

Design of A Miniatured Planar Dual-Band Filter Using Embedded Metamaterial Resonators (EMRs)

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Abstract— A novel dual band filter has been proposed. It is shown that the two transmission bands can be excited and designed using proposed resonators which combine an open-loop resonator and the composite right/left-handed (CRLH) material structure. The CRLH material structure is embedded into the ends of the folded open-loop resonators. The open-loop resonator can excite the low-band resonant frequency and the circuit which is designed to be unbalanced, a left handed (LH) mode in the β - ω diagram can control the high-band resonant frequency. With dual-feeding structures added, the performances of the filter such as frequency selectivity and insertion loss are much improved. Besides, the embedded resonators structure (EMRs) can further miniaturize the dimensions of the overall structure. Finally, a novel dual band filter based on the 0° feeding structure has been designed and fabricated with 2.4 and 1.1 dB insertion loss at the center frequency of 2.45 and 5.2 GHz. Experimental circuits on substrates with $\epsilon_r = 3.38$ are measured to validate the theory and design. The die size of the scheme is $10 \text{ mm} \times 8.55 \text{ mm}$.

Index Terms— Composite right/left-handed (CRLH) transmission lines (TLs), dual feeding structure, embedded resonator, bandpass filters (BPF).*

I. INTRODUCTION

RECENTLY, it is crucial to keep radio frequency (RF) filter structures to a minimum size, low insertion loss, and high selectivity within the intended passband. The dual-band filters which are applied to the unlicensed industrial-scientific-medical (ISM) 2.4-GHz band and the ISM 5.2-GHz band have been attractive components for wireless communication products at RF/microwave frequencies. The dual-band passive circuits can create the dual-passband operation as the reported literatures [1]–[2]. In [3], it has pass bands located at 2.4/5.2 and 2.45/5.7 GHz. However, adjacent resonators providing two paths for cross coupling effect may result in larger size.

The left-handed metamaterial was first proposed by Veselago in the late 1960s [4]. Shelby et al. [5] showed that the wave vector \vec{k} and Poynting vector \vec{P} are anti-parallel and the reversal of some basic electromagnetic phenomena such as the Snell's law, the Doppler effect, and the Vavilov-Cerenkov effect. Some related devices have been presented such as an inductively coupled two-pole bandpass filter using the zeroth-order the composite right/left-handed CPW resonators [6] and a novel forward coupler using coupled composite right/left-handed transmission lines [7].

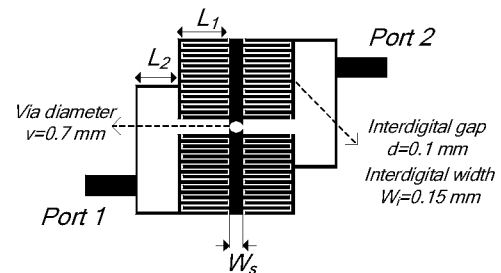


Fig. 1. Dual-band filter with embedded metamaterial resonators (EMRs)

In this paper, a novel dual band filter using embedded metamaterial resonators (EMRs) and dual-feeding structures shown in Fig. 1 is proposed. The EMRs are comprised of the composite right/left-handed (CRLH) structure and an open-loop resonator. The CRLH material structure is embedded into the ends of the folded open-loop resonator. The open-loop resonator is designed to operate at the 2.45GHz and the CRLH transmission line structure dominates the operation band of 5.2GHz. Refer to the unbalanced CRLH transmission line structures, the gap between left handed (LH) and right handed (RH) modes in the β - ω diagram can control the bandwidth of rejection band. The filter with wide stop-band can be achieved when the RH mode moves far away from the LH mode. With the open-loop resonator excited at the 2.45GHz, a dual band filter can be realized. The proposed EMRs structure can effectively reduce the size of the overall structure. Furthermore, by using the 0° feeding associated structure [8] and dual-feeding structures, the low insertion loss and high selectivity are further improved.

