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ANALYSIS OF A SMALL UWB FILTER WITH NOTCH AND IMPROVED STOPBAND

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Abstract—A microstrip based Ultra-Wideband (UWB) Bandpass Filter (BPF) with a notch at WLAN and simultaneously improved stopband till 18 GHz is proposed. Meander shaped Defected Ground Structures (DGS) are used to implement the notch within the passband and two double U-shaped DGS structures present under the input and output feeding lines are used to attain the suppressed stopband. An equivalent circuit model of the proposed UWB filter structure is presented in the manuscript. Experimental results are in good agreement with the simulated data.

1. INTRODUCTION

Research on UWB filters have attracted the interest of scientific community ever since the frequency range of 3.1 to 10.6 GHz was allocated by the Federal Communications Commission (FCC) in 2002, for use in UWB systems [1]. Till date several UWB filters have been proposed and implemented in this direction [2–8]. A filter qualifies as an UWB-BPF provided it satisfies the criteria of 110% fractional bandwidth, a flat passband, i.e., minimum insertion loss and flat group delay within the passband [3]. The early years concentrated mostly on the passband requirement, but of late, research shifted focus on adding new features to these UWB-BPFs like improved stopband and addition of notch within the passband. Several structures were developed in this respect [9–12]. Of these [9] showed stopband improvement only till 16 GHz. Presence of narrow, single and dual notches was reported

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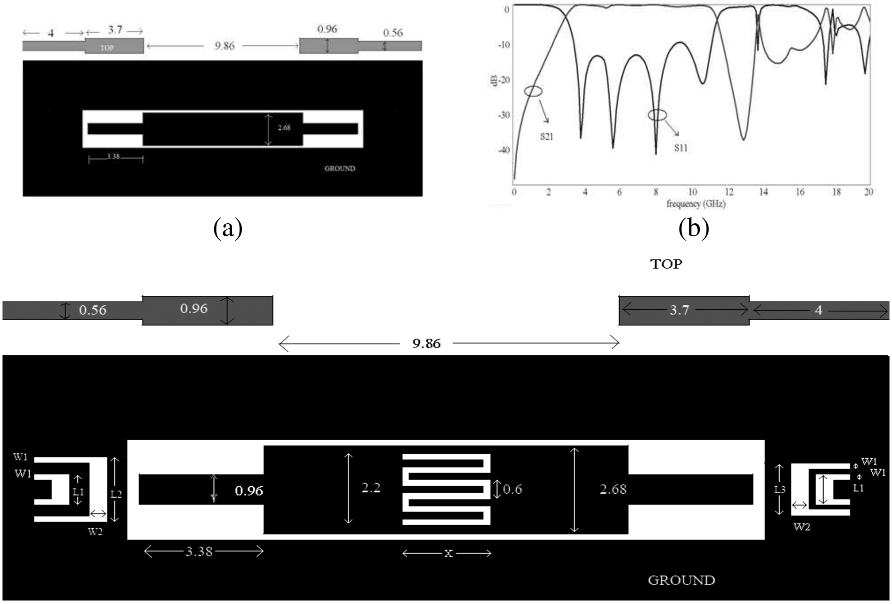
in [10, 11] while [12] showed a narrow notch with stopband extended till 15 GHz.

Here in this letter we propose a filter which has an extended stopband till 18 GHz and a controllable notch (with intention of suppressing the WLAN band of 5.725 to 5.825 GHz). Meander based DGS etched in the Multiple Mode Resonator (MMR) on the Co-planar Waveguide (CPW) is used to implement the notch while square shaped double-U DGS [13] etched under the input and output feeding lines are used to implement the extended stopband. The notch width and number (dual/triple) are functions of dimension and number of the meander DGS unit respectively. The proposed UWB filter circuit is fabricated on RT Duroid 6010 of dielectric constant 10.8 and height 0.635 mm.

2. UWB BPF DESIGN

The MMR based filter (without the double-U and meander DGS units) and its transmission characteristics are shown in Figures 1(a)–(b).



(a) (b)

(c)

Figure 1. (a) The MMR based filter, shaded part metal and unshaded part etched. (b) Transmission characteristics. (c) The proposed filter, all dimensions in mm.

