*Progress In Electromagnetics Research C, Vol. 11, 237–243, 2009*

# A COMPACT UWB HMSIW BANDPASS FILTER BASED ON COMPLEMENTARY SPLIT-RING RESONATORS

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**Abstract**—A novel complementary split ring resonators (CSRR) is applied to realize a compact Ultra-Wide Band (UWB) bandpass filter based on half-mode substrate integrated waveguide (HMSIW) in this paper. Sharpened rejection skirts and widened upper stopband are achieved due to the two resonant frequencies of the proposed CSRR. Very good agreement is observed between measurement and simulation results.

## 1. INTRODUCTION

Ultra-wide band (UWB) bandpass filters (BPF) have a wide range of applications in wireless communications [1–3]. Recently, a new concept "half-mode substrate integrated waveguide (HMSIW)" [4, 5] has also attracted much interest in the design of bandpass filter. Compared with original substrate integrated waveguide (SIW) [6], HMSIW has a nearly one-half reduction in size since HMSIW can only support $TE_{(m+0.5),0}$ ($m = 0, 1, 2\ldots$) mode. Furthermore, HMSIW restrains the $TE_{(m,0)}$ ($m = 1, 2\ldots$) mode which is equivalent to the $TE_{(2m,0)}$ ($m = 1, 2\ldots$) mode in SIW, so the first spurious passband becomes more far away from the passband of a bandpass filter.

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The HMSIW can be equivalent to a highpass filter due to its inherent sharp cut-off in lower frequency. To form a bandpass filter, it can be cascaded with a lowpass filter directly [9]. However, the increased dimension is inevitable. To solve this problem, an artificial electromagnetic structure complementary split resonance ring (CSRR) is introduced. In the vicinity of CSRR resonant frequency, it can be equivalent to a negative effective permittivity, very high and narrow rejection with sharp cutoffs in the forbidden bands is formed due to the characteristics of CSRR [10]. CSRR is employed to the design of HMSIW bandpass filters by many researchers [11, 12]. Because of the defect of poor rejection skirt, narrow bandwidth and insufficient harmonic suppression, to further improve the out-band suppression, more CSRR units are needed. Recently, a novel CSRR has been proposed for the design of microstrip lowpass filter, which has the characteristics of two resonant frequencies and a wider stopband [13].

In this paper, a mutative CSRR (as depicted in Fig. 1(b)) is proposed to implement a better application for HMSIW. The highlight of the proposed CSRR unit is that it generates two adjustable resonant frequencies, which result in a sharper cut-off response even a widened band-gap. Combined with HMSIW, a compact UWB bandpass filter, which has compact size, better spurious passband suppression and low insert loss, is achieved. By using only 3 CSRRs, sharp rejection skirts and wide upper stopband are obtained. Finally, UWB band-pass filter with 10-dB cut-off frequency of 4.6 GHz–10.6 GHz is fabricated, and a good agreement between measured and simulated results is obtained.

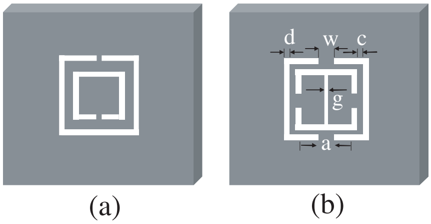



**Figure 1.** Geometries dimension of (a) the conventional CSRR and (b) the proposed CSRR, grey zones represent the metallization.

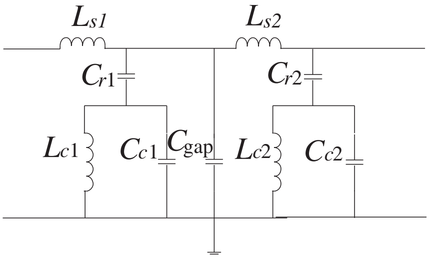



**Figure 2.** Equivalent circuit of the proposed CSRR.

## 2. DESIGN OF CSRR FOR UWB BAND-PASS FILTER

### 2.1. New CSRR Unit and Equivalent Circuit

The geometry dimensions and the equivalent circuit of the proposed CSRR are shown in Figs. 1 and 2 respectively. The resultant dimensions of the new CSRR are given below: The length of the inner square ring $a = 2.4\,\text{mm}$, slit width $w = 1.2\,\text{mm}$, square ring width $d = 0.4\,\text{mm}$, gap between inner and outer square rings $c = 0.2\,\text{mm}$, width of the additional slot in the inner square ring $g = 0.2\,\text{mm}$.

