Dual Band Shorted Sectoral Microstrip Antenna

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ABSTRACT
The dual band microstrip antenna is realized by placing the open circuit stub or by cutting the slot inside the patch. The compact microstrip antenna is realized by placing the shorting post or plate along the zero field line at the fundamental mode of the patch. In this paper, a compact variation of equilateral triangular microstrip antenna, a shorted 60^0 sectoral microstrip antenna is discussed. Further, dual band antenna realized by placing an open circuit stub on the edges of the shorted 60^0 sectoral patch is proposed. The analysis to study the effects of stub on the dual band response is presented. The stub reduces the higher order TM_{21} mode resonance frequency of the patch and along with fundamental TM_{10} mode yields dual frequency response. Further by studying the surface current distributions at fundamental and higher order mode of the shorted patch, a formulation in resonant length is proposed. The frequencies calculated using the proposed formulations agrees closely with simulated frequencies with an % error less than 5% over the complete stub length range.

Keywords
Equilateral Triangular microstrip antenna, Shorted 60^0 sectoral microstrip antenna, Dual band microstrip antenna, Open circuit stub, Higher order mode

1. INTRODUCTION
The compact microstrip antenna (MSA) is realized by placing the shorting post or plate along the zero field line at the fundamental mode of the patch [1 – 2]. The shorting technique converts conventional half wavelength resonator into a compact quarter wavelength resonator. The dual band MSA is realized by placing an open circuit nearly quarter wavelength stub on the edges of the patch [2 – 5]. The stub offers inductive or capacitive impedance around the resonance frequency of the patch to realize dual frequency response. However while designing stub loaded MSAs at desired frequencies this simpler approximation of stub length against the wavelength does not give closer results. Also, simpler formulation to design dual band stub loaded MSA in desired frequency range is not available. An analysis to study the effects of stub on the dual band response in stub loaded MSA is reported [6]. It was observed that the stub reduces the resonance frequency of higher order orthogonal mode of the patch and along with the fundamental patch mode yields dual band response. The stub also modifies the surface current distribution at higher order mode and aligns them in the same direction as that of the currents at fundamental patch mode. Thereby it gives broadside radiation pattern over the dual frequencies.

In this paper, compact variation of equilateral triangular MSA (ETMSA), a shorted 60^0 sectoral MSA is discussed. The fundamental and higher order modes of ETMSA and equivalent shorted patch are discussed. Further by placing the open circuit stub at the vertex point of the shorted patch, a dual band MSA is proposed. The analysis to study the effects of stub on the dual band response is presented. The stub reduces the resonance frequency of second order TM_{21} mode of the shorted patch and along with the fundamental TM_{10} mode yields dual frequency response. The radiation pattern at the dual frequency is in the broadside direction. Further by studying the surface current distribution at the modified TM_{10} and TM_{21} modes in the shorted patch, a formulation of resonant length at the two frequencies is proposed. The frequencies calculated using the proposed formulations agrees closely with the simulated results obtained using IE3D software which agrees within 2% with the measured results [7]. The proposed analysis is carried out on glass epoxy substrate (h = 0.16 cm, ε_r = 4.3, tan δ = 0.02). The proposed analysis will help in understanding the dual band response of stub loaded compact MSAs.

2. ETMSA and 60^0 sectoral MSA
The ETMSA on glass epoxy substrate with the field distribution at its fundamental TM_{10} mode is shown in Fig. 1(a). The patch side length 'S' is calculated such that it operates in its TM_{10} mode at frequency of around 900 MHz. The patch is simulated using IE3D software for the feed point location (x_f) at 1.6 cm from the patch centroid and the resonance curve plot for the same is shown in Fig. 1(c). The plot shows the peak due to TM_{10} (957 MHz), TM_{11} (1674 MHz), TM_{20} (1909 MHz), TM_{21} (2544 MHz) and TM_{30} (2851 MHz) modes. The surface current distribution at the first three modes is shown in Fig. 1(d – f). At TM_{10} mode, patch shows one half wavelength variations along patch side length and it remains almost constant along the base of the patch. AT TM_{11} mode, surface currents show one half wavelength variations from the centroid point and towards the vertex of the ETMSA. At TM_{20} mode, the currents shows two half wavelength variation along the patch side length and field remaining nearly constant along base of the patch. The compact 60^0 sectoral MSA is realized by placing the shorting plate along the zero field line at TM_{10} mode as shown in Fig. 1(b). The MSA is simulated using IE3D and its resonance curve plot is shown in Fig. 1(c).

