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A COMPACT ZEROTH ORDER RESONATING ANTENNA USING COMPLEMENTARY SPLIT RING RESONATOR WITH MUSHROOM TYPE OF STRUCTURE

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Abstract—A compact zeroth order resonance (ZOR) antenna based on composite right left handed Transmission Line (CRLH TL) with complementary split ring resonators (CSRR) is presented in this paper. In the proposed antenna, CRLH TL is realized by the conventional mushroom type (CMT) of structure. The unit cell of proposed antenna comprises the CMT structure and CSRR where the CSRR is etched on the patch of the mushroom. Presence of CSRR introduces the lumped components in the shunt arm of the unit cell which results in the reduction of the shunt resonance frequency. The presented antenna consists of 4 unit cells and is excited by the quarter wavelength TL. The simulation and experimental results are in close agreement. The proposed structure has nearly 8.32% footprint area of the conventional half wavelength antenna.

1. INTRODUCTION

In present time, the communication devices are becoming smaller due to the great integration of electronics, still the antenna system occupies the larger part of the overall package volume. So the developments in the wireless communication system call for the more compact antenna along with omnidirectional radiation pattern is also required to meet the current demands. Evolution of the Left handed metamaterials (LHM) give a new approach to realize the compact antennas [1–6], multi split ring resonator antenna [7] and patch antennas loaded with metamaterials [8]. They have some unique and unusual properties such as anti parallel phase and group velocity, zero propagation constant etc. which are not found in naturally occurred material.

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In Microwave integrated circuit (MIC) environment they have been realized using the both resonant structures (split ring resonators (SRR) & complementary split ring resonators (CSRR)) and CRLH TL [9–14]. Zeroth order resonance (ZOR) is the inherent property of the CRLH TL in which TL supports the infinite wavelength, so that the zero phase constant can be achieved at specific frequency. At this Zeroth order resonance mode, the resonance condition becomes independent of the resonator size, so this property is especially useful for the design of compact antennas. Based on this property, ZOR antennas are widely reported where the structures are composed with interdigital capacitor, shorted stub and CMT structure [9–14]. The CMT structure suppresses the surface current and gives the vertical electric field distribution at the infinite wavelength frequency. Several works have been reported in variation of CMT structure for different application areas especially in the field of antenna [15–18]. The concept of high-impedance electromagnetic surfaces is developed by Sievenpiper et al. using mushroom type of structure [19].

This paper presents the compact zeroth order resonating antenna based on CMT structure with CSRR. In unit cell structure, CSRR is etched on the top of the patch of the CMT structure. The antenna, consisting four unit cells of proposed structure is simulated and fabricated. The experimental ZOR frequency of the antenna is observed at 2.66 GHz with monopolar radiation pattern in elevation plane and omnidirectional pattern in azimuth plane. The physical size of the unit cell and antenna at ZOR frequency are $0.072\lambda_0 \times 0.072\lambda_0 \times$

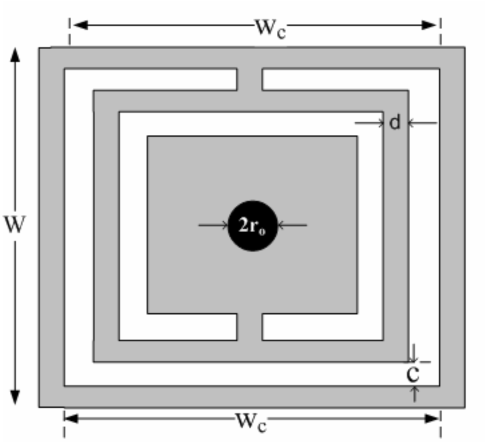


Figure 1. Unit cell design.

$0.014\lambda_0$ and $0.072\lambda_0 \times 0.29\lambda_0 \times 0.014\lambda_0$ respectively (with respect to simulated ZOR frequency), where λ_0 is the free space wavelength.

