Formulation of Resonant Length for Triple Band Slot Cut Stub Loaded Rectangular Microstrip Antenna

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ABSTRACT
The multi band microstrip antenna is realized either by placing stub on the edges of the patch or by cutting slots at an appropriate position inside the patch or by using the combination of these two methods. In this paper an analysis to study the effects of stub and slot in dual stub loaded and stub loaded pair of rectangular slot cut rectangular microstrip antennas is presented. The additional stub or slot reduces the resonance frequency of higher order mode of the single stub loaded patch and along with the modified modes of stub loaded rectangular patch, yields triple frequency response. Further by studying the surface current distributions at modified modes of the rectangular patch, a formulation in resonant length in terms of stub and slot dimensions is proposed. The frequencies calculated using the proposed formulations agrees closely with the simulated results. The proposed study gives an insight into the functioning of slot cut and stub loaded antennas and proposed formulations can be used to design them at give frequencies.

Keywords
Rectangular microstrip antenna, Multi-band rectangular microstrip antenna, Open circuit stub, Rectangular slot, Higher order mode

1. INTRODUCTION
The multi-band microstrip antenna (MSA) is realized by cutting more than one slot inside the patch or by placing dual stubs on the edges of the patch or by using the combinations of slot and stub [1 – 6]. It is a general understanding in these stub loaded MSAs that when stub length nearly equals quarter wavelength then it offers capacitive or inductive impedance around the resonance frequency of the patch to realize dual frequencies. Also in slot cut MSAs, when slot length equals either half wave or quarter wave in length then it adds another resonant mode near the fundamental patch mode, to realize dual and triple band response. However, while designing these multi-band MSAs at given frequencies this simpler approximation of slot length against wavelength does not give closer results. The detail analysis to study the effects of slot or stub in these dual and triple band MSAs have been carried out [7, 8]. It was observed that the slot or stub does not introduce any additional mode near the patch resonance frequency but they reduces the resonance frequency of higher order orthogonal mode of the patch and along with fundamental patch mode yields dual and triple band response. The slot and stub also modifies the surface current distribution at higher order patch mode and aligns them in the same direction as that of the currents at fundamental patch mode which yields broadside radiation pattern over dual and triple frequencies.

In this paper, triple band configurations of stub loaded and slot cut rectangular MSA (RMSA) are discussed. The dual stub loaded and pair of rectangular slot cut stub loaded RMSAs are analyzed to study the effect of additional open circuit stub on the other edge of RMSA or the effects of pair of rectangular slot cut along the non-radiating edges of stub loaded RMSA. The additional stub or pair of rectangular slots mainly reduces the resonance frequency of higher order TM_{12} mode of the patch and further along with the modified modes (TM_{10} and TM_{02}) of stub loaded RMSA realizes triple frequency response. Since the surface currents at modified first two modes remains along horizontal direction inside the patch, radiation pattern at them is in the broadside direction with E and H-planes aligned along $\Phi = 0^0$ and 90^0, respectively. The surface currents at TM_{12} mode in stub loaded RMSA is varying along patch length and width. This gives radiation pattern with maximum in the end-fire direction with E and H-planes aligned along $\Phi = 90^0$ and 0^0 respectively. With increasing stub or slot length the surface currents at modified TM_{12} mode is aligned along horizontal direction inside the patch which gives broadside radiation pattern with E-plane aligned along $\Phi = 0^0$. Thus the polarization at three frequencies remains in the same direction. Further by studying the surface current distribution at modified modes in dual stub loaded and slot cut stub loaded RMSAs, a formulation in resonant length at triple frequencies is proposed. The frequencies calculated using the proposed formulation agrees closely with the simulated results obtained using IE3D software [9]. The proposed analysis is carried out and the formulations are proposed on glass epoxy substrate (h = 0.16 cm, ε_r = 4.3, tan δ = 0.02). The proposed analysis will help in understanding the functioning of slot cut stub loaded antennas.

