Dual-Band Filters Using Complementary Split-Ring Resonator and Capacitive Loaded Half-Mode Substrate-Integrated-Waveguide

David E. Senior, Xiaoyu Cheng, and Yong Kyu Yoon

Electrical and Computer Engineering Department
University of Florida,
Gainesville, Florida, United States
dsenior30@ufl.edu

***Abstract*—Novel dual-band bandpass filters are implemented for 3.5GHz and 5.8GHz operation by using the half-mode substrate integrated-waveguide (HMSIW) loaded with a complementary split-ring resonator (CSRR) and a capacitive metal patch. Forward electromagnetic wave transmission below the characteristic waveguide cutoff frequency is achieved at two arbitrary frequency bands. Relatively independent control of the resonance frequencies, external Q factor and mutual coupling are possible. A dual band resonator and a two-pole miniaturized bandpass filter are demonstrated. The external and internal mutual coupling variations are fully investigated. Full wave structure simulation and measurement results are provided.**

I. INTRODUCTION

Miniaturized, planar and integrable microwave bandpass filters with high performance and multiple frequency bands of operation are in a constant demand for modern wireless communication systems, mainly motivated by the growing personal mobile and satellite communication applications. Multiple band microstrip filters have been conventionally implemented with different approaches, such as coupled lines and stepped impedance resonators, which however have suffered from low quality factor [1-2]. On the other hand, the substrate integrated waveguide (SIW) and the half mode substrate integrated waveguide (HMSIW) technologies have also been recently explored for the easy implementation of planar filters with performance comparable to that of the bulky waveguide based implementations [3-4]. However, dual band implementations with conventional SIW and HMSIW have suffered from large size.

Recently, a new kind of filters using the SIW and HMSIW structures loaded with complementary split ring resonators (CSRR) have been introduced [5-6]. The two approaches, which operate below the waveguide cutoff frequency due to evanescent wave amplification, are useful for the design of miniaturized, low cost, single and dual band bandpass filters with high performance [5-7]. The HMSIW features a smaller size when compared with the initially introduced SIW [4],[6], while it also provides low radiation and insertion losses, which is advantageous. However, the previous work on dual band HMSIW filters does not allow independent control of the external Q factors and mutual coupling coefficients at both bands [6]. In this work, compact, planar dual band HMSIW filters are investigated. By loading the HMSIW with both a CSRR on the top surface and a capacitive metal patch, two independent frequency bands are generated. Moreover, the external Q factor and mutual coupling coefficient for both bands can be independently controlled. The dual band resonator offers a compact size, low loss, and good selectivity, which makes it useful for filter applications. A dual band resonator and a two-pole dual band filter with a size of $0.221\lambda_0 \times 0.106\lambda_0$ are demonstrated on conventional printed circuit board (PCB) technology. Full wave structure simulation results are compared with measurement ones.

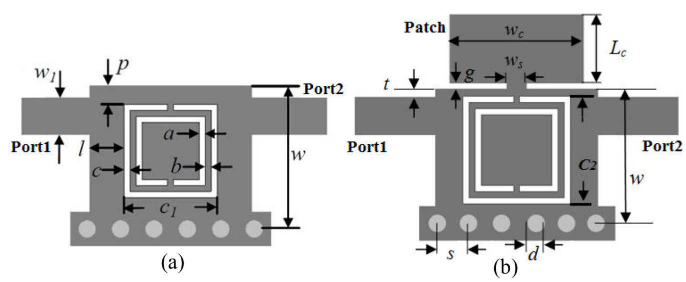
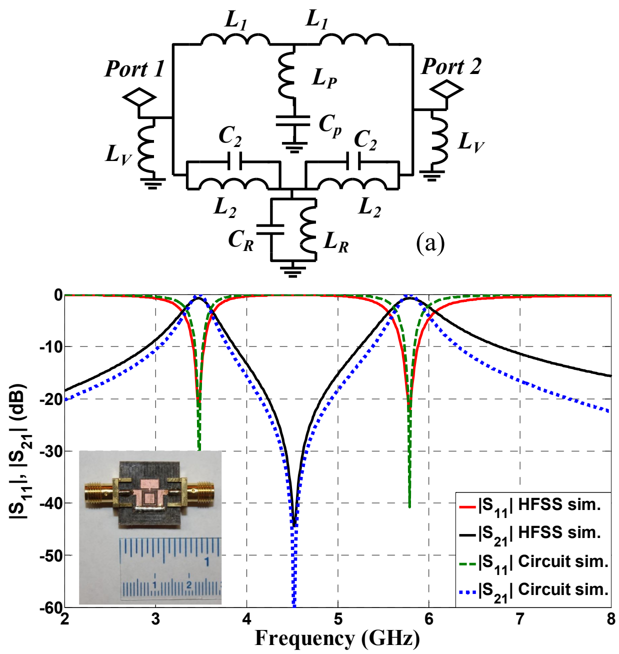


Fig. 1. (a) Single band resonator in [6], (b) Proposed dual band resonator

II. DUAL BAND FILTER DESIGN AND IMPLEMENTATION

Fig. 1(a) illustrates the previously introduced single band CSRR loaded HMSIW resonator [6]. The newly proposed dual band resonator is introduced in Fig. 1(b). Two loading structures, a CSRR and a capacitive metal patch, are integrated in the waveguide for providing two relatively independent frequency bands below the waveguide cutoff frequency. A row of metalized vias with a diameter d of 0.7mm and a pitch s of 1.4mm is used to realize the electrical sidewall of the HMSIW. The external Q factor of the lower frequency band is controlled by adjusting the input distance l, while the combination of the distance l and the width w_s in the metal patch offers the controllability of the second band. The substrate Arlon Diclad 880 (ε_r=2.2 and a thickness of 0.508mm) has been used for the implementation.