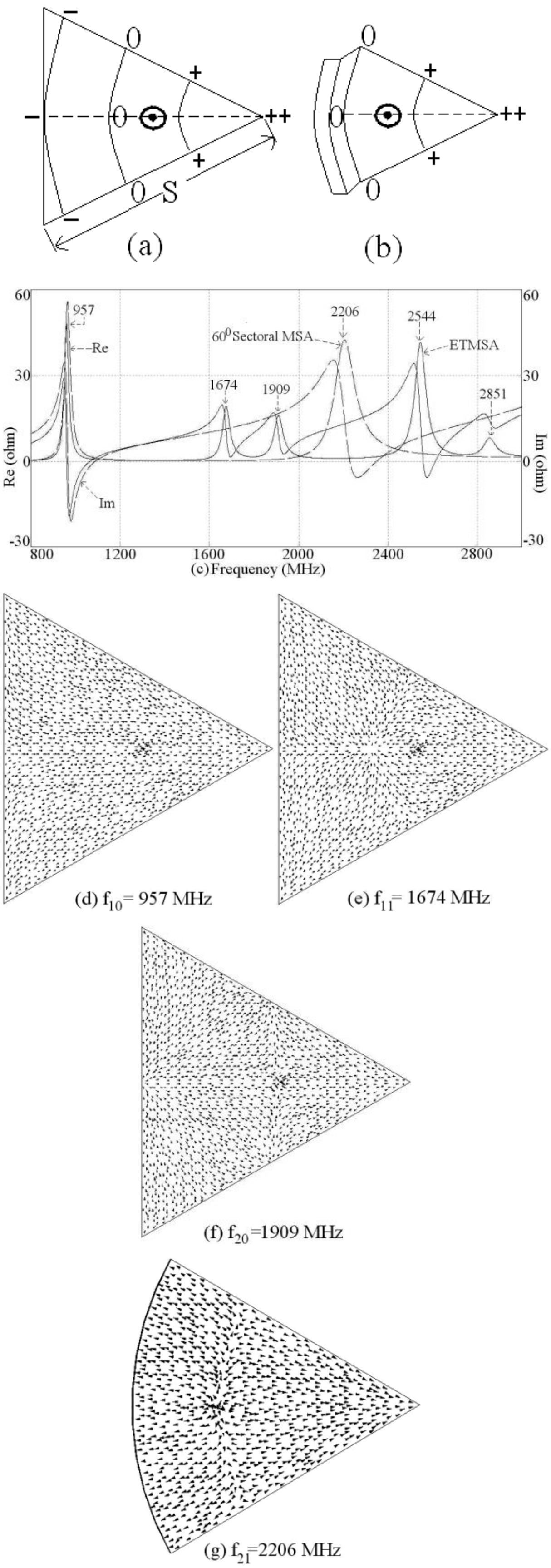

Fig. 1 (a) ETMSA, (b) shorted 60^0 sectoral MSA and there (c) resonance curve plots, surface current distribution at (d) TM_{10} (e) TM_{11} (f) TM_{20} modes for ETMSA and (g) TM_{21} mode for shorted 60^0 sectoral MSA

The resonance curve plot shows peaks due to TM_{10} and TM_{21} modes. The peaks due to the other modes are absent as impedance matching for them in shorted patch is not realized. The surface current distribution for TM_{21} mode in shorted patch is shown in Fig. 1(g). It shows three quarter wavelength variations in surface currents along the shorted length. To realize dual band response, an open circuit stub of length ‘l’ and width ‘w’ is placed at the vertex position on the patch as discussed in the following section.

3. DUAL BAND STUB LOADED SHORTED 60^0 SECTORAL MSA

The dual band stub loaded shorted 60^0 sectoral MSA is shown in Fig. 2(a). To understand the effects of stub, its length is varied in steps of 0.5 cm from 0.5 to 5 cm, and for each of the lengths, resonance curve plot, surface current distributions at various peaks and the simulated radiation pattern are studied. The resonance curve plot for stub length of 1.0 to 3.0 cm is shown in Fig. 2(b, c). The surface current distribution at TM_{21} mode for stub length of 1.5 cm and simulated radiation pattern at TM_{21} mode without stub and for stub length of 1.5 cm is shown in Fig. 3(a – c).

