Ring Shape Microstrip Antenna for Multi-band Response

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***Abstract* — Design and analysis of multi-band dual polarized ring shape microstrip antenna embedded with rectangular slot in 1000 MHz frequency range is proposed. The ring shape patch demonstrates fundamental mode TM_{11} and higher order mode TM_{21} modes. Placement of rectangular slot in ring-shape patch degenerates TM_{11} and TM_{21} resonant modes of the equivalent circular patch into dual orthogonal modes to yield multi-modal response. Further the rectangular slot optimizes the input impedance at degenerated resonant modes and also alters the surface current distribution to realize bandwidth of 1 to 2% at each of the frequencies. The suspended configuration of proposed dual polarized antenna is also optimized, which gives more than 1.5 to 4 dBi of broadside gain across various frequencies.**

Keywords — Circular microstrip antenna, Ring shape microstrip antenna, Multi-band response, Dual polarzation, Rectangular slot, Higher order mode.

I. INTRODUCTION

Microstrip antennas (MSA) have become extremely demanding in the recent years and have paved the way for development in both research and engineering applications [1 – 4]. The range of advantages it provides over other similar radiating structures is the low cost, low profile and planar configuration, along with the ease of patch integration with the microwave integrated circuits in high frequency applications. In applications which require the transmission and reception of signals at closely spaced frequencies, dual or multi-band MSAs are needed [1 – 4]. The traditional MSAs like Rectangular MSA, Circular MSA etc. cannot exhibit dual or multi-band response as the frequency ratio between two consecutive modes is higher and the radiation pattern characteristics over them are varying. The dual or multi-band MSAs are realized by cutting the slot or by placing an open circuit stubs on the patch edges [4 – 10]. These dual band techniques yields tunable frequency ratio from 1.0 to 1.5 and even below 1.0. The slot cut technique is most preferred one since it neither increases patch size nor it affects the radiation pattern characteristics. In few application signal transmission and reception is done at closely spaced frequencies but with orthogonal polarizations. The dual polarized response in MSA is realized when the mode introduced by slot is orthogonal to the patch mode [1 – 4]. In these multi-band MSAs, slot is said to introduce an additional resonant mode near the fundamental patch mode when its length equals either half wave or quarter wave in length. However recent study showed that slot modifies the resonance frequency of higher order patch resonant mode which yields multi-band characteristics [11]. Further, it is a benefit to employ MSAs with multi-band dual polarization characteristics, because polarization diversity promotes antenna performance in multipath environment [12].

In this paper, a ring shape MSA, realized by modifying circular MSA (CMSA), is discussed and its design as well as analysis is explained. The ring shape structure is realized by incorporating a circular slot at the center of the CMSA [3]. Initially, a parametric study to explain the observed frequency response in CMSA and ring shape MSA is discussed and comparison of both the responses is presented. Ring shape MSA excites the resonant modes similar to that of CMSA but at lower frequencies. Thus ring shape MSA can be considered as a compact alternative to CMSA [3]. Next, a parametric study is performed for varying circular slot radius to understand the observed response. Further to realize multi-band characteristics, a rectangular slot is etched in the ring shape structure. The addition of rectangular slot in the patch degenerates patch's TM_{11} and TM_{21} modes into two closely spaced orthogonal modes, thereby realizing multi-band response. Also, the study is conducted for variation in the rectangular slot dimensions. With increasing slot length, the proposed antenna yields tunable frequency ratio varying from 0.8 to 1.2 over four resonant modes. Also the slot optimizes the input impedance at the four resonant modes. Over the dual resonant modes, due to uni-directional surface currents, pattern shows broadside radiation with an E-plane aligned along $\Phi = 90^0$ and 0^0, respectively. However due to bi-directional current variations over degenerated TM_{21} mode, the pattern across higher modes is conical. The proposed multi-band configuration yields 1 to 2% BW at each frequency. The proposed MSA is optimized on glass epoxy substrate ($\varepsilon_r = 4.3$, h = 0.16 cm and tan $\delta = 0.02$). Due to lossy substrate the proposed antenna has lower gain and this has been increased by designing the corresponding suspended configuration. At each of the frequencies suspended design yields co-polar gain of more than 1.5 to 4 dBi. The proposed configurations are first optimized using IE3D software followed by experimental verification. Antenna's input impedance response is measured using 'ZVH – 8' vector network analyzer whereas its co and cross-polar radiation pattern were measured in antenna lab using RF source (SMB 100) and spectrum analyzer (FCS6). The novelty of proposed configuration lies in the realization of the multi-band tunable frequency response for compact ring shape MSA that is not reported in the available literatures.