2. UNIT CELL DESCRIPTION

2.1. Unit Cell Design

Figure 1 shows the unit cell of the proposed antenna structure. It consists of a square patch of dimension W, a complementary split ring resonator (CSRR) with outer dimension W_c and a short circuit post (via) of radius r_0 which are located at the center.

The inner and outer rings of the CSRR having width c are separated by distance d. The unit cell is analyzed using commercially available simulator (Ansoft HFSS). For designing of antenna, Taconic substrate ($\varepsilon_r = 2.2$, thickness = 1.57 mm and $\tan\delta = 0.0009$) is used. The design parameters taken for the analysis are given in Table 1.

The dispersion diagram for the left handed (LH) region of the proposed unit cell is shown in the Figure 2. The shunt resonance frequency is observed at 2.87 GHz.

Table 1. Dimensions of proposed antenna.

W	W_c	c	d	r_0
8 mm	7 mm	0.5 mm	0.3 mm	0.3 mm

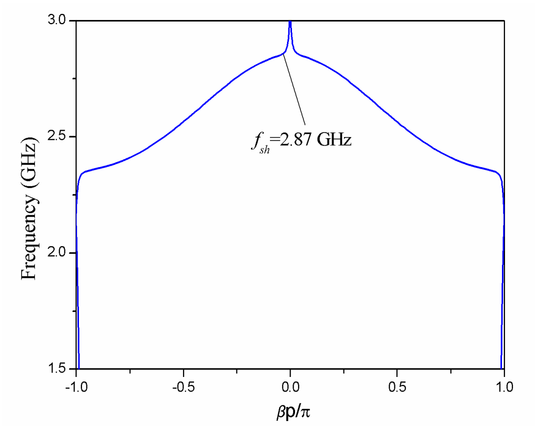


Figure 2. Dispersion diagram for proposed unit cell.

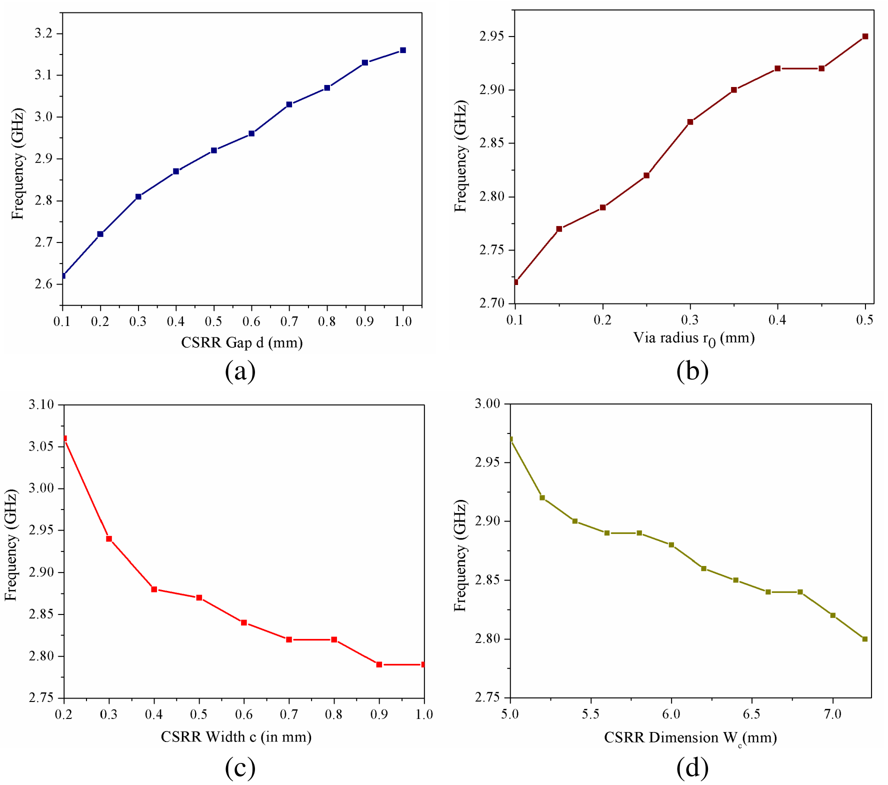


Figure 3. Effect on shunt resonance frequency for proposed unit cell. (a) CSRR gap d. (b) Via radius r_0. (c) CSRR width c. (d) CSRR outer dimension W_c.

