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Effects of Two Identical Notches in the Same and Opposite Non Radiating Edges of a Rectangular Microstrip Patch Antenna

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Abstract

In this paper the effects of two identical notches in the same non radiating edge and opposite non radiating edges have been studied extensively. The effect on resonant frequency and gain with the variation of the notch length and notch width are studied. It has been observed that the notches in the opposite non radiating edges affect more on resonant frequency than the notches in the same non radiating edge of a microstrip patch antenna. About 80.2% size reduction has been achieved by the dual notches in the same non radiating edge and about 87.5% size reduction is achieved for the dual notches in the opposite non radiating edges.

Keywords: *Microstrip patch antenna, notch, radiating edge, non-radiating edge*

1. Introduction

Due to different attractive features of microstrip patch antenna like low profile, light weight, easy fabrication, conformal to mount structures etc., microstrip patch antennas (MPA) are very popular in modern communication systems [1] though they suffer mainly from two serious limitations one is low gain and the other is narrow bandwidth. To overcome these limitations several approaches are made in different research articles. Along with overcoming the main two limitations in current research significant emphasis have been taken to use microstrip patch antennas in portable devices utilizing the advantages of them [2]. As a result, there has been taken considerable efforts in many literatures to reduce the antenna size. But reduction in size of the antenna impacts adversely on the antenna parameters like return loss, bandwidth, resonant frequency, radiation efficiency, gain etc. Many researchers have used different techniques to design compact microstrip patch antenna. *S. Bhunia et al.*, [3-4] has investigated on compactness and multi frequency operation of microstrip patch antenna cutting rectangular slots on the patch and almost 85% size reduction is reported. Size reduction by slot loading in the radiating patch of the microstrip patch antenna has also been reported in the literature [5-7]. *A. Roy et al*., [8-9] has investigated on compactness of microstrip patch antenna, utilizing spur lines and strip loading to the patch and 87% size reduction with dual band operation has been reported. Size reduction of the slot antenna using reactive terminations at the ends of the slot was reported in [10]. Size reduction was reported in [11] by loading the slot using series inductive slits. Miniaturization of slot antennas using slit and strip loading was reported in [12]. Some research articles have shown the analysis of the effects of slot cutting on the patch, with equivalent

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circuits and theoretical studies [13-19]. A compact dual band rectangular microstrip antenna, realized by two different single slits has been designed in [20]. In this design 53.73% compactness has been found. *S. Mathew et. al.*, [21] has proposed a compact circular microstrip patch antenna with V shaped slit and 48% size reduction has been reported. Some investigations on size reduction by cutting different slots on patch have been carried out in [22-27]. *A. A. Deshmukh et al.*, [28] has discussed the variation of resonant frequency with the variation of slot length and reduced resonant frequency has been validated with current path calculation. Compact microstrip antenna has been designed utilizing meandered strips and rectangular slots on patch with monopole structure and antenna characteristics has been discussed with parametric studies and current distributions in some literatures [29-31]. In [31], the resonant frequency has been calculated from the slot length and the results have been validated by simulated current distribution and measured values.

In this paper effects of two identical notches in the same and opposite non-radiating edges of a microstrip patch antennas are extensively studied. The antennas for the best results are fabricated and the simulated & measured results are compared. The measured results are well agreed with the simulated results.

2. Antenna Design Concept

The configuration of the reference antenna (Antenna 1) resonating at frequency $f_r = 10\ GHz$ is shown in Figure 1. The length (L = 9mm) and width (W = 12mm) of Antenna 1 have been calculated from conventional rectangular microstrip patch antenna design equations. The substrate (Arlon AD300A) with dielectric constant ε_r= 2.2, loss tangent tan δ = 0.002 and thickness h = 1.5875mm has been taken for this design. The dimensions of the ground plane have been taken as more than three times of the patch size as if it behaves as an infinite ground plane, and the antenna has been fed by a coaxial cable at optimum location to achieve the impedance very close to the characteristic impedance of the coaxial line, *i.e.*, 50Ω. The antenna structures under study are shown in Figure 2 and Figure 3. In Figure 2 the rectangular notches are in the same non radiating edge and in Figure 3 the rectangular notches are in the opposite non radiating edge. All the relevant parameters of the antenna structures under study are shown in Figure 2 & Figure 3.

