Design of BPF using Pseudo-Interdigital Structure for Impedance Bandwidth enhancement of Monopole Antenna for UWB Application

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Abstract

This paper presents a design of combine structure of multimode resonator as bandpass filter with monopole antenna aimed at enhancing the impedance bandwidth keeping the radiation pattern almost same as of monopole antenna in E-field and H-field. Pseudo-interdigital structure is used as multimode resonator showing passband characteristics for ultra wide band application. To improve the return loss, Insertion loss and to remove the ripples in the passband the traditional Interdigital structure is modified to pseudo-interdigital structure. The BPF is first designed and simulated showing lower and higher cut off frequency as 3.1 GHz and 11.8 GHz with minimum Insertion loss as 0.22 dB and return loss as more than 13 dB. Secondly the UWB monopole antenna is designed and simulated covering a range of 3.2 GHz to 10.85 GHZ with return loss more than 13.8 dB. The integration of designed UWB bandpass filter with UWB monopole antenna is presented and results in advantage over impedance bandwidth of overall system. The lower and higher cutoff frequency of filter – antenna is found to be 2.7 GHz and 10.6 GHz with return loss more than 11 dB. The resulting parasitic element is engineered to produce its fundamental resonant mode in such a manner that overall compact design is realized illustrating an enhancement in 10 dB rejection fractional bandwidth of 0.5 GHz at lower frequency side is obtained while maintaining impedance matching without any significant changes to the original design parameters with sharp frequency cutoff at both the edges of UWB band. The proposed integrated filter-antenna is designed and simulated in Agilent Advance Design System.

Keywords: Pseudo-interdigital structure, ultra wideband, bandpass filter, UWB monopole antenna and Impedance bandwidth.
INTRODUCTION

UWB devices and circuits became more popular and efficient in microwave communication systems when Federal Communication Commission (FCC) has commercialized the unlicensed ultra wide band (UWB) frequency spectrum ranging from 3.1 to 10.6 GHz [1]. The planar configuration of UWB devices and systems is of valuable interest because of its superior s-parameter performance characteristics leading to low cost, easy fabricable and integration with monolithic RF circuits with compact size and simple structure [2]. Planar design causes radiation pattern degradation as in high accuracy positioning system, portable devices and cognitive radios, to overcome these drawbacks the system should have stable radiation pattern over the bandwidth of ultra wide band spectrum [3, 4]. Several techniques that have been used for stable radiation pattern, one of them are loading of parasitic elements [4-6] and modification of the radiating patches such as rectangular notch embedded patch, epitrochoid-shaped patch, and miniaturized patch [7-9], another method is by modifying ground planes (ex. Fractal ground) and by improving feeding element such as differential feeding techniques [10-16]. These design strategies made the radiation pattern stable but with certain drawbacks such as increases in physical size, multilobe problems and impedance mismatch defects may arise.

In this paper, a designed planar and compact UWB BPF is integrated at the feeding point of UWB monopole antenna to enhance the impedance bandwidth of filter-antenna. Step impedance radiating patch with defected ground structure is used for improving impedance matching of antenna. The integration is demonstrated by simulation, designed by UWB BPF using pseudo-interdigital structure. The individually design of an antenna, filter and combine structure is done on substrate FR4_epoxy of permittivity 4.4 with dielectric thickness of 1.6 mm.

2. ANALYSIS AND DESIGN OF PROPOSED UWB BPF

The proposed UWB BPF structure consists of pseudo-interdigital structure loaded with rectangular slots at both the ports, see Fig. 1. This pseudo-interdigital structure is a combline structure with coupled finger lines. As compared to interdigital structure the effect of inductance and capacitance is generated by the length of fingers and the space between them respectively. The Capacitors, CP1 and CP2 generated due to dielectric material of the filter, are shown in the equivalent circuit, Fig. 2 and Fig. 3.

![Figure 1. Configuration of the proposed filter.](image)
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**Figure 2.** Interdigital Structure.