2.2. Parametric Analysis

Parametric analysis has been carried out for the shunt resonance frequency (f_{sh}) of the unit cell structure. Figures 3(a), (b), (c) and (d) show the effect of the parameters variation on the shunt resonance frequency when the other parameters are kept constant. The design parameters value which are taken for this analysis, are mentioned in the Table 1. Figure 3(a) shows the variation of the shunt resonance frequency with the gap d between the CSRR rings. On increasing the gap between the rings, resonance frequency will increase. Figure 3(b) shows the variation of the shunt resonance frequency with the via radius r_0. Similarly Figures 3(c) and (d) shows the variation for the CSRR width c and CSRR outer dimension W_c respectively. From the parametric analysis we can conclude that shunt resonance frequency can be increased by increasing the gap between the rings and via radius. Similarly the frequency can be decreased by increasing the CSRR width and CSRR outer dimension.

3. DESIGN OF 4-CELLS ZEROTH ORDER RESONATING ANTENNA

3.1. Antenna Design

In this section a compact zeroth order resonating (ZOR) antenna design based on modified conventional mushroom type (CMT) structure, where the modification is done with complementary split

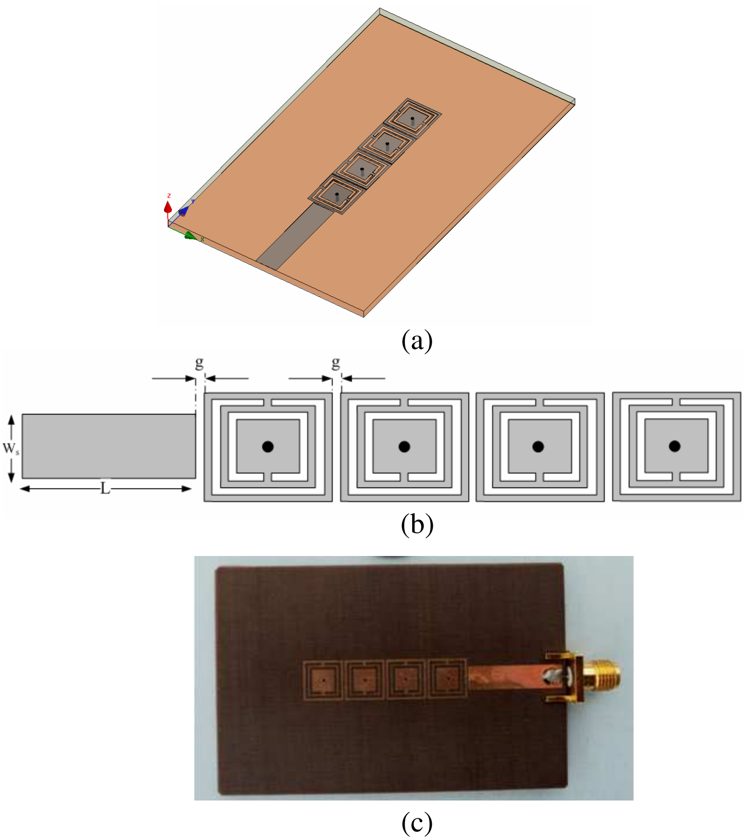


Figure 4. (a) 3D view of proposed 4-cell ZOR antenna. (b) Layout of proposed 4-cell ZOR antenna. (c) Fabricated structure of 4-cells ZOR antenna.

ring resonators (CSRR), is presented. The model of 4-cells ZOR antennas is shown in Figures 4(a), 4(b) and 4(c). The proposed antenna is realized on Taconic TLY substrate ($\varepsilon_r = 2.2$, thickness = 1.57 mm and $\tan\delta = 0.0009$). The proposed antenna is excited through a edge coupled quarter wavelength long microstrip transmission line to match the input impedance. The dimensions of the designed parameters which are used in antenna design are given in Table 2.

