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Design and Analysis of Slit-cut Stacked Equilateral Triangular Microstrip Patch Antenna

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ABSTRACT

In this paper, a novel structure of slit-cut stacked equilateral triangular microstrip antenna (ETMA) has been theoretically studied using cavity model and found in agreement with the stimulated result calculated by high frequency simulator structure (HFSS). The analysis of stacked ETMA and slit-cut ETMA is done. The theoretical and simulated results of stacked ETMA and slit-cut ETMA are presented and compared. The main concentration is to find the different results, i.e. input impedance and return loss of the slit-cut ETMA and slit-cut stacked ETMA.

Keywords: Microstrip antenna, bandwidth, resonant frequency

1. INTRODUCTION

Microstrip antennae have vast applications in missiles, secure cryptographic communication systems, mobiles, satellite communication systems to biomedical equipment, because of their conform ability, simple in use, low production rate, lightweight, and ease in manufacture and amalgamation with microwave components. These smart and beneficial qualities have raised the usage of microstrip antennae and simulated superior work to explore their performance. Microstrip antennae shape may vary; it may be of any geometrical shape[1-3].

For miniaturisation of size of patch, an equilateral triangular microstrip patch antenna is preferred. It has similar radiation properties with rectangular patch antenna. For design of periodic arrays, radiating elements are organized in such a way to lessen ominously connection between end-to-end elements of the array, this will help in design of antenna array. In equilateral triangular microstrip patch antenna designs, important is to calculate the resonant frequencies of the microstrip antenna precisely because microstrip patch antennae have narrow bandwidths which can only activate successfully in the locale of the resonant frequency.

In this paper, the authors have discussed the stacked equilateral triangular microstrip patch antenna analysis, slit-cut equilateral triangular microstrip antenna analysis, and slit-cut stacked equilateral triangular microstrip antenna analysis. Variation of input impedance *vs* frequency is shown. Theoretical and simulated results were shown.

2. THEORETICAL CONSIDERATIONS

2.1 Stacked Equilateral triangular Microstrip Antenna Analysis

The geometry of stacked ETMA is shown in Fig. 1(a) in which upper equilateral triangular patch (UETP) fed by coaxial cable. Lower equilateral triangular patch (LETP) is analysed as equilateral triangular patch antenna with superstrate and deserting the effect of upper patch. By changing the effective side of LETP, dielectric layer above radiating patch disrupts

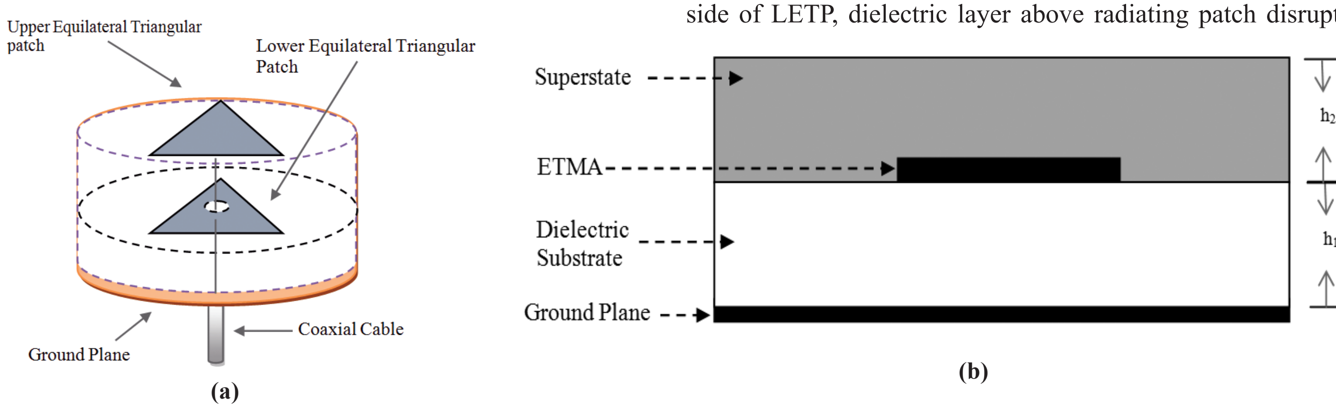

Figure 1. (a) Stacked equilateral triangular microstrip antenna, and (b) Equilateral triangular patch antenna covered with a dielectric substrate: a cross-sectional view.