2. Triple band RMSAs
The triple band stub loaded and slot cut RMSAs are shown in Fig. 1(a, b). The equivalent patch length 'L' is selected such that it resonates in its TM_{10} mode at frequency of around 900 MHz. Using glass epoxy substrate, 'L' was found to be 8 cm. The patch width 'W' is selected to be 10 cm. The open circuit stub of length 4 cm and width 0.4 cm is placed on one of the radiating edges of the patch as shown in Fig. 1(a). The feed point is placed towards the other radiating edge of the RMSA. The resonance curve plot for the stub loaded RMSA is shown in Fig. 1(c). The placement of stub reduces the TM_{10} and TM_{02} mode resonance frequencies of RMSA to realize dual frequency response. The stub has also reduced TM_{12} mode resonance frequency of the RMSA. To realize triple frequency response, another stub of length 'l_1' and width 'w' is placed on the other edge of the patch as shown in Fig. 1(a). To optimize for triple frequency response, a parametric study for variation in stub length is carried out and resonance curve plot for stub length variation from 0 to 3 cm are shown in Fig. 1(c). The placement of second stub further reduces the resonance frequency of TM_{10}, TM_{02} and TM_{12} modes. The

reduction in TM_{12} mode frequency is higher and it comes closer to other two resonance frequencies. The surface current distribution and radiation pattern at TM_{12} mode for two different stub lengths are shown in Fig. 2(a – d). Since the surface currents at modified TM_{12} mode for smaller second stub length are directed along patch length and width, the radiation pattern is conical i.e. maximum in the end-fire direction. With an increasing stub length the contribution of surface currents along patch length increases which leads to the broadside radiation pattern. Also with an increasing stub length, E-plane direction shifts from $\Phi = 90^0$ to 0^0. This leads to the same polarization over the three frequencies. Similar study is carried out for triple band pair of rectangular slot cut stub loaded RMSA as shown in Fig. 1(b) and the resonance curve plot for the same is shown in Fig. 3(a).

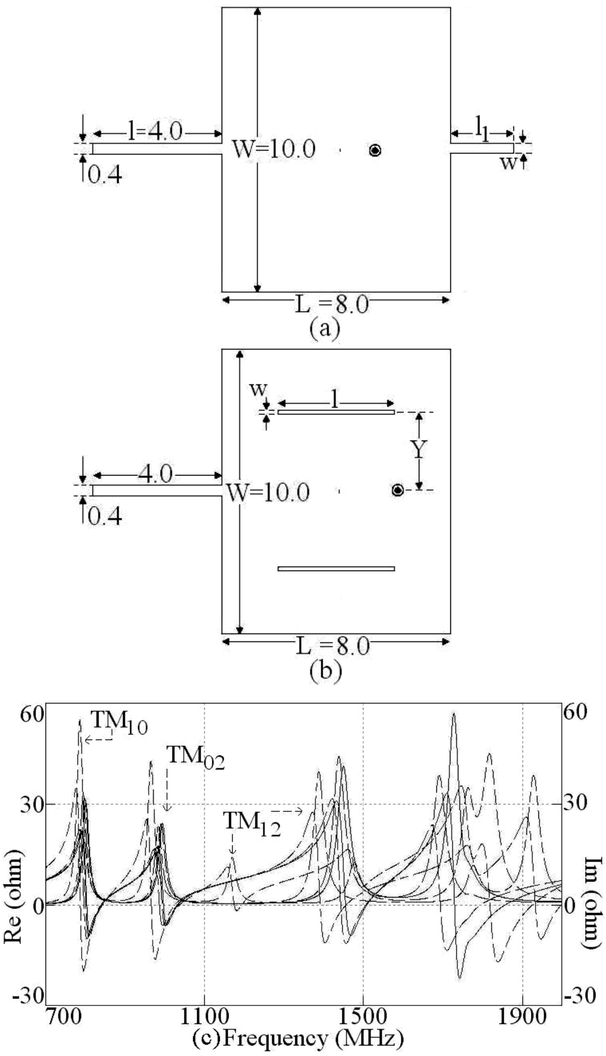

Fig. 1 Triple band (a) stub loaded and (b) pair of rectangular slot cut RMSAs and (c) resonance curve plots for dual stub loaded RMSA, (——) l_1 = 0 cm, (— —) l_1 = 1 cm, (—‒‒—) l_1 = 2 cm, (‒‒‒) l_1 = 3 cm