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II. CIRCULAR SLOT CUT MULTI-BAND CMSA

A CMSA is designed by calculating the radius of the circular patch by using equations (1) and (2) such that it's fundamental TM_{11} mode frequency is around 1000 MHz [3]. The radius is calculated to be 4.5 cm. A co-axially fed CMSA, of radius 'a' = 4.5 cm, is shown in Fig. 1(a). Using SMA-panel type connector feed (inner probe diameter = 0.12 cm), CMSA is simulated and its resonant curve plot is shown in Fig. 1(b). It displays two peaks which are due to the fundamental and higher order TM_{11} and TM_{21} resonant modes. The surface current distributions at the observed two resonant TM_{11} and TM_{21} modes are shown in Fig. 2(a, b).

$$K = \frac{8.794}{f_r\sqrt{\varepsilon_r}} \quad (1)$$

$$a = \frac{K}{\sqrt{1+\frac{2h}{\pi\varepsilon_r K}\left(\ln\frac{\pi K}{2h}+1.7726\right)}} \quad (2)$$

where, f_r = frequency in GHz, h = substrate thickness in cm a = patch radius in cm.

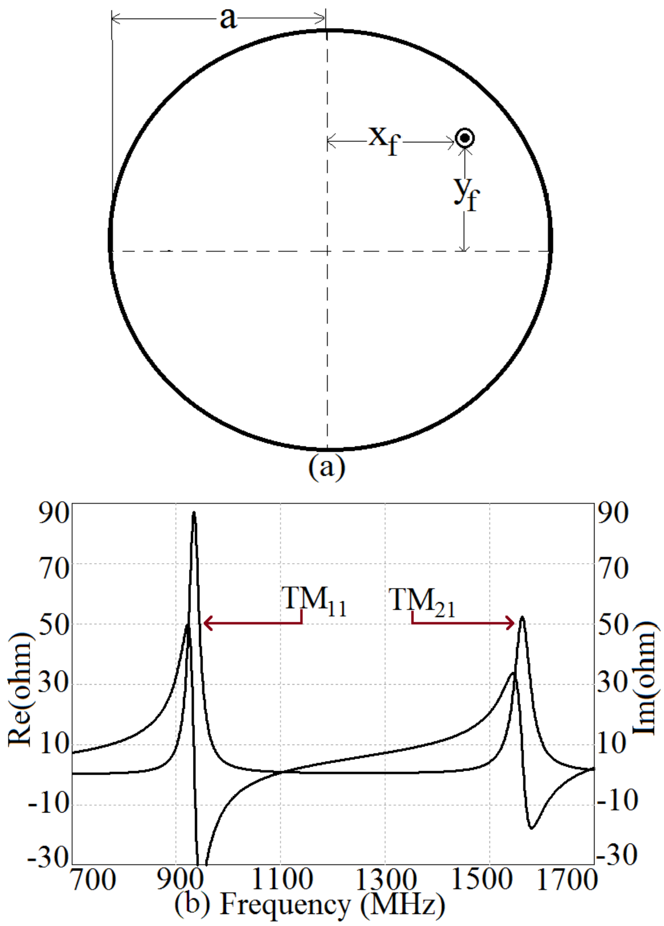

Fig. 1 (a) Co-axially fed CMSA in 1000 MHz range and its (b) resonance curve plot

