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MICROSTRIP SQUARE RING ANTENNA FOR DUAL-BAND OPERATION

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Abstract—This paper presents a generalized approach to design an electromagnetically coupled microstrip ring antenna for dual-band operation. By widening two opposite sides of a square ring antenna, its fractional bandwidth at the primary resonance mode can be increased significantly so that it may be used for practical applications. By attaching a stub to the inner edge of the side opposite to the feed arm, some of the losses in electrical length caused by widening can be regained. More importantly, this addition also alters the current distribution on the antenna and directs radiations at the second resonant frequency towards boresight. It has also been observed that for the dual frequency configurations studied, the ratio of the resonant frequencies (f_{r2}/f_{r1}) can range between 1.55 and 2.01. This shows flexibility in designing dual frequency antennas with a desired pair of resonant frequencies.

1. INTRODUCTION

During the last decade wireless communication industries grew rapidly, influenced by improvements in RF circuit fabrications, large scale circuit integration and other miniaturization technologies, which made wireless devices inexpensive and more reliable. Miniaturized microstrip antennas played an important role in improving the performance and reducing the overall size of wireless devices [1]. In an effort towards multi-functional wireless terminals, several designs of microstrip dual-band, multiband and wideband antennas with same and orthogonal

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polarizations have been reported recently [2–9]. Multi-band antennas with a single radiator are desirable in most applications [6].

Ring type patches of various shapes have been studied in various contexts [10–17]. If higher order modes are excited, these provide better bandwidth and higher radiation resistance than similar sized regular patch antennas. The size of the resonant ring is substantially smaller than that of the corresponding rectangular patch. For the primary mode, the mean circumference of the ring equals the guided wavelength of the microstrip line. Ring antennas are usually excited with a capacitive strip or a patch or ring in another layer in a stacked configuration [1, 13].

In recent studies, concentric annular rings have been used for designing dual band antenna, where a second ring was placed within the first ring, each operating in the TM_{12} mode [10, 11] and [12]. In [12], the impedance properties of a dual frequency concentric annular ring microstrip patch antenna are described. This patch operates at two frequency bands which may be closely spaced about the TM_{12} mode however independent control of resonant frequency does not appear to be easy.

This group has recently proposed an out-of-plane capacitive feed arrangement for the square ring type (printed loop) geometry to design multi-band antennas [5]. However since the antenna operated at the primary mode of each ring, the bandwidths at the individual resonant frequencies was small. In the present paper, a modification is proposed to the basic square ring antenna to improve its bandwidth at the primary mode. A second improvisation results in dual frequency operation with just one ring.

2. SIMULATION STUDIES

The basic geometry of the microstrip square ring antennas studied here is shown in Figure 1 [5]. A square ring antenna with a uniform width of 1 mm is designed for 2.4 GHz operation on two-layers of dielectric materials with relative dielectric constant of 2.5 (Arlon), loss factor of 0.0023, and thickness of 1.56 mm. The 50 Ω microstrip line with a width of 4 mm on the bottom layer is used to feed the ring on the top. Initial simulations of these antennas are performed using IE3D version 12. It has been observed that at the primary resonant frequency of this antenna, its mean perimeter is a guided wavelength. But this antenna has a very narrow bandwidth for it to be of use in any practical applications.

The resonance behavior of this antenna is similar to that of an annular ring. One of the well-known approaches to improve the bandwidth of annular ring antennas is to increase the width of the ring. Hence a square ring antenna of uniform width is studied by increasing the ring width (w_r) uniformly at all four sides, without changing the mean perimeter of the ring (white dotted lines on the ring, Figure 1(b)). Simulated results given in Table 1 establish that an increase in width of the ring increases the bandwidth of the antenna. However, the resonant frequency is also slightly shifted to a lower frequency and this antenna continues to operate at the fundamental mode. As the width of ring antenna is increased, the effective permittivity increases causing the resonant frequency to decrease. It may be noted that the mean perimeter of the ring ranges from $1.026\lambda g$ to $1.053\lambda g$ as the width is increased from 1 mm to 7 mm. Since there is no sudden change in the