II. DESIGN METHODOLOGY

A. CRLH Transmission Line

Analysis in a typical dispersion diagram is convenient for distinguishing unbalanced mode and balanced mode from CRLH transmission line. As shown in Fig. 2, the CRLH transmission with LH behavior has the characteristics of opposite signs of a group and phase velocities in the lower frequency band. On the other hand, the CRLH transmission line with RH behavior has the same signs of the group and phase velocities in the higher frequency band. In the unbalanced mode, both RH and LH behaviors can result in two passbands and there is a bandgap between them. Following the theory [9], the phase constant β of the CRLH transmission line in the passbands is given by:

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$$\beta(\omega) = \frac{1}{p} \cos^{-1} \left\{ 1 - \frac{1}{2} \left[\frac{1}{C_L L_L \omega^2} + L_R C_R \omega^2 - \left(\frac{L_R}{L_L} + \frac{C_R}{C_L} \right) \right] \right\} \quad (1)$$

From equation (1), it can be seen that the phase constant is function of the lumped-element values of the circuit model shown in Fig 3. Both edge frequencies of right/left-handed bands are calculated as [10]:

$$\omega_{cr} = \omega \sqrt{\frac{X\omega^2 + \sqrt{X^2\omega^4 - 4}}{2}} \quad \omega_{sh} = \frac{1}{\sqrt{C_R L_L}} \quad (2)$$

$$\omega_{cl} = \omega \sqrt{\frac{X\omega^2 - \sqrt{X^2\omega^4 - 4}}{2}} \quad \omega_{se} = \frac{1}{\sqrt{C_L L_R}} \quad (3)$$

Where $X = \kappa + (2/\omega_L)^2$ $\kappa = C_L L_R + C_R L_L$

$$\omega_R = \frac{1}{\sqrt{L_R C_R}} \quad \omega_L = \frac{1}{\sqrt{L_L C_L}} \quad \omega = \frac{1}{\sqrt[4]{L_R C_R L_L C_L}}$$

The ω_{CL} is the lower edge frequency of the LH band, and the ω_{sh} and ω_{se} are the edge frequencies of the bandgap, and the ω_{CR} is the higher edge frequency of the RH band. It is called a balanced structure when the series resonance ω_{se} and the shunt resonance ω_{sh} are equal ($1/\sqrt{L_R C_L} = 1/\sqrt{L_L C_R}$). On the other hand, an unbalanced structure results from the case of $\omega_{se} \neq \omega_{sh}$ ($1/\sqrt{L_R C_L} \neq 1/\sqrt{L_L C_R}$)

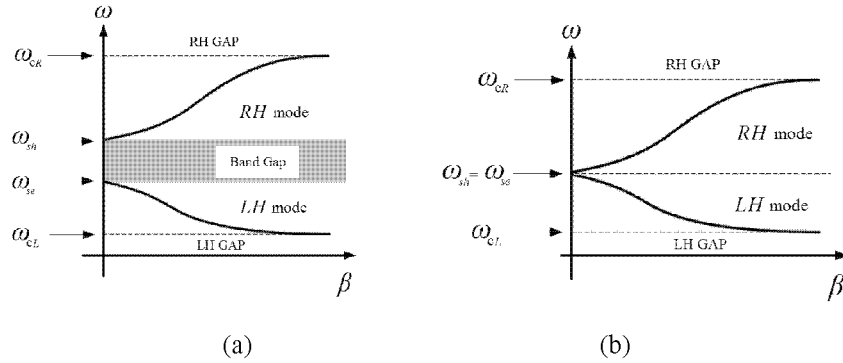


Fig. 2. Typical dispersion diagram (a) balanced type and (b) unbalance type.