The model can be equivalent to a right-hand transmission line. $L_s$ is the HMSIW line inductance; $C_r$ is the coupling capacitance between the HMSIW and CSRR. $C_{gap}$ is the slot capacitance of inner ring. The CSRR unit is described by means of a parallel LC circuit, $L_{c1}$, $C_{c1}$ and $L_{c2}$, $C_{c2}$ being the reactive elements of outer and inner rings. Actually, $f_1$ and $f_2$ are the transmission zeros of elliptic function, as well as the parallel resonant frequencies of the equivalent circuit. The two resonant frequencies are given by:

$$f_1 = \frac{1}{2\pi\sqrt{L_{c1}(C_{c1} + C_{r1})}} \tag{1}$$

$$f_2 = \frac{1}{2\pi\sqrt{L_{c2}(C_{c2} + C_{r2})}} \tag{2}$$

Compared with the conventional one, shaper cut-off at the falling edge, widened stopband and two resonant frequencies are shown in Fig. 3.

Both conventional and proposed CSRRs are embedded on the HMSIW with the same parameters as those in Section 2.2. The geometry dimensions of the CSRRs are given below: the length of the inner square ring $a = 1.1\,\text{mm}$, slit width $w = 0.2\,\text{mm}$, each square ring width $d = 0.2\,\text{mm}$, gap between inner and outer square rings $c = 0.4\,\text{mm}$.

### 2.2. Design of CSRR-HMSIW UWB Bandpass Filter

To realize an UWB bandpass filter, the most simplified method is cascading a highpass filter and a lowpass filter. The lower and higher cut-off frequencies are determined by the highpass and lowpass sections, respectively, but it is not compact enough. However, DGS structures such as CSRR can efficiently avoid the unnecessary enlargement in size. To sufficiently exhibit the excellent characteristics of proposed CSRR, such as sharpened rejection skirt and widened stopband, we integrate the highpass HMSIW and new CSRR with lowpass characteristics into a compact UWB bandpass filter design.

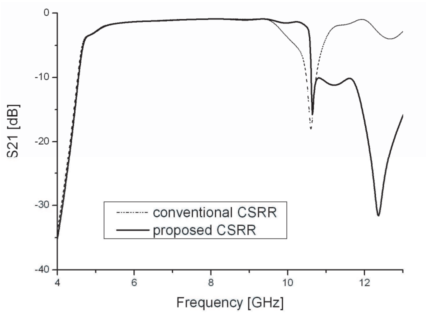



**Figure 3.** Comparison of stopband properties of conventional and new CSRR unit.

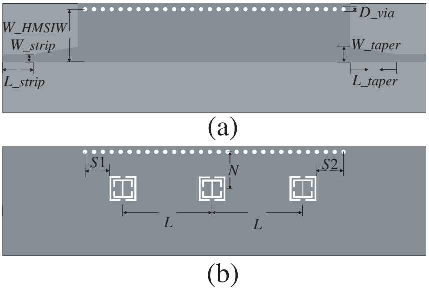



**Figure 4.** Layout of the proposed CSRR-HMSIW UWB BPF, (a) top layer, (b) bottom layer. $S_1 = 6.95\,\text{mm}$, $S_2 = 7.65\,\text{mm}$, $L = 15\,\text{mm}$, $N = 8.6\,\text{mm}$.

The SIW exhibits high-pass characteristics. It was depicted in [14] that the dispersion characteristics of $TE_{10}$-like mode in the SIW can be approximated equal to the mode of a dielectric rectangular waveguide with an equivalent width. The equivalent width of the equivalent dielectric rectangular waveguide is given by:

$$W\_eqv = W\_SIW - \frac{D\_via^2}{0.95 \cdot H} \tag{3}$$

where $W\_SIW$ and $H$ are the width and thickness of the full-mode SIW, respectively. $D_{via}$ is the diameter of the metallic via hole. The HMSIW is just half the structure of a SIW, and its dominant mode is approximately half of the $TE_{10}$ mode. The dispersion characteristics of HMSIW are similar to SIW. The cut-off frequency of $TE_{10}$ mode of dielectric rectangular waveguide is given by:

$$f_c = \frac{C}{2 \cdot W\_eqv \cdot \sqrt{\varepsilon_r}} \tag{4}$$

where $C$ is the light velocity in vacuum, $\varepsilon_r$ is the permittivity of the dielectric rectangular waveguide. Due to the inherent relationship of the SIW and HMSIW, we can have:

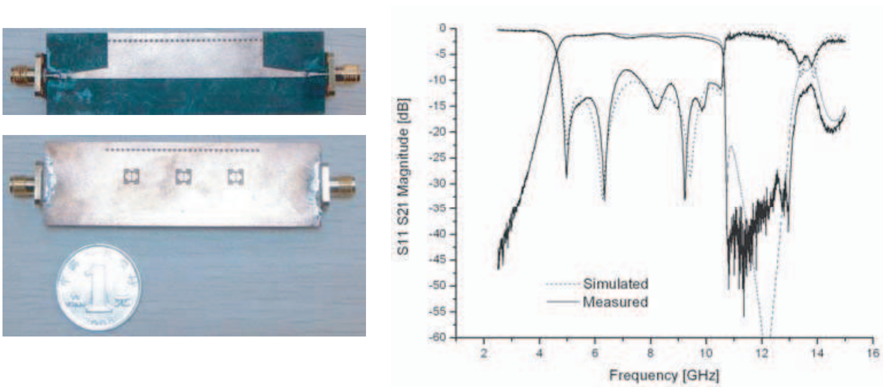
$$W\_HMSIW = 0.5 \cdot W\_SIW \tag{5}$$

Based on this property, existing design techniques for rectangular waveguide can be applied to analyze and design various components. Therefore, the lower cut-off frequency of the designed UWB bandpass filter can be easily obtained. In order to display the lowpass performance, the resonant frequencies $f_1$ and $f_2$, determined by proposed CSRR, are depicted in Section 2.1. The higher cut-off frequency of the UWB bandpass filter is the minimum of $f_1$ and $f_2$.

The half-mode substrate integrated waveguide (HMSIW) is composed of dielectric substrate with $\varepsilon = 2.2$ and height $H = 0.5$ mm, as shown in Fig. 4. Based on the design algorithm of half-mode substrate integrated waveguide [12, 13], the dimensions of the HMSIW can be determined as below: Width $W\_HMSIW = 10.8$ mm, cylinder diameter $D\_via = 0.6$ mm, cylinder spacing $s = 1.2$ mm, width of microstrip $W\_strip = 1.5$ mm, microstrip length $L\_strip = 10$ mm, width of taper transmission line $W\_taper = 6$ mm, its length $L\_taer = 9.8$ mm. The HMSIW transmission line is used for 50 Ω impedance matching. The transmission characteristic of HMSIW demonstrates typical highpass performances with cut-off frequency 4.6 GHz.

The resultant HMSIW-CSRR UWB BPF using proposed CSRR is illustrated in Fig. 5. CSRR must be excited by a proper time-varying electric field parallel to the rings' axis. Thus, it is etched on the ground plane of HMSIW bottom. By adjusting the size of CSRR, the resonant frequency is adjustable. In this paper, 3 CSRR-HMSIW units are used to implement the design objects.

The filter is designed with −10 dB fractional bandwidth of 79% (4.6 GHz–10.6 GHz), the insertion loss of about −1 dB, and the return loss of about −10 dB. At the falling edge of upper cut-off frequency, insertion loss decreases at least −30 dB between 10.55 GHz–10.74 GHz as shown in Fig. 5.




(a) (b)

**Figure 5.** (a) Photograph of the fabricated CSRR-HMSIW UWB BPF, (b) comparison of $S$-parameters between simulation and measurement of CSRR-HMSIW UWB BPF.

## 3. CONCLUSION

In this paper, a half-mode substrate integrated waveguide UWB band-pass filter based on proposed CSRR has been designed and successfully tested. The geometry dimensions and the equivalent circuit of the new CSRR unit are presented. The characteristics of the conventional and the proposed CSRR are also discussed. The validity of the new CSRR with spurious passband suppression, sharpened rejection skirts and widened stopband etc. is testified. The HMSIW-CSRR UWB BPF has an excellent performance of low insert loss, better out-bands characteristics and high-density integration, which may have further applications in microwave systems by mature PCB technology.

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