A Dual-Band Coupled Line Based Microstrip Diplexer for Wireless Applications

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Abstract

In this article, a coupled line stepped impedance resonator are used to build diplexer microstrip filters. The design method is based on mathematical expressions to determine the effective properties for tuning the resonance frequencies. A coupled line resonator attempts to improve insertion losses and return losses on the two bands without extending the total isolation. The planned diplexer introduced with overall Scale14×75 mm2 works at 2.6 GHz and 6 GHz with WiMAX and wireless technological advances. The insertion loss are 0.8 dB and 0.9 dB at first and second resonance frequencies, with return loss of 17 dB and 25 dB respectively it simulates, produces and tests the proposed framework. The findings of the calculation are fully in line with the simulations

Keywords: Diplexer, Coupled Lines, Microstrip, Step Impedance

1. Introduction

An important tool for new wireless communication designs is the microstrip diplexer. Two ports multiplexes to another port for multiband isolation/ wideband antenna frequencies. Two Bands are connected together as a diplexer to accomplish this task. In general, high-performance diplexers need to be lightweight and inexpensive, such as strong insulation, low losses, high selectivity and easy manufacturing.

Designers have tried to achieve 3 microstrip diplexers in recent years, utilizing different structures for conventional microwave transceivers. Nonetheless, Jian-Kang Xiao and Min Zhu in 2015 a high isolation and better selective is produced by using a coupling technique is mixed electromagnetic coupling. Transmission zeros may also be balanced with the aid of the electrical and magnetic coupling. The diplexer is developed and weighed, and the latest concept is proved through measurement [1].
Mohammad Reza Salehi and Sina Keyvan for 4G wireless communication system in 2016 based on triangle open loop asymmetric stepped impedance resonator to be a limited scale and simple structure. The diplexer is developed at 2.30 GHz and 2.55 GHz. The measurements indicate strong compatibility between a simulated diplexer and a fabricated model [2].

X. Wu, F. Wan and J. Ge Stub-loaded principle reviewed in 2016 is extended and introduced for the design of balanced multi band pass filter with bandwidths and passband frequencies independently controlled. Conferring the proposed principle of loaden stub, the 1\textsuperscript{st} differentiation resonance mode may be prepared separately by the loaded stub, when the 2\textsuperscript{nd} may not be affected. In comparison, with the exception of the key coupling direction, the first passband's coupling coefficient can be independently controlled by one more coupling path between the loaded stubes [3].

Leila Noori and Abbas Rezaei in 2017 a new combining the coupling Sections for lines loops, low impedance and step-impedance are applied to build a diplexer with microstrip. The concept approach is based on the obtain transmitting matrices and consider appropriate parameters for resonance frequency tuning. This diplexer is worked on two bands the first is 2.6 GHz for WIMAX and 6GHz for wireless application [4].

Abdessamed Chinig in 2017 a diplexer is designed for DCS and WIMAX application using 2.5 GHz and 1880 MHz each filter based on mender line and feed line resonators. Good electrical performances are obtained after an optimization of the proposed circuit [5].

Qun Li and Yonghong Zhang in 2018 a high isolation microstrip diplexer filter is designed using feeding line coupling technology based on stubs load resonator to create transmission zero at lower frequency. Its working on two channel 3 ang 5 GHz for wireless application with high isolation [6].

Jian-Kang Xiao and Min Zhang in 2018 a novel structure of magnetic coupling has been designed to produce high selective dual band pass filter. This diplexer is worked on 2.6 and 3.3 GHZ for WIMAX application [7].

Salif N. Dembele and Jingfu Bao [14] a dual band pass diplexer for x band application, worked on 8.3 and 10 GHz and it's based on dual closed loop stepped impedance resonator (DCLSIR). The planned microstrip diplexer consists of two compounds bandpass filters for DCLSIR (BPFs) [8].

Salah I. Yahya and Abbas Rezaei in 2020 design a flat dual-channel bandpass microstrip diplexer. It has a very compact size of 0.0081 λg 2 (95.7 mm2) manufactured at a height of 0.798 mm with a dielectric constant of substrate. It has a wide fractional bandwidth (FBW per cent) of 34.3 per cent on the first channel with 38.9 per cent on first one. Make the proposed diplexer suitable for 2nd channel broadband applications. The resonance frequencies for the L-band are located at f1 = 1.6 GHz. For WiMAX applications, f2 = 3 GHz [9].

Abbas Rezaei and Salah I. Yahya in 2020 The architecture is focused on the flicker and small cells optimized then work at 0.79 GHz and 1.86 GHz for communications requirements. Because of proposed resonator's symmetrical configuration, Analyzes of the odd and even modes was carried out to obtain information on the resonator behaviour. The introduced diplexer has several advantages with respect to low insertion losses, low return losses, good insulation and compact size [10].

