Analysis of Multi-band stub loaded and two Half U-slot cut Rectangular Microstrip Antenna

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ABSTRACT
The multi-band microstrip antennas are realized by cutting more than one slots at an appropriate position inside the patch or by placing the open circuit stub on the edges of the patch or by using the combination of slots and stub. In this paper, an analysis to study the multi-band response in stub loaded two half U-slot cut rectangular microstrip antenna is presented. The first half U-slot in rectangular patch tunes the spacing between TM_{10} and TM_{01} mode frequencies to yield dual frequency response. The second half U-slot further optimizes the spacing between TM_{10}, TM_{01} and TM_{11} modes of the patch to yield triple frequency response. The placement of open circuit stub on patch edges further reduces the frequencies of TM_{11} and TM_{20} modes of rectangular patch to yield multi-band frequency response. The two half U-slots and open circuit stub re-orients the surface current distributions at first four patch resonant modes, to realize broadside radiation pattern over four frequencies without any variations in the directions of principle planes. The proposed analysis gives an insight into the functioning of slot cut stub loaded multi-band rectangular microstrip antennas and will help to design them at desired frequencies.

Keyword
Rectangular microstrip antenna, Multi-band microstrip antenna, Rectangular slot, Half U-slot, Open circuit stub, Higher order mode

1. INTRODUCTION
The multi-band microstrip antenna (MSA) are realized either by cutting the slots at an appropriate position inside the patch or by placing the stub on the edges of the patch or by using the combinations of slots and stub [1 – 12]. The slot is said to introduce an additional resonant mode near the fundamental patch mode when its length nearly equals half wave or quarter wave in length. The slot of different shapes like, U-slot, V-slot, pair of rectangular slots or their modified variations like, half U-slot, rectangular slot have been used to generate dual or triple frequency response. In stub loaded MSAs, stub introduces two modes around the fundamental mode frequency of the patch when its length nearly equals quarter wave in length. It is reported that mode introduced by slot or stub gives identical polarization over multiple frequencies thereby giving broadside radiation pattern with no variations in the directions of E and H-planes. However it was observed that simpler approximations of stub length or slot length against the multiples of half or quarter wavelength does not give closer results while designing them at given frequencies. The analysis to study the effects of pair of rectangular slot, U-slot in dual band rectangular MSA (RMSA) is reported [13]. It was observed that slot does not introduce any additional resonant mode but it reduces the resonance frequency of higher order orthogonal TM_{02} mode and along with fundamental patch TM_{10} mode, yields dual frequency response. The slot also re-orients surface current distributions at orthogonal mode to yield broadside radiation pattern over dual frequencies without any variations in the directions of E and H-planes. In this paper, an analysis to study multi-band response in stub loaded two half U-slot cut RMSA is presented. The analysis of single half U-slot and dual half U-slot is presented first. The first half U-slot reduces the frequency of TM_{01} mode of the patch and along with TM_{10} mode yields dual band response. The second half U-slot further reduces the frequency of TM_{11} mode of half U-slot cut RMSA to realize triple frequency response. The placement of open circuit stub on the edges of two half U-slot cut RMSAs tunes the spacing between RMSA's TM_{10}, TM_{01}, TM_{11} and TM_{20} modes of RMSA to yield four band response. The surface current distributions over the first four resonant modes show orthogonal variations. The slot and stub length modifies the surface current contributions over four resonant modes that realizes broadside radiation pattern over multiple frequencies without any variations in the directions of E and H-planes. In the present analysis, stub loaded and half U-slot cut RMSAs were investigated on glass epoxy substrate (ε_r = 4.3, h = 0.16 cm, tan δ = 0.02) and the analysis is carried out using IE3D software [14]. The simulated results in stub loaded and slot cut RMSA, has been verified using measurements which is carried out on finite dielectric finite ground plane substrate. The impedance measurement was carried out using ZVH-8 vector network analyzer. Thus the proposed analysis gives an insight into the functioning of stub loaded and slot cut multi-band RMSA and it will help to design similar antennas in desired frequency range.

