A Compact Bandpass Microstrip Filter for Wireless Communication Applications

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Abstract: A design of Compact Bandpass Microstrip Filter is proposed for wireless communication applications like Bluetooth, Wi-Fi, and 5G. Filter is constructed using parallel-coupled Microstrip lines to form 5th order filter of an inverted C structure. Ground slotted technique is used to enhance the bandwidth with dielectric constant of 9.9. The designed filter is simulated at a center frequency of 5.87GHz and bandwidth of 1.9GHz with an insertion loss of -0.5dB, return loss of greater than 12dB. The proposed filter has a compact size, good increased bandwidth and cost-effective. These results are verified with the theoretically designed values and good agreements are recorded. Hence the proposed compact filter will provide a platform for designing and development of compact filters for the microwave regime.

Keywords: Bandwidth (BW), Compact Bandpass Microstrip filter, Low Pass Filter (LPF), compactness, Frequency.

I. Introduction
The recent advances in modern communication technology and wireless communication applications demand high performance and compact bandpass filters. Due to the rapid growth of wireless communication systems leads to a requirement of bandpass filters for good selectivity, compactness, and economic, etc. [1-3]. Hence bandpass Microstrip filters are very commonly used due to its ease of fabrication using printed circuited technology which is very cost effective. In the field of handheld communication systems, the miniaturized size of the system or the device plays an important role in parallel with multi functionalities to be performed by the same device [4-5]. As the functionalities increase like multitasking by a single device its size may increase, but in new technologies incorporating many features and reducing the size of the particular device is the main concern like mobile phones. Therefore, much attention has been given to compact Bandpass Microstrip filters (CBMF). A Microstrip filter is designed to operate between the resistive source and the load impedance of 50 ohm in most of the microwave systems [6-8]. These type of filters have a lot scope because of its compact size, low price, less weight, low insertion loss, wide stopband, and easy fabrication techniques. Used in many real-time applications of wireless communications in transceivers, for today’s modern wireless communication systems [9-11]. Hence these Microstrip bandpass filters constitutes a group of electric filters, aimed to operate at frequencies ranging from megahertz to gigahertz frequency. This band of frequency is used in most of the broadcasting applications, TV, Bluetooth, 5G etc and its frequency spectrum ranges from 300 kHz to 300GHz called as microwave frequency range [12]. Due to low fabrication expenditure and miniaturization process, implementation of Microstrip filters using electronics and devices is thriving. In [13], a compact Microstrip bandpass filter is designed by coupling a loaded resistor micro strip lines to form a square open-loop resonator and to enhance its selectivity a square open-loop resonator is loaded with an open-circuited stub for realizing two transmission zeros in the upper stopband. [14] A new design method for a tunable bandpass filter with independently and more widely tunable transmission zeros. This paper in [15] filter structure gives a closer coupling, and performs better than the first coupled micro strip. In [16, 17], a compact and highly-selective six-pole filter with a triple-mode resonator loaded with stub and patch is proposed. The designed six-pole filter is of two identical triple-mode resonators is designed.

II. Mathematical Analysis and Design:
Step1: Calculate the center frequency and angular frequencies: Centre Frequency \( f_0 = \sqrt{f_1 f_2} = 5.87 \, \text{GHz} \) \( \text{And Bandwidth (BW)} = f_2 - f_1 = 1.9 \, \text{GHz} \) \( (1) \)
Angular Frequencies:
\( \omega_1 = 2\pi(f_1) = 31.4 \, \text{GHz} \), \( \omega_2 = 2\pi(f_2) = 43.33 \, \text{GHz} \), \( \omega_3 = 2\pi(f_3) = 36.864 \, \text{GHz} \) \( (2) \)

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Relative angular difference:
\[ \Delta = \omega_2 - \omega_1 / \omega_0 = 0.324 \] (3)