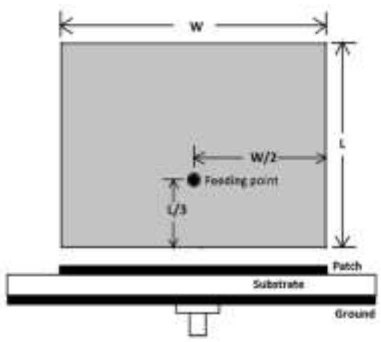


Figure 1. Reference Antenna (Antenna 1) Configuration

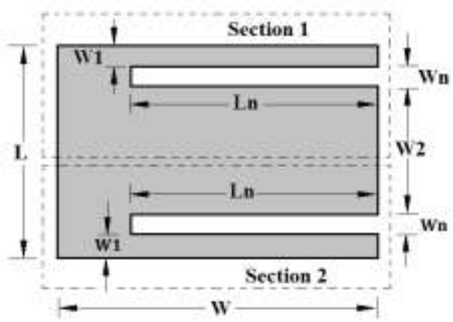


Figure 2. Antenna 2 Configuration

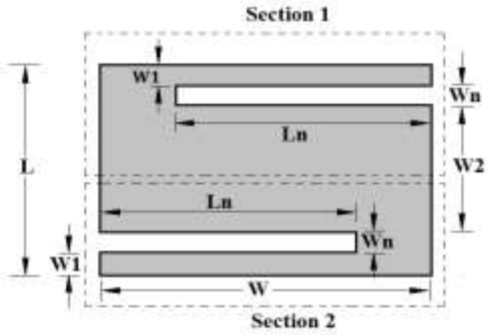


Figure 3. Antenna 3 Configuration

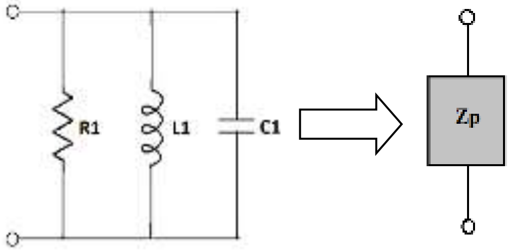


Figure 4. Equivalent Circuit of the Patch of Section 1 or 2 without Notch

3. Theoretical Formulation and Equivalent Circuit

The microstrip patch antenna under study can be treated as the combination of two sections *i.e.*, Section 1 and Section 2. Section 1 and Section 2 both are identical notch loaded microstrip patch antenna with patch dimension $W \times \frac{L}{2}$ and notch dimension $W_n \times L_n$. The equivalent circuit of the patch of either section 1 or section 2 without notch is the parallel combination of resistance (R_1), inductance (L_1) and capacitance (C_1). The equivalent circuit of the patch can be modelled as shown in Figure 4.

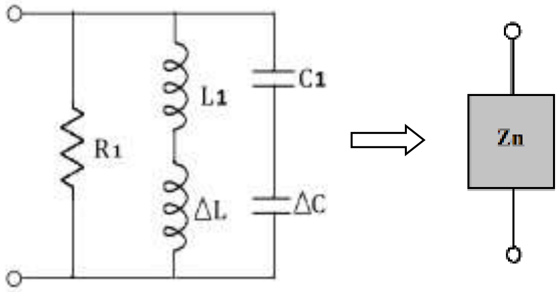


Figure 5. Equivalent Circuit due to the Effect of Notch

Where R_1,L_1, C_1 can be defined as [16]

$$C_1 = \frac{\epsilon_0 \epsilon_{eff} LW}{2h} Cos^{-2}\left(\frac{\pi y_0}{L}\right), \tag{1}$$

$$L_1 = \frac{1}{\omega^2 C_1}, \tag{2}$$

$$R_1 = \frac{Q_r}{\omega c_1}, \tag{3}$$

Where L and W are the length and width of the rectangular patch antenna and h is the thickness of the dielectric substrate of effective permittivity ϵ_{eff}.

$Q_r = \frac{C\sqrt{\epsilon_{reff}}}{4fh}$ and $\epsilon_{reff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2}\left(1+12\frac{h}{W}\right)^{-\frac{1}{2}}$; Where the symbols have their usual meanings.

When a notch is incorporated in a patch two currents are flowing in the patch one is the normal current and the other is the current around the notch. Due to insertion of the notch in a patch discontinuities occur for magnetic field as well as electric field both which can be modeled as an additional inductance ΔL and additional capacitance ΔC with the existing inductance and capacitance of the equivalent circuit of the patch [10] shown in Figure 5.

