Progress In Electromagnetics Research C, Vol. 23, 27–39, 2011

DUAL FREQUENCY RING ANTENNAS WITH COPLANAR CAPACITIVE FEED

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Abstract—In this paper, design of a coplanar capacitive coupled probe fed microstrip ring antenna for dual frequency operation is presented. The proposed antenna is excited by a single probe feed connected to a capacitive feed strip placed along one of the radiating edges of the ring antenna. The coplanar capacitive feed strip is modified to obtain the best possible match with the antenna input impedance and to tune out the excessive capacitive reactance due to feed strip. It is also demonstrated that the modified feed strip can be placed either inside or outside the ring and similar radiation characteristics can be obtained at both the resonant frequencies. Ring dimensions decide the resonant frequencies values and their separation. Measured data fairly agree with the simulated characteristics.

1. INTRODUCTION

Microstrip antennas are versatile candidates for the modern wireless applications because of their numerous advantages [1–3]. Among microstrip antenna geometries, ring geometry has specific advantages. It requires smaller size than the corresponding rectangular patch to resonate at the same frequency. Another advantage of ring antenna is that it offers wide bandwidth and high radiation resistance when it is excited to operate at higher order modes [2].

There are several microstrip patch/ring antennas have been reported in literature which operate at dual resonant frequencies [4–14]. However, many of these have relatively complex assembly like stacked configuration [4], suspended configuration (with air gap) [5], modified ground shape [6], dual feed [7] etc., which in some cases is

Received 1 June 2011, Accepted 19 July 2011, Scheduled 28 July 2011
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contrary to the fundamental attraction of microstrip antennas. On the other hand antenna reported in [8] uses modified probe feed which requires precise alignment. In this work, a design that uses single layer (no air gap and stacked dielectric substrates) and single feed, which offers a dual frequency operation is proposed.

The basic geometry of the antenna is presented in Section 2. In Section 3, the parametric studies and geometry optimization will be discussed. Experimental validations are presented in the Section 4 followed by conclusions of this study in Section 5.

2. BASIC ANTENNA GEOMETRY AND ITS WORKING

The basic geometry of the ring antenna with a coplanar capacitive feed strip is shown in Figure 1. The radiating ring along with the capacitive feed strip is located on the same substrate. Here the feed strip is fed by the coaxial probe which is coupled to the ring radiator by capacitive means. Initially the design of single ring will be considered and once it is optimized, design of double ring for dual frequency will be explained.

The antenna (single ring) is basically designed to operate at 2.4 GHz. The dielectric substrate used for the simulation is Rogers make with dielectric constant (ε_r) = 2.5, loss tangent ($\tan\delta$) = 0.0016, and height of the substrate is equal to 1.56 mm. The external dimensions of the ring geometry are 24 mm (square ring) length and 1 mm width. The square ring length is chosen such that its perimeter is close to guided wavelength [2] and then optimized through IE3D EM software. Feed strip dimensions are 1.5 mm length and 16 mm width. Separation between the ring geometry and the feed strip is equal to 0.5 mm. More details on feed strip design and its separation from radiator element can be found in [5, 14]. However, the basic problem with the ring antenna geometry with rectangular feed strip shown in Figure 1 is that it works fine with the air gap [5, 9]. This is due to the fact that air gap introduces the probe inductance (due to increased probe length) [15, 16] which is effectively tuned out by capacitive feed strip that leads to the proper coupling between feed strip and the ring radiator. More details on the air gap variation and its effect on input impedance can be found in [14, 17]. When no air gap is used, the total input impedance at the input of the antenna is capacitive (due to conventional rectangular feed strip) and huge impedance mismatch occurs (pl. ref. Figures 6 and 8). This problem can be solved by modifying the feed strip and is explained in the next paragraph.

It can be recalled that the tapered microstrip edges introduce inductive reactance, which can be used to effectively tune out the

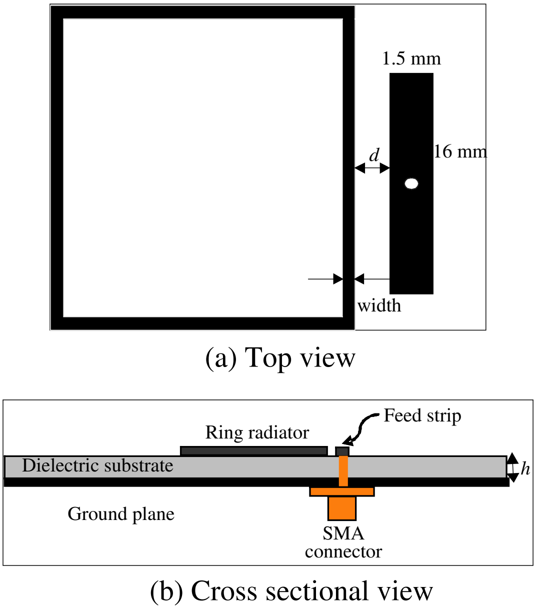


Figure 1. Geometry of ring antenna with capacitive feed.