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the fringing fields. Equilateral triangular patch antenna covered with a dielectric substrate is shown in Fig. 1(b) in which height of dielectric substrate h_1 and dielectric substrate h_2 are the same, i.e. $h_1=h_2=0.159$ cm, as shown in Fig. 1(b).

The effective dielectric constant of equivalent substrate is given as

$$\begin{aligned}\varepsilon_{reff} &= \varepsilon_{r1}p_1+\varepsilon_{r1}(1-p_1)^2\times \\ &[\varepsilon_{r2}{}^2p_2p_3+\varepsilon_{r2}\{p_2p_4+(p_3+p_4)^2\}] \\ &[\varepsilon_{r2}{}^2p_2p_3p_4+\varepsilon_{r1}(\varepsilon_{r2}p_3+p_1)\times \\ &(1-p_1-p_4)^2+\varepsilon_{r2}p_4\{p_2p_4+(p_3+p_4)^2\}]^{-1}\end{aligned} \tag{1}$$

where

$$p_1 = 1-\frac{h_1}{2w_e}\ln\left(\frac{\pi w_e}{h_1}-1\right)-p_4 \tag{2}$$

$$p_2 = 1-p_1-p_3-2p_4 \tag{3}$$

$$p_3 = \frac{h_1-g}{2w_e}\ln\left[\frac{\pi w_e}{h_1}\frac{\cos\left(\frac{\pi g}{2h_1}\right)}{\pi\left(0.5+\frac{h_2}{h_1}\right)+\frac{g\pi}{2h_1}}+\sin\left(\frac{g\pi}{2h_1}\right)\right] \tag{4}$$

$$p_4 = \frac{h_1}{2w_e}\ln\left(\frac{\pi}{2}-\frac{h_1}{2w_e}\right) \tag{5}$$

$$g = \frac{2h_1}{\pi}\arctan\left[\frac{\frac{\pi h_2}{h_1}}{\left(\frac{\pi}{2}\right)\left(\frac{w_e}{h_1}\right)-2}\right] \tag{6}$$

$$w_e = \sqrt{\frac{\varepsilon_r'}{\varepsilon_{reff}}}\left[\begin{aligned}&\left\{w+0.882h_1+0.164h_1\frac{(\varepsilon_r'-1)}{\varepsilon_r'^2}\right\}+\\ &h_1\frac{(\varepsilon_r'-1)}{\pi\varepsilon_r'}\left\{\ln\left(0.94+\frac{w}{2h_1}\right)+1.451\right\}\end{aligned}\right] \tag{7}$$

$$\varepsilon_r' = \frac{2\varepsilon_{reff}-1+\left(1+\frac{10h_1}{w_e}\right)^{-0.5}}{1+\left(1+\frac{10h_1}{w_e}\right)^{-0.5}} \tag{8}$$

$$w = a(\pi-2) \tag{9}$$

By choosing a suitable thickness, the surface waves are concentrated to an assured level, when the relative dielectric constant of superstrate is greater than the substrate.

$$\varepsilon_{re} = \frac{\varepsilon_{r1}}{\varepsilon_{reff}} \tag{10}$$

Currently effective side of LETP is calculated as

$$a_{eff1} = a_1\sqrt{(1+q)} \tag{11}$$

LETP's input impedance is calculated as

$$Z_{in1} = \frac{1}{\left\{\left(\frac{1}{R_1}\right)+(j\omega C_1)+\left(\frac{1}{j\omega L_1}\right)\right\}} \tag{12}$$

