Concentric Open End Rings Resonator Filter

Mahmood Karami, **Ramezan Ali Sadeghzadeh**, **and Mahdi Oliaei**
Electrical & Computer Engineering Department, K. N. Toosi University of Technology, Iran

Abstract— In this paper, a single open ring resonator (ORR) filter with three resonants within its equivalent circuit has been investigated. This filter has a good response at ISM band from 3.13 GHz to 5.56 GHz. According to this filter, a concentric double open end ring resonator filter with an ultra wide band (UWB) behavior has been approached. The frequency response of this one is very appropriate up to 15 GHz. The loop of the filter constitutes both periodic self and mutual inductive-capacitive property between two rings which provides many resonants in these frequencies. The interconnections between these tanks are an important factor of its UWB behavior and they have overlap on each other impressively.

1. INTRODUCTION

In the recent years, various metamaterial structures have been investigated and studied in different frequency ranges. One of those structures is open-ring resonator (ORR) commonly. The ORRs are utilized in the planar filtering applications and as planar antenna elements [1–3]. This structure is used for generating backward wave propagation in the planar configurations. In addition, ORRs have been used for creating artificial magnetic phenomena and it is a tool for analyzing the effects of a negative refractive index [4]. 3.1–10.6 GHz frequency band has been allocated to ultra-wideband (UWB) systems by Federal Communication Commission (FCC) [5] and this spectrum has an important considerations of interests in both the academic and commercial domains because of potentially its high-data rate. Many applications such as satellite communications, global positioning system (GPS), wireless universal serial bus (USB), personal computers (PC) and etc.. cover this frequency band.

The UWB systems are usually divided to WLAN (5.15–5.825 GHz), IEEE 802.11a, IEEE 802.11b and WiMAX (5.25–5.85 GHz) systems [6–8]. DCS (1.71–1.88 GHz), PCS (1.75–1.87 GHz), UMTS (1.92–2.17 GHz) and 2.4 GHz WLAN are other frequencies that are used for wireless and personal area network (PAN) communications which are lower than UWB systems frequencies [9, 10].

In front of ORR, there is split ring resonator or SRR (or its complementary form, CSRR) which has a similar but different behavior [11, 12].

ORR and SRR have their different electromagnetic operation characteristics and different element values for the same equivalent circuit. When they have been inserted in a coplanar transmission line and combined with short circuiting wires, these particles can produce backward-wave phenomena and this has been proved through the analysis of the phase of the transmission coefficient [11].

In this paper, a single open ring resonator is investigated with its equivalent lossless circuit at first; then, it is introduced a novel concentric double end ring resonator by means of this structure.

2. SINGLE OPEN END RING RESONATOR FILTER

A single open ring resonator (ORR) has an inner and outer radius as shown in Fig. 1. The equivalent lossless circuit of this structure composes of three LC tanks which creates three resonants and each parameter value has been illustrated in Fig. 2. The dimensions of this filter have been brought in Table 1.

3. DISTRIBUTED CIRCUIT

The mentioned ORR has been connected between two ports and simulated by ANSYS HFSS software which collaborated with Finite Element Method (FEM). The dimensions of microstrip line between the ports and the ring has been optimized in order to achieve the best frequency response in the range of industrial, scientific and medical (ISM) band. There is a discontinuity when the microstrip line meets the ring and this discontinuity affects on the bandwidth. The substrate material which has been used for this structure is Rogers RO3003 with relative permittivity of $\epsilon_r = 3$ and thickness of $h = 1.27$ mm.

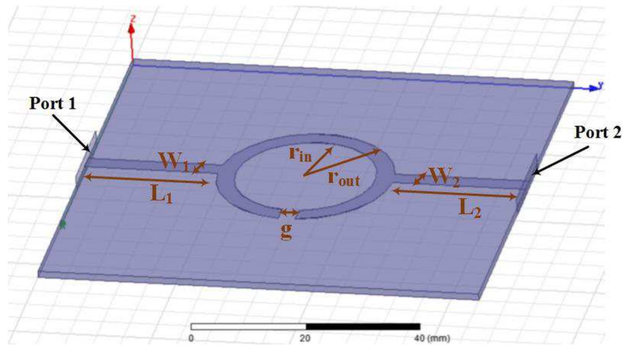

Figure 1: Distributed circuit of single open end ring resonator filter.

