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Original Article

Tuning of Microstrip Patch Antenna by Adding an Extra Portion at the Upper End of the Antenna

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Abstract - *This paper proposes a simple rectangular patch antenna for its operation in the S-band at 2.43GHz frequency. The length and width of the antenna are increased gradually, and the variations in different parameters are recorded thereof. This observation reveals that the antenna can be tuned for different frequencies by varying the dimensions. Here different antenna models are simulated by using High-Frequency Structured Simulator (HFSS version 13.0.0) and observed the prominent results of the antenna parameters tuned from the L band to the S-band. The results are then compared with the ideal solid rectangular patch antenna. It is observed that adding an extra portion to the patch increases the electrical length of the antenna. As a result, its antenna parameters are changed. Based on the simulation results, antenna prototypes with the best configuration are fabricated. Here antenna performances and antenna parameters are measured experimentally and compared with that of the simulated one.*

Keywords - *FR-4 substrate, Radiation pattern, RMSA, Tuning, Upper.*

1. Introduction

One of the major challenges in the electronic communication system is to design a compact antenna with variable resonant frequencies. The microstrip patch antenna is become popular and attractive for communications, such as aerospace and missile technology, due to its low profile, lightweight, compact size, conformability to mount structure, and easy fabrication. It can also be integrated with solid-state devices. Although the main drawback of rectangular microstrip antenna (RMSA) is its narrow bandwidth (BW), recent technological advances have paved the way for broadband applications. This narrow BW drawback can be overcome by making multiple frequencies resonant antenna at the required band of operation. By varying the electrical length, we can achieve multiple frequencies. By tuning an antenna, we can use it for different frequencies and different purposes. Tuning of the antenna offers an adaptive solution in a dynamic communication environment, demonstrating the ability to change radiation pattern, polarization and operating frequency. The design of the tuning antenna is a kind of intelligence. Various techniques have been used to tune an antenna; these are electrical, mechanical, optical, metamaterial, material etc. Some techniques used to generate multiple frequencies are: shorting post [1-3], antenna loaded with multiple split ring resonators [4], tuning stubs over the patch feed line [5-7], using RF MEMS Technology [8,10,37], using PIN diode and varactor diode [11-13], liquid crystal by varying channel length [14-16]. For mechanical tuning gears, linkages, pulleys, origami techniques, adjusting fluid level within a device etc., are used [17]. Tuning mechanism by placing shorting posts in pre-drilled holes between the ground and patch [18,19], dielectric properties of the antenna are changed mechanically to tune the antenna [20]. Integrating a shape memory alloy actuator into the Kirigami-inspired mechanical transformation is used for tuning [38]. Meta surface (MS) is used to reconfigure an antenna [22, 23]. An asymmetric polarizer is rotated mechanically to tune an antenna [24]

A tunable aperture-coupled MSA was developed and integrated into [25]. In [26], a digitally tunable Capacitor (DTC) is used for reconfiguring an antenna. Insertion of slits on the patch to reconfigure an antenna was reported in [27]. Tuning of the fork-shaped antenna with the n-shaped parasitic element and the partial slotted ground was presented in [28]. By varying the reverse bias voltage of a varactor diode, the electrical length of the radiating patch can be varied and make the antenna tunable, as reported in [39]. An inverted F-antenna (IFA) having an open slit etched on the top plate has been designed and reported in [30]. Metamaterial-based monopole patch antenna to tune frequency over a wide bandwidth was proposed in [31]. A novel varactor loading scheme has been proposed in [32] to reconfigure a dielectric patch antenna. Shorting posts have been used between the patch and ground plane at different locations to tune an antenna over the entire 5GHz WLAN band, as presented in [33].

In this work, a rectangular patch antenna is initially designed and simulated for its operation at a frequency of 2.43GHz. Next, different RMSA is simulated by varying the dimensions of the patch by adding extra patch strips at the upper side of the patch, which varies the length (l) and width (w) of the antenna. Simulation results are observed for the modified patches for different length (X) and width (Y) values. It is observed that by increasing the dimension, we can tune the antenna towards lower resonant frequencies. A linear gear and pulley system are used to tune the antenna mechanically. Mechanical tuning is simpler than electrical and magnetic tuning because no external circuit is required, and the technique used is very simple.