The resonance resistance R_1 of LETP

$$R_1 = \frac{S}{T\omega p\delta_{eff}k^2} \tag{13}$$

The inductance L_1 can be given as:

$$L_1 = \frac{S}{T\omega^2 p\mu_0\varepsilon\omega_{mn}{}^2} \tag{14}$$

The conductance C_1 can be given as:

$$C_1 = \frac{T\omega^2 p\mu_0\varepsilon}{S} \tag{15}$$

where

$$T = (\omega^2-\omega_{mn}{}^2)\mu_0{}^2\varepsilon^2+\delta_{eff}{}^2k^4 \tag{16}$$

$$S = (\omega p\delta_{eff}k^2)^2+(\omega p\mu_0\varepsilon(\omega^2-\omega_{mn}{}^2))^2 \tag{17}$$

The UETP is examined like an uncovered microstrip patch antenna as it is a driven element. By the change of diameter in UETP, the resonant frequency of LETP rests unaffected. For two different fringing field cavities, their effective sides are different even though when their physical sides are the same. Therefore, the expectation is of two resonant frequencies. With the thickness as h_2 and dielectric constant as ε_{r2} of single-patch antenna, the analysis of upper patch is performed. Reverse current induced at lower patch acts as ground plane. Due to its finite size, the current gets reflected from the edges of the lower patch, this shows ground plane is not finite which is considered in calculation.

The input impedance of upper cavity for UETP is calculated as

$$Z_{in2} = \frac{1}{\left\{\left(\frac{1}{R_2}\right)+(j\omega C_2)+\left(\frac{1}{j\omega L_2}\right)\right\}} \tag{18}$$

In the above expression resistance (R_2), capacitance (C_2) and inductance (L_2) are equivalent components of circuit for equilateral triangular patch antenna expressed as parallel combination for TM_{mn} mode.

The resonance resistance (R_2) of UETP is expressed by

$$R_2 = \frac{S}{T\omega p\delta_{eff}k^2} \tag{19}$$

The inductance (L_2) can be given as:

$$L_2 = \frac{S}{T\omega^2 p\mu_0\varepsilon\omega_{mn}{}^2} \tag{20}$$

The conductance (C_2) can be given as:

$$C_2 = \frac{T\omega^2 p\mu_0\varepsilon}{S} \tag{21}$$

There is no variation of electric field in z direction so total electric field is sum of the electric fields in LETP and UETP[9]. Likewise, LETP is signified as parallel combination of a resistance (R_1), an inductance (L_1), and a capacitance (C_1).

$$Z_{in} = Z_{in1} + Z_{in2} \tag{22}$$

Resonant frequency of the proposed design is shown below.

$$f_{ri} = \frac{2c}{P_e\sqrt{\varepsilon_r}}\left(m^2 + mn + n^2\right)^{\frac{1}{2}} \tag{23}$$

where c is a speed of light, P_e is the effective perimeter of modified triangular patch.

2.2 Slit-cut Equilateral Triangular Analysis

Suitable slots are embedded in the ETMA, the bandwidth should be enhanced with reduced antenna size. Here embedding a pair of slot of proper dimensions i.e. slit-cut, the first broadside radiations modes of ETMA can be disturbed such that their resonant frequencies are lowered and close to each other to form a wide impedance bandwidth. The resonant frequency of the proposed slit-cut ETMA design is proved[4-6].

2.3 Slit-cut Stacked Equilateral Triangular Analysis

The regular ETMA is replaced by slit-cut ETMA in the lower patch of the stacked ETMA[10-11]. The analysis of the stacked structure is based on stacking as discussed in Section A where the lower patch is taken as slit-cut ETMA. The structure of slit-cut stacked equilateral triangular microstrip Antenna is shown in Fig. 2. LETP is analysed as slit-cut ETMA patch antenna with superstrate and negligence of the effect of upper patch. By change of effective side of LETP, the dielectric layer above radiating patch disturbs the fringing fields. Height of dielectric substrate h_1 and dielectric superstrate h_2 are the same, i.e. h_1=h_2=0.159 cm.

