A Flexible Design Approach for a Dual-Frequency Microstrip Ring Antenna

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1. Introduction

With the widespread use of many new wireless technologies, approaches have also been investigated to incorporate multi-frequency antennas that may facilitate multi-functional terminals. Several modern telecommunication systems require antennas with wider bandwidths and smaller dimensions than conventionally possible. Many of these also require antenna that are low profile and conformal. Although microstrip antennas [1] can be made to meet several of these requirements, few systematic approaches are available to design these for two or more resonant frequencies with similar radiation characteristics at each band. Planar inverted F antenna [2] with slits and/or slots may be considered one such possibility, even though it is difficult to identify one design parameter that would affect the antenna performance.

Compared to microstrip patches, microstrip ring type antennas offer advantages such as improved radiation resistance and reduced size [1]. However these usually have a very small bandwidth. A common approach to increase the bandwidth is to increase the width of the ring. Recently this group has shown that it is possible to use an out-of-plane capacitive coupled feed for a systematic combination of several of such rings to design multi-frequency antennas [3].

In this paper we propose a set of modifications to the square ring geometries which allows dual frequency operation. Unlike square rings, the radiation patterns of such modified rings are similar at both resonant frequencies. It is also demonstrated that flexibility in choosing the relative separation between operational frequencies can be achieved for the resultant antenna. Results from a fabricated antenna are compared with numerical simulations in Section 3.

2. Antenna Geometry and Parametric Studies

The antenna geometry proposed here has two dielectric layers. In our study we used a standard microwave substrate Neltec NY9220 (ε_r = 2.2, tan δ = 0.0009, thickness = 0.787mm). The dielectric layer at the bottom has a microstrip transmission line patterned on one side of this and copper ground on the other side. The top dielectric layer has a modified ring antenna on the upper side (Figure 1).

This out-of-plane electromagnetically coupled feed configuration has a microstrip line with a rectangular strip placed at the end of it to couple energy to the radiating ring [3]. Several parameters such as the widths of the ring (w_{r1} and w_{r2}) and the dimensions (l_s, w_s) of the strip attached to the transmission line, could be varied to arrive at an optimum antenna design. The depth of indentation of a third of the left arm of the ring is indicated by d. In this study we kept the width of feed strip equal to that side of the ring ($w_s=w_{r1}$). Our studies indicated that the dimensions of the feed strip have the effect of changing the input resistance of the antenna at its resonant frequency and hence its length (l_s) can be optimized easily by electromagnetic simulations. This strip is placed directly beneath the side of the ring.

The antenna geometry shown in Figure 1 reduces to a simple square resonant ring antenna for d=0, and $w_{r1}=w_{r2}$. For a mean perimeter of 100mm and a uniform width of 1mm, this geometry

has a resonance at 2.43GHz. Hence in this study we first demonstrate the additional features obtained by making the said modifications to the geometry.
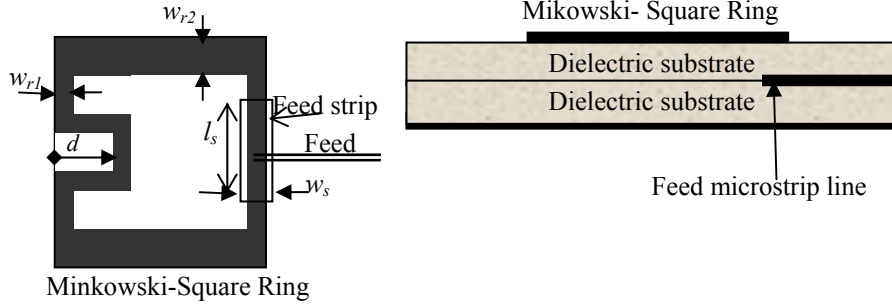

Figure 1 Basic schematic of the Minkowski-Square Ring Antenna.

2.1. Effect of Varying w_{r2} in Square Ring

In this study we vary the width of two horizontal sides of the microstrip square ring antenna obtained by making the indentation d=0 for the geometry shown in Figure 1. The simulation results for these antennas obtained using IE3D are listed in Table 1. As mentioned earlier, the length of the feed strip is suitably designed to have a good impedance match in each design.