2. DUAL BAND RMSA
The multi-band stub loaded two half U-slot cut RMSA is shown in Fig. 1(a) [15]. It yields four band frequency response in 600 to 1400 MHz frequency range [15]. In this paper an analysis to study the four band response in this configuration is presented. First the frequency response of RMSA and half U-slot cut RMSAs is studied. The equivalent half U-slot cut RMSA is shown in Fig. 1(b). The dimensions of equivalent RMSA in slot cut configuration are L = 8.0 cm and W = 5.0 cm. It is simulated using IE3D software and its resonance curve plots for two different feed point locations is shown in Fig. 1(c). With the feed placed along patch length,

resonance curve shows excitation of TM_{10} and TM_{20} modes whereas when placed along offset location, in addition to these two modes, TM_{01} and TM_{11} modes are also present.

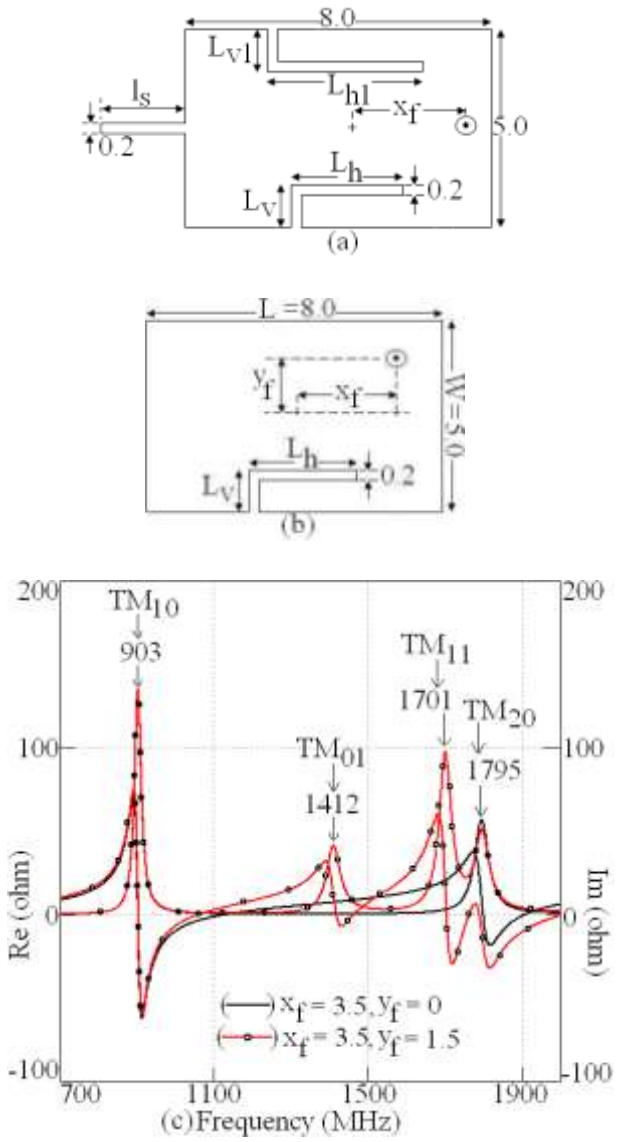

Fig. 1 (a) Multi-band RMSA [15], (b) half U-slot cut RMSA, (c) resonance curve plots for different feed point locations for RMSA

Inside this RMSA, half U-slot of dimension 'L_h' and 'L_v' is cut and resonance curve plots for increasing slot dimension is shown in Fig. 2(a). Here first vertical slot is cut followed by horizontal slot length. The increase in slot length reduces the frequencies of TM_{10}, TM_{01} and TM_{11} modes. The reduction in TM_{01} mode frequency is slightly higher and it comes closer to TM_{10} mode frequency. The dual band response is obtained for L_h = 3.0 cm as shown in Fig. 2(c). The simulated dual frequencies and BW's are 705 and 1085 MHz and 10 and 20 MHz, respectively. The surface currents at TM_{10} mode are horizontally directed whereas that at TM_{01} mode is vertically directed. The half U-slot re-orients some contribution of TM_{01} mode currents along the horizontal direction. The radiation pattern at TM_{10} mode (705 MHz) is in the broadside direction with E and H-planes aligned along $\Phi = 0^0$ and 90^0, respectively. The pattern at modified TM_{01} mode (1085 MHz) shows higher cross polar content due to vertical surface currents.

