An Ultra-Wideband (UWB) Bandpass Filter with Multiple-Notched Band using Embedded Fold-Slot Structure

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Abstract

This study, an ultra-wideband (UWB) bandpass filter based on embedded fold-slot structure and slotted step impedance resonator (SSIR) is presented. The proposed filter has multiple-notched in the passband, resulting from the embedded fold-slot structure. The center frequencies and bandwidths of the notched bands can be controlled by adjusting dimensions of the embedded fold-slot structure. The wider upper stopbands caused by slotted resonator characteristics have been also obtained. The simulated and experimental results show multiple-notched band at 5.9 GHz, 7.5 GHz, 9.4 GHz and 11 GHz, respectively. High stopband performances with better than 20 dB for a frequency range up to 18 GHz and sharpened rejection skirts have also been obtained.

Keywords: UWB bandpass filter, embedded structure, slotted step impedance resonator, multiple-notched band.

1. Introduction

The Ultra-wideband (UWB) frequency between 3.1 to 10.6 GHz for a variety of applications for commercial wireless communication system has been authorized by the U.S. Federal Communications Commission (FCC) since 2002⁽¹⁾. The UWB system has become one of the most promising technologies for short-range low-power indoor wireless communications. UWB bandpass filters as one of the essential components of UWB systems, have gained much attention in recent years. The various techniques have been recently developed for UWB bandpass filters. Stepped impedance resonators with multi-mode resonators (MMRs) were used for UWB bandpass filters consisting of a low

impedance line in the center, high impedance parallel lines at both ends, resulting in size reduction and improved stopband performance⁽²⁾. The interdigital coupled lines were formed to assign their transmission zero towards the fourth-order resonant frequency of the MMRs⁽³⁻⁴⁾. Most of these UWB bandpass filters have superior performance and are suitable for implementation. Moreover, covering wide frequency, the UWB systems can be interfered by the existing undesired radio signals, such as wireless local-area network, WiMAX and RFID. In order to avoid interferences from the undesired signals, UWB bandpass filters with multiple-notched band have been required.

The UWB bandpass filters with notched bands using different methods have been proposed to reject these signals, such as adding stubs to the arms of interdigital coupled line⁽⁵⁾, using embedded structures in the feed line⁽⁶⁾, and adding a parasitic coupled line which resulted in a narrow notch band as proposed in⁽⁷⁾. The UWB bandpass filter with compact size band has been designed by using embedded step-impedance resonator⁽⁸⁾. Many researches proposed multiple-notched bands with defected ground structures⁽⁹⁾, using parallel U-shaped defected microstrip⁽¹⁰⁾ and stub loaded resonator⁽¹¹⁾.

This paper proposes an UWB bandpass filter with multiple-notched band and improved stopband performance. It consists of two slotted step impedance resonators driven by interdigital coupled lines at both ends of the resonator to improve the stopband performances. Also, it has embedded fold-slot structure at the input, output feed lines and resonator, which can create multiple-notched bands. In section 2, the UWB bandpass filter will be designed and optimized. The experimental verification and measured results of the proposed UWB bandpass

filter will be described in details in section 3. Finally, our conclusions will be given in section 4.

2. Filter Design and Optimization

The configuration of the proposed UWB bandpass filter is shown in Fig.1. The UWB bandpass filter using multiple-mode resonator (MMR) and interdigital coupled line for enhancing coupling degree has been studied in the literature (2). It has been widely used as a capacitive coupling with two $50\ \Omega$ feed lines in the UWB bandpass filters. However, it must be redesigned to achieve design-specified coupling factor between two adjacent line resonators. To achieve a tight coupling degree, the strip and slot widths must be reduced. It therefore design and optimize the interdigital coupled line on the RT/Duroid 3003 substrate with a dielectric constant of 3.0, a thickness of 1.524 mm, and a loss tangent of 0.0013. By using IE3D program(13), it results to $l_2 = 6.45$ mm, $w_2 = 0.5$ mm, and $g_1 = 0.2$ mm, as shown in Fig.1. It has been found that this new coupled line has better superior passband characteristics than conventional one.

The conventional UWB bandpass filter⁽³⁾, using $\lambda g/2$ microstrip resonator, has inherently spurious resonant frequencies at $2f_o$ and $3f_o$, where f_o is the fundamental frequency(6.7 GHz), which may be too close to the desired passband. MMR is formed by attaching slotted resonators in the middle of step impedance resonator for extending stopband in the upper frequency to be larger than 10 dB over 12 GHz to 18 GHz. Thus, microstrip SSIRs have been proposed as shown in⁽⁴⁾ for higher stopband performances.

