Coupled CRLH transmission lines for compact and high selectivity bandpass filters

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Abstract— **A compact size and high selective bandpass filter is presented in this paper. The filter is designed to serve at 3.5 GHz with two transmission zeros at 3.35 GHz and 3.85 GHz. The filter is designed as two gap capacitor coupled to coupled composite right left handed transmission lines. The coupled lines were designed to demonstrate a zeroth order phase at 3.5 GHz. Also, the transmission zeros were achieved as a consequence of the electrical / magnetic couplings between the two coupled transmission lines. The employed cell, filter design equations are emphasized. The filter S-parameters were extracted based on the circuit model, full wave simulation and experimental measurements. A good agreement between modeled, simulated and measured results is achieved. The measured centre frequency of the bandpass filter is 3.55 GHz and 100 MHz bandwidth which is suitable for WiMAX applications. Also, the filter has low measured insertion loss which does not exceed 1 dB within passband. Finally, the filter has advantageous of compactness (size is only 20×18 mm^2) which is only 50% compared to conventional non-selective one stage coupled line filter.**

Index Terms—**CRLH TL, Bandpass Filters, Coupled-Line Coupler.**

I. INTRODUCTION

Microwave bandpass filters play an important role in various RF/microwave circuits and systems. With the rapid growth of microwave and millimeter wave communication systems, the band pass filter must have several requirements such as compact size, low insertion loss and low cost. In order to realize band pass filters, different configurations may be designed. Researchers designed band pass filters which are based on parallel-coupled lines. The planer structure of parallel coupled line is simple, easy of implemented and has low fabrication cost [1],[2]. Also, coupled microwave resonators are used as main block of designing sharp bandpass filters. Conventional coupled resonators filter uses two coupled half guided-wave long transmission lines as resonators [3]. However, at low microwave frequencies, the dimensions of the resonators are significantly large. Several ideas have been introduced to reduce the resonator size by modifying its structure like open loop folded half-wavelength resonator [4] and DGS structures [5]. To improve the selectivity of the filter,

number of transmission zeros (TZs) around the passband have to be employed. By achieving multiple transmission zeros, the filter ability to reject unnecessary bands is increased. Various design techniques have been reported to create TZs around the filter passband. [6]. Such approaches uses the extraction pole method [7], a structures which has 0° between the feeding lines [8] and coupling which is between the source and the load [9]-[11]. The previous approaches usually need to produce coupling paths therefore; coupling matrix needs to be synthesized to produce the desired filter response.

Composite right left handed transmission lines (CRLH-TL) have been presented as novel transmission lines with backward wave propagation (characterized with anti-parallel phase and group velocities) [11],[12]. A consequence, they have nonlinear positive/negative zero phase shift. It has been shown in that two coupled CRLH transmission lines can have very high backward coupling that can reach 0 dB [13]. Thanks to these properties, compact microwave resonators [14] filters [15] - [17] and couplers [18] are designed.

In this paper, a compact bandpass filter is introduced. The filter is an air gap coupled to two identical coupled CRLH TLs. The filter is designed to have a centre frequency of 3.55 GHz and 100 MHz bandwidth which is suitable for WiMAX applications. Also the filter design has achieved two transmission zeros at 3.35 GHz and 3.85 GHz. The proposed filter is simulated, fabricated and measured. A good agreement between modeled, simulated and measured result is achieved

II. FILTER THEORY AND STRUCTURE

The schematic circuit of the designed filter is based on two coupled CRLH TLs as shown in Fig. 1 (a). It is based on using two coupled CRLH lines with open circuit termination for each. The input / output are coupled to the two coupled CRLH lines through two air gap capacitors. The circuit model for the proposed filter is shown in Fig. 1 (b). In the equivalent circuit, C_L and L_L are referring to the loading left handed elements; C_R and L_R are the patristic elements of the hosting TL whereas C_m and L_m are the mutual capacitance and inductance, respectively. Finally, C_{ac} is the coupling air gap capacitor.

The employed cell was designed to introduce a zero phase at

the desired center frequency calculated as

$$\theta = \beta \, l = \beta_l \, d_l + \beta_r \, d_r = n\pi \tag{1}$$
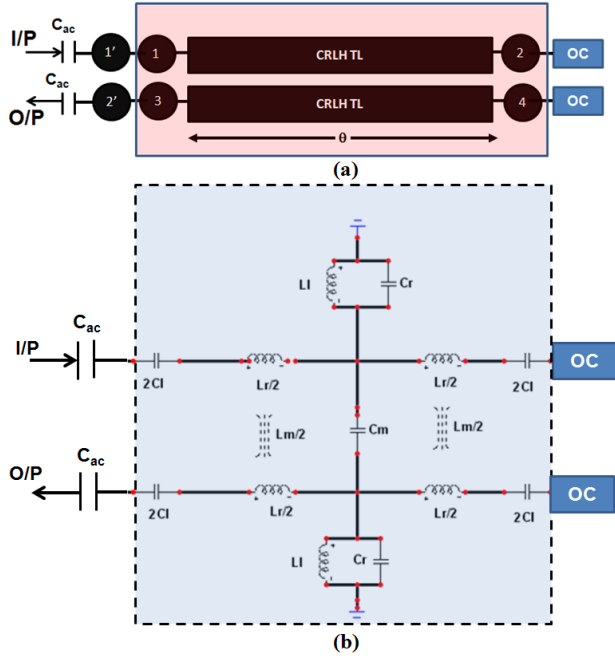