It is normally expected that an increase in the width of a square ring antenna results in improvement in its radiation characteristics. However in this study we changed only two of its sides, but yet a comparable improvement in the gain and % bandwidth of the antenna could be observed. This may be attributed to the fact that the resonant modes of the square ring antenna causes current maximas on the sides for which the width is increased. The fractional bandwidth of this type of antenna is thought to be determined by the current loops through two edges (inside and outside) of the ring, and is therefore proportional to the difference in path lengths caused by this increase in width. It may however be noted that the second resonance of this antenna results in radiations away from the boresight direction and hence this antenna can not be considered a useful dual frequency antenna.

Table 1. Performance and design parameters of the Micro strip Square Ring Antennas studied. All antennas have a mean perimeter of 100mm. w_{r1}= 1mm.

Width of horizontal sides (w_{r2}) mm	Length of feed strip (l_s) mm	Resonant frequency (f_r) GHz	Bandwidth ($S_{11}<$ -10dB) MHz	Gain (dBi)
1	0.9	2.316	5.1	4.24
2	1.1	2.534	6.6	5.43
3	2.1	2.7	10.2	6.04
4	2.7	2.831	13.6	6.4
5	3.1	2.94	16.5	6.62
6	3.6	3.035	20	6.8
7	4.4	3.113	25	6.93
8	5.2	3.186	30.3	7.04
9	6	3.251	35.3	7.11
10	6.8	3.309	39.8	7.17

2.2. Effect of the Indentation depth d

The left side of the antenna geometry is obtained by replacing the straight line by five line segments. This geometry is similar to the fractal Minkowski curve. The length of all constituent segments can be equal ($x=l/3$). In this study we investigated several antenna geometries with the same mean perimeter (=100mm) and uniform ring width (=1mm). Therefore the area occupied by the antenna reduces as the indentation depth (d) is increased. As the aspect ratio of the indentation depth (d/x) is increased, there is a marginal increase in the primary resonant frequency. This increase may be attributed to the mutual reactance between various segments of the left arm of the ring. However more importantly, the bore sight gain at the second resonant frequency of the

antenna increases as the aspect ratio is increased. The boresight gain of these Minkowski-square ring (MSR) antennas is plotted as a function of the aspect ratio of the left arm in Figure 3. For an aspect ratio greater than 0.7 the radiated beams of the antenna has peak in the bore sight direction and such antennas may be used as a dual frequency antennas. However, the ratio of the second to the first resonant frequency is about 2. Furthermore, the bandwidths at these resonant frequencies are small.

2.3. Effect of Varying w_{r2} in the Modified Ring

In this study we vary the widths of the two sides of the Minkowski-square ring (MSR) geometry as in Section 2.1, and study its effects on the relative placement of the resonant frequencies. As expected, the resonant frequencies of these ring antennas correspond to those for which the mean perimeter of the ring becoming equal to integer multiples of wavelength. Since the previous study indicated dual frequency operation is possible with MSR geometry, we investigated its behavior at the second resonance as the width (w_{r2}) is changed. As before, the mean perimeter is kept constant at 100mm and the width of side arms of the ring (including all segments of the fractal geometry) are maintained at 1mm. It is observed that this frequency changed far more significantly than the primary resonant frequency. Further, slopes of these variations are different, thereby resulting in a larger change in their ratio. The ratio of resonant frequencies varies from about 1.5 to 2 by this range of variation. This ratio (f_{r2}/f_{r1}) can however be increased if one starts with a ring having horizontal arms thinner than the others. Similar behavior is observed for antennas with different ring widths (w_{r1}).
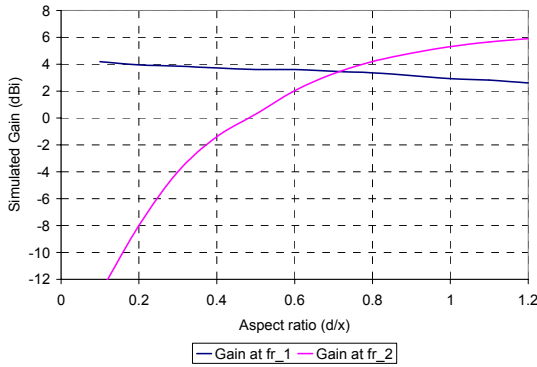

