A Compact Ultra Wide Stopband Filter Based on Quarter-Mode Substrate Integrated Waveguide

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***Abstract*— In this paper, a compact quarter-mode substrate integrated waveguide bandpass filter with extremely wide stopband based on a novel integrated face-to-face complementary split ring resonators (CSRRs) is studied and developed. A combination of complementary split ring resonator and quarter-mode substrate integrated waveguide (QMSIW) is used in this development. Equivalent circuit model simulations from ADS Momentum are in good agreement with HFSS electromagnetic analysis for the QMSIW filter unit, demonstrating the feasibility of QMSIW resonators. The center frequency of the designed filter is 1.54GHz with return loss better than 19dB and insertion loss less than 0.6dB. Its first spurious appears at about 16.8GHz (about 10.9 times the central frequency) with high rejection level of 20dB, providing an ultra wide out-of-band rejection performance. The QMSIW filter was fabricated and the measured results agree very well with simulated ones.**

Keywords—QMSIW, CSRR, wide out-of-band rejection.MSIW, CSRR, wide out-of-band rejection

I. INTRODUCTION

With the development of the wireless communication system, the shortage of spectrum resource is becoming more and more obvious. The filter, as one of the most important components is widely and deeply researched. However, the design of a filter with stringent selectivity, low insertion loss, and potential integration into the circuit for high and wide band application is a great challenge. Substrate integrated waveguide (SIW) [1] is a new guided wave structure and it has already attracted much interest due to its low-cost [2], low insertion loss, high quality factor, high power capacity and small size. Moreover, quarter mode substrate integrated waveguide (QMSIW) exhibits similar propagation characteristics to SIW and obtains the advantage of more compact size. The QMSIW [3] has been widely used in filters, diplexers, duplexers and other active and passive components.

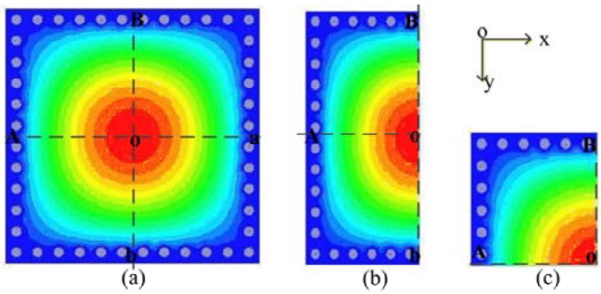
In order to further reduce the size and improve the performa nce of SIW components, some special electromagnetic structur es has been proposed. These structures are defected ground stru cture (DGS) [4], complementary split ring resonator (CSRR) [5], complementary spiral resonator(CSR) [6] and composite ri ght/left-handed structures(CRLH) [7], which are etched as feat ured patterns on the top or the bottom metal of planar circuit bo ard to change the current distribution, further leading a change on the effective permittivity. By this means, size of the cavities can be reduced.

Based on a novel integrated face-to-face complementary split ring resonators, a compact quarter-mode substrate integrated waveguide bandpass filter with extremely wide stopband is proposed and investigated in this letter. The filter consists of the CSRR etched on the top metal plane and the input-output coupling feedline. To achieve an ideal matching performance during a wide frequency band, multiple quarter-wavelength step impedance converters are used as input-output coupling feedlines. The high-pass characteristic of SIW and band-stop characteristic of CSRR are utilized to build a bandpass filter. The dominant resonant mode of the designed resonator is TE_{101}, and the designed bandpass filter is analyzed by the full-wave EM simulator software (Ansys HFSS 15).

II. FILTER DESIGN

A. Quarter Mode Substrate Integrated Waveguide

As we all know, the SIW evolves from conventional rectangular waveguide (RW). RW cavity is a half - half-wavelength resonator with shorted circuits at both ends. Fig. 1 shows the electric field distribution and the evolution process of the proposed filter from the SIW cavity to the QMSIW cavity. As can be observed, the electric fields in a square SIW resonators are symmetrical at the center plane along A-a and B-b in Fig. 1(a). Hence, the symmetrical planes of the SIW cavity can be regarded as a virtual magnetic wall. The HMSIW, as shown in Fig. 1(b), is realized by bisecting Fig. 1(a) along the perfect magnetic wall B-b while keeping half of electric field distribution of the dominant mode TE101. The field distribution of the HMSIW is the same as that of the original SIW. Similarly, the QMSIW cavity can be obtained by bisecting the HMSIW along the plane A-O, as shown in Fig. 1(c). The QMSIW cavity almost preserves a quarter of original field distribution of SIW cavity. And the QMSIW has only 25% size of SIW, while the advantage of the SIW has been inherited. The resonant frequencies of SIW, HMSIW and QMSIW cavities can be given by:



(a) (b) (c)

Fig. 1. Electric filed distribution of full-mode SIW, HMSIW and QMSIW cavities.