capacitive reactance offered by the feed strip. The geometry of the ring antenna with the tapered feed strip is shown in Figure 2(a). Amount of tapering is indicated in Figure 2(a). It may be noted that the feed strip can also be placed inside the ring geometry (Figure 2(b)) to get the similar performance.

3. RING ANTENNA OPTIMIZATION WITH CAPACITIVE FEED STRIP

Parametric study was carried out to optimize the ring antenna geometry shown in Figure 2(a). Parameters considered for this study are the amount of feed strip tapering, distance between the ring and the feed strip (d) and the width of the ring. Same kind of study can be carried out on the ring antenna with feed strip inside the ring (Figure 2(b)). For different amount of tapering the feed strip edge parallel to the ring, return loss characteristics are shown in Figure 3. It can be noticed from Figure 3 that only the depth of return loss curve below -10 dB changes but the resonant frequency does not get affected. Input characteristics for different values of distance between

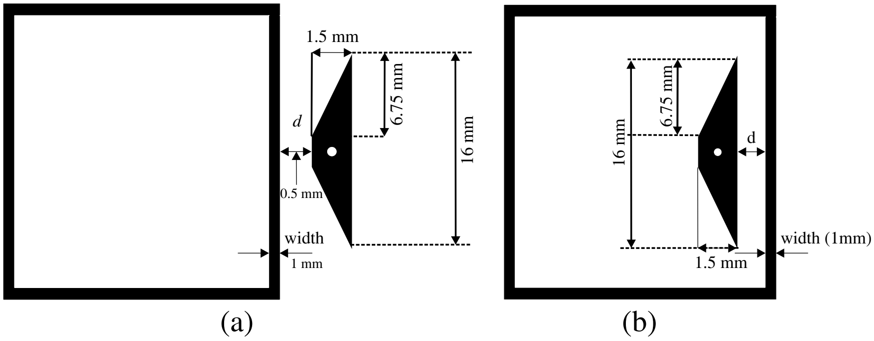


Figure 2. Ring antenna with tapered feed strip. (a) Feed strip outside the radiator. (b) Feed strip inside the radiator.

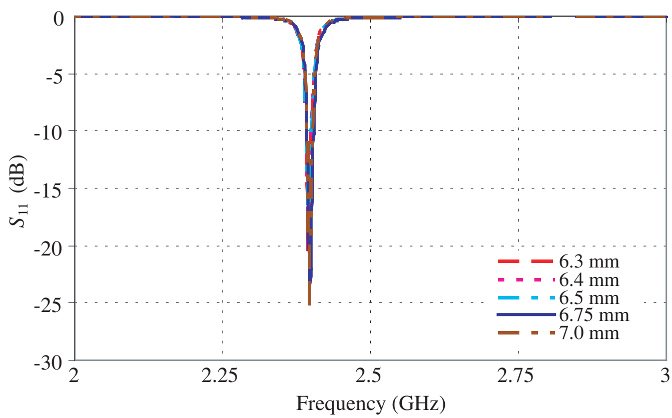


Figure 3. Return loss characteristics for the ring antenna with different amount of feed strip tapering.

the ring radiator and the feed strip (d) are shown in Figure 4. It can be seen from the Figure 4 that 0.5 mm is the optimum distance between feed strip and the ring radiator. The results of the effects of the width variation of the ring are shown in Figure 5. Ring antenna with 1.0 mm width gives the optimum results (Figure 5).

