Compact UWB Band-Pass Filter with Dual Notched Bands Based on Novel Defected Ground Structures

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Abstract — A compact ultra-wide-band (UWB) band-pass filter (BPF) with dual notch bands is presented using novel defected ground structures (DGS). A couple of triangle-ring resonators with four open-stubs fed by a couple of inter-digital coupled structures is developed to meet the UWB requirement of a uniform 3.1GHz to 10.6GHz full-band transmission response. Dual notch bands are generated for filtering out the interference caused by strong signals transmitted from 8/7 X-band systems whose down-link is from 7.25GHz to 7.75GHz and whose up-link is from 7.9GHz to 8.4GHz. The sharp rejection of down-link signals is achieved by etching the first ring DGS on the bottom ground plane. The other rejection of up-link signals is introduced by coupling resonance of the second and third ring DGSs etched on the bottom layer. Moreover, two pairs of ring-arc DGSs are used to achieve a wider upper stop-band. Further, through the surface current analysis, the rejection band and pass-band performances are testified. Eventually, the designed UWB BPF with dual notch bands shows a good pass-band performance from 2.5 to 9.9 GHz and the high stop-band rejection -15dB up to 23GHz from the simulated results.

Keywords - Defected Ground Structures (DGS), Dual Notched Bands; Ultra-Wide-Band (UWB), Band-Pass Filter (BPF), X-band

I. INTRODUCTION

In 2002, the U.S. Federal Communications Commission (FCC) allowed 3.1-10.6GHz frequency band to the civil and commercial applications. Because of its high data rate more and more scholars and companies fall into the study of the UWB communications. There are many exiting communication 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. In recent years, the multiple-mode resonators (MMR) are largely used in the UWB filters [1-3]. A micro-strip line UWB band-pass filter with high performances using a pair of MMRs is proposed [4], which can’t fit the high frequency communications environment with a poor upper stop-band. A new UWB band-pass filter is proposed, with dual stepped-impedance stub-loaded resonators(SISLRs) [5]. 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 dual notch bands are studied for rejecting the disturb signals, such as WIMAX, WLAN or X-band and so on [6]. Taking [7] as an example, this paper presents a compact UWB BPF with dual notch band using a tri-layer structure for rejecting WLAN and WiMAX interference. 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 dual notched bands of X-band and wide upper stop-band performance. On the top layer of this filter with dual notch bands 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, two kinds of different DGS units are used to realize three kinds of different functional benefits. The sharp rejection of X-band signals is achieved by adding the three-ringed DGS unit. The ring-arc DGS unit is introduced to widen the upper stop-band rejection and enhance the band-pass character. This paper analyzes the current distribution form to show the working theory of the filters. The UWB filter with relative bandwidth of 119% is effective with dual notched bands of 7.29GHz and 8.46GHz and wide upper stop-band rejection -15dB up to 23GHz.

II. UWB BAND PASS FILTER

Fig.1: Schematic of the proposed UWB filter with dual notched bands. (a) Top view and (b) bottom view
Fig.2: Simulated results of the proposed UWB BPF with L1 = 0.60mm and 4.3mm

Fig.1(a) 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 0.738 mm and the relative permittivity is 10.8. The values of the structural parameters are set as follows: L1 = 4.30mm, L2 = 4.40mm, L3 = 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 [8], 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 [9].

III. UWB BPF WITH DUAL NOTCHED BANDS

A. DGS unit analysis

Base on the electromagnetic band-gap (EBG), DGS is developed by J. I. Park and his team through etching defected shapes on the metallic ground layer. The DGS can form a kind of coupling mode with its upper layer structure to produce the new syn-tonic result, which effectively changed the equivalent circuit to give the novel way to meet different design requirement. 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. Since that, DGS begins to be used to the study of electromagnetic devices [10]. This paper fully takes advantage of different electromagnetic performances of the proposed DGS units to acquire the novel UWB BPF with dual notch bands. Fig.3(a) and (b) show the three-ringed DGS unit and the symmetrical ring-arc DGS unit, respectively. To analyze the electromagnetic characters, the two kinds of DGS units respectively are simulated with the substrate whose thickness is 0.738 mm and relative permittivity is 10.8. The width of the micro-strip line is 0.6 mm and the length is 23.8 mm. The width of the three ring and the ring-arc all is d = 0.2mm.

Fig.3: Schematic top view of two kinds of DGS units. (a) the three-ringed DGS unit. (b) the ring-arc DGS unit

Fig.4 shows the simulated results of the two proposed DGS units. In Fig. 4(a), there are three kinds of collocation patterns as follow: the first simulated curve with square shapes is the result of the only first ring DGS unit, the second curve with circle shapes is the one of the first and second DGS units, and the third curve with triangle shapes is the one of the three-ringed DGS unit. The dimensions of the three ring DGSs are set as follows: $R_1 = 2.9$mm, $R_2 = 2.5$mm, $R_3 = 1.5$mm. From Fig.4(a), we can see, the first ring DGS unit can produce a notch band at 7.58GHz, the two-ringed DGS unit can produce dual notch bands at 7.58GHz and 11GHz, and the three-ringed DGS unit also can produce dual notch bands at 7.38GHz and 9.72GHz. The perimeter of the first ring is about half of the wavelength of the notch-band frequency. From the simulate results, the third ring DGS can produce the coupling with the second ring DGS, equivalently increasing the electrical length of the second ring, to alter the second notch band to the lower frequency in the limited space. In Fig4(b), these are shown that the ring-arc 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. These analysis results are used in this proposed filters. Because the width of the Ring DGSs can’t affect the simulated results largely, the simulated results of different widths aren’t shown.

