Journal of Engineering Science and Technology Review 9 (3) (2016) 134 - 137

JOURNAL OF
Engineering Science and Technology Review

Research Article

www.jestr.org

Stepped Impedance Resonator and Spiral Resonator Based Metamaterial Unit-Cell

Amandeep Singh* and Rajni

Department of Electronics and Communication Engineering, Shaheed Bhagat Singh State Technical Campus, Ferozepur, Punjab 152004, India

Received 11 April 2016; Accepted 2 July 2016

Abstract

In order to resolve the scaling down issue of metamaterial unit-cells, a novel Stepped Impedance Spiral Resonator (SI-SR) metamaterial unit-cell has been proposed in this paper. This structure has been designed by means of Spiral Resonator (SR) and Stepped Impedance Resonator (SIR) techniques. Miniaturization factor of 0.75 is attained with Stepped Impedance Double Split Ring Resonator (SI-DSR) when compared with simple Double Split Ring Resonator (DSR) whereas further miniaturization factor of 0.55 is achieved with SI-SR while compared with SI-DSR. The SI-SR structure offers a compact unit-cell of metamaterial for bandpass filters and duplexers.

Keywords: Double Split Ring Resonator; Metamaterial; Miniaturization; Stepped Impedance Resonator; Spiral Resonator

1. Introduction

Metamaterials are, artificially designed Materials, having negative permeability and negative permittivity. The media, having these properties, are termed as Double Negative Media (DNM) or Left Handed Materials (LHM). This hypothesis was given by a Russian scientist V.G. Veselago in 1968 [1] which was actually realized almost after thirty years [2]. Pendry et al. suggested use of Split Ring Resonator (SRR) and thin wires for showing the negative permeability and negative permittivity [2]. Later, these two structures are united to form DNM by Smith et al. [3]. The Double Split Ring Resonator (DSR) has become the most noteworthy building block for a DNM structure, which is an arrangement of two split rings, displaced by 180 degree. Numerous configurations including diamond shaped SRR [4], horn shaped SRR [5], pi-shaped SRR [6] and complementary edge-coupled SRR [7] have been used as the building blocks of DNM structures. These DNM structures, employed as a superstrate, have potential to improve the gain of the antenna [8]. These structures can also be employed for the antenna miniaturization when this block is used as substrate. The most predominant issue with these building blocks is the miniaturization while manipulating in radio communication field. Miniaturization leads to light-weight systems which enrich portability and lessen the electromagnetic interference [9]. In past, many techniques have been employed for miniaturizing the size of building blocks of DNM structures such as fractal resonators [10] and spiral resonators [11] etc.

Miniaturization is being presented in this paper with novel miniaturized building block named as Stepped Impedance Spiral Resonator (SI-SR). The SI-SR furthermore contributes in miniaturization of DNM structures to a great extent. This proposed unit-cell is modeled and numerically analyzed with Finite Element Method (FEM) based High Frequency Structure Simulator (HFSS). This paper is planned into five sections. Section 1 gives the details about DNM and Stepped Impedance Resonator (SIR). Section 2 provides the structure dimensions followed by Section 3 in which simulation methodology, boundary conditions and excitations, are explained. Simulation results are presented in Section 4. Reported work is concluded in the Section 5.

1.1. Stepped Impedance Resonator

Lumped and distributed elements have been used in earlier resonators [12]. But more space requirements in distributed elements and low Q-factor of lumped elements generate problems while using them in the filter applications. High Q-factor and compactness are the basic design requirements for filters which remain unfulfilled by these elements. In order to meet these requirements, SIR techniques have been developed [13]. A SIR is made up of two transmission lines having different lengths and characteristic impedances. Due to its beneficial characteristics like high Q-factor, compactness and harmonic suppression capability, SIR technology has been employed in Duplexers and Band pass Filters [14]. Straight transmission line and its corresponding stepped impedance configuration are depicted in Fig. 1 (a) and Fig. 1 (b) [15] respectively.