$$f_{TE_{101}}^{SIW}=\frac{c}{2\pi\sqrt{\mu_r\varepsilon_r}}\sqrt{(\frac{\pi}{a_{eff}})^2+(\frac{\pi}{b_{eff}})^2}\,, \tag{1}$$

$$f_{TE_{101}}^{HMSIW}=\frac{c}{2\pi\sqrt{\mu_r\varepsilon_r}}\sqrt{(\frac{\pi}{a_{eff}^{HMSIW}})^2+(\frac{\pi}{b_{eff}^{HMSIW}})^2}\,, \tag{2}$$

$$f_{TE_{101}}^{QMSIW}=\frac{c}{2\pi\sqrt{\mu_r\varepsilon_r}}\sqrt{(\frac{\pi}{a_{eff}^{QMSIW}})^2+(\frac{\pi}{b_{eff}^{QMSIW}})^2}\,, \tag{3}$$

$$a_{eff}=a-\frac{d^2}{0.95m},b_{eff}=b-\frac{d^2}{0.95m}\,, \tag{4}$$

where c is the light speed in free space, ε_r is the relative dielectric constant, μ_r is the permeability, a and b are the length and width of the cavity, d is the metallic via holes diameter, m is the center-to-center distance of the metallic via holes, respectively.

B. CSRR Loaded with QMSIW

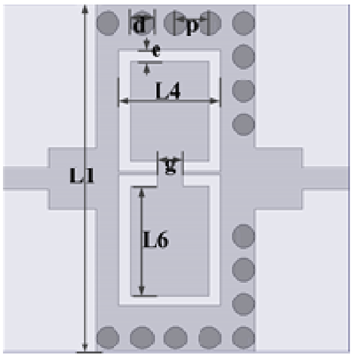


Fig. 2. Configuration of the QMSIW filter unit cell.

The complementary split ring resonator (CSRR) [8] is a widely used resonator etched on the metal plane. Fig. 2 shows the configuration of the QMSIW unit cell by incorporating CSRR on the QMSIW top surface. A single-ring CSRR is selected for this work. The structure is synthesized on a substrate of Rogers 5880 with a thickness of 0.787mm, and relative permittivity of 2.2. All the metallic via holes have a diameter of 2.4mm and a center-to-center spacing of 3.6mm. As can be observed, the equivalent circuit model is presented in Fig. 3. The proposed QMSIW structure can be modeled as an ordinary two-wire transmission line (formed by the top metal surface and ground) loaded and the metallic vias-walls form the short-circuited stubs. The metallic vias-walls are modeled as the inductance Ld. The CSRR can be equivalently interpreted as the shunt resonant tank denoted by the capacitance Cr and the inductance *L*r. The inductive connection of the waveguide transmission line and the face-to-face oriented CSRRS is denoted by *L*c, *L*s, respectively. The slot coupling between the waveguide transmission line and CSRRS is represented by Cc and Cs to implement the capacitance coupling.

Fig. 4. shows the comparison between the CSRR-QMSIW unit cell simulated by the commercial full-wave solver Ansys HFSS and the equivalent circuit model performed by Advanced Design System (ADS). It is evident that an excellent agreement is obtained between them. (Parameters are *Ls* = 3.8 nH, *Ld* = 6 nH, *Ld*1 = 6 nH, *Lc* = 3.8nH, *Lr*1 = 8 nH, *Lr* = 8 nH, *Cs* = 0.4pF, *Cc* = 0.4 pF, *Cr* = 3 pF, *Cr*1 = 3 pF). This confirms the validity of the model.

The filter is connected to two 50 Ω microstrip lines through the ladder transition with the same dimensions. The central fre quency of the proposed filter is f_0=1.54GHz. Electromagnetic analysis of the structure is performed with the commercial full wave solver Ansys HFSS 15.0.

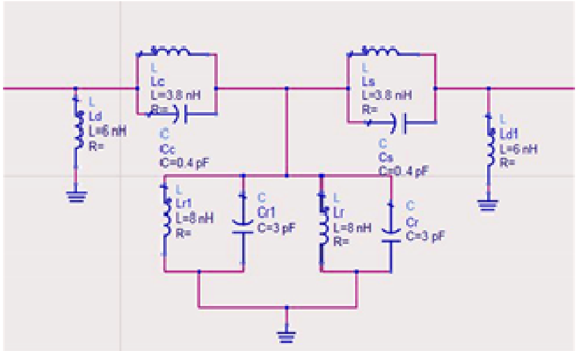


Fig. 3. Equivalent circuit model of QMSIW filter unit cell.

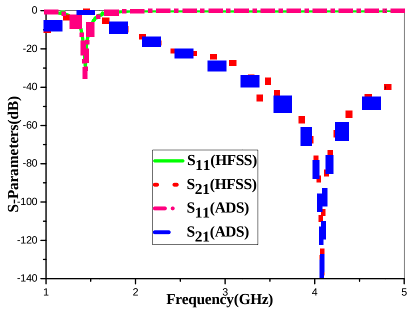


Fig. 4. Simulated responses corresponding to HFSS and ADS.

