Investigation to Meta material Transmission Line Filters Based on the CL-Loaded Approach

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El-Sayed Mahmoud El-Rabaie
Faculty of Electronic Engineering, Menouf

Maher Khaliel
University of Duisburg-Essen

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Amr Elawamry[1] and Maher Khaliel[1]
[1]Benha Faculty of Engineering, 13512 Benha, Qalubia, Egypt

Abstract-This paper investigates the design of narrow band, dual band, and ultra wideband bandpass fiters using metamaterial transmission line Cl-loaded approach. In this paper we present a suggested design methodology for designing such filters. The size of filters produced is very compact and easy to integrate. Beside compact size we obtain comparable filter performance. Using methodology proposed the upper passband harmonics of the obtained filter can be rejected and hence the stopband performance is improved. These metmaterial filters are designed based on the composite right left handed (CRLH) Transmission line CL-loaded approach. The unit cell used in the design consists of interdigital capacitor and short circuited stub. For the methodology verification a narrow band bandpass filter is designed and tested. The filter designed has the following properties, resonant frequency at 900MHz for mobile communications, bandwidth equal to 80 MHz, insertion loss lower than -1 dB, with in-band return loss lower than -25 dB, and a wide stopband. The total filter size is about 2 cm x 2.4 cm which is very compact compared to other metamaterial and conventional microstrip filters. Also in this paper an ultra-wideband (UWB) filter is designed and tested. The filter has a passband from 2.3 to 11.3 GHz with a maximum insertion loss of -2 dB, and a wide stopband up to more than 10 GHz with a rejection mostly better than -7 dB. The total filter size is about 1.2 cm x 1.8 cm which is also very compact compared to other metamaterial and conventional microstrip filters. The design steps, simulated and experimental results of the designed filters are presented. The simulation results agree with the experimental results.

I- Introduction

Metamaterial transmission lines can be used in the design of microwave devices such as filters. On the basis of their controllable characteristics, these lines have been applied in the design of microwave devices showing compact dimensions, and improved performance. Several kinds of lines have been applied in the implementation of filters with different performances. Some of them were based on the CRLH transmission line CL-loaded approach.

Recently, CRLH transmission lines have been used for constructing various filters in several papers. These CRLH structures are artificial transmission lines constructed of cascaded unit cells, composed of capacitors and inductors. In [1], a narrow bandpass filter is proposed where CRLH transmission line structure is implemented in the form of interdigital capacitors and short-circuited stubs. But the insertion loss of the filter is about -5dB which is quite big and the overall area of the filter is about 6cm×4cm which is also still big to be integrated in a very compact system. A research in [2] presents a narrow bandpass filter which is based on left handed transmission line zeroth order resonators. This filter in [2] consists of 15 cells and the unit cell is 4.8mm long. These cells are cascaded to form the filter, so the filter size is also relatively large to what is introduced by us. A research in [3] presents a miniaturized narrow bandpass filters depends on metamaterial transmission lines resonant type approach. The filter in [3] consists of three coupled metamaterial closed loop resonators, has insertion loss about -3dB which is quite big, and the overall area of the filter is about 8.5cm×5.5cm. Another research in [4] which is also depends on metamaterial square loop resonators and the size of the filter is about 3.5cm×2.5cm.

Also, the UWB bandpass filters can be designed using the CRLH metamaterial cells. In [5], an UWB filter is proposed that use three interdigital line and short-circuited stub cells. It has fractional bandwidth equal to 42.86% which does not fully utilize the whole range of the FCC's spectrum mask, and with insertion loss equal to -1.1dB. A research in [6] presents an UWB filter based on a simplified composite right/left-handed transmission line (SCRLH- TL). It has fractional bandwidth equal to 110%, but it consists of five unit cells and uses U- slot etched in the ground makes it not considered as a planar structure.

Regarding to the design of narrow and ultra wideband bandpass filters using metamaterial transmission line Cl-loaded approach we present a suggested design methodology for designing such filters based on only one unit cell. The use of one unit cell results in a significant size reduction compared with other microstrip and metamaterial filters. So the size of the produced filters is very compact and easy to integrate. The unit cell used in the design consists of interdigital capacitor and short circuited stub.

