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CSRR Based Compact S-Shaped Dual-Planar Electromagnetic Bandgap Microstrip Low-Pass Filter

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ABSTRACT: In this paper, a new topology for the design of a highly compact complementary split-ring resonator (CSRR) based dual planar electromagnetic bandgap (DP-EBG) microstrip low-pass filter with a S-shaped geometry is proposed. With the DP-EBG configuration and the S-shaped geometry of microstrip line (MLIN), the proposed structure achieves a very sharp stopband with high attenuation and high selectivity within a very small circuit area. Its passband ripple level is negligible due to the square patch inserted in the MLIN and CSRR in the ground plane of S-shaped geometry. By introducing complementary split-ring resonator (CSRR), the selectivity and the roll-off of the microwave low-pass filter is highly improved. The proposed structure is very simple and easy to fabricate and is highly compatible with monolithic microwave integrated circuit (MMIC) technology.

KEYWORDS: Complementary split-ring resonator (CSRR), Electromagnetic bandgap (EBG), low-pass filter.

1 INTRODUCTION

The electromagnetic bandgap (EBG) structure has been a term widely accepted in today's time to name the artificial periodic structure that prohibits the propagation of electromagnetic waves in certain frequency bands at microwave frequencies. These periodic structures were originally proposed at optical frequencies [2]-[4] and are called as photonic bandgap (PBG) structure or photonic crystal (PC). Analogous to crystals where periodic arrays of atoms produce bandgaps in which the propagation of photon is prohibited, an artificial periodic structure consist of periodic macroscopic cells. These periodic structures are scalable over a large frequency range in the electromagnetic spectrum. Due to this scalability, research has advanced into the range of microwave and millimeter wave.

The distinctive feature of EBG structure is the existence of the bandgap where electromagnetic waves are not allowed to propagate. They have been extensively applied to the substrate of microwave circuit such as patch antennas and power amplifiers to enhance their performance [6]-[7]. The introduction of the planar EBG structure, where two-dimensional (2-D) periodic elements are inserted in the ground plane or the microstrip line (MLIN), simplifies the fabrication process of EBG structures while keeping a similar control on the wave propagation to that of an electromagnetic crystal where three-dimensional (3-D) periodic elements are organized in a host medium The only compromise of planar EBG structures is that they are not able to control the propagation of waves in the entire 3-D space. However, planar EBG structures have appealed much consideration because of their prominent stopband characteristic, their ease of fabrication, and their compatibility with monolithic circuits.

In previously proposed straight 1-D EBG microstrip structure [8], stopband performance obtained is good and can be upgraded by increasing the number or size of the EBG cells, thus resulting in an enlarged circuit area. They show a compromise between good filtering performance and small physical size [9]. The problem above faced was solved by inserting multiple bands in the MLIN giving rise to an EBG filter structure with great rejection band in a relatively small physical size. The circuit area can be reduced by proposing a dual planar EBG (DP EBG) configuration where EBG cells are in both the MLIN and ground plane to obtain good filtering functionality.

Previously, some designs have been proposed with a U-shaped geometry to diminish the circuit area compared to the straight microstrip line structure. But those structures are complex and involves various tapering. Also, the attenuation obtained at the stopband is not so appropriate. Therefore, to reduce the circuit area and increase the attenuation performance an S-shaped geometry is proposed which is highly compact.

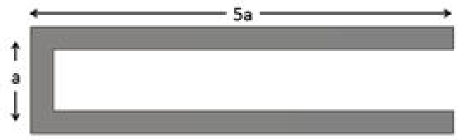
In this paper, a high-performance CSRR based compact DP-EBG microstrip low-pass filter structure with a S-shaped MLIN geometry is proposed and implemented. Introducing the Complementary split-ring resonator (CSRR) [10]. The selectivity and the roll of factor of the microwave low pass filter in improved. The CSRR particle does not require any extra space and for this reason it is highly suited for constructing an miniaturizing microwave devices. The CSRR element has mainly been utilized for stopband filter design and to eliminate the unwanted spurious mainly in microstrip structures. Moreover, this particle has also been successfully integrated into passband filters too.

The proposed structures are simulated using CST microwave studio suite 2010. The substrate used is FR-4 Lossy (normal) with a dielectric constant $\in_r$ of 4.4 and a thickness of 1.6mm. the center frequency of the stopband f_0 is set to 1.8GHz.

