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MINIATURIZED MICROSTRIP-FED CIRCULAR SPLIT RING RESONATOR ANTENNA

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Abstract—A miniaturized microstrip-fed antenna composed of a broadside coupled split ring resonator and an excitation arc-shaped monopole is presented. Numerical and experimental results are presented for an antenna configuration of 1/25 wavelength in diameter (ka $\sim$ 0.126). The antenna size including the ground plane is $60 \times 38.5\,\text{mm}^2$ and it is operating at 200 MHz. Its resonant frequency can be tuned over a good range of frequency without changing the antenna size, which can increase its usable bandwidth using reconfigurable antenna techniques.

1. INTRODUCTION

In the modern wireless communications, there is an increasing need for greater capacities and transmission speeds, which, together with a growing demand from users for more complicated services, require the design of higher performance systems [1]. As communication devices become smaller due to greater integration of electronics, the antenna becomes a significantly larger part of the overall package volume. This results in a demand for similar reductions in antenna size. Therefore researchers investigated different methods for miniaturization of the microstrip antenna [2–20].

A dielectric substrate with high permittivity is used to decrease the effective guided wavelength, and decrease the antenna size [2–5]. A newly developed ceramic substrate is used in [4] because of its very high permittivity. Shorted pins or walls are also used in case of symmetry to eliminate half or three quarter of the antenna [6–9]. Using meander, zigzag or spiral shapes can also reduce the antennas as they increase the electrical length of the antenna in a small area. Up to $\lambda/10$ antenna is designed using these shapes [10–13].

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Employing Hilbert geometry can produce an overall size reduction of 77% with antenna size close to quarter wavelength [14–16]. Artificial magnetic materials based on fractal Hilbert curves are also used as a substrate to increase the effective permeability, thus leading to antenna size miniaturization [15]. The metamaterial technology is recently used for antenna miniaturization [17–20]. The split ring resonator (SRR), which is a basic element in metamaterial design, inspired new antenna miniaturized designs with very small size [19–20]. The antenna presented in [20] is only 0.043λ ($\lambda/23.4$). However, in order for this antenna to work, a large circular ground plane of 400 mm diameter is used at 305 MHz.

In this paper, a simplified version of the self-resonant miniaturized antenna presented in [20] is designed and studied for more size reduction. The proposed antenna has microstrip feedline which makes it easier to fabricate and much lower in profile. In addition, the antenna total size is $60 \times 38.5\,\mathrm{mm}^2$ with respect to the 400 mm diameter circular ground plane in [20]. The antenna geometry and its results will be explained in the next two sections. The full-wave electromagnetic simulations and analysis for the presented antenna are performed using the commercial computer software package Ansoft High Frequency Structure Simulator (HFSS) [21], which is based on the finite element method. Measurement of the return loss is also conducted to verify the simulation results and demonstrate the feasibility of the proposed configuration.

2. ANTENNA DESCRIPTION

Split ring resonators have outstanding miniaturization potentialities and ability to produce strong electromagnetic response; therefore they form a very attractive basis for designing electrically small antennas. For this purpose, a broadside-coupled SRR is used due to its favorable radius to wavelength ratio as compared to other SRR structures [22]. In this paper, a SRR based antenna is presented. The proposed antenna is depicted in Fig. 1. The antenna consists of 50 ohm microstrip-fed arc monopole which excites broadside coupled split ring resonator (SRR). The monopole consists of two non-concentric half circles of radii Rfi and Rfo, and their centers are separated by a distance "Offset". The starting width of the monopole is Wfs and the ending width is $2Rfo - 2Rfi - Wfs$. The SRR is printed on the top and bottom substrate layers. The ring width is t, and the distance between its inner edge and the monopole is Sr. The SRR on the bottom layer is connected to the ground plane from the right side and disconnected from the left side with a distance S. On the top layer, it is connected to

