Polarization and Multi-Band Characteristics of Loaded Microstrip Square Ring Antennas

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1. Introduction

Microstrip square ring antennas are recently studied extensively because of their attractive features such as compactness, ease of fabrication, usefulness in arrays etc. Its resonant wavelength for the dominant mode TM_{11} is approximately equal to the average circumferential length of the square ring. Therefore, the antenna size is much smaller than that of the regular microstrip antenna [1]. The width of the conducting strip of the ring antenna determines the frequency of operation of this antenna. As the width is made narrower, the resonance frequency goes down, however, at the expense of high input impedance. Capacitive feeding has been proposed to improve the matching [2]. Different types of loading, e.g. stub, notch, gap, shorting post etc., also help improve the impedance matching [3, 4]. However, the loading contributes to the increase in the cross-polar level. Moreover, an interesting phenomenon has been observed when the square ring antenna is loaded with a narrow gap. Several additional resonances become excited along with the unloaded mode, with one at a much lower frequency than that of the unloaded mode. The multi-frequency capability of the loaded square ring antenna, along with its polarization characteristics will be discussed in this paper.

2. Gap Loaded Square Ring Antenna

We are going to start the discussion with regular square ring antenna, shown in Fig. 1(a), and show step by step the effects of gap loading on this antenna. The square ring is on a dielectric material with permittivity ε_r of 2.5, thickness of 1.57 mm, and loss tangent of 0.0019. The antenna parameters are: L_1 = 35 mm, L_2 = 17.5 mm, W = 8.75 mm. The probe is centered on one arm along the y-axis. For this antenna, the low S_{11} value at resonance frequency f_u = 2.132 GHz (called later 'unloaded mode frequency) indicates a poor impedance matching, Fig. 1(c). The antenna is x-polarized at this frequency, as shown in Fig. 1(b). A vertical gap, centrally located on the upper arm of the square ring antenna with an off-center feed point on the arm along the y-axis, Fig. 2(a), improves the impedance matching at f_u, as can be noticed in Fig. 2(e). However, we can see two more resonances, f_{L1} and f_{L2}, namely loaded mode frequencies, with $f_{L1} < f_u < f_{L2}$, and they are almost equally separated from each other. If we observe the current distributions at these three frequencies in Figs. 2(b) to 2(d), we can see that the polarization of the antenna at f_u has changed from x-polarization to y-polarization. At f_{L1} and f_{L2}, the antenna is x-polarized. However, the S_{11} value is poor at f_{L1}. If we introduce the loading on the other arm along y-axis, keeping the feed point off-centered, Fig. 3(a), a better impedance match can be achieved for f_{L1} and f_{L2}, with poor S_{11} value for f_u, Fig. 3(e). Interestingly, the antenna polarization for all three frequencies rotates 90^o (x- to y-polarization or y- to x-polarization), as can be seen in Figs. 3(b) to 3(d). The results discussed so far are obtained using a Method of Moments based software package 'Ansoft Designer ver. 3.0', and summarized in Table I. To confirm the simulation, we fabricated one square ring antenna with gap loading on a foam substrate in the Antenna Lab at the University of Manitoba. The dimensions are mentioned in the caption of Fig. 4. Fig. 4(a) shows the simulated and measured return loss plots for the first loaded mode frequency. Both simulated and measured -10 dB return loss bandwidths, at this frequency, are 3.75 MHz, however, a small shifting of the resonance frequency can be noticed. It is necessary to mention here that, for simulation, an infinite ground is considered, whereas for measurement, a ground plane size of 32cm×32cm was used. Figs. 4(b) and 4(c) show the simulated and measured co- and cross-polarization levels of the antenna at the first loaded mode frequency, respectively. A good agreement is observed between simulated and measured results. It is clear that the cross-polar level is high at the loaded mode frequency, due to the high orthogonal currents for the unloaded mode.