The slots are parallel to the surface currents at modified TM_{10} and TM_{02} modes, hence reduction in there frequency with slot length is negligible. The slots are orthogonal to the surface currents at modified TM_{12} mode hence reduction in its frequency is higher. This frequency comes closer to modified TM_{10} and TM_{02} modes to realize triple frequency response. The surface current distribution and radiation pattern for two different slot lengths is shown in Figs. 3(b, c) and 4(a, b).

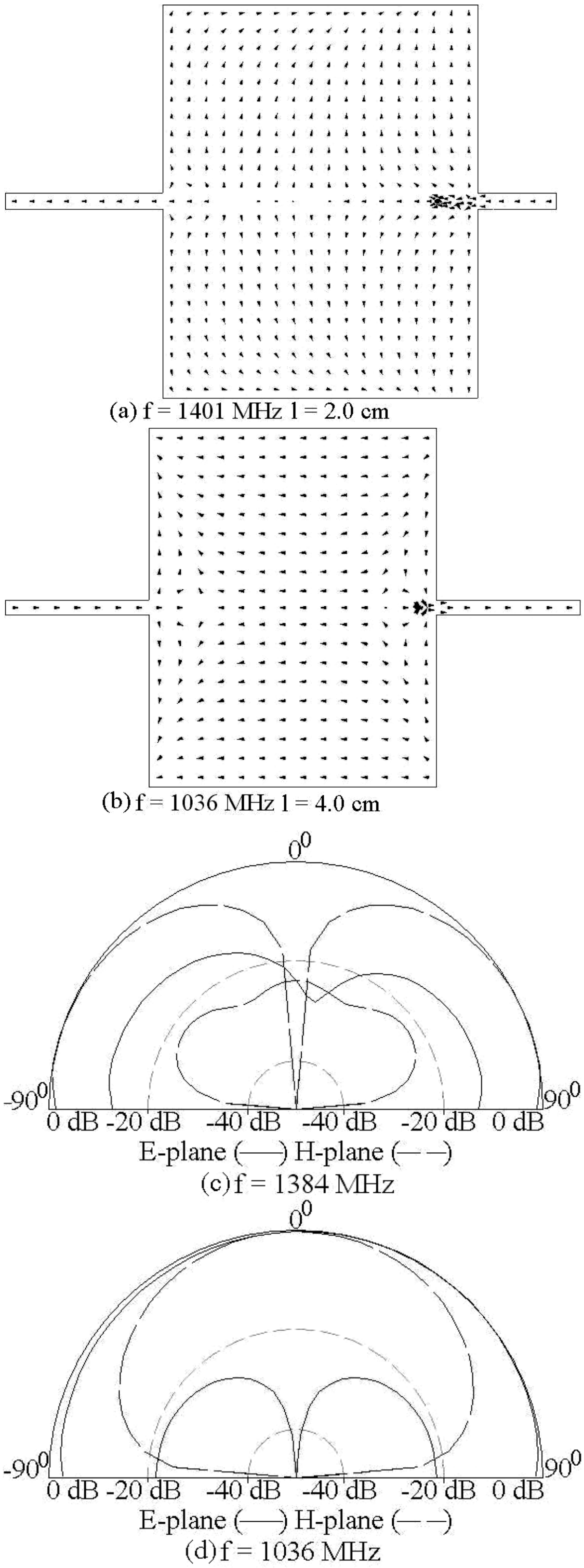

Fig. 2 (a, b) Surface current distribution and radiation pattern at modified TM_{12} mode for l_1 = (c) 2 cm and (d) 4 cm

