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A MINIATURIZED UWB BPF BASED ON NOVEL SCRLH TRANSMISSION LINE STRUCTURE

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Abstract—A miniaturized ultra-wideband (UWB) bandpass filter (BPF) with U-slot etched around the metallic via in the ground is proposed based on a simplified composite right/left-handed transmission line (SCRLH TL) structure. The U-slot etched in the ground makes it feasible to reduce the overall size. A demonstration of FCC standard UWB bandpass filter (BPF) is designed, fabricated and measured. Very good agreement is shown between measurement and simulation.

1. INTRODUCTION

The UWB system has received much attention both in academic and industrial fields since it was approved for civilian use in 2002 by the U.S. Federal Communications Commission (FCC). UWB filter as an important component in the UWB system has been realized in many ways [1, 2].

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During the past decade, metamaterials with simultaneously negative permittivity (ε) and permeability (μ) have received substantial attention in the scientific and engineering communities for their unique electromagnetic properties. In 2002, Caloz, Itoh and Eleftheriades developed the transmission line theory for metamaterials, respectively [3]. As early as 2004, Sanada et al. proposed a general composite right/left-handed (CRLH) TL structure [4], which led to a suite of novel guided-wave, radiated-wave and refracted-wave devices and structures. Since then, a variety of microwave devices based on CRLH TL are presented [5, 6]. Recently, a simplified CRLH TL with no equilibrium condition is introduced by Lin et al. [7], in which, both the size and the structure complexity are reduced by taking away the series capacitor or shunt inductor. The SCRLH Mushroom structure without interdigital finger which causes parasitical high-order mode has been presented in [8]. However, the shunt inductance value is determined by the size of the metallic via which depends on the thickness of the substrate and the fabricating precision, and tunable limitation narrows its applications in microwave systems.

In this paper, a novel SCRLH structure by etching U-slot in a ground plane of mushroom structure is proposed to further reduce filter size. The U-slot is designed to increase shunt inductor (shown in Fig. 2(b)). Compared with the conventional SCRLH TL structure (shown in Fig. 2(a)), the shunt inductance value in the proposed SCRLH TL structure is not only determined by the size of the metallic via but also determined by the size of the stub connecting the metallic via to the ground. And the shunt inductance becomes much greater than the conventional structure. Therefore, without expanding the structure size, the passband of the proposed structure can move towards to the lower region, and the new SCRLH structure miniaturization can be achieved. The actual size of structure is adjusted to the desired UWB passband. By cascading multiple units, the UWB BPF can realize satisfactory rejection skirts. Finally, UWB bandpass filter with 3-dB passband frequency from 3.1 GHz to

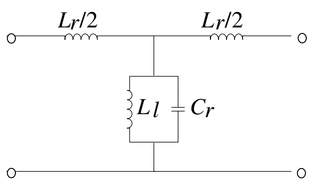

Figure 1. Equivalent circuit of the proposed structure.

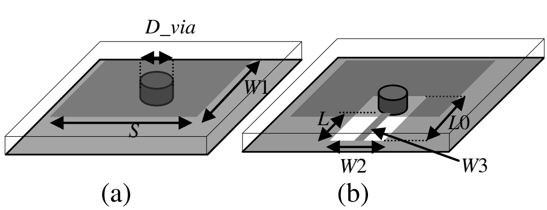

Figure 2. Geometries dimension, (a) the conventional SCRLH structure, (b) the proposed SCRLH structure.

10.6 GHz is fabricated and very good agreement is achieved between measurement and simulation.

2. THEORY AND DESIGN METHOD

2.1. Theory

Compared with CRLH, the SCRLH TL structure is more convenient to design microwave devices because it needn't equilibrium condition. The design of the UWB BPF is based on the SCRLH TL by removing the series capacitance in the general CRLH TL model. The equivalent circuit of unit cell of the proposed SCRLH TL structure is shown in Fig. 1, in which L_r is the series inductor, L_l is the shunt inductor and C_r is the shunt capacitor. According to the Bloch-Floquet theory, the dispersion relation and characteristic impedance can be obtained as [9]