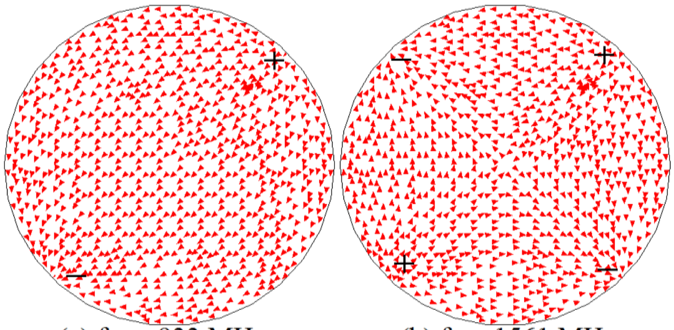

Fig. 2 (a – b) Surface current distributions at the observed modes of CMSA

Now taking the same radius as CMSA, a ring shape MSA is designed by embedding a circular slot of radius 'r' in the patch center as shown in Fig. 3(a). The CMSA and ring shape MSA are compared and analyzed by simulating both the configurations and their responses are shown in the Fig. 3 (b). As seen from the figure, there are two peaks observed in CMSA and ring shape MSA which corresponds to the TM_{11} and TM_{21} mode frequencies. The current distributions of the observed modes in ring shape MSA is shown in Fig. 4 (a, b). Now, as observed from the figure, the modes corresponding to the ring shape MSA have much lower frequencies as compared to that of CMSA. This concludes that the ring shape MSA excites similar modes of CMSA, but at much lower frequencies. Thus the ring shape MSA can be looked upon as compact MSA.

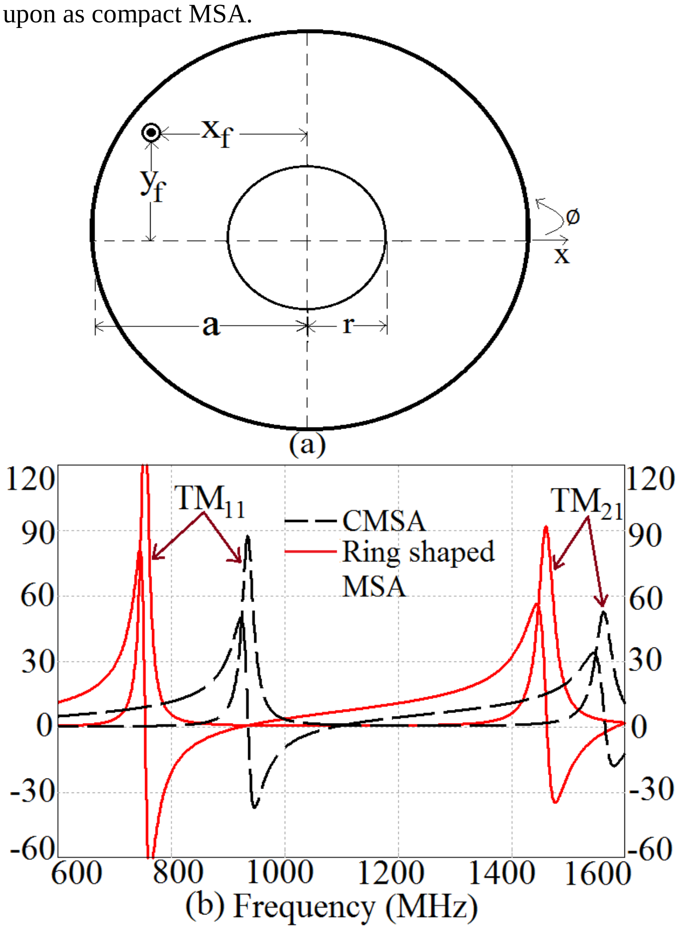

Fig. 3 (a) Co-axially fed ring shape MSA and (b) resonance curve plots for comparison of CMSA and ring shape MSA