Fig. 1. The coupled composite right left handed bandpass filter.(a) The schematic circuit, (b) The equivalent circuit model of the proposed gap coupled CRLH filter, C_{ac}=0.15 pF, C_L=0.375 pF, L_r=2.5 nH, K_m=0.75, C_m=0.11 pF, C_r=1.4 pF, L_L=1.4 nH.

where n is an integer. Zeroth order resonance occurs at n = 0. where β_l and β_r are the propagation constants of LH and RH sections, respectively, whereas d_l and d_r represent the lengths of these sections, respectively, while l is the total length of the combined line. On the other hand, the achieved transmission zeros were achieved based on the backward CRLH coupling coefficients. This can be extracted using analysis of the proposed filter configuration using full wave analysis of coupled line CRLH couplers [18] as

$$S_{21} = \alpha = \frac{A e^{-j\beta_I l} + B e^{-j\beta_{II} l}}{A + B} \tag{2}$$

$$S_{31} = j\beta = \frac{A(\beta_I - \beta_{LH}) e^{-j\beta_I l} + B(\beta_{II} - \beta_{LH}) e^{-j\beta_{II} l}}{A(\beta_I - \beta_{LH}) + B(\beta_{II} - \beta_{LH})} \tag{3}$$

$$\beta_{I,II} = \sqrt{\beta_{LH}^2 - C_{BW}^2} \tag{4}$$

For open circuit termination at port 2 ($V_2^-=V_2^+$) and port 4 ($V_4^-=V_4^+$), the coupled line coupler can serve as filter with

$$s'_{11} = \frac{\alpha^2}{1+\beta^2} \tag{5}$$

$$S'_{21} = j\left(\frac{\alpha^2 \beta}{1+\beta^2} + \beta\right) \tag{6}$$

Following this circuit diagram, the employed CRLH cell was designed such as its geometry is shown in Fig. 2 (a). The loading capacitor (C_L) is realized as 6 fingers interdigital capacitor whereas the inductor (L_L) is realized using via hole stub. The synthesizing of these elements has been done based

on the the formulas in [11] where they have been optimized using circuit model. Finally, the loading elements are calculated as given in Fig. 1 (b) and the distributed elements are in table I.

TABLE I
THE EMPLOYED CRLH CELL GEOMETRY DIMENSIONS

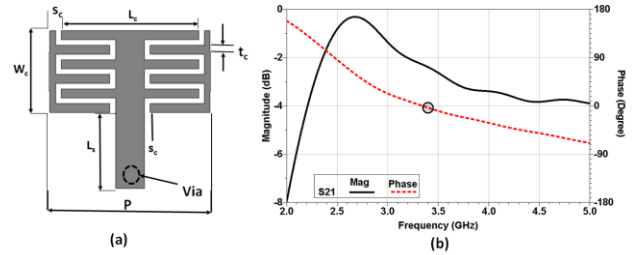| Design parameters in mm					
Parameter	L	W	Lc	Wc	tc
Dimension (mm)	18	20	4.8	2.8	0.3
Parameter	sc	Ls	p	wf	
Dimension (mm)	0.2	1.2	5.2	1.3	

Fig. 2. The used CRLH cell (a) the cell geometry, (b) the simulated scattering parameters magnitudes.
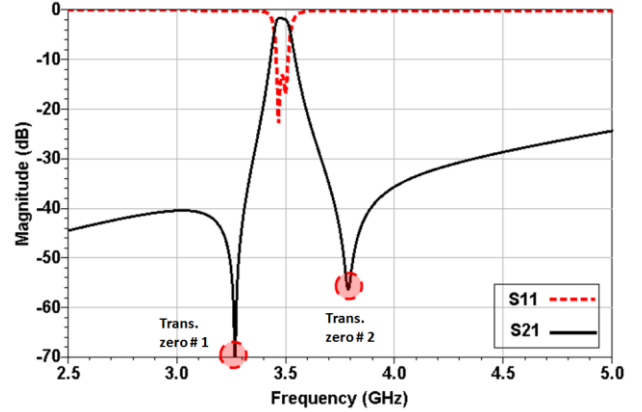

Fig. 3. The simulated scattering parameters magnitudes for the equivalent circuit model.