Fig. 1. (a) Straight Transmission Line and (b) its SIR configuration

* E-mail address: amansaggu650@gmail.com
ISSN: 1791-2377

The ABCD matrices, for straight transmission line and its analogous SIR structure, will be identical in addition with smaller total physical length of SIR than its straight transmission line [15]. The ABCD matrix of straight transmission line is given by Equation (1).

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} \cos\theta & jZ_0 \sin\theta \\ j\frac{1}{Z_0}\sin\theta & \cos\theta \end{bmatrix} \quad (1)$$

where $\boldsymbol{Z_0}$ is the characteristic impedance and $\boldsymbol{\theta}$ is the length of the straight transmission line.

This matrix can be employed with SIR configuration by interchanging it with three matrices for each section of SIR [16]. More design parameters are associated with SIR's than the conventional resonators which are actually having uniform impedance. In conventional resonators, their resonance conditions are exclusively dependent on their line lengths. But impedance ratio as well as length ratio must be taken into consideration while deducing the resonance condition of SIR's. In SIR, the resonance condition is given by Equation (2).

$$K = tan\,\theta_1 .\ tan\,\theta_2 \quad (2)$$

where 'K' is served as impedance ratio coefficient which is also defined as $Z2/Z1$ and $\theta 1$ and $\theta 2$ are the electrical lengths of SIRs. It is already demonstrated that for $0 < K < 1$, resonator length is minimum and maximum for $K > 1$ [17]. But for high values of K, large discontinuity is observed in SIR which results in poor insertion loss [18].

2. Materials

The suggested building block contains spiral ring of two turns which is modified using SIR technique and patterned on the top of substrate as shown in Fig. 2 (a). It also comprises of three-sectioned stepped thin line which is patterned on the bottom of substrate as depicted in Fig. 2 (b). The substrate, having dimensions 11×11 mm, is made up of Rogers RT/Duroid 5880 having the relative permittivity of 2.2 with 1.575 mm thickness. The geometrical parameters of the SI-SR are mentioned in Table 1. Three-sectioned line is used for defining the characteristic impedance of each section of SI-SR.

Table 1. Geometrical Parameters of SI-SR

S.No.	Parameters	Size (mm)
1.	Length of SI-SR (L)	9.7
2.	Width of SI-SR (W)	9.7
3.	Gap of SI-SR (G)	2.02
4.	Spacing between two turns (S)	0.17
5.	B	8.22
6.	C	6.74
7.	D	3.91
8.	Width of SI-SR (W1)	0.31
9.	W2	1.31
10.	L1	3.11952
11.	L2	2.643552
12.	L3	2.167584
13.	L4	1.257456
14.	L5	3.5376
15.	L6	11

