Compact UWB Band-pass Filter with Single Notched Band and High Stop-band Rejection

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Abstract **— A compact ultra-wide-band (UWB) band-pass filter (BPF) consisting of a pair of triangle ring resonators with four open-stubs and three pairs of defected ground structures (DGS) is designed to reject the X-band inference and satisfy the high stop-band requirement. There are a couple of triangle ring resonators with four open-stubs fed by double inter-digital coupled structures to achieve the condition of UWB communications. Additionally, three kinds of different DGSs used on the bottom layer realize three kinds of different functional benefits. The sharp rejection of X-band signals is achieved by adding the first innermost ring DGS. The second inner pairs and the third outer pairs of ring arc DGSs are introduced to raise the high stop-band rejection and enhance the band-pass character, respectively. Further, through the 2D and 3D surface current analysis, the rejection band and pass-band performances are testified. Eventually, the designed triangle ring UWB BPF with three special DGSs show the good pass-band performance from 2.6 to 10.2 GHz and the high stop-band rejection -20dB up to 20GHz from the simulated results.**

Keywords - defected ground structures(dgs); notched band; ultra-wide-band (uwb); band-pass filter (bpf)

I. INTRODUCTION

In 2002, the U.S. Federal Communications Commission (FCC) allowed 3.1~10.6GHz frequency band to the civil and commercial applications [1]. Because of its high data rate more and more scholars and companies fall into the study of the UWB communications. There are many exiting communications system among 3.1~10.6GHz, which results in the inference problems. To meet the IEEE 802.11a standards, the UWB BPFs with the required notched band rises in response to the proper time and conditions, which effectively suppresses the pass-band inferences. There are many theories and methods to finish the design of UWB filters. At the first time, UWB filters are realized by integrating the low pass filers and the high pass filter, but this method increases the size.

In recent years, the multiple-mode resonators (MMR) are largely used in the UWB filters [2-4]. A micro-strip line UWB band-pass filter with high performances using a pair of MMRs is proposed in [2], which can't fit the high frequency communications environment with a poor upper stop-band. In [5] of 2014 year, a new UWB band-pass filter is proposed, with dual stepped-impedance stub-loaded resonators (SISLRs). But whose pass-band suppression is only -10dB and high stop-band rejection only up to 16GHz. At the same time, some UWB filters with notch band are studied for rejecting the disturb signals, such as WIMAX, WLAN or X-band and so on [6-8]. Taking [8] as an example, this paper presents an UWB band-pass filter for UWB applications and notch filter for the purpose of reducing interference from the WLAN (802.11a) when it coexist with UWB radio system, which consist of a hexagonal shaped MMR with inter-digital coupling at both sides. The same problem occurs in this design that the filters have poorer upper stop-band performance. To meet the requirement which can coexist with X-band and higher frequency communications, this paper presents a compact UWB BPF with a notched band of X-band and good upper stop-band performance. On the top layer of this filter with notched band there are a couple of triangle ring resonators , also a kind of MMR, and a couple of inter-digital coupled micro-strip lines, which together form a 3.1~10.6GHz frequency band. On the bottom layer, three kinds of different DGSs are used to realize three kinds of different functional benefits. The sharp rejection of X-band signals is achieved by adding the first innermost ring DGS. The second inner pairs and the third outer pairs of ring arc DGSs are introduced to raise the high stop-band rejection and enhance the band-pass character, respectively. This paper analyzes the current distribution form to show the working theory of the filters. The notched band UWB filter with relative bandwidth of 119% is effective with a notched band of 8.39GHz and high stop-band rejection -20dB up to 20GHz.

II. UWB BAND PASS FILTER

Fig. (1) shows the structure graphing of the proposed UWB filter. A couple of mirror symmetrical triangle rings constitute, four embed open-stubs on the spot of the two outer angles of each triangle ring and inter-digital coupled constructions at two sides. Where, the two equilateral triangle rings are connected using two fan rounds of 60° by tangent mode. The thickness of the substrate is 0.738mm and the relative permittivity is 10.8. The values of the structural parameters are set as follows: L1 = 4.30mm, L2 = 4.40mm, L2=1.73mm, L4 = 1.73mm, W1 = 0.10mm, W2 = 0.05mm, W3 = W4 = 0.20mm, r =0.20mm.

