Dual Band Shorted Rectangular Microstrip Antenna

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ABSTRACT
The compact rectangular microstrip antenna is realized by placing the shorting post or plate along the zero field line at the fundamental mode of the patch. The dual band antenna is realized by placing the stub on the edges of the patch. In this paper, first a compact shorted rectangular microstrip antenna is discussed. Further a dual band antenna realized by placing the stub on the opposite edge of the shorted rectangular patch, is proposed. The analysis to study the effects of stub on the dual band response in stub loaded antenna is presented. The stub reduces the resonance frequency of second order $TM_{3/4,0}$ mode of the shorted patch and along with the fundamental $TM_{1/4,0}$ mode yields dual frequency response. Further by studying the surface current distribution at the fundamental and higher order modes, the formulation in resonant length is proposed. The frequencies calculated using them agrees closely with simulated results with a % error less than 5% over the complete stub length range.

Keywords
Rectangular microstrip antenna, Shorted rectangular microstrip antenna, Compact microstrip antenna, Open circuit stub, Higher order mode

1. INTRODUCTION
With the advent of personal mobile communication the need for compact antenna has increased. The microstrip antenna (MSA) has been used in many of such applications. The more common techniques to realize compact MSA is by placing the shorting post or plate along the zero field line at the fundamental patch mode or by cutting the slot at an appropriate position inside the patch [1 – 3]. The shorting method converts the conventional half wave length resonator into quarter wavelength resonator whereas the slot increases surface current length for the given mode, thereby reducing its resonance frequency. Further dual band MSA is realized by cutting the slot inside the patch or by placing an open circuit stub of nearly quarter wave in length on the edges of the patch [4 – 8]. The stub is said to offer capacitive and inductive impedance around the resonance frequency of the patch to realize dual frequencies. To get an insight into the functioning of stub loaded MSAs, an analysis for varying stub length in dual band MSAs has been carried out [9]. The stub reduces the resonance frequency of orthogonal higher order mode of the patch and along with the fundamental patch mode yields dual band response. The stub also modifies the surface current directions at higher order mode and thereby gives broadside radiation pattern at the dual frequencies.

In this paper, first fundamental and higher order modes of the rectangular MSA (RMSA) and shorted RMSA for different feed point locations are discussed. All the modes which are present in the conventional RMSA are not present in the shorted patch as the impedance matching at them is not realized. Further a dual band stub loaded shorted RMSA is proposed. An analysis to study the effects of stub length on the dual band response is presented. The stub reduces the resonance frequencies of fundamental and higher order modes of the shorted RMSA and realizes dual frequency response. Since the shorted patch is used, the radiation pattern at the two frequencies is maximum in end-fire direction. Further by studying the surface current distribution at the dual frequencies, a formulation in resonant length is proposed. The frequencies calculated using them agrees closely with the simulated results obtained using IE3D software which agrees closely with the measured results [10]. The proposed analysis is carried out using glass epoxy substrate (h = 0.16 cm, ε_r = 4.3, tan δ = 0.02). The antenna is fed using the coaxial probe of 0.12 cm inner wire diameter and the measurement of optimized dual band antenna was carried out using R & S vector network analyzer.