$$\beta(\omega)\, d = \cos^{-1}\left(1 + \frac{ZY}{2}\right) \tag{1}$$

$$ZB = \frac{\sqrt{(ZY/2)^2 + ZY}}{Y} \tag{2}$$

where β is propagation constant for Bloch waves ZB is the characteristic impedance and d is the length of the unit cell of the SCRLH TL structure. The series impedance and shunt admittance are given by

$$Z(\omega) = j\omega L_r \tag{3}$$

$$Y(\omega) = \frac{1 - \omega^2 C_r L_l}{j\omega L_l} \tag{4}$$

When β is a real number and the passband impedance matching is achieved, the electromagnetic wave can propagate through the transmission line [10]. So it need to meet $-4 \le ZY \le 0$. The resulting equation is

$$\sqrt{\frac{1}{L_l C_r}} < \omega < \sqrt{\frac{1}{C_r L_l} + \frac{4}{L_r C_r}} \tag{5}$$

It is obvious that the lower cutoff frequency is determined by C_r and L_l whereas the upper cutoff frequency is determined by C_r, L_l, and L_r. When L_l is much larger than L_r, the passband can be simplified as

$$\sqrt{\frac{1}{L_l C_r}} < \omega < \sqrt{\frac{4}{L_r C_r}} \tag{6}$$

From (6), it's easy to find that the lower cutoff frequency can be adjusted independently by changing the value of L_l.

2.2. Design Method

The conventional SCRLH structure is shown in Fig. 2(a) [8], and the proposed structure is shown in Fig. 2(b). In the conventional SCRLH structure, the shunt inductance value is only determined by metallic via. And, in the proposed structure, by etching U-slot around the metallic via connecting the patch to the ground, the shunt inductance is not only determined by the size of the metallic via but also determined by the size of the stub connecting the metallic via to the ground. Compared with the conventional structure, the shunt inductance of the proposed structure becomes much greater. From (5), we know that the passband will move towards to the lower region by increasing L_l. Therefore, the structure can be of compact size. Fig. 3 shows the transmission coefficient S_{21} of the conventional and proposed SCRLH TL under the same size. Compared with the conventional structure, the passband of the proposed structure moves towards to the lower region by introducing U-slot. And the new SCRLH structure miniaturization can be achieved.

A UWB filter has been designed based on this SCRLH TL structure, L_r and C_r are the parasitical inductance and capacitance of the microstrip transmission line. L_l is realized by metallic via and the stub connecting metallic via hole to ground. The resultant dimensions of the novel SCRLH structure are given below: the length of unit cell structure $S = 7.5\,\text{mm}$ the width of the structure $W_1 = 3.8\,\text{mm}$ the outer width and length of the U-slot $W_2 = 2.4\,\text{mm}$ $L_0 = 3.8\,\text{mm}$ the length and width of the stub connecting the metallic via to the ground $L = 1.85\,\text{mm}$, $W_3 = 0.1\,\text{mm}$. The diameter of the metallic via $D\_via = 1.5\,\text{mm}$. From Fig. 4, we can find the performance of

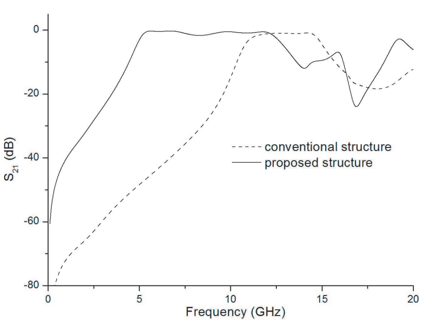

Figure 3. Transmission coefficient S_{21} of the conventional and proposed SCRLH TL.

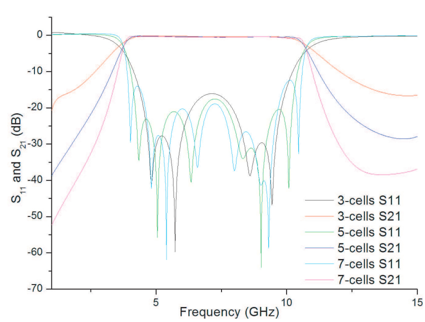

Figure 4. Simulated results of the proposed UWB filters with different number of unit cells.

rejection skirts gets better as the unit cells become larger. So that we can choose a suitable number of unit cell to adjust to the design standards. Finally, the 5-unit-cell structure is shown in Fig. 5. A feed line is designed to match the impedance of the input and output ($50\,\Omega$). The width and length of the feed line are $W = 1.5\,\text{mm}$, $L_1 = 4.75\,\text{mm}$, respectively.