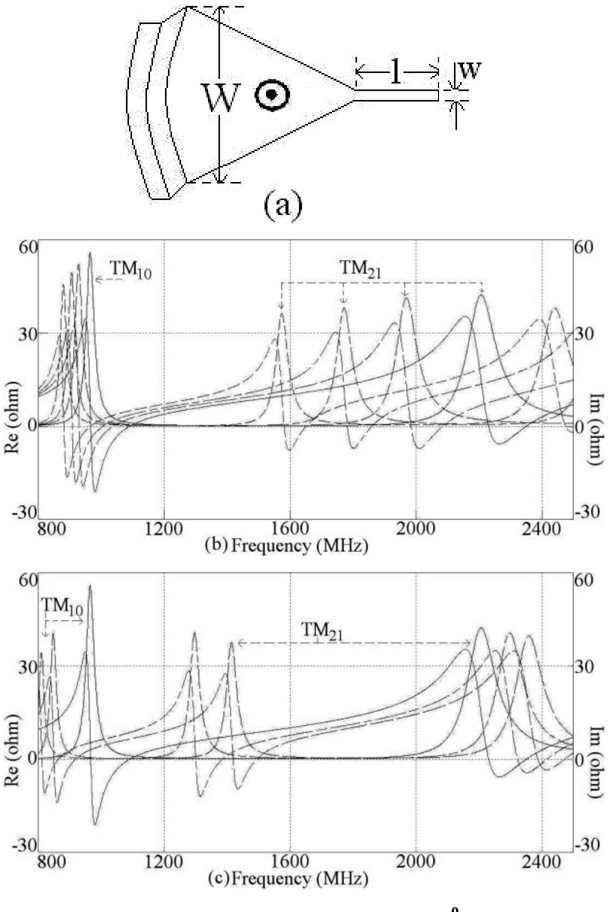

Fig. 2 (a) Dual band stub loaded shorted 60^0 sectoral MSA and its resonance curve plots for (b) (──) l = 0 cm, (— —) l = 1.0 cm, (—‐—) l = 1.5 cm, (‐‐‐) l = 2.0 cm, (c) (──) l = 0 cm, (— —) l = 2.5 cm, (—‐—) l = 3.0 cm

With an increase in stub length the TM_{21} mode frequency reduces and it comes closer to TM_{10} mode frequency. The dual band response is realized when the spacing of TM_{21} mode frequency is optimized with respect to TM_{10} mode frequency. The surface currents at TM_{21} mode without stub are varying along shorted patch length and it shows radiation pattern having maximum in the end-fire direction. With an increase in stub length the surface currents remains in the horizontal direction and the radiation pattern maximum is in the end-fire direction. The similar behavior is observed for other stub widths. Thus the dual frequencies are realized due to the fundamental and higher order modes and not due to the modes introduced by the stub. Further by studying the surface current distribution at modified TM_{10} and TM_{21} modes, the formulation in resonant length at dual frequencies is proposed.

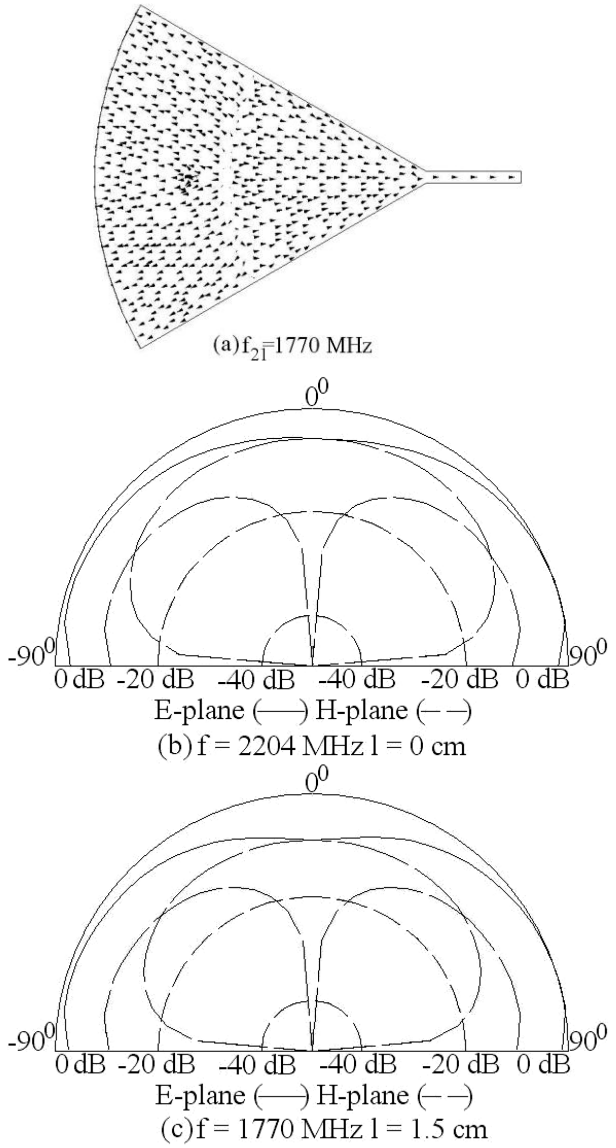

Fig. 3 (a) Surface current distribution and (b, c) radiation pattern at modified TM_{21} modes for stub loaded shorted 60^0 sectoral MSA

