Design of an UWB Bandpass Filter Using Dual MMR with Highly Attenuated Upper Stopband Using DGS

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Abstract

A miniature sized microstrip UWB (ultra wideband) BPF (bandpass filter) having highly attenuated upper stop band performance using a dual MMR (multimode resonator) and the DGS (defected ground structure) is proposed. Combining these two topologies, a prototype of the proposed UWB BPF is fabricated using FR-4 substrate of 1.6 mm thickness with dielectric constant of 4.4. This BPF is modelled and simulated using Ansoft high frequency structure simulator (HFSS) Software. The simulated and measured results show a wide FBW (fractional bandwidth) of 119%. The insertion loss is less than -1.0 dB throughout the pass band of 2.78 to 10.95 GHz. All the ripples of return loss are lower than –14 dB in the passband. The BPF has a high rejection of more than -30 dB in the upper stop band up to 16.8 GHz. The simulated and measured group delays variation in the passband are found to be less than 0.2 ns. The overall length of the resonator is 7 mm.

Index Terms: UWB (ultra-wideband), BPF (band pass filter), MMR (multimode resonator), DGS (Defected ground structure), Stopband.

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1. Introduction

The FCC (Federal Communications Committee) authorized the unlicensed version of UWB frequency

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spectrum for wireless communication since 2002 [1]. One of the major component for an UWB communication system is bandpass filter with a FBW of more than 100%. It is a challenge to design a BPF with compact size, wide bandwidth, low insertion loss and also wideband rejection. Reducing resonator size is an effective approach to miniaturize the filter size.

Generally two approaches are used to reduce the resonator size. One is to modify the physical structure. Another is to modify the traditional resonator to generate additional modes and behave as a MMR. Several researchers have proposed different UWB BPF structures [2–17]. In 1998, a lumped-element equivalent circuit was proposed for a dual mode dielectric-resonator BPF that included mode coupling, excitation, and I/O electrode coupling schemes [2]. In 2003, a broad bandpass filter was achieved with bandwidth extended to 70% from 40% [3]. The bandwidth was increased at 86.6% with the design of a ring resonator with a stub in 2004 [4]. In 2005, an UWB bandpass filter was achieved with five transmission poles. The construction of MMR using quarter-wavelength parallel coupled lines in the input and output ports was introduced [5]. In 2007, an UWB bandpass filter was fabricated with combination of high pass filter consisting of inter-digital capacitors and short-circuited stubs and low pass filter realized by non-uniform defected ground structure array [6]. An UWB BPF using stub loaded MMR was presented that achieved FBW of 114% [7]. In 2009, one article described a class of recently developed MMR based bandpass filters for UWB transmission system with stepped-impedance or stub-loaded non-uniform configurations and analyzed their properties based on the transmission line theory [8]. A novel multimode bandpass filter with high and wide rejection band using an open stub was proposed to have two functions, one is perturbation for the multimode operation and the other is zero point generation at the stop band for the stop band control [9]. An UWB BPF with notched band was developed in 2010, by inserting a parasitic coupled line to block any unwanted existing radio signals that may interfere with conventional UWB systems [10]. In 2011, compact UWB BPF using stub-loaded MMR was proposed where two transmission zeros generated by the stepped-impedance stub [11]. A super UWB BPF with FBW of 138% was proposed to realize a wider passband, based on a simplified composite right/left-handed transmission line (SCRLH TL), while the complementary split ring resonators were etched in the ground plane to achieve better performance of the upper stop band [12]. A novel UWB microstrip filter was proposed using short circuited stub with etched rectangular lattice and better return loss was achieved [13]. In 2014, an UWB-BPF is constructed from the step impedance lowpass filter, optimum distributed high pass filter and four rectangular shaped DGS [14]. In 2015, an UWB bandpass filter was presented by stub-loaded MMR and a fan-shape stub-loaded stepped impedance in the center. The length of coupled line produced odd mode frequencies and the stub-loaded stepped impedance effected even mode frequencies [15]. To achieve wideband common mode (CM) suppression and compact design simultaneously, the concept of half-mode DGS was introduced in the two stacked microstrip layers of an UWB BPF using half mode dumbbell DGS in 2016 [16].

