UWB Bandpass Filter with Improved Rejection Band Performance Using Defected Ground Structure and Slotted Step Impedance Resonator

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***Abstract*—This paper presents an ultra-wideband (UWB) bandpass filter with high performances for sharp rejection bands and wide stopband. The filter is designed with the combination of defected ground structure (DGS) and slotted step impedance resonator (SSIR). Two transmission zeros for controlling the stop band can be generated designing with the defected ground structure utilized as a stop band resonator. Also its structure can be designed for improving the sharp rejection band. The wider upper stopbands caused by slotted resonator characteristics have also been obtained. The simulated and experimented results exhibited in good agreement and high sharpened rejection stopbands shown at 2.90 GHz and 11.50 GHz. High stopband performances are better than 15 dB in the frequency range up to 18 GHz.**

I. INTRODUCTION

Ultra-wideband (UWB) technology has been interested and begun in use since 2002 [1]. This is due to the majority of large bandwidth requirement which is an importance dealing with increasing channel capacity preparing for the next generation of communication in the future. The advantages of UWB system can be applicable with short-rang low-power indoor wireless communications. UWB bandpass filters is a one of the components in UWB systems utilizing for selecting a large frequency passband bandwidth between 3.1 GHz and 10.6 GHz that has compact size, low insertion loss, widened upper-stopband, sharp rejection bands and easily-implemented structures. There have been the various techniques in available development for UWB bandpass filters presented in [2]-[7]. The multi-mode resonators (MMRs) integrated with UWB bandpass filters were initially proposed in [2] The MMR characteristics consist of a low impedance line in the center, high impedance parallel lines at both ends, that can be used to reduce size and improve stopband performance of UWB filters. In [3]-[4], the interdigital coupled lines with MMRs have been designed for generating their transmission zero level in the stop band for the fourth-order resonant frequency. The stub-loaded MMR and an electromagnetic bandgap (EBG) MMR were presented to design UWB filters in order to improve the stopband performance of UWB filters [5]-[7]. Those proposed UWB filter design techniques have been mentioned for reducing the resonator size, improving high stop band level at the fourth order resonant frequency, but they did not show the performance for a stop band frequency under frequency range than 3 GHz. The UWB bandpass filters with improved rejection bands by using many methods have been proposed such as using stepped-impedance stub-loaded resonator which can be generated two transmission zeros at both lower and upper side of the passband [8]. Many researches have proposed sharp rejection bands with stepped-impedance stub-loaded resonator [9]-[10]. However, a large size in vertical direction of the loaded open stubs is still occurred after designed. In [11], the use of high-temperature superconducting (HTS) materials has been implemented with the UWB bandpass filter in order to improve sharp rejection bands and miniature the realized filter size , but the fabrication process was very complicated and hardly for realizing the filter.

In this paper, an UWB bandpass filter with improved stopband performance is presented. Also, the defected ground structure is designed and fabricated at the bottom layer, which can be designed to improve sharp rejection bands. In section II, the UWB bandpass filter will be presented in the design and optimize procedures. The simulated and measured results of the proposed UWB bandpass filter will be described in details for section III. Finally, the conclusions will be discussed in section IV.

II. UWB BANDPASS FILTER DESIGN

Fig.1 shows all the designed structure of the proposed UWB bandpass filter and its equivalent filter circuit. A defected ground structure designed at the bottom layer shown in Fig.2 is used as a bandstop filter circuit that can improve the rejection band performance of this filter. The designed structure of UWB bandpass filter here consists of a half-wavelength slotted low-impedance line section at the middle, two identical quarter-wavelength high-impedance line sections are between two sides and two defected ground designed at the bottom layer.

A. Interdigital Coupled Line

Fig.3 (a) shows a conventional interdigital coupled line presented in [5]. Its equivalent circuit can be represented as a capacitive coupling element for designing in multi-stage bandpass filters. The optimized structure of the interdigital coupled line with a specified coupling factor must be obtained in order to improve the filter performance. The design procedure can be successful by reducing in both its strips and slot widths for resulting in a tight coupling and lower insertion loss. However, it may cause of difficulties in the design and also fabrication processes due to its sensitivity to the strip/slot widths and conductor thickness/ configuration.