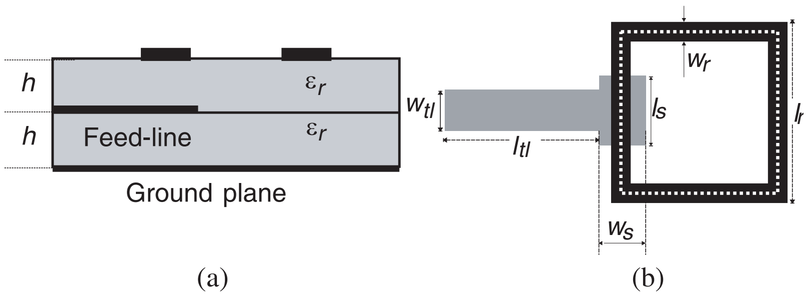

Figure 1. Geometry of the ring antenna. (a) Cross section view of the two-layer structure. (b) Geometry of the uniform width ring antenna (top view).

Table 1. The simulated performance of square ring antenna as its width is varied. The mean perimeter (MP) of the antenna is kept constant at 90.8mm (white dotted lines).

Width of the ring w_r (mm)	f_r (GHz)	Return loss, S_{11} (dB)	% BW	Boresight Gain (dBi)
1	2.469	−42.3	0.665	5.31
2	2.458	−26.31	0.838	5.6
3	2.4502	−22.28	0.9876	5.78
4	2.4442	−20.46	1.13	5.91
5	2.443	−40.5	1.203	6.05
6	2.437	−44.8	1.363	6.12
7	2.431	−36.19	1.52	6.1

resonant frequency or bandwidth, the mode of operation of the square ring antenna is analogous to TM_{11} mode in annular rings, even as the width is increased.

However, it has been seen that the bandwidth and other radiation characteristics of antenna configuration shown in Figure 2 improve significantly as the width of two arms of the square ring is increased, as opposed to four sides in the previous study. This however causes the resonant frequency to shift to a higher frequency (Table 2). But the behavior of radiation efficiency (gain) is similar to the previous case. In addition, it has been noted that the second resonant frequencies of both antenna configurations (in Figures 1 and 2) are not useful as the radiation patterns have a null in the bore sight direction.

This improvement in bandwidth is larger than what one may get by uniformly increasing the width of the complete ring. In the case of rings with uniform width, all four corners are separated by a quarter wavelength. Hence at the primary resonant frequency, the net transformed reactance due to the bends is nearly zero at the feed location. In the case of ring with unequal width however, the electrical lengths of the four sides of the ring are no more equal. Hence the reactance due to microstrip bend discontinuities at the four corners of the ring appears to have a strong influence on the bandwidth and the resonant frequency. The mean perimeter of the antenna differed significantly from the net guided wavelength. Yet the antenna operates at the primary mode and the current distributions and the radiation patterns of the antenna do not change significantly compared to the previous case.

In the next variation studied, a stub is attached symmetrically to

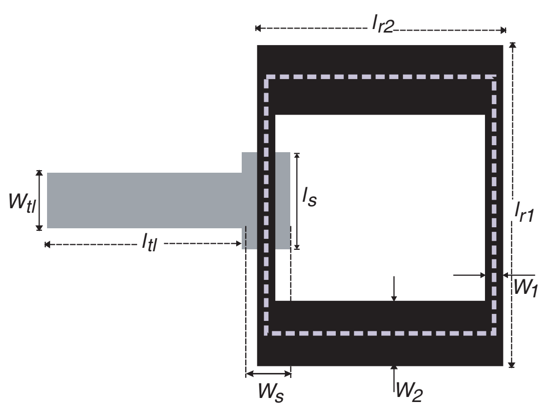

Figure 2. Geometry of the asymmetric ring antenna (top view).

the inner edge of the ring opposite to the feed as shown in Figure 3. As the length of the stub is increased, the bore-sight gain at the second resonant frequency shows major improvements. As noted from Table 3, the null in boresight direction disappears for stub lengths greater than 5 mm. The current distributions at the second resonant frequencies of antenna geometries from Figures 2 and 3 are shown in Figure 4. These appear to be significantly different, especially at the base of the stub, and cause the radiation patterns to be different. Hence for stub lengths greater than 5 mm, the resultant antenna may be useful as a dual frequency antenna. Both bands have reasonable bandwidth, good radiation characteristics and gain.