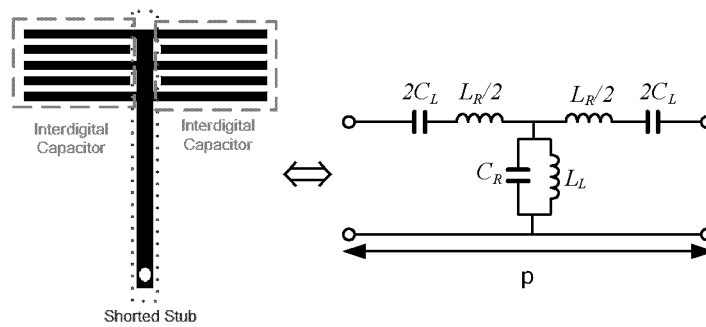
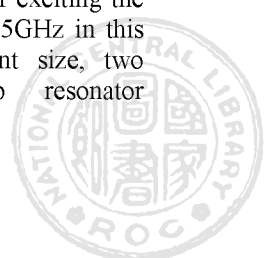


Fig. 3. Layout and equivalent circuit model of a symmetric configuration CRLH transmission line unit cell.

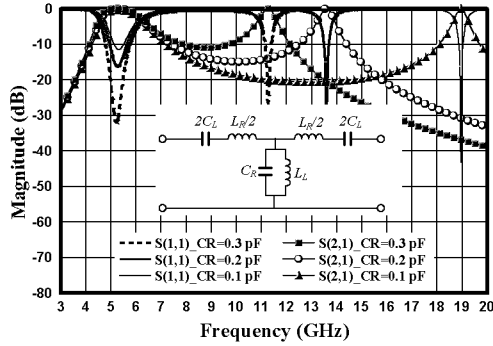
B. 2.45/5.2 GHz Dual Band Filter Design

Since the CRLH transmission line is comprised with both the left handed mode and the right handed mode, a rejection band can be created and designed by controlling the gap between LH and RH modes in the β - ω diagram. Illustrated in Fig. 4(a), when a LH band is designed around the 5.2 GHz, a RH band can be extended to 11.2, 13.6 and 19 GHz. The control of the edge frequencies of the bandgap are carried out using the different capacitance values. It is evident that the edge frequency of the bandgap becomes higher as the capacitance value decreases. Both ω_{sh} and ω_{se}

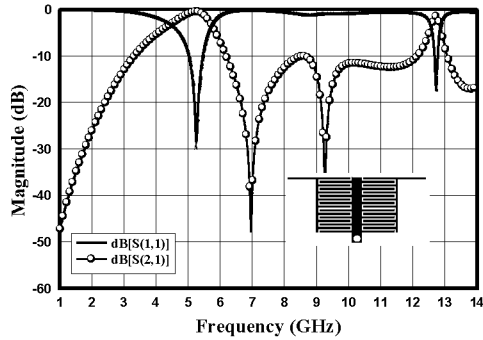
can be independently adjusted. With the lower passband unchanged, the higher frequency passband can be designed to move far away from the low frequency passband by decreasing C_R . The filter with wide stop-band shown in the Fig. 4(b) can be achieved. In this paper, the unbalanced CRLH transmission line structure with left-handed behavior is designed to provide a passband with the resonant frequency of 5.2GHz. Microstrip half-wave length open-loop resonator with couplings capable of exciting the passband has been designed to operate at 2.45GHz in this RF filter design. To reduce the component size, two microstrip half-wave length open-loop resonator



implemented using asymmetric folded-line resonators are combined and coupled to each other to realize a mixed coupling structure. The CRLH material structure is embedded into the ends of the folded open-loop resonators as illustrated in Fig. 5. Finally, by using the 0° feeding associated structure, two extra transmission zeros are created just outside the low-band resonant frequency.



(a)



(b)

Fig. 4. (a) Unbalanced CRLH TL characteristics for the parameters, $C_R = 0.3, 0.2$ and 0.1 pF, $L_R = 5$ nH, $L_L = 1.02$ nH, $C_L = 0.15$ pF (b) Implementation of the Unbalanced CRLH transmission line structures using microstrip technology.