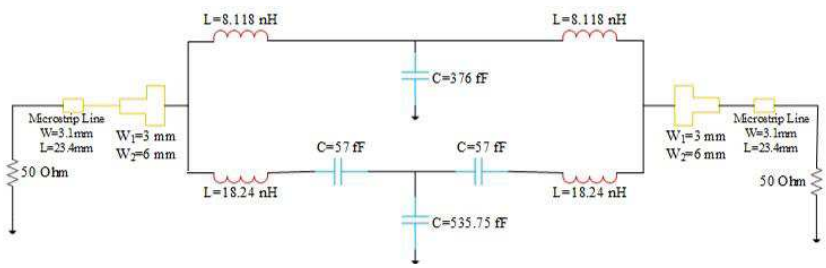

Figure 2: Equivalent lossless circuit of single open end ring resonator filter.

Table 1: Dimensions of Fig. 1 in mm.

L_1	L_2	W_1	W_2	r_{in}	r_{out}	g
23.4	23.4	3.1	3.1	12.7	15.9	3

4. LUMPED CIRCUIT

The lumped circuit parameters of this single ORR have been earned by [4, 11–13]:

$$r = \frac{r_{in} + r_{out}}{2} \tag{1}$$

$$w = r_{out} - r_{in} \tag{2}$$

$$L = \mu_0 r \left(\log\left(\frac{2r}{w}\right) + 0.9 + 0.2 \left(\frac{w}{2r}\right)^2 \right) \tag{3}$$

$$C = \frac{2\epsilon_0 (t + w)}{\pi} \log\left(\frac{4r_{in}}{g}\right) \tag{4}$$

$$C_g = \frac{\epsilon_0 L}{2} \left[\frac{K(k'_0)}{K(k_0)} + \epsilon_r \frac{K(k'_1)}{K(k_1)} \right] \tag{5}$$

which r, w, t, g, L, C, and C_g are effective ring's radius, width, thickness, gap, inductance, capacitance and gap capacitance, respectively. Also $K(k'_0)$, $K(k_0)$, $K(k'_1)$ and $K(k_1)$ are the complete elliptic integrals of the first kind with $k'_0 = \sqrt{1 - {k_0}^2}$ and $k'_1 = \sqrt{1 - {k_1}^2}$.

k_0 and k_1 are obtained from

$$k_0 = \frac{g}{2w + g} \tag{6}$$

and

$$k_1 = \frac{\tanh(\frac{\pi g}{4h})}{\frac{\tanh(\pi(2w+g))}{4h}} \tag{7}$$

The resonant frequency attains by

$$f_0 = \frac{1}{2\pi\sqrt{L(C_g + C)}} \tag{8}$$

This equivalent circuit has been simulated by Advanced Design System (ADS) software and the results show good agreement between these distributed and lumped circuits results.

5. SIMULATION RESULTS

The simulation results of single ORR has been illustrated in Fig. 3. As shown here, the frequency response is very good at ISM band.

6. CONCENTRIC DOUBLE OPEN END RING RESONATOR FILTER

The two rings concentrate with each other by two microstrip line which each ring has been connected with one line (Fig. 4). Dimensions of each part is illustrated in Table 2.

By means of Equations (1) to (8) and [13], the parameters of each line and ring can be found and the LC tank of the rings with their dominant resonant frequencies determined.

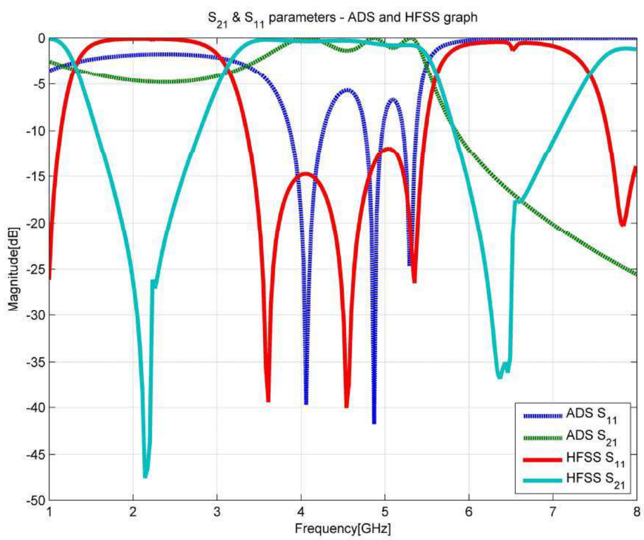

Figure 3: S parameters of single open end ring resonator filter simulation results.

Table 2: Dimensions of Fig. 4 in mm.