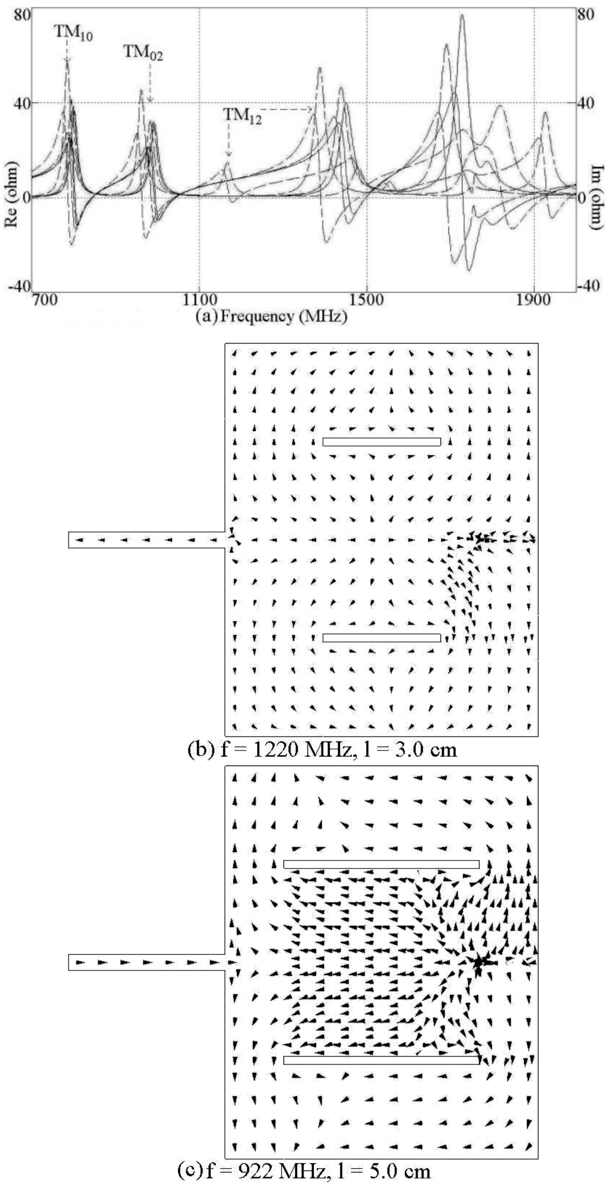

Fig. 3 (a) Resonance curve plot, (—) l = 0 cm, (— —) l = 2 cm, (— – —) l = 3 cm, (– – –) l = 4 cm and (b, c) surface current distribution at modified TM_{12} mode for pair of rectangular slot cut stub loaded RMSA

With an increase in slot length the contribution of surface currents along the patch length increases. This changes the direction of radiation pattern from end-fire to broadside and the direction of E-plane from $\Phi = 90^0$ to 0^0. At first two modes, surface currents are aligned along the horizontal direction which gives E-plane along $\Phi = 0^0$. Thus slot cut stub loaded antenna has same polarization at the three frequencies.

3. FORMULATION OF RESONANT LENGTH FOR TRIPLE BAND RMSAs

By studying the surface current distribution the formulation in resonant length for triple band RMSAs is proposed. In dual stub loaded RMSA, the placement of second stub modifies all the three frequencies. The formulation at TM_{10}, TM_{02} and TM_{12} modes is obtained by using equations (1) – (10). In the proposed formulations, the effective patch length (L_e) or width (W_e) is calculated by modifying L or W in terms of stub length. The resonance frequencies at individual modes are calculated by using equations (2), (5) and (9) and the % error between the calculated and simulated values is obtained by using equations (3), (6) and (10). For w = 0.4 cm, they are plotted in Fig. 5(a – c). For complete stub length range a closer approximation between two results is obtained.