II- The Suggested Design Approach

Our suggested procedures for narrowband and UWB metamaterial bandpass filters include mainly four steps:-

1- Calculating the circuit elements (C_L, L_L, C_R, L_R) which produce the response required using initial circuit design.

2- Calculating the physical dimensions of the unit cell using equations (1-a, b, c, d) to produce such inductance and capacitance values required.

3- These initial values are entered in layout simulation software and iterations are done until the optimized response is obtained.

4- Using stepped impedance lowpass filter to act as a mask for the filter. As an effect of step in width impedances the periodicity of the cell will be suppressed, and the other higher different harmonics will be disappeared in case of narrowband filters, and the stopband performance will be improved in case of UWB filters.

III- Narrow Bandpass Filters Using CRLH Metamaterial Cell

Following the design steps, first of all the values of capacitances and inductances are calculated using initial circuit design as shown in figure (1) to produce a passband at 900MHz with bandwidth equal to 80MHz. So, the interdigital line’s sizes, and short circuited stub are calculated to realize such capacitances and inductances values. The unit cell that is used in narrowband filter design is shown in figure (2).Via the iterative steps using equations (1-a, b, c, d, e) the final cell dimensions are shown in table (1). As shown from figure (3), the aimed response is obtained and we have a passband centered at 900MHz with bandwidth of 80MHz. From figure (3), it is shown that the second passband is spaced about 2.2GHz from the first resonance. If we intend to use such a unit cell as a mono-bandpass filter only at 900MHz and reject the other passbands to improve the stopband performance, we can use a stepped impedance lowpass filter [7] in series with the unit cell to act as a mask for the desired band. If a dual bandpass filter is intended, pay attention that the space between the first and second passband cann't be controlled using only one unit cell. So we must add another cell for the second passband, with the same methodology calculating the dimensions of the first and second cell and tune them together with appropriate matching element after that we can mask the first and second passband together. So this approach can be used for designing dual band bandpass filters also. The layout mask and the photograph of the fabricated 900MHZ filter are shown in figure (4). Figure (5) shows the response of the filter after adding the stepped impedance mask. As shown from figure (5), the second harmonic of the unit cell is suppressed besides improving the out-of-band performance of the filter. The final dimensions of the stepped impedance sections are 0.1mm×1mm, 0.2mm×1mm followed by 10mm×1mm. We add 5mm×1.478mm microstrip sections at the two sides of the filter for input and output port extension.

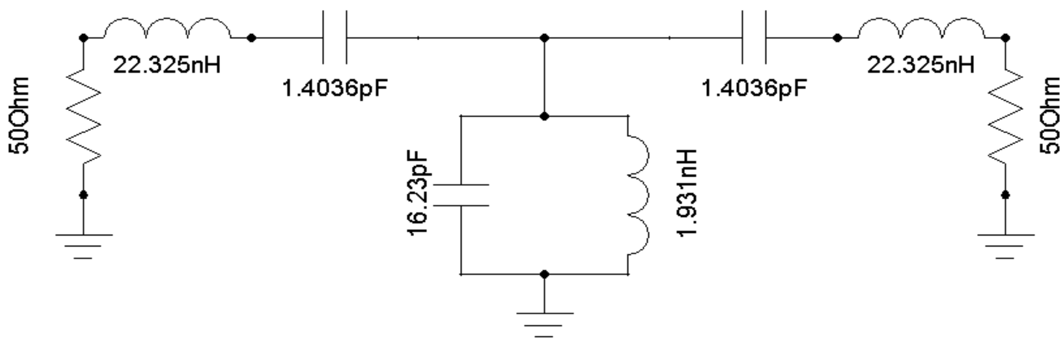


Figure (1): Circuit elements of the 900MHz bandpass filter.