3.1. Optimized Single Ring Antenna

The antenna was optimized with the commercially available IE3D V. 12 electromagnetic (EM) simulation software. The co-axial probe with 0.7 mm radius was used to excite the antenna through small capacitive

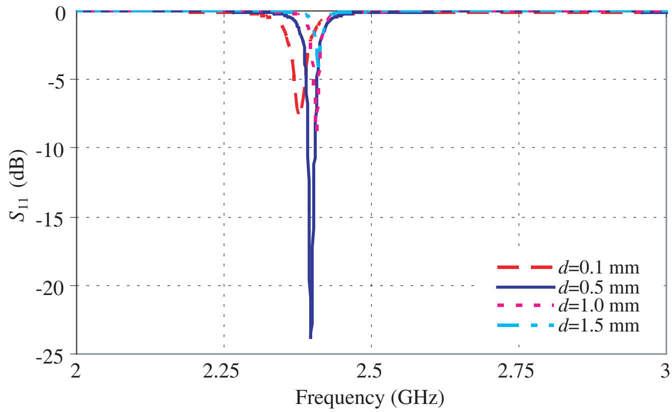


Figure 4. Return loss characteristics for the ring antenna with different distances between the ring and the feed strip (d).

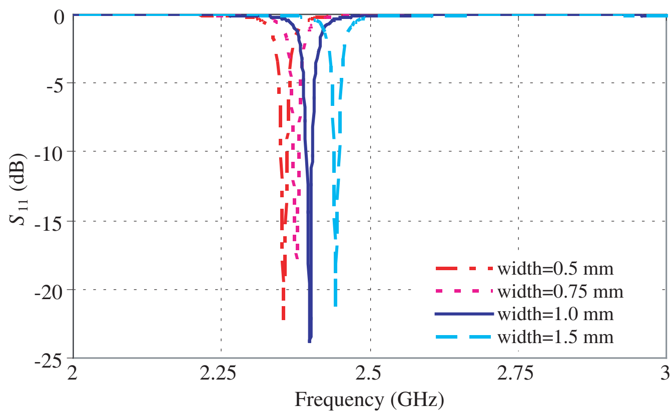


Figure 5. Return loss characteristics for the ring antenna with different width.

rectangular (tapered) feed strip. Input impedance characteristics of the antennas (Figure 1 and Figure 2(a)) are shown in Figure 6. It can be noticed from Figure 6 that significant improvement can be achieved from the tapered feed strip. This improvement may be attributed due to the cancellation of feed strip capacitance by inductive reactance of tapered feed strip [14, 17]. Radiation patterns corresponding to resonant frequency are shown in Figure 7.

In another attempt, feed strip was located inside the ring radiator as shown in Figure 2(b). This time, the straight edge of the feed strip was located near the edge of the ring. Similar input characteristics

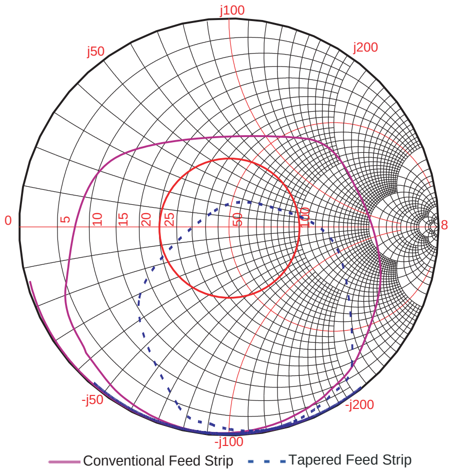


Figure 6. Impedance characteristics of the ring antennas shown in Figures 1 and 2.

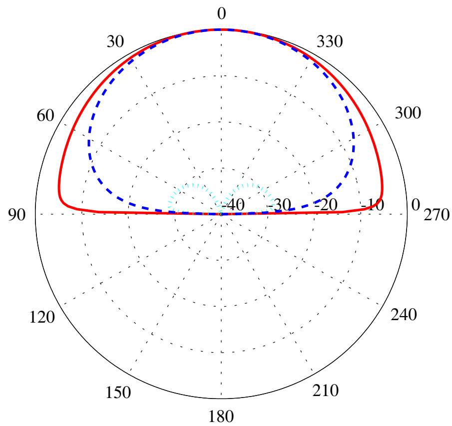


Figure 7. Radiation characteristics of ring antenna (Figure 2(a)) at resonant frequency (2.4 GHz). Solid line (Red): E_Co poln. Dashed line (Blue): H_Co poln. Dotted Line (Cyan): E_Cross poln., and Dash-dot (Magenta): H_Cross poln. Note: H-cross cannot be seen in patterns as it is well below -40 dB.

for this antenna have been obtained (Figure 8) and radiation patterns remain unaltered.