2. RMSA and Shorted RMSA
The RMSA on glass epoxy substrate operating in its fundamental TM_{10} mode is shown in Fig. 1(a). Using the reported resonance frequency equation, the patch length 'L' is calculated such that it operates in TM_{10} mode at frequency of around 900 MHz. The patch width 'W' is taken to be more than its length. Around 900 MHz, the patch dimensions are, L = 8.0 cm and W = 10.0 cm. For feed point at location 'A', RMSA is simulated using IE3D software and its resonance curve plot is shown in Fig. 1(c). The plot shows peaks due to TM_{10} (892 MHz), TM_{02} (1436 MHz), TM_{12} (1713 MHz) and TM_{20} (1779 MHz) modes. The RMSA was simulated for offset feed point location 'B' as shown in Fig. 1(a) and its resonance curve plot is shown in Fig. 1(c). The plot shows additional peaks due to TM_{01} (720 MHz), TM_{11} (1161 MHz) and TM_{21} (1927 MHz) modes. At TM_{10} mode the RMSA shows zero field in the center. The compact RMSA is realized by placing the shorting plate along this zero field line as shown in Fig. 1(b). The shorted RMSA is a quarter wavelength resonator as against RMSA which is half wavelength resonator. It is simulated for two different feed point locations as shown in Fig. 1(b). The resonance curve plots for them are shown in Fig. 1(d). The surface current distribution at two peaks for feed point location 'C' and additional peak for feed point location at point 'D' are shown in Fig. 1(e – g).

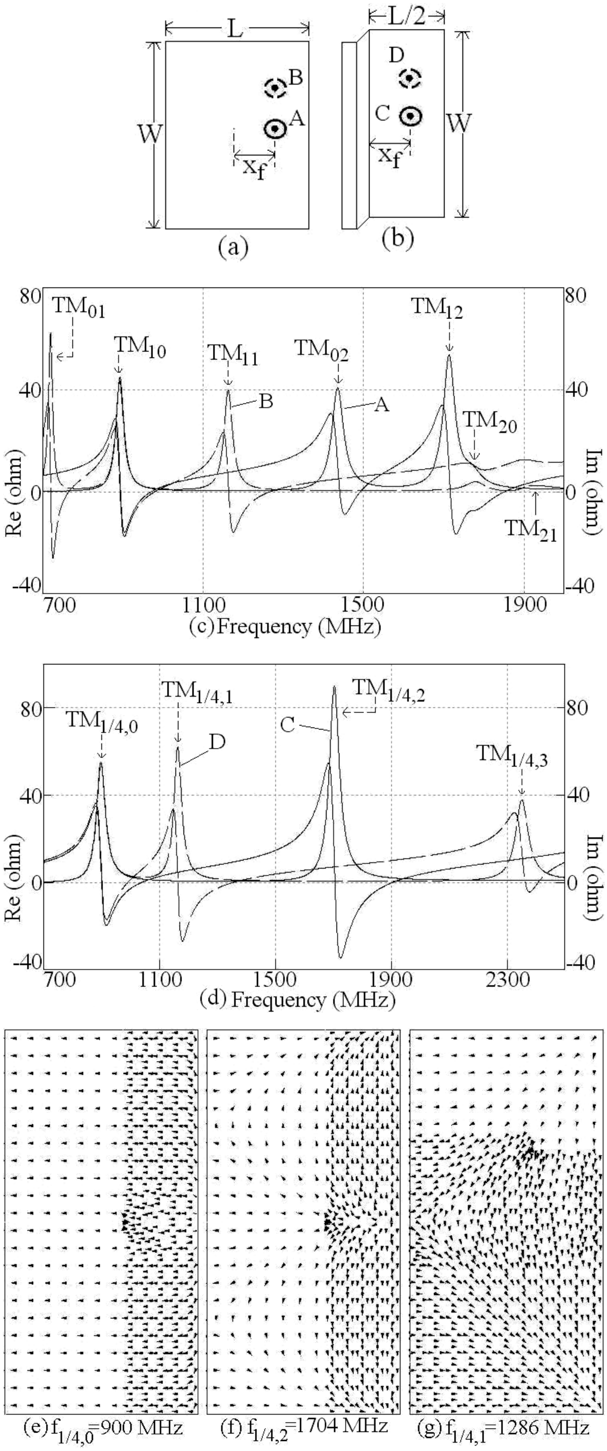

Fig. 1 (a) RMSA, (b) shorted RMSA, (c) resonance curve plots for RMSA with feed point at point (——) A, (— —) B, (d) resonance curve plots for shorted RMSA with feed point at point (——) C, (— —) D, (e – f) surface current distribution at various modes for shorted RMSA