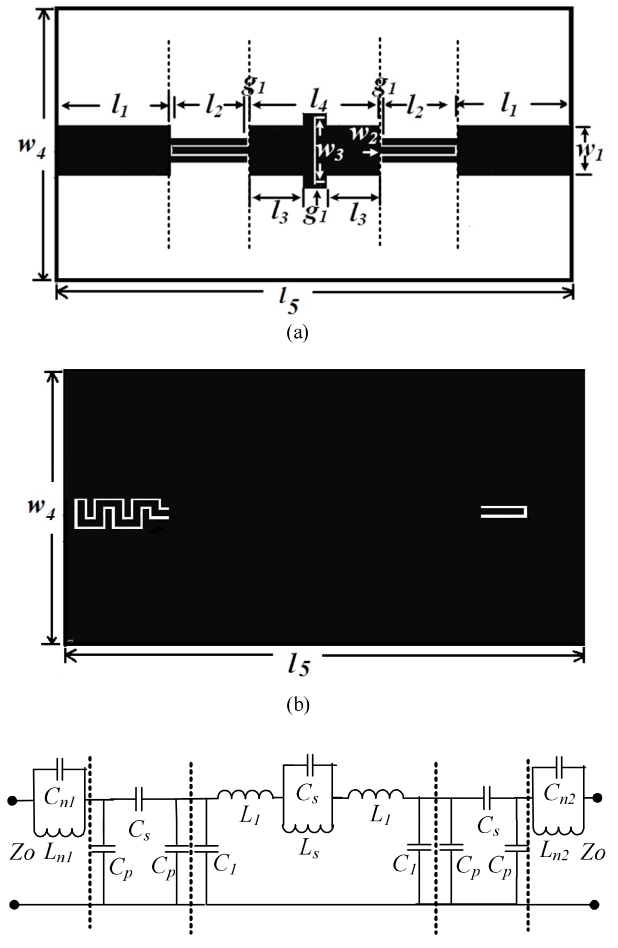
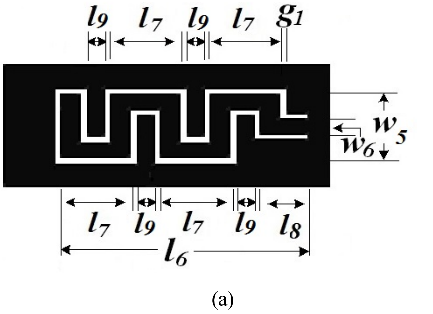


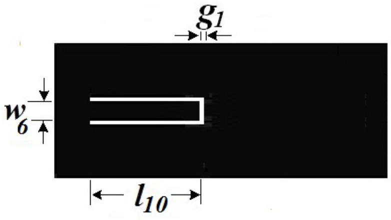
Fig. 1. The proposed filter for sharp rejection bands (a) top layer (b) bottom layer and (c) the equivalent transmission line network with $l_1 = 10.00$ mm, $l_2 = 6.45$ mm, $l_3 = 4.50$ mm, $l_4 = 11.00$ mm, $l_5 = 44.30$ mm, $w_1 = 4.00$ mm, $w_2 = 0.50$ mm, $w_3 = 6.10$ mm and $w_4 = 20.0$ mm



(a)