Furthermore, as noted from Table 3, this modification also makes the primary resonant frequency to shift to a lower frequency. This may be due to the increase in the stub reactance located at half wavelength away from the feed location. The parametric studies are also done by varying the width of the stub with its length kept constant. The summary of the simulated performances given in Table 4 shows some variations. From the parametric studies in Tables 3 and 4, the antenna configuration with stub can be useful for dual frequency operation. In these parametric studies, we have seen that the dimensions of the feed strip do not seriously change the resonant frequency. Hence dimensions of feed strip may be adjusted for the best impedance match [5].

Combining this approach with the previous study of varying the width of two sides of the ring (w_2) one may be able to tune the individual resonant frequencies. This is demonstrated in Table 5. The parametric studies are done on w_2 with a set of appropriate values

Table 2. Summary of the simulated performance of the ring antenna as the width of only two sides are varied. Other parameters: $w_1 =$ 1 mm, Mean Perimeter (MP) = 90.8 mm (white dotted lines). The dimensions of feed strip used as $l_s = 6$ mm, $w_s = 2.5$ mm for all cases.

Width of the ring Modified, w_2 (mm)	f_r (GHz)	Return loss, S_{11} (dB)	% BW	Boresight Gain (dBi)
1	2.469	−42.3	0.665	5.31
2	2.662	−30.7	0.962	5.81
3	2.799	−27	1.136	6.01
4	2.906	−43	1.501	6.1
5	2.998	−43.9	1.795	6
6	3.08	−21.8	1.87	6.25
7	3.15	−24.3	2.23	6.27

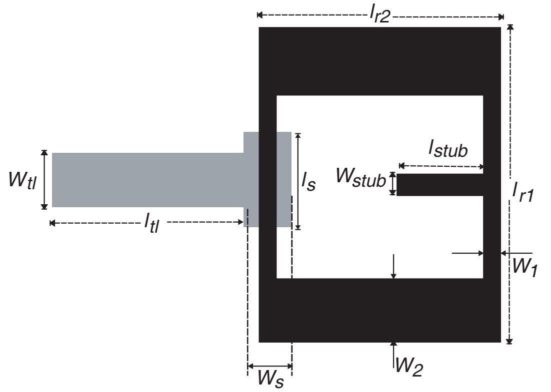

Figure 3. Geometry of the asymmetric ring antenna with stub (top view).

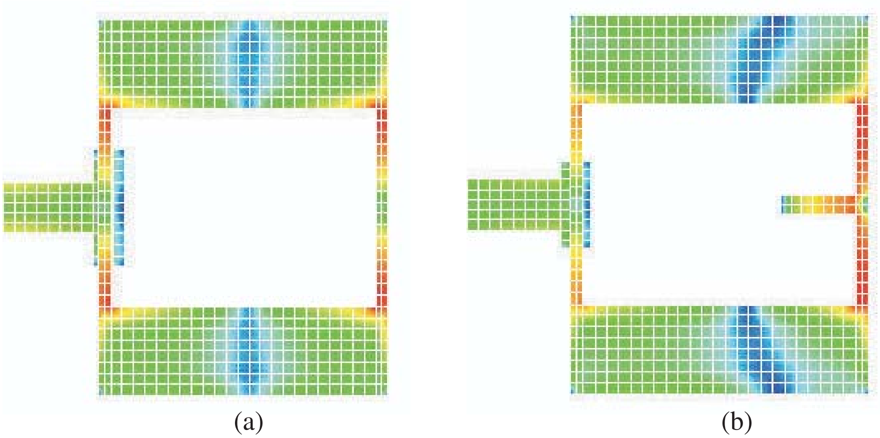

Figure 4. Comparison of current distributions at the second resonant frequencies of Antenna geometries shown in Figure 2 and Figure 3.

for the dimensions of the stub. For the configurations studied here the maximum and minimum values of the ratio of resonant frequencies (f_{r2}/f_{r1}) are 2.014 and 1.55, respectively.