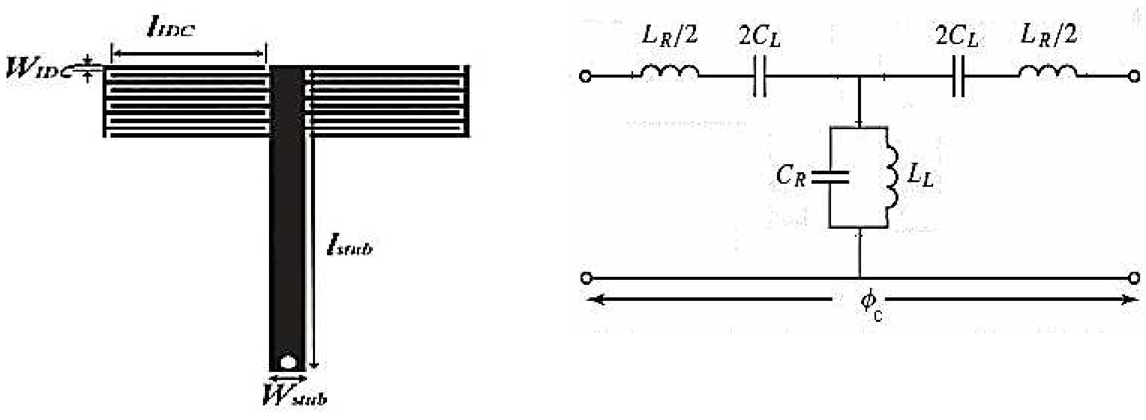


Figure (2): Unit cell T-equivalent.

Variables	Final dimension
Unit cell period (p)	5.5mm
Stub length (ℓ_{stub})	23.5mm
Stub width (w_{stub})	2mm
Interdigital finger length (ℓ_{IDC})	1.5mm
Interdigital finger width (w_{IDC})	0.5mm
Spacing between fingers	0.2mm
Via radius	0.5mm
Number of fingers n	9

Table (1): Final cell dimensions of the 900MHz filter.

$$C_L = \frac{(\varepsilon_r+1)}{W} l_c(\varepsilon_r + 1)[0.1(n-3) + 0.11] \quad \text{pF (1-a)}$$

$$L_R = 2 \times 10^{-4} l_c \left[\ln\left(\frac{l_c}{W_c+t}\right) + 1.193 + 0.224\frac{W_c+t}{l_c}\right] . K_g \quad \text{nH (1-b)}$$

$$K_g = 0.57 - 0.145 \ln\left(\frac{W_c}{h}\right) \quad \text{(1-c)}$$

$$L_L \approx \frac{Z_c^{si}}{\omega} \tan(\beta^{si} \ell^{si}) \quad \text{H (1-d)}$$

$$C_R = \varepsilon_{eff} . \frac{w_{stub} \cdot L_{stub}}{h} \quad \text{F (1-e)}$$

Where n is the number of fingers, is the finger length, is the finger width, and W is the width of the microstrip interdigital capacitor, as shown in figure (2). The above h and t mean the thickness of the substrate and metallization in use.

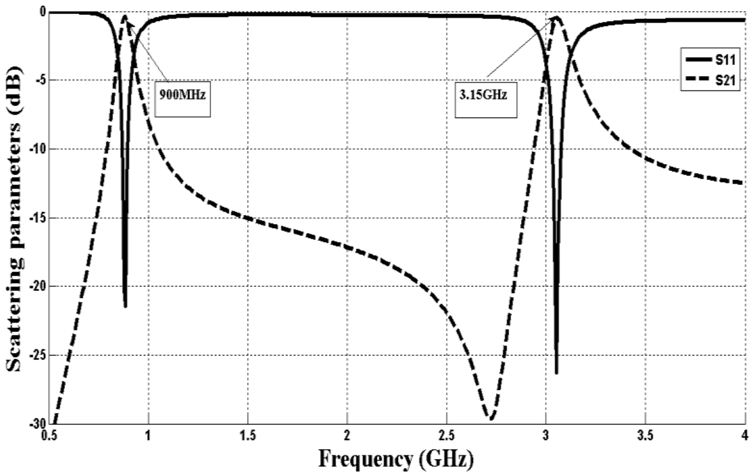
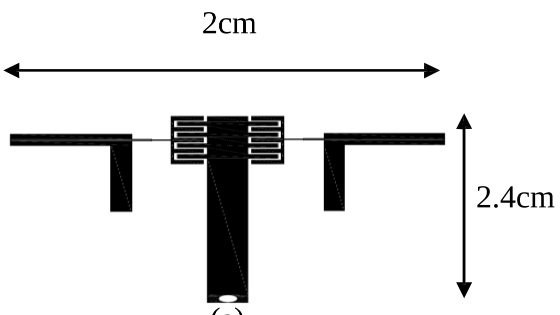
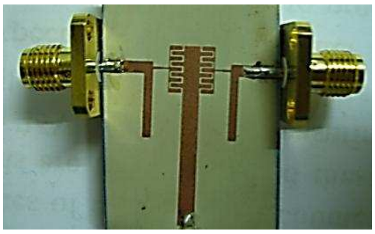


Figure (3): Layout simulation of the 900MHz bandpass filter.



