side length of the patch calculated theoretically according to proposed equation (1) is given below:

$$a = \frac{343.4 * f^{-1.009}}{\sqrt{\epsilon_r}} = \frac{343.4 * 5^{-1.009}}{\sqrt{3.7\ 5}}$$

= 34.965 mm

When a triangular patch having side of 34.965 mm as stated above, has been simulated in CST, it should resonate at the designing frequency i.e. at 5 GHz or as near as possible to the designing frequency to achieve the accuracy. After simulation using CST microwave studio, the patch resonates at 4.977 GHz. The absolute error between the designing frequency and the resonating frequency of the patch is 23 MHz

4 COMPARISON AND ANALYSIS

A comparative study of the proposed equation and previously existing equation is requisite to analyze the accuracy of the proposed equation. According to the cavity model analysis, the resonating frequency corresponding to various modes is being given by equation (2), [1]-[2]

$$f_T = \frac{2C}{3a\sqrt{\epsilon_r}} \qquad (2)$$

Where, C = $3*(10)^8$ m/s, is the velocity of light

The side length of an equilateral triangular microstrip patch antenna has been computed using equation (2) for the same parameters stated in section III. When the simulated results of both equations are compared, the design parameter calculated using previously existing equation (2) shows more deviation from the designing frequency as compared to the design parameter computed by new proposed equation, which is drawn in Figure 2. Observations made from Figure 2, that for f = 5 GHz, patch designed using proposed equation resonates at 4.977 GHz whereas when designed using previously existing equation (2), it resonates at 4.4837 GHz. It is clearly observed that simulated results of the patch designed using proposed equation resonates closer at the designing frequency as compared to the previous equation (2).

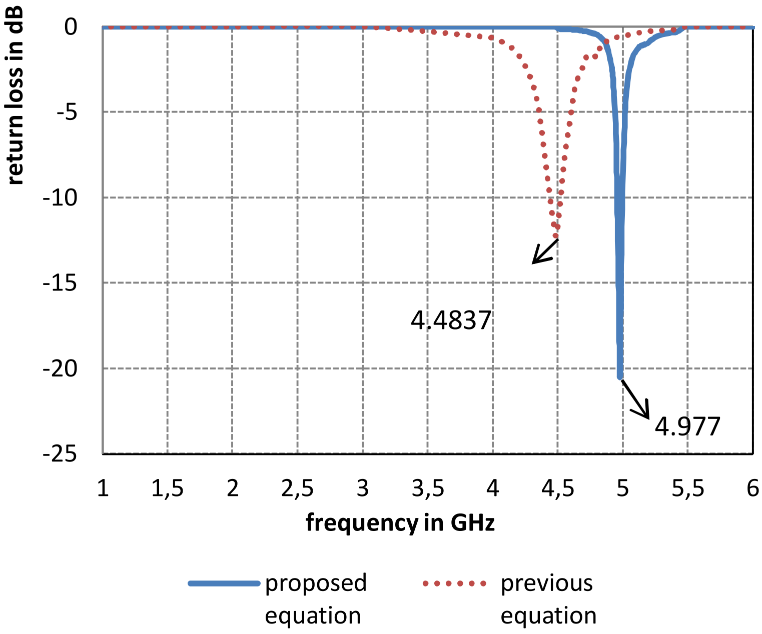


Fig. 2. Comparison of the Antenna Simulated Using Proposed and Existing Equation

To analyze better, few more antennas have been simulated using CST for the design parameter of the patch calculated using proposed equation mentioned in equation (1) and previously existing equation (2) respectively. The dielectric substrate FR4 having dielectric constant 4.4 at substrate height 1.6 mm has been taken as specified designing parameters. Simulated results of patch, calculated using proposed and previous equation have been shown in Table 1.

Table 1 provides a comparative study of both the equations, proposed and previous equation respectively. Simulated results are compared to determine better accuracy. Table 1 reveals the simulated frequencies f1 for the side length calculated using proposed equation (2) are much closer to the corresponding designing frequencies as compared to f1'. It is clearly observed and concluded that when the dimensions of the patch is theoretically calculated, using proposed equation yields better accuracy in the simulated results as compared to the dimensions calculated using previous equation.

Table 1. Comparative Study of Proposed Equation with the Dahele & Lee [4] Measurement Method

Designing Frequency f (GHz)	Simulated Resonating frequency	
	Side calculated using proposed equation f1(GHz)	Side calculated using previous equation (1) f1'(GHz)
1.9	1.901	1.88
3.2	3.25	3.12
4	4.06	3.86
6.5	6.6	6.12
8	8.22	7.44

For the verification of the proposed equation, Table 2 shown below provides simulated resonant frequencies with their different designing parameters. For the various designing frequencies, their corresponding side lengths have been calculated using proposed equation and the patches of the calculated dimension have been simulated in CST microwave studio. Table 2 draws the comparison of results among the calculated values of proposed equation and simulated values. Testing of equation was performed for those values of the designing frequencies which are not included in the development of equation and the results were found satisfactory as shown in Table 2.