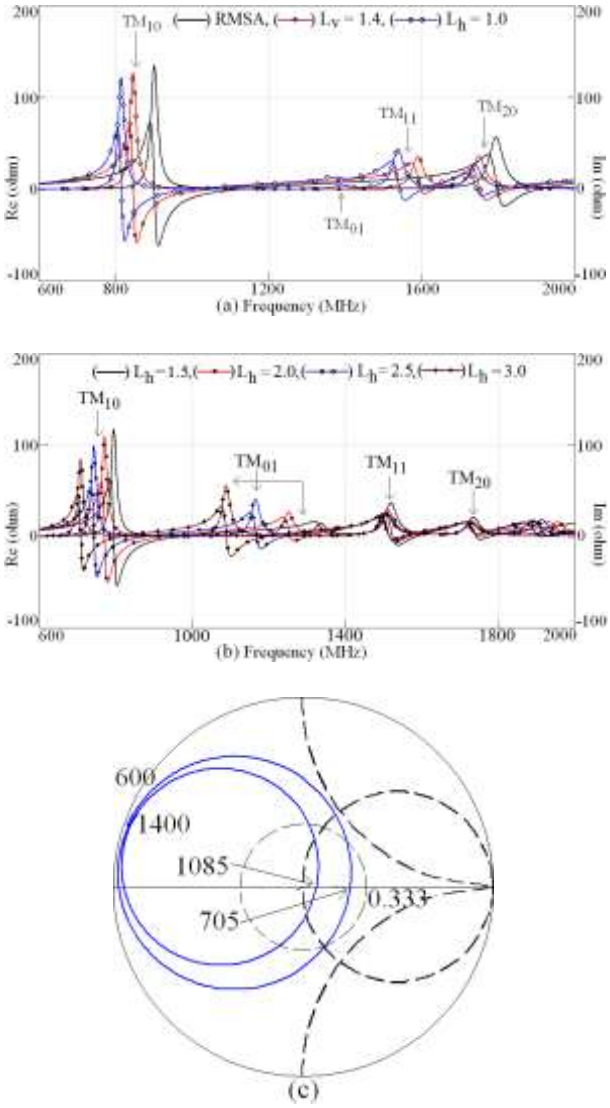

Fig. 2 (a, b) Resonance curve plots for varying slot dimension for half U-slot cut RMSA, and its (b) optimized simulated dual band response

Inside this slot cut RMSA, second half U-slot is cut on the other non-radiating edge of the patch as shown in Fig. 3(a). The resonance curve plots for length variation are shown in Fig. 3(b, c) and 4(a). It is observed from resonance curve that second half U-slot tunes the resonance frequencies of TM_{01} and TM_{11} modes with respect to TM_{10} mode. The reduction in TM_{11} mode frequency is slightly higher as compared to TM_{01} mode frequency. The triple frequency response is obtained for horizontal slot length of second half U-slot of 5.0 cm and its input impedance plots are shown in Fig. 4(b). The simulated triple frequencies and BW's are, 620, 754 and 1148 MHz and 8, 9 and 20 MHz, respectively. The input impedance plot also

shows formation of loop at 1591 and 1724 MHz. They are due to RMSA higher order modes like, TM_{20}. The surface current distribution at first four resonant modes for two half U-slot cut RMSA is shown in Figs. 4(c, d) and 5(a, b). Due to two half U-slots surface currents over all the modes are aligned along horizontal direction. Due to this over triple frequencies radiation pattern is broadside with E and H-plane aligned along $\Phi = 0^0$ and 90^0, respectively.

