Progress In Electromagnetics Research Letters, Vol. 28, 121–128, 2012

NOVEL BANDPASS FILTER BASED ON CSRR USING KOCH FRACTAL CURVE

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Abstract—In this paper, on the basis of proposing a novel complementary split-ring resonator (CSRR) using Koch fractal curve, a bandpass filter based on such a new structure is designed To validate the designing method. Transmission characteristics and reflection characteristics of the presented filter are given by both software simulation and experiment measurement. Consistent results have confirmed the design concept and excellent performance of the new structure and indicated that the proposed filter has a low insertion loss a high selectivity and small size.

1. INTRODUCTION

In the complicated microwave communication systems, compact filters with excellent performance are needed all the time [1–3]. To reject insertion loss and heighten selectivity, left handed materials (LHMs) and fractal curve have been widely used in the design of coupled resonator filters [4–7] in recent years.

LHMs are a series of engineering materials that show negative permittivity and/or negative permeability over a finite frequency band [4], which have become a subject of intensive research since it was first fabricated from metallic posts and split ring resonators (SRRs) by Smith and his co-workers [5]. Then other structures such as spiral resonators (SRs) [7, 8], S-shaped resonators [9, 10] and complementary split ring resonators (CSRRs) [11–13] were proposed to realize the negative values of permittivity and permeability.

Received 29 August 2011, Accepted 30 November 2011, Scheduled 12 December 2011

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However, a majority of LHMs, such as CSRRs, have the features of large insertion loss, big volume, and incident wave with rigorous requirement of certain excitation etc., which restrict their practical application in microwave engineering to some degree. So, many academicians try to apply fractal theory to LHMs to get over these disadvantages In this letter, a novel CSRR based on Koch fractal curve is proposed. By using the new CSRR as a resonant unit, a compact bandpass filter is fabricated which is characterized with low insert loss, high out-of-band rejection and small size.

2. CSRR BASED ON KOCH FRACTAL CURVE

In 2004, the complementary counterpart of the split ring resonator which is named complementary split ring resonator was proposed by Falcone et al. [11], depicted as Fig. 1. CSRRs are realized by etching two concentric SRRs in the ground plane, which have different sizes and inverse split directions. In the figure, the gray layer denotes the ground while the white one denotes the etched part. Because of the impedance discontinuity, the split-ring is equal to a parallel resonator, which will form a band-gap property when placed in the ground of the microstrip transmission line.

By replacing the two rings with two foursquare rings, foursquare CSRRs can be received, shown in Fig. 2. In Fig. 2, the geometry unit of the foursquare CSRRs with a series capacitive gap in the signal strip is described. The black layer denotes the signal strip In this structure. CSRRs are etched in the ground plane, beneath the microstrip, with their axes parallel to the vector of the electric field, thus contributing to the negative effective dielectric permittivity. On the other hand, the effective negative permeability is achieved by periodically etching capacitive gaps in the conductor strip. So, this structure can obtain left-handed behavior.

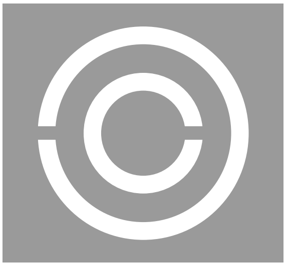

Figure 1. Schematic representation of CSRR.

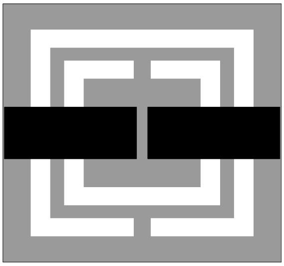

Figure 2. Schematic representation of foursquare CSRR.

The LC equivalent resonant circuit, seeing as its equivalent circuit, can take the place of foursquare CSRR structure, which is depicted in Fig. 3. The CSRRs are modeled by the parallel resonant circuit (with inductance L_c and capacitance C_c), electrically coupled to the host microstrip line through the line capacitance C. The microstrip line is modeled by the inductance L, while the capacitance C_g models the series gap in the microstrip.