It may be noted that the resultant dual-band antenna can be thought of as a square patch antenna with a large U-slot [18, 19]. However, its behavior is quite different from the U-slot patch which is considerably broadband. Yet this similarity may offer some possibilities in analyzing the behavior of the proposed dual-band

Table 3. SSimulated results for the dual frequency antenna in Figure 3 for a variation in the length of the stub (l_{stub}. Other design parameters are $w_1 = 1$ mm, $w_2 = 6$ mm, Mean Perimeter = 90.8 mm, $w_{stub} = 1.5$ mm.

Length of the stub l_{stub} (mm)	First resonance			Second resonance		
	f_{r1} (GHz)	Boresight Gain (dBi)	Radiation Efficiency(%)	f_{r2} (GHz)	Boresight Gain (dBi)	Radiation Efficiency(%)
1	3.0612	6.1	76.88	5.29	− 10	49.05
2	3.0375	4.34	77.17	5.21	− 11.51	48.54
3	3.012	4.12	76.19	5.1136	− 10.3	48.19
4	2.9828	5.6	75.98	5.002	− 4.25	47.63
5	2.9512	6.13	75.67	4.8756	0.29	53.67
5.5	2.935	6.14	75.82	4.808	1.62	55.72
6	2.917	6.13	74.91	4.737	2.736	57.87
6.5	2.899	6.138	74.526	4.6651	3.58	61.87
7	2.879	6.07	73.6	4.59	4.22	65.686

Table 4. Simulated results for the dual frequency antenna shown in Figure 3 for a variation in the width of the stub (w_{stub}). Other design parameters are $w_1 = 1$ mm, $w_2 = 6$ mm, Mean perimeter = 90.8 mm, $l_{stub} = 6$ mm.

Width of the stub w_{stub} (mm)	First resonance		Second resonance	
	f_{r1} (GHz)	Boresight Gain (dBi)	f_{r2} (GHz)	Boresight Gain (dBi)
0.5	2.974	6.16	4.913	− 0.29
1	2.943	6.126	4.812	1.693
1.5	2.917	6.13	4.737	2.736
2	2.89	6.13	4.672	3.45
2.5	2.868	6.065	4.624	3.89

antenna.

As noted before, the behavior of the antenna may be explained based on the current distributions on the geometry. In general, almost all the electric field lines are confined within the dielectric materials with very low fringing fields. Hence the field distribution is TM in the vertical direction (boresight). In the case on annular rings, the primary mode (TM_{11}) has been found to be of high Q whereas the second mode (TM_{12}) is highly preferred for antenna applications [10, 13, 17]. The reactive loading by corner discontinuities and the transformed

Table 5. Simulated results for the dual frequency antenna with different ratios of second and first resonant frequencies. A suitable dimension is chosen for the stub section opposite to the feed arm (Figure 3), as the width w_2 is varied.

w_2 (mm)	Stub dimensions		First resonance			Second Resonance			Ratio f_{r2}/f_{r1}
	l_{stub} (mm)	w_{stub} (mm)	f_{r1} (GHz.)	% BW_1	Boresight Gain (dBi)	f_{r2} (GHz.)	% BW_2	Boresight Gain (dBi)	
1	6	3.5	2.25	0.694	2.8	4.53	0.786	2.07	2.014
2	6	3.5	2.43	0.704	4.45	4.49	0.876	3.09	1.848
3	5	5.5	2.533	0.49	5.13	4.52	0.56	2.343	1.7844
4	5	5.5	2.638	0.971	5.627	4.5368	1.0626	3.07	1.7198
5	5	4.5	2.759	1.269	5.95	4.5988	1.3136	3.21	1.6668
6	5	4.5	2.843	1.4	6.08	4.636	1.527	3.696	1.6307
7	6	1.5	2.9924	1.525	6.18	4.784	1.497	3.03	1.5987
8	6	1.5	3.06	1.647	6.02	4.48	1.634	3.03	1.58
9	6	1.5	3.12	1.41	5.84	4.88	1.352	2.88	1.564
10	6	1.5	3.18	0.88	5.78	4.93	0.892	2.05	1.55

reactance of the stub provides a control of the resonances of the case of this square ring antenna. At the first mode, the low Q of the wide sides aides the improvement in the bandwidth while at the second mode, the cross currents along the ring width helps attain reasonable bandwidth. Since operation of this antenna is linked to the corner discontinuities it may not be possible to equate this with an annular ring with analogous behavior. Hence it may not be accurate to assign TM_{11} and TM_{12} modes for the resonant frequencies shown above. However, it may be recalled that the basic antenna shown in Figure 1 has resonances appearing at periodic frequencies as in the case of annular ring antennas [1]. But the resonant frequencies of the modified antenna in Figure 3 are seriously affected by the corner discontinuities and hence are not periodic.

