A Direct Synthesis Method for UWB Bandpass Filters Based on Metamaterial Transmission lines

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Abstract

Direct synthesis method for designing metamaterial transmission line based bandpass filter (BPF) is presented. As a start, an ultra-wideband (UWB) filter is designed as a symmetric network implemented in low temperature co-fired ceramics (LTCC) technology. The proposed synthesis method was applied to a design of BPF with additional transmission zero based on composite right/left-handed (CRLH) transmission lines. The proposed synthesis method dramatically simplifies the design process of the UWB BPF with transmission zero. A home-made software is also developed and used to obtain the final circuit model parameters. The design was verified by the full-wave simulation and measurement of the multilayer structure performance. The proposed filter exhibited low insertion loss, sharp rejection, and compact size.

1. Introduction

Recently, the interest in designing ultra-wideband (UWB) bandpass filters (BPF) has been increased [1]. For UWB application, it is usually required that the filters are of compact size, demonstrate a low insertion loss and a high selectivity. To meet these requirements, the works listed in [1] are all based on conventional design method. In this paper, a new design approach of UWB filter, based on metamaterial transmission line, has been proposed and investigated. To start with, a wideband filter using artificial transmission line with symmetric structure is presented in Section 2. Then a direct synthesis method is detailed in Section 3 and used to design a UWB BPF with additional transmission zero.

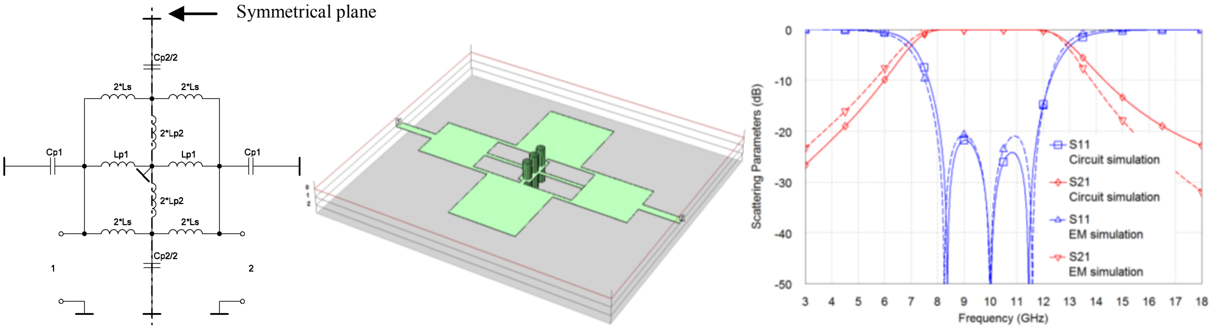
2. Wideband filter using symmetric network

An attempt to implement a UWB BPF using a symmetrical structure was made in [2], where the BPF was designed as a symmetric network with a single stub and compact microstrip resonant cell [3]. In this paper we suggest to use an artificial transmission line with symmetric structure to design a wideband BPF.

A new symmetric network (Fig. 1 (a)), is adopted for designing a wideband filter with central frequency f_0=9.4 GHz and 65% fractional bandwidth. This network can be synthesized by the following steps [4]: 1) conventional synthesis using Chebyshev filter prototype; 2) synthesis of the

ISBN 978-952-67611-2-1

BPF using parallel tanks and inductive inverters giving the conventional circuit; 3) the structure from step 2) is transformed into symmetric network in Fig. 1 (a). Then it could be seen that the capacitance C_{p2} can be decreased by 50%, with the cost that the inductances L_s and L_{p2} are doubled, which, is easy to implement in LTCC package. The filter is designed using multilayer stripline structure (Fig. 1 (b)). Four layers of DuPont Green Tape™ 951 with each layer thickness of 216 um, ε_r=7.8 and tan(δ)=0.0015 are used. The overall size of the filter is 7×7 mm^2, which is $0.6\lambda_g \times 0.6\lambda_g$. Results of full wave simulation using Sonnet software are shown in Fig. 1 (c) together with circuit simulation.



(a) (b) (c)

Fig. 1: (a) Symmetric filter prototype (C_{p1}=0.677 pF, C_{p2}=2.320 pF, L_{p1}=1.165 nH, L_{p2}=0.164 nH, and L_s=0.5 nH). (b) LTCC structure of the filter (area of the structure is 7×7 mm^2). (c) Simulated responses.

3. Direct synthesis of UWB filter using composite right/left-handed transmission line

Traditional composite right/left-handed transmission line (CRLH-TL) [5] is another artificial metamaterial structure which can be used for UWB filter design (Fig. 2 (a)). Due to the highpass nature of left-handed (LH) elements C_l and L_l and the lowpass nature of the right-handed (RH) elements C_r and L_r a bandpass response can be produced.

For a practical design of filters with various specifications, a direct synthesis method, was derived. With highpass (LH) and lowpass (RH) elements, the synthesis starts with formulas (1), which are close approximations for the lower and higher cutoff frequencies, f_l and f_r, respectively. Then, based on the balanced CRLH transmission line conditions, formulas (2) should be used to set the series resonant frequency f_{se} and shunt resonant frequency f_{sh} , which are equal to the central frequency f_0. Based on these, the values of the LH and RH elements can be found and this provides a UWB bandpass response as shown in Fig. 2 (b) in dashed lines.