The layout of the proposed UWB filter, shown in Figure 1(c), is designed using the integral equation based full wave EM solver, IE3D Zeland [14]. The length of the MMR on the ground is adjusted to half of guided wavelength so as to achieve the required passband of the UWB spectrum. The Microstrip/CPW coupled line is modeled to allocate the enhanced coupling peak near the central UWB frequency.

2.1. Implementation of Notched Band

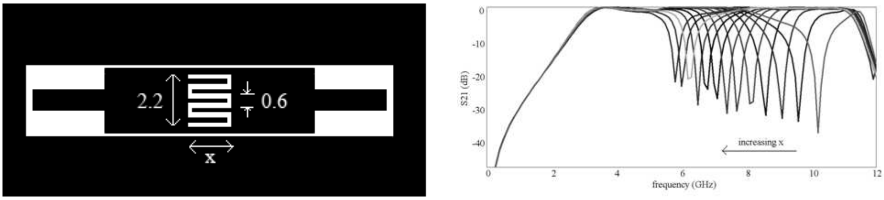
The presence of a notch in the passband acts as an added feature for the UWB-BPF in order to remove any unwanted interference from within the passband. Here the notch is introduced by etching a meander shaped DGS in the ground plane and the notch obtained is controllable and can be increased in width and number. The width of the meander is kept constant throughout at 2.2 mm and the widths of gaps and slots are fixed at 0.2 mm as shown in Figure 1(c). The resonant frequency of the notch, given by the formula $f = 1/2\pi\sqrt{(LC)}$, where L and C are inductance and capacitance, is dependent upon the length of the meander (x) and the slot width. The values of L and C are calculated from [15] as:

$$C = 1/(Z_0 * 4 * \pi * \Delta f_{3\,\mathrm{dB}}) \quad \text{and} \quad L = 1/(2 * \pi * f)^2 * C$$

where Z_0 is the characteristic impedance 50 Ohm, $\Delta f_{3\,\mathrm{dB}}$ the fractional 3 dB bandwidth. and f the notch frequency.

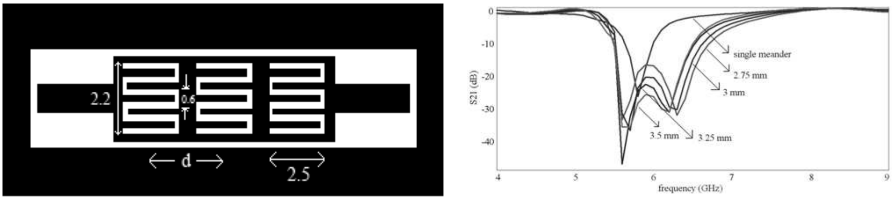
The chosen meander DGS structure, Figure 2(a), is like an interdigital capacitor. The metal fingers constitute the inductance (L) while the effective capacitance (C) is mainly contributed by the following factors: capacitance due to the gap between metal fingers, gap at the finger ends, finger length etc. [16].

For a single meander etched at the centre of the MMR, Figure 2(a), increasing length x of meander increases the electrical path traversed



(a) (b)

Figure 2. (a) Ground plane with single meander structure etched. (b) Notches for variable x dimension.



(a) (b)

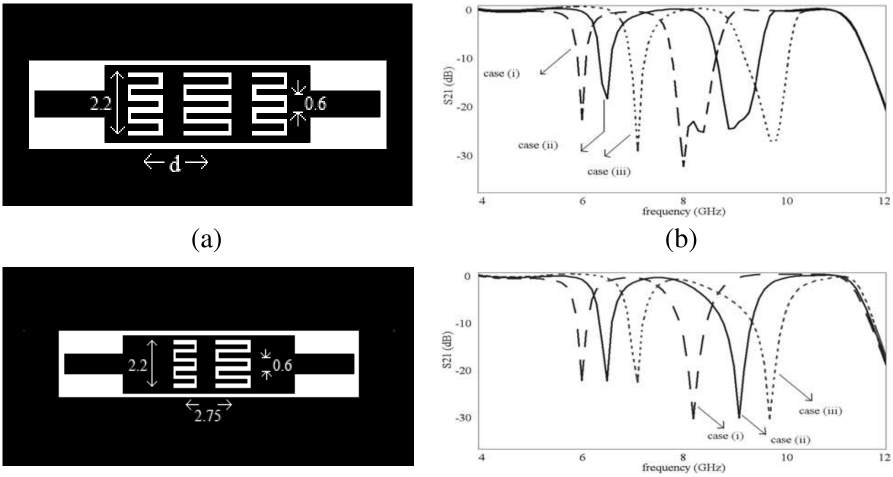
Figure 3. (a) Ground plane with three equi-dimensional meanders placed 2.75 mm apart. (b) Widened notch centered at 5.7 GHz.

