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Analysis of Stub Loaded Half U-Slot and Rectangular Slot Cut Multi-Band Rectangular Microstrip Antenna

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ABSTRACT
A microstrip antenna produces a multiband response due to various modifications done to the patch. These modifications include adding multiple stubs on the patch, or cutting multiple slots on the patch or using combination of stubs and slots. In this paper, an analysis to study the multi-band response in stub loaded half U-slot and rectangular cut rectangular microstrip antenna is presented. The paper begins with an analysis of half U slot cut and rectangular slot cut antenna which yields a triple band response. Here variations in current distribution and resonance frequencies are studied with respect to variation in length of the rectangular slot and then the position with half U slot cut dimensions kept constant. The paper then moves on to study the effect of variation of half U slot cut dimensions with rectangular slot length and position kept constant. Lastly the analysis of adding a stub on to this dual slot configuration is explained in detail. 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.

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

Keywords
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1. INTRODUCTION
A rectangular microstrip antenna (MSA) produces a single band response, fundamental mode of the patch being TM_{10}. Introducing stubs on the edges of the patch or cutting slots on this configuration gives rise to multi band response [1-5]. Dual band and triple band antennas using rectangular slot or half U slot or combination of the two is reported. The resonance curve plots, surface current distributions and radiation pattern plots for different slot lengths were studied. In dual band RMSAs, slot reduces the resonance frequency of orthogonal TM_{01} mode of the patch and along with TM_{10} mode yields dual frequency response. The slot also reduces TM_{11} mode resonance frequency of the RMSA. Further when an additional slot is cut it reduces higher order TM_{11} mode frequency of the slotted rectangular patch and along with TM_{10} and TM_{01} modes, yields triple frequency response. The formulation of resonant length in terms of slot and patch dimensions at dual and triple frequencies is also reported [6]. In another reported configuration, an analysis to study multi-band response in stub loaded two half U-slot cut RMSA is presented. It reports that a single half U-slot reduces the frequency of TM_{01} mode of the patch and along with TM_{10} mode yields dual band response. On introducing a second half U-slot TM_{11} mode frequency further reduces 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 [7]. In this paper, an analysis to study multi-band response in stub loaded half U-slot and rectangular slot cut RMSA is presented. The analysis of single half U-slot and rectangular slot cut at the side of the patch 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 rectangular slot further reduces the frequency of TM_{11} mode of half U-slot cut RMSA to realize triple frequency response. Effect on the frequency response and current distribution when the rectangular slot length or the position is varied when half U slot cut dimension are kept constant is presented in detail. Next the paper discusses the effect frequency modes and current distribution if the dimensions of the half U slot is varied keeping the rectangular slot length constant. Finally the placement of open circuit stub on the of this multi slot cut configuration tunes the spacing between RMSA's TM_{10}, TM_{01}, TM_{11} and TM_{20} modes of RMSA to yield four band response. 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 [8]. 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. 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. TRIPLE BAND DUAL SLOT CUT RMSA
The multi-band half U-slot and rectangular slot cut RMSA is shown in Figure 1(a). When a rectangular slot is added to a half U slot cut RMSA, it yields a triple band frequency response in 600 to 1500 MHz frequency range. Dimensions of half U slot vertical length (L_v) and horizontal length (L_h), are given as , L_v = 0.4 cm, L_h = 4.2 cm and w = 0.2 cm. The rectangular slot is cut at the edge of the patch, where Y = 4 cm and w = 0.2 cm. 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 different dimensions of slot are studied. The first analysis of this configuration includes observing the effects of length variation (l_1) of rectangular slot on current distribution and resonance curves, keeping the position of slot (Y) constant, Y= 4 cm. For this the half U slot cut dimensions are also kept

constant, L_h = 4.2 cm, L_v = 0.4 cm, and w = 0.2 cm. The three resonance frequencies that appear on the graph reflect TM_{10}, TM_{01}, and TM_{11} modes. It is observed that as l_1 increases TM_{11} frequency starts dropping. It is shown in Figure 1(b). The current orientation of this mode is along length and width of the patch. The increase in rectangular slot which is orthogonal to these currents causes them to realign with the patch length. This causes drop in frequency. The first two modes have current directions aligned with the patch length. The increase in l_1 is parallel to these currents and hence they have negligible effect. The current distributions for all three modes are shown in Figure 1(c-h).