2. Design Consideration

The RMSA is designed to have an operation in the dominant mode of TM_{10} resonating at 2.43 GHz, which can be calculated from the equation as given below [34]:

$$\boldsymbol{f_r} = \frac{\mathbf{1}}{\mathbf{2}\sqrt{\boldsymbol{\mu_o \varepsilon_o}}}\sqrt{\left(\frac{\boldsymbol{m}}{\boldsymbol{l}}\right)^{\mathbf{2}} + \left(\frac{\boldsymbol{n}}{\boldsymbol{w}}\right)^{\mathbf{2}}} \quad (\mathbf{1})$$

Where μ_0=permeability of the medium, ε_0=permittivity of the medium. l = length of the patch, w = width of the patch and m, n=0, 1, 2, 3 …

For an efficient radiator, a practical width that leads to good radiation efficiency is [35]:

$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \qquad (2)$$

Where v_0 is the free space velocity of light. Equation (2) makes the width W equal about half a wavelength. It leads to good radiation efficiencies and acceptable dimensions.

For practical design, it is essential to have a finite ground plane. The ground plane dimensions would be [36]

$$L_g = 6h + l (3)$$

$$W_g = 6h + w (4)$$

The antenna is designed on FR-4 (Flame retardant-4) substrate having a dielectric constant of 4.4, where the microstrip line feeding technique is used to excite the patch. Here a strip of the patch with variable dimensions at the original patch's upper side is introduced. Where "*X*" is the variable length and "*Y*" is the variable width. Fig. 1. (a & b) show the schematic diagram of the proposed antenna.

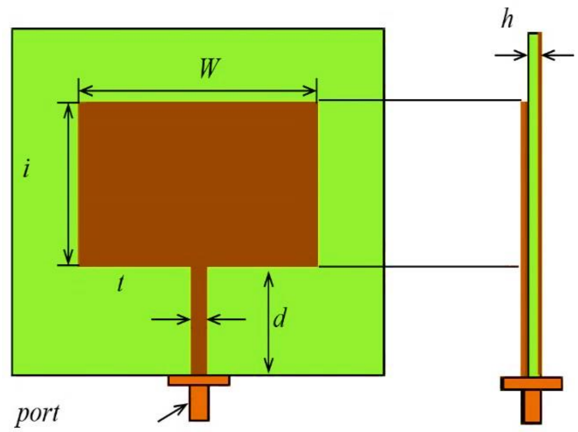

Fig. 1(a) Schematic diagram of the simple RMSA

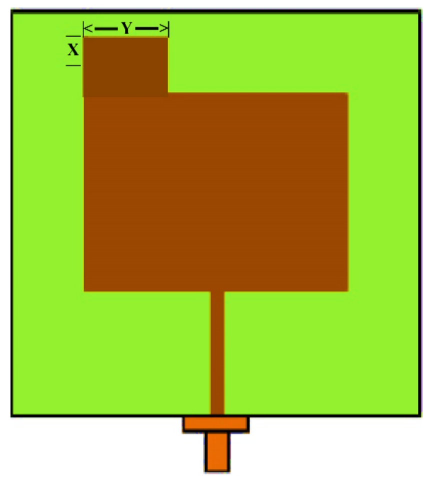

Fig. 1(b) Schematic diagram of the RMSA with added upper strip

The design parameters of the simulated and the fabricated antenna are given in Table 1.

Table 1. The design parameters

Parameters	Values
fr	2.4 GHz
l	28.2 mm
w	47 mm
h	1.5 mm
a	1.8mm
b	15mm
X	1, ….,15mm
Y	1,…..,45mm

Initially, a prototype solid antenna was designed having dimensions mentioned as given in Table 1. Next, a linear gear and pulley system was introduced at the top of the antenna, which helps to smoothly move the required dimension of the copper sheet above the original patch. This mechanism helps achieve different antenna dimensions on a single antenna instead of designing different prototypes. The schematic of the designed antenna is shown in Fig. 2.

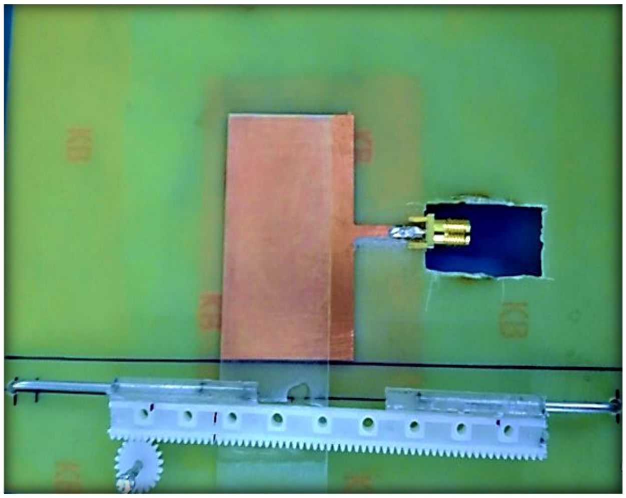

Fig. 2 Designed antenna with linear gear and pulley.

