Design and Development of Bandpass Filter using Parallel-Coupled CRLH Unit-Cells

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***Abstract*— This report is concerned with design of a compact Composite Right/Left-Handed (CRLH) parallel couple line filter on FR-4 substrate for WLAN applications. The proposed filter, with overall dimensions of 14.68mm × 5.89 mm, shows a good response offering return loss of 21 dB and insertion loss of 2.41 dB at center frequency of 2.47GHz and bandwidth *BW* = 241 MHz. The relevant design considerations and results are also discussed.**

***Keywords*— CRLH filter, parallel-coupled bandpass filter, unit-cell.**

I. Introduction

Microwave filter is a one of the most important blocks of any communication system, which provides transmission at certain frequencies and rejection on other frequencies called stopband. The common process of achieving a band-pass filter (BPF) is by combining a low-pass filter(LPF) and a high-pass filter (HPF). Obtaining the ideal BPF at radio frequencies is nearly impossible.

Planar filters play an essential role in microwave circuits, especially in MMICs. Parallel coupled transmission-line filters can be implemented within other PCBs and circuits, and this has been motivation of many researches and the work continues. However, all the proposed topologies are limited to conventional microstrip edge-coupled lines which are limited to the bandwidth up to 20% of central frequency. Many procedures of designing such a filter including Butterworth and Chebyshev methods can be found in microwave engineering references.

Electromagnetic metamaterials (MTMs) are broadly defined as artificial effectively homogeneous electromagnetic structures with unusual properties not readily available in nature. In RF circuit applications, left-handed metamaterials (LH MTMs) have been approved to significantly reduce the size of passive components, without sacrificing circuit performance, due to their dispersive phase properties[1]-[4]. In planar technology, many implementations of metamaterial filters have been presented [1]–[6]. In mid-2002, three groups of researchers simultaneously proposed a new approach to design planar LH metamaterials based on the dual transmission line concept, [7]-[9].

A CRLH structure is intended to be used as a transmission line or transmission structure. Only the passband is directly useful. The stopbands are usually parasitic effects limiting the operation bandwidth of the MTM. Thus, the filtering characteristic of the network are generally not used in MTM as in filters[1]. However, novel topologies and arrangements using MTMs, have the possibility of good filtering response. To date, so many filtering structures are built using MTMs or CRLH materials.

This report discusses a parallel couple line CRLH BPF at center frequency of 2.45, which is commonly used by WLAN/Wi-Fi (IEEE 802.11 b/g/n) and also in satellite communication systems.

II. The Proposed Filter Design

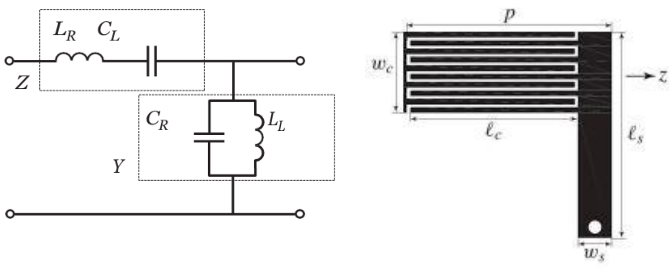
Microwave filters can significantly benefit from metamaterial technology to have high selectivity, low insertion loss in the passband, and compact dimensions. Metamaterial-based filters are generally designed by CRLH transmission line (TL) or by negative refractive index resonators.

The conventional parallel-coupled filter design can be obtained by [10]. Based on design demands, a 3rd order filter is required for common application in 2.4GHz-2.6GHz. Coupling factor is based on the difference between even mode and odd mode characteristic impedances [11]. Two common mechanisms involved in designing of coupled-line filters are: 1) forward wave coupling mechanism and 2) backward wave coupling mechanism. In both cases, scattering parameters are derived from following:

$$S_{11} = \frac{S_{11_{even}} + S_{11_{odd}}}{2} \quad , \quad S_{21} = \frac{S_{21_{even}} + S_{21_{odd}}}{2} \qquad (1)$$

Assuming a forward wave coupling mechanism, leads us to large physical dimensions, poor coupling level of maximum 10 dB due to fabrication constrains (PCB manufacturers have the fabrication limitation of 0.15 mm for minimum clearance between traces), whereas using CRLH resonators reduces the overall size of the filter while allowing coupling level between unit cells increases impressively.

Many different topologies for CRLH transmission lines and resonators are proposed. One of these, called interdigital/stub configuration, consists of two interdigital capacitors (IDCs) embracing a stub grounded by via with no metal patterning in the ground plane as shown in (Fig. 1).



(a) (b)

Fig. 1. (a) Schematic and (b) layout of CRLH unit-cell [1].

Equivalent circuit model for each unit cell consists of series capacitor and series inductor along with shunt capacitor and shunt inductor [1] (Fig. 1).