**Figure 3.** Equivalent circuit of interdigital structure.

Equivalent circuit and frequency response symbolizes the nature of interdigital structure as bandpass filter with ripples. These ripples are generated due to different coupling of capacitors and inductors. To eliminate these ripples from the passband, couplings of fingers is modified known as pseudo interdigital structure, see Fig. 4 and Fig. 5.

**Figure 4.** Pseudo-Interdigital Structure.
The length of fingers L1 and L2 in the proposed UWB BPF structure controls the higher cut off frequency of the filter. On increasing any of the length either L1 or L2 and keeping the other as constant, the inductive effect of structures increases and because of this, the higher cut off frequency of filter decreases, see Fig. 6 and Fig. 7.
**Figure 7.** S-Parameter of Pseudo-Interdigital Structure when L1 is kept constant and L2 is varied.

For further improvement in S-parameter of passband, a rectangular slot is introduced at the interface of pseudo-interdigital structure at its input/output ports, see Fig 1. The impact of these additional structures can easily be seen from simulated response, shown in Fig. 8. The higher cutoff frequency reduces by 0.37 whereas lower cutoff frequency remains almost constant keeping insertion loss constant with slight change in return loss. For selectivity a transmission zeros can be created near the cut off frequencies of filter by loading stubs on pseudo interdigital structure but due to radiation loss the stubs can’t be loaded as calculated from expression $1 - (|S_{11}|^2 + |S_{21}|^2)$ [25-28]. By optimizing the dimensions of fingers and rectangular slots, the pass band range of the filter is achieved between 3.1 GHz and 11.8 GHz, with 117% as 3dB fractional bandwidth. The minimum insertion loss achieved is 0.22 dB whereas return loss is more than 13 dB, see Fig. 9. The optimized dimensions of the design are as follows: L1 = L2 = 5.3 mm, W1 = 0.15 mm, W2 = 2.87 mm, W3 =1.65 mm, S1 = 0.15 mm, S2 = 0.2mm. The overall size of the filter is 6.15 mm x 1.65 mm.
ANALYSIS AND DESIGN OF PROPOSED UWB MONOPOLE ANTENNA.

To design an ultra wide band antenna two or more resonant parts operating at its frequency is required and overlapping of these multiple resonance frequencies on each other results in multiband performances. On one side of the dielectric substrate of proposed antenna, it comprises of step impedance radiating rectangular patch having microstrip feeding and on other side, it comprises of defected ground structure, see Fig. 10 and Fig. 11. The overall design generates three or four resonant bands.
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achieving ultra wide band bandwidth, see Fig 12. The defected ground structure near the feeding is used to improve the return loss and bandwidth of the proposed antenna. The ground is extended upward around the radiating patch achieving V-shaped structure, to increase the bandwidth of antenna. A good impedance matching is obtained over the entire operating band with four resonant bands.

**Figure 10.** Configuration of the Ground structure of proposed Antenna

**Figure 11.** Configuration of the radiating patch of proposed Antenna.
The proposed antenna is designed with dimensions as follows: $L_3 = 22$, $L_4 = 11$, $L_5 = 3.18$, $L_6 = 2.79$, $L_7 = 2.7182$, $L_8 = 0.1501$, $L_9 = 1.05$, $L_{10} = 0.5$, $L_{11} = 4.98$, $L_{12} = 2.41$, $L_{13} = 5.25$, $L_{14} = 2.71$, $L_{15} = 2.7922$, $L_{16} = 3.92$, $W_2 = 2.8683$, $W_4 = 4$, $W_5 = 7.4494$, $W_6 = 2.79$, $W_7 = 0.81$, $W_8 = 0.75$, $W_9 = 1$, $W_{10} = 1$, $W_{11} = 1$, $W_{12} = 0.8$, $W_{13} = 1.65$, $W_{14} = 4.43$, $W_{15} = 0.585$, $W_{16} = 0.39$, $W_{17} = 24$, $W_{18} = 11.3$, $W_{19} = 4.99$, $W_{20} = 1.9895$ (all dimensions are in mm). Total area of proposed antenna is $24 \times 22 \times 1.6 \text{ mm}^3$ with patch and ground on either side of dielectric substrate. Total dimension of step impedance radiating patch is $14 \times 11 \text{ mm}^2$ for introducing different resonance and for improving the return loss. Microstrip feeding technique is used in the proposed antenna with length $5.25 \text{ mm}$ and width of $2.87 \text{ mm}$.