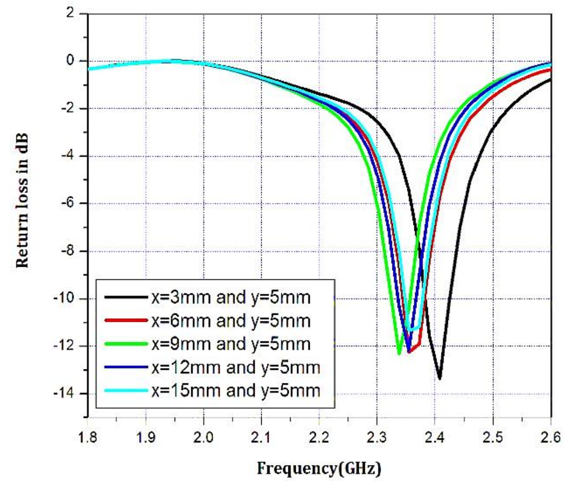

Fig. 3(b) Measured return loss plot for RMSA having *Y* = 5mm.

3. Experimental Results and Discussion

The antenna is simulated by using HFSS (ver 13.0.0). Different antennas are simulated and fabricated with various values of "*X"* and "*Y"*, and prominent results are observed. These observed antenna models are for top variation of *X* = 3, 6, 9, 12 and 15mm for every value of *Y*= 5, 15, 25, 35 and 45mm.

3.1. Return Loss Measurement

From the simulated and the measured results, it is observed that the simple RMSA shows a resonant frequency in the S-band. However, after adding the extra patch portion to the top for varying values of "X" and "Y", a tuning behavior is observed with resonant frequencies varying from S to L band. Table 2 gives the return loss values at their corresponding resonant frequencies for both the simulated and designed antennas. The return loss plots for the observed antennas (simulated and measured) are shown in Fig. 3 (a, b, c, d, e, f, g, h, i & j).

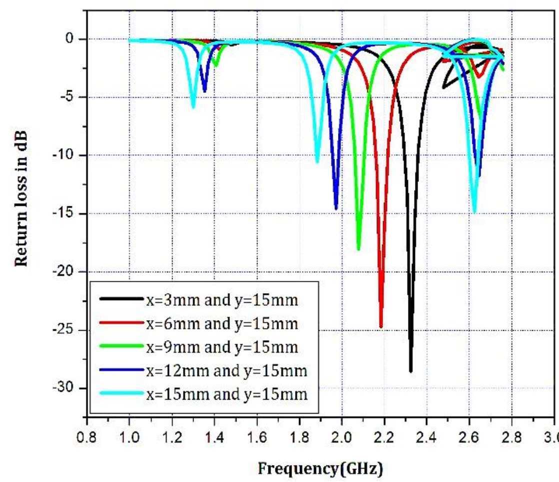

Fig. 3(c) Simulated return loss plot for RMSA having *Y* = 15mm.

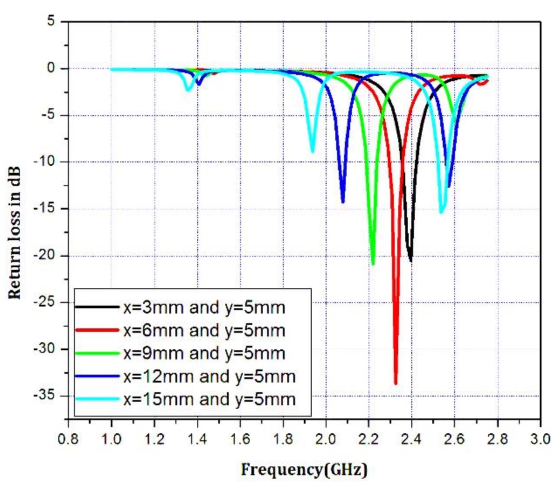

Fig. 3(a) Simulated return loss plot for RMSA having *Y* = 5mm.

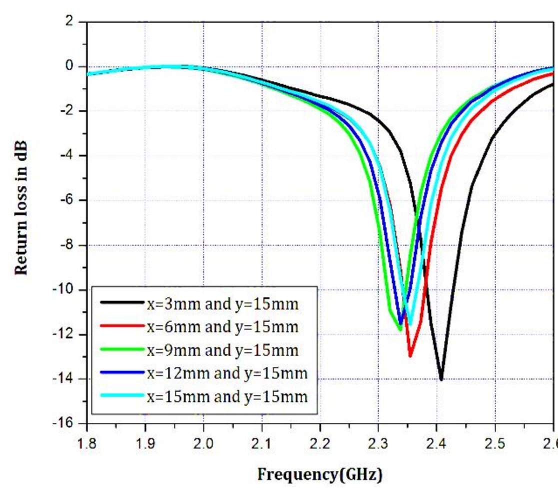

Fig. 3(d) Measured return loss plot for RMSA having *Y* = 15mm.