3. Stacked Gap Loaded Square Ring Antenna for Braodband

From previous discussion, we see that the antenna has a very narrow impedance bandwidth, especially at the loaded mode frequency. This can easily be overcome by using the concept of stacked resonator. A representative design is presented next for a center frequency of 1.575 GHz. Two gap loaded rings are considered, as shown in Fig. 5(a). The sizes of both rings are chosen to be close. The driven ring has $L_3 = 31.5$ mm, $W_b = 7.25$ mm, and $g_b = 1$ mm, with the probe positioned at $X_F = -9.5$ mm, $Y_F = 4$ mm. A Foam of thickness, $h_b = 10$ mm is used for this ring. The parasitic ring is separated from the driven ring by a Foam, having a thickness, $h_t = 25$ mm. The dimensions of the top ring are: $L_1 = 29.5$ mm, $L_2 = 17$ mm, $g_t = 1$ mm. The simulated return loss and impedance plots are shown in Fig. 5(b). –10dB return loss bandwidth is 41.2MHz (1546.8 to 1588 MHz) or 2.63%, which is 10 times larger than that of the single layer case.

4. Conclusion

The multi-band operation of the loaded square ring antenna is discussed with its polarization characteristics. Depending on the location of the loading and feed points, the polarization of the antenna at different frequencies changes. The polarization can also be controlled by selecting suitable locations for the loading. An asymmetric location of feed point with respect to loading is required to excite multiple resonances, around the unloaded mode resonance frequency.

References

[1] P. M. Bafrooei, and L. Shafai, "Characteristics of Single- and Double-Layer Microstrip Square-Ring Antennas", *IEEE Trans. Antennas Propagat.*, vol. AP-47, no. 10, October 1999, pp. 1633-1639.

[2] J. S. Row, "Design of square-ring microstrip antenna for circular polarisation", *Electron. Lett.*, vol. 40, no. 2, January 2004, pp. 93-95.

[3] R. Garg, and V. S. Reddy, "Edge feeding of microstrip ring antennas", *IEEE Trans. Antennas Propagat.*, vol. AP-51, no. 8, August 2003, pp. 1941–1946.

[4] S. –S. Oh, and L. Shafai, Investigation into the cross-polarization of loaded microstrip ring antennas, *IEEE Antennas Propagat. Soc. Int. Symp.*, Washington, DC, July 2005, 243 – 246.

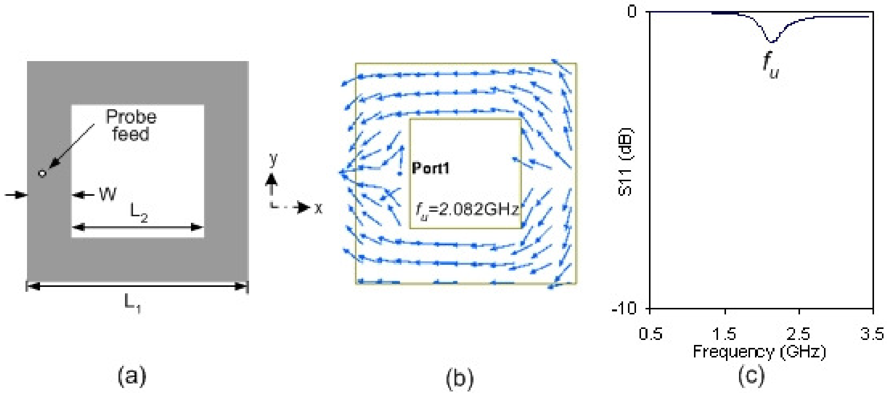


Fig. 1: (a) Geometry of the square ring antenna, (b) its current distribution and (c) return loss plot. The antenna parameters are: $L_1 = 35$ mm, $L_2 = 17.5$ mm, $W = 8.75$ mm.