(a)



(b)

Figure (4): (a) Layout mask (b) Photograph of the fabricated 900MHz filter.

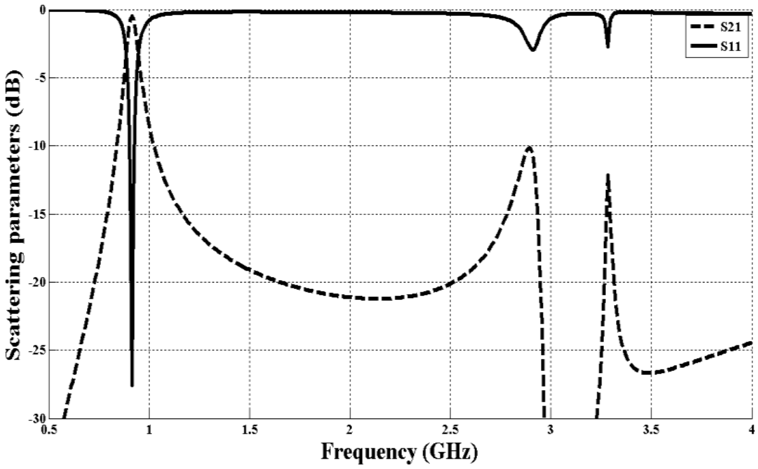


Figure (5): Layout simulation after adding the stepped impedance lowpass filter.

IV Ultra Wideband Bandpass Filter Using CRLH Metamaterial Cell

In this section the design of UWB bandpass filter which is based on the metamaterial Composite Right and Left Handed Transmission-line (CRLH-TL) is proposed. The goals that are put on the design beside size and harmonic suppression goals are to achieve a fractional bandwidth more than 100% with lower insertion loss, and flat group-delay with an acceptable in-band return loss performance. We make the specifications of the UWB bandpass filter is equal to the FCC mask values (frequency band from 3.1GHz to 10.6GHz with center frequency = 6.85). The values of the capacitances and inductances required can be calculated from these specifications. Following the design steps described before, the proposed circuit elements are identified to be:

$$C_L = 1.619\text{pF},\ L_R = 0.4763\text{nH},\ L_L = 4.454\text{nH},\ C_R = 0.1731\text{pF}$$

The next step is to determine the geometric parameters of the interdigital capacitor and the short circuited stub to achieve these design goals. Via iterative steps and using equations (1-a, b, c, d, e) the final cell dimensions are shown in table (2). We use step in width impedances to improve the filter out of band performance. Transmission line lengths and widths of the steped impedances are $L_1 = 1.5, L_2 = 2.5, W_1 = 1.52, W_2 = 1.72$.

Variables	Second designed values
Unit cell period (p)	3.254mm
Stub length (ℓ_{stub})	9.8mm
Stub width (w_{stub})	1.00mm
Interdigital finger length(ℓ_{IDC})	2mm
Interdigital finger width(w_{IDC})	0.1mm
Spacing between fingers	0.12mm
Via radius	0.12mm
Number of fingers n	16

Table (2): UWB metamterial filter cell dimensions.

V- The Experimental Results

Based on physically realizable cell dimensions given in table (1), table (2) and stated above, the filters have been fabricated on Rogers R6010 substrate with ε_r = 10.2, substrate height h = 0.05", loss tangent = 0.001, and conductor used is copper. The layout mask and the photograph of the UWB fabricated filter are shown in figure (6).