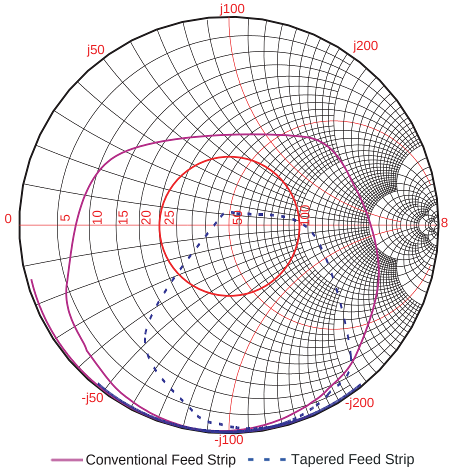


Figure 8. Impedance characteristics of ring antenna with feed strip located inside the ring (Figure 2(b)).

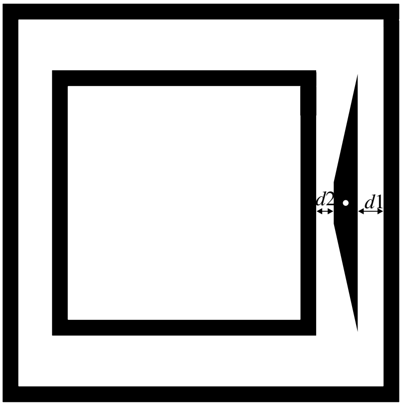


Figure 9. Antenna with two rings fed by feed strip located between the two rings (other geometry parameters are as defined in Figures 2(a) and 2(b)).

3.2. Two Rings for Dual Resonant Operation

In this case, second ring (16 mm square ring with 1.0 mm width) is inserted inside the outer ring (24 mm square ring with 1.0 mm width), and feed strip was placed in between the edges of two rings as shown in Figure 9. Basically the geometry shown in Figure 9 is the combination of antennas shown in Figure 2(a) and Figure 2(b). However, the

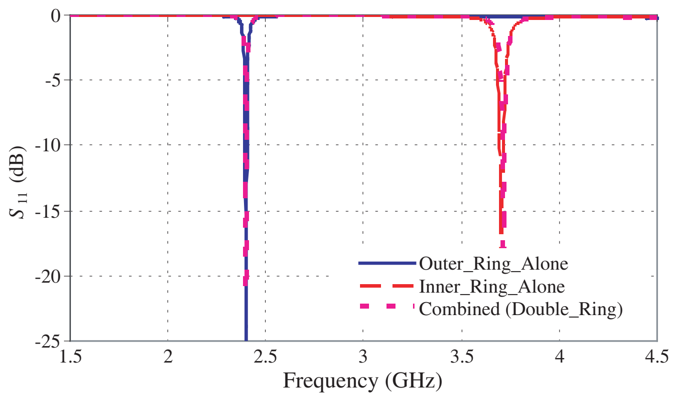


Figure 10. Return loss characteristics of antenna shown in Figure 9.

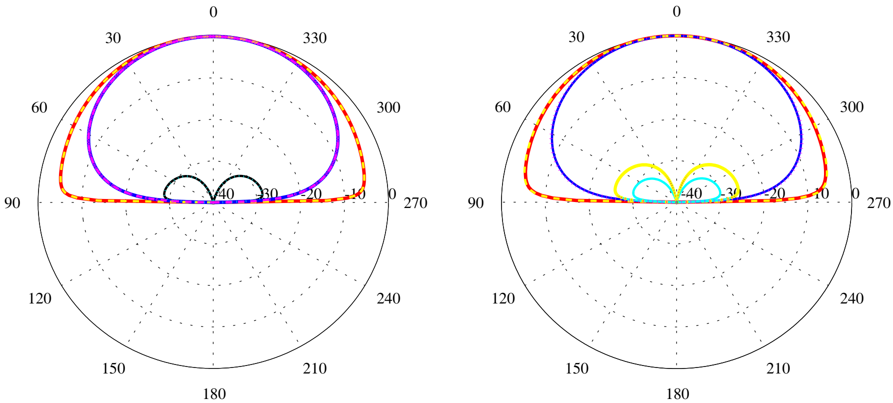
Table 1. Resonant frequency deviation due to variation in the width of inner ring (outer ring's width = 1.0 mm constant. (Feed strip parameters & its separation are as indicated in Figure 2(a)).

Width of inner Ring (mm)	0.5	1.0	1.5	2.0	2.5
First Resonant Frequency (f_{r1}) (GHz)	2.4	2.4	2.4	2.4	2.4
Second Resonant Frequency(f_{r2}) (GHz)	3.6	3.71	3.83	3.97	4.12

Table 2. Resonant frequency deviation due to variation in the width of outer ring (inner ring's width = 1.0 mm constant. (Feed strip parameters & its separation are as indicated in Figure 2(a)).