3.2. Results and Discussion

For the proposed antenna prototype, simulated and experimental input reflection coefficient are shown in Figure 5. The values of input reflection coefficient are −14.96 dB (simulated) and −11.96 dB (measured) at the ZOR frequencies 2.735 GHz (simulated) and 2.660 GHz (measured) respectively. The input impedance (at ZOR frequency) of the proposed antenna is shown in Figure 6. The value of input impedance is observed to be $34.392 + j0.6973$ Ohm (simulated)

Table 2. Design parameters for 4-cells ZOR antenna design.

W_s	L	g	W	W_c	c	d	r_0
4.725 mm	18.6 mm	0.22 mm	8 mm	7 mm	0.5 mm	0.3 mm	0.3 mm

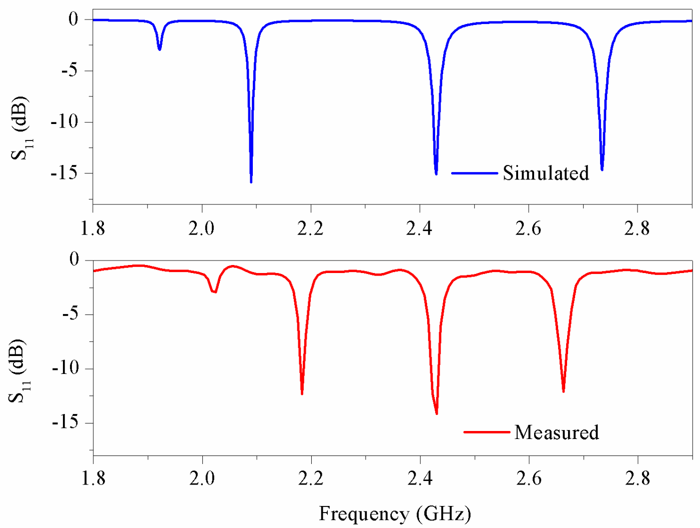


Figure 5. Simulated and measured input reflection coefficient (S_{11}) of 4-cell antenna.

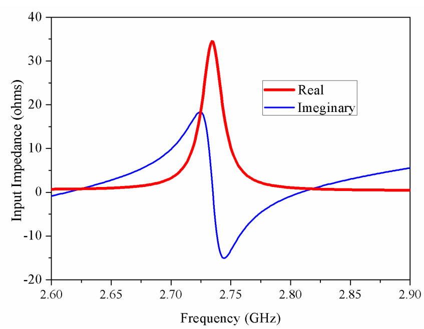


Figure 6. Simulated input impedance of 4-cell antenna.

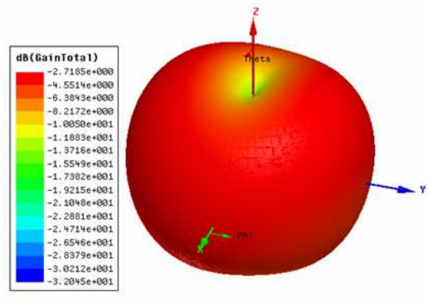
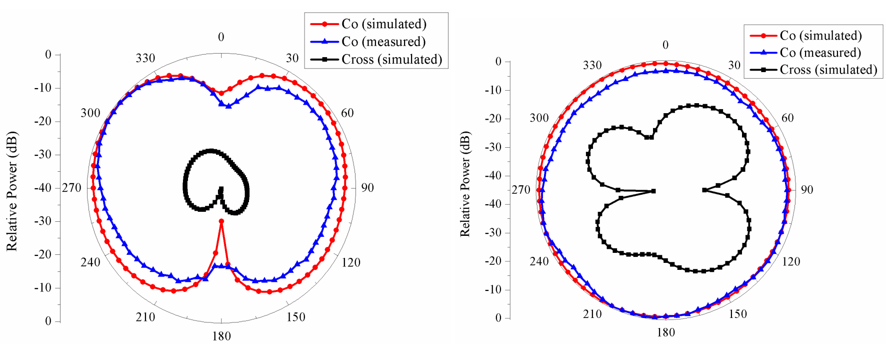


Figure 7. 3D gain pattern of 4-cell ZOR antenna.