**Step 2:** Design of LPF prototype using Coefficients for the maximally flat LPF for N=5
\[ g_1.g_2 .1.6180, g_3 = 2.0000, g_4 = 1.6180, g_5 = 0.6180, g_6 = 1.0000 \] (4)
The Coefficients for maximally flat LPF from \( g_1 \) to \( g_6 \) are taken from the Butterworth table because our work \( N=5 \). From these values of \( g \) construct the LPF prototype circuit as shown in Fig 1 below:

**Step 3:** Conversion of low pass prototype to bandpass filter values and calculations of L and C as follows
For capacitor: \( C_2 = \frac{c}{\omega_0 \Delta}, L_2 = \frac{L}{\omega_0 \Delta} \), For Inductor: \( C_2 = \frac{\Delta}{\omega_0 \Delta}, L_2 = \frac{L}{\omega_0 \Delta} \) (5)

<table>
<thead>
<tr>
<th>( g )</th>
<th>Values of L and C</th>
</tr>
</thead>
<tbody>
<tr>
<td>( g_1, g_5 )</td>
<td>( C_1 = 51.7 \mu F, L_1 = 0.0142 \mu H )</td>
</tr>
<tr>
<td>( g_2, g_4 )</td>
<td>( L_2 = 0.1354 \mu H, C_2 = 5.432 \mu F )</td>
</tr>
<tr>
<td>( g_3 )</td>
<td>( C_3 = 167.4 \mu F, L_3 = 0.004395 \mu H )</td>
</tr>
<tr>
<td>( g_6 )</td>
<td>( L_6 = 0.08372 \mu H, C_6 = 8.789 \mu F )</td>
</tr>
</tbody>
</table>

Table 2: Values of L and C for Schematic Design

Here in Table 2 the \( g_1 \) to \( g_6 \) represents capacitor and inductance values of filter for the corresponding \( g \) values. In band pass filter \( g_0 = g_6 = 1, g_1 = g_5 \) and \( g_2 = g_4 \) to form a symmetrical network and its respective capacitor and inductor values are calculated using the equ. (5)

**III. Simulation results and discussions:**
1. Schematic circuit for Bandpass filter design using lumped components:

By using Table 2 the Schematic Bandpass filter is constructed and its corresponding simulation results are verified with the design value of 1.9 GHz as shown in Eqs (1). Calculation of Even and Odd mode impedance \( (Z_{\text{e}} \& Z_{\text{o}}) \) for Microstrip line circuit is shown in Eqs [5] and tabulated in Table 2

\[ Z_{\text{0}} J_1 = \sqrt{\frac{\Delta}{2g_1}}, Z_{\text{o}1} = Z_{\text{0}} (1+ Z_{\text{0}} J_1 + (Z_{\text{0}1} J_1)^2), Z_{\text{0}2} = Z_{\text{0}} (1+ Z_{\text{0}2} + (Z_{\text{0}2} J_2)^2) \] (9)

\[ Z_{\text{0}2} = \frac{\pi \Delta / 2}{\sqrt{g_1 g_2}}, Z_{\text{0}2} = Z_{\text{0}} (1+ Z_{\text{02}} + (Z_{\text{02}} J_2)^2) \] (10)

Figure 2: Schematic Bandpass filter design using lumped components and its corresponding simulations results.

By using table 2 the Schematic Bandpass filter is constructed and its corresponding simulation results Fig 2 are verified with the design value of 1.9 GHz as shown in Eqs (1). Calculation of Even and Odd mode impedance \( (Z_{\text{e}} \& Z_{\text{o}}) \) for Microstrip line circuit is shown in Eqs [5] and tabulated in Table 2
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\[ Z_{0j3} = \pi \Delta/2 \sqrt{g_2 g_3}, Z_{0e3} = Z_0[1 + Z_0J3 + (Z_0J3)^2], Z_{0o3} = Z_0[1 - Z_0J3 + (Z_0J3)^2] \] (11)