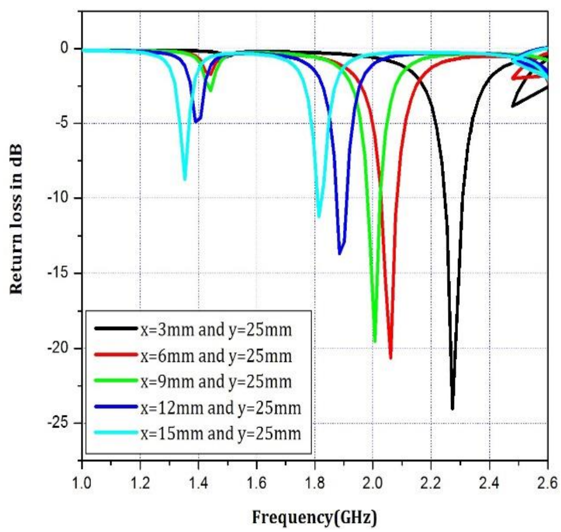

Fig. 3(e) Simulated return loss plot for RMSA having *Y*=25mm.

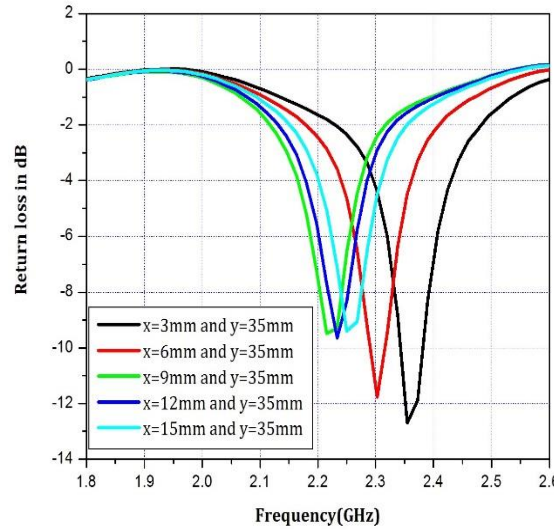

Fig. 3(h) Measured return loss plot for RMSA having *Y*=35mm.

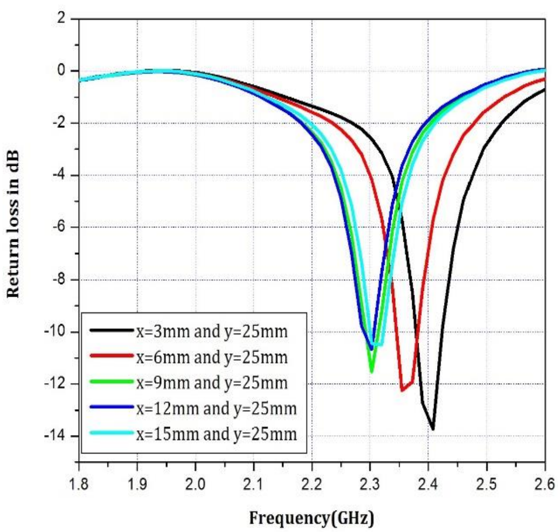

Fig. 3(f) Measured return loss plot for RMSA having *Y*=25mm.

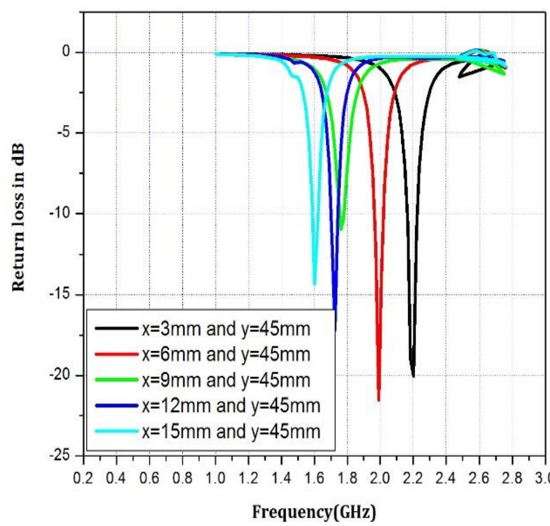

Fig. 3(i) Simulated return loss plot for RMSA having *Y*=45mm.

