Spiral Inductor and Interdigital Capacitor Based Coupled Resonator Bandpass Filter

Dhara P Patel
V.T Patel Department of Electronics and Communication Engineering,
C.S Patel Institute of Technology,
Faculty of Technology and Engineering,
Charotar University of Science and Technology (CHARUSAT),
Gujarat, India. ORCID ID: 0000-0002-2125-7599.

Abstract - 5G Wireless Communication systems are gradually becoming compact and more advanced. As a part of future wireless transceiver, the bandpass filter has been designed using coupled spiral inductor and interdigital capacitor using Microstrip technology. Their quasi-lumped dimensions make the proposed filter compact and its high frequency equivalent circuit prove them as RLC resonator. The proposed resonator filter is analyzed and optimized using High frequency Structure Simulator on GaAs substrate using High Frequency Structure Simulator (HFSS). The results are compared with the existing Bandpass filter and it shows better performance.

Keywords—Bandpass Filter, Inter-digital Capacitor, Coupling, Compact, Filter Resonator, Spiral Inductor

I. INTRODUCTION

5G connects practically everyone and everything, including computers, objects and devices, to be linked together. Ultra-high-speed 5G mobile networks are accelerating in research to meet this. Because of their advantageous properties, including wave propagation and usable bandwidth, lower 5G bands (3.3 GHz-4.2 GHz and 4.4 GHz-4.99 GHz) are suitable for early implementation. Ultra-wideband filter has been developed and simulated in order to meet this challenge and to meet the current demands [1].

For the design of radio frequency RF/Microwave filters, coupled resonator circuits are of importance, particularly the narrow-band bandpass filters (BPFs) that play a significant role in many applications [1]. Various techniques such as design of waveguide filter, dielectric resonator filter, ceramic combline filter, microstrip filter, superconducting filters and micro-machined filters are discussed in [4] to extend the bandwidth of bandpass filter. Another way of constructing broadband filters is cascading high pass and low pass filters. In order to achieve an optimal bandpass response, no systematic way to measure the ideal response of the low- and high-pass sections is known [2]. At high frequency active components are also playing vital role to design the RF components [5-8].

The proposed bandpass filter presents the design of bandpass filter which is beyond the narrowband approximation. It consists of two lumped elements (spiral inductor and Interdigital capacitor) in shunt form to design coupled resonator based filter. The designed bandpass filter covers the pass band range of 1.6 GHz to 10 GHz frequency. The filter designed on GaAs substrate having the height of 0.8 mm. The filter shows insertion loss of 0.1 dB and return loss of 58 dB, fractional bandwidth of 145% and dimensions are 4mm×8mm.

II. METHODS

(A) COUPLED RESONATOR FILTER

For representing a broad range of coupled-resonator filter topologies, the general coupling matrix is of interest as shown in Fig.1. Inductance, capacitance, and resistance, respectively, are denoted by L, C, and R. The network representation is presented in Fig.2.

Qualumped monolithic components—Inter-digital capacitor and Rectangular Spiral Inductor are used to design wideband filter. The electrical circuit proves to behave like a resonator.

(B) INTER DIGITAL CAPACITOR

Interdigital capacitor is one type of monolithic or integrated capacitor. It is a periodic system with several fingers, as seen in Fig.3.
The expression Kg represents the existence of a ground plane and decreases as the plane on the ground is brought closer. The terms W, t, h and Rsh are the line width, line thickness, substrate thickness, length of the section, and sheet resistance per square of the conductor, respectively.

(D) COUPLING COEFFICIENT
Resonator coupling coefficients are commonly used in the design of resonators. They provide a reasonably precise method for the direct synthesis of narrow-band filters and provide initial estimation parameters of the structure for wide-band filter optimization synthesis [10].
A dimensionless physical quantity representing the coupling coefficient is the coupling between two lumped components. The value of coupling coefficient defines how well the lumped components are coupled to each other [11]. Their Electric Coupling (kE), Magnetic Coupling (kM) and mixed coupling (kX) are defined as Eqs. (iii), (iv) and (v), respectively.

\[
k_E = \frac{f_{2m}^2 - f_{1m}^2}{f_{1m}^2 + f_{2m}^2} = \frac{c_m}{c} \quad \text{(iii)}
\]

C and \( c_m \) represent the self-capacitance and mutual capacitance, respectively.

\[
k_M = \frac{f_{2m}^2 - f_{1m}^2}{f_{1m}^2 + f_{2m}^2} = \frac{\lambda_m}{\lambda} \quad \text{(iv)}
\]

L and \( \lambda \) represent the self-inductance and mutual inductance, respectively.

\[
k_X = \frac{f_{2m}^2 - f_{1m}^2}{f_{1m}^2 + f_{2m}^2} = \frac{c_m L}{L_m + c_m} \quad \text{(v)}
\]

Where, \( C, L, C_m \) and \( L_m \) are self-capacitance, the self – inductance, the mutual capacitance and the mutual inductance of an associated equivalent lumped element circuit. Resonance frequency and quality factor are listed as Eq. (vi) and (vii), respectively. Where, \( Q_u \) is the unloaded quality factor and \( Q_e \) is the external quality factor of the resonator.

\[
\text{Resonance frequency } f_0 = \frac{1}{2\pi\sqrt{LC}} \quad \text{(vi)}
\]

\[
\frac{1}{Q_u} = \frac{1}{Q_0} + \frac{1}{Q_e} \quad \text{(vii)}
\]

III. RESULTS AND DISCUSSION
Fig 7 shows the proposed band pass filter configuration. Rectangular spiral inductor and Interdigital capacitor are connected to form parallel LC tank circuit. Fig.8 presents implementation on the band pass filter on microstrip technology. Fig 9 depicts its physical dimensions. The quasi-lumped dimensions \( \frac{h}{h} \) are taken with reference to the guided waveguide at cut off frequency of 8GHz.
Figure 7: Spiral Inductor and Inter-digital Capacitor based LC tank Circuit

Figure 8: Micro strip design of Figure 7

Figure 9: Dimensions of Proposed Resonator Filter

By considering the GaAs substrate dielectric constant 12.9 and height of 0.8mm the bandpass filter is simulated. The input and output port are of 50 ohm resistance. Fig. 10 illustrates its S-parameter response that shows the return loss of 58 dB and insertion loss of 0.1 dB.

Table 1. Comparison with existing research work.

<table>
<thead>
<tr>
<th>Sr.No.</th>
<th>Passband range (GHz)</th>
<th>Fractal Bandwidth (%)</th>
<th>Insertion loss (dB)</th>
<th>Dimension (mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ref.12</td>
<td>2.8 - 10.6</td>
<td>116</td>
<td>0.4</td>
<td>34.6 x 14.6</td>
</tr>
<tr>
<td>This work</td>
<td>1.6 - 10.1</td>
<td>145</td>
<td>0.1</td>
<td>4 x 8</td>
</tr>
</tbody>
</table>

IV: CONCLUSION

Table 1 compares the latest UWB bandpass filter and proposed filter. The presented design offers the better response in terms of fractral bandwidth, Insertion loss and miniaturization. For compact wireless communication transceivers, the proposed bandpass filter demonstrates its improved application.

REFERENCES