L_1	L_2	W_1	W_2	r_{in1}	r_{out1}	g_1	r_{in2}	r_{out2}	g_2
27.4	27.97	3.1	3.1	11.73	12.13	0.5	12.3	12.7	6

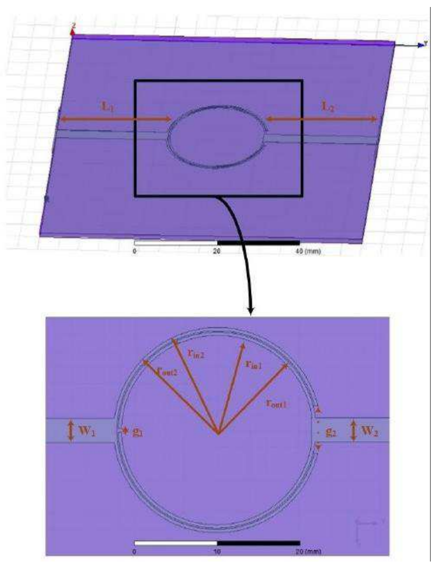

Figure 4: Concentric double open end ring resonator filter circuit.

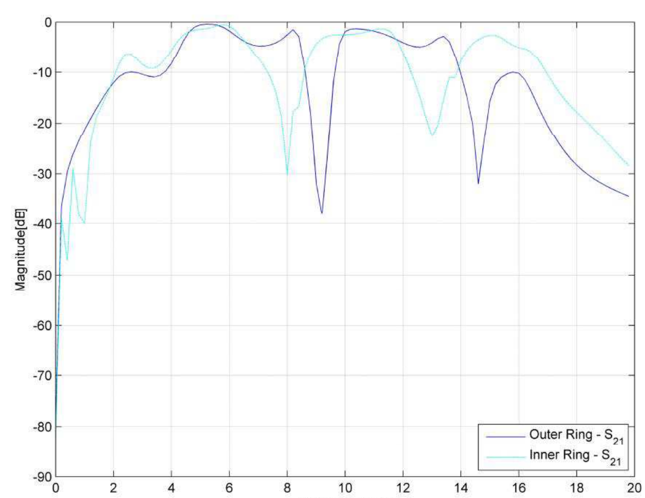

Figure 5: Inner and outer rings transmission parameter of concentric double open end ring resonator filter.

Computations for the right microstrip line and inner ring (ring No. 1):

$$L_{\mu_1} = 16.81\,(\text{nH}) \quad C_{\mu_1} = 2.93\,(\text{pF}) \quad L_{ring_1} = 40.11\,(\text{nH}) \quad C_{ring_1} = 4.64\,(\text{fF})$$
$$C_{g_1} = 101.53\,(\text{nF}) \quad f_0 = 6.53\,(\text{GHz})$$

Computations for the left mirostrip line and outer ring (ring No. 2):

$$L_{\mu_2} = 17.27\,(\text{nH}) \quad C_{\mu_2} = 2.87\,(\text{pF}) \quad L_{ring_2} = 42.35\,(\text{nH}) \quad C_{ring_2} = 2.15\,(\text{fF})$$
$$C_{g_2} = 2.98\,(\text{fF}) \quad f_0 = 10.8\,(\text{GHz})$$

Transmission and reflection frequency responses of each ring have been simulated and illustrated in Fig. 5 and Fig. 6, respectively and they are followed and covered by each other.

The mutual periodic inductive-capacitive property between these two rings cause an ultra wide band (UWB) behavior from 1.8 GHz to 15 GHz with center frequency of 8.4 GHz (almost 13.2 GHz bandwidth and more than 150% FBW) which transforms this filter to a novel one in this frequency band for ultra wide band frequency systems.

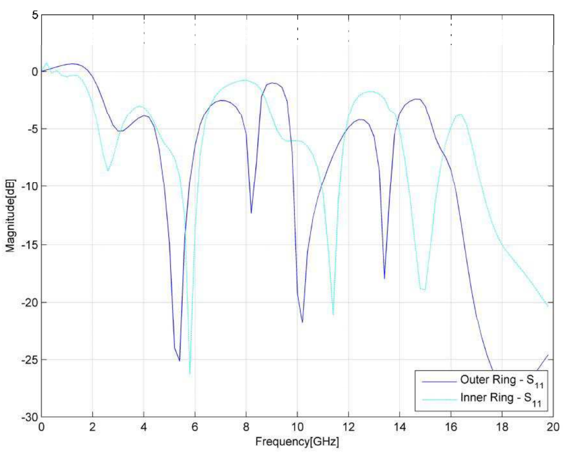

Figure 6: Inner and outer rings reflection parameters of concentric double open end ring resonator filter.