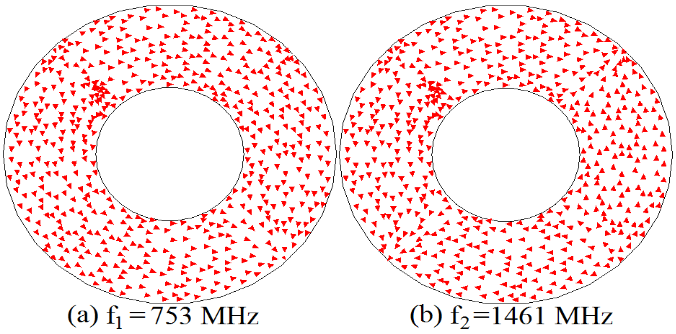

Fig. 4 (a, b) Surface current distributions of modes in ring shape MSA

To analyse the antenna configuration, a parametric study is carried out by varying the circular slot radius ‘r’. The resonance curve plots showing the variation in the real and imaginary part of the impedance against radius ‘r’ is shown in Fig. 5. It is observed from the response that an increase in the slot radius perturbs the path of the surface currents and hence reduces the frequencies of the two resonant modes.

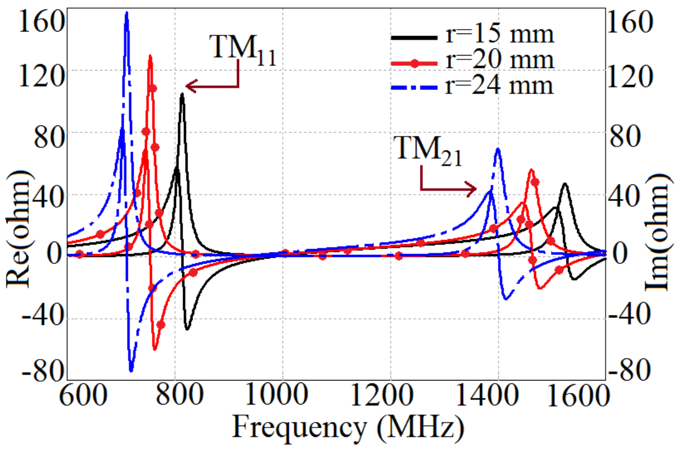

Fig. 5 Resonance curve plots for variation in circular slot radius for ring shape MSA

The ring shape MSA configuration displays only two peaks corresponding to TM_{11} and TM_{21} modes, thus in order to achieve multi-band frequencies, a rectangular slot is introduced in the patch as shown in Fig. 6(a). The rectangular slot alters the path of surface currents and thus introduces perturbations due to which the modes are degenerated into orthogonal modes. Next, a parametric study is performed to understand the effects of varying rectangular slot dimensions on the patch modes. As seen from the resonance curve plots in Fig. 6(b), TM_{11} and TM_{21} resonant mode starts degenerating into two closely spaced modes. For higher values of ‘L’ and for ‘r’ = 20 mm, the degenerated modes are prominently observed and the optimum result is obtained for slot length of 15 mm. With reference to the four modes, the antenna depicts multi-band response. The surface current distributions at the observed resonant peaks are shown in Fig. 7(a – d). From the figure it is seen that the modes are horizontally and vertically polarizing, thus forming orthogonal modes. The currents are uni-directional for the degenerated TM_{11} mode which gives broadside radiation pattern, however for TM_{21} degenerated modes the currents are bi-directional and hence the radiation pattern is conical.