The IE3D program has been used to determine the filter performances. The optimized dimensions of the slotted resonators and the interdigital coupled lines have been obtained in the previous work⁽⁴⁾ including $l_2 = 6.45$ mm, $l_3 = 5.4$ mm, $l_4 = 11.0$ mm, $w_1 = 4.0$ mm, $w_2 = 0.5$ mm, $w_3 = 5.5$ mm and $w_4 = 6.0$ mm. Also, the optimized dimensions of the embedded fold-slot at the feed line and resonator for 5.9 GHz, 7.5 GHz, 9.4 GHz and 11 GHz with multiple-notched bands have been obtained to be $l_1 = 10.0$ mm, $l_5 = 2.12$ mm,

Fig. 1. The proposed filter with multiple-notched bands.

(a)

(b)

(c)

Fig. 2 The embedded structures (a) input feed (b) output feed and (c) resonator

$l_6 = 1.47$ mm, $l_7 = 5.94$ mm, $l_8 = 1.53$ mm, $l_9 = 3.82$ mm, $l_{10} = 4.44$ mm, $l_{11} = 3.19$ mm, $l_{12} = 6.5$ mm $w_5 = 0.6$ mm, $w_6 = 2.1$ mm, $w_7 = 0.52$ mm $w_8 = 1.7$ mm and $g_1 = 0.2$ mm. These all parameters are in Fig.1 and Fig.2.

Fig.3 (a) shows the part of embedded slot feed and its frequency responses of S_{21} when varying the length L of the embedded slot from 5 to 10 mm. It can be found that a center frequency of notched frequency can be adjusted from 9 GHz down to 5 GHz. When increasing the width W of the embedded slot while keeping the center frequency to be the same, the bandwidth of notched band is increased as shown in Fig.3 (b). The embedded slot structure derives from varying the width W of the embedded slot from 0.6 to 1.6 mm and varying the length L of the embedded slot from 8.593 to 8.393 mm. It can be clearly seen that, at 3 dB, bandwidth of the notched band is increased. Therefore, by

Fig. 3 S_{21} magnitude responses of the embedded slot structure with a slot of 0.2 mm When (a) varying L (b) varying W .

tuning the length and width of the embedded slot, center frequencies and bandwidth of notched band can be easily adjusted. Embedded slot is thus suitable for use in the UWB bandpass filter when a notched band is required.

To study the notched bands, the simulated current distributions of embedded structure at resonant notched frequency of 5.9 GHz, 7.5 GHz, 9.4 GHz and 11 GHz are shown in Fig.4. It is observed that the current distribution cannot pass through the proposed structure.

Fig. 4 Current distributions of notch bands at (a) 5.9 GHz (b) 7.5 GHz (c) 9.4 GHz and (d) 11.0 GHz.

3. Experimental and Measured Results

The proposed UWB bandpass filter is implementation on the RT/Duroid 3003 substrate. Fig.5 shows the photograph of the fabricated filter for multiple-notched band. Fig.6 shows a comparison of measured and simulated responses of the filter with multiple-notched band. It can be found that the measured results agree with the simulation expectations, confirming that the proposed filter is capable of generating multiple-notched band, having good insertion

losses within the passband and also widening the upper stopband. The measured return and insertion losses are found to be lower than 10 dB and higher than 3 dB, respectively over desired UWB passband. The notched frequencies of about 5.9 GHz, 7.5 GHz, 9.4 GHz and 11 GHz have a bandwidth of about 400 MHz, 320 MHz, 480 MHz and 700 MHz, respectively. The proposed filter shows multiple-notched band and improved upper stopband performances with high insertion loss. The upper stopband with the insertion loss lower than 20 dB occupies an enlarged range of 14 to 18 GHz. The group delay of filter slightly varies between 0.2 to 0.3 ns in the passband. Moreover, the proposed filter exhibits notched bands and a wide upper stopband with values of S_{21} lower than 35 dB at 14 GHz, 15 GHz and 17.5 GHz, respectively. These superior stopband performances are caused by the stopband characteristics and sharpened rejection skirts outside the passband.

Fig. 5 Photograph of fabricated UWB filter for multiple-notched bands

Fig. 6 Comparison of measured and simulated responses of the UWB filter with multiple-notched bands.

4. Conclusions

In this paper, an UWB bandpass filter with improved upper stopband performances and created multiple-notched band have been presented and implemented. By properly forming SSIR together with two interdigital coupled lines at both ends and embedded fold-slot at feed line and resonator, the UWB bandpass filter is constructed and its performances are extensively investigated in simulation and measurement. The proposed filter demonstrates its capabilities in generating multiple-notched band with the embedded fold-slot structure and suppressing spurious responses with slotted resonator. Also, it can widen the upper stopbands and sharpen rejection skirts outside the passband.

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