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![Fig.4: Simulated results of the proposed DGS units. (a) the three-ringed unit for three different ways. (b) the ring-arc unit for different dimensions of R4 (d = 0.20mm)](image)

**B. Design of the UWB BPF with single notched band**

As known in Fig.5 that the first ring DGS and the two-ringed DGS unit can perform a single notch character. So the two-ringed DGS unit is adopted to design a UWB band pass filter (BPF) with a notched band, which consisted of the unit shown in Fig.1 on the top layer and the first and second ring DGSs shown in Fig.3(a) on the bottom layer. To analyze the electromagnetic characters, the filters with the two kinds of DGS units respectively are simulated. The values of the structural parameters on the top layer are the same as that in Fig.1. The values of the structural parameters on the bottom layer are set as follows: R1 = 2.90mm, R2 is changed from 2.2mm to 1.5mm.

As the curve with solid square shapes shown in Fig.5, the first ring DGS is etched on the ground plane to construct an UWB filter with a notch band of 8.43GHz. When the second ring DGS is added on the ground plane, the notch band moves the frequency from 7.62GHz to 8.07GHz as R2 is changed from 2.2mm to 1.5mm. The second notch band appears as R2 = 2.3 and R2 = 2.4, which is sufficient evident of the propose dual-notch-bands filter.

![Fig.5: Simulated results of the UWB BPF with the two-ring DGS unit](image)

III. DESIGN OF THE UWB BPF WITH DUAL NOTCHED BANDS

Based on the proposed DGS units, we adopt a set of DGS units to design a UWB BPF with dual notch bands whose whole schematic is shown in Fig.1. The values of the structural parameters in Fig.1(a) are the same as that in Fig.1. The values of the structural parameters in Fig.1(b) are set as follows: R1 = 2.90mm, R2 = 2.50mm, R4 = 3.70mm, R5 = 4.50mm.

As the simulated results shown in Fig.6, the first ring DGS produces a notch band of 7.29GHz, and the second and third ring DGSs makes the other band. The second notch band moves the frequency from 10.17GHz to 8.46GHz as R3 is changed from 0.6mm to 2.2mm, at the same time the first notch band almost does not move, which realizes the second notch band adjusted separately. These notch bands almost cover the whole frequency in the UWB, which can solve the interference problem of X-band better. To study other performances of this proposed filter with dual notch band, R3 is set into 2.2mm in the below simulation. The initial simulated result is shown in Fig.7(a).

In Fig.7(a), we can see, though the filter has a good performance in dual notch bands, its upper stop-band performance is very poor after adding the three-ringed DGS unit. For obtaining the better pass-band and upper stop-band performance, two couples of ring-arc DGS is etched at the both outside of the tree-ringed unit. Through Fig.4(b), we can know, the ring-arc DGSs 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. So the two pairs can enhance the pass-band performance and get the better out-band rejection. The final simulated result is shown in Fig.7(b). Through the observation of Fig.7(b), the summing-up is obtained that while the BPF with the integrity proposed DGS unit has a measured 15 dB attenuation bandwidth extending to at least 23 GHz outside the pass-band and the return loss of at least -15dB in the pass-band.

![Fig.6: Simulated results of the UWB BPF with the three-ringed DGS unit when R3 of the third ring is changed](image)
The finally simulated results are shown in the Fig. 7(b). The filter exhibits a pass band from 2.5 to 9.9 GHz for UWB communications and dual notch bands at 7.29 GHz and 8.46 GHz for suppressing the interference of 8/7 GHz X-band. The filter exhibits a pass band from 2.5 to 9.9 GHz for UWB communications and dual notch bands at 7.29 GHz and 8.46 GHz for suppressing the interference of 8/7 GHz X-band. The attenuation is greater than 25 dB at the center of each band. The bandwidth of the notched band is about 0.52 GHz at 7.29 GHz and 0.49 GHz at 8.46 GHz. The variation of measured group delay is less than 0.6 ns in the pass-band except dual notch bands. These indicate that this filter is to comply with the technical requirements, and is a qualified UWB filter with dual notch bands.

IV. CONCLUSION

A three-ringed DGS unit for dual notch bands in UWB band-pass filter and a ring-arc DGS unit for the wider and better upper stop-band has been developed and presented. The novel technology for generating dual notch bands is based on etching the three-ringed defected shape on the bottom ground plane. The higher notch band can be controlled properly by adjusting the radius of the third ring DGS and the dual notch bands is rejected better for interference transmitted from X-band system. Down-link of 8/7 GHz X-band is from 7.25 GHz to 7.75 GHz, up-link frequency is from 7.9 GHz to 8.4 GHz, which is kept consistency with the two notch band of this proposed UWB filter. The ring-arc DGS unit etched on the both sides of the three-ringed unit is generating the high frequency notch bands to get the wide upper stop-band. Therefore, the presented UWB BPF with dual notch bands is promising for the applications in UWB wireless communications systems and providing a good method for working out the challenge of X-band disturbance.

REFERENCES