(b)

Fig. 2. (a) Electrical equivalent circuit of the dual band resonator, (b) Simulated performance. Design parameters are: $a=b=c=0.25$mm, $c_1=c_2=4.5$mm, $w=6$mm, $L_C=2.8$mm, $W_C=5.5$mm, $g=0.25$mm, $W_s=$ 0.6mm, l = 1.7mm, $t=0$mm, $p=0.3$mm, w_1 = 1.55mm. Extracted values are $Lv=0.6$nH, $L_1=1.07$nH, $L_2=0.88$nH, $C_2=0.53$pF, $L_P=0.39$nH, $C_p=0.665$pF L_R =2.77nH, C_R = 3.05pF.

The symmetric electrical equivalent circuit of the dual band resonator is introduced in Fig. 2(a). The resonant tank formed by L_R and C_R models the CSRR, while the capacitor C_2 models the capacitive coupling of the HMSIW with the CSRR [5]. The effect of the capacitive patch is modeled as a series reactance formed by L_p and C_p. The inductances L_1 and L_2 model the inductive contribution of the HMSIW, while the inductance L_v models the inductive effect of the via wall. In Fig. 2(b), the electromagnetic and circuit simulation results are compared. It is clearly observed that two independent resonances are generated at 3.5GHz with an external Q factor of 20.5 and at 5.8GHz with an external Q factor of 22.3, which is calculated as $Q=2f_0/BW_{3dB}$ for a doubly loaded resonator [5]. The implemented resonator is presented in the inset of Fig. 2.

The dual band filter is implemented by cascading two resonators, as shown in Fig. 3(a). The mutual coupling coefficients of both frequency bands are controlled by the inter-resonator distance L_{IR}, while the distance L_{IC} fine tunes that of the second frequency band. The metal patch does not need to be centered with respect to the HMSIW, which allows easy control of the mutual coupling coefficients. Fig. 3(b) shows the variation of the coupling coefficients. A two-pole coupled resonator filter is designed for 3.5GHz and 5.8GHz operation [6]. Fig. 4 shows the simulated and measured results for the implemented filter. The frequency shifts in both frequency bands are attributed to the tolerance in the fabrication process, which can be further optimized. Nevertheless, simulated results are in good agreement with measurement ones. The inset of Fig. 4 shows the implemented filter.

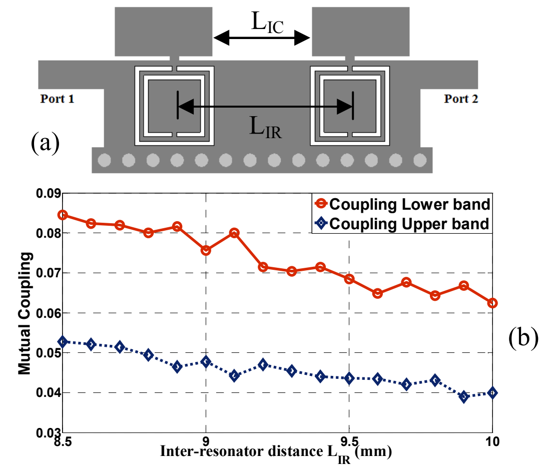


Fig. 3. (a) Topology of the proposed filter (b) Coupling coefficient variation. L_{IC} is kept constant as 5.6mm.

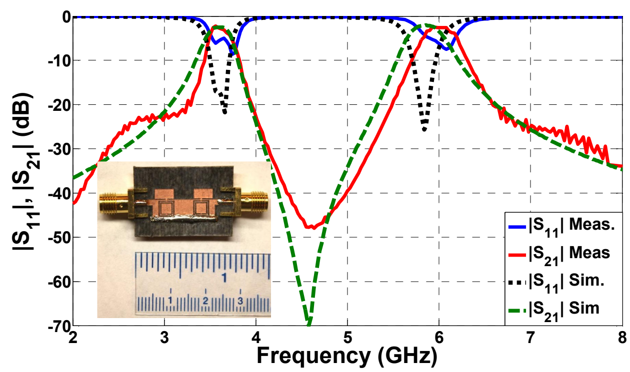


Fig. 4. Simulated and measured performance of the two-pole filter. The 3dB bandwidth : 7.3% at 3.5GHz, 5.5% at 5.8GHz.

In conclusion, the proposed approach allows the independent control of the external Q factor and coupling coefficient of both bands. Arbitrary frequencies of operations can be selected, demonstrating that the topology can be a good candidate to implement miniaturized dual band filters.

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