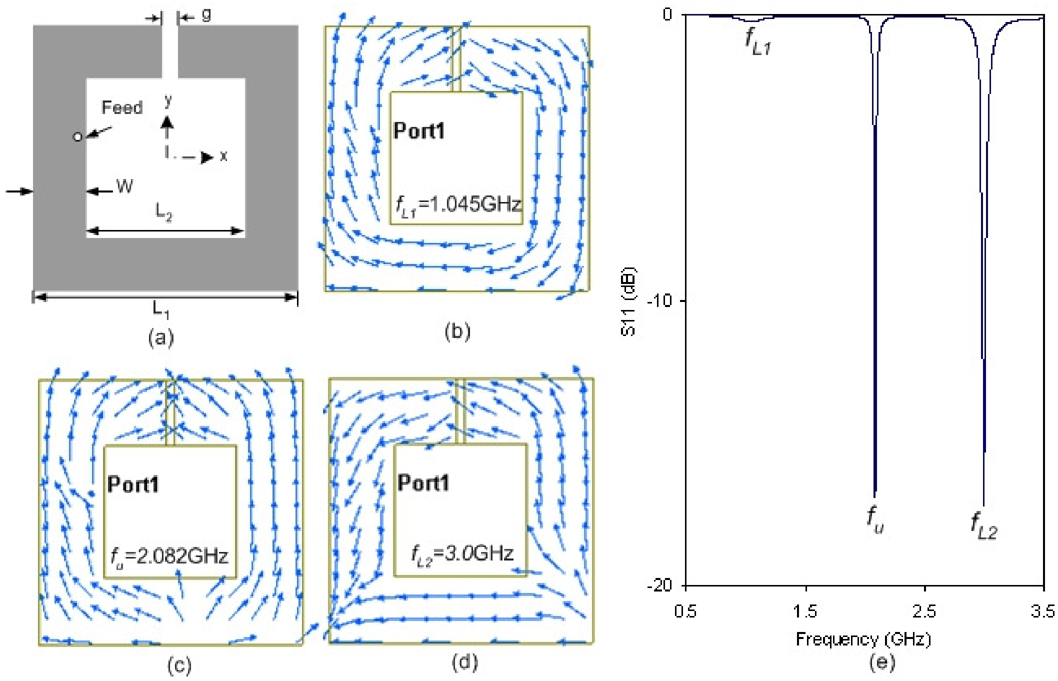


Fig. 2: (a) Geometry of loaded square ring antenna with a vertical gap, current distributions of the antenna at (b) f_{L1}, (c) f_u, (d) f_{L2}, and (e) its return loss plot. Gap size, g = 1 mm.