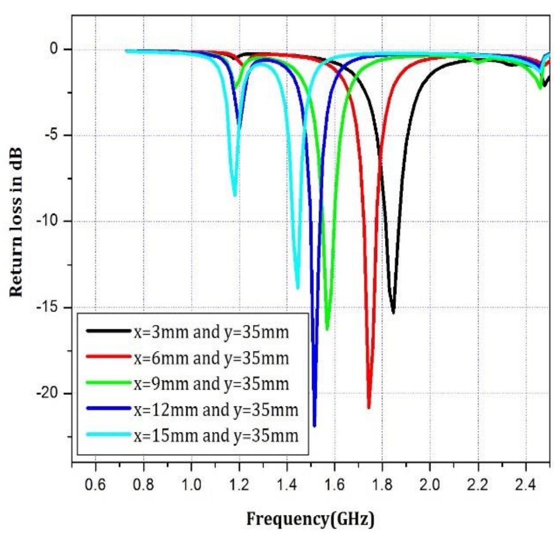

Fig. 3(g) Simulated return loss plot for RMSA having *Y* = 35mm.

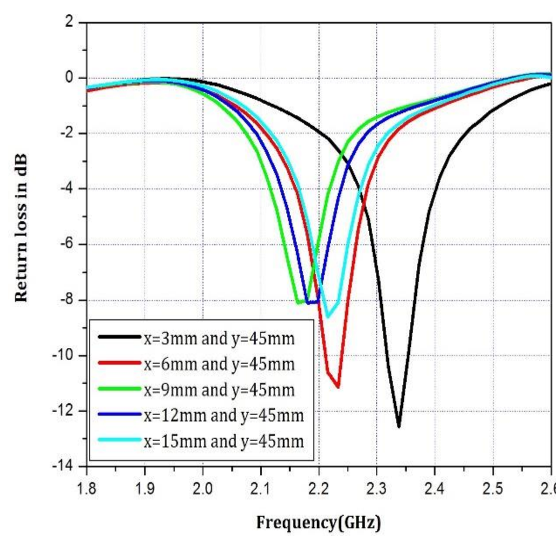

Fig. 3(j) Measured return loss plot for RMSA having *Y*=45mm.

Table 2. Simulated and measured return loss values at their corresponding resonant frequency.

Y (mm)	X (mm)	Simulated		Measured	
		f_r (GHz)	S_{11}	f_r (GHz)	S_{11}
5	3	2.40	-20.50	2.40	-13.37
	6	2.33	-33.67	2.36	-12.26
	9	2.22	-20.90	2.34	-12.32
	12	2.08	-14.28	2.35	-12.18
	15	1.94	-9.00	2.35	-11.35
15	3	2.33	-28.57	2.40	-14.04
	6	2.18	-24.73	2.37	-11.43
	9	2.08	-18.05	2.34	-11.80
	12	1.98	-14.58	2.33	-11.54
	15	1.88	-10.57	2.35	-11.57
25	3	2.27	-24.04	2.40	-13.73
	6	2.06	-20.65	2.36	-12.25
	9	2.00	-19.52	2.30	-11.54
	12	1.88	-13.67	2.30	-10.67
	15	1.81	-11.24	2.32	-10.48
35	3	2.13	-15.30	2.36	-12.70
	6	2.03	-20.82	2.30	-11.77
	9	1.85	-16.26	2.22	-9.50
	12	1.80	-21.88	2.23	-9.64
	15	1.72	-13.84	2.25	-9.40
45	3	2.20	-20.05	2.34	-12.58
	6	1.97	-12.03	2.23	-11.13
	9	1.76	-11.00	2.16	-8.10
	12	1.72	-17.21	2.18	-8.10
	15	1.60	-14.35	2.21	-8.60

3.2. *Voltage Standing Wave Ratio (VSWR)*

Ideally, VSWR must lie in the range of 1-2. The VSWR for different configurations of the patch antenna at different resonant frequencies is given in Table 3. The relation between VSWR and return loss (S_{11}) is as below [22]:

$$VSWR = \frac{1 + 10^{\frac{-S_{11}}{20}}}{1 - 10^{\frac{-S_{11}}{20}}} \quad (5)$$

The simulated and the measured values of VSWR of the tuned antenna at their respective resonant frequencies are given in Table 3.