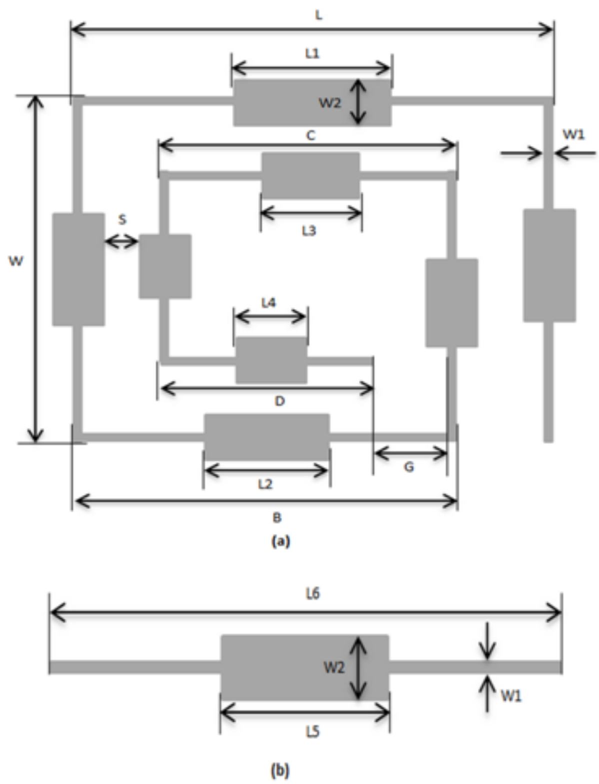

Fig. 2. (a) Top View and (b) Bottom view of SI-SR

In SI-SR, length of the thicker part of each line is attained by multiplying the length of line with the factor of 0.3216 and its position is centered along its corresponding line. Some restrictions also exist with the parameters in order to attain a better miniaturization factor. By keeping in mind the limitations of fabrication technology, dimensions of building block must not be lesser than 0.15 mm. So, by considering these limitations, large K value is not used because with this, the loops of SI-SR might cross each other. Therefore, the value of K is 0.086 for the dimensions of SI-SR.

3. Numerical Method

SI-SR structure is simulated with HFSS software with appropriate boundaries and excitations. Figure 3 depicts the geometry of the SI-SR encased in a radiation box in HFSS environment. For the simulation of SI-SR structure, Perfect H boundary condition is assigned on the z-faces of the radiation box while Perfect E boundary condition is assigned on the x-faces of the radiation box [19]. Two wave port excitations are assigned on the y-faces of the radiation box and for the structure; evaluation of S parameters is done.

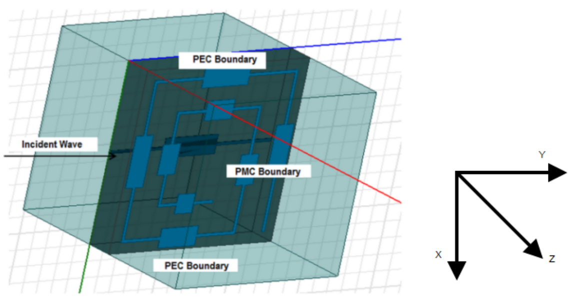

Fig. 3. Geometry of SI-SR in waveguide

4. Results and Discussion

The simple spiral resonator (SR), SI-SR and SI-DSR structures are designed on the same substrate by taking same physical size of all structures. The magnitudes of S_{11} and S_{21} of SI-SR, compared with SI-DSR and SR, are shown in Fig. 4 and Fig. 5 respectively and the phases of S_{11} and S_{21} are demonstrated in Fig. 6 and Fig. 7 respectively. In Fig. 6 and Fig. 7, the phases are reversed only at the resonant frequencies which are desirable in metamaterials.