3. EXPERIMENTAL VALIDATION AND DISCUSSIONS

Three prototype antennas are fabricated using standard printed circuit fabrication techniques and characterised using a vector network analyser. The top dielectric sheet has the microstrip radiating ring patch on one side of it. The other sheet has the microstrip line with the feed arrangement on one side and ground plane on the other side of the sheet. The cross sectional view of these antennas is shown in Figure 1(a). Geometry details of these antennas are given in Table 6. The radiation patterns and gain of these antennas are measured in a shielded anechoic chamber and are plotted at the respective resonant frequencies.

The measured and simulated return loss characteristics of the uniform width square ring antenna are shown in Figure 5. These are in good agreement and the first and second resonant frequencies are 2.43 and 5.23 GHz respectively. The polar plots of the radiation pattern of this antenna at these resonant frequencies are shown in Figure 6. It may be noted that the boresight radiations at the second resonant frequency is poor compared to the first. In addition the cross polarization behavior of this antenna is also poor.

The second prototype antenna has a ring with non-uniform sides. The side of the ring directly above the feed line has 1 mm width. The two widened sides have 7 mm width. It may be recalled from the simulation studies that this configuration resulted in better bandwidth than the previous case. The measured and simulated return loss characteristics of this antenna are in Figure 7. As in the previous case, the experimental return loss characteristic is in good match with the simulation study. The bandwidth at the primary mode is doubled by this modification.

The far field patterns in both E- and H-planes of this antenna are plotted at its resonant frequencies. Figure 8 shows that the behavior of

Table 6. Geometrical parameters of various prototype antennas fabricated. All dimensions in mm.

Parameters		Uniform Width Antenna	Non-uniform width Antenna	Dual frequency Antenna
Ring width	w_1	7	1	1
	w_2	7	7	7
Feed strip	Width w_s	7.5	2.5	2.5
	Length l_s	0.9	7.4	9.4
Stub	Length l_{stub}	-	-	6
	Width w_{stub}	-	-	1.5
Top view of geometry		Figure 1(b)	Figure 2	Figure 3

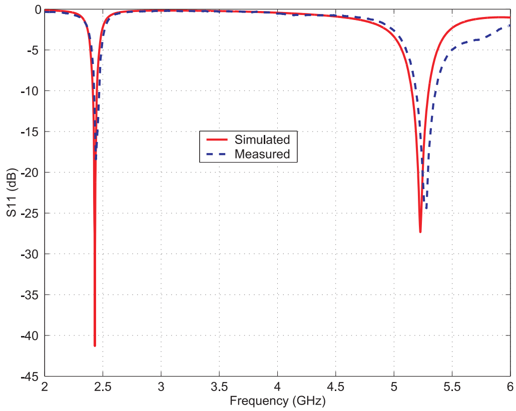

Figure 5. Simulated and measured return loss characteristics of the antenna configuration shown in Figure 1(b) with a uniform ring width of 7 mm.

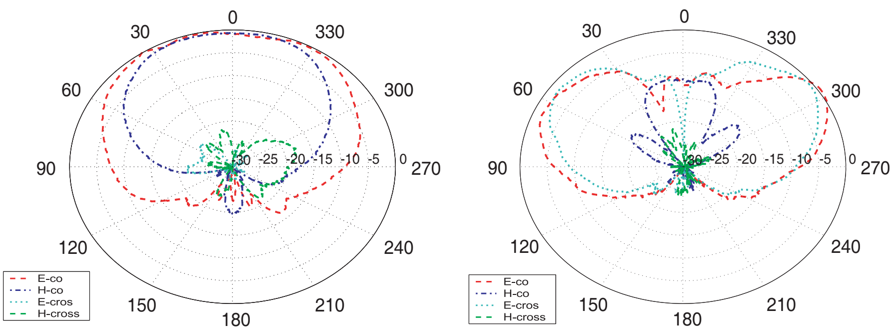

Figure 6. Measured radiation patterns of the uniform width antenna at (a) 2.431 GHz and (b) 5.23 GHz.

the radiation pattern of this antenna is similar to that of the previous case (Figure 6). These confirm that both these antennas are not useful at their second resonant frequencies as the radiation pattern causes null towards the boresight direction.