When the L_l is much larger than the L_r, the upper cutoff frequency will not be influenced by the L_l, so L_l can be adjusted to proper lower cutoff frequency. Fig. 6 shows that when W_3 (related to L_l) decreases, the lower cutoff frequency increases. The simulated results have confirmed the design formula. Finally, the UWB BPF is designed and fabricated, and the photograph is shown in Fig. 7.

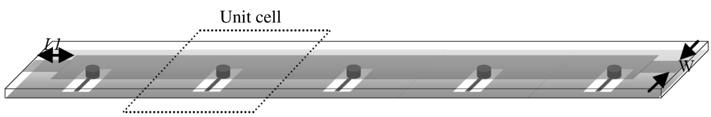

Figure 5. Geometry of the UWB filter with 5-unit-cell.

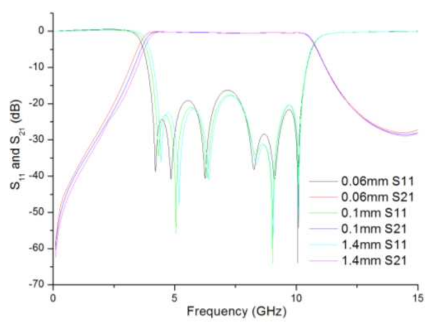

Figure 6. Simulated results of the proposed UWB filters with different W_3.

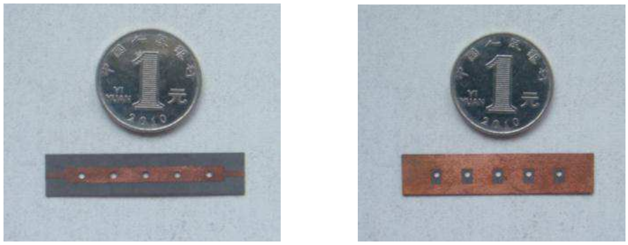

Figure 7. Photograph of the fabricated UWB filter.

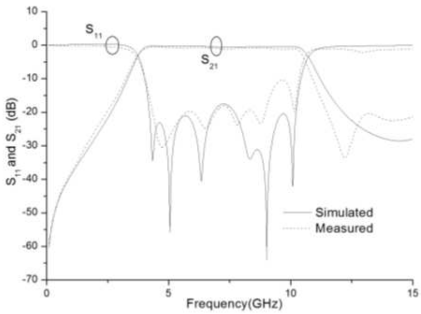

Figure 8. Simulated results and the measured results of the UWB microstrip filter.

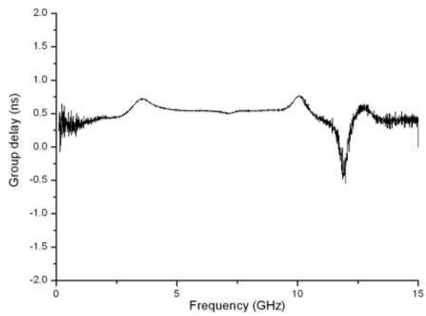

Figure 9. Group delay of the UWB bandpass filter.

3. SIMULATED AND MEASURED RESULTS

All the simulated results in the paper are obtained by the full-wave simulation using Ansoft HFSS. The substrate used in the filter is RT/Duroid 5880, which has relative permittivity of 2.2, height of 0.508 mm. The simulated and measured results of the filter are plotted in Fig. 8 and they agree very well. It is designed with bandwidth of 110% (3.1 GHz–10.6 GHz), the insertion loss of about 0.5 dB, and the return loss of about 18 dB.

For wideband application, the investigation of the flat Group delay is important and required. The measured group delay for the BPF is shown in Fig. 9. The group delay varies between 0.53 and 0.7 ns with a maximum variation of 0.17 ns over its whole passband.

4. CONCLUSION

In this paper, the UWB bandpass filter based on SCRLH TL has been designed and successfully tested. It is very suitable for application in low cost and compact size microwave planar circuits by mature PCB technology. The geometries dimension and the equivalent circuit of the novel SCRLH TL is presented. The BPF has an excellent performance of low insert loss and miniaturization characteristics, which may have further applications in microwave systems.

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