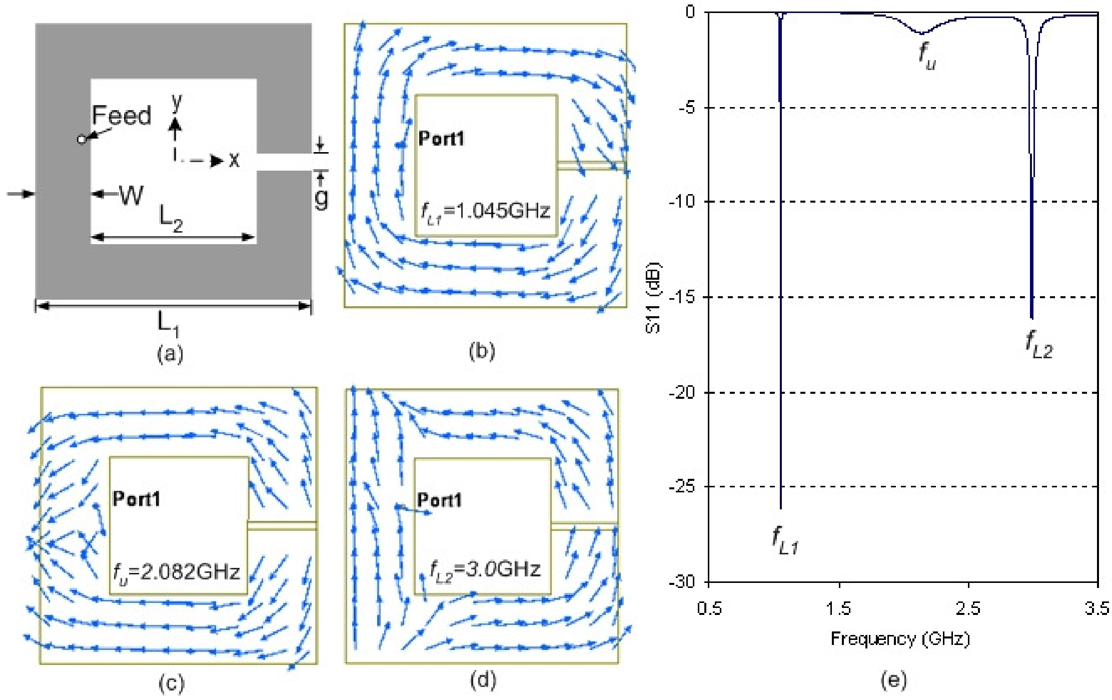
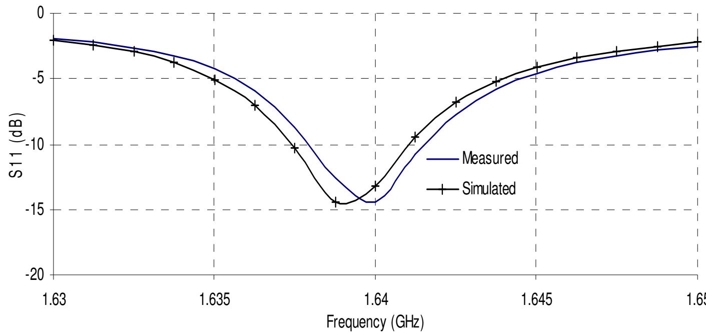


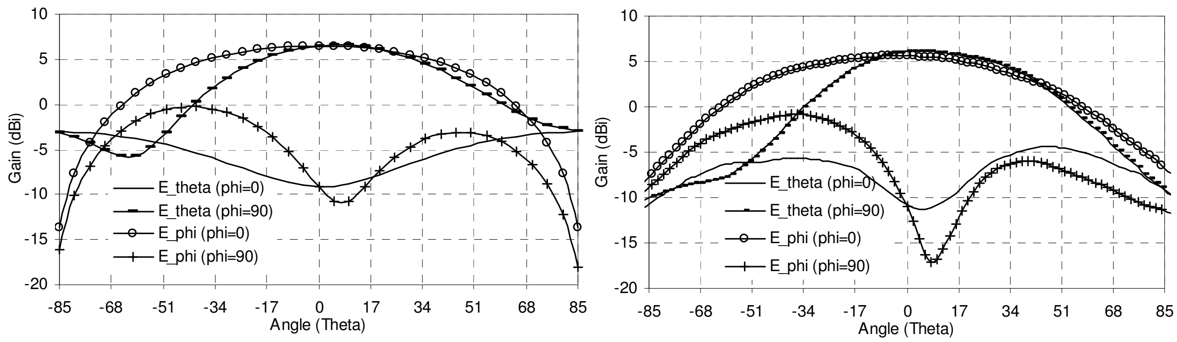
Fig. 3: (a) Geometry of loaded square ring antenna with a horizontal gap, current distributions of the antenna at (b), f_{L1}, (c) f_u, (d) f_{L2}, and (e) its return loss plot. Gap size, g = 1 mm.

Table I: Polarization and gain of loaded square ring antenna

Antenna Type	Polarization			Boresight Accepted Gain (dBi)											
				$\Phi = 0^o$						$\Phi = 90^o$					
				E_θ			E_φ			E_θ			E_φ		
	f_{L1}	f_u	f_{L2}	f_{L1}	f_u	f_{L2}	f_{L1}	f_u	f_{L2}	f_{L1}	f_u	f_{L2}	f_{L1}	f_u	f_{L2}
Unloaded	-	x	-	-	5.5	-	-	-80	-	-	-80	-	-	5.5	-
Vertical Gap	x	y	x	-6.3	-60	5.7	-60	5.37	-30	-60	5.37	-30	-6.3	-60	5.68
Horizontal Gap	y	x	y	-35	5.5	-14	-6.3	-34	5.6	-6.3	-34	5.6	-35	5.5	-14