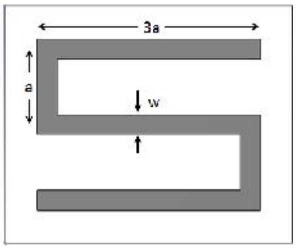
2 COMPARISON OF S-SHAPED GEOMETRY WITH U-SHAPED GEOMETRY

When a S-shaped microstrip filter is designed with the same microstrip length as that of the U- shaped geometry it is found that the circuit area of S-shape is reduced by 12%. Also, the response of S-shaped geometry is better than that of u-shaped geometry.

Figure 1(a) and 1(b) shows the schematic of a U-shape EBG microstrip structure and S-shape EBG microstrip structure respectively.



1 (a)



1 (b)

Fig. 1. Schematic of: 1(a) U-shaped MLIN and 1(b) S-shaped MLIN

3 DESIGN OF S-SHAPED GEOMETRY

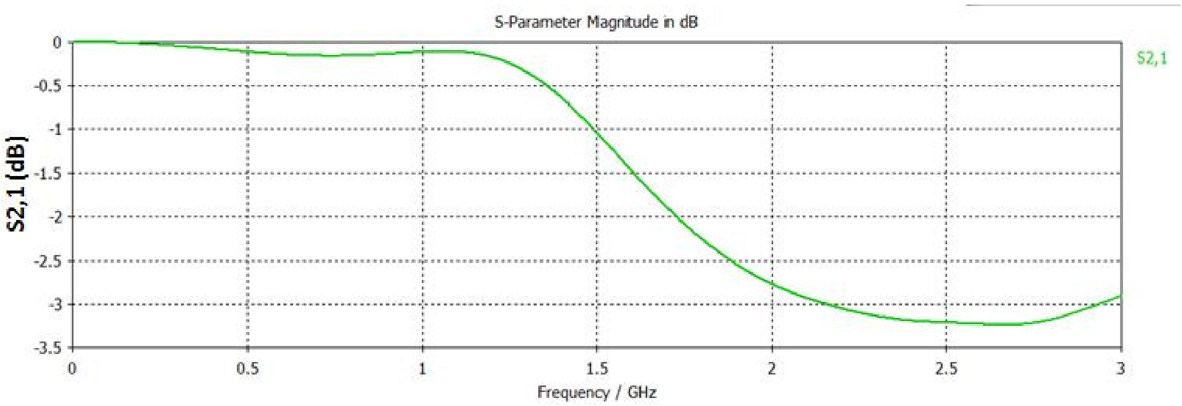


Fig.1(c) Schematic of Simulated S-parameter of S-shaped MLIN.

S-Shaped EBG Microstrip Structure:

Fig. 1(b) shows the schematic of a S-shaped EBG microstrip structure with five microstrip lines.The length of microstrip lines M1, M3 and M5 is 3a and the distance between the two parallel sections is a.

the straight EBG microstrip structure is figure 1(b) satisfies the Bragg reflection condition [8], which is expressed by the following equation

$$\beta.a = \pi \qquad (1)$$

Where β is the wave number in the substrate material and a is the period of the structure.

Since, $\beta = 2\pi / \lambda_g$ where λ_g is the guided wavelength corresponding to the center frequency of the stopband f_0, f_0 is decided by

$$f = \frac{c}{2a\sqrt{\in_{eff}}} \qquad (2)$$

Where c is the speed of light in free space and $\in_{eff}$ is the effective dielectric constant. The straight EBG microstrip structure is not a conventional stepped-impedance microstrip low-pass filter[1].

TABLE 1
PARAMETERS OF THE PROPOSED LOW-PASS FILTER

Parameter	Dimension
W	3.05897498 mm
A	11.41623883 mm
Cut-off frequency (f)	1.8 GHz
Height of substrate (h)	1.6 mm
Substrate used	FR -4 (lossy)
Z_0	50 Ω

Since, $a = n.\frac{\lambda_g}{2}$

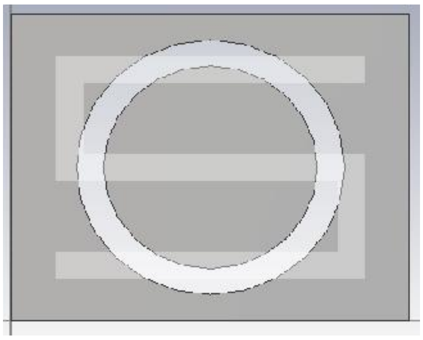
Where, n is any real valueTaking $n = \frac{1}{4}$