There are simulated results of the proposed UWB BPF with L1 = 0.60mm and 4.3mm in Fig. (2). The weak coupling (L1 = 0.60mm) of S21 - magnitudes is also plotted in Fig. (2) to clearly exhibit the distribution of all the excited resonant modes. The first three resonant modes are made use of constituting the UWB filter as shown in Fig. (2). Through comparing with the reported first filter in [4], it is known that the method of connecting the two equilateral triangle rings effectively suppress the higher order modes to get the better upper-stop-band than that of the reported first filter in [4].

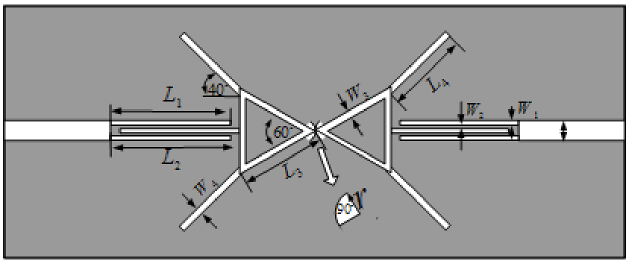


Figure 1. Schematic of the proposed UWB filter

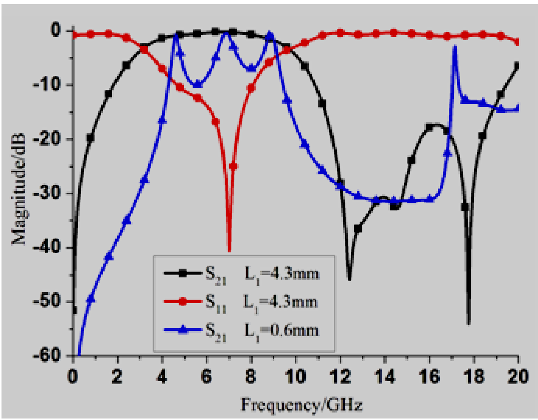
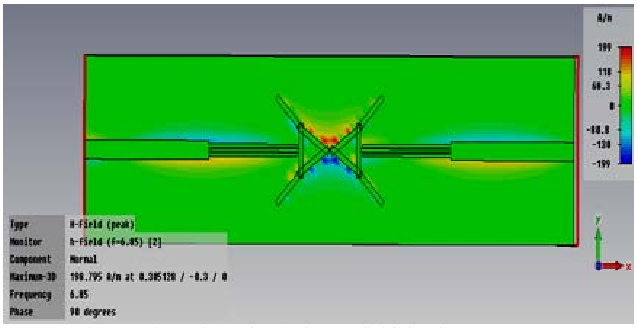
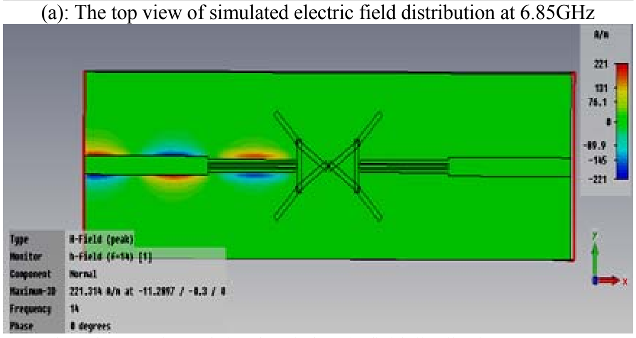