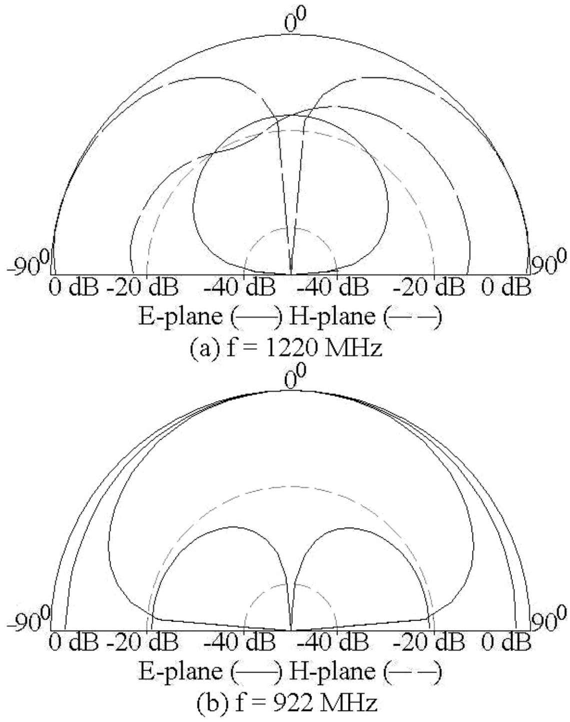

Fig. 4 Simulated radiation pattern for pair of rectangular slot cut stub loaded RMSA for l = (a) 3 and (b) 5 cm

At TM_{10} mode,

$$L_e = L + 2\left(h/\sqrt{\varepsilon_r}\right) + l_1\left(l_1/(3L)\right)\sin\left(\pi l_1/W\right) + 0.9w + 2l\left(l/(4L)\right)\sin\left(\pi l/W\right) \quad (1)$$

$$f_{10} = \frac{c}{2L_e\sqrt{\varepsilon_{re}}} \quad (2)$$

$$\%error = \left(\frac{f_{10} - f_{ie3d}}{f_{ie3d}}\right)x100 \quad (3)$$

At TM_{02} mode,

$$W_e = W + 2\left(h/\sqrt{\varepsilon_r}\right) + l_1\left(l_1/(0.45W)\right)\sin\left(\pi l_1/W\right) + w + 2l\left(l/(1.3W)\right)\sin\left(\pi l/W\right) \quad (4)$$

$$f_{02} = \frac{c}{W_e\sqrt{\varepsilon_{re}}} \quad (5)$$

$$\%error = \left(\frac{f_{02} - f_{ie3d}}{f_{ie3d}}\right)x100 \quad (6)$$

At TM_{12} mode,

$$L_e = L + 2\left(h/\sqrt{\varepsilon_r}\right) + l_1\left(l_1/(1.5L)\right)\sin\left(\pi l_1/W\right) + w + 2l\left(l/(1.3L)\right)\sin\left(\pi 1.3l/W\right) \quad (7)$$

$$W_e = W + 2(h/\sqrt{\varepsilon_r}) + l_1(l_1/(1.5W))\sin(\pi l_1/W) + w + 2l(l/(0.7W))\sin(\pi 1.3l/W) \quad (8)$$

$$f_{12} = \frac{c}{2\sqrt{\varepsilon_{re}}}\left(\sqrt{\left(\frac{m}{L_e}\right)^2 + \left(\frac{n}{W_e}\right)^2}\right) \quad (9)$$