The additional inductance ΔL can be written as[17-18],

$$\Delta L = \frac{Z_1+Z_2}{16\pi f Cos^{-2}\left(\frac{\pi y_0}{L/_2}\right)} tan\left(\frac{\pi f L_n}{c}\right) \quad (4)$$

where

$$Z_1 = \frac{120\pi / \sqrt{\epsilon_{reff}}}{\left(\frac{W_1}{h}\right)+1.393+0.667 ln\left(\frac{W_1}{h}+1.444\right)} \quad (5)$$

$$Z_2 = \frac{120\pi / \sqrt{\epsilon_{reff}}}{\left(\frac{W_2}{2h}\right)+1.393+0.667 ln\left(\frac{W_2}{2h}+1.444\right)} \quad (6)$$

The capacitance ΔC is calculated as gap capacitance by [17]

$$\Delta C = 2(L_n)\frac{\epsilon_0}{\pi}\left[ln\left(2\frac{1+\sqrt{k'}}{1-\sqrt{k'}}\right) + \ln Coth\left(\frac{\pi W_n}{4h}\right) + 0.013 C_f \frac{h}{W_n}\right] Cos^2\left(\frac{\pi y_0}{L}\right) \quad (7)$$

where $k' = \sqrt{1-k^2}$,$k^2 = \frac{1+\frac{W_1}{W_n}+\frac{W_2}{W_n}}{\left(1+\frac{W_1}{W_n}\right)\left(1+\frac{W_2}{W_n}\right)}$

C_f is the fringe capacitance [14] and is given by

$$C_f = \frac{1}{2}\left[\frac{\sqrt{\epsilon_{reff}}}{cZ_0} - \epsilon_0 \epsilon_r \frac{W}{h}\right], \quad (8)$$

Z_0 is the characteristic impedance of the microstrip patch.

The equivalent circuit of section 1 or section 2 with notch loaded can be modeled as shown in Figure 6.

The value of the coupling capacitor C_c is defined as [17]

$$C_c = \frac{-(C_1+C_2)+\sqrt{\left((C_1+C_2)^2-4C_1C_2\left(1-\frac{1}{C_p{}^2}\right)\right)}}{2}, \quad (9)$$

Where $C_2 = C_1 + \Delta C$and$C_p$is the coupling factor [17]

The designed antenna of Figure 2 can be modeled as a combination of Section 1 and Section 2 side by side in back to back termination and the designed antenna of Figure 3 can be modeled as the combination of Section 1 and Section 2 side by side but in back to front termination. The equivalent circuit of designed antenna shown in Figure 2 can be drawn in conventional way as, the parallel combination of equivalent circuit of notch loaded Section 1 & 2, shown in Figure 7. The equivalent circuit of designed antenna shown in Figure 3 can be drawn as, the series combination of equivalent circuit of notch loaded Section 1 & 2, shown in Figure 8.

The total input impedance Z_T can be easily found out from the equivalent circuit shown in Figure 7 and Figure 8. The proposed antenna is fed with a co-axial cable of characteristic impedance $Z_0 = 50\Omega$. After finding the total input impedance Z_T one can easily find out the reflection co-efficient, VSWR, and return loss [18].

Reflection coefficient, $\Gamma = \frac{Z_0-Z_T}{Z_0+Z_T}$, (10)

VSWR $= \frac{1+|\Gamma|}{1-|\Gamma|}$, (11) Return Loss$R_L = 20\ log|\Gamma|$. (12)

The radiation pattern E_θ and $E_\emptyset$can also be easily found out using the well-known formula [18].