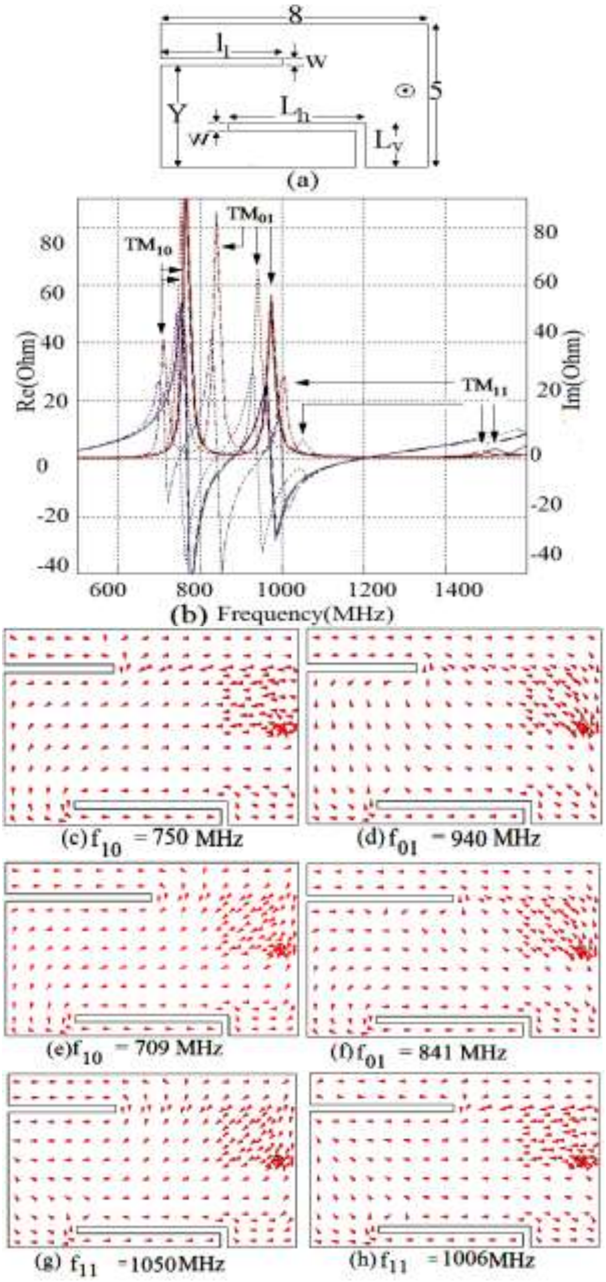

Figure 1(a): Triple band half U slot and rectangular slot cut RMSA, (b): Resonance frequency plot for l_1= 0(—), 1(--), 3(····), 4(.._..) cm, current distribution for l_1 = 3 cm (c) TM_{10} mode (d) TM_{01} mode, current distribution for l_1 = 4 cm (e) TM_{10} mode (f) TM_{01} mode, and current distribution for TM_{11} mode (g) l_1 = 3 cm (h) l_1 = 4 cm

The above configuration is then analyzed by keeping the dimensions of rectangular slot and half U slot constant. The position (Y) of the rectangular slot is however varied. Y which was initially taken at 4 cm is now taken as 3.5 cm and 4.5 cm. As observed in Figure 2 (a), when Y is moved towards the half U slot (Y = 3.5 cm), TM_{10} and TM_{01} mode frequency reduces, while TM_{11} frequency increases. On the other hand, when Y is moved away from the half U slot (Y= 4.5 cm), TM_{10} and TM_{01} frequency increases while TM_{11} frequency reduces. The differences in frequencies of TM_{10} for different Y values is around 40 MHz. It is almost similar for frequencies of TM_{01} mode for different Y locations. This difference is however seen less for third mode frequency. The current distribution for the same is shown below in Figure 2(b-g).