A S-shaped structure is proposed with $a = \frac{\lambda_g}{8}$

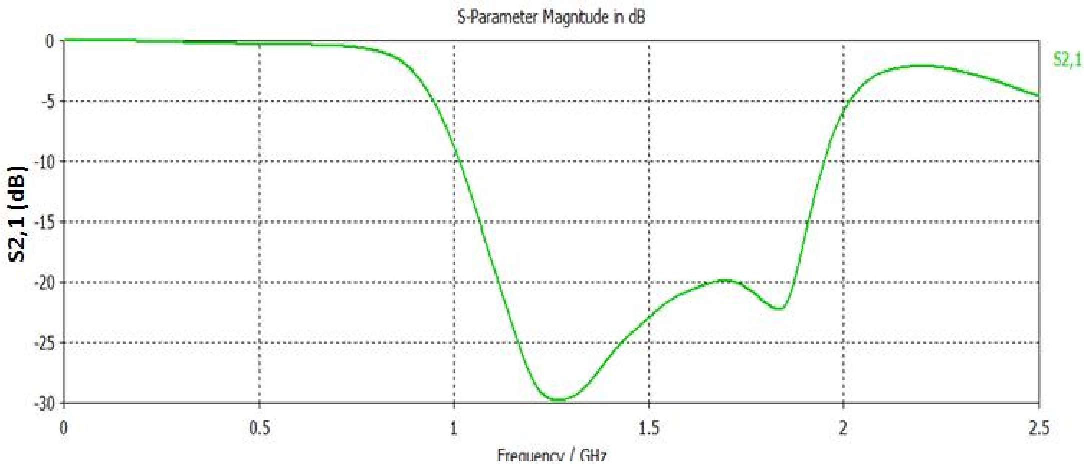
Where the horizontal MLIN has a length of 3a and a vertical MLIN has a length of a (center to center) and a width of w.

4 S-SHAPE WITH RING IN THE GROUND PLANE

When a ring is etched in the ground plane of S-shaped MLIN structure as shown in figure 2(a) and 2(b), it is observed that a low-pass filter response is obtained with a transmission loss of 30dB at 1.25GHz frequency. Cut-off frequency obtained at 3dB point is 0.93GHz. the filters roll-off is not so good.



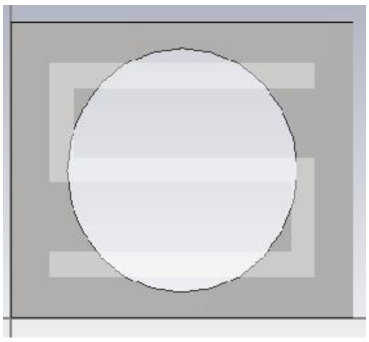
2(a)



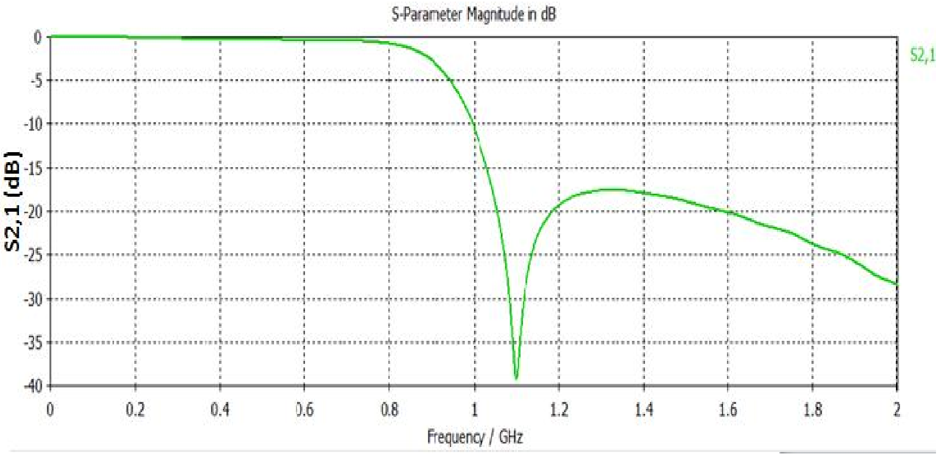
2 (b)

Fig.2 Schematic of: 2(a) S-shaped MLIN structure with ring etched in ground Plane, 2(b) Simulated S-parameter of structure.