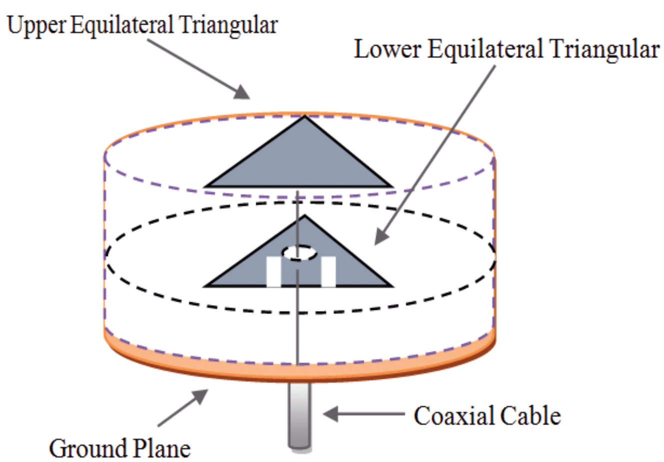


Figure 2. Slit-cut stacked equilateral triangular microstrip antenna.

3. ANTENNA DESIGN PARAMETERS

The analysis of the ETMA has been designed with the following specifications:

Material used as substrate	RT Duroid
Relative permittivity of the substrate	ε_r = 2.32
Thickness of dielectric substrate	h = 0.159 cm
Sides of equilateral triangular patch	a = 10 cm
Slit width	S_1=S_2 = 0.2 cm
Slit length	b = c = 2.0 cm

4. RESULTS

The various parameters of the stacked equilateral triangular microstrip antenna when feed alone at a point are calculated using the above equations. The input impedance and return loss is calculated for the same as the function of frequency, as shown in the Figs 3(a) and 3(b), respectively. The various parameters of the slit-cut ETMA when feed alone at a point are calculated using the above equations. The input impedance and return loss is calculated for the same as the function of frequency as shown in the Figs 4 (a) and 4(b), respectively.

The various parameters of the stacked slit-cut ETMA, when feed alone at a point, are calculated using the above equations. The input impedance of stacked slit-cut ETMA is calculated as the function of frequency, as shown in Fig. 5(a). The return loss is also calculated as the function of frequency as shown in Fig. 5(b). Theoretical and simulated variation of return loss *vs* frequency of stacked ETMA is shown in Fig. 6. Theoretical and simulated variation of return loss *vs* frequency