The filter response can be improved by introducing additional transmission zero at the upper stopband by using a coupling capacitor C_0. The synthesis can be continued by calculating S parameters of the two port network. By presetting the location of the transmission zero, all the elements values can be found. To get an optimal response, a quick optimization is performed by using recently developed software. All element values are listed in Fig. 2 (a). The circuit simulation results are shown in Fig. 2 (b). Only six elements and a capacitive coupling are used for the filter design.

$$f_l = \frac{1}{2\pi\sqrt{L_l C_l}}, f_r = \frac{1}{2\pi\sqrt{L_r C_r}}, \tag{1}$$

$$f_{se} = f_{sh} = f_0, f_{se} = \frac{1}{2\pi\sqrt{L_r C_l}}, f_{sh} = \frac{1}{2\pi\sqrt{L_l C_r}}. \tag{2}$$

The filter was fabricated using a liquid crystalline polymer (LCP) technology. Multilayer structure of the filter consists of 5 layers of Rogers ULTRALAM® 3000 series (ε_r=3, tan(δ)=0.0025), as shown in

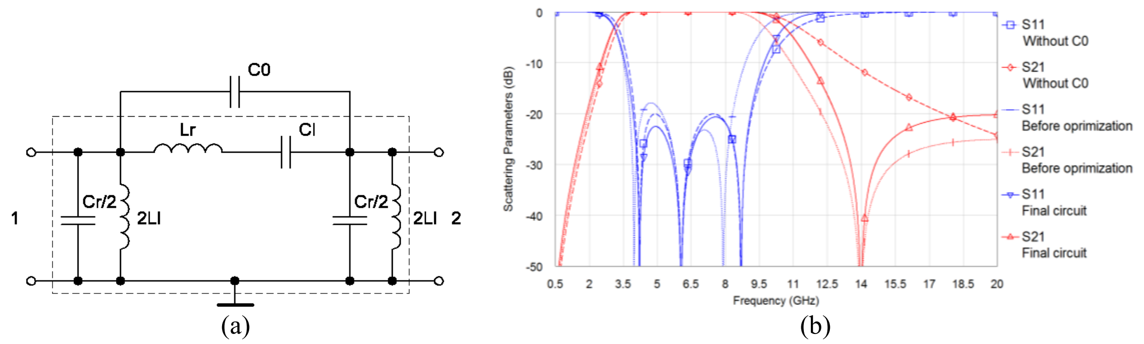


Fig. 2: (a) UWB BPF based on CRLH-TL. (b) Simulated responses: without coupling (dashed lines), with coupling before optimization (dotted lines), and after optimization (solid lines) (C_r=0.845 pF, L_r=1.430 nH, C_l=0.4 pF, L_l=0.720 nH, and C_0=0.117 pF).

Fig. 3 (a). The overall size of the BPF is 13×9.5 mm^2 corresponding to $0.4\lambda_g \times 0.3\lambda_g$. The photograph of the fabricated filter is shown in Fig. 3 (b). Good agreement between the measured, EM simulated, and circuit model results was obtained and demonstrated in Fig. 3 (c).

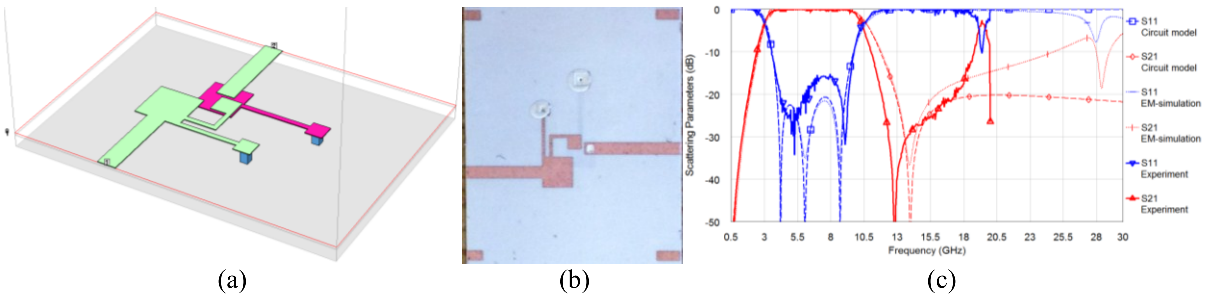


Fig. 3: (a) LCP structure of the filter (5 layers of Rogers ULTRALAM® 3000: bottom 1 – core ULTRALAM® 3850 d=100 um, 2 and 4 layers – prepreg ULTRALAM® 3908 d=50 um, 3 layer and top 5 – core ULTRALAM® 3850 d=50 um). (b) The photograph of the fabricated UWB filter. (c) Responses: circuit model (dashed lines), EM-simulation (dotted lines), and measurement (solid lines).

4. Conclusion

The UWB filter design based on metamaterial transmission lines is suggested and investigated. A new direct synthesis method for BPF using CRLH transmission lines is developed. The synthesized filter exhibits a high selectivity with additional transmission zeros. The experimental filter exhibited low insertion loss, high selectivity, and compact size.

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