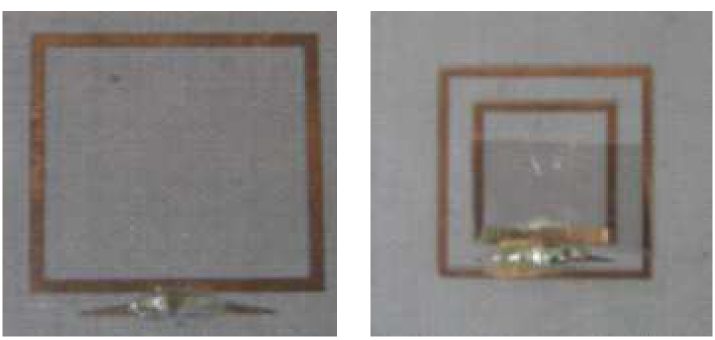
Width of outer ring (mm)	0.5	1.0	1.5	2.0
First resonant frequency (f_{r1}) (GHz)	2.35	2.4	2.44	2.5
Second resonant frequency(f_{r2}) (GHz)	3.71	3.71	3.71	3.71

separation between the feed strip and the two rings needs to be re-optimized. In this case the distance between the inner ring and feed strip was chosen equal to 0.5 mm whereas 1.0 mm was used between the outer ring and the feed strip to have better impedance match. Simulated return loss characteristics are shown in Figure 10. The two resonant frequencies may be tuned by changing the width of the rings. If lower frequency is to be changed by keeping higher frequency constant, width of the outer ring may be varied and vice versa. The parametric study on this variation is presented in Table 1 and Table 2. When outer ring width is varied (keeping inner ring's width constant), resonant frequency ratio (f_{r2}/f_{r1}) changes from 1.48 to 1.57. Similarly,



(a) (b)

Figure 11. Radiation patterns comparisons of individual and double rings. (a) First resonance (2.4 GHz). Red (solid): E_Co-Inner ring alone, Yellow (dashed): E_Co-Double ring; Blue (solid): H_Co-Inner ring alone; Magenta (dashed): H_Co-Double ring; Black (solid): E_Cross-Inner ring alone, Cyan (dashed): E_Cross-Double ring. (b) Second resonance (3.71 GHz). Red (solid): E_Co-Outer ring alone, Yellow (dashed): E_Co-Double ring; Blue (solid): H_Co-Outer ring alone; Magenta (dashed): H_Co-Double ring; Yellow(solid): E_Cross-Outer ring alone, Cyan (solid): E_Cross-Double ring. (Note: H-cross curves cannot be seen in patterns as these are well below −40 dB.



(a) (b)

Figure 12. Fabricated prototypes. (a) Single ring antenna. (b) Double ring antenna.