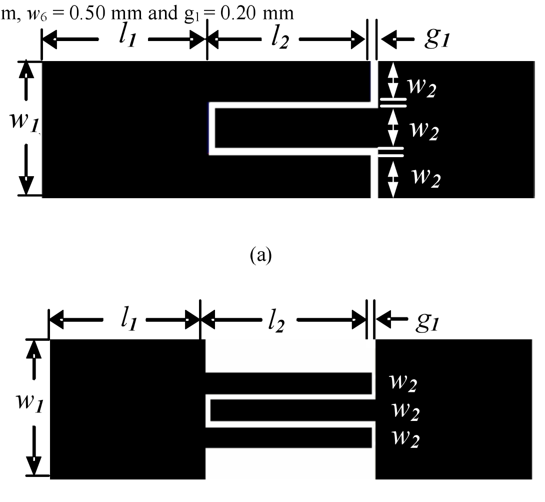
A method that is utilized for improving the UWB bandpass filter by inserting the MMR resonator with interdigital coupled line for enhanced coupling degree discussed in [2]. An interdigital coupled line is conventionally used as a capacitive coupling with the input/output 50 ohm feed lines in the UWB bandpass filters. Here we have redesigned the interdigital coupled line smaller than a conventional size for improving the strong input/output coupling in best passband transmission.

In this work, we have designed and optimized the interdigital coupled line structure on the top layer of RT/Duroid 3003 microstrip that has a dielectric constant of 3.0 and a thickness of 1.524 mm and a loss tangent of 0.0013. The completed dimensions of the interdigital coupled line are $l_2 = 6.45$ mm, $w_2 = 0.5$ mm, and $g_1 = 0.2$ mm, as shown in Fig.3 (b). The response curves for different coupled line width that are compared and shown in Fig.4. It has been found that this new coupled line show the better superior passband characteristics than conventional one.



(b)

Fig. 2 The defected ground structure (a) lower stopband (b) upper stopband with $l_6 = 7.25$ mm, $l_7 = 1.92$ mm, $l_8 = 1.37$ mm, $l_9 = 0.52$ mm, $l_{10} = 3.95$ mm, $w_5 = 3.30$ mm, $w_6 = 0.50$ mm and $g_1 = 0.20$ mm



(a)

(b)

Fig.3. Interdigital coupled lines (a) the conventional one and (b) the optimized one

Fig. 5 (a) shows a conventional structure of UWB bandpass filter. It consists of one half-wavelength resonators at the middle filter connected between two quarter-wavelength interdigital coupled lines before both ends of the input/output resonators. Fig. 5 (b) shows simulated magnitude responses of interdigital coupled lines and MMR under weak/strong coupling, respectively. The first three modes in the weak coupling case for different $l_2 = 0.1$, 2.0 and 4.0 mm, that are corresponded to occur the peak of three frequencies around 4, 7, and 9 GHz, respectively. As increases from 0.1 to 4.0 mm, the magnitude curve slightly rises. As largely increases to 6.45 mm that approximately equals to quarter-wavelength at 6.85

GHz, the whole magnitude realizes an almost flat frequency response nearly to 0-dB horizontal line over the desired UWB bandpass filter. In the meantime, the fifth mode is unwanted out off band frequency is located around 18 GHz need to suppressing undesired. The dimensions of the interdigital coupled lines and MMR have been obtained including l_1 = 10.00 mm, l_2 = 6.45 mm, l_3 = 11.00 mm, l_4 = 6.45 mm, l_5 = 44.30 mm, w_1 = 4.00 mm, w_2 = 0.50 mm and w_3 = 6.10 mm.