Simulated results of proposed antenna is defined by $S_{11}$ parameter i.e. Return Loss of proposed antenna. The proposed antenna covers the impedance bandwidth from $3.2 \text{ GHz}$ to $10.85 \text{ GHz}$ with four resonance points on $3.6 \text{ GHz}$, $5.854 \text{ GHz}$, $8.120 \text{ GHz}$ and $10.06 \text{ GHz}$ frequency. Return Loss at their respective resonance frequencies are $11 \text{ dB}$, $28.73 \text{ dB}$, $21.321 \text{ dB}$ and $27.365 \text{ dB}$, see Fig. 13.
The 2D far-field Radiation pattern of proposed antenna is measured at different frequency of 3.67 GHz, 5.33 GHz and 9.78 GHz, see Fig. 14. A uniform, stable and good radiation pattern is obtained for the antenna proposed. Table 1 shows the E-field and H-field simulated performance in decibel of the proposed antenna. Fig. 15 shows the 3D radiation pattern of omnidirectional monopole antenna. Fig. 16 shows the surface current distribution on the patch of the proposed antenna.

**Table 1.** E-field and H-field simulated characteristics of the proposed Antenna.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Properties</th>
<th>Antenna</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>E-Field</td>
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<tr>
<td></td>
<td></td>
<td>3.67 GHz</td>
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<tr>
<td>1.</td>
<td>Radiated Power (Decibel)</td>
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</tr>
<tr>
<td>2.</td>
<td>Directivity (Decibel)</td>
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<tr>
<td>3.</td>
<td>Gain (Max) (Decibel)</td>
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<tr>
<td>4.</td>
<td>Efficiency (%)</td>
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</table>
Figure 14. Simulated radiation Pattern of proposed antenna at frequencies (a) 3.67 GHz, (b) 5.33 GHz, (c) 9.78 GHz.

Figure 15. 3D radiation pattern of proposed UWB monopole antenna.
An antenna with microstrip feeding is proposed for UWB application. The simulated result shows stable radiation pattern overall bandwidth of UWB. The good impedance matching characteristics and omni-directional radiation patterns over the UWB bandwidth is obtained.

INTEGRATION OF PROPOSED UWB BPF WITH PROPOSED UWB MONOPOLE ANTENNA.

Next, the proposed pseudo-interdigital structure as multimode resonator for UWB BPF is integrated to the proposed UWB monopole antenna, the filter was connected directly to the microstrip feed line, see Fig. 17 and Fig. 18. It is clear from the frequency response that the integration of proposed filter with the proposed monopole antenna shows remarkable improvement in 10 dB rejection fractional bandwidth at low frequency side, The integrated structure bandwidth extends from 2.7 GHz to 10.6 GHz, see Fig. 19. Fig. 20 shows the gain performance of the filter-antenna and antenna for UWB application. The integrated filter antenna has a good omnidirectional radiation performance and shows almost same radiation pattern considering cross polarization, see Fig. 21. The optimize structural overall size is 32.9 X 22 mm².
Figure 17. Configuration of the integrated filter-antenna radiating patch.