(a) (b)

Figure 8. Simulated and measured radiation pattern of 4-cell antenna. (a) YZ plane (E-plane). (b) XY plane (H-plane).

at ZOR frequency.

The 3D gain pattern of this antenna is shown in Figure 7. The simulated and experimental radiation patterns of this antenna are shown in Figure 8. Figure 8(a) shows the normalized co and cross polarized radiation pattern in E plane (YZ plane) whereas Figure 8(b) shows the normalized co and cross in H plane (XY plane). Absolute gain of the proposed antenna is observed -2.71 dB (simulated) and -3.62 dB (measured). The radiation efficiency and physical size are observed to be 34.1% (simulated) & 23.8% (measured) and $0.072\lambda_0 \times 0.29\lambda_0 \times 0.014\lambda_0$ respectively.

The 3D gain pattern shows that the gain pattern is symmetrical in XZ and YZ plane and omnidirectional in XY plane which confirmed that the resulting radiation patterns of the proposed

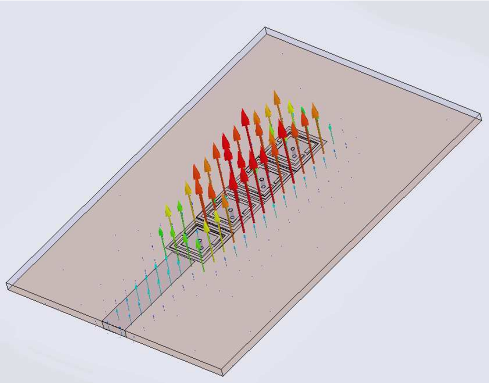


Figure 9. Electric field distribution of 4-cell ZOR antenna.

antennas (Figure 7) are similar to the monopolar radiation pattern. The simulated electric field distribution underneath the 4-cell antenna is shown in Figure 9. Electric field distribution at ZOR frequency is in phase which verifies that operation is going on at infinite wavelength frequency.

4. CONCLUSION

In this study, a compact ZOR antenna based on CMT structure along with CSRR is presented. The proposed antenna exploits the ZOR property of the CRLH TL. Using the ZOR property of CRLH TL, one can reduce the antenna size. Using the concept of CSRR, this shunt resonance frequency can be further reduced because it adds the lumped component in the shunt arm of the unit cell. The size of the proposed antenna structure has been shrunk to 8.32% of the conventional half wavelength patch antenna at its ZOR frequency. The proposed antenna offers omnidirectional radiation pattern in XY plane. Therefore due to its features, the proposed antenna is suitable for use in wireless communication.

REFERENCES

1. Sanada, A., M. Kimura, I. Awai, C. Caloz, and T. Itoh, "A planar zeroth order resonator antenna using left handed transmission line," *IEEE European Microwave Conference*, 1341–1344, 2004.
2. Lai, A., K. M. K. H. Leong, and T. Itoh, "Infinite wavelength resonant antennas with monopole radiation pattern based on