Figure 2. Simulated results of the proposed UWB BPF with L1 = 0.60mm and 4.3mm

The electric field distribution of the UWB filter in the pass band (6.85GHz) and stop band (14GHz) when L1=4.3mm is shown in Fig. (3a) and (3b). It is seen in the vertical view of electric field distribution in 6.85GHz that the current flows along the micro-strip line from one end to the other, the same conclusion as Fig. (2), which explains that 6.85GHz is in the pass band. In the upward view of electric field distribution in 6.85GHz the electric field is mainly concentrated in the slot of double upper triangle ring with four open-stubs and double inter-digital structures. In the vertical view of 14GHz the current flows along the micro-strip line from one end to the intermediate and gradually decreases, almost no current flowing to the other end, the same conclusion as Fig. (2), which explains that 14GHz is in the stop band. Through the combinatory analysis of Fig. (2) and Fig. (3), it is explained that the ring is influenced in the pass band (6.85GHz) and stop band (14GHz) by the slot of triangle ring resonators and inter-digital coupled structures, therefore the future research about the adjustment range of band-pass filter can mainly analyze L3 and L4.



(a): The top view of simulated electric field distribution at 6.85GHz

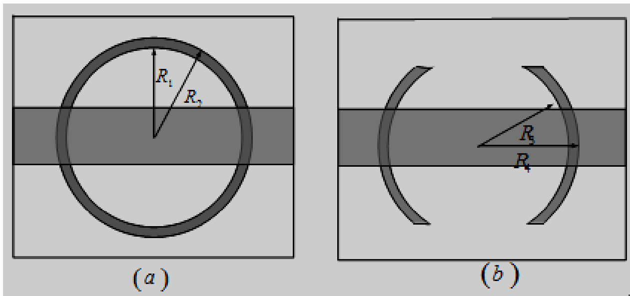


(b): The top view of simulated electric field distribution at 14GHz

Figure 3. Simulated results of the proposed UWB BPF with L1 = 0.60mm and 4.3mm

III. UWB BPF WITH A NOTCHED BAND

A. *DGS Unit Analysis*



(a) The First DGS Unit. (b) The Second DGS Unit

Figure 4. Schematic top view of two kinds of DGS units.

The DGS formed by means of etching defected patterns on the backside of the metallic ground plane is found base on the electromagnetic band-gap (EBG) by J. I. Park and his colleagues, which can alter the surface current spreading to adjust the circuit characteristic of metallic structures like the effective inductance and capacitance [9]. It is adopted to produce the transmission zero in the frequency band, which can achieve the resistance property of single pole or improve the BPF frequency performance. So it is used in related research of microwave devices. Based on traditional DGS [11], [10], the shapes of the three DGS units proposed in this

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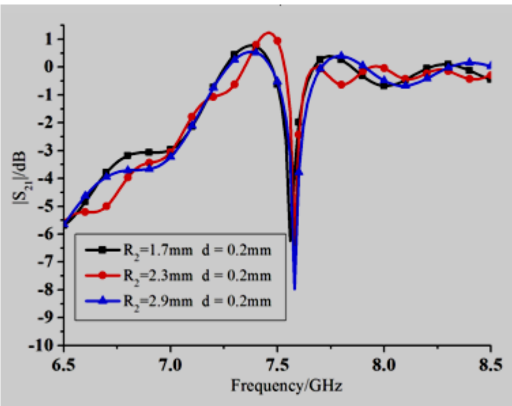
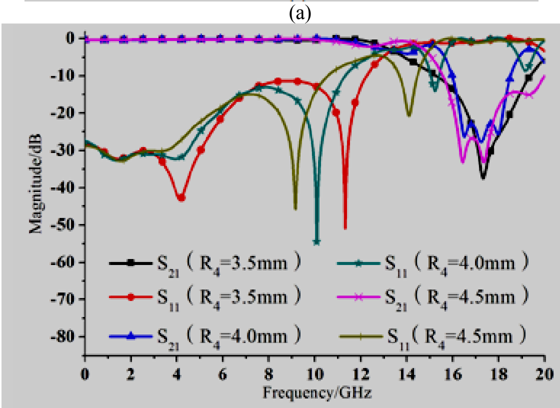
letter respectively are a circle ring DGS unit, two pairs of symmetry ring arc DGSs. Fig. (4a) and (4b) show the first DGS unit and the second DGS unit, respectively. The thickness of the substrate is 0.738 mm and the relative permittivity is 10.8. The width of the micro-strip line is 0.6 mm and the length is 23.8 mm.