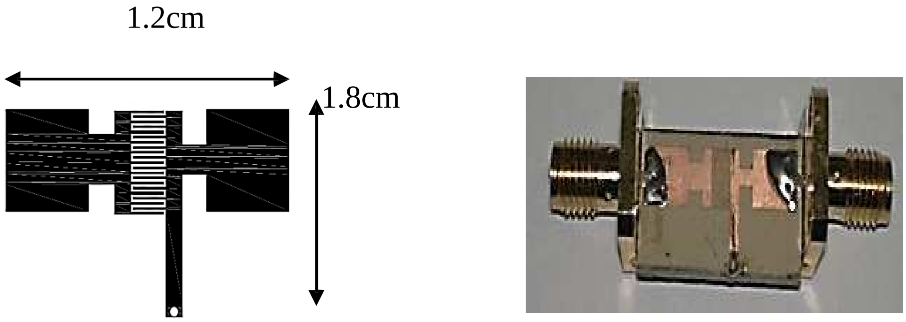


Figure (6): (a) Layout mask (b) Photograph of the fabricated UWB filter.

The comparisons between the simulated and measured results for the 900MHz filter are shown in figures (7, 8), and that for the UWB filter are shown in figure (9, 10). From the comparison there is a little frequency shift between the measured results and the simulated results. Also the in-band insertion and return loss are different from each other. It is shown that the insertion loss increased in the measured result than the simulated result and the return loss decreased in the measured result than the simulated result. Also the stopband performance of the measured results is different than the simulated results. These small different in results comes from losses of the two SMA connectors and the human tolerance in fabrication.

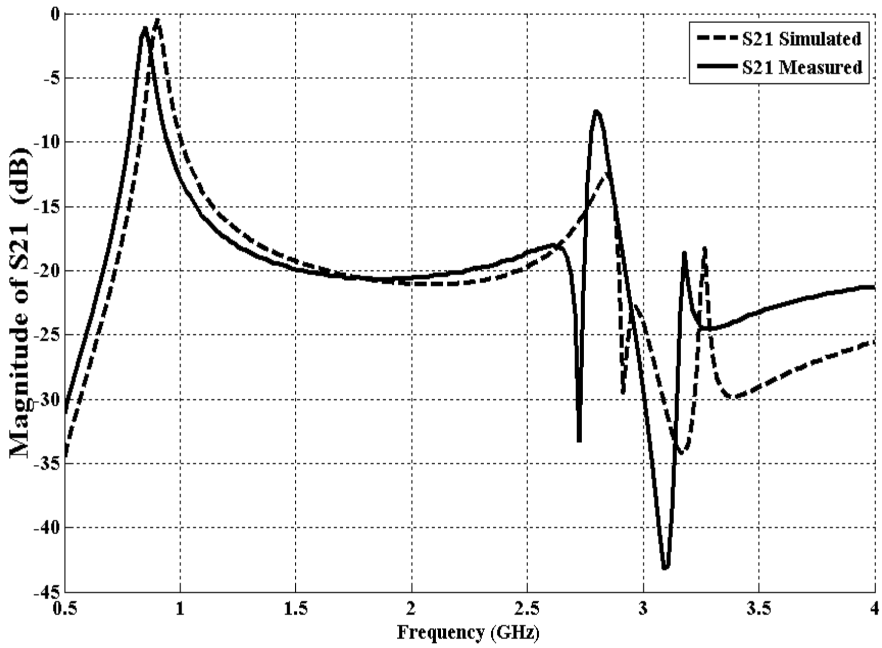


Figure (7): Insertion loss comparison of the measured and simulated results for the (900MHz) filter.

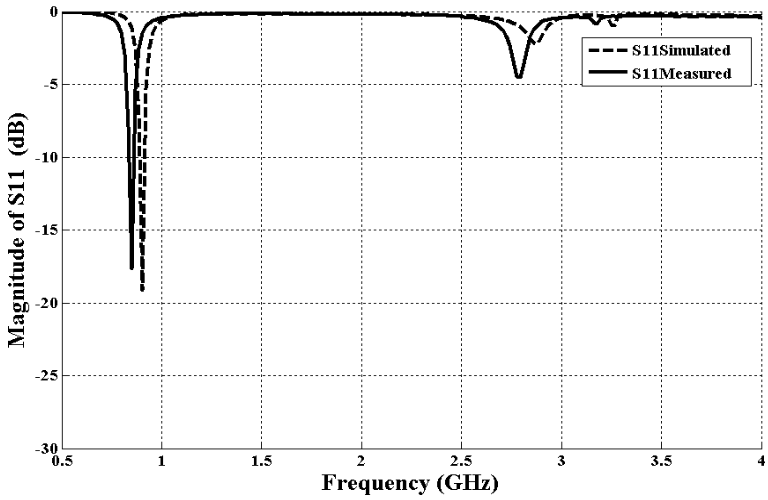


Figure (8): Return loss comparison of the measured and simulated results for the (900MHz) filter.