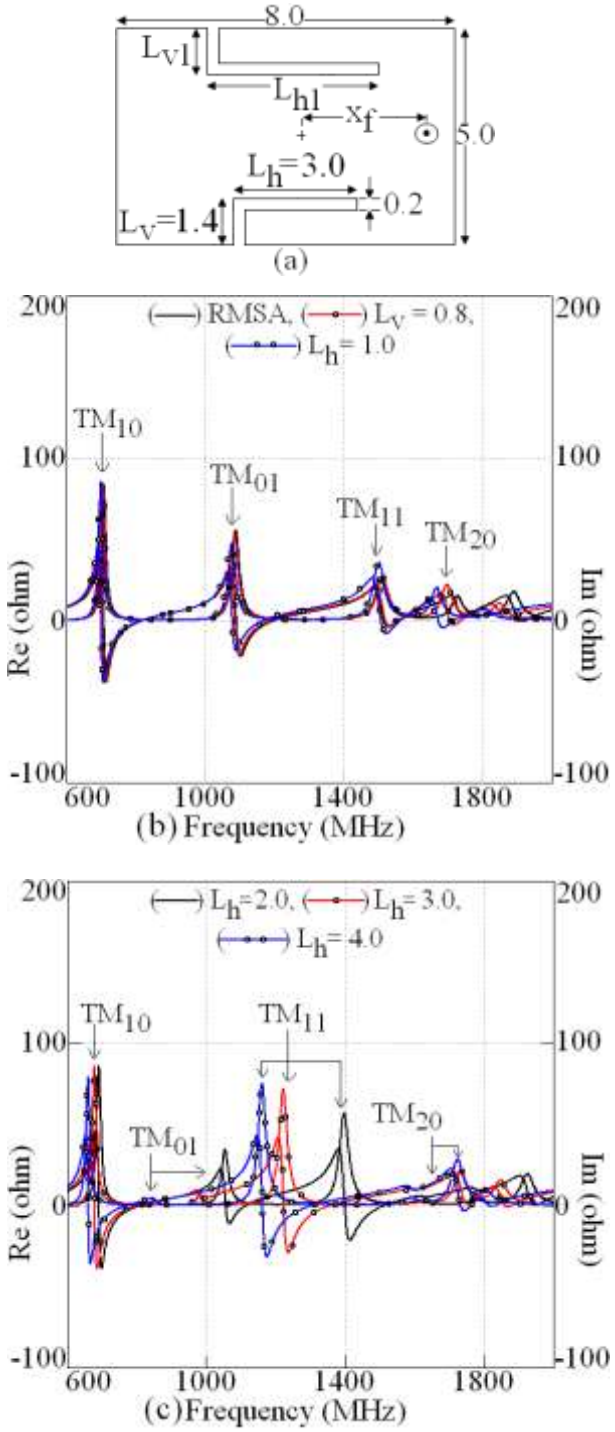

Fig. 3 (a) Two half U-slot cut RMSA and its (a, b) resonance curve plots for varying slot dimension