3.3. The Radiation Pattern

First, different antennas with the required specific dimensions are simulated in the HFSS platform to observe the radiation patterns. Then, we designed our solid patch antenna on FR4. Then we varied its dimensions according to our requirement with the linear pulley system, as shown in Fig.2. The simulated results show that the RMSA without the extra portion has a good broadside radiation pattern for both the E (x-z) plane and the H (y-z) plane. But in the case of measured radiation patterns for the H (y-z) plane, larger back lobe radiation is observed in comparison with that of the simulated result. The compared simulated and measured patterns in 2D for some prominent extended dimensions are shown below in Fig.4 through Fig. 8. (----- SIMULATED, ----- MEASURED)

Table 3. Simulated and measured VSWR values at their corresponding resonant frequency.

Y (mm)	X (mm)	Simulated		Measured	
		f_r (GHz)	VSWR	f_r (GHz)	VSWR
5	3	2.40	1.20	2.40	1.54
	6	2.33	1.04	2.36	1.64
	9	2.22	1.20	2.34	1.63
	12	2.08	1.48	2.35	1.65
	15	1.94	2.09	2.35	1.74
15	3	2.33	1.08	2.40	1.50
	6	2.18	1.12	2.37	1.73
	9	2.08	1.28	2.34	1.69
	12	1.98	1.46	2.33	1.72
	15	1.88	1.84	2.35	1.71
25	3	2.27	1.13	2.40	1.52
	6	2.06	1.20	2.36	1.65
	9	2.00	1.24	2.30	1.72
	12	1.88	1.52	2.30	1.82
	15	1.81	1.75	2.32	1.85
35	3	2.13	1.41	2.36	1.60
	6	2.03	1.20	2.30	1.69
	9	1.85	1.36	2.22	2.00
	12	1.80	1.17	2.23	1.98
	15	1.72	1.51	2.25	2.02
45	3	2.20	1.22	2.34	1.61
	6	1.97	1.67	2.23	1.76
	9	1.76	1.78	2.16	2.30
	12	1.72	1.32	2.18	2.30
	15	1.60	1.47	2.21	2.18

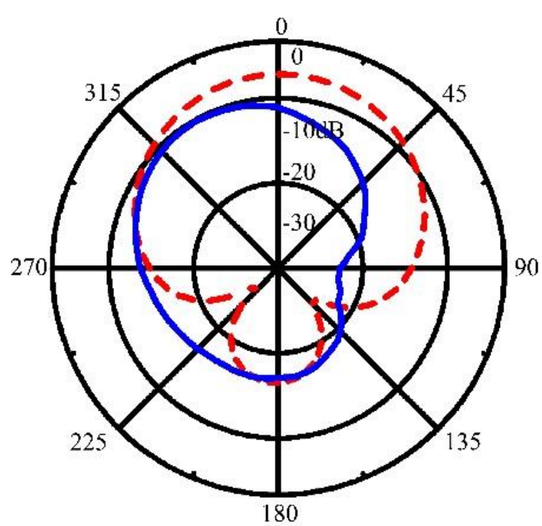

Fig. 4(a) 2D E(x-z) plane pattern for solid RMSA at 2.43GHz

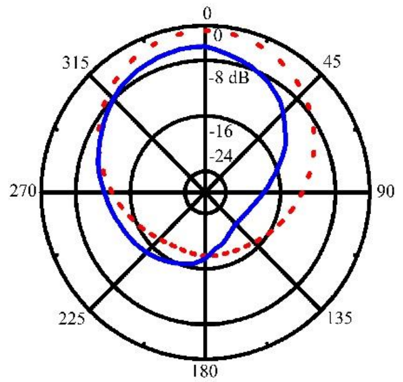

Fig. 4(b) 2D H(y-z) plane pattern for solid RMSA at 2.43GHz

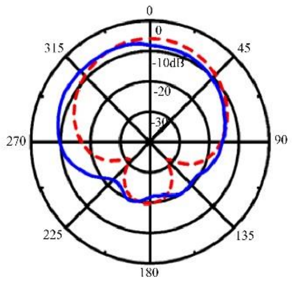
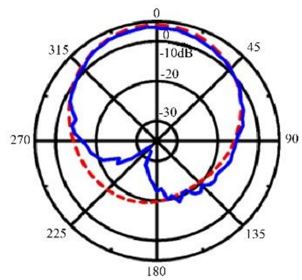

Fig. 5(a) **Fig. 5(b)**

Fig. 5 (a) 2D E(x-z) compared plane pattern for RMSA with *X* =3mm and *Y* =5mm.

(b) 2D H(y-z)compared plane pattern for RMSA with *X* =3 mm and *Y* =5 mm.