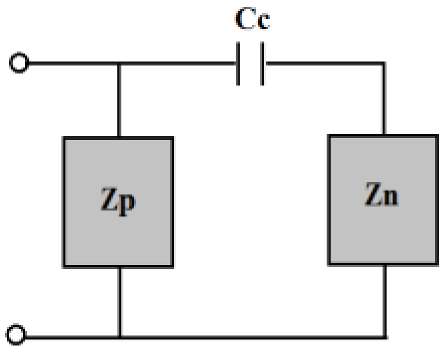


Figure 6. Equivalent Circuit of Notch Loaded Section 1 or Section 2

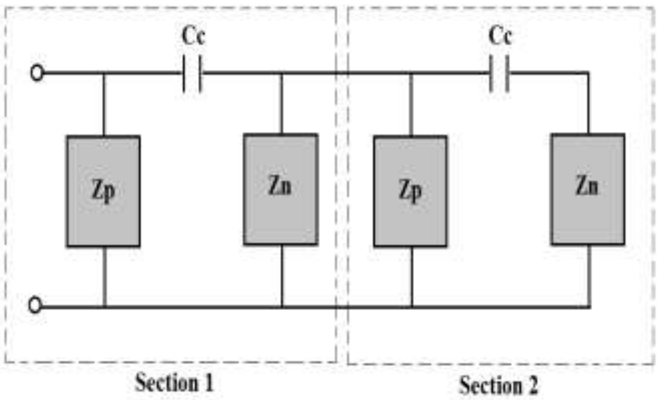


Figure 7. Equivalent Circuit of Antenna 2

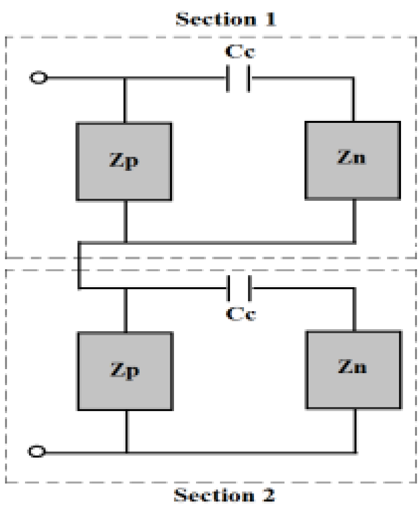


Figure 8. Equivalent Circuit of Antenna 3

4. Parametric Study

To achieve the dimension of the final designed antenna extensive parametric studies have been carried out. The simulated results of the designed antenna with the variation of notch dimensions *i.e.*, W_n and L_n are shown in Table 1 to Table 6. The graph for variation of resonant frequency with notch length (L_n) and variation of gain with notch length (L_n) have been shown in Figure 9.

Table 1. Variation of Antenna Characteristics with $L_n(mm)$ where $W_n = 1mm$

Notch length L_n(mm)	Notches are in same edge			Notches are in opposite edges		
	Resonant frequency $f_r(GHz)$	Return Loss (dB)	Gain (dBi)	Resonant frequency $f_r(GHz)$	Return Loss (dB)	Gain (dBi)
1	7.752	25.66	4.3	7.718	38.23	3.7
2	7.749	11.08	4.2	7.576	19.28	3.5
3	7.681	15.27	4	7.449	21.2	3.2
4	7.583	13.01	4	7.339	17.84	3.5
5	7.508	10.78	3.7	6.721	15.94	3.6
6	7.111	17.12	3.3	6.439	16.34	3.7
7	6.406	13.89	3.6	6.182	20.56	3.6
8	5.782	11.48	3.4	5.542	26.91	3.2
9	5.269	21.9	3.5	5.013	11.84	3.1
10	4.805	15.59	3.5	4.565	17.24	3.1

Table 2. Variation of Antenna Characteristics with $L_n(mm)$ where $W_n = 2mm$

Notch length L_n(mm)	Notches are in same edge			Notches are in opposite edges		
	Resonant frequency $f_r(GHz)$	Return Loss (dB)	Gain (dBi)	Resonant frequency $f_r(GHz)$	Return Loss (dB)	Gain (dBi)
1	7.721	20.01	4.2	7.716	14.33	3.6
2	7.701	11.76	4	7.493	18.92	3.5
3	7.601	15.76	3.7	7.391	21.1	3.1
4	7.489	12.51	3.9	7.339	11.98	3.2
5	7.403	11.89	3.2	6.641	11.81	3
6	6.743	21	3.5	6.294	12.86	2.7
7	6.102	31.08	3	5.606	17.74	2.5
8	5.526	25.38	3.3	5.029	17.47	3
9	5.029	18.66	3.2	4.549	14.59	2.1
10	4.565	13.19	3	4.148	10.64	2