Figure 3. Variation in the boresight gain at the first (f_{r1}) and second (f_{r2}) resonant frequencies of Minkowski-Square Ring antennas as the indentation depth is varied.
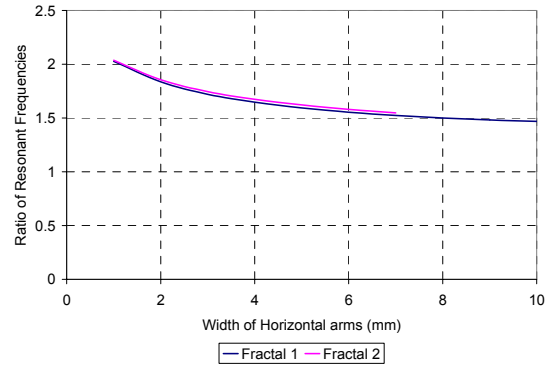
Figure 5. Ratio of resonant frequencies as the width of two arms of the Minkowski Square Ring antenna is varied. All other segments have a width of 1mm.

3. Experimental Validation

Four antennas were fabricated to validate the results of this study. The square ring antenna with uniform width is used for reference. The square ring with non-uniform width verifies the improvements at the first resonance frequency by increasing the width of two arms. The Minkowski Square Ring (MSR) Antenna with uniform width is used for verifying the dual frequency characteristics. The Minkowski Square Ring Antenna with 5mm is to verify the additional aspect of flexibility in locating the second resonant frequency.

Two layers of Neltec NY9220 substrates (each with 0.78mm thickness) are stacked in these designs. A vector network analyzer is used for the return loss characterization. Geometrical dimensions are provided in Table 2. The resonant frequencies and bandwidth are tabulated for comparison in Table 2. Radiation patterns of the MSR antennas measured inside a microwave anechoic chamber showed similar radiation patterns at the two resonant frequencies. Results in the table confirm the conclusions made from simulations. Complete results would be presented during the conference.

Table 3. Geometrical Parameters and performance of fabricated antennas. Two layers of Neltec NY9220 substrates are stacked in these designs.

	Square ring (uniform)	Square ring (non-uniform)	MSR (uniform)	MSR (non-uniform)
Occupied area [mm x mm]	22x22	29x22	23.8x23.8	27.8x23.8
Ring width w_{r1} [mm]	1	1	1	1
Ring width w_{r2} [mm]	1	8	1	5
Strip width w_s [mm]	1	1	1	1
Strip length l_s[mm]	1	5	0.23	1.73
Indentation d[mm]	0	0	4.3	4.3
Simulated 1st resonant frequency f_{r1}, GHz	2.77	3.83	2.38	3.07
Gain at f_{r1}	4.52	6.73	3.15	5.33
Bandwidth MHz (S11<-10dB)	7	34	9	14
Simulated 2nd resonant frequency f_{r2}, GHz	5.6	6.39	4.81	4.95
Gain at f_{r2}	NA	NA	3.96	5.8
Measured 1st resonant frequency f_{r1}, GHz	2.769	3.86	2.364	3.11
Bandwidth MHz (S11<-10dB)	6.2	14	6.4	17
Measured 2nd resonant frequency f_{r2}, GHz	5.685	6.7	4.81	5.09
Ratio of Resonant Frequencies	NA	NA	2.03	1.64

4. Conclusions

In this paper a systematic approach to design a dual frequency microstrip ring antenna with similar radiation patterns at both frequencies is proposed. It has been shown that by replacing a side of the square ring with Minkowski fractal geometries, dual frequency operation can be achieved. Furthermore, variation of the relative widths of two other sides of the ring introduces the flexibility to choose the relative placement of resonant frequencies of the resultant antenna. These behaviors may be explained based on current distributions on the antenna geometry. Experimental results validate the usefulness of this approach.

References

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