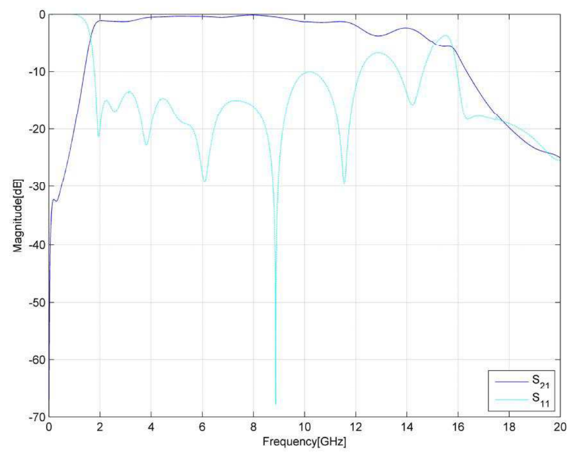

Figure 7: Transmission and reflection parameters of concentric double open end ring resonator filter.

7. CONCLUSION

A single open ring resonator (ORR) filter with three resonants within its equivalent circuit investigated and had a good response at ISM band from 3.13 GHz to 5.56 GHz. According to this filter, a concentric double open end ring resonator filter with an ultra wide band (UWB) behavior approached. The frequency response of this one was very appropriate up to 15 GHz. The loop of the filter constituted both periodic self and mutual inductive-capacitive property between two rings which provided many resonants in these frequencies. The interconnections between these tanks were an important factor of its UWB behavior and they overlapped on each other effectively.

ACKNOWLEDGMENT

The authors would like to give special thanks to Faculty of Microelectronics for financial support.

REFERENCES

1. De Ronde, F. R. and S. Shammas, "MIC bandfilters using open-ring resonators," *Proc. 4th Eur. Microwave Conf.*, 531–535, Montreux, Switzerland, Sept. 1974.
2. Lo, Y. T., D. Solomon, and W. F. Richards, "Theory and experiment on microstrip antennas," *IEEE Transaction on Antennas and Propagation*, Vol. 27, 137–145, 1979.
3. Wolff, I. and V. K. Tripathi, "The microstrip open-ring resonator," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 32, No. 1, Jan. 1984.
4. Elhawil, A., J. Stiens, C. De Tandt, W. Ranson, and R. Vounckx, "An equivalent circuit model of single circular open-ring resonators," *IEEE Journal of Selected Topics in Quantum Electronics*, Vol. 16, No. 2, Mar./Apr. 2010.

5. FCC, "First report and order," *Rev. 15 Comm. Rules Regarding Ultra wideband Transm. Syst.*, 11–18, 2002.
6. Chu, Q. X. and Y. Y. Yang, "A compact ultrawideband antenna with 3.4/5.5 GHz dual band-notched characteristics," *IEEE Transaction on Antennas and Propagation*, Vol. 56, No. 12, Dec. 2008.
7. Barbarino, S. and F. Consoli, "UWB circular slot antenna provided with an inverted-L notch filter for the 5 GHz WLAN band," *Progress In Electromagnetics Research*, Vol. 104, 1–13, 2010.
8. Zhu, J. and G. V. Eleftheriades, "A simple approach for reducing mutual coupling in two closely spaced metamaterial inspired monopole antennas," *IEEE Antennas and Wireless Propagation Letters*, Vol. 9, 2010.
9. Dilip, K. A. and R. Kumar, "Design of flower shape UWB fractal antenna with modified ground plane," *International Journal of Microwaveand Optical Technology*, Vol. 7, No. 4, 239–246, Jul. 2012.
10. Mahatthanajatuphat, C., P. Akkaraekthalin, S. Saleekaw, and M. Krairiksh, "A bidirectional multiband antenna with modified fractal slot fed by CPW," *Progress In Electromagnetics Research*, Vol. 95, 59–72, 2009.
11. Rogla, L. J., J. Carbonell, and V. E. Boria, "Study of equivalent circuits for open-ring and split ring resonators in coplanar waveguide technology," *IET Microw. Antennas Propag.*, Vol. 1, No. 1, 170–176, 2007.
12. Oliaei, M., M. Tayarani, and M. Karami, "Compact microstrip bandpass filter improved by DMS and ring resonator," *Progress In Electromagnetics Research Letters*, Vol. 45, 7–12, 2014.
13. Hong, J. S. and M. J. Lancaster, *Microstrip Filters for RF/Microwave Applications*, John Wiley & Sons, Inc., 2001.