Table 3. Variation of Antenna Characteristics with $L_n(mm)$ where $W_n = 3mm$

Notch length L_n(mm)	Notches are in same edge			Notches are in opposite edges		
	Resonant frequency $f_r(GHz)$	Return Loss (dB)	Gain (dBi)	Resonant frequency $f_r(GHz)$	Return Loss (dB)	Gain (dBi)
1	7.703	11.76	3.7	7.656	15.29	3
2	7.686	18.56	4	7.433	12.69	2.5
3	7.541	15.78	3.6	7.294	11.92	2.7
4	7.389	20.01	3.9	7.239	10.1	3
5	7.292	10.57	3	6.583	27.27	2.5
6	6.567	21.35	2.9	5.75	10.2	2
7	5.942	29.25	3.2	5.061	12.21	2
8	5.381	13.2	2.8	4.501	15.03	1.5
9	4.901	10.47	2.7	4.068	13.22	1.3
10	4.452	10.12	2.8	3.716	10.43	1

Table 4. Variation of Antenna Characteristics with $L_n(mm)$ where $W_n = 3.5mm$

Notch length L_n(mm)	Notches are in same edge			Notches are in opposite edges		
	Resonant frequency $f_r(GHz)$	Return Loss (dB)	Gain (dBi)	Resonant frequency $f_r(GHz)$	Return Loss (dB)	Gain (dBi)
1	7.689	12.76	3.5	7.495	12.39	2
2	7.66	17.21	3.1	7.341	15.29	1.7
3	7.503	10.57	3	7.294	14.81	1
4	7.307	13.89	2.7	7.143	12.31	0.5
5	7.239	31.02	3.2	6.342	16.1	0.7
6	6.519	18.13	3	5.477	14.44	1
7	5.894	32.17	2.6	4.709	15.81	0
8	5.349	18.89	2.7	4.148	12.1	0.7
9	4.869	12.53	2.6	3.748	18.51	-0.5
10	4.42	20	2.5	3.427	15	-0.5

It has been seen from the simulated results that resonant frequency decreases with the increase of the notch length or width irrespective of the notch position which is quite obvious as the increased notch dimensions disturbed current lines more. This meandered current lines increase the equivalent current length on the patch and as a result reduction of frequency occurs. Again when the notch dimensions are increases the radiating patch area decreases which results of decrease in gain. But it is interesting to note that along with notch dimension the notch position is also very important. Simulated results show that notches are in opposite non-radiating edges has more effect on resonant frequency and gain than the notches are in the same non radiating edge.