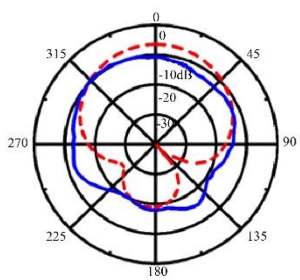
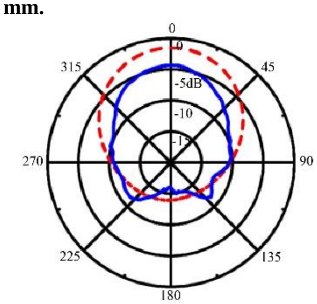

Fig. 6(a) **Fig. 6(b)**

Fig. 6(a) 2D E(x-z) compared plane pattern for RMSA with *X* =3mm and *Y* =45mm.

(b) 2D H(y-z) compared plane pattern for RMSA with *X* =3mm and *Y* =45mm.

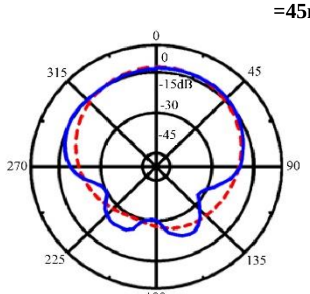
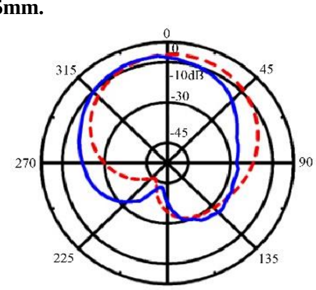

Fig. 7(a) **Fig. 7(b)**

Fig. 7(a). 2D E(x-z) compared plane pattern for RMSA with *X*=15mm and *Y*=5mm.

(b). 2D H(y-z) compared plane pattern for RMSA with *X* =15mm and *Y* =5mm.

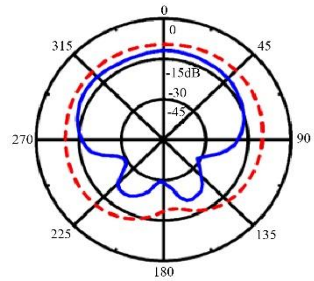
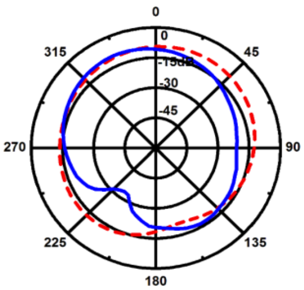

Fig. 8(a) **Fig. 8(b)**

Fig. 8(a) 2D E(x-z) compared plane pattern for RMSA with *X* =15mm and *Y* =45mm.

(b) 2D H(y-z) compared plane pattern for RMSA with *X* =15mm and *Y* =45mm.

The simulated current distributions over the patch at their respective resonant frequencies for different extended dimensions ("*X*" in mm and "*Y*" in mm) are shown in Fig. 9 through Fig. 13.

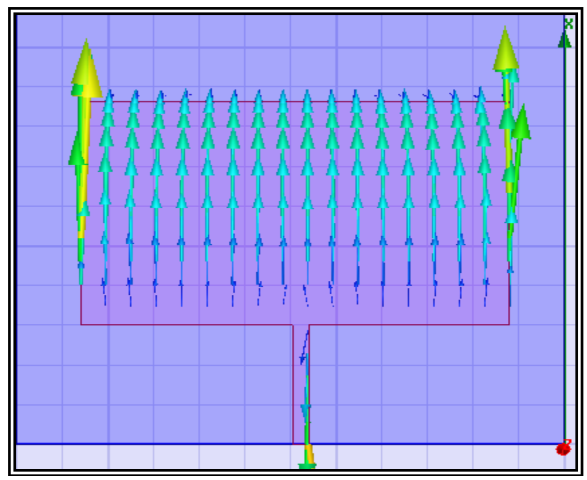

Fig. 9 Surface current distribution over the patch for *X* = 0mm and *Y* =0mm at 2.43GHz

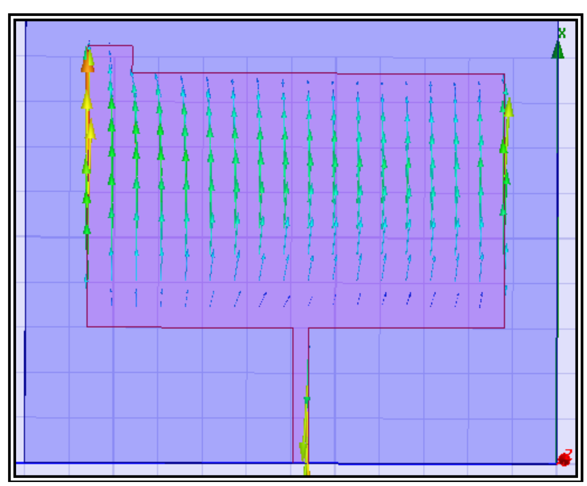

Fig. 10 Surface current distribution over the patch for *X* = 3mm and *Y* =5mm at 2.40GHz