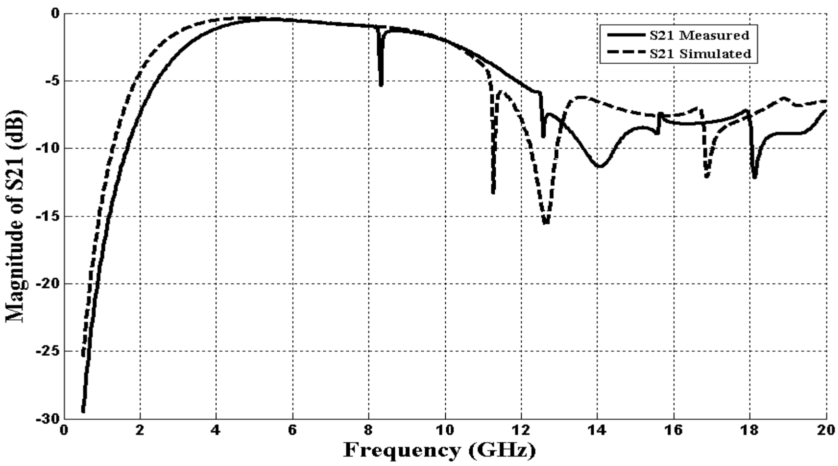


Figure (9): Insertion loss comparison of the measured and simulated results for the UWB filter.

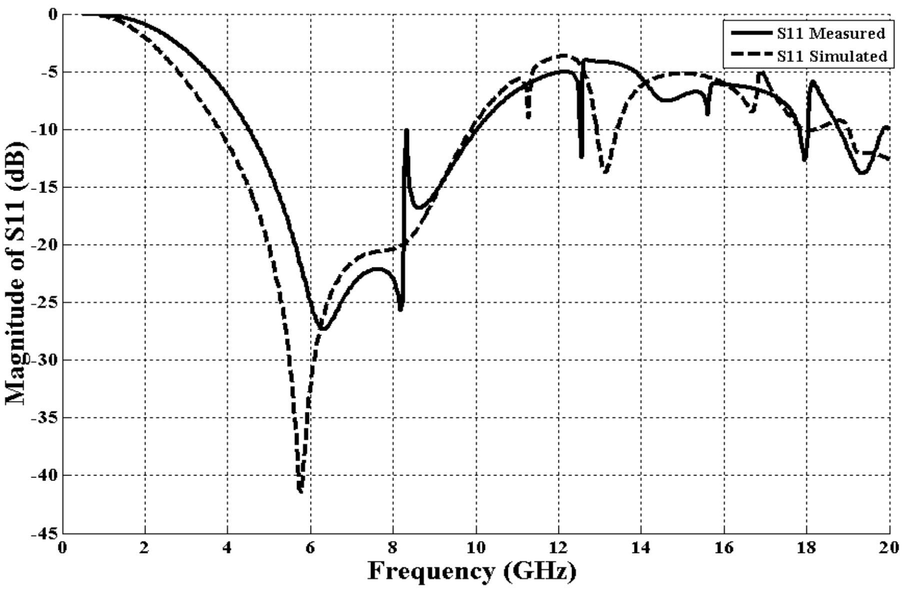


Figure (10): Return loss comparison of the measured and simulated results for the UWB filter.

V-Conclusion

This paper presents a design methodology for designing metamaterial filters based on the composite right left handed (CRLH) Transmission line CL-loaded approach. It has been shown theoretically and experimentally that the proposed methodology is able to realize narrowband as well as UWB filters. The novelty in the design is that we use step in width impedances to improve the stopband performance instead of increasing the number of cells. So, the size of filters produced is very compact. From these results we can confirm the method of design, and it was shown that the simulated and measured results are in good agreement.

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