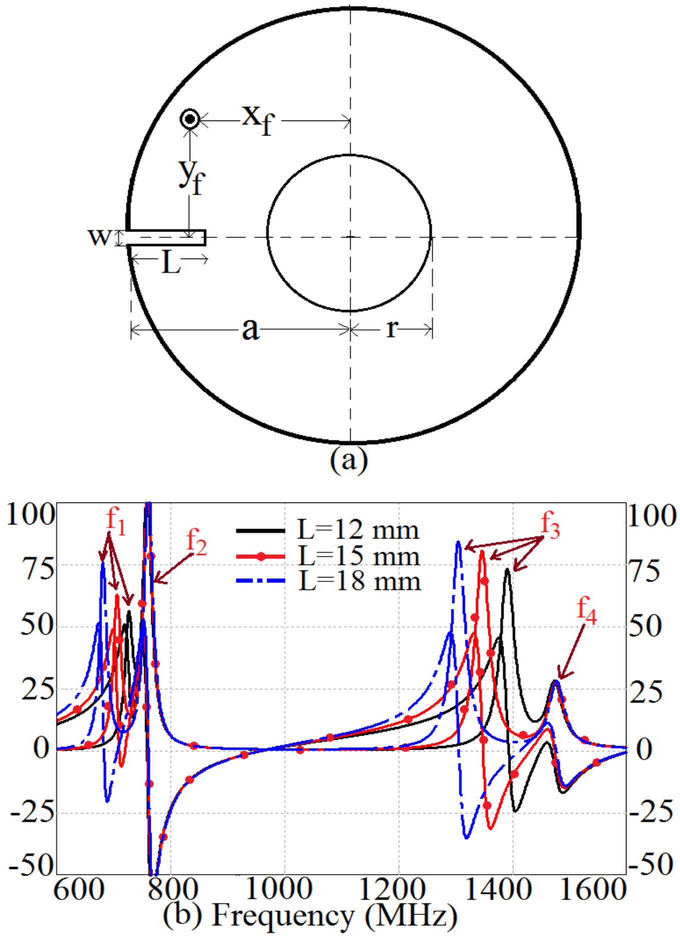

Fig. 6 (a) Ring shape MSA with a rectangular slot and its (b) resonance curve plots for variation in rectangular slot length

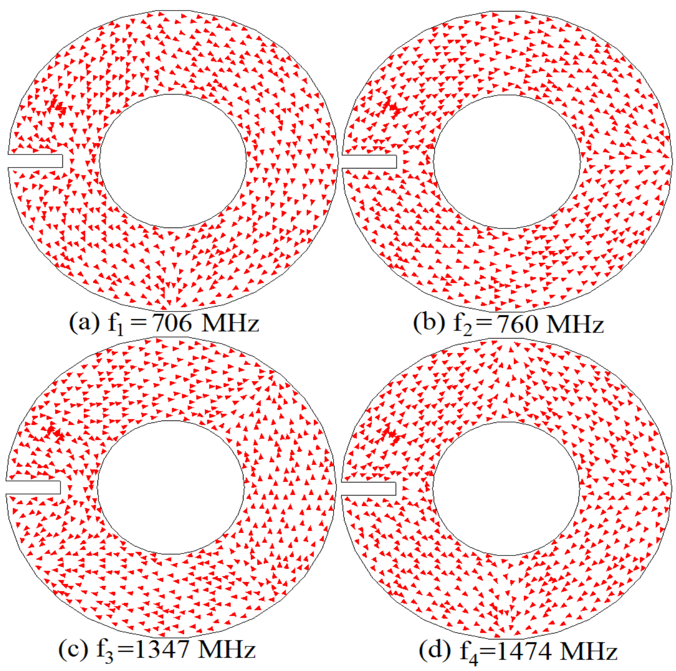

Fig. 7 (a – d) Surface current distributions of modes for ring shape MSA with rectangular slot

Now, to obtain the best possible results in terms of multi-band characteristics, the input impedances of all the modes should be matched in 25 to 100 Ω range. The input impedance plot of the optimized configuration of the ring shape MSA embedded with rectangular slot is shown in Fig. 8(a). The simulated frequencies and their respective BW's are 706, 760, 1347 and 1474 MHz and 14, 7, 21 and 10 MHz, respectively. The measured frequencies and their respective BW's are 721, 743, 1360 and 1426 MHz and 10, 8, 20 and 9 MHz, respectively. The fabricated prototype of the proposed configuration is shown in Fig. 8 (b).