5 S-SHAPE WITH CIRCLE IN THE GROUND PLANE



3(a).

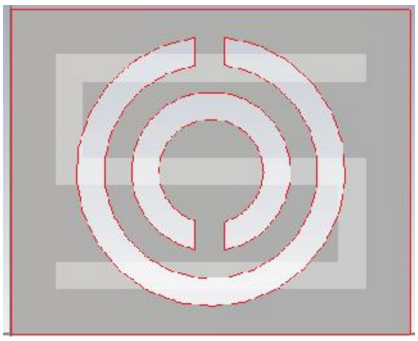


3 (b)

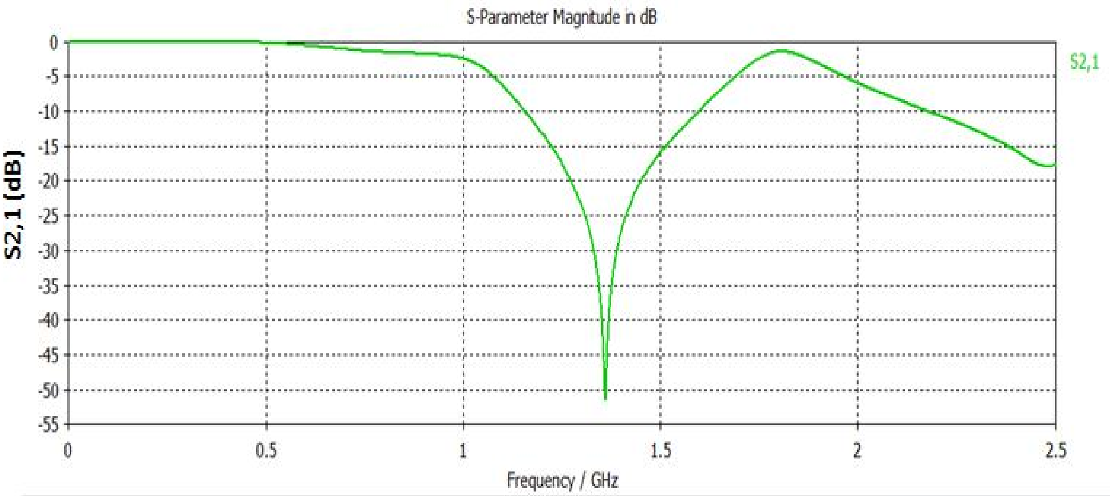
Fig.3 Schematic of: 3(a) S-shaped MLIN structure with circle etched in ground Plane, 3(b) Simulated S-parameter of structure.

Figure 3(a) and 3(b) shows S-shaped MLIN structure with a circle etched in the ground plane and its response respectively. When a circle is etched in the ground plane of S-shaped MLIN structure, it is observed that the response obtained is better than that of the ring structure in the ground plane. The transmission loss attained is 39dB at 1.1GHz with a improved roll-off. The cut-off frequency at 3dB is 0.91GHz. But the selectivity of the response is not satisfactory.

6 S-SHAPE WITH CSRR IN THE GROUND PLANE



4(a)



4 (b)

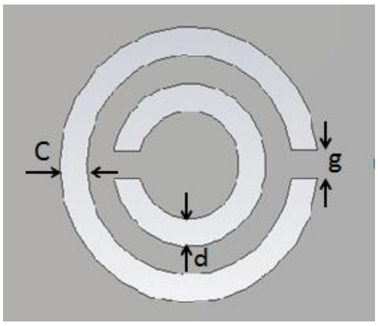
Fig.4 Schematic of: 4(a) S-shaped MLIN structure with circle etched in ground Plane, 4(b) Simulated S-parameter of structure.

When a CSRR is etched in the ground plane of S-shaped MLIN structure as shown in figure 4(a), it is observed that the response obtained has a transmission loss of 45dB at 0.9 GHz. The roll-off of the filter is significantly improved. A narrow stopband is obtained with a sharp cut-off. The CSRR has improved the selectivity of the microwave filter as well.