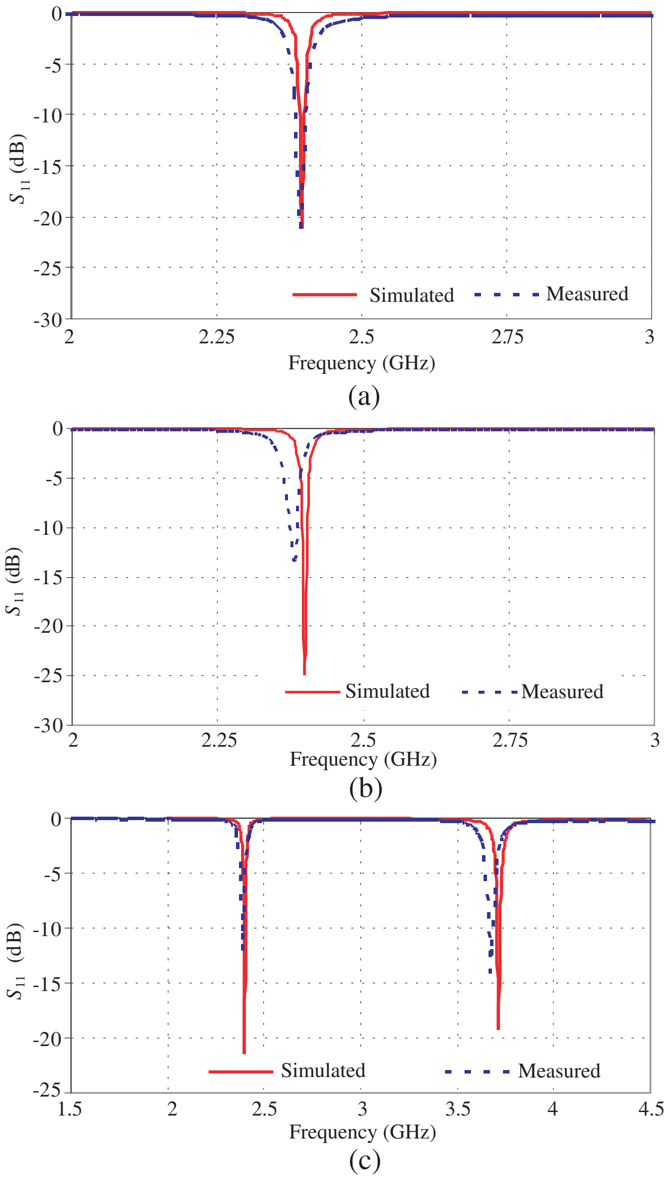


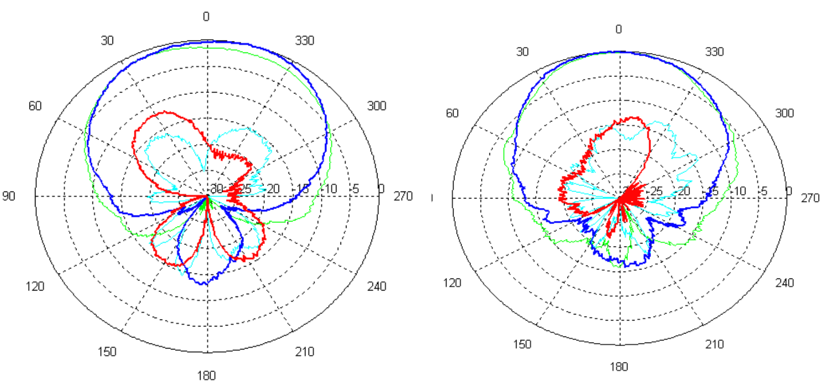
Figure 13. S_{11} characteristics comparisons of (a) Ring antenna with feed strip outside. (b) Ring antenna with feed strip inside. (c) Double ring antenna.

when inner ring's width is varied this deviation is from 1.5 to 1.71. These data indicate that both resonant frequencies may be tuned more flexibly by changing the widths of these rings.

From Figure 10 it can be noted that individual rings produce similar characteristics when they clubbed together. As discussed earlier, two resonances (of two rings) produce useful radiation characteristics and are shown in Figure 11. It can be noted that radiation patterns obtained from individual rings (only one of the two rings considered at a time) and combined case (double ring antenna) produced similar radiation patterns.

4. EXPERIMENTAL RESULTS AND DISCUSSIONS

The antenna geometries shown in Figures 2, 3, and 9 have been fabricated and tested. All the antennas have been fabricated on Roger's make substrate with dielectric constant of 2.5, loss tangent of 0.0016, and thickness of 1.56 mm. Photographs of the fabricated prototypes are shown in Figure 12. The return loss characteristics obtained from simulation and measurement are shown in Figure 13. It can be noticed from Figure 13 that measured data are in good agreement (small difference may be attributed due to fabrication inaccuracies) with the simulated results (obtained from the IE3D). The ratio of resonant frequency (f_{r2}/f_{r1}) for the measured case is found to be 1.54. This ratio can be changed to some extent by varying widths



(a) (b)

Figure 14. Radiation patterns at (a) First resonance (2.4 GHz). (b) Second resonance (3.7 GHz) (Blue: H_Co; Green: E_Co; Red: E_Cross; Cyan: H_Cross polarizations).

of ring geometries as discussed in Section 3.2. Radiation patterns were measured in anechoic chamber. At both the resonant frequencies stable radiation patterns were obtained (Figure 14).

5. CONCLUSIONS

In this paper, a coplanar capacitively coupled probe fed square ring microstrip antennas suitable for dual frequency operation applications have been presented. Coplanar capacitive feed strip has been modified to tune out the capacitive reactance and match the input impedance. Resonant frequencies may be tuned by varying the widths of rings. The overall ratio of resonant frequency (f_{r2}/f_{r1}) can be changed from 1.48 to 1.71. Both the bands have similar input and radiation characteristics. Measured results agreed with the simulated values.

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