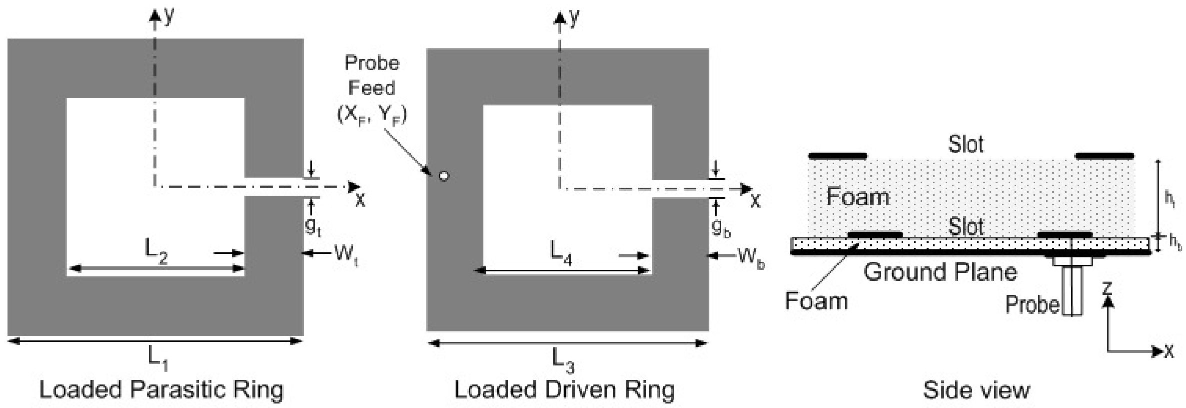


(a)

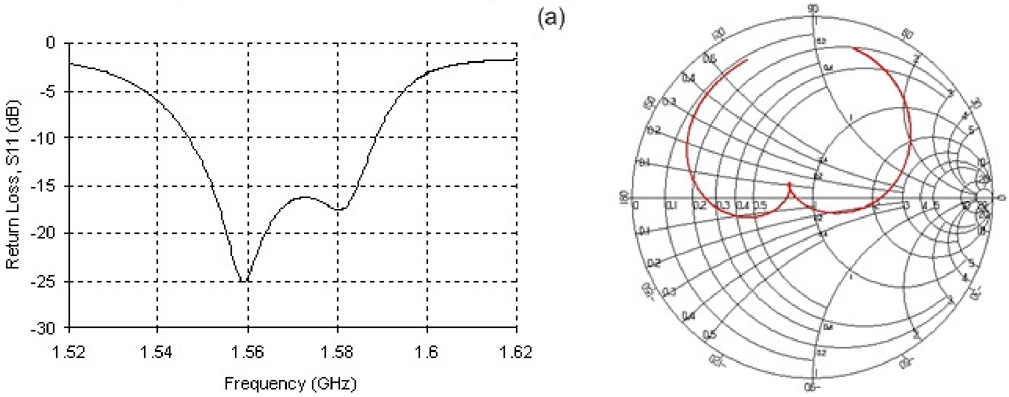


Phi = 0^o Phi = 90^o

Fig. 4: (a) The simulated and measured return loss plot and (b) gain patterns of the square ring antenna loaded with a horizontal gap, for loaded mode frequency of 1.64 GHz. The antenna parameters are (in mm): L_1=34, L_2=17.1, W=8.45, g=2, h=10. Foam substrate is used.



(a)



(b)

Fig. 5: (a) The geometry and (b) return loss and impedance plot of the stacked loaded square ring antenna. The antenna parameters are (in mm): L_1=29.5, L_2=17, W_t=6.25, g_t=1, h_t=25, L_3=31.5, L_4=17, W_b=7.25, g_b=1, h_b=10.