$$\%error = \left(\frac{f_{12} - f_{ie3d}}{f_{ie3d}}\right) x100 \quad (10)$$

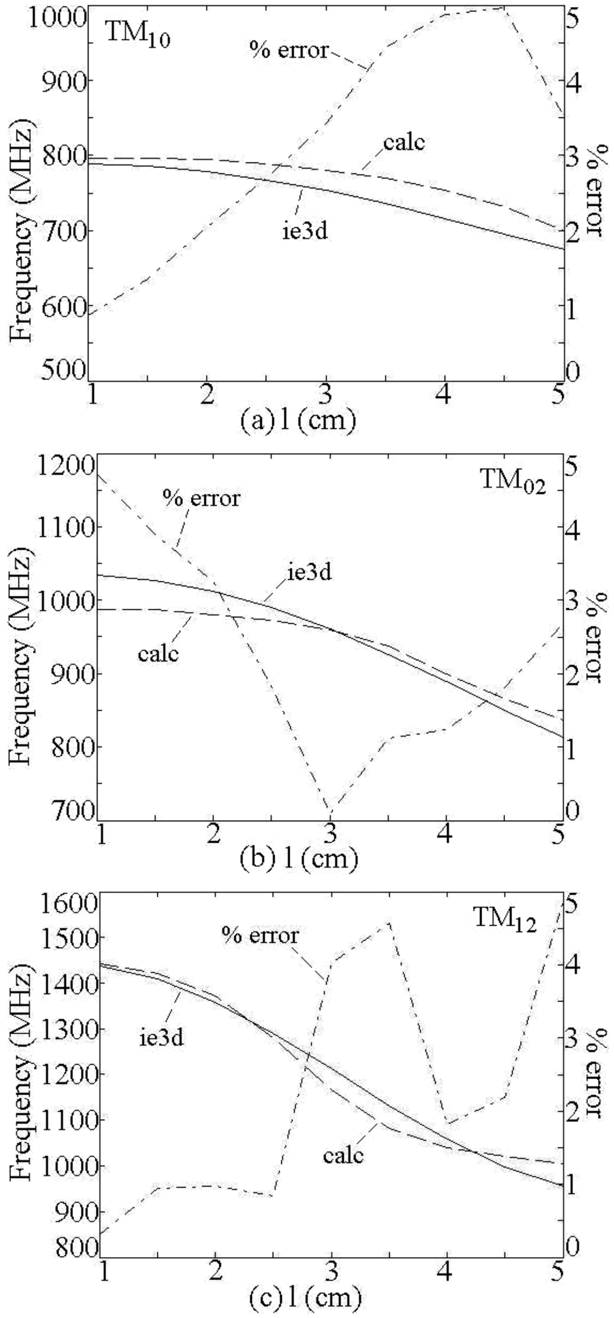

Fig. 5 (a – c) Resonance frequency and % error plots for dual stub loaded RMSA

In pair of slot cut stub loaded RMSA, decrease in modified TM_{10} and TM_{02} mode frequencies with slot length is negligible. Hence formulation in their resonant length is not proposed. The modified TM_{12} mode frequency reduces with slot length and the formulation at the same is given by using equations (11) and (12). The resonance frequency and % error between simulated and calculated values is obtained by using equations (9) and (10). For different values of Y, they are plotted in Fig. 6 (a – c). For the complete slot length range a closer match between simulated and calculated values is obtained.

$$L_e = L + 2(h/\sqrt{\varepsilon_r}) + l_1(l_1/(1.5L))\sin(\pi l_1/W) + w + 4l(l/(2L))\sin(\pi l/W) \quad (11)$$

$$W_e = W + 2(h/\sqrt{\varepsilon_r}) + l_1(l_1/(1.5W))\sin(\pi l_1/W) + w + 4l(l/(2.5W))\sin(\pi l/W) \quad (12)$$