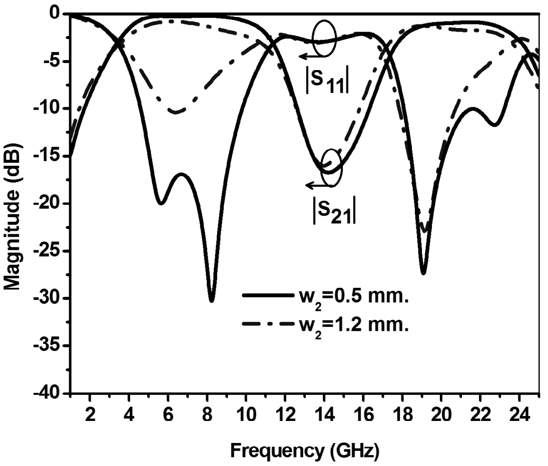
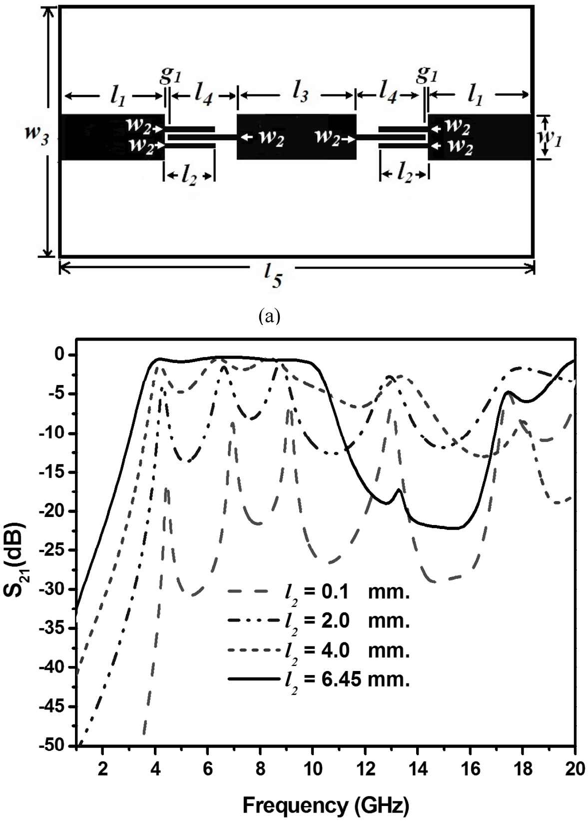


Fig.4 Responses of interdigital coupled lines with w_2 = 1.2 mm for the conventional one and w_2 = 0.5 mm for the optimized one

B. SSIR Characteristics

In the design, MMR is still required for improving the stop band performance, but it needs a further improvement of its size and very good suppression in the harmonic by attaching slotted resonators in the middle of slotted step impedance resonator for extending stopband in the upper frequency to be larger than 10 dB over 12 GHz to 18 GHz. This resonator is namely *Step-Step Impedance Resonators* or *SSIR* [4]. Conventional UWB bandpass filter [3], using λg/2 microstrip resonator, has shown inherently spurious resonant frequencies at $2f_o$ and $3f_o$, where f_o is the fundamental frequency, which may be very closed to a desired passband. Consequently, microstrip SSIRs have been proposed its performance for higher stopband, as exhibited in [4]. Fig. 6 illustrates a comparison of simulated responses magnitude of the step impedance resonator filters with slotted step impedance resonator and without slotted step impedance resonator. It can be seen that the proposed SSIR filter has shown a better stopband performance with a very high harmonic suppression less than −15 dB.

Fig.7 shows the current distributions of the step-impedance resonators at $3f_0$ as about 21 GHz stopband frequency. We can notice that in Fig.7 (a) the current densities pass through the resonators. For the proposed resonators in Fig.7 (b) the current densities on the surface of resonators is difficulty passed by the slot. It may be a cause of the stopband frequency appeared at $3f_0$ or 3rd harmonic as about 21GHz.



(a)

(b)

Fig.5 S_{21} magnitude responses of interdigital coupled lines and MMR resonator under weak/strong coupling

The RT/Duroid 3003 substrate has been provided for designing the filter. The IE3D program has been used to demonstrate the filter performances. The optimized dimensions of the slotted resonators and the interdigital coupled lines have been obtained using an optimizer from the EM simulation software. All the dimensions are shown in Fig. 1. Also, the optimized dimensions of the defected ground structure are shown in Fig. 2.