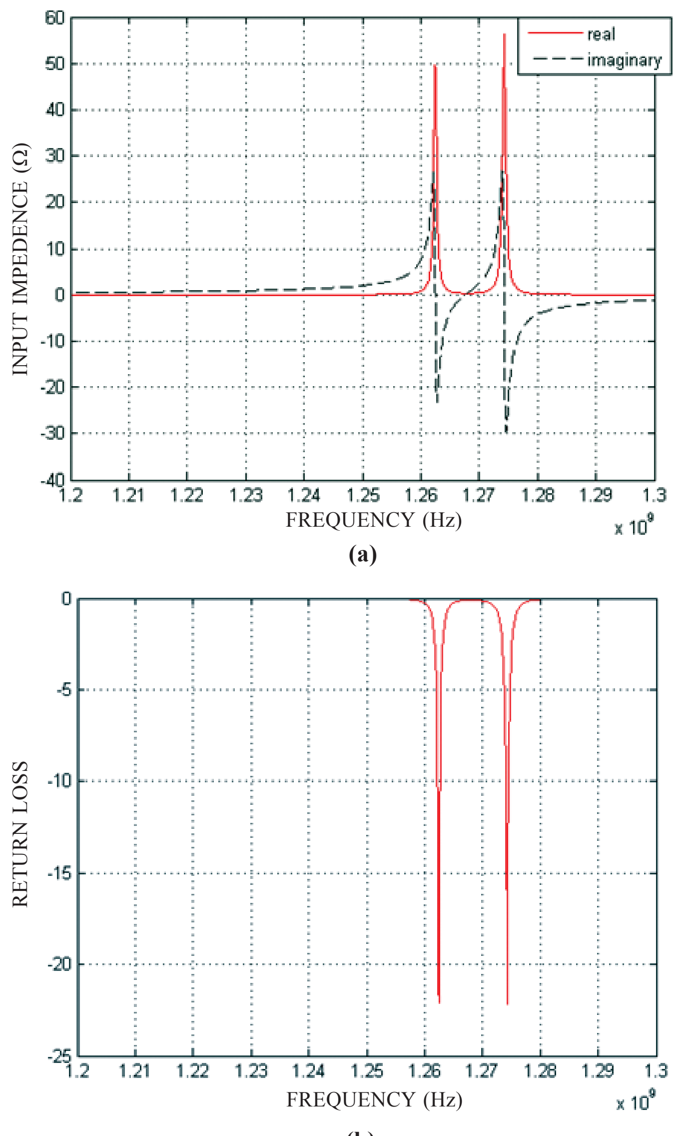


Figure 3. (a) Variation of input impedance *vs* frequency of stacked ETMA, and (b) Variation of return loss *vs* frequency of stacked ETMA.

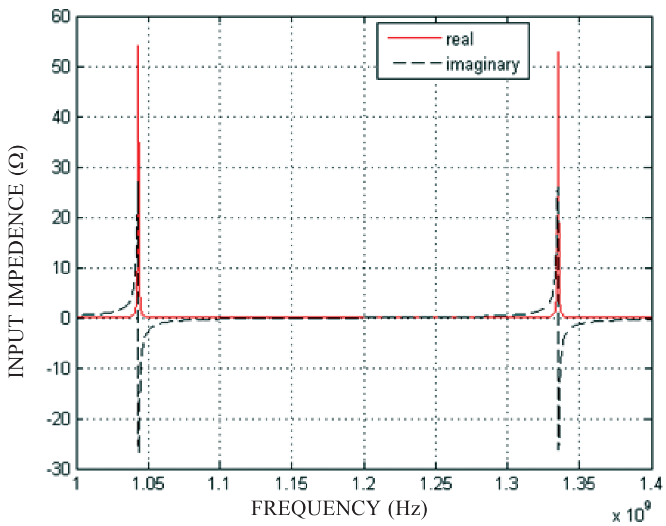
of slit-cut ETMA is shown in Fig. 7. Theoretical and simulated variation of return loss *vs* frequency of stacked slit-cut ETMA is shown in Fig. 8. Theoretical and simulated results with percentage error are shown in Table 1.

5. CONCLUSIONS

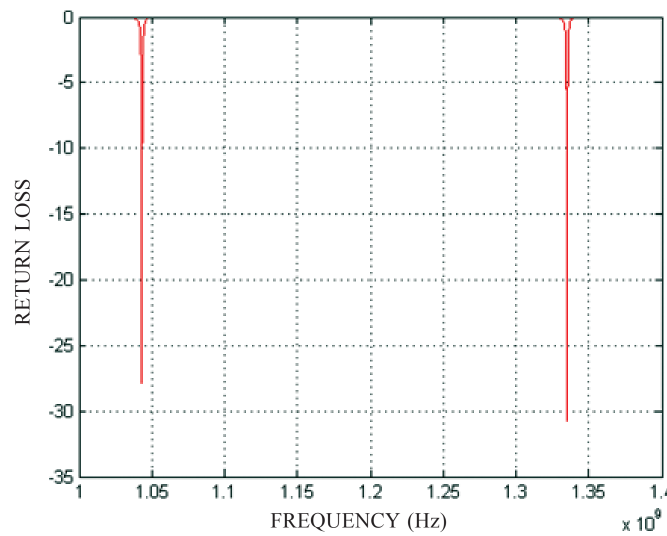
It has been concluded from the proposed model of antenna that efficiency, gain, and bandwidth are far much better which can be further use for commercialisation. The major characteristics of our antennae were accurately verified by theoretical and simulation data. The results shown in this research paper are encouraging and helpful for those researchers who are working in this field. It was shown that proposed multiband ETMA was simple in design with improved version. We have formulated the proposed design to calculate the resonant frequencies, in future aspects; researchers can extend this work for practical scenarios and constraints and implement this to industries.