The simulation results with different DGS dimensions of the first unit are shown in Fig. 5, which are calculated by CST Microwave Studio 2011. From the Fig. (5a), we can see, the first DGS unit can produce a notched stop-band at around 7.5GHz. In Fig (5b), these are shown that the second DGS unit produces a wide notched band at around high frequency of 17GHz and increases the attenuation to larger than 20dB in the pass-band of UWB. Because the width of two Ring DGSs can't affect the simulated results largely, the simulated results of different width aren't shown.



(a)



(b)

Figure 5. Simulated results of the proposed DGS units. (a) The first unit for different dimensions of R2 (d = R2 - R1). (b) The second unit for different dimensions of R4 (R4 - R3 = 0.20mm).

B. *Design of the UWB BPF with a Notched Band*

Based on the proposed DGS unit structures, we adopt a set of DGS units to design a UWB band pass filter (BPF) with a notched band whose whole schematic is shown in Fig. 6. The values of the structural parameters in Fig. (6a) are the same as that in Fig. 1. The values of the structural parameters in Fig. (6b) are set as follows: R1 = 2.70mm, R2 = 2.90mm, R3 = 3.50mm, R4 = 3.70mm, R5 = 4.30mm, R6 = 4.50mm.

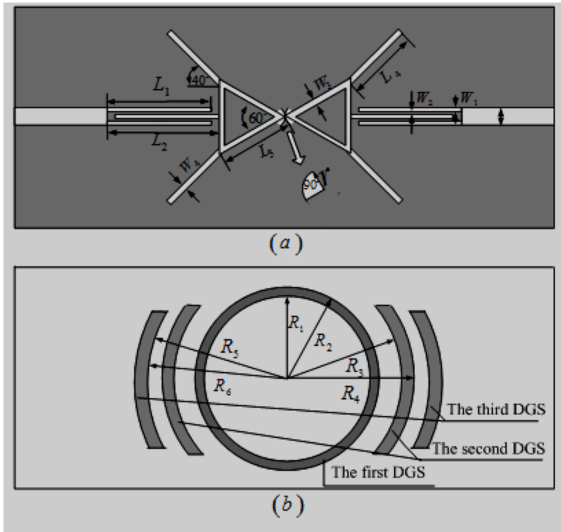


Figure 6. Schematic of the proposed UWB filter with a notched band. (a) Top view and (b) Bottom view