It can also be observed from table 2 that the errors among the designing frequencies and simulated frequencies of their corresponding patch are very small. The patches of calculated side length, using proposed equation, when simulated in CST microwave studio, resonate closer to the designing frequency. The mean square error is very low for each value of designing frequency. The root mean square error for the proposed equation is 0.4618.

Table 2. Analysis of Proposed Equation for Various Designing Resonant Frequencies of Equilateral Triangular Microstrip Patch Antenna with Optimum Feed

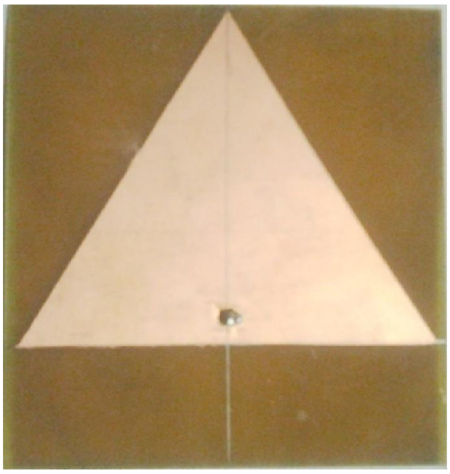
Designing resonant frequency f (GHz)	Calculated side a(mm) using equation (1)	ϵ_r	simulated frequency f' (GHz)	Absolute error |f-f'|	Mean square error 'e'
0.9	182.07	4.4	0.9	0	0
1.2	192.61	2.2	1.196	0.004	1.6e-05
2	66.92	6.5	2.025	0.025	6.25e-04
3.2	33.75	9.9	3.242	0.042	0.0018
5.1	34.26	3.75	5.075	0.025	6.25e-04
6	22.08	6.5	6.05	0.05	0.0025

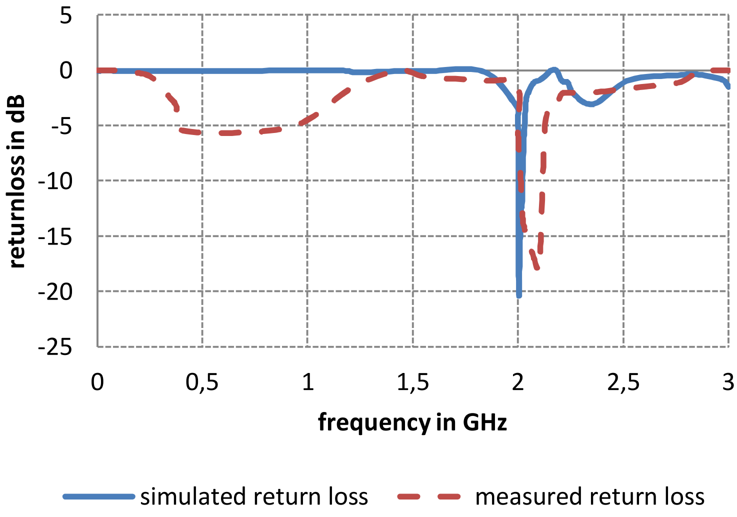
In order to affirm the results of the proposed equation, few antennas have been simulated and fabricated as shown in Table 3. Dielectric constant of substrate is 4.4 and the height of the substrate is 1.6 mm has been taken in the account as specified design parameters.

Table 3. Simulated and Measured Results of the Fabricated Antennas

Designing Frequency In GHz	Calculated side In mm	Simulated frequency In GHz	Measured frequency In GHz
2	81.34	2.004	2.1
2.4	67.67	2.412	2.38
2.9	55.913	2.89	2.902

Figure 3(a) shows one of the fabricated antennas, resonating at 2.1 GHz while designed for resonating frequency 2 GHz, as listed in Table 3. Figure 3(b) shows a comparative chart of simulated and measured results of the antenna drawn in Figure 3(a), reveals that measured results are very close to the simulated results. Two more antennas have been fabricated and their measured results have been shown in the Table 3, which reveals that measured results are very close to the designing frequencies. An examination of Table 1 and Table 3 clearly shows that, the results theoretically calculated by the proposed equation are in good agreement with the results of fabricated antenna with good accuracy.





(a) *(b)*

Fig. 3. (a) Fabricated Antenna at 2 GHz (b): Simulated and Measured RL of Fabricated Antenna

5 CONCLUSION AND REMARKS

By analyzing the data very carefully an improved formula relating the side length and the corresponding resonating frequency has been developed in this paper. Resonating frequency of the patch antenna is inversely proportional to its dimensions. Proposed equation relates the dimensions to the patch in nonlinear manner. Calculated side length values using proposed equation for equilateral triangular microstrip patch antenna for various dielectric materials and constant substrate height when simulated using CST for centrally and arbitrarily fed, shows a good measure of accuracy. Few of them have been fabricated in order to verify the relevance of the equation practically. Proposed equation shows a higher measure of accuracy among the theoretically analyzed and simulated values in CST and the fabricated measured values.

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