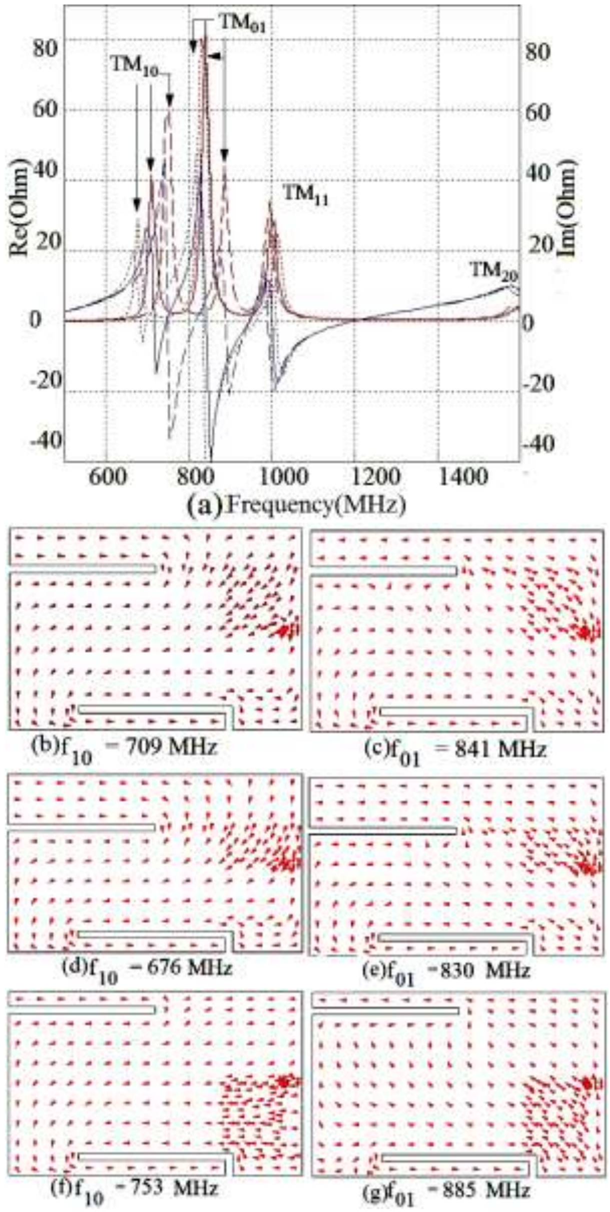

Figure 2(a): Resonance frequency plot for Y= 4(—), 4.5(--), 3.5(····) cm, current distribution for Y = 4 cm (b) TM_{10} mode (c) TM_{01} mode, current distribution for Y = 3.5 cm (d) TM_{10} mode (e) TM_{01} mode, and current distribution for Y = 4.5 cm (f) TM_{10} mode (g) TM_{01} mode.

The third modification to the same configuration is the done by changing the half U slot dimensions. In most of the reported slot cut designs, while designing at desired frequencies, slot length is taken to be either half wave or quarter wave in length. According to this approximation we have taken the dimensions as, L_v = 0.4 cm, and L_h = 4.2 cm. The total outer length of the half U slot becomes 4.6 cm. Maintaining this total length, we have changed L_v and L_h. On increasing L_v and reducing L_h it was observed that all three mode frequencies reduce, as shown in Figure 3(a). The TM_{10}, TM_{01} and TM_{11} mode frequencies for (L_v, L_h) = (4.2cm, 0.4 cm) are 764 MHz, 973 MHz and 1520 MHz respectively. For (L_v, L_h) = (3.6 cm, 1 cm) the frequencies for first two modes reduce by almost 150 MHz where as this reduction is around 450 MHz for third mode frequency. The current distributions shown in Figure 3 (b-g) clearly shows how the re orientation of current vector takes place.