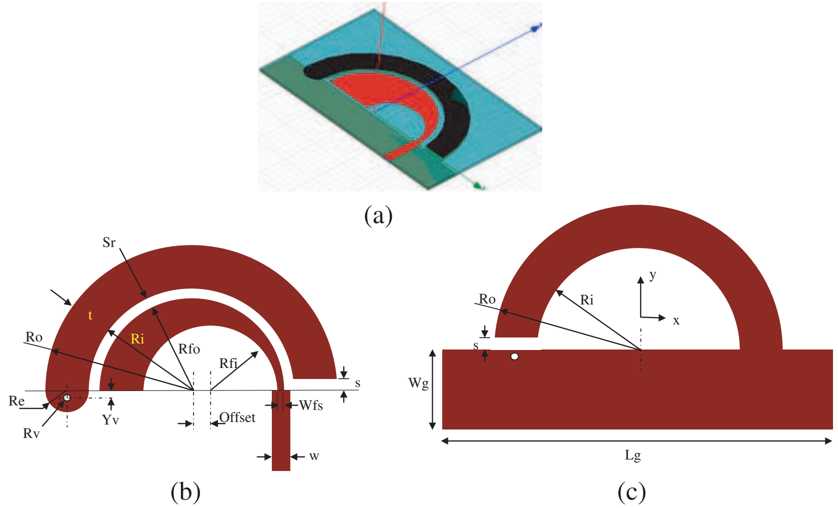

Figure 1. Antenna geometry and parameters. (a) 3D view, (b) top layer, and (c) bottom layer.

the ground plane in the left side through via hole, and in the right it is separated by distance S. The total ground plane size is $W_g \times L_g$. The substrate size is $60 \times 38.5\,\text{mm}^2$ from Duroid 5870 with $\varepsilon_r = 2.33$ and height $h = 0.787\,\text{mm}$. This geometry of the SRR has big inductance from the two half rings and the ground, and capacitance in the gap between the ring and the ground plane, the region between the two half rings, and the slot between the half rings and the monopole. These inductances and capacitances make this antenna resonate at low frequency.

3. PARAMETRIC STUDY

The antenna parameters of this antenna are studied in order to understand the effect of each one, which is required for antenna optimization process. In addition, by knowing the effect of each parameter, we can use one or more parameters to reconfigure the antenna using MEMs to overcome the narrow bandwidth of this antenna. The initial dimensions are shown in Table 1, with Offset equals to $Rfo - (Rfi + Wfs)$ and Re is $t/2$.

Figures 2 to 7 show the effect of the antenna parameters. One parameter is changed at a time, while the others are kept as in Table 1. Figs. 2 and 3 show that Wfs and S do not have much effect on the S_{11}, so they could be used to improve the return loss level. Figs. 4 to 7 show that the antenna is very sensitive to Rfi, Rfo, Sr, and t, which is expected because this antenna is highly resonant electrically small antenna. Figs. 4 to 7 prove that this antenna possesses high tuning capabilities that by far compensate its sensitivity, and make it good candidate to be reconfigured using MEMs. Another advantage of this design is that its tuning capability does not affect the overall antenna size.

Table 1. Antenna initial dimensions in mm.

W_g	L_g	S	w	Rfi	Rfo
10	60	0.85	2.3	8.6	15.9
Rv	Yv	Wfs	t	Sr	
0.4	1.1	1.3	6.2	1.6	

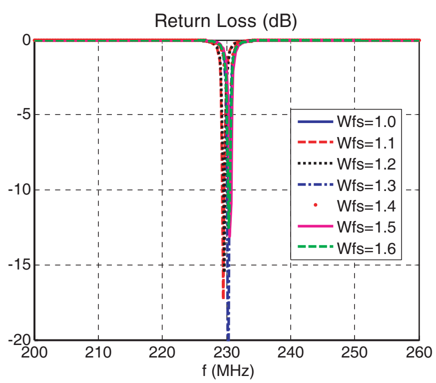

Figure 2. Effect of Wfs.

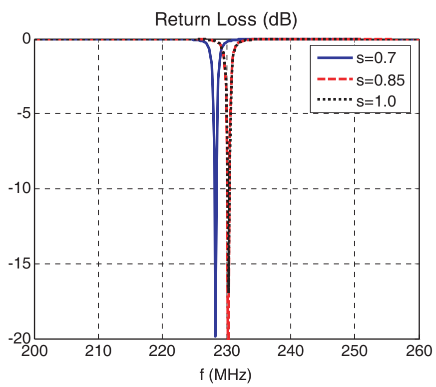

Figure 3. Effect of S.