Similarly, the dual frequency antenna as shown in Figure 9 (fabricated) is also characterized using vector network analyzer. The measured return loss characteristic is plotted together with the simulated return loss characteristic of this antenna in Figure 10. In Figure 11, the co- and cross-polarization patterns in both E- and H-

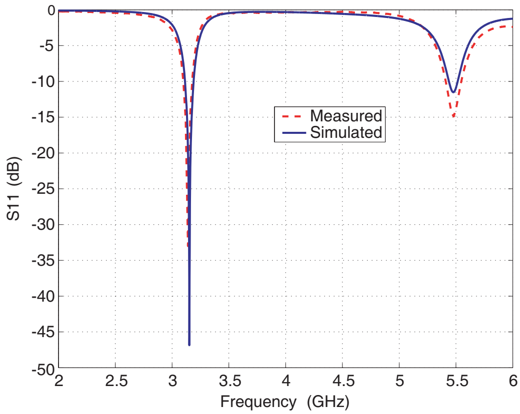

Figure 7. Simulated and measured return loss characteristics of the antenna configuration shown in Figure 2. These geometries have a width of 1 mm at the feed side and 7 mm at the radiating sides of the ring.

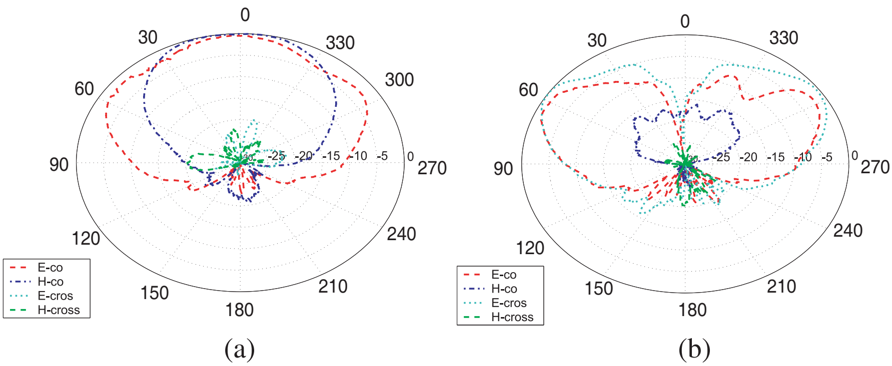

Figure 8. Measured radiation patterns of the non-uniform antenna at (a) 3.15 GHz and (b) 5.48 GHz.

planes of this antenna are presented at its resonant frequencies. It has been observed that this antenna has radiations towards the boresight at both resonant frequencies. However, the crosspolarization levels of all antennas are generally high in the H-plane. This is similar to the behavior of annular ring antennas at their TM_{12} mode [10]. However, this antenna also shows a cross-polarization level better than -15 dB in the boresight direction, at both resonant frequencies (Figure 11). It may be noted that the addition of the stub has effectively changed the radiation pattern of the antenna at the second resonant frequency.

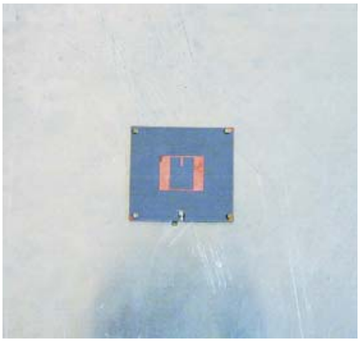

Figure 9. Fabricated dual frequency antenna.