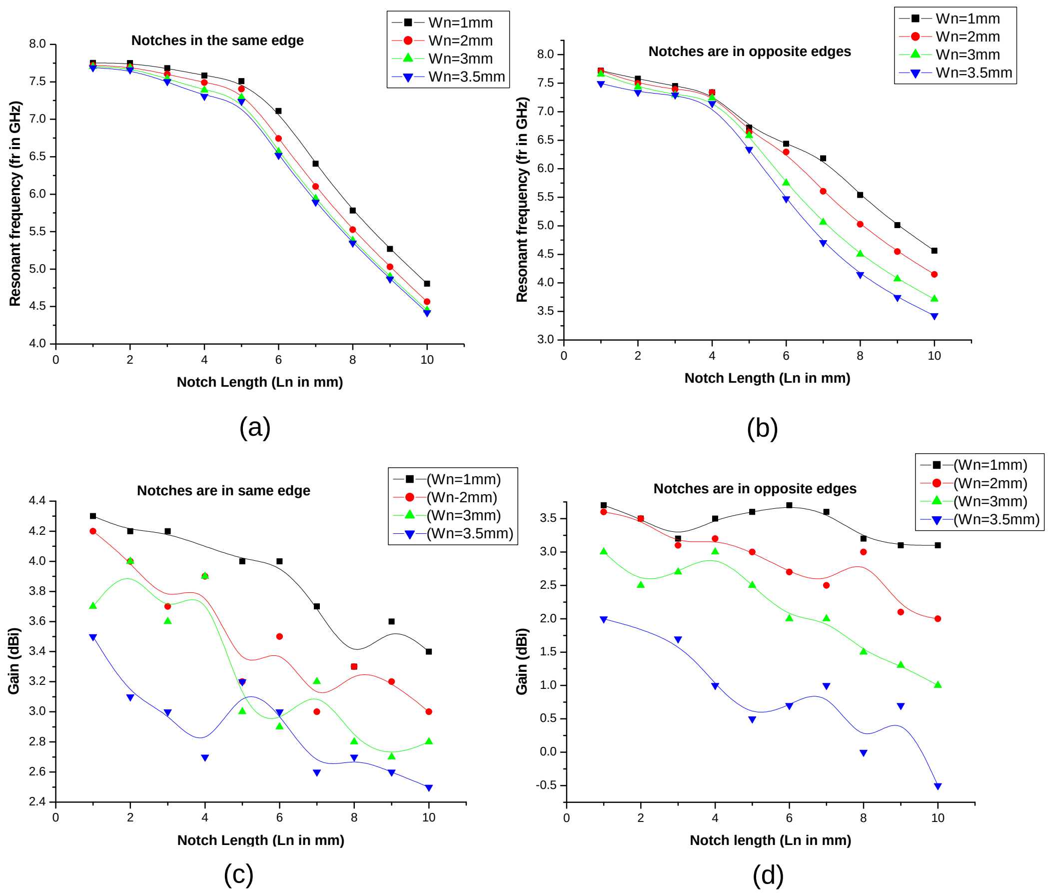


Figure 9. Variation of Resonant Frequency with Notch Length for (a) Antenna with Notches in same Edge, (b) Antenna with Notches in Opposite Edge, and Variation of Gain with Notch Length for (c) Antenna with Notches in same Edge, (d) Antenna with Notches in Opposite Edge

5. Results and Discussion

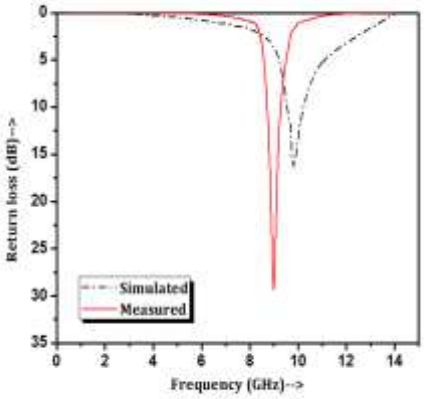
The reference antenna Antenna1 and the designed antenna Antenna2 (with $W_n = 3.5mm, L_n = 10mm$) & Antenna 3 (with $W_n = 3.5mm, L_n = 10mm$) are fabricated which is shown in Figure 10 and the measured results are compared with the simulated results. The measured results have been agreed very well with the simulated results. The simulated and measured results are shown in Table 5 and frequency vs return loss graphs of reference antenna, Antenna 2 and Antenna 3 are shown in Figure 11.

(a) (b) (c)

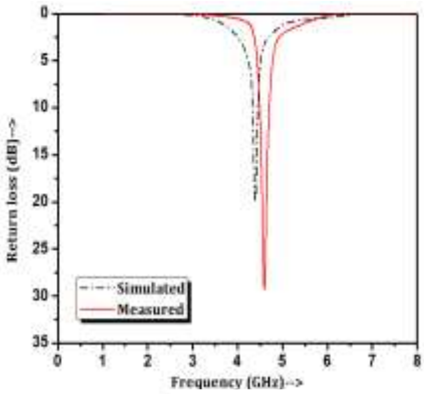
Figure 10. Fabricated (a) Reference Antenna (b) Antenna 2 and (c) Antenna 3

Table 5. Simulated and Measured Results

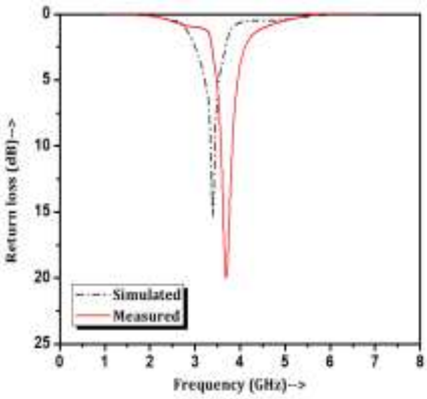
Antenna Structure		Reference Antenna 1	Antenna 2	Antenna 3
Simulated results	Resonant frequency (GHz)	9.8	4.4	3.4
	Return Loss(dB)	16	20	15
	Bandwidth (MHz, %)	520, 5.3	100, 2.3	80, 2.4
	Gain (dBi)	5.6	2.5	-0.5
Measured results	Resonant frequency (GHz)	9	4.6	3.7
	Return Loss(dB)	30	28	20
	Bandwidth (MHz, %)	500, 5.5	200, 4.3	200, 4.3
	Gain (dBi)	6	3	0.2



(a)



(b)