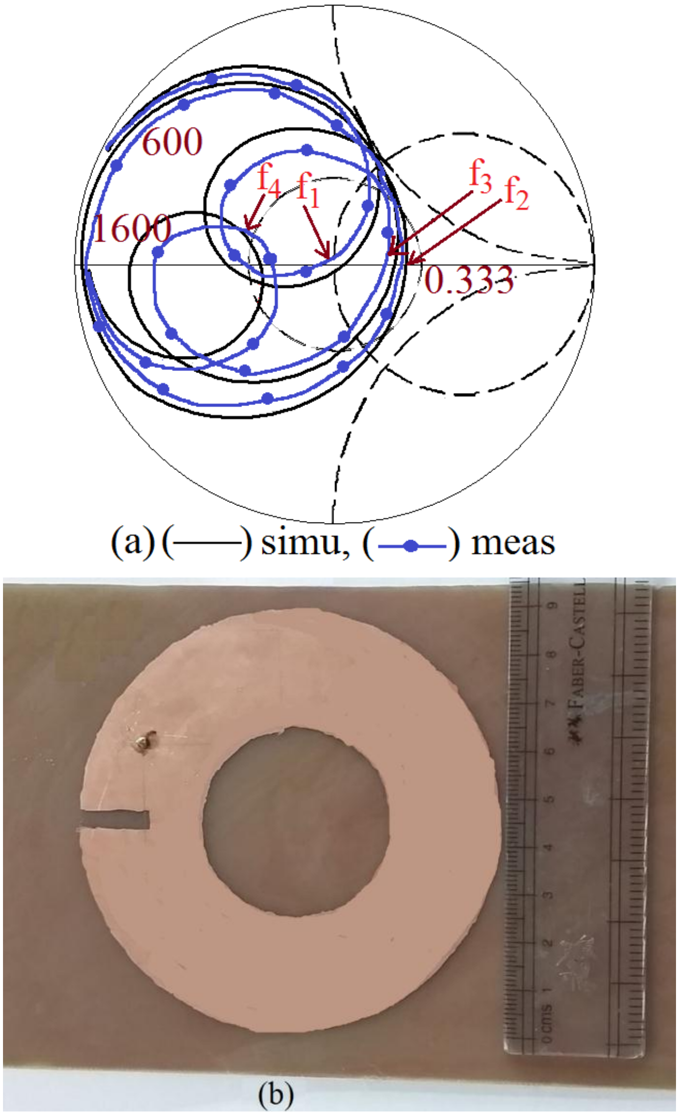

Fig. 8 (a) Input impedance plot and (b) fabricated prototype of optimized configuration for slot cut ring shape MSA

The antenna shows broadside radiation pattern at lower frequencies with E-plane aligned along the $\Phi = 0^0$ at second and fourth frequency and along $\Phi = 90^0$ at the first and third frequency. On account of the proposed MSA being fabricated on the lossy glass epoxy substrate it has gain less than 0 dBi. The suspended configuration of the ring shaped MSA with rectangular slot has been studied. It gives identical impedance and radiation pattern characteristics but with broadside co-polar gain of more than 1.5 to 4 dBi across various frequencies. In future scope of the work, formulations at patch resonant modes in terms of patch and slot dimensions will be developed to achieve similar antenna design at any other frequency.

III. CONCLUSIONS

The multi-band design of novel ring shape MSA with rectangular slot is proposed. The explanation on the effects of circular and rectangular slots over the observed resonant modes is presented through the detailed parametric study. The ring shape MSA excites modes similar to that of CMSA at much lower frequencies, to become a compact alternative. The circular slot in the ring shape structure reduces the modal frequencies. The multi-band characteristics are achieved by introducing a rectangular slot in the patch. The rectangular slot degenerates patch TM_{11} and TM_{21} modes into two orthogonal modes. Further rectangular slot modifies the surface current distributions and input impedances at all the four resonant modes to realize 1 to 2 % BW. It also yields tuning of the frequencies by varying frequency ratio from 0.8 to 1.2. Due to lossy substrate multi-band design displays gain of less than 0 dBi. In order to improve upon the same, suspended design of the proposed configuration is studied which gives gain of more than 1.5 to 4 dBi across each of the modal frequencies.

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