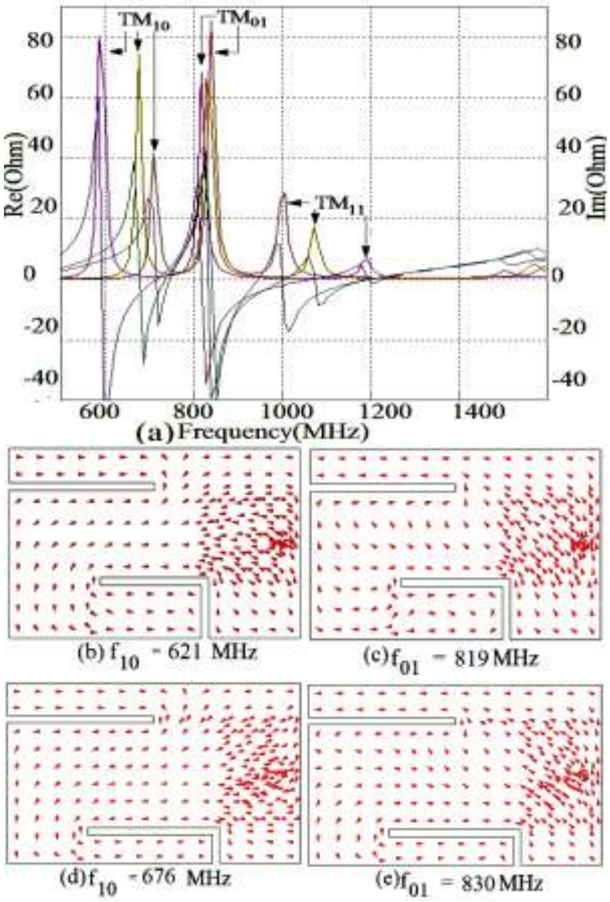

Figure 3(a): Resonance frequency plot for (L_v, L_h)= (4.2cm, 0.4cm)(—), (3cm, 1.6cm)(—),(3.6cm, 1cm) (—), current distribution for (L_v, L_h)= (3cm, 1.6cm) (b) TM_{10} mode (c) TM_{01} mode, current distribution for (L_v, L_h)=(3.6cm, 1cm) (d) TM_{10} mode (e) TM_{01} mode, and current distribution for (L_v, L_h) TM_{11} mode (f) (3cm, 1.6cm) (g))(3.6cm, 1cm)

3. MULTI BAND STUB LOADED SLOT CUT RMSA

The final analysis presented in this paper is when a stub is included on the radiating edge of the above multiple slot cut configuration. It is shown in Figure 4(a). In this configuration, length of the stub (L) is varied while keeping half U slot and rectangular slot dimensions same. With the feed placed along patch width, resonance curve shows excitation of TM_{10}, TM_{01}, TM_{11} and TM_{20} modes which is shown in Figure 4(b). The first two modes have already aligned with the length of the patch. The third mode TM_{11} reduces further with increase in stub length. Along with this we can also see that a new mode TM_{20} also appears and this mode frequency starts reducing with increase in stub length as shown in Figure 4 (c-f).

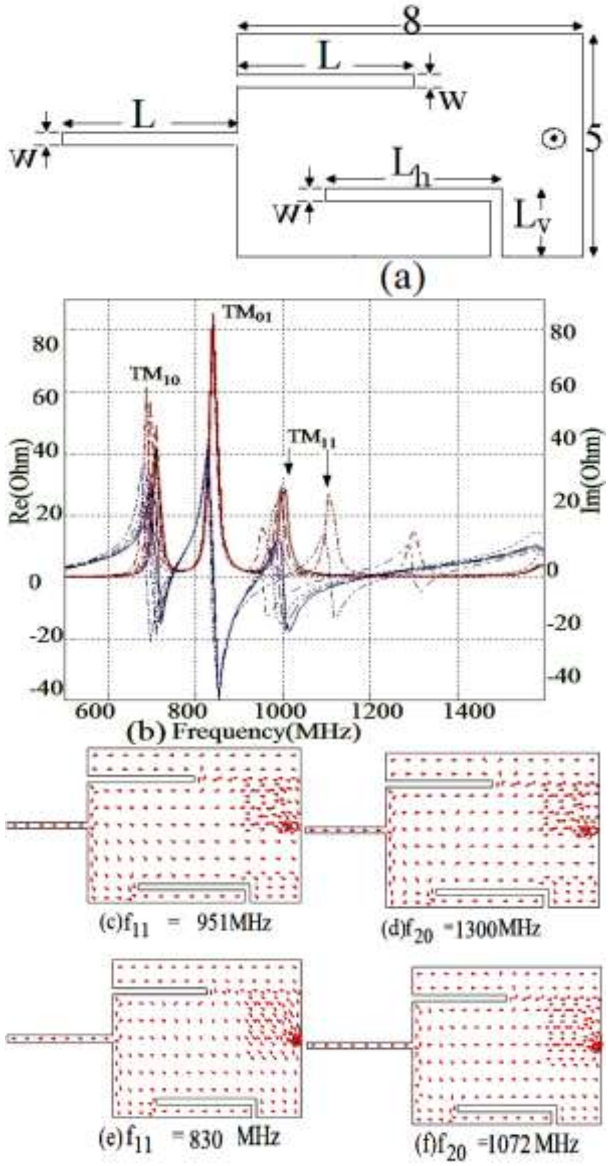

Figure 3(a) Stub loaded half U slot and rectangular slot cut RMSA, (b) Resonance frequency plot with L== 0(—), 1(--), 2(⋯), 3(._.), 4(.._..) cm, current distribution for L= 3cm, (c) TM_{11} mode (d) TM_{20} mode, current distribution for L= 4.5 cm, (e) TM_{11} mode (f) TM_{20} mode.

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.

4. CONCLUSIONS

An analysis to study the multi-band response in stub loaded rectangular slot and 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.

5. REFERENCES

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