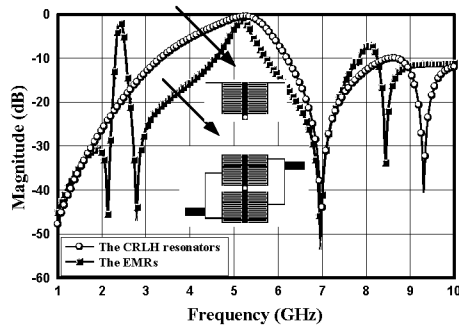


Fig. 5. Simulated frequency responses of the CRLH resonators and EMRs.

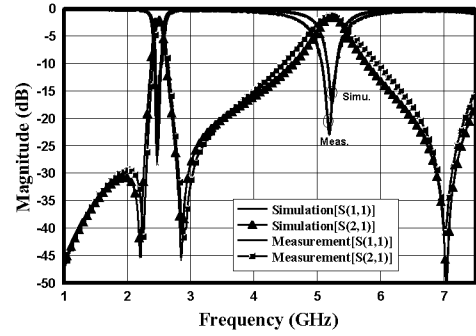


Fig. 6. Simulation and measurement results of the proposed filter.

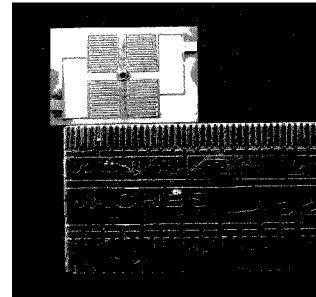


Fig. 7. Structure photograph (scheme size : 10 mm x 8.55 mm).

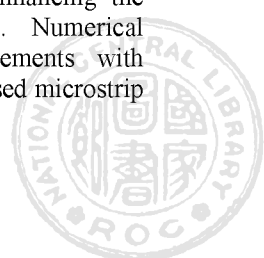
III. SIMULATION AND MEASUREMENT RESULTS

To demonstrate the applications of the studies in the previous sections, the new scheme comprises the series interdigital capacitors and the shunt short-circuited stub inductors in the symmetric configuration. With careful design, a novel dual band filter using dual-feeding structures and the EMRs based on the 0° feeding structure is proposed. It can improve the skirt selectivity and realize dual band filter. They are designed using the simulation solver IE3D and fabricated on an RT/duroid 4003 substrate with a thickness $h = 20$ mil and a relative dielectric constant $\epsilon_r = 3.38$. The dimensions of the proposed filter are specified as follows: $L_1 = 2.3$ mm, $L_2 = 2.1$ mm, $W_s = 0.7$ mm, $W_1 = 0.15$ mm, $d = 0.1$ mm, $v = 0.7$ mm and the scheme size is 10 mm x 8.55 mm.

The S-parameter simulation and measurement results for this designed filter are shown in Fig. 6. The passband with low frequency of 2.45 GHz has less than 2.4 dB insertion loss and greater than 27 dB return loss and high frequency of 5.2 GHz has less than 1.1 dB insertion loss and greater than 24 dB return loss. The 3-dB bandwidth is 80MHz from 2.41GHz to 2.49GHz and 300MHz from 5GHz to 5.3GHz. Fig. 7 shows the photograph of this structure.

IV. CONCLUSION

This letter presents a novel dual band filter using dual-feeding structures and the EMRs based on the 0° feeding structure. Compared with the reported documents, it has the advantages of low insertion loss, enhancing the interference immunity, and compact size. Numerical simulations using IE3D show good agreements with experiments. It has been shown that the proposed microstrip



dual band filter can provide good rejection between two transmission bands and each of the passband frequencies can be independently adjusted.

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BIOGRAPHY

Chu-Yu Chen received his B.S. degree in the department of engineering science from National Cheng-Kung University, Tainan, Taiwan, in 1990, and his M.S. degree in the department of electrical engineering from the University of Detroit, MI, USA, in 1995. From 1996 to 1999, he was a teaching and research assistant in the department of electrical engineering at Oakland University, MI, USA. In November 1999, he obtained his Ph.D. degree. He is currently a professor in the department of electrical engineering at University of Tainan, Tainan, Taiwan. His research interests include electromagnetic compatibility, microwave passive circuit design and computational electromagnetic.