by the current which in turn increases the inductance and capacitance thereby lowering the resonant frequency f and generating notches, with maximum and minimum limit of 10.4 and 5.7 GHz respectively, as shown in Figure 2(b).

The notch can be increased in width and number by cascading multiple meanders on the MMR. When three equi-dimensional meanders (width $= 2.2$ mm and $x = 2.5$ mm) are placed equal distances ($d = 2.75$, 3, 3.25 and 3.5 mm) apart (Figure 3(a)), from Figure 3(b) we notice a wider notch at 5.7 GHz compared to the narrow notch at the same frequency due to a single meander of the same dimension. The widths of narrow and widest notches are 0.22 and 1.3 GHz respectively. Cascading multiple meanders enhances the electromagnetic coupling among them which reduces with increase of distance, d.

For creating dual notches, two equi-dimensional meanders are placed at a fixed distance of 2.75 mm (equal to quarter of the guided wavelength, λ_g) from the central meander of another dimension as shown in Figure 4(a). We study the same for three different cases. From Figure 4(b), for case (i), we have two meanders of $x = 1.7$ mm on either sides of meander of $x = 2.4$ mm creating notches at 8.2 and 6 GHz respectively. Case (ii) with two meanders of $x = 1.5$ mm on either sides of meander of $x = 2.2$ mm creates notches at 9.2 and 6.5 GHz respectively. For case (iii), two meanders of $x = 1.4$ mm on either sides of meander of $x = 2$ mm generates notches at 9.8 and 7.1 GHz respectively. It is to be mentioned that for the above three cases the notches at the higher frequency end are wider because of the combined effect of the similar meanders on the either side of the central meander.

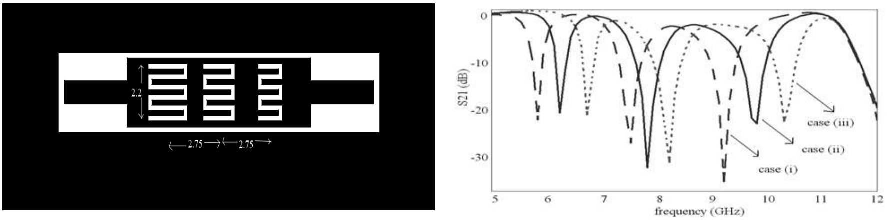
In order that both the notches of dual notch are narrow, two unequal meanders separated by $d = 2.75$ mm, are placed on the MMR as shown in Figure 4(c). Considering the same three cases as above, it is observed from Figure 4(d) that notches at the higher frequency end



(a) (b)

(c) (d)

Figure 4. (a) Ground plane with three meanders (two similar and one different) placed 2.75 mm apart. (b) Dual notches (one narrow, another wide) for three different cases. (c) Two non equi-dimensional meanders placed 2.75 mm apart. (d) Dual notches (both narrow), for three different cases.



(a) (b)

Figure 5. (a) Ground plane with three meanders of variable lengths placed 2.75 mm apart. (b) Triple notches for three different cases.