Table 1. Comparison chart of theoretical and simulated results

	Results		
	Theoretical	**Simulated**	**per cent Error**
Simple ETMA	1.274	1.23	3.45
Stacked ETMA[4]	1.262	1.218	3.49
	1.274	1.251	1.81
Slit-cut ETMA	1.043	1.04	0.29
Stacked Slit-cut ETMA	1.33	1.242	6.62
	0.993	1.01	1.68
	1.261	1.216	3.57
	1.274	1.264	0.78

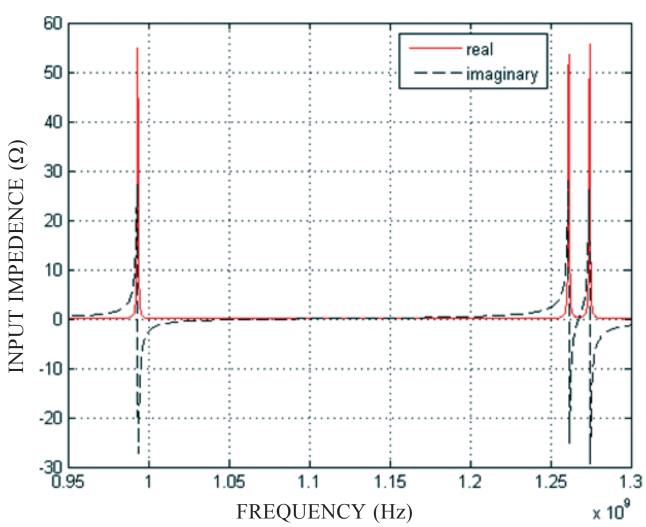


(a)

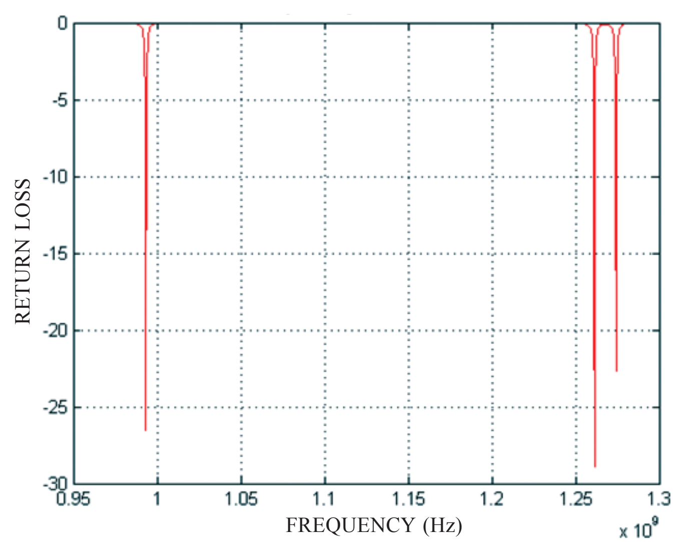


(b)

Figure 4. (a) Variation of input impedance *vs* frequency of slit-cut ETMA, and (b) Variation of return loss *vs* frequency of slit- cut ETMA.



(a)



(b)

Figure 5. (a) Variation of input impedance *vs* frequency of stacked slit-cut ETMA, and (b) Variation of return loss *vs* frequency of stacked slit-cut ETMA.