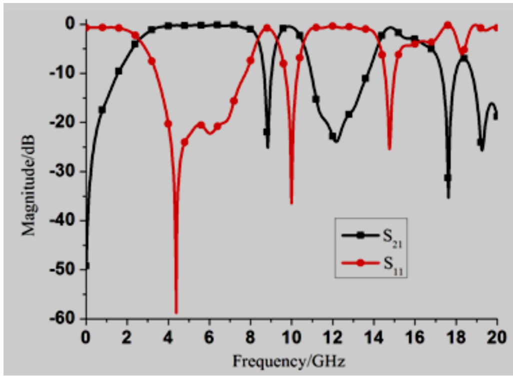


Figure 7. Simulated results of the UWB BPF with the first DGS

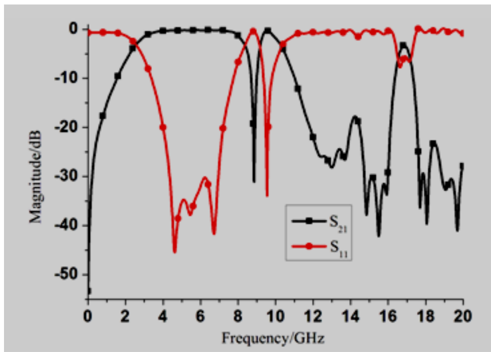


Figure 8. Simulated results of the UWB BPF with the first and second DGSs

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As shown the simulated results in Fig. (7), the first DGS creates the notched band, but at the same time the upper stop-band performance of this filter becomes poorer after adding the DGS. For obtaining the better pass-band and upper stop-band performance, optimization process is as follows. First, the second DGS is arranged as shown in Fig. (5). From the simulated results of Fig. (8), it is seen that the attenuation is greater than 30dB at the notched band and the return loss in the pass-band except the notch is larger than 30dB. In order to change the poor upper stop-band performance, the third DGS is arranged as shown in Fig. (6). Through the observation of Fig. (9), we can see, while the BPF with DGS has a measured 20 dB attenuation bandwidth extending to at least 20 GHz outside the pass-band.

Two transmission skirts are shown in Fig. (9). The maximum attenuation rate (MAR) is defined as

$$\mathrm{MAR} = \frac{S_{21}(fz) - S_{21}(fd)}{fz - fd} \tag{1}$$

MAR of the first transmission skirt is 19dB/GHz which calculated from 0 GHz with -52.4dB to 2.6GHz with -3dB. Also, MAR of the other transmission skirt is 15.5dB/GHz calculated from 10.2GHz with -3dB to 13.02GHz with -46.7dB.

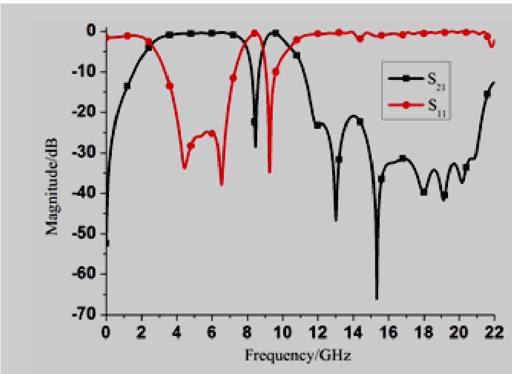
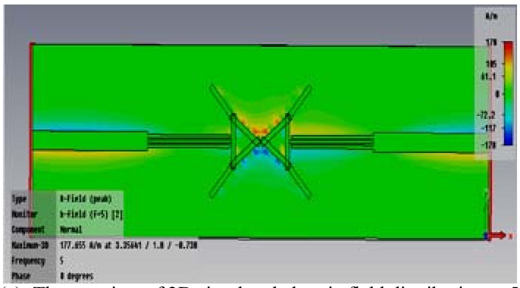
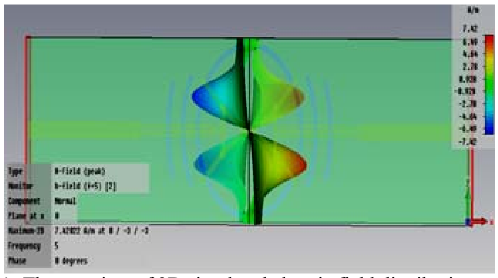


Figure 9. Simulated results of the proposed UWB BPF with a notched band

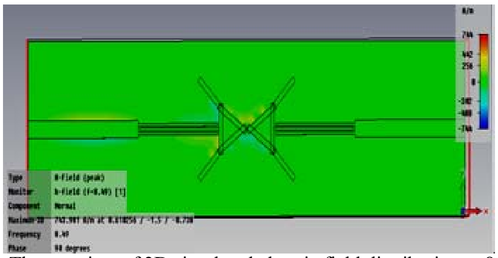
The electric field distribution of the UWB filter with notched band in the pass band (5GHz) and stop band (8.49GHz) is shown in Fig. (10a) ~ (10d). It is seen in Fig. 10(a) of 5GHz that the current flows along the micro-strip line from one end to the other, the same conclusion as Fig. (9), which explains that 5GHz is in the pass band. In the upward view of electric field distribution in 5GHz the electric field is mainly concentrated in the slot of upper triangle ring and the edge of inter-digital line. In the vertical view of 8.49GHz the current flows along the micro-strip line from one end to the intermediate and gradually decreases, almost no current flowing to the other end. But because of no enough current strength the result can't been seen clearly. Fig. (10d) is the 3D field of the electric field distribution in 8.49GHz, which can show clearly the same conclusion as Fig. 9, which explains that 8.49GHz is in the stop band. Fig. (10b) is the 3D field of the electric field distribution in 5GHz. In the upward view of 8.49GHz the electric field is mainly concentrated in the same position as in 5.0GHz, which shows the current analysis vividly. Through the combinatory analysis of Fig. (9) and Fig. (10), it is explained that the filter is influenced differently in the pass band (5GHz) and stop band (8.49GHz).