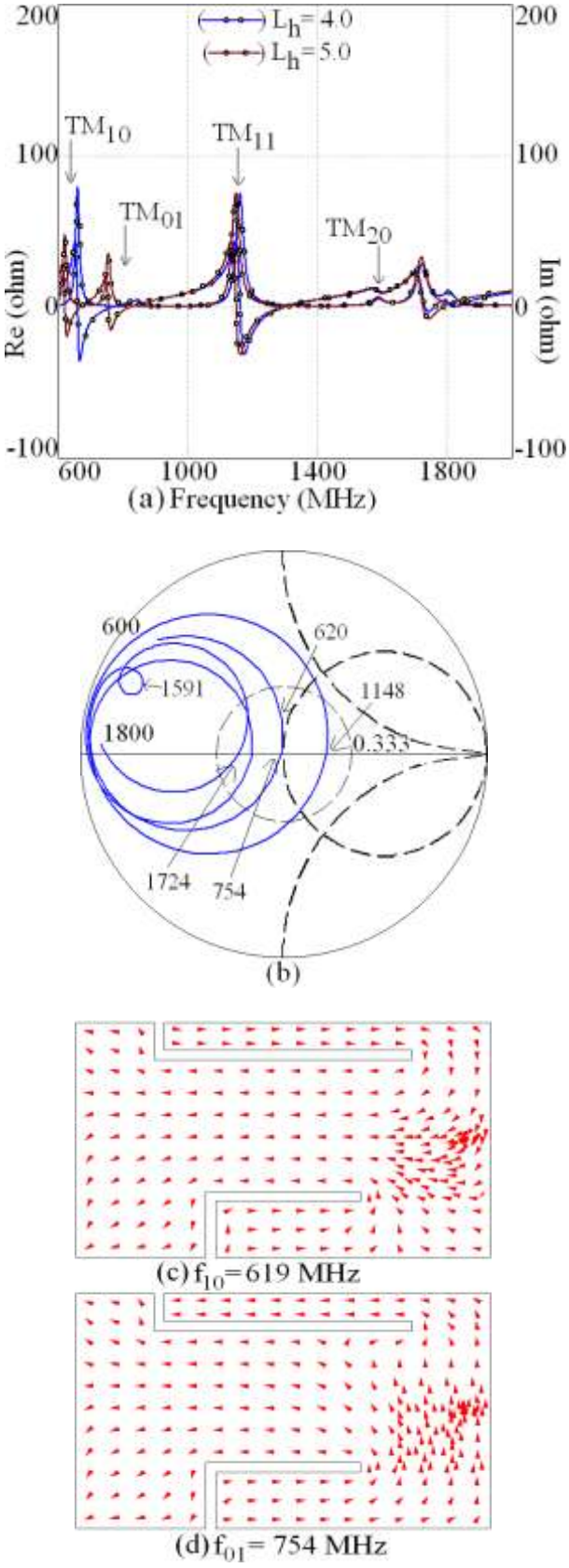

Fig. 4 (a) Resonance curve plots for varying slot dimension, (b) optimized simulated input impedance plots and (c, d) surface current distribution at first two modes for two half U-slot cut RMSA

The effects of variation in feed positions and effects of variation in horizontal and vertical slot dimensions in two half U-slot cut RMSA is also studied. The resonance curve plots for them are shown in Fig. 5(c) and 6(a, b), respectively.