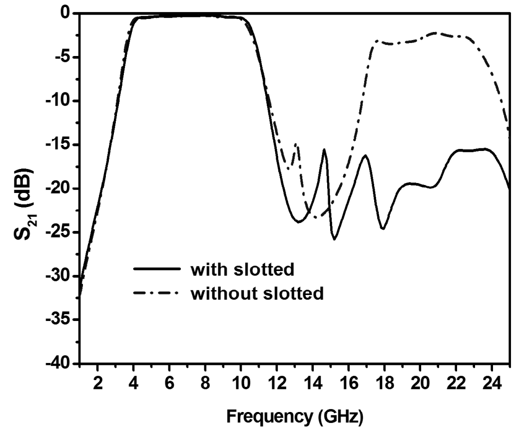
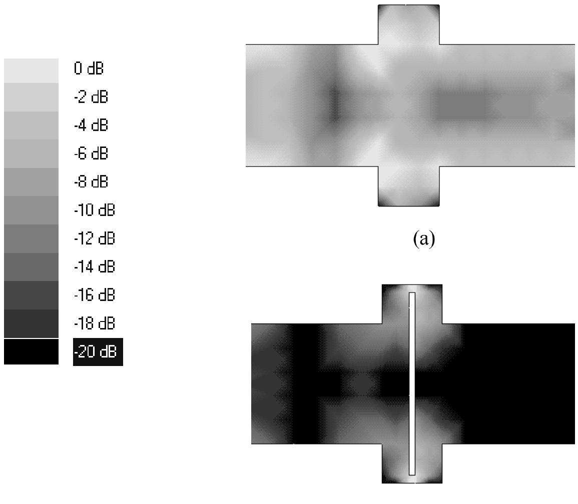


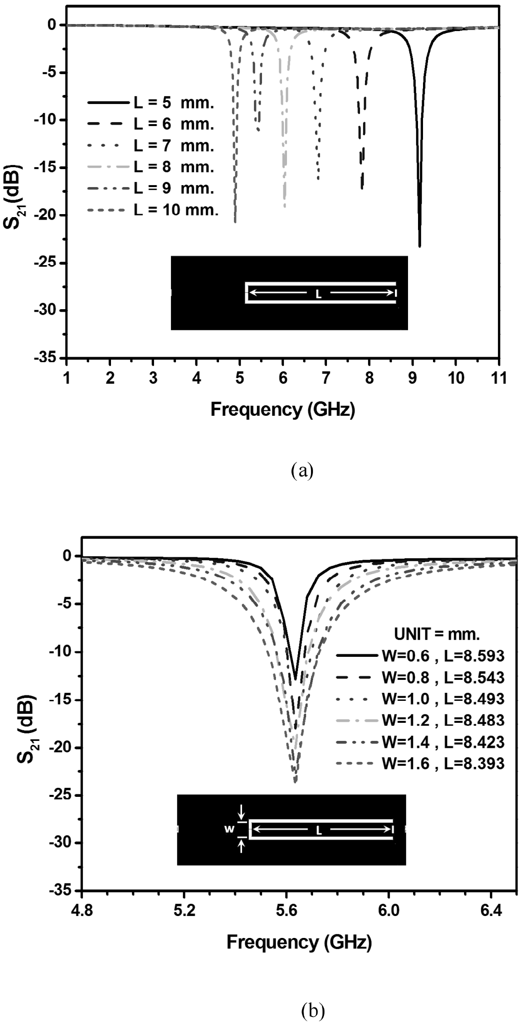
Fig. 6 Comparison of simulated S_{21} magnitude responses of the UWB filter with slotted step impedance resonator and without slotted step impedance resonator



(a)

(b)

Fig. 7 Current distributions of resonator at 21 GHz (a) convention step impedance resonator (b) slotted step impedance resonator



(a)

(b)

Fig. 8 S_{21} magnitude responses of the defected ground structure with a slot of 0.2 mm when (a) varying L (b) varying W