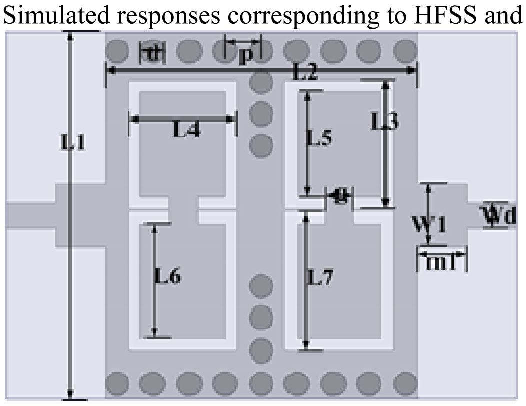


Fig. 5. Configuration of the proposed QMSIW filter.

C. QMSIW-CSRRs Bandpass Filter

The configuration of the two-section QMSIW bandpass filter based on the original unit is shown in Fig. 5. The required coupling can be obtained by tuning the distance between two resonators. Fig. 6. shows the simulated wide frequency response of the QMSIW filter from 1 to 17 GHz band. The simulated central frequency of the proposed filter is 1.54 GHz with the insertion loss about 0.6dB and the return loss better than 20dB. Next, the dimensions of the cavity resonators have been calculated in order to satisfy the frequency requirements, which are further optimized using the commercial full-wave solver Ansys HFSS 15.0 software.

III. EXPERIMENTAL RESULTS AND DISCUSSION

Table I. Dimensions of the proposed SIW bandpass filter (Unit: mm)

Parameter	Value	Parameter	Value	Parameter	Value
L1	37	L6	11.55	g	2.7
L2	31.2	L7	13.95	W1	6.41
L3	12.95	d	2.4	m1	5
L4	10.8	p	3.6	Wd	2.41
L5	10.55	e	1.2	h	0.787

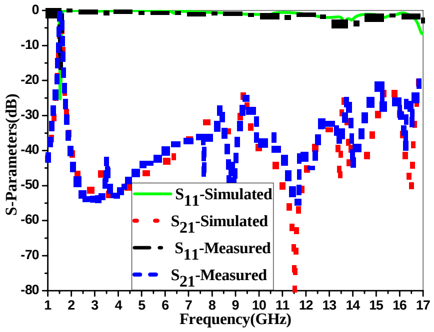


Fig. 6. Simulated and measured frequency wideband responses of the proposed filter.

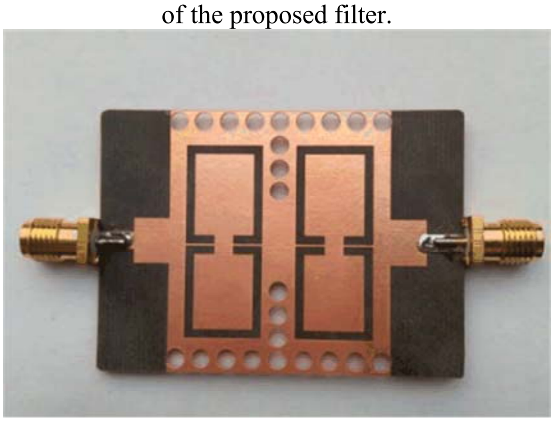


Fig. 7. Photograph of the fabricated filter

To verify the validity of the presented design method shown above, the filter was fabricated on the substrate of Rogers RT/Duroid 5880 with a thickness of 0.787mm using linear arrays of metallic via-holes with a diameter of 2.4mm. The whole filter structure is optimized to satisfy the desired response. The final dimensions (in millimeters) are listed in Table I. A photograph of the fabricated filter is shown in Fig. 7. The whole circuit has a compact size with an overall dimension of 37* $31.2mm^2$, about 0.28λg × 0.24λg, where λg is the guided-wavelength at the centered frequency (f_0) 1.54GHz. It was measured using a vector network analyzer.

IV. CONCLUSION

In this paper, an ultra wide stopband filter using CSRR with a low insertion loss is presented. The BPF is comprised of QMSIW filter with face-to-face CSRR. It is centered at f_0=1.54GHz with return loss better than 19dB and a 0.8dB insertion loss. The proposed filter exhibits favorable stopband performance and only occupies a size of 0.28λg*0.24λg. Its first spurious appears at about 16.8GHz, which is about 10.9 times the central frequency. Wide stopband and high selectivity have been obtained. The measurement results are in perfect agreement with the simulation results. The proposed filter is an attractive and promising candidate for wireless application.

ACKNOWLEDGMENT

This work is supported by the National High-tech Research Development Plan (863 Plan) (2015AA016201).

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