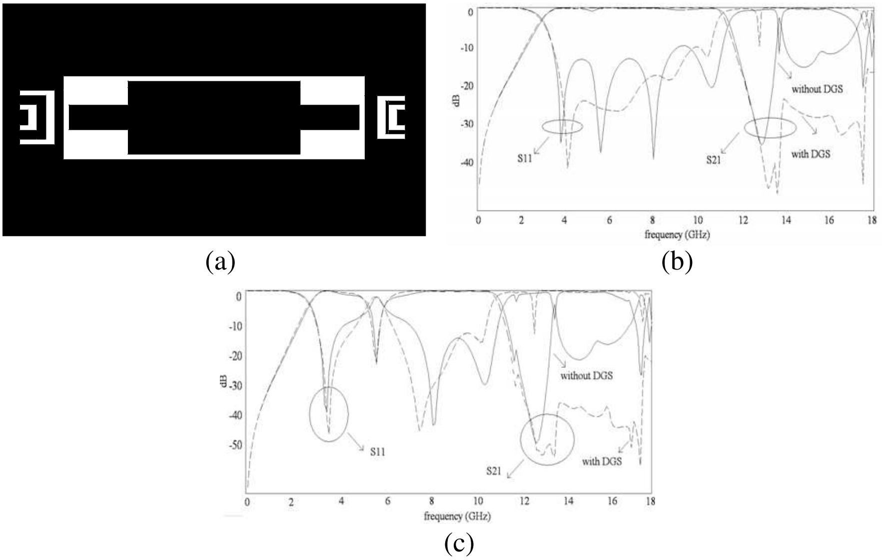
are much narrower unlike before.

Triple notches can be obtained by cascading three meanders of different lengths at variable distances. From Figure 5(a), for meanders separated by a distance of 2.75 mm for the three cases we have, in Figure 5(b), for case (i) meanders of $x = 2.5$, 1.9 and 1.5 mm creating notches at 5.7, 7.5 and 9.2 GHz respectively. Case (ii) with meanders of $x = 2.3$, 1.8 and 1.4 mm generates notches at 6.2, 7.8 and 9.9 GHz respectively. Case (iii) has notches at 6.8, 8.2 and 10.4 GHz for meanders of $x = 2.1$, 1.7 and 1.3 mm, respectively.

2.2. Extended Stopband

Figure 1(b) shows that the out of band performance of the original filter (without meander and double U-shaped DGS units) is not satisfactory because of the presence of spurious bands at 13.7 GHz and 17.5 GHz. In order to improve the stopband we etch square shaped double-U DGS units under the input and output feeding lines on the ground plane with open end alignment. Ting et al showed in [13] that the double U-shaped DGS unit places two finite attenuation poles at two different frequencies, with almost no change in the characteristics of other frequencies. With lengths ($L1$ and $L2/L3$) fixed, these two attenuation poles are shifted to lower frequencies for larger widths $w1$ ($w2$ constant) and both are pushed to higher frequencies for larger $w2$ ($w1$ constant). For variable lengths, with widths fixed, the lower attenuation pole is attributed to longer length $L2$ while higher pole is due to shorter length $L1$.

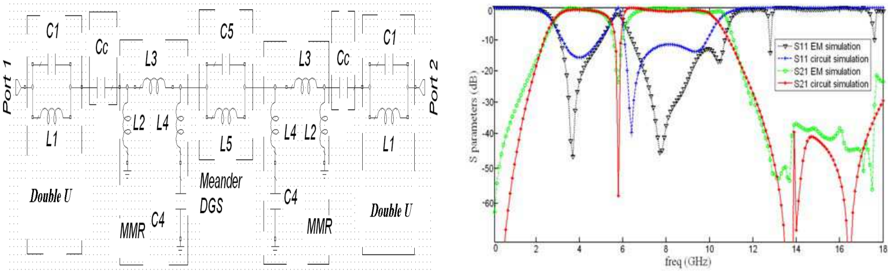
Initially this double-U shaped DGS unit is applied to the original structure as shown in Figure 6(a). For $w1 = 0.2$, $w2 = 0.5$, $L1 = 0.96$, $L2 = 2$ and $L3 = 1.6$ mm respectively, from Figure 6(b), we notice that the stopband improves (below −25 dB till 17.6 GHz) without



(a) (b)

(c)

Figure 6. (a) Ground plane of the original filter with double-U shaped DGS. (b) Improved characteristics. (c) Improved characteristics with double-U shaped DGS units applied to the proposed filter.



(a) (b)

Figure 7. (a) Approximate equivalent circuit. (b) Comparative Scattering parameters EM and circuit simulation.

bringing any distortion to the passband. Similarly when the same double-U shaped DGS units are applied with the proposed structure of Figure 1(c), for a single meander with $x = 2.5\,\text{mm}$, we observe an improved passband with no disturbance to the notch and stopband (well below $-40\,\text{dB}$ till 17.6 GHz) extended till 18 GHz as shown in Figure 6(c).