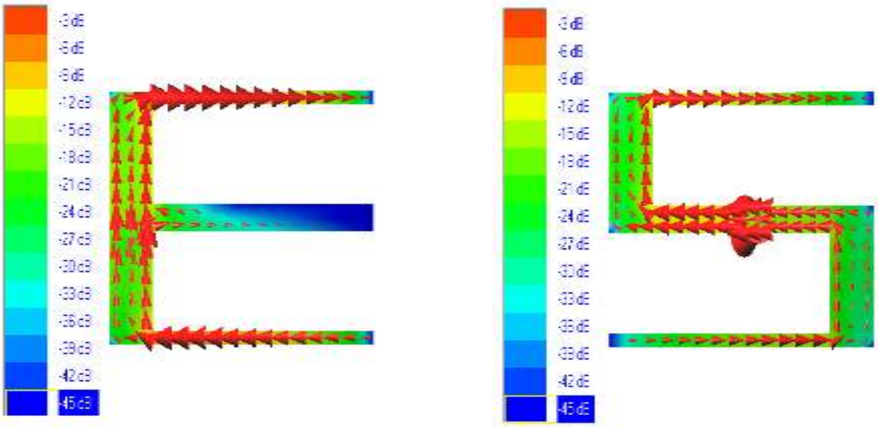


(c)

Figure 11. Simulated and Measured Frequency vs Return Loss Graphs for (a) Reference Antenna, (b) Antenna 2 and (c) Antenna 3

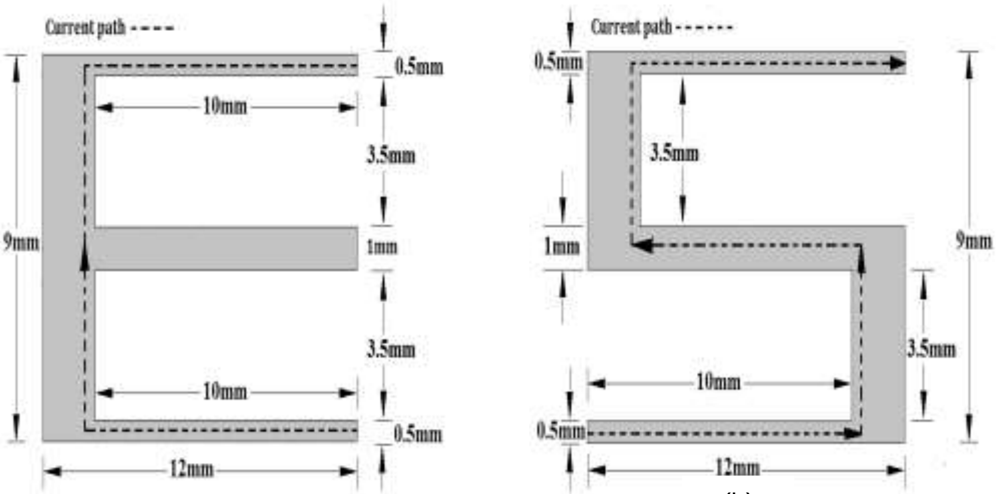
The measured resonant frequency of reference antenna has been found as 9GHz with 30dB return loss and 6dBi gain. Antenna 2 and Antenna 3 resonates at 4.6GHz with 28dB return loss and 3.7GHz with 20dB return loss as per measured results. The measured gains for Antenna 2 and Antenna 3 have been found as 3dBi and 0.2dBi respectively.

The current distribution on the slotted patch for Antenna 2 and Antenna 3 at 4.4GHz and 3.4 GHz respectively have been shown in Figure 12. The resonant frequency can be calculated from the current path length as shown in Figure 13 for Antenna 2 and Antenna 3.



(a) (b)

Figure 12. Current Distribution for (a) Antenna 2 at 4.4GHz and (b) Antenna 3 at 3.4GHz



(a) (b)

Figure 13. Current Path for (a) Antenna 2 at 4.4GHz and (b) Antenna 3 at 3.4GHz

The electrical lengths have been approximated from simulated current distribution and these are assumed as L_{c1} for Antenna 2 at 4.4GHz and L_{c2} for Antenna 3 at 3.4GHz. The L_{c1} and L_{c2} are calculated from Figure 13 as follows,