In this paper, an UWB bandpass filter is realized by a dual MMR and narrow DGS slots. The main feature of the proposed filter is the incorporation of MMR with slots at the ground plane to increase the coupling level which in turn decreases the back radiation without wide aperture. The proposed BPF is modelled and simulated using Ansoft HFSS Software. The center frequency of the filter is 6.86 GHz with a wide band rejection in the stop band. The passband covers the frequency range of 2.78 – 10.95 GHz while the group delay variation in the passband is less than 0.2 ns. The proposed structure is fabricated on a low cost FR-4 epoxy substrate with dielectric constant of 4.4 and thickness of 1.6 mm and has a compact size of 20 mm × 13 mm. The overall length of the resonator is 7 mm. The fabricated structure is measured by Vector Network Analyzer (VNA). The simulation results are in good agreement with those obtained experimentally with the realized filter.

2. UWB-BPF Design and Analysis

In this paper, an UWB BPF is designed using a dual MMR with narrow transverse DGS slots as shown in Fig. 1. The input and output feeding lines are connected to the coupled lines on the top side of the substrate while the DGS is etched on the other side below the coupled lines. An array of four DGS is etched in the ground plane of a planar transmission line to achieve better stopband performance of the designed microstrip filter. The
The proposed MMR causes a high degree of coupling without any wide aperture in the ground plane. The absence of wide aperture underneath the MMR provides a reduction in back radiation.

![UWB band pass filter with DGS slots](image1)

Fig.1. UWB band pass filter with DGS slots

Very narrow transverse DGS slots are adopted to improve the upper stop band performance. The transmission line dimensions are selected on the basis of resonant length and quarter wave coupling. Proposed filter consists of an MMR, which are formed by two identical set of parallel coupled lines. The effects of variation of transverse type DGSs and coupling finger lengths of the filter structure are analysed on parameter basis.

Fig. 2 gives an equivalent transmission line network of Fig. 1, where the two ports (b1 and b2) are far away from the reference planes (a1 and a2). The entire layout is divided into two identical error terms [Xf] and an equivalent J-inverter network. These error terms give the approximation of source excitation and inconsistency of MOM-based impedance definitions [17]. The MMR section can be extracted as a two port admittance matrix with discontinuity effects. The equivalent transmission line network allows the transformation of the admittance matrix into a J-inverter susceptance (J) and two electrical lengths (θ/2), which represent its series capacitive coupling and equivalent phase shifts, respectively. The total electric length of coupled line resonator is ϕ = θ/2 + θ/2[18].

2.1. Effect of DGS width

The bottom view of the BPF structure is shown in Fig. 3(a). The variation of filter performances due to change in defected ground array width (Wa) is shown in Fig. 3 (b) and (c). Table 1 shows the FBW variation for different array width. For the smallest array width (Wa = 0.3 mm), the passband bandwidth is smallest and S11 (in dB) is lower than -11 dB. As the array width increases, S11 in the passband exceeds -11 dB. However, the number of poles remain nearly constant (2 poles) in the passband. The zeros in the stop band move towards its edges as the slot width increases.
Fig. 3. (a) Bottom view of the designed BPF; (b) $S_{11}$ performance and (c) $S_{21}$ performance against different DGS widths ($W_a$).
Table 1. Effect of the DGS widths

| Width(W_a)(mm) | Band Width (GHz) | FBW  | 1st zero | 2nd zero |
|---------------|-----------------|------|----------|----------|
| 0.3           | 4.01-11.95      | 99.4 | 0.11     | 13.92    |
| 0.5           | 3.3-11.03       | 107.88 | 0.095 | 14.04    |
| 0.7           | 2.78-10.95      | 118.24 | 0.09 | 14.3     |
| 0.9           | 2.77-10.1       | 113.9  | 0.086   | 14.48    |
| 1.1           | 2.75-9.74       | 111.92 | 0.081   | 14.66    |
| 1.3           | 2.74-9.51       | 110.53 | 0.074   | 14.84    |
| 1.5           | 2.72-9.3        | 109.48 | 0.07  | 15.32    |

2.2. Effect of DGS array gap

Considering the bottom view of the BPF as shown in Fig. 3 (a), the effect of DGS array gaps (g_a (= g_1 = g_3) and g_2) on the filter performances is shown in Fig. 4 (a) and (b).