4. FORMULATION IN RESONANT LENGTH FOR DUAL BAND MSA

The resonance frequency for ETMSA is given by using equation (1). The ETMSA is a half wave length resonator at its fundamental TM_{10} mode and hence the same equation cannot be used for its compact variation i.e. shorted 60^0 sectoral patch. The equation (1) is modified to realize the equation for shorted sectoral patch as given in equation (2). Using the same the resonance frequencies calculated for TM_{10} and TM_{21} modes are, 878 and 2297 MHz. The simulated frequencies are 955 and 2206 MHz, respectively which are closer to the calculated frequencies.

$$f_r = \frac{2\sqrt{m^2 + mn + n^2}}{3S_e\sqrt{\varepsilon_{re}}} \quad (1)$$

$$f_r = \frac{\sqrt{m^2 + mn + n^2}}{3S_e\sqrt{\varepsilon_{re}}} \quad (2)$$

Further the formulation at two modes is realized by modifying the shorted patch length 's' in terms of the stub dimensions. The formulation at TM_{10} mode is obtained by using equation (3). The effective dielectric constant (ε_{re}) is calculated by using equation (4). The w_e is taken equal to W/2. The resonance frequency is calculated by using by equation (2) using m = 1 and n = 0. The % error between the calculated and simulated values is calculated by using equation (5) and they are plotted in Figs. 4(a), 5(a) and 6(a), for w = 0.2 to 0.6 cm. For most of the stub length range, a smaller % error is observed.

At TM_{10} mode,

$$S_e = S + \Delta l + \left(l + w\right)\frac{l}{1.8S} \quad (3)$$

$$\varepsilon_{re} = \left(\frac{\varepsilon_r + 1}{2}\right) + \left(\frac{\varepsilon_r - 1}{2}\right)\frac{1}{\sqrt{1 + \frac{12h}{w_e}}} \quad (4)$$

$$\%error = \left(\frac{f_r - f_{ie3d}}{f_r}\right)x100 \quad (5)$$

Further the formulation at modified TM_{21} mode is obtained by using equation (6). The variation in TM_{21} mode frequency with stub length is not linear. This non-linear variation is modeled by using sinusoidal function as shown in equation (6). The resonance frequency is calculated by using equation (2) using m = 2 and n = 1. The % error between calculated and simulated values is calculated by using equation (5) and for w = 0.2 to 0.6 cm, they are plotted in Figs. 4(b), 5(b) and 6(b), respectively. Over most of the stub length range, a smaller % error is observed.

At TM_{21} mode,

$$S_e = S + \Delta l + 1.35 l \sin\left(\frac{\pi\left(l + w\right)}{1.4S}\right) \quad (6)$$

5. CONCLUSIONs

The fundamental and higher order modes of ETMSA and its compact variation, shorted 60^0 sectoral MSA are discussed. In shorted patch, the modes like TM_{11} and TM_{20} modes are absent since the impedance matching at them is not realized. Further an analysis of stub loaded shorted 60^0 sectoral MSA is presented. The stub does not introduce any additional mode but reduces the resonance frequencies of TM_{21} mode of the shorted patch and along with the fundamental TM_{10} mode yields dual frequency response. By modifying the resonance frequency equation for ETMSA, resonance frequency equation for shorted sectoral patch is proposed. The frequencies calculated using proposed equation closely agrees with the simulated frequencies. Further by studying the surface current distribution at TM_{10} and modified TM_{21} modes, the formulation in resonant length is proposed. The frequencies calculated using proposed formulations closely agrees with the simulated result. The proposed analysis gives an insight into the functioning of stub loaded MSAs and proposed formulations can be used to design them at desired frequencies.