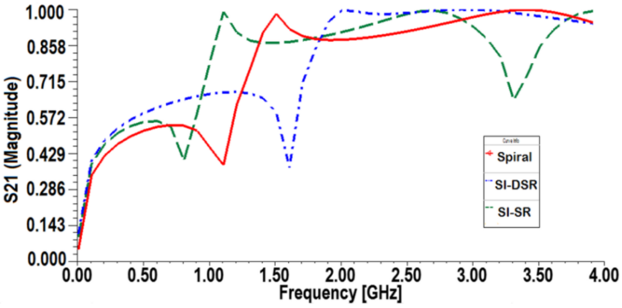

Fig. 4. Transmission parameter of SI-SR, SI-DSR and SR

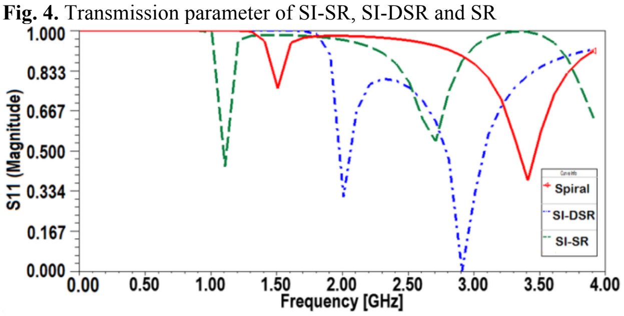

Fig. 5. Reflection parameter of SI-SR, SI-DSR and SR

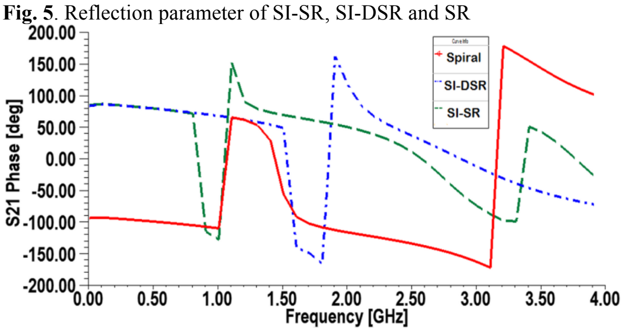

Fig. 6. Transmission Parameter of SI-SR, SI-DSR and SR in terms of phase

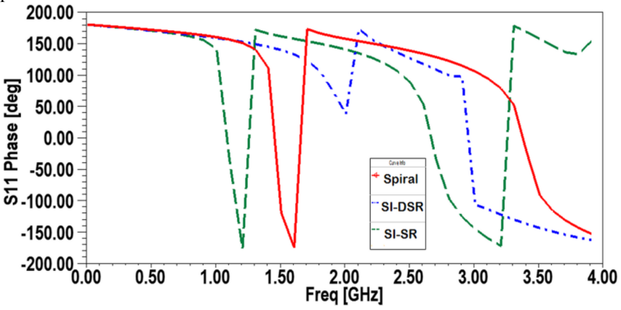

Fig. 7. Reflection Parameter of SI-SR, SI-DSR and SR in terms of phase

The electrical sizes of SR and SI-DSR are larger than that of SI-SR which is much evident from the downward frequency shift observed from their S-parameters. It is well known fact that almost 50% reduction can be achieved with SR while compared with DSR of same size [20]. Miniaturization factor of 0.75 is obtained with SI-DSR while comparing with DSR as showed in Table 2 [16]. The downward shift in S_{11} is detected from 1.5050 GHz to 1.1029 GHz in case of SI-SR as compared to SR. This downward shift is due to wider line SIR configuration which surges the total capacitance of SR due to the spacing between adjacent turns. As a result of this, resonance frequency of SI-SR is down shifted as compared to SR. Therefore, miniaturization factor of 0.73 is obtained by comparing the SI-SR with SR as displayed in Table 2. The shift, in S_{11}, is detected from 2.0082 GHz to 1.1029 GHz in case of SI-SR as compared to SI-DSR. This downward frequency shift is because of the combination of SIR and SR techniques and as a result of this, resonance frequency of SI-SR is shifted downward. Therefore additional miniaturization factor of 0.55 is further attained with use of SI-SR instead of using SI-DSR unit-cell as indicated in Table 2.

Table 2. Miniaturization Factor of Different Unit-Cells

S.No.	Case	Miniaturization Factor (New Resonant Frequency (f_2) / Old Resonant Frequency (f_1))
1.	SI-DSR and DSR	2.0082/2.6804 = 0.75
2.	SI-SR and SR	1.1029/1.5050 = 0.73
3.	SI-SR and SI-DSR	1.1029/2.0082 = 0.55

5. Conclusions

With the idea of SIR and SR techniques, a novel miniaturized metamaterial building block is designed. Its characteristics are evaluated and compared with SI-DSR and SR of same size. The use of Stepped Impedance technique with DSR and SR helps in miniaturization with a miniaturization factor of 0.75 and 0.73 respectively. It has been seen that a further miniaturization factor of 0.55 is obtained with use of SI-SR unit-cell in place of SI-DSR. It is concluded that spiral resonator with stepped impedance is capable of miniaturing the DNM to great extent. Therefore this structure is beneficial for the design of electrically small antennas.

References

[1] Veselago V.G. 1968. The electrodynamics of substances with simultaneously negative values of ε and μ, *Soviet Physics Uspekhi* 10(4): 509-514.

[2] Pendry J.B, Holden A.J, Robbins D.J, et al. 1999. Modified E-Shaped Microstrip Patch antenna loaded with metamaterial for Ku band, *IEEE Transactions on Microwave Theory and Technologies* 47(11): 1084-2075.