Figure 18. Configuration of the integrated filter-antenna ground structure.
The simulated performance characteristics of the integrated filter-antenna are given by the magnitude of the reflection coefficients over the UWB frequency range. The simulated 10 dB rejection fractional bandwidth of the integrated filter-antenna is from 2.7 GHz to 10.6 GHz is 118.8 %. Comparing the frequency response of the antenna and the filter-antenna, it is seen that the lower cutoff frequency is downshifted by 0.5 GHz whereas the higher cutoff frequency is downshifted by 0.25 GHz. This small difference is due to the presence of filter since it is well known (diagnosed) that the presence of filter reduces the error associated with long coaxial cable on the measured impedance performance as reported earlier [32 and 33]. Table 2 shows the E-field and H-field simulated performance in magnitude and decibel of the proposed filter-antenna.
Table 2. E-field and H-field simulated characteristics of the proposed Filter-Antenna.

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Properties</th>
<th>Filter-Antenna</th>
<th>Filter-Antenna</th>
</tr>
</thead>
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<tr>
<td></td>
<td></td>
<td>E-Field</td>
<td>H-Field</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.67 GHz 5.33 GHz 9.78 GHz</td>
<td>3.67 GHz 5.33 GHz 9.78 GHz</td>
</tr>
<tr>
<td>1.</td>
<td>Radiated Power (Decibel)</td>
<td>-34.97  -36.3  -34.22</td>
<td>-53.81  -36.1  -58.8</td>
</tr>
<tr>
<td>2.</td>
<td>Directivity (Decibel)</td>
<td>4.15  4.125  6.22</td>
<td>-14.69  -15.7  -18.2</td>
</tr>
<tr>
<td>3.</td>
<td>Gain (Max) (Decibel)</td>
<td>2.06  0.82  2.815</td>
<td>-16.78  -18.9  -21.6</td>
</tr>
<tr>
<td>4.</td>
<td>Efficiency (%)</td>
<td>61.89  46.77  45.6</td>
<td>61.89  46.77  45.6</td>
</tr>
</tbody>
</table>

(a) E-Field

(b) H-Field
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(c)

**Figure 21.** Simulated radiation Pattern of filter-antenna at frequencies (a) 3.67 GHz (b) 5.33 GHz (c) 9.78 GHz.

**Figure 22.** 3D radiation pattern of proposed filter-antenna.
On comparing the gain of antenna and filter-antenna, it is found to be almost same, see Fig. 20. The co-polarization and cross polarization of filter-antenna is found to be almost same as in antenna, see Fig. 14 and Fig. 21. The impedance bandwidth is found to be improved at both higher and lower frequency side, see Fig. 13 and Fig. 19. Fig. 22 shows a good omnidirectional radiation pattern of filter-antenna. Fig. 23 shows the current distribution of filter-antenna. Current distribution of antenna and filter-antenna clears that the integration of filter with antenna changes the current distribution at the feed point due to which current is enhanced on the patch at microstrip feedline improving the impedance bandwidth.

**CONCLUSIONS**

A compact and planar pseudo-interdigital UWB BPF structure is proposed. Insertion loss and return loss of the filter is good. The filter has small size of 6.15 mm x 1.65 mm with 3 dB fractional bandwidth of 119.5 %. An omnidirectional Monopole antenna is also proposed for UWB application with overall size of 24 mm x 22 mm. The simulated and measured result shows stable omnidirectional radiation pattern on overall bandwidth of UWB. A good impedance matching is achieved in the proposed antenna. 10 dB rejection fractional bandwidth of the proposed antenna is 109 %. When this proposed UWB monopole antenna is integrated with the proposed UWB BPF, then an enhancement in UWB bandwidth is seen that is 10 dB rejection fractional bandwidth from 109 % to 118.8 %. The integration of proposed filter to proposed antenna shows the down shifting of lower and higher cutoff frequency in s-parameter performance by 0.5 GHz and 0.25 GHz keeping the gain performance and
cross polarization in both E plane and H plane nearly same to as of proposed antenna. A good omnidirectional radiation pattern is obtained in both antenna and filter-antenna. The overall size of the integrated filter-antenna structure is 32.9 x 22 mm$^2$.

REFERENCES