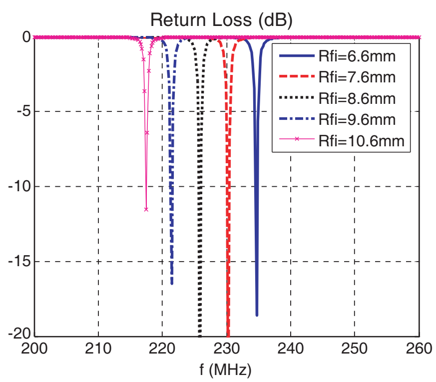

Figure 4. Effect of Rfi.

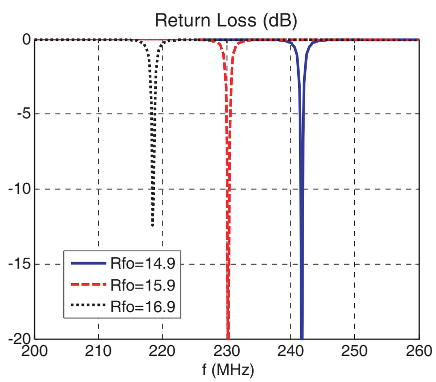

Figure 5. Effect of Rfo.

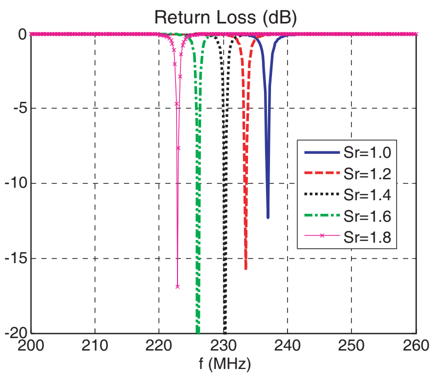

Figure 6. Effect of Sr.

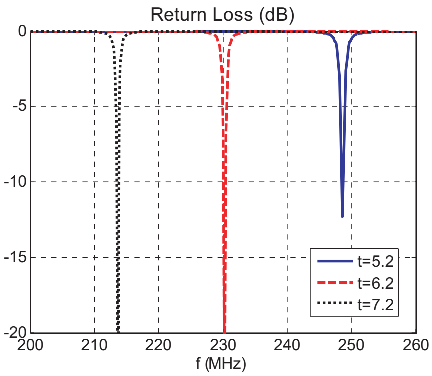

Figure 7. Effect of t.

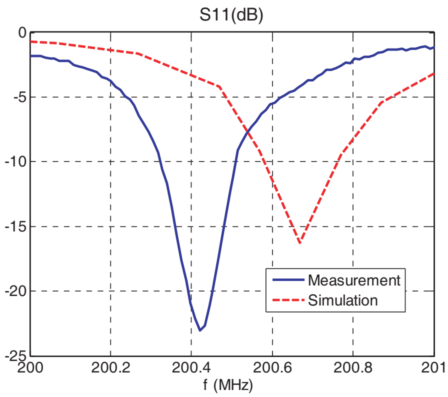

Figure 8. Measured and computed return loss (dB).

The final design has the same dimensions in Table 1 with $t = 8.2$ mm. A prototype of this antenna is fabricated using the LPKF milling machine and measured using the vector network analyzer. The measured and computed return losses of the final design are presented in Fig. 8. A good agreement between the measured and computed results is obtained which verifies the computed results using Ansoft HFSS. The antenna is operating at 200.4 MHz hence it can serve as VHF TV receiving antenna. However, we can make this antenna operate at any other frequency by scaling it.