periodic structures," *IEEE Trans. Antennas Propag.*, Vol. 55, No. 3, 868–875, 2007.
3. Sanada, A., C. Caloz, and T. Itoh, "Planar distributed structures with negative refractive properties," *IEEE Trans. Microwave Theory Tech.*, Vol. 52, No. 2, 1252–1263, 2004.
4. Lee, J. G. and J. H. Lee, "Zeroth order resonance loop antenna," *IEEE Trans. Antennas Propag.*, Vol. 55, No. 3, 994–997, 2007.
5. Park, J. H., Y. H. Ryu, and J. H. Lee, "Mu zero resonance antenna," *IEEE Trans. Antennas Propag.*, Vol. 58, No. 6, 1865–1875, 2010.
6. Erentok, A. and R. W. Ziolkowski, "Metamaterial-inspired efficient electrically small antennas," *IEEE Trans. Antennas Propag.*, Vol. 56, No. 3, 2008.
7. Alici, K. B., A. E. Serebryannikov, and E. Ozbay, "Radiation properties and coupling analysis of a metamaterial based, dual polarization, dual band, multiple split ring resonator antenna," *Journal of Electromagnetic Waves and Applications*, Vol. 24, Nos. 8–9, 1183–1193, 2010.
8. Alù, A., F. Bilotti, N. Engheta, and L. Vegni, "Subwavelength, compact, resonant patch antennas loaded with metamaterials," *IEEE Trans. Antennas Propag.*, Vol. 55, No. 1, 13–25, 2007.
9. Veselago, V. G., "The electrodynamics of substances with simultaneously negative values of ε and μ," *Soviet Physics Uspekhi*, Vol. 10, 509–514, 1968.
10. Lai, A., C. Caloz, and T. Itoh, "Composite right/left-handed transmission line metamaterials," *IEEE Microwave Magazine*, Vol. 5, No. 3, 34–50, 2004.
11. Caloz, C. and T. Itoh, "Novel microwave devices and structures based on the transmission line approach of meta-materials," *IEEE-MTT International Symp.*, Vol. 1, 195–198, 2003.
12. Falcone, F., T. Lopetegi, J. D. Baena, R. Marqués, F. Martín, and M. Sorolla, "Effective negative stopband microstrip lines based on complementary split ring resonators," *IEEE Microw. Wireless Compon. Lett.*, Vol. 14, No. 6, 280–282, 2004.
13. Baena, J., J. Bonache, F. Martin, R. Marques, and F. Falcone, "Equivalent-circuit models for split-ring resonators and complementary split-sing resonators coupled to planar transmission lines," *IEEE Trans. Microwave Theory Tech.*, Vol. 53, No. 4, 1451–1461, 2005.
14. Bonache, J., M. Gil, I. Gil, J. Garcia-Garcia, and F. Martin, "Limitations and solutions of resonant-type metamaterial transmission

lines for filter applications: The hybrid approach," *IEEE MTT-S Intl. Microwave Symp. Digest*, 939–942, San Francisco, CA, USA, 2006.

15. Baek, S. and S. Lim, "Miniaturized zeroth order resonating antenna on spiral slotted ground," *Electronic Letter*, Vol. 45, 2009.
16. Peng, L., C. L. Ruan, and Z.-Q. Li, "A novel compact and polarization-dependent mushroom-type EBG using CSRR for dual/triple-band applications," *IEEE Microw. Wireless Compon. Lett.*, Vol. 20, No. 9, 489–491, 2010.
17. Lee, M. J., S. Pyo, W. S. Yoon, I. C. Shin, and Y. S. Kim, "A size reduced CRLH resonant antenna based on Interdigital capacitors with defected ground," *Microwave Opt. Technol. Lett.*, Vol. 52, 2142–2145, 2010.
18. Jang, K. D., J. H. Kim, D. H. Lee, and W. S. Park, "Compact resonant antenna based on composite right/left handed transmission line with magneto dielectric substrate," *Microwave Opt. Technol. Lett.*, Vol. 51, 1994–1997, 2009.
19. Sievenpiper, D., L. Zhang, R. F. Jimenez Broas, N. G. A. Opolous, and E. Yablonovitch, "High-impedance electromagnetic surfaces with a forbidden frequency band," *IEEE Trans. Microwave Theory Tech.*, Vol. 47, No. 11, 2059–2074, 1999.