For the feed point location at ‘C’, surface currents at first peak (900 MHz) show one quarter wavelength variation along shorted patch length. This is due to the $TM_{1/4,0}$ mode. At second peak (1704 MHz), the currents show one quarter wavelength variation along shorted patch length and two half wavelength variations along patch width. This mode is called as $TM_{1/4,2}$. For the offset feed point location at ‘D’, at an additional peak (1286 MHz), currents shows one quarter wave length variation along shorted patch length and one half wavelength variation along patch width. This mode is referred to as $TM_{1/4,1}$. To realize compact configuration, the patch width is reduced. The resonance curve plots for different shorted patch widths are shown in Fig. 2(a). With decrease in patch width from 10 to 6 cm, the resonance frequency of $TM_{1/4,0}$ mode remains constant whereas that of $TM_{1/4,2}$ mode increases from 1704 to 2685 MHz. The resonance curve plot for shorted RMSA using five shorting post against shorting plate is shown in Fig. 2(b). When the MSA is shorted using shorting posts, various mode resonance frequencies decreases.

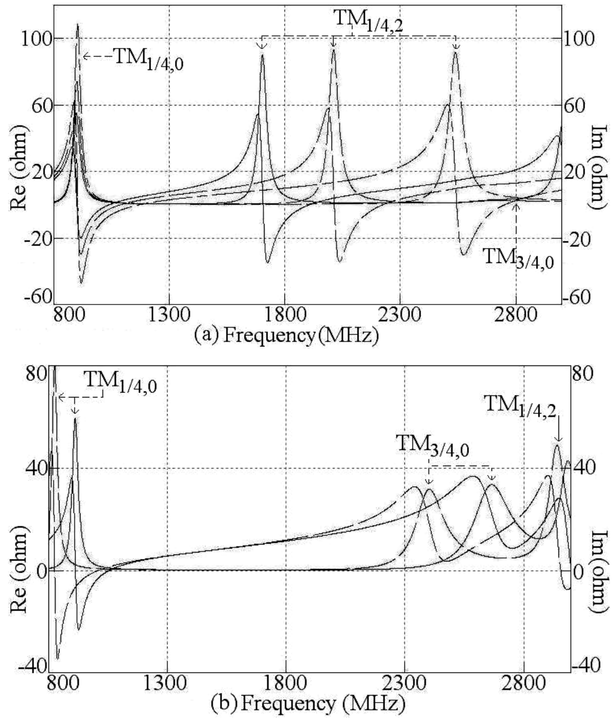

Fig. 2 Resonance curve plots for (a) varying patch width, (——) W = 10 cm, (— —) W = 8 cm, (— - —) W = 6 cm and (b) for RMSA with (——) shorting plate, (— —) shorting post

3. DUAL BAND STUB LOADED SHORTED RMSA

To realize dual band configuration, an open circuit stub of length ‘l’ and width ‘w’ is placed on the other edge of the shorted patch as shown in Fig. 3. For different ‘w’, stub length is increase in steps of 0.5 cm and for each of the lengths, resonance curve plots, surface current distribution and simulated radiation pattern plots were studied. The resonance curve plot for varying stub length is shown in Fig. 4(a).