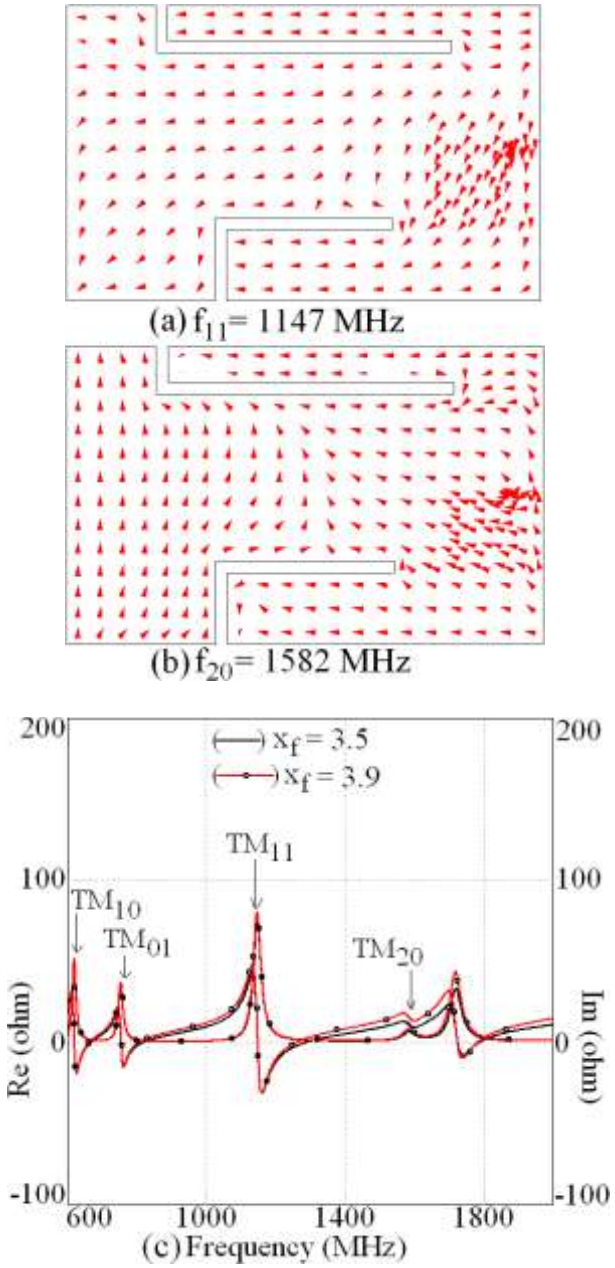

Fig. 5 (a, b) Surface current distribution at first two modes and (c) resonance curve plots for variation in feed point location for two half U-slot cut RMSA

The marginal variations in impedance at various modes are observed. With variation in half U-slot dimensions (L_{h1}, L_{v1}) TM_{10} mode frequency reduces whereas TM_{01} and TM_{11} mode frequencies increases. With variation in half U-slot dimension (L_h, L_v) all the modal frequencies increases. On one of the radiating edge of this slot cut RMSA, open circuit stub of length 'L_s' is placed as shown in Fig. 1(a). The resonance curve plots for varying stub length 'l_s' are shown in Figs. 6(c) and 7(a). With increases in stub length frequencies of various modes and impedance at them is optimized.

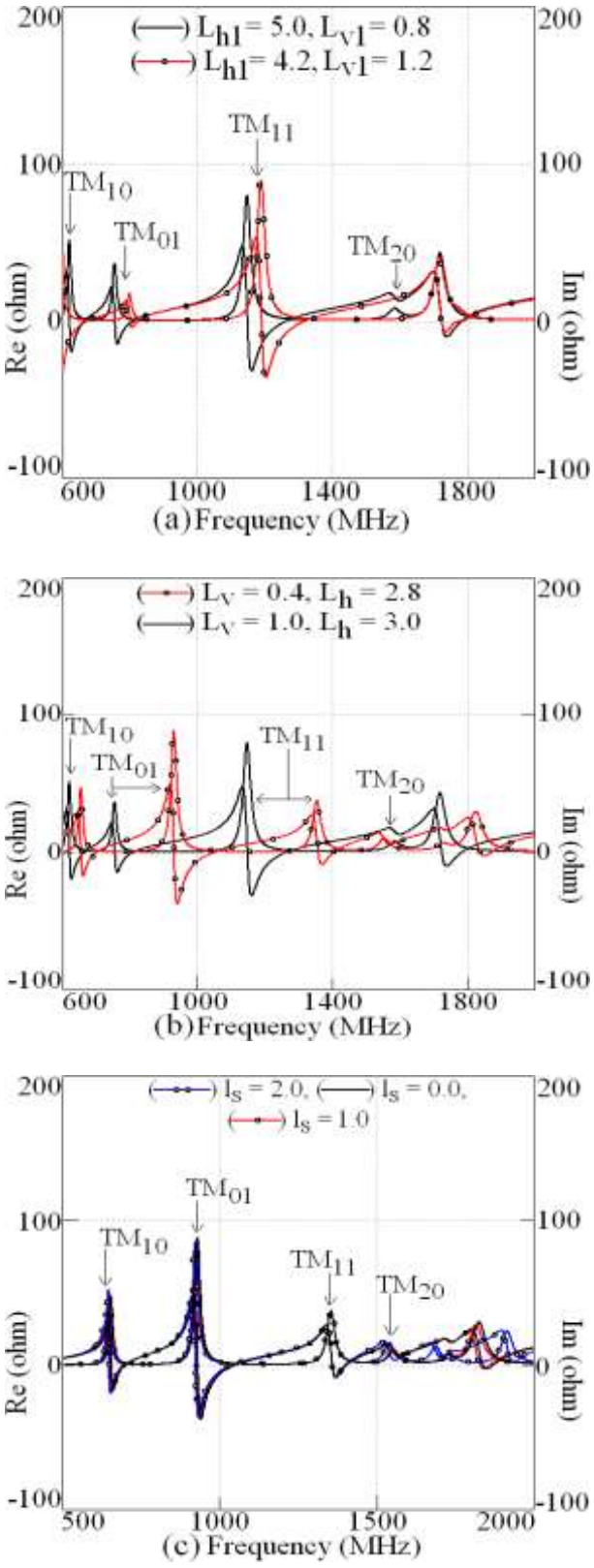

Fig. 6 (a, b) Resonance curve plots for variation in half U-slot dimensions and (c) resonance curve plots for variation in stub length in stub loaded two half U-slots cut RMSA