The zeroth order mode of the designed cell has been confirmed by simulating 2 port CRLH cell. The simulated scattering magnitudes of the cell are shown in Fig. 2 (b). As shown in the figure, the cell demonstrates zero phase at 3.4 GHz. This result has been used later for optimizing the center frequency of the filter to be at 3.5 GHz. On the other hand, the simulated circuit model of the proposed filter is shown in Fig. 3. As shown in the figure, the filter is centered at 3.5 GHz with insertion loss = 0.5 dB and return loss close to 18 dB. Also, the filter has two transmission zeros at 3.3 GHZ and 3.8 GHz. These two zeros are -80 dB and -60 dB at the two former frequencies, respectively.

III. THE FILTER RESULTS

The gap coupled coupled CRLH filter layout is shown in Fig. 4 (a). It is formed by using two air gap coupling capacitors to two coupled previously designed CRLH cells. The filter is printed on Rogers 6010 substrate with a relative dielectric constant of 10.2 with loss tangent of 0.0023 and a thickness of 1.27 mm and with 50 Ω microstrip feed line. The fabricated

filter prototype is shown in Fig. 4(b). The coupling length is only 4 mm whereas the filter size is (20×18 mm^2). The filter size comparison illustrates that the filter has 50%
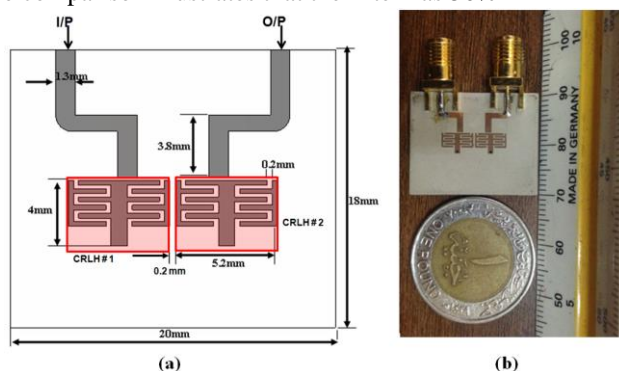

Fig. 4.   The gap coupled CRLH filter (a) The 2D layout (b) The fabricated filter prototype.
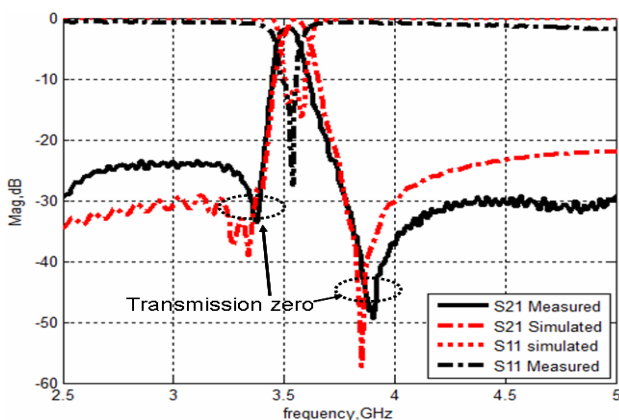

Fig. 5.   The simulated and measured scattering parameter magnitudes of the proposed gap coupled CRLH filter.

size reduction than the conventional filter illustrated in [3].

The fabricated filter was tested by measuring the scattering parameter. The simulated and measured scattering parameters magnitudes of the proposed filters were compared to each other as illustrated in Fig. 5. It is clear that from the simulated results the proposed filter operates at 3.55 GHz with bandwidth of 100 MHz and there are two transmission zeros at 3.35 GHz and 3.85 GHz. These two transmission zeros are due to there is a coupling between input /output ports. In Table II, a comparison between the proposed filter and most recent published filter works with transmission zeros where our filter competitive characteristics are obvious.

TABLE II
COMPARISON BETWEEN THE PROPOSED FILTER AND MOST RECENT PUBLISHED WORK

Ref	f_o (GHz)	ϵ_r/ Thickness (mm)	BW (GHz)	IL/RL	TZs	Size (mm)
This Work	3.55	10.2/1.27	0.1	0.5/15	2	10.6×4
[2]	2	6.15/1.52	0.2	1.2/20	0	48×38
[9]	4.32	2.56/0.77	0.27	1.5/18	3	16.3×10.4
[15]	4.35	22/1.57	0.29	0.7/18	1	6.07×5.14
[16]	3.5	10.2/1.27	-	1/20	1	12.8×5.29

IV. CONCLUSION

A compact second order bandpass filter has been presented. The bandpass filter is based on composite right left handed transmission line. The two resonators have been designed using only one composite right left handed unit cell. The filter has the advantage of compactness. The filter with a centre frequency of 3.55 GHz and two transmission zeros at 3.35 GHz and 3.85 GHz has been designed, simulated and measured. A Good agreement between simulated and measured result has been achieved. The filter shows low measured insertion loss which does not exceed 1 dB within passband. The designed filter is suitable for WiMAX applications.

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