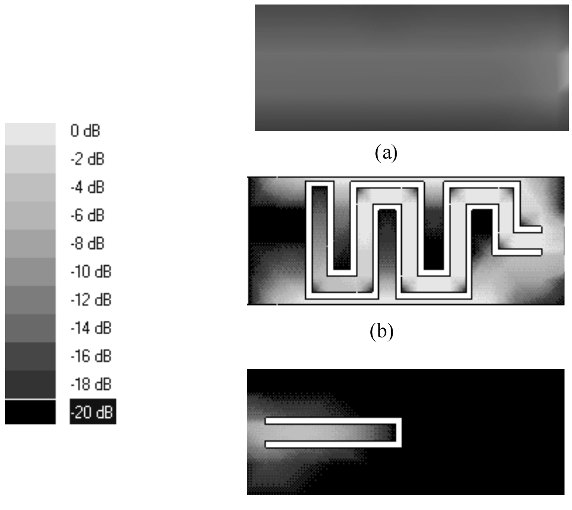
C. Defected Ground Structure

The defected ground chip at the bottom layer of the filter structure has been proposed. The RT/Duroid 3003 substrate has been used in this study. Fig.8 (a) shows a part of defected ground structure and its frequency responses of S_{21} for different values of the length L from 5 to 10 mm. It can be found that a middle frequency of stopband can be moved down from 9 GHz to 5 GHz. Whilst increasing the width W of the defected ground , then the center frequency is remained at the same value, the bandwidth of stopband is increased as shown in Fig.8 (b). It can be clearly seen that a 3 dB bandwidth of the stopband is increased from 220 MHz to 810 MHz. Therefore, by tuning L and W of the defected ground, center frequencies and bandwidth of sharp rejection bands can be easily adjusted. Thus, defected ground is suitable for utilizing within the UWB bandpass filter when sharp rejection bands are required. To make the sharp rejection bands at 2.84 GHz and 11.28 GHz, the dimensions of the proposed defected ground structure include l_6 = 7.25 mm, l_7 = 1.92 mm, l_8 = 1.37 mm, l_9 = 0.52 mm, l_{10} = 3.95 mm, w_5 = 3.30 mm, w_6 = 0.50 mm and g_1 = 0.20 mm.

To verify the sharp rejection bands mechanism, the current distributions of defected ground structure at 2.84 GHz and 11.28 GHz sharp rejection bands frequencies are shown in Fig.9. We can notice that in Fig.9 (a) the current distribution passes thoroughly the conventional bottom layer but the current direction cannot be through the proposed structure as shown in Fig.9 (b)-(c).

III. SIMULATED AND MEASURED RESULTS

Fig.10 shows a comparison of simulated responses of the UWB filter with defected ground structure and without defected ground structure. We can see that defected ground structure can create sharp rejection bands in the lower stopband and upper stopband. Fig. 11 shows the photograph of the fabricated UWB filter for sharp rejection bands. Fig.12 shows a comparison of measured and simulated responses of the UWB filter with sharp rejection bands.



(a)

(b)

(c)

Fig. 9 Current distributions of sharp rejection band at 2.84 GHz and 11.28 GHz (a) convention structure (b) – (c) defected ground structure

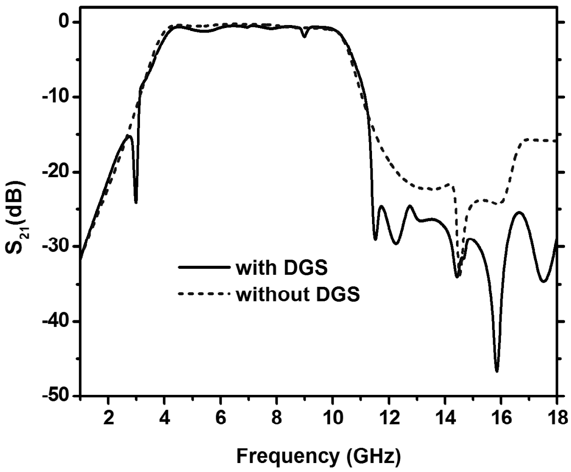
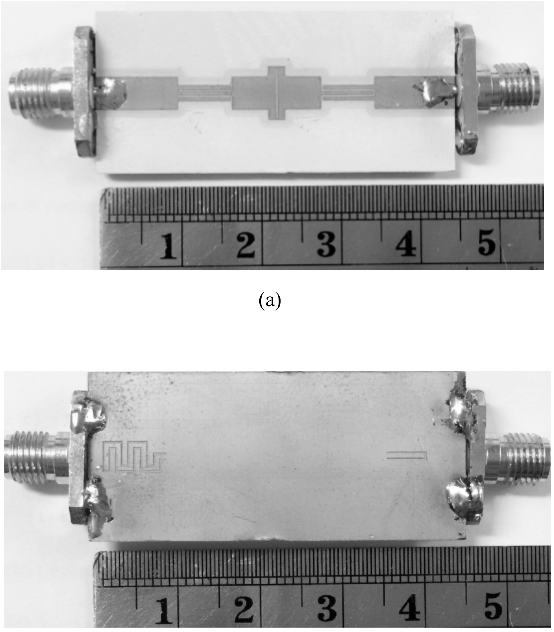