This yields multi-band response as shown in Fig. 7(b). The multiple frequencies and BW's are, 632, 887, 1046 and 1355 MHz and 10, 14, 12 and 16 MHz, respectively The current distributions over four resonant modes are varying along one direction inside the patch that gives broadside radiation pattern without any variations in directions of E and H-planes.

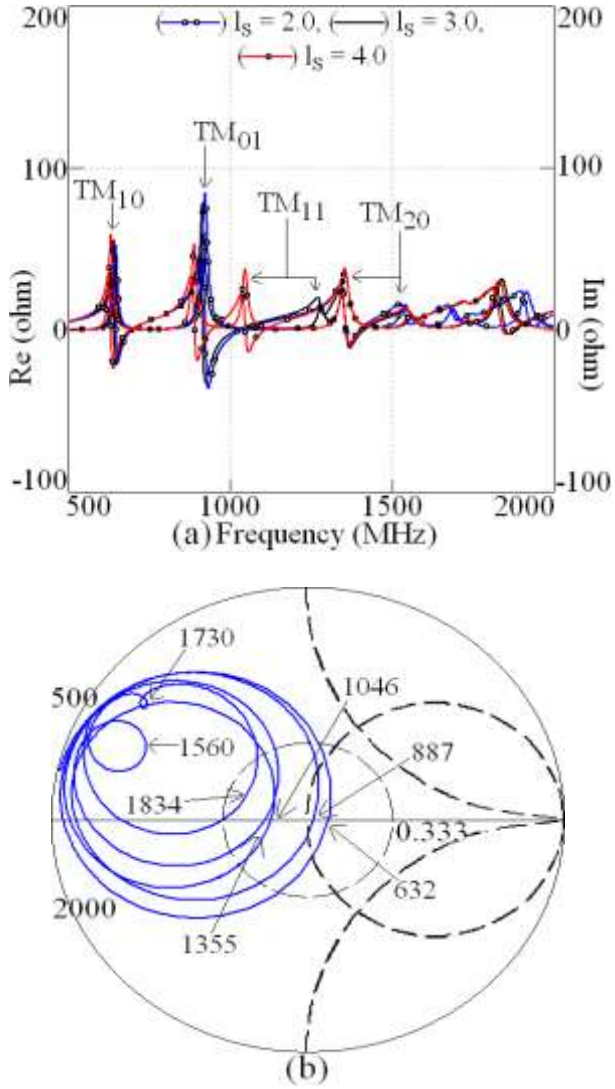

Fig. 7 (a) Resonance curve plots for variation in stub length and (c) optimized simulated input impedance plot for stub loaded two half U-slots cut RMSA

The above multi-band response in stub loaded and slot cut RMSA has been experimentally verified which shows closer agreement with simulated result [8]. Thus it can be inferred from above study that stub or slot does not introduce any modes but they modifies the resonance frequencies of higher order patch modes to realize multi-band response.

3. CONCLUSIONS

An analysis to study the multi-band response in stub loaded two half U-slot cut RMSA is presented. The stub and slot reduces the resonance frequencies of TM_{10}, TM_{01}, TM_{11} and TM_{20} modes of RMSA to yield multi-band response. The stub and slot also modifies surface current distributions at orthogonal higher order modes to realize broadside radiation pattern without any variations in directions of E and H-planes over the multiple frequencies. Thus the proposed analysis will help in understanding the functioning of stub loaded and slot cut MSAs which will help to design them at similar frequencies.

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