$L_{c1} = 10 + 3.5 + 1 + 3.5 + 10 = 28mm$

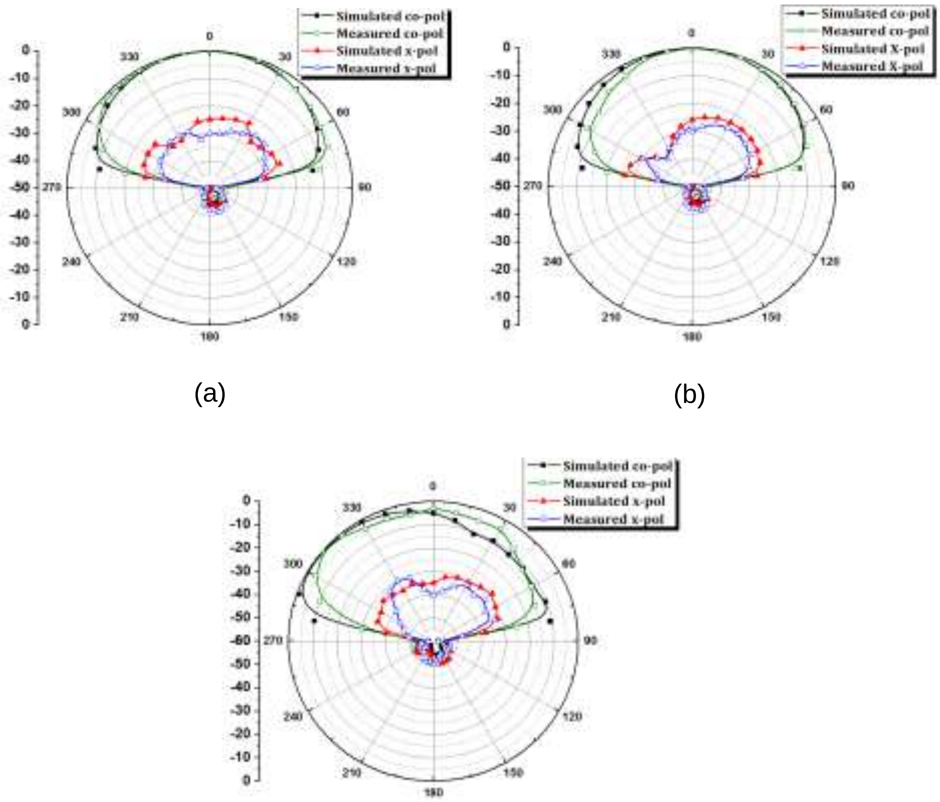
And $L_{c2} = 10 + 3.5 + 0.5 + 8 + 0.5 + 3.5 + 10 = 36mm$

The resonant frequencies have been calculated from the following equations,

$f_1 = \frac{c}{2L_{C1}}\sqrt{\frac{2}{1+\varepsilon_r}}$ And $f_2 = \frac{c}{2L_{C2}}\sqrt{\frac{2}{1+\varepsilon_r}}$

The calculated resonant frequencies for Antenna 2 are $f_1 = 4.24GHz$ and for Antenna 3 are $f_2 = 3.3GHz$ which are very close to the simulated and measured results.

The simulated and measured radiation patterns for reference antenna, Antenna 2 and Antenna 3 have been shown in Figure 14. The simulated and measured 3dB beam width of all antennas under study is within 60^0-70^0. The cross polarized field is well below than the co-polarized field.



(a) (b)

(c)

Figure 14. Radiation Pattern of (a) Reference Antenna at 9GHz, (b) Antenna 2 at 4.6GHz and (c) Antenna 3 at 3.7GHz

6. Conclusion

In this paper effects of two identical notches parallel to the radiating edges are studied when they are in the same side and opposite side. It has been found that when the notches are in the opposite side the resonant frequency and gain are lower than the resonant frequency and gain when the notches are in the same side. The measured results are well agreed with the simulated values. The equivalent circuits are drawn with the concept of the series and parallel resonant circuit's frequency and gain responses. The resonant frequency can also be found out by taking the total current length path from the current distribution. About 80.2% size reduction has been achieved by the dual notches in the same non radiating edge and about 87.5% size reduction is achieved for the dual notches in the opposite non radiating edges. But the gain of the antenna for the dual notches in the opposite non radiating edges falls drastically which may be increased by any gain enhancement method. The proposed antenna may be suitable for INSAT system and WiMAX applications at 4.6GHz and 3.7GHz respectively.

Acknowledgments

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