![Fig. 4](image-url)

Fig. 4. (a) S_{11} performance and (b) S_{21} performance for different DGS array gaps (g_a (= g_1 = g_3) and g_2).
Table 2. Effect of DGS array gaps

| Gap(g)(mm) | Band Width (GHz) | FBW  | 1st zero | 2nd zero |
|------------|------------------|------|----------|----------|
| g₁=2.94, g₂=3.5 | 3.32-11.3 | 109.16 | 0.1 | 13.88 |
| g₁=2.96, g₂=3.52 | 3.34-11.29 | 108.68 | 0.095 | 13.89 |
| g₁=2.98, g₂=3.54 | 3.36-11.28 | 108.19 | 0.09 | 13.97 |
| g₁=3, g₂=3.56 | 3.4-11.27 | 107.29 | 0.088 | 13.99 |
| g₁=3.02, g₂=3.58 | 3.41-11.26 | 107.02 | 0.084 | 14.02 |
| g₁=3.04, g₂=3.61 | 3.3-11.25 | 109.27 | 0.08 | 14.13 |
| g₁=3.06, g₂=3.62 | 3.42-10.89 | 104.4 | 0.07 | 14.31 |

As the gap value increases, although the FBW is nearly constant, but the zeros in the stop band move slightly towards its edges. So the variation of ‘g’ has negligible effect on the resonant modes of the filter and the number of poles remain constant (2 poles). The fractional bandwidth (FBW) and the frequency ranges \( S_{11} \) against the array gap variations are given in Table 2 above.

2.3. Effect of DGS length

The effect of DGS lengths \( (L_3, L_4, L_5 \) and \( L_6) \), on the filter performances is shown in Fig. 5 (a) and (b), considering the bottom structure of BPF as shown in Fig. 3 (a). Table 3 shows the FBW variation for \( S_{11} < -13 \) dB versus array lengths. For small lengths \( (L_3=5.2 \text{ mm}, L_4=5.26 \text{ mm}, L_5=5.32 \text{ mm}, L_6=5.38 \text{ mm}) \), the passband bandwidth is small and \( S_{11} \) (in dB) is lower than \(-13 \) dB. As the defected ground array length increases, \( S_{11} \) (in dB) in the passband exceeds \(-13 \) dB.

Table 3. Effect of DGS lengths

| Length(L)(mm) | Band Width (GHz) | FBW  | 1st zero | 2nd zero |
|---------------|------------------|------|----------|----------|
| \( L_3=5.2, L_4=5.26, \) | 4.12 - 11.19 | 92.3 | 0.08 | 15.95 |
| \( L_3=5.32, L_4=5.38 \) | 4.1 - 11.24 | 93 | 0.078 | 15.78 |
| \( L_3=5.4, L_4=5.46, \) | 4.1 - 11.3 | 95 | 0.075 | 15.54 |
| \( L_3=5.52, L_4=5.58 \) | 3.8 - 11.33 | 99 | 0.069 | 15.24 |
| \( L_3=5.6, L_4=5.66, \) | 3.8 - 11.43 | 106.27 | 0.065 | 14.14 |
| \( L_3=5.72, L_4=5.78 \) | 3.601 - 11.425 | 104.1 | 0.062 | 13.53 |
| \( L_3=5.8, L_4=5.86, \) | 3.6 - 11.43 | 104.19 | 0.06 | 12.9 |
| \( L_3=5.92, L_4=5.98 \) | 3.5 - 11.423 | 106.27 | 0.065 | 14.14 |
| \( L_3=6, L_4=6.06, \) | 3.5 - 11.423 | 106.27 | 0.065 | 14.14 |
| \( L_3=6.12, L_4=6.18 \) | 3.601 - 11.425 | 104.1 | 0.062 | 13.53 |
| \( L_3=6.2, L_4=6.26, \) | 3.6 - 11.43 | 104.19 | 0.06 | 12.9 |
| \( L_3=6.32, L_4=6.38 \) | 3.6 - 11.43 | 104.19 | 0.06 | 12.9 |
2.4. Effect of coupling finger lengths