Fig. 10 Comparison of simulated responses of the UWB filter with defected ground structure and without defected ground structure

It can be found that the measured results show very good agreement with the simulated results, which can be confirmed that the proposed UWB filter with sharp rejection bands is capable of sharp rejection band at the lower sharp rejection band and upper sharp rejection band, having good insertion losses within the passband and also widening the upper stopband.



(a)

(b)

Fig. 11 Photograph of fabricated UWB filter (a) top layer (b) bottom layer

The measured return and insertion losses are found to be lower than -10 dB and higher than -2 dB, respectively over desired UWB passband. The sharp rejection bands frequency of about 2.90 GHz and 11.50 GHz. The proposed filter shows sharp rejection bands and improved upper stopband performance with high insertion loss. The upper stopband with the insertion loss lower than -15 dB occupies an enlarged range of 11.75 to 18 GHz. The group delay of filter slightly varies between 0.3 to 0.5 ns in the passband. Moreover, the proposed filter exhibits sharp rejection bands at the lower sharp rejection band and upper sharp rejection band at 2.90 GHz and 11.50 GHz with values of S_{21} lower than -17 dB and a wide upper stopband with values of S_{21} lower than -25 dB at 13 GHz and 17 GHz. These superior stopband performances are caused by the stopband characteristics of the proposed slotted resonator structure, and sharp rejection band is caused by defected ground structure.

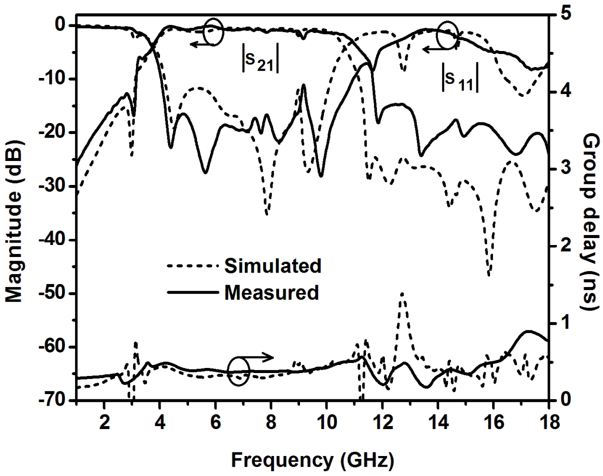


Fig. 12 Comparison of measured and simulated responses of the UWB filter with sharp rejection band

IV. CONCLUSIONS

The defected ground structure designed at the bottom layer with sharp rejection stopband and slotted step impedance resonator designed at the top layer with the improvement of wide upper stopband performances for UWB bandpass filter have been presented and implemented. By properly forming SSIR together with two interdigital coupled lines at both ends and defected ground structure at the bottom layer that are used to construct the filter. Its performances are extensively investigated in simulation and measurement. The proposed UWB filter demonstrates its capabilities in sharp rejection bands with the defected ground structure and suppressing spurious responses with slotted resonator. Also, the fabricated UWB filter proves that it can create sharp rejection bands and widen the upper stopbands.

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