In order to the realize miniaturization and heighten the quality factor of conventional CSRR, fractal geometry is introduced. Fractal theory can be traced back to the Cantor Set which is founded by G. Cantor in 1872. And the Koch fractal curve appeared in 1904 after a publication of the mathematician Niels Fabian Helge von Koch [14, 15]. Fig. 4 shows the recursive construction of a triadic Koch curve up to three fractal iterations. The triadic Koch fractal curve is generated when the iteration number n becomes infinite. Changing the edges of the foursquare CSRRs into Koch fractal curve shape, the proposed CSRRs using Koch fractal curve can be described as shown in Fig. 5.

The proposed novel CSRRs based on Koch fractal curve can be modeled by the equivalent circuit shown in Fig. 3, too, regardless of the type of CSRR used (conventional or Koch fractal) [16, 17]. But this model is valid only under the assumption that the size and distance between the adjacent rings are both electrically small.

Figure 6 shows the comparison of responses obtained from electromagnetic simulations of unit cells that use conventional CSRR (C CSRR) and novel CSRR (N CSRR). It is simulated by Ansoft Designer, with copper line width l = 2.4 mm, series gap width s = 0.4 mm, the etched split ring's width w = 0.15 mm, and distance

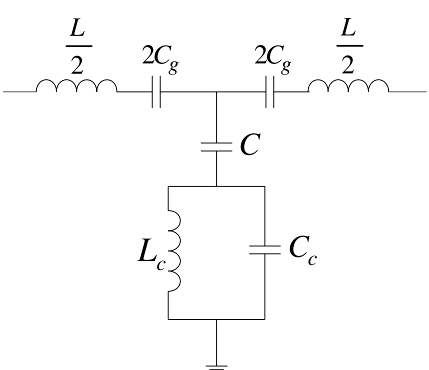

Figure 3. Equivalent circuit of foursquare CSRR.

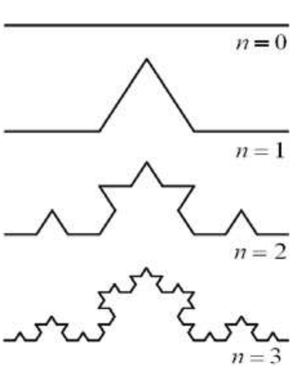

Figure 4. Koch fractal curve.

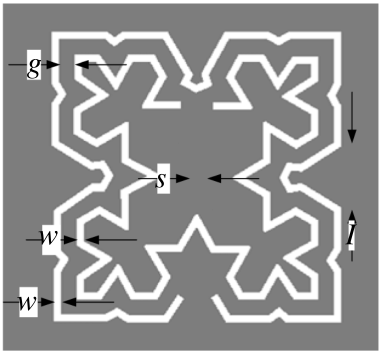

Figure 5. Schematic representation of CSRR based on Koch fractal curve.

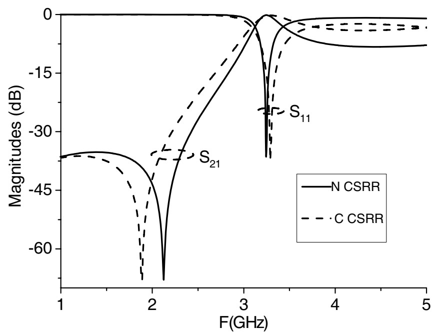

Figure 6. Simulation results of C CSRR and N CSRR.

between two etched split rings $g = 0.3\,\mathrm{mm}$. The substrate of Rogers RT/duriod5880 (tm) with dielectric constant $\varepsilon_r = 2.2$, and thickness $d = 0.79\,\mathrm{mm}$ is employed here. Since the resonant frequency is concerned with the length of the resonant rings, the same length of C CSRR and N CSRR is set in the simulations.

The comparison of unit cells that use C CSRR and N CSRR gives the evidence to improved performances of the fractal geometry compared with conventional one. Although both structures have exactly the same ring length, they occupy different areas: the area of the C CSRR unit cell is $7.5\,\mathrm{mm} \times 7.5\,\mathrm{mm}$, while that of the N CSRR is $6.0 \times 6.0\,\mathrm{mm}$. Area of the unit cell that uses N CSRR is approximately 36% lower, due to the specific shape of the fractal curve. Furthermore, fractal structure exhibits higher value of the quality factor and higher sharpness of selection than the conventional one.