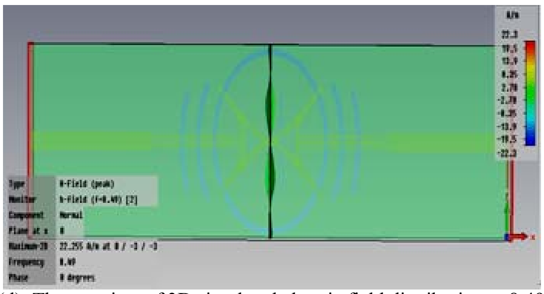
(a): The top view of 2D simulated electric field distribution at 5GHz



(b): The top view of 3D simulated electric field distribution at 5GHz



(c): The top view of 2D simulated electric field distribution at 8.49GHz



(d): The top view of 3D simulated electric field distribution at 8.49GHz

Figure 10. Simulated Electric Field Distribution on the UWB Filter with a Notch Band at 5GHz (Pass Band) and 8.49GHz (Stop Band)

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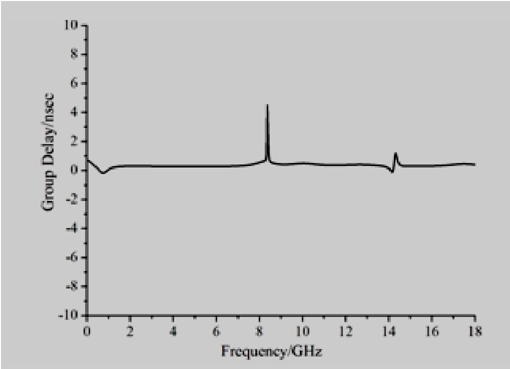

Figure 11. Simulated Group delay of the proposed UWB BPF.

The finally simulated results are shown in the Fig. (9). The filter exhibits a pass band from 2.6 to 10.3 GHz and a notched band at 8.49GHz. The attenuation is greater than 30 dB at the center of the band. The bandwidth of the notched band is about 1.1 GHz at 8.49 GHz. Then the simulation graph of another important characteristics is the group delay characteristic curve, as shown in Fig. (11), the following conclusions after observing is: the group delay of two pass band, from 3.1GHz to 8.0GHz and from 8.6GHz to 10.6GHz, is in 0.2ns to 0.6ns range, the group delay increases rapidly when the resonant frequency is 8.49GHz, which is the same as the reaction of the transmission curve. These indicate that this filter is to comply with the technical requirements, and is a qualified UWB filter.

IV. CONCLUSIONS

Novel DGSs for single notched band and high stop-band suppression performance in the UWB BPF have been developed and presented. The novelty technology for generating the notched band and high frequency suppression harmonic is based on adding three groups of DGSs on the bottom layer. The presented filter not only provides the 2.6~10.2GHz pass-band of UWB communication but also introducing the notched band of 8.49GHz for inferences from X-band. Though adjusting the two ring arcs the upper stop-band with the 20dB attenuation reaches the 21.3GHz and the return loss in the pass-band achieves larger of 20dB. Therefore, the presented UWB BPF with single notch band is promising for the applications in UWB wireless communications systems to provide a good method for working out the challenge of X-band disturbance.

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