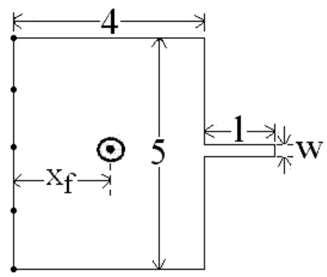

Fig. 3 Dual band stub loaded shorted RMSA

With an increase in stub length, resonance frequencies of $TM_{1/4,0}$, $TM_{3/4,0}$ and $TM_{1/4,2}$ mode decreases. The amount of decrease in $TM_{3/4,0}$ mode resonance frequency is larger. For larger stub length it comes closer to $TM_{1/4,0}$ mode resonance frequency. The dual band response is realized when the spacing of $TM_{3/4,0}$ mode frequency is optimized with respect to $TM_{1/4,0}$ mode. The surface current distribution at modified $TM_{3/4,0}$ and $TM_{1/4,2}$ modes is shown in Fig. 4(b, c). With an increasing stub length, more amounts of surface currents are oriented along the horizontal direction inside the patch. Since at the two modes, surface currents show one and three quarter wavelength variations, the radiation pattern at the two frequencies remains maximum in the end-fire direction with higher cross-polarization levels. Further by studying the surface current distribution at $TM_{1/4,0}$ and $TM_{3/4,0}$ frequencies, a formulation in resonant length is proposed as discussed in the following section.

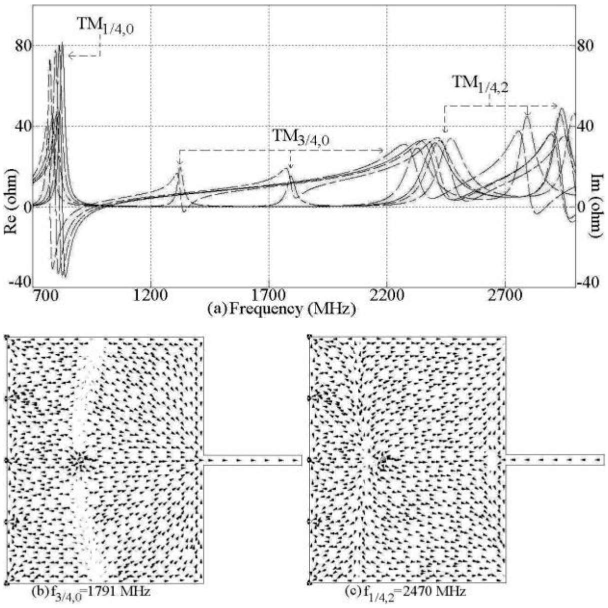

Fig. 4 (a) Resonance curve plots, (——) l = 0 cm, (— —) l = 1 cm, (— - -—) l = 2 cm, (- - -) l = 3 cm, and (b, c) surface current distribution at two modes for stub loaded shorted RMSA for l = 2.0 cm

4. FORMULATION OF RESONANT LENGTH FOR SHORTED STUB LOADED RMSAs

The formulation of resonant length at $TM_{1/4,0}$ and $TM_{3/4,0}$ modes is obtained by modifying shorted patch length in terms stub dimensions. At $TM_{1/4,0}$ mode, formulation in resonant length is obtained by using equation (1). The second term in equation (1) accounts for fringing field extension towards the open circuit edges of the patch. The third term in equation (1) accounts for extension in shorted patch length due to stub length. The resonance frequency is calculated using equation (2) and % error (E) between simulated and calculated values is calculated using equation (3) and they are plotted in Fig. 5(a – c) for w = 0.2 to 0.6 cm. For the complete stub length range a closer approximation between calculated and simulated values is obtained. Similarly formulation of resonant length at $TM_{3/4,0}$ mode is obtained by using equations (4) and (5).