<table>
<thead>
<tr>
<th>Order of filter</th>
<th>( Z_0e (\Omega) )</th>
<th>( Z_0o (\Omega) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>136.524</td>
<td>45.730</td>
</tr>
<tr>
<td>1</td>
<td>88.375</td>
<td>37.505</td>
</tr>
<tr>
<td>2</td>
<td>68.140</td>
<td>39.860</td>
</tr>
<tr>
<td>3</td>
<td>68.140</td>
<td>39.860</td>
</tr>
<tr>
<td>4</td>
<td>88.375</td>
<td>37.505</td>
</tr>
<tr>
<td>5</td>
<td>136.524</td>
<td>45.730</td>
</tr>
</tbody>
</table>

Table 3: odd and even impedance

The Selection of actual Microstrip lines is done using Line Clac in ADS, Substitute the values of \( Z_{0e} \), \( Z_{0o} \) as per table 3 in LineClac. Note down the values of Length (L), Width (W) and spacing(S) between the Microstrip line in mil respectively and tabulate the values for all the lines as shown in Table 4.

<table>
<thead>
<tr>
<th>Order of the filter</th>
<th>W (mil)</th>
<th>S (mil)</th>
<th>L (mil)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L_1</td>
<td>6.7842</td>
<td>5.7513</td>
<td>208.3094</td>
</tr>
<tr>
<td>L_2</td>
<td>21.0640</td>
<td>8.4331</td>
<td>200.5882</td>
</tr>
<tr>
<td>L_3</td>
<td>31.6245</td>
<td>19.4311</td>
<td>195.9032</td>
</tr>
<tr>
<td>L_4</td>
<td>31.6245</td>
<td>19.4311</td>
<td>195.9032</td>
</tr>
<tr>
<td>L_5</td>
<td>21.0640</td>
<td>8.4331</td>
<td>200.5882</td>
</tr>
<tr>
<td>L_6</td>
<td>6.7842</td>
<td>5.7513</td>
<td>208.3094</td>
</tr>
</tbody>
</table>

Table 4: Tabulation of W, S and L in mil

2. Equivalent microstrip line schematic circuit using table 4

Figure 3: Schematic microstrip line and its Simulation results

Bandpass Filter using Microstrip lines and its simulation results are shown in Fig 3 and verified with the designed value of bandwidth as shown in the Eqs (1)

3. Compact Bandpass Microstrip Filter
A Compact Bandpass Microstrip Filter is a 5th order Filter with Folded inverted C structure using Microstrip lines as shown in the Fig 4 by doing so its size is reduced to almost to 1/3rd and bandwidth is also achieved.

<table>
<thead>
<tr>
<th>Type of Filter</th>
<th>Size</th>
<th>BW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hairpin Filter[1]</td>
<td>Width=27.7156mm, Height=8.5204mm</td>
<td>0.4GHz</td>
</tr>
<tr>
<td>Proposed Filter</td>
<td>Width=7 mm, Height=10mm</td>
<td>1.9GHz</td>
</tr>
</tbody>
</table>

Table 5: Comparative study

The proposed filter is very good in two parameters compactness and bandwidth as shown in table 5

IV. Conclusion:
As the frequency increases the reactance of the lumped components (Inductors and Capacitors) varies and it’s not constant hence size of the filter will be very large. Therefore it is not possible to maintain the proper characteristics of the filter at higher frequencies and difficulty to fabricate the large-size structure. Therefore, to overcome this difficulty, it’s better to use Microstrip Line Filters to reduce the size. Hence, a Compact Bandpass Microstrip Filters presented in this paper using Keysight’s ADS software with the operating frequency at 5.87GHz. The design has been performed using parallel-coupled Microstrip transmission line structures with good compactness and BW of 1.9GHz, minimum insertion loss of -0.5dB. This filter is much useful for wireless communication applications like Bluetooth, WiFi, and 5G.

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