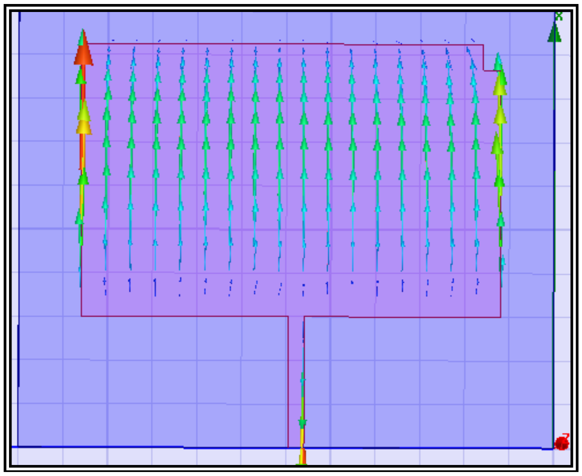

Fig. 11 Surface current distribution over the patch for *X* = 3mm and *Y* =45mm at 2.20GHz

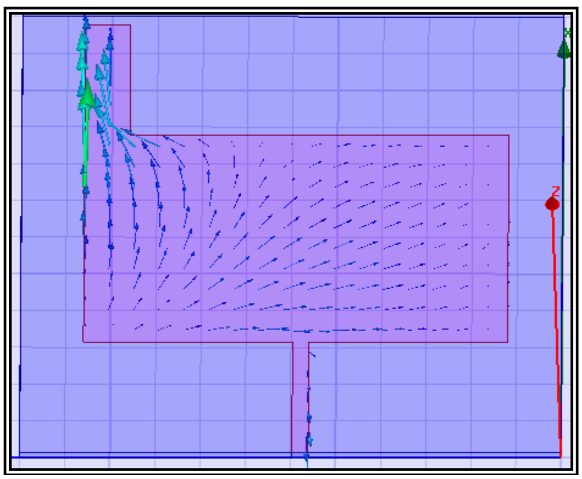

Fig. 12 Surface current distribution over the patch for *X* = 15mm and *Y* =5mm at 1.94GHz

In Fig. 10 and Fig. 11, it has been observed that due to the addition of the extra portion, the current path direction has made a slight bend as compared to the original solid RMSA, as shown in Fig. 9. Due to the slight bending of the current path, there is an increase in electrical length of the patch as a result produce resonant frequency in L-band less than the resonant frequency of the original solid patch. In Fig. 12 and Fig. 13, it has been observed that the current path direction is tilted along the width of the patch, which produces much increase in the patch's electrical length and produces low resonant frequency.

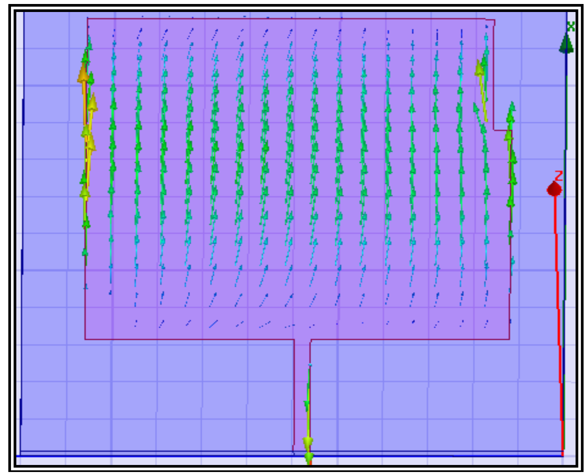

Fig. 13 Surface current distribution over the patch for *X* = 15mm and *Y* =45mm at 1.60GHz

4. Discussion and Conclusion

From the comparative study of the simulation and measured results of the different RMSA, it can be concluded that by introducing an extra portion of the RMSA, one can achieve different resonant frequencies and improve the antenna performances. It has been observed that when the dimension of the added portion is increased, the antenna is tuned towards lower resonant frequencies. With the introduction of the extra portion on pure RMSA, the surface area of the antenna increases, which is the reason for a shift in resonant frequency to the lower side of the RF spectrum. It has been observed from the experimental results that the fabricated antenna's performance is poorer than the simulated antenna. This may be due to some deformation in introducing an extra portion to the patch or may be due to excess etching of the sides of the antenna. The utmost care is required to be taken during the time of fabrication of the antenna for better performance. The tuning mechanism reported by other researchers is very complex, but our tuning mechanism is simple.

Acknowledgments

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