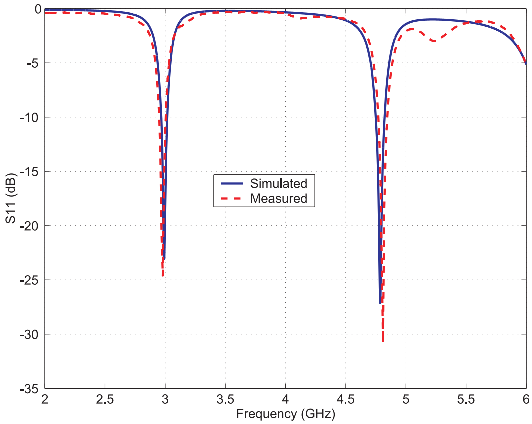

Figure 10. Simulated and measured return loss characteristics of the dual frequency antenna configuration.

This feature may be implemented dynamically by connecting the stub with a switching means to realize beam steering characteristics [20, 21].

This antenna also shows a cross polarization level better than $-15\,\mathrm{dB}$ at both resonant frequencies (Figure 10).

The performance characteristics of the fabricated antennas are compared with simulations in Table 7. The geometrical configurations of these antennas are provided in Table 6. Simulations studied are obtained using IE3D. The designs listed here are modified versions of those obtained from parametric studied listed in Tables 1–4. All antenna configurations have been further optimized for the best impedance matching by adjusting the dimensions of the feed strip.

A comparison of performance improvements obtained by the

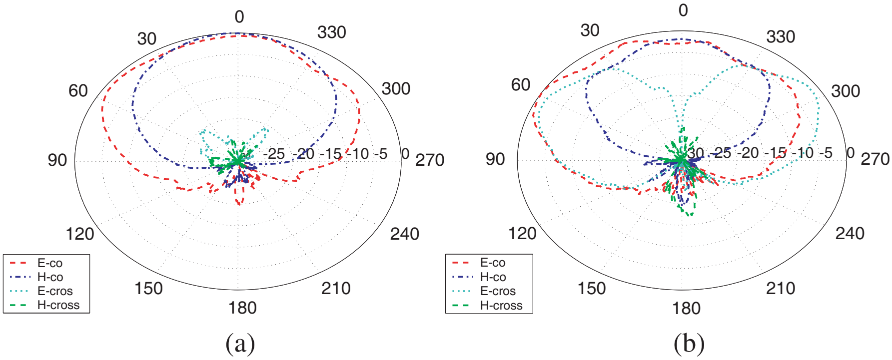

Figure 11. Measured radiation patterns of the dual frequency antenna at (a) 2.99 GHz and (b) 4.78 GHz.

Table 7. Comaprison of the simulated performances of the ring antennas with three diferent configurations. The geometrical parameters of these antennas are given in Table 6.

		Uniform Width Antenna		Non-uniform width Antenna		Dual frequency Antenna	
		Simulated	Measured	Simulated	Measured	Simulated	Measured
First resonance	Frequency [GHz]	2.431	2.431	3.152	3.15	2.992	2.99
	Bandwidth [MHz]	36.4	36	75.2	75.5	50.2	52
	Gain [dBi]	6.15	4.8	6.23	5.4	6.2	5.53
Second resonance	Frequency [GHz]	5.228	5.23	5.478	5.48	4.787	4.78
	Bandwidth [MHz]	144	144	77.2	76	73	71.5
	Gain [dBi]	–8.1	–12	–6.14	–11.0	3	2.42

suggested modifications is clear from Table 7. While the non-uniform width antenna has double the bandwidth as compared to the one with uniform width, its radiation performance at the second resonant frequency is poor. The dual frequency antenna (i.e., non-uniform width square ring with a stub as shown in Figure 3) has reasonable bandwidth at two resonant frequencies.

4. CONCLUSIONS

In this paper, an electromagnetically coupled square ring antenna with stub loading is proposed for dual-band operation. This has a two layer configuration, in which the antenna on a dielectric layer is excited from the a transmission line on another below. It has been demonstrated that the bandwidth of the antenna can be increased significantly by increasing the widths of two sides away from the feed line.The addition of a stub to the third side of the ring results in dual frequency operation. It has also been observed that the ratio of widths of the sides of the ring is directly proportional to the ratio of the two resonant frequencies for this type of antenna. Hence by appropriately choosing the width of the ring and dimensions of the stub one can design an antenna for the desired pair of resonant frequencies. Both the bands have reasonable bandwidth, good radiation characteristics and good gain. The experimental results of the fabricated antennas agree well with simulation results.

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