[3] Smith D.R, Padilla W.J, Vier D.C, et al. 2000. Composite medium with simultaneously negative Permeability and Permittivity, *Physical Review Letters* 84(18): 4184-4187.

[4] Horestani A.K, Fumeaux C, Al-Sarawi F, et al. 2013. Displacement sensor based on Diamond-shaped Tapered split ring resonator, *IEEE Sensors Journal* 13(4): 1153-1160.
[5] Horestani A.K, Fumeaux C, Al-Sarawi F. 2013. Rotation sensors based on horn-shaped split ring resonator, *IEEE Sensors Journal* 13(8): 3014-3015.
[6] Islam S.S, Faruque M.R.I, Islam M.T. 2015. A near zero refractive index metamaterial for electromagnetics invisibility cloaking operation, *Materials* 8(8): 4790-4804.
[7] Kim J, Cho C.S, Lee J.W. 2006. 5.2 GHz notched ultra-wideband antenna using slot-type SRR, *Electronics Letters* 42(6): 315-316.
[8] Attia H, Yousefi L, Bait-Suwailam M.M, et al. 2009. Enhanced-gain microstrip antenna using engineered magnetic superstrates, *IEEE Antenna and Wireless Propagation Letters* 8: 1198-1201.
[9] Mirza I.O, Shi S, Fazi C, et al. 2007. A study of loop antenna miniaturization using split ring resonators, *IEEE Antennas and Propagation Society International Symposium, Honolulu*. pp. 1865-1868.
[10] Palandoken M, Henke H. 2010. Fractral negative-epsilon metamaterial, *IEEE International Workshop on Antenna Technology, Lisbon*. pp. 1-4.
[11] Baena J.D, Bonache J, Martin F, et al.2005. Equivalent circuit models for split-ring resonators and complementary split-ring resonators coupled to planer transmission lines, *IEEE Transactions on Microwave Theory and Technologies* 53(4): 1451-1461.
[12] Iveland T.D. 1971. Dielectric Resonator Filters for Application in Microwave Integrated Circuits, *IEEE Transactions on Microwave Theory and Techniques* 19(7): 643-652.
[13] Makimoto M, Yamashita S. 1979. Compact Bandpass Filters using Stepped Impedance Resonators, *Proceedings of the IEEE* 67(1): 16-19.
[14] Lerdwanittip R, Namsang A, Akkaraekthalin P. 2011. Bandpass filters using T-shape Stepped Impedance Resonators for wide harmonics suppression and their application for a duplexer, *Journal of Semiconductor Technology and Science* 11(1): 65-72.
[15] Zarghooni B, Denidni T.A. 2012. Design and Simulation of a novel compact unit cell for DNG metamaterials based on Stepped-Impedance Resonator technique, *IEEE Antennas and Propagation Society International Symposium, Chicago*. pp. 1-2.
[16] Zarghooni B, Denidni T.A. 2014. New compact metamaterial unit-cell using SIR technique, *IEEE Microwave and Wireless Component Letters* 24(5): 315-317.
[17] Makimoto M, Yamashita S. 1980. Bandpass filters using parallel coupled stripline stepped impedance resonators, *IEEE Transactions on Microwave Theory and Technologies* 28(12): 1413-1417.
[18] Hang M, Wu H.W, Su Y.K. 2007. Compact and low loss dual-band bandpass filter using Pseudo-Interdigital Stepped Impedance resonators for WLANs, *IEEE Microwave and Wireless Component Letters* 17(3): 187-189.
[19] Rajni, Marwaha A. 2015. Resonance characteristics and effective parameters of New Left Hand Metamaterials, *TELKOMNIKA Indonesian Journal of Electrical Engineering* 15(3): 497-503.
[20] Rajni, Marwaha A. 2015. Magnetic Resonance in Spiral Resonators, *International Journal of Applied Engineering Research* 10(13): 33291-33295.