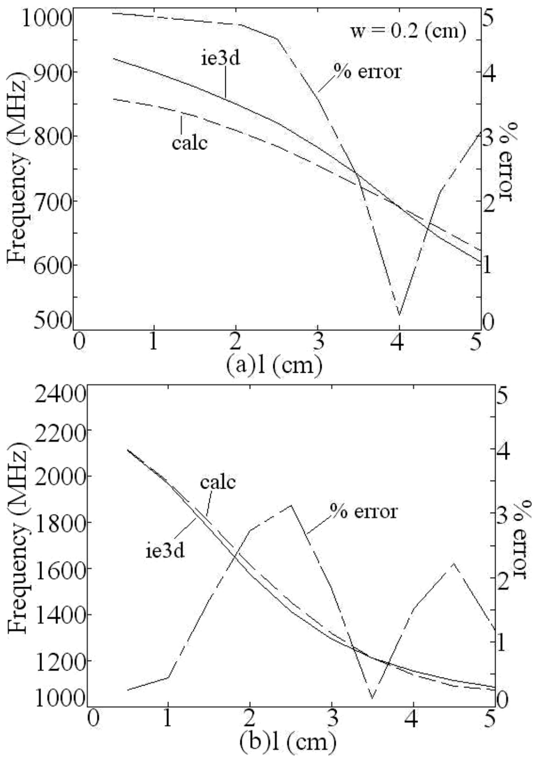

Fig. 4 (a, b) Resonance frequency and % error plots for stub loaded shorted 60^0 sectoral MSA for w = 0.2 cm

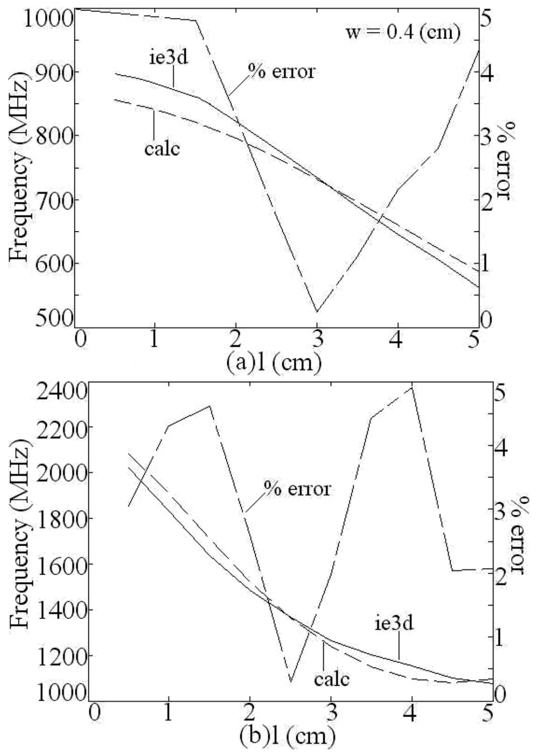

Fig. 5 (a, b) Resonance frequency and % error plots for stub loaded shorted 60^0 sectoral MSA for w = 0.4 cm

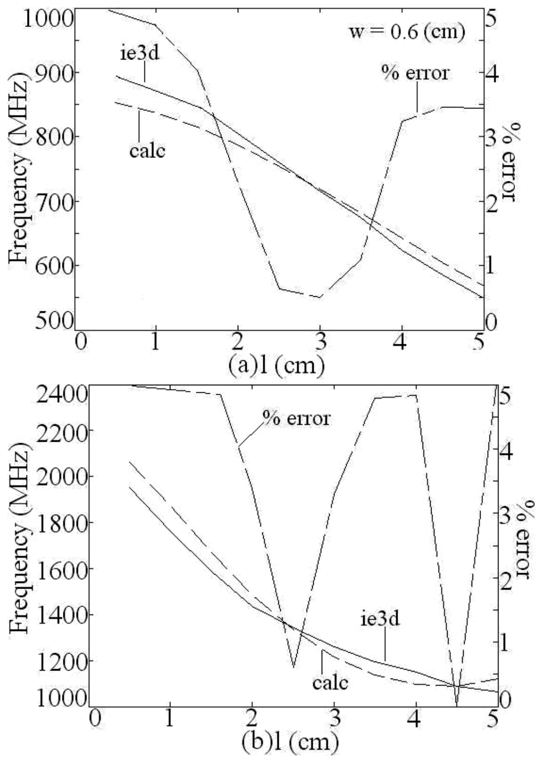

Fig. 5 (a, b) Resonance frequency and % error plots for stub loaded shorted 60^0 sectoral MSA for w = 0.6 cm

6. REFERENCES

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

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

[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] Daniel, Asha E., Tunable dual band Rectangular Microstrip antennas and their Arrays, Ph.D. Thesis, 2006, I. I. T. Bombay, India

[5] 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.

[6] 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.

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