$$L_e = L + \Delta l + l\left(\frac{l}{4.5L}\right) + 0.5w \quad (1)$$

$$f_r = \frac{c}{4L_e\sqrt{\varepsilon_{re}}} \quad (2)$$

$$E = \left(\frac{f_r - f_{ie3d}}{f_r}\right) x100 \quad (3)$$

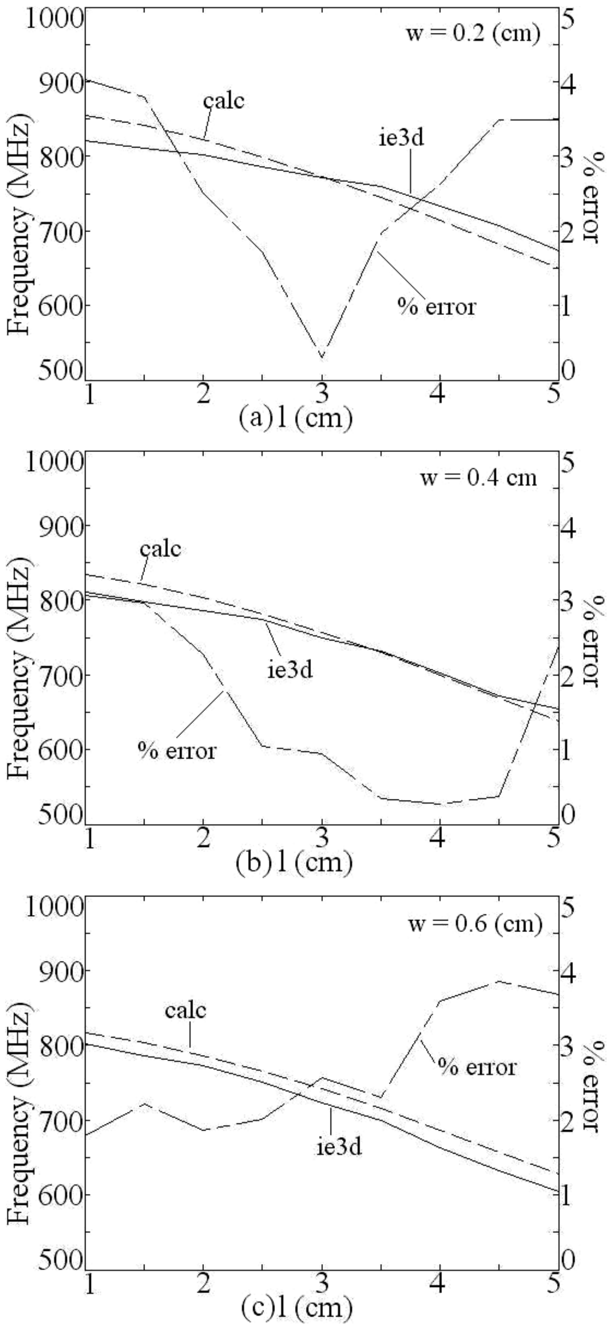

Fig. 5 (a – c) Resonance frequency and % error plots at $TM_{1/4,0}$ mode for shorted stub loaded RMSA

$$L_e = L + \Delta l + l\left(\frac{1.75l}{L}\right)\sin\left(\frac{0.63\pi.}{L}\right) + w \quad (4)$$

$$f_r = \frac{3c}{4L_e\sqrt{\varepsilon_{re}}} \quad (5)$$

The variation in $TM_{3/4,0}$ mode resonance frequency with stub length is non-linear. Therefore to model this variation, sinusoidal function is used in equation (4). The frequency is calculated by using equation (5) and % error between calculated and simulated values is calculated by using equation (3) and for w = 0.2 to 0.6 cm, they are plotted in Fig.

6(a – c). For the complete stub length range, a good approximation between calculated and simulated values is obtained. To validate the dual band response, for stub length of 4.0 cm and width of 0.2 cm, stub loaded shorted RMSA was fabricated on glass epoxy substrate and the measurement was carried out using R & S vector network analyzer. The simulated dual frequencies and BW's are 700 and 1080 MHz and 12 and 14 MHz respectively. The measured dual frequencies and BW's are 680 and 1080 MHz and 12 and 17 MHz respectively. The fabricated prototype of the configuration is shown in Fig. 7.