Substrate permittivity of 4.7 is assumed and lossy copper with electric conductivity of 5.8 x 10-7 Ω·m is considered as the metal conductor for both metal planes surrounding the substrate. A combination of unit cells by cascading them results in quasi-2.4 dB return loss, $|S_{11}|$ and quasi-21 dB insertion loss,$|S_{21}|$. Total dimension is 14.68 × 5.89 mm. More specifications are listed below (Table 1).

Table 1. Physical dimensions of each unit cell.

Parameter	**Dimension**
Interdigital capacitor finger width	1.36074 mm
Stub width	1.36074 mm
Left IDC finger length	5 mm
Right IDC finger length	5 mm
Via radius	0.25 mm
Clearance (minimum gap between traces)	0.15 mm
Copper thickness	35 µm
Substrate thickness	1.6 mm
50-ohm microstrip line	2.84 mm

Two open circuited stubs are included to enhance the out-of-band rejection at upper cut-off frequency. The proposed filter layout including port designations is shown in Fig. 2.

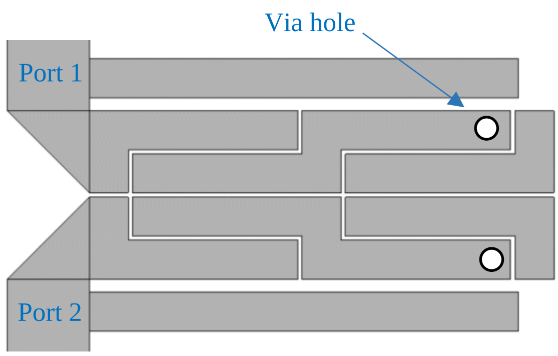


Fig. 2. Layout of the proposed filter with appropriate port designations.

To validate the design concept, the response of proposed CRLH BPF is numerically calculated using a 3D full-wave simulation software, CST Studio Suit as shown in Fig. 3.

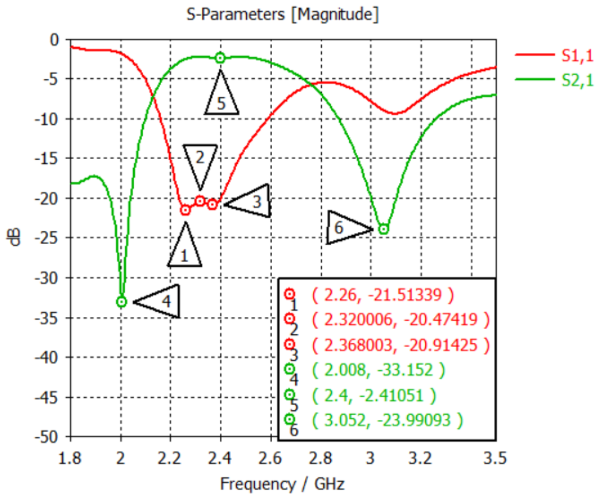


Fig. 3. Simulated response of CRLH BPF

According to formula given in (2), upper cut-off frequency (f_h) and lower cut-off frequency (f_l), this filter has a bandwidth of 241 MHz.

$$BW = \frac{f_l - f_h}{f_0} \qquad (2)$$

As expected, due to the symmetricity of the novel CRLH BPF, its has the reciprocity property (Fig. 4).

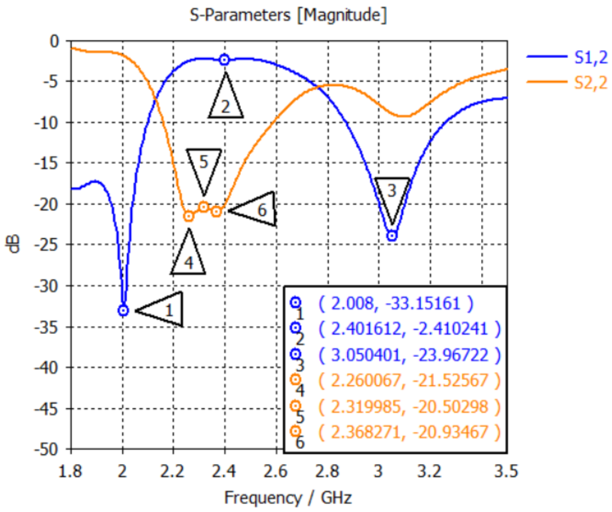


Fig. 4. Reciprocity verification response of CRLH BPF.

III. Conclusion

In this letter, a novel CRLH-based band-pass filter for 2.45 GHz application was presented. Insertion and return losses are numerically calculated and has satisfactory insertion loss which is slightly better than 2dB, even with a lossy substrate (FR-4). The proposed filter is impressively smaller in size than its conventional counterpart.

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