The S parameter results for different coupling finger lengths (L₇, L₈, L₉ and L₁₀) which lie on the top plane of the designed BPF are shown in Fig. 6. For 5.8 mm length i.e. the designed length, proper pass band is generated.
The undesired modes are generated due to the notch for 4.9 mm coupling finger length. The rejection band at upper frequency edge is not at the desired level for 6.7 mm length. The change in length also changes the cut off frequencies and so it is observed that the pass band is controlled by the coupling length.

Comparing the results from above three tables, the optimized dimensions of the UWB BPF are fabricated and the final design dimensions are: \(L = 20\) mm, \(W = 13\) mm, \(W_1 = W_2 = 3\) mm, \(L_1 = L_2 = 6.5\) mm, \(W_3 = 0.7\) mm, \(L_3 = 6\) mm, \(L_4 = 6.06\) mm, \(L_5 = 6.12\) mm, \(L_6 = 6.18\) mm, \(L_7 = L_8 = L_9 = L_{10} = 5.8\) mm, \(S = 0.17\) mm, \(W_5 = 0.2\) mm, \(g_1 = g_3 = 3.04\) mm, \(g_2 = 3.6\) mm as labeled in Fig. 1.

3. The UWB-BPF simulations

In this design of UWB BPF, a dual mode MMR is properly made so that its two resonant modes lie close to the lower end and upper end of the specified UWB passband. The performance of the bandpass filter is improved by the inclusion of the DGS array in the ground plane and the coupling finger lengths in the top plane to cover the UWB frequency range. The simulation results using ansoft HFSS show an operating passband (where \(S_{11} < -14\) dB) that extend from 2.78 GHz – 10.95 GHz is shown in Fig. 7 (a). The proposed BPF has a wide -30 dB rejection in the upper stop band upto 16.8 GHz is shown in Fig. 7 (b).

![Graph](image-url)

Fig.7. (a) Simulated S parameters performance of proposed UWB BPF; (b) Upper stop band performance
4. Group delay of the UWB-BPF

Group delay is defined as the rate of change of transmission phase angle with respect to frequency. The proposed UWB-BPF group delay is obtained from the simulated as well as measured results as shown in Fig. 8. It is clear that the variations in the group delay are around 0.2 ns for the frequency band of 2.78 - 10.95 GHz.

![Group Delay Graph](image_url)

Fig.8. Simulated and measured group delay of proposed UWB BPF.

5. Fabrication and measurements

A prototype of the proposed UWB-BPF with MMR and transverse DGS slots is fabricated as shown in Fig. 9 (a) with top view and Fig. 9 (b) with bottom view. It is also measured by VNA. The substrate used to realize the designed filter is FR-4 epoxy with dielectric constant \( \varepsilon_r = 4.4 \), substrate height \( h = 1.6 \text{ mm} \) and has a compact size of 20 mm × 13 mm.

The simulated and measured results are in good agreement and show good in-band filtering performance and sharp selectivity as shown in Fig. 10.

![Fabricated UWB-BPF](image_url)

Fig.9. The photograph of the fabricated UWB-BPF (a) Top view; (b) Bottom view
6. Conclusions

A microstrip UWB BPF using a dual MMR and the transverse narrow DGS array is proposed here in this paper. The MMR structure is analyzed, and the corresponding transmission line equivalent model is given. The parametric analysis of different variables of the DGS array used in the design is carried out to obtain the optimized dimensions. The filter is modeled and simulated with Ansoft HFSS software. The designed filter is realized using photolithographic technique. It is seen that the DGS array improves the upper stop band of the UWB BPF. The simulated and measured results show a wide FBW of 119% and insertion loss is less than -1.0 dB throughout the pass band of 2.78 GHz - 10.95 GHz. The simulation results are in good agreement with the measured ones and a sharp selectivity is achieved. The BPF has more than -30 dB high rejection in the upper stop band up to 16.8 GHz.

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