The CSRR can be described as an LC resonant tank whose resonant frequency [10] is:

$$f = \frac{1}{2\pi\sqrt{L_c C_c}}$$

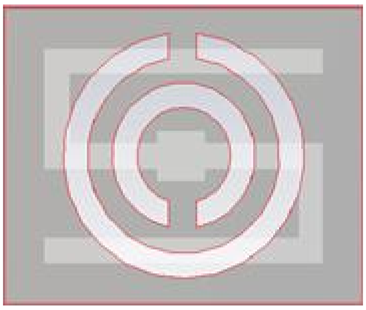
the geometry of the CSRR is as follows:



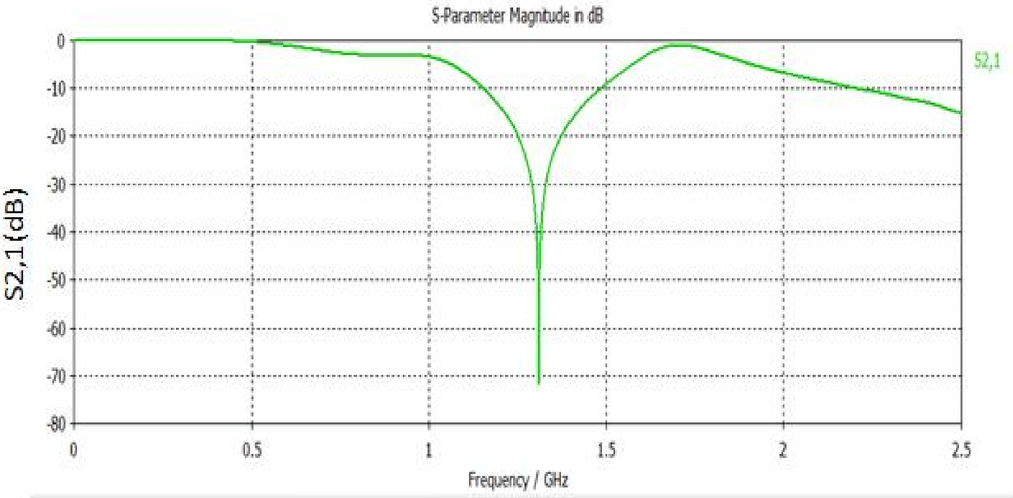
where c=d=g= 3.05897498

It is clear from the figure 4(b) that the CSRR particle at the 3dB point is 1.034GHz has a roll-off which reaches 20dB at 1.15GHz. As the CSRR particle is etched in the ground plane, the cut-off shifts to a lower frequency corresponding to a sharper roll-off.

7 S-SHAPE WITH PATCH IN SUBSTRATE AND CSRR IN GROUND PLANE



5(a)



5 (b)

Fig.3 Schematic of: 5(a) S-shaped MLIN structure with patch and CSRR etched in ground Plane, 5(b) Simulated S-parameter of structure.

Figure 5(a) shows the S-shaped geometry with the CSRR etched in the ground plane and a patch etched in the substrate giving it a dual planar EBG structure. In this proposed structure, the attenuation at the stopband is improved by etching the square patch on the substrate. Due to this patch, the attenuation obtained in the stopband is 72dB at 1.4GHz which was 45dB when compared with the previous structure ie figure 4(a). also, the roll-off and the selectivity is highly improved in the proposed structure due to the presence of CSRR in the center of ground plane. The response is extremely sharp with a very high attenuation.

8 PERFORMANCE OF DIFFERENT STRUCTURES WITH RESPECT TO Q-FACTOR

TABLE 2

S-shaped structure	Transmission loss at stopband (dB)	Ripple Level (dB)	Q-factor (dB/GHz)
Basic MLIN	3.3	Negligible	1
MLIN with Ring	30	Negligible	72.5
MLIN with circle	39.17	Negligible	144.1
MLIN with CSRR	51.14	Negligible	147.6
MLIN with patch and CSRR	72	Negligible	189.3

9 CONCLUSION

In this paper, the design and implementation of a high performance CSRR based compact S-shaped DP-EBG microstrip low pass filter has been presented. Due to the S-shaped geometry of the MLIN and the dual planar arrangement of EBG structure, this proposed EBG filter gains excellent stopband performance and a high selectivity in a small circuit area. The passband ripple level of the CSRR based S-shaped DP-EBG structure is extremely low. Also, the construction of the proposed structure is very simple and easy to fabricate. the proposed structure is highly compatible with monolithic microwave integrated circuit (MMIC) technology. The design of this structure is able to achieve a superior passband and stopband characterstic in compact physical size.

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