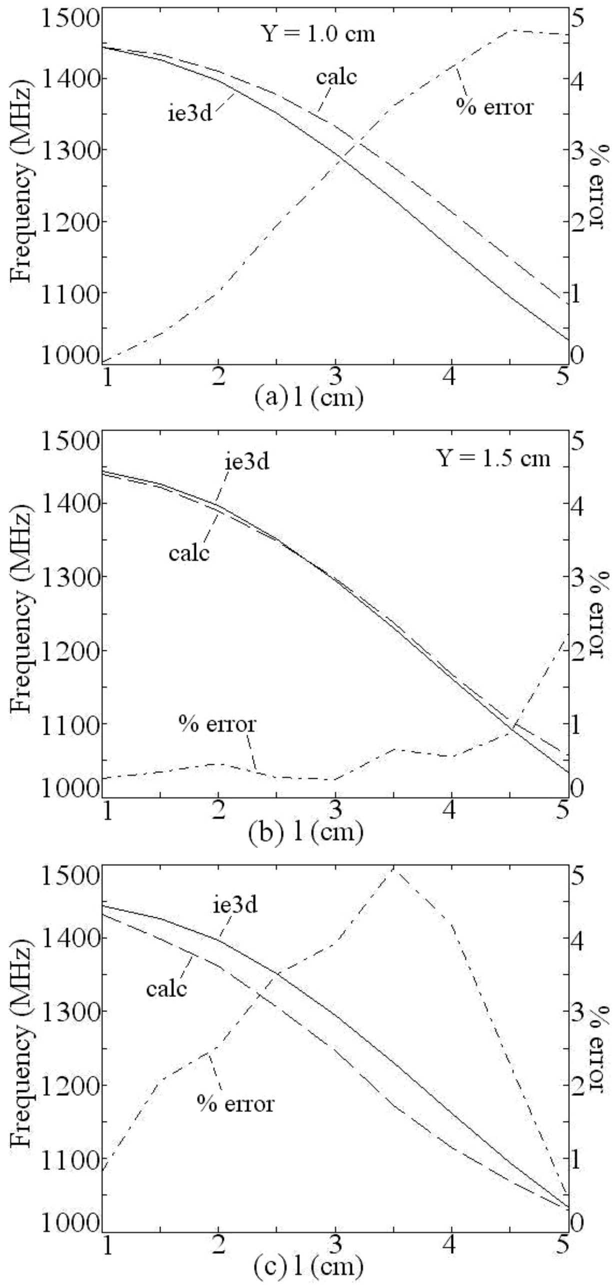

Fig. 6 (a – c) Resonance frequency and % error plots for dual stub loaded pair of rectangular slot cut RMSA

4. CONCLUSIONS

The triple band stub loaded and slot cut RMSAs are discussed. An analysis to study the effect of additional stub or pair of slots on the triple band response in stub loaded RMSA is presented. The additional stub or slot reduces higher order TM_{12} mode resonance frequency of the patch to realize triple frequency response. It also modifies the surface current distribution at higher order mode, thereby it realizes same polarization over all the frequencies. Further by studying the surface current distribution at modified TM_{10}, TM_{02} and TM_{12} modes of the patch, a formulation in resonant length is proposed. The frequencies calculated using the proposed formulation agrees closely with the IE3D results, which agrees within 2% with the measured results. The proposed study gives an insight into the functioning of slot cut stub loaded antennas and proposed formulations can be used to design them at given frequencies.

5. REFERENCES

[1] Kumar, G., and Ray, K. P. 2003, Broadband Microstrip Antennas, *First Edition*, USA, Artech House

[2] Garg, R., Bhartia, P., Bahl, I., and Ittipiboon, A., Microstrip Antenna Design Handbook, 2001, Artech House, USA.

[3] Ray, K. P., and Kumar, G., Circular Microstrip Antennas with double stubs, Proceedings of ISRAMT-99, Malaga, Spain, December 1999, pp. 381 – 384.

[4] Deshmukh, A. A., and Ray, K. P., Stub Loaded Multi-band Slotted Rectangular Microstrip Antennas, IET Proceedings on Microwave, Antennas & Propagation, vol. 3, no. 3, April 2009, pp. 529 – 535.

[5] Lee, K. F., Luk, K. M., Mak, K. M., and Yang, S. L. S., On the use of U-slots in the design of Dual and Triple band Patch Antennas, IEEE Antennas and Propagation Magazine, Vol. 53, No. 3, June 2011, pp. 60 – 74

[6] Lee, K. F., Yang, S. L. S., and Kishk, A. A., Dual and Mutliband U-slot patch Antennas, IEEE Antennas and wireless Propagation Letters, Vol. 7, 2008, pp. 645 – 647

[7] Deshmukh, A. A., Ray, K. P., Baxi, P., Kamdar, C., and Vora, B., Analysis of Stub Loaded Rectangular Microstrip Antenna, Proceedings of NCC – 2012, 3rd – 5th February 2012, IIT Kharagpur, India.

[8] Deshmukh, A. A., Ray, K. P., and Kadam, A., Analysis of slot cut Broadband and Dual band Rectangular Microstrip Antennas, Accepted for publication in IETE Journal of Research.

[9] IE3D 12.1, 2004. Zeland Software, Freemont, USA