3. FILTER BASED ON CSRR USING KOCH FRACTAL CURVE

Figure 5 shows the unit cell of novel CSRR. A unit cell being in series with another can reap a model of filter. Changing the distance of the cells can lead to different results. The equivalent model circuit of the considered filter can be depicted as Fig. 7. By using linear optimization modeling data in Serenade software, a series value of elements is achieved, shown in Table 1. And Fig. 8 shows the comparison of the electrical simulation of the circuit and the electromagnetic simulation of the microstrip structure.

Table 1. Extracted parameters for unit cells that use novel CSRRs.

	L (nH)	L_g (nH)	C_g (pF)	C (pF)	C_c (pF)
Values	3.4086	1.9309	0.1188	1.7843	1.9309

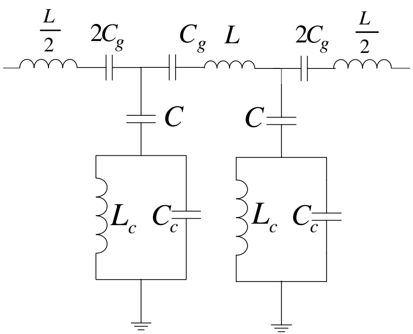

Figure 7. Equivalent circuit of proposed filter.

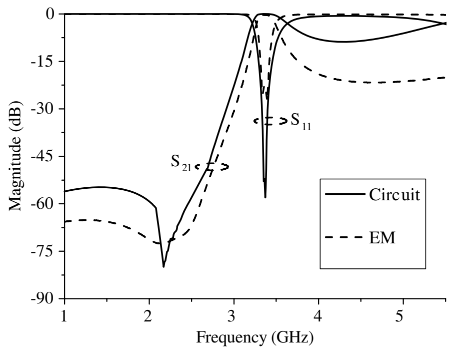

Figure 8. Simulation results of proposed filter with electrical and electromagnetic.

(a) top view of the fabricated filter

(b) bottom view of the fabricated filter

Figure 9. Prototype of designed bandpass filter based on CSRR using Koch fractal curve.

In order to validate simulation results, a filter based on the proposed novel CSRRs whose prototype is shown in Fig. 9 is fabricated on the substrate mentioned above. The parameters are $s = 0.2$ mm, $w = 0.25$ mm, $g = 0.2$ mm, and the distance between two unit cells is 4 mm. The input and output ports are microstrip line with characteristic impedance of 50 ohm, which are located on the top layer of the circuit and can be seen from the top view in Fig. 9(a). Fig. 9(b) shows the bottom view of the filter.

Figure 10 shows the magnitude functions for the complex transmission (S_{21}) and complex refection (S_{11}) parameters of both

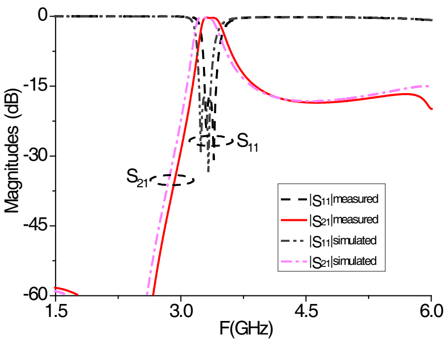

Figure 10. Simulation and measurement results of designed filter based on proposed CSRR.

simulation and measurement results. A good agreement can be observed, except for a shift in frequency approximately equal to 2.5% that occurrs in both cases. Results indicate that the proposed filter has a series of advantages such as 0.21 dB of insertion loss, 20.25 dB of reflection loss, 113 dB/GHz of selectivity, small size, etc.

4. CONCLUSION

In this paper, a novel CSRR using Koch fractal curve is applied to bandpass filter. Simulations and measurements show that the application of fractal geometries significantly lowers the size of the structure, therefore revealing the high potential of fractal topologies for unit cell miniaturization. Moreover, the improved frequency selectivity in the upper transition band is achieved. Using LHM and fractal structure enables to make a good capability filter, which is demonstrated by theory and experiment.

ACKNOWLEDGMENT

This work is supported by the National Natural Science Foundation of China (Grant No. 60971118).

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