The measured and computed co-polarized xz, xy and yz radiation patterns are shown in Fig. 9 at the resonance frequency. Unlike the design in [20], the proposed antenna provides dipole like radiation pattern with low directivity because there is no ground plane. The

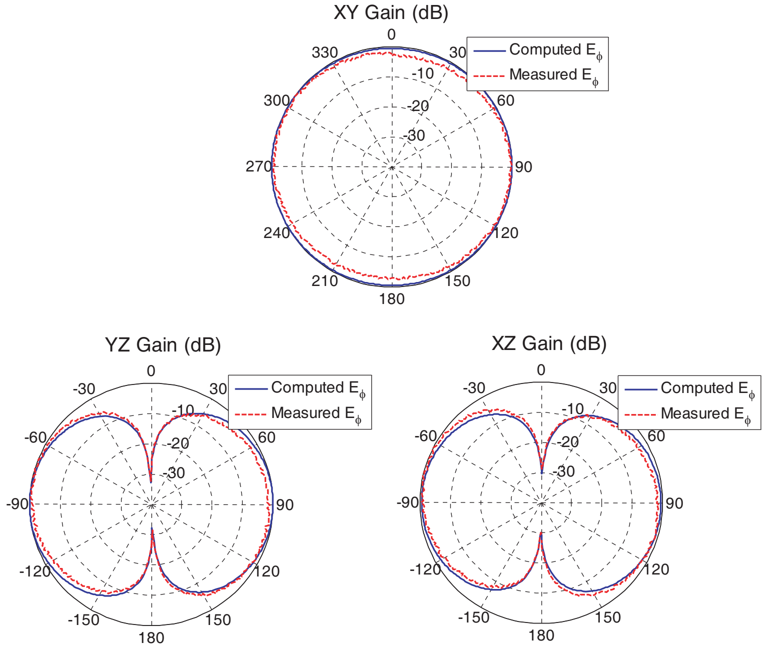

Figure 9. Measured and computed radiation patterns at the resonant frequency.

overall antenna size (including the ground plane and substrate) is 1/25 wavelength (ka $\sim$ 0.126) compared to the 0.4λ in [20] as it has circular ground plane of diameter 400 mm and it operates at 305 MHz. The antenna exhibits a computed efficiency of 13% (Gain $= -8.8$ dB) which is smaller than the 17% in [20]. Future research will investigate methods to improve the radiation efficiency and gain of the antenna [23–25].

4. CONCLUSIONS

The presented antenna is simple design with very small size. A microstrip feedline is used to decrease the antenna profile. Our modification to the geometries of the monopole and the SRR, and introducing the microstrip line and the truncated ground plane instead of coaxial feed and the large circular ground resulted in much smaller size and lower resonant frequency. The numerical and experimental results show that this antenna provides dipole like radiation pattern with 1.9 dB directivity and computed efficiency of 13%. The overall antenna size including the ground plane and substrate is 1/25 wavelength.

REFERENCES

1. Eldek, A. A., "A compact multi-band meanderline antenna for wireless communications applications," *Microwave Opt. Tech. Lett.*, Vol. 50, No. 4, 1117–1121, Apr. 2008.
2. Lo, T. K., C.-O. Ho, Y. Hwang, E. K. W. Lam, and B. Lee, "Miniature aperture-coupled microstrip antenna of very high permittivity," *Electronics Letters*, Vol. 33, No. 1, 9–10, 1997.
3. Lee, B. and F. J. Harackiewicz, "Miniature microstrip antenna with a partially filled high-permittivity substrate," *IEEE Transactions on Antennas and Propagation*, Vol. 50, No. 8, 1160–1162, 2002.
4. Kula, J. S., D. Psychoudakis, W.-J. Liao, C.-C. Chen, J. L. Volakis, and J. W. Halloran, "Patch-antenna miniaturization using recently available ceramic substrates," *IEEE Antennas and Propagation Magazine*, Vol. 48, No. 6, 13–20, 2006.
5. Kim, J.-S., W.-K. Choi, and G.-Y. Choi, "Small proximity coupled ceramic patch antenna for UHF RFID tag mountable on metallic objects," *Progress In Electromagnetics Research C*, Vol. 4, 129–138, 2008.
6. Ruvio, G. and M. J. Ammann, "A novel wideband semi-planar miniaturized antenna," *IEEE Transactions on Antennas and Propagation*, Vol. 55, No. 10, 2679–2685, 2007.
7. Ko, C.-H., M.-J. Chiang, and J.-Y. Sze, "Miniaturized planar annular slot antenna design utilizing shorting conducting strip," *IEEE Antennas and Wireless Propagation Letters*, Vol. 8, 1360–1363, 2009.
8. Mak, C. L., R. Chair, K. F. Lee, K. M. Luk, and A. A. Kishk, "Half U-slot patch antenna with shorting wall," *Electronics Letters*, Vol. 39, No. 25, 1779–1780, 2003.
9. Chiu, C. Y., C. H. Chan, and K. M. Luk, "Small wideband patch antenna with double shorting walls," *2004 IEEE Antennas and Propagation Society International Symposium*, Vol. 4, 3844–3847, 2004.
10. Sharma, S. K. and L. Shafai, "Investigations on miniaturized endfire vertically polarized quasi-fractal log-periodic zigzag antenna," *IEEE Transactions on Antennas and Propagation*, Vol. 52, No. 8, 1957–1962, 2004.