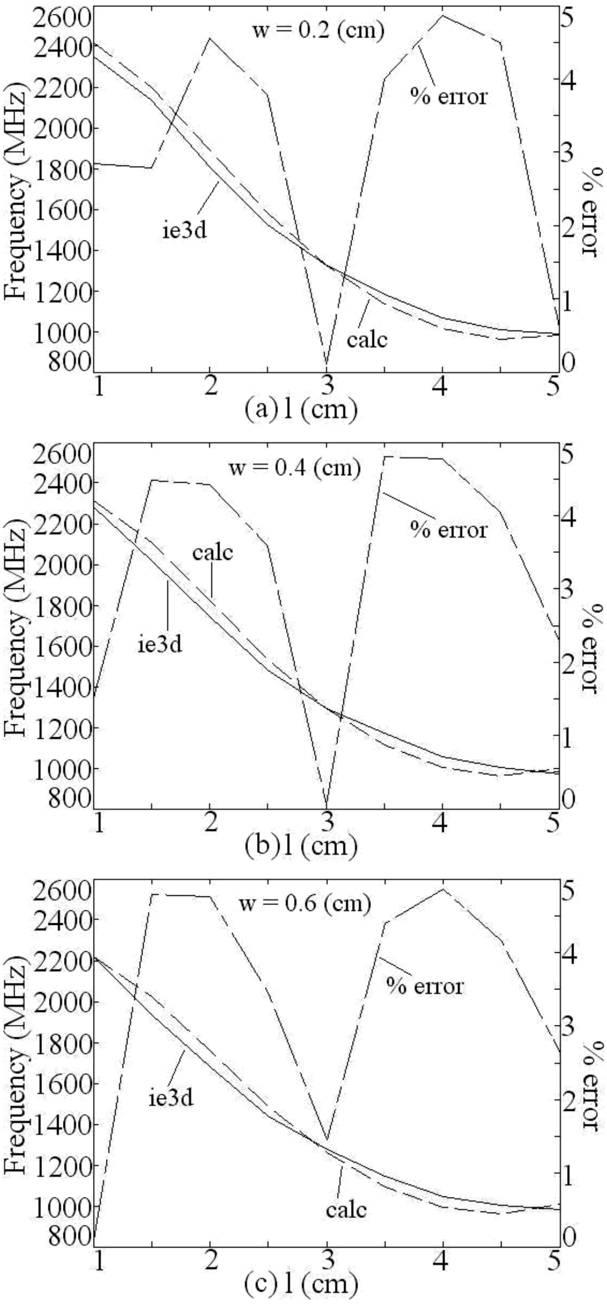

Fig. 6 (a – c) Resonance frequency and % error plots at $TM_{3/4,0}$ mode for shorted stub loaded RMSA

5. CONCLUSIONS

The fundamental and higher order modes of RMSA and shorted RMSA are discussed. The dual band stub loaded shorted RMSA is proposed. The analysis to study the effects of stub length on the modes of shorted patch is presented. The stub reduces second order $TM_{3/4,0}$ mode resonance frequency of the shorted patch and along with the fundamental $TM_{1/4,0}$ mode yields dual frequency response. The surface currents at modified $TM_{1/4,0}$ and $TM_{3/4,0}$ are aligned along the shorted patch length. Therefore radiation pattern at dual frequencies are maximum in the end-fire direction. By studying the surface current distribution, the formulation in resonant length at the dual frequencies is proposed. The frequencies calculated using them agrees closely with the simulated frequencies which agree within 2% with the measured results.

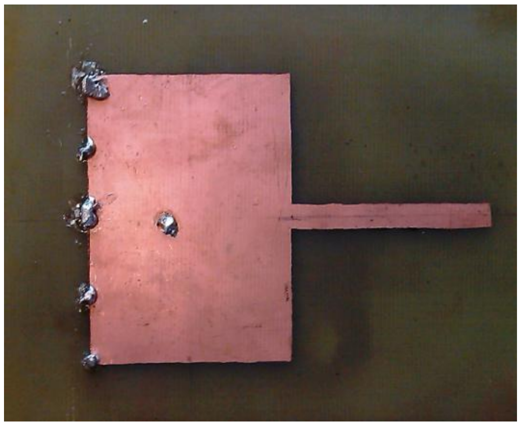

Fig. 7 Fabricated prototype of dual band shorted stub loaded RMSA

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