2.3. Equivalent Circuit

Figure 7(a) depicts the equivalent circuit model of the MMR, meander and the double-U shaped DGS.

The meander DGS that generates the notch is essentially a parallel resonator circuit and the notch frequency is decided by $f = 1/2\pi\sqrt{(L5C5)}$. This meander shaped DGS is embedded in the MMR. MMR profile dimensions control the passband width of the UWB filter by varying the values of inductances ($L2$, $L3$ and $L4$) and capacitance ($C4$). The coupling capacitor Cc, couples the MMR with double-U DGS. The double-U DGS provides two attenuation poles in the stopband of the UWB filter and in the equivalent circuit model is represented by parallel resonant circuit of $L1$ and $C1$.

After optimization of the circuit model, the values of the parameters are found to be, $L1 = 0.082\,\text{nH}$, $L2 = 3.63\,\text{nH}$, $L3 = 1.16\,\text{nH}$, $L4 = 1.72\,\text{nH}$, $L5 = 0.367\,\text{nH}$, $Cc = 0.76\,\text{pF}$, $C1 = 1.6\,\text{pF}$, $C4 = 0.078\,\text{pF}$, $C5 = 2.05\,\text{pF}$.

Figure 7(b) shows the comparison of the transmission characteristics of the proposed UWB BPF using circuit optimization and 3D full wave electromagnetic simulation.

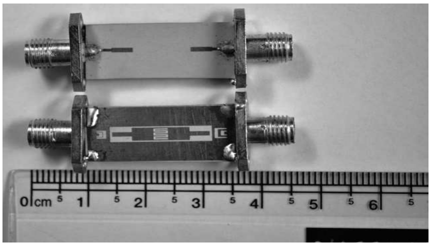
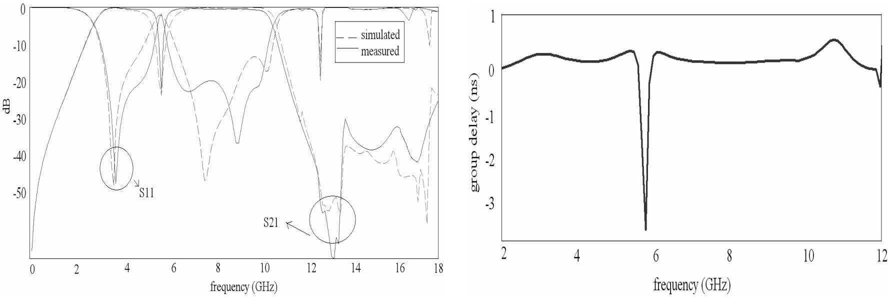


Figure 8. The fabricated filter.



(a) (b)

Figure 9. (a) Measured and simulated transmission and reflection characteristics. (b) Group delay, measured.

2.4. Fabrication and Measurement

The proposed structure is fabricated on RT Duroid 6010 of dielectric constant 10.8 and height 0.635 mm, as shown in Figure 8.

The measured response of the fabricated filter, Figure 9(a) is found to be in good agreement with the simulated data. Also the group delay measured is within 0.28 ns in the passband (3.1–10.6 GHz) of the UWB spectrum, as shown in Figure 9(b).

3. CONCLUSIONS

An UWB-BPF having a notch at WLAN (5.725 to 5.825 GHz), with an improved stopband till 18 GHz and flat group delay (< 0.28 ns) is proposed and developed. The equivalent circuit of the proposed filter is developed and its response is found to be in good agreement with the simulated results. It is shown that by using meanders of variable dimensions placed variable distances apart, notches (single, dual and triple) flexible with control over its width and number could be obtained. The filter was fabricated and the measured results were found to be in excellent agreement with the simulated ones. The filter measures 25.26 mm × 11.01 mm. The tunability of the notch (5.7 to 10.4 GHz), with the added feature of being wide, dual and triple, and the extended stopband (till 18 GHz) makes it the only filter with these unique qualities unlike any of the reported ones so far.

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