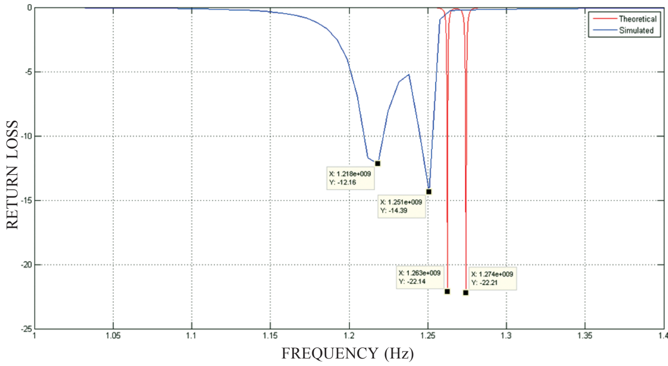


Figure 6. Theoretical and simulated variation of return loss *vs* frequency of stacked ETMA.

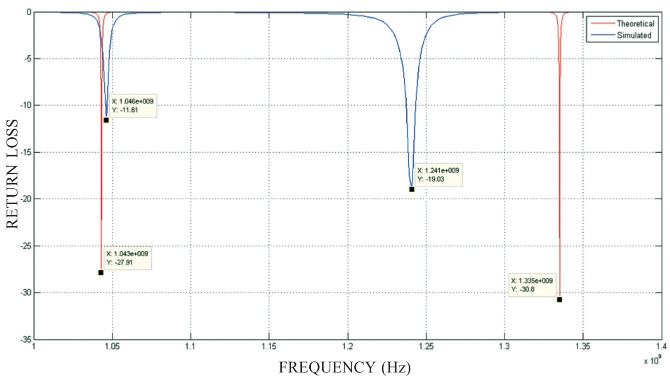


Figure 7. Theoretical and simulated variation of return loss *vs* frequency of slit-cut ETMA.

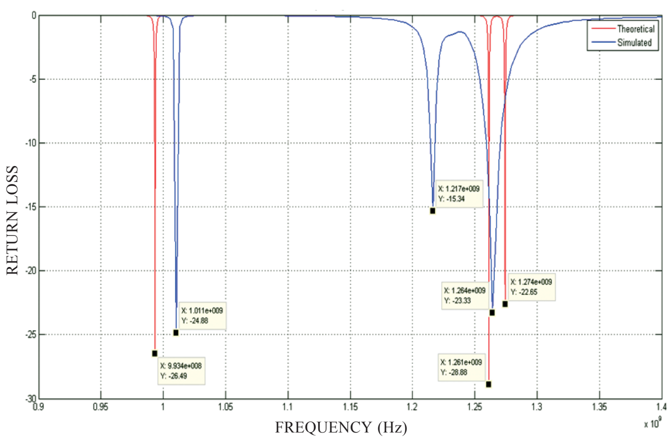


Figure 8. Theoretical and simulated variation of return loss *vs* frequency of stacked slit-cut ETMA.

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CONTRIBUTORS

Mr Prabal Pratap has done theoretical study and analysis of stacked equilateral triangular microstrip antenna (ETMA) and slit-cut stacked equilateral triangular analysis and finds results. He calculate the simulated results and findings using high frequency simulator structure (HFSS).

Dr Ravinder Singh Bhatia has suggested a new design of slit-cut stacked equilateral triangular microstrip antenna and verified all theoretical and simulated results and find percentage error.

Dr Biond Kumar Kanaujia has suggested all the comparative study and findings of stacked equilateral triangular, slit-cut equilateral triangular, slit-cut stacked equilateral triangular microstrip antenna.

Mr Mohd. Nazir has done analysis of upper equilateral triangular patch (UETP) fed by coaxial cable and lower equilateral triangular patch (LETP) and mathematical calculations.

Mr Saurabh Pratap has compared the theoretical and simulated results in terms of variation of return loss vs. frequency of stacked ETMA and slit-cut stacked ETMA.