11. Sarabandi, K. and R. Azadegan, "Design of an efficient miniaturized UHF planar antenna," *IEEE Transactions on Antennas and Propagation*, Vol. 51, No. 6, 1270–1276, 2003.
12. Abbosh, A. M., "Miniaturized microstrip-fed tapered-slot antenna with ultrawideband performance," *IEEE Antennas and Wireless Propagation Letters*, Vol. 8, 690–692, 2009.
13. Hong, W. and K. Sarabandi, "Low profile miniaturized planar antenna with omnidirectional vertically polarized radiation," *IEEE Transactions on Antennas and Propagation*, Vol. 56, No. 6, 1533–1540, 2008.
14. Huang, J.-T., J.-H. Shiao, and J.-M. Wu, "A miniaturized hilbert inverted-F antenna for wireless sensor network applications," *IEEE Transactions on Antennas and Propagation*, Vol. 58, No. 9, 3100–3103, 2010.
15. Yousefi, L. and O. M. Ramahi, "Miniaturised antennas using artificial magnetic materials with fractal hilbert inclusions," *Electronics Letters*, Vol. 46, No. 12, 816–817, 2010.
16. Azaro, R., F. Viani, L. Lizzi, E. Zeni, and A. Massa, "A monopolar quad-band antenna based on a hilbert self-affine prefractal geometry," *IEEE Antennas and Wireless Propagation Letters*, Vol. 8, 177–180, 2009.
17. Volakis, J., C. C. Chen, and K. Fujimoto, *Small Antennas — Miniaturization Techniques and Applications*, McGraw Hill, 2010.
18. Chen, P. Y. and A. Alu, "Dual-mode miniaturized elliptical patch antenna with mu-negative metamaterials," *IEEE Antennas and Wireless Propagation Letters*, Vol. 9, 351–354, 2010.
19. Li, M., X. Q. Lin, J. Y. Chin, R. Liu, and T. J. Cui, "A novel miniaturized printed planar antenna using split-ring resonator," *IEEE Antennas and Wireless Propagation Letters*, Vol. 7, 629–631, 2008.
20. Kim, O. S. and O. Breinbjerg, "Miniaturized self-resonant split-ring resonator antenna," *Electronics Letters*, Vol. 45, No. 4, 196–197, 2009.
21. HFSS, *High Frequency Structure Simulator Based on the Finite Element Method*, Ver. 12, Ansoft Corp., 2008.
22. Marques, R., F. Mesa, J. Martel, and F. Medina, "Comparitive analysis of edge and broadside-coupled split ring resonators for metamaterial design — Theory and experiments," *IEEE Transactions on Antennas and Propagation*, Vol. 51, No. 10, 2572–2581, 2010.
23. Políka, M. and A. Holub, "Electrically small loop antenna

surrounded by a "shell" of concentric split loops," *2010 Proceedings of the Fourth European Conference on Antennas and Propagation (EuCAP)*, 1–3, 2010.

24. Holub, A. and M. Polivka, "Electrically small loop surrounded by a "shell" of concentric split rings: Principle and properties," *2010 15th International Conference on Microwave Techniques (COMITE)*, 27–30, 2010.

25. Attia, H., O. F. Siddiqui, and O. M. Ramahi, "Artificial magneto-superstrates for gain and efficency improvement of microstrip antenna arrays," *PIERS Online*, Vol. 6, No. 6, 555–558, 2010.