The diplexer filter with substrate of RO4350 have insertion loss of 0.5 dB and 2 dB and return loss of 16 dB and 25 dB with dimensions of 14×75 mm² and it
was the best response compared with other published work.

2. Design of Coupled Line

The cross section of a coupled line is shown in Figure 1. Widely applied in the filter design, they support two modes of even and odd excitation [11].

![Coupled line structure](image)

**Figure 1: Coupled line structure**

I. Even and Odd Modes

In even mode the microstrip coupled lines perform the same voltage potential in a magnetic wall at the symmetry plane in even mode excitation together as shown in Figure 2. Even capacitance mode is proved by [12]:

\[ C_e = C_p + C_f + C'_f \]  

(1)

Where \( C_p \) is the capacitance of the parallel layer among the microstrip panel with ground plane, therefore:

\[ C_p = \epsilon_0 \epsilon_r \frac{w}{h} \]  

(2)

While \( C_f \) is capacitance of the fringe set as:

\[ 2 C_f = \frac{\sqrt{\epsilon_r \epsilon_e}}{c Z_e} - C_p \]  

(3)

Then

\[ A = e^{-0.1e^{(2.33-2.53)W/\pi}} \]  

(4)

The characteristic impedance of even mode can be getten from the capacitance too.

\[ Z_{ce} = \left( \frac{c}{\sqrt{\epsilon_r \epsilon_e}} \right)^{-1} \]  

(5)

While \( \epsilon_r^a \) is also the capacitance mode with the dielectric air\( c_e \) and the effective dielectric constant for even mode is given as:

\[ \epsilon_{re} = \frac{c_e}{\epsilon_e} \]  

(6)

The Z even for coupled line can found by using :

In odd mode the coupled microstrip line has opposite potentiality in odd mode. That results in the symmetry of an electrical wall. The cross section graph that follows shows the same as shown in Figure 2 (a) [13].

An odd mode capacitance is proved by [14]:

\[ C_o = C_p + C_f + C_{gd} + C_{ga} \]  

(7)
Where $C_{ga}$ and $C_{gd}$ acts as a fringe capacitance through the two microstrip line cross the air and the dielectric.

$$C_{ga} = \varepsilon_{\infty} \frac{k'(k')}{2\sqrt{\varepsilon_{\infty}}} \quad (8)$$

while

$$K = \frac{h}{\frac{2w}{\pi}} \quad (9)$$

$$k' = \sqrt{1 - k^2} \quad (10)$$

The elliptical feature ratio $\frac{K(k')}{K(k)}$ is given by

$$\frac{K(k')}{K(k)} = \begin{cases} \frac{1}{\pi} \ln \left( \frac{1+\sqrt{k'}}{1-\sqrt{k'}} \right) & \text{for } 0 \leq k^2 \leq 0.5 \\ \frac{\pi}{\ln \left( 2^{1+\sqrt{k'}} \right)} & \text{for } 0 \leq k^2 \leq 0.5 \end{cases} \quad (11)$$

The odd mode feature impedance and $\varepsilon_{\text{eff}}$ is set as [15].

$$Z_{co} = \left( c \sqrt{\varepsilon_{\infty} c^2_0} \right)^{-1} \quad (12)$$

Where $c^2_0$ is the even mode capacitance with air as a dielectric [16]:

$$\varepsilon^0_{re} = \frac{c_0}{c^2_0} \quad (13)$$

![Figure 2: The Coupled Microstrip Modes (a) Even (b) Odd](image)

**III. Parallel-Coupled, Half-Wavelength Resonator Filters**

A general layout of parallel-coupled (or edge-coupled) microstrip bandpass filters demonstrates in Figure 3 that utilize resonators with half-wavelength axes. They are positioned in such a way that adjacent resonators along half their length are parallel to each other. This parallel system offers fairly broad interconnections for a defined spacing.
Figure 3: Microstrip bandpass filters demonstrate

This filter structure is especially handy between resonators to create filters with a wider bandwidth compared to the end-coupling microstrip filter structure. The design equations for this filter type are indicated by [17].

\[
\frac{J_{01}}{Y_0} = \sqrt{\frac{\pi}{2}} \frac{FBW}{g_1 g_2} \quad (14)
\]

\[
\frac{J_{n,n+1}}{Y_0} = \sqrt{\frac{\pi FBW}{2g_1 g_{n+1}}} \quad (15)
\]

\[
\frac{J_{j,j+1}}{Y_0} = \frac{\pi FBW}{2 \sqrt{g_1 g_{j+1}}} \quad j = 1 \text{ to } n-1 \quad (16)
\]

where \(g_0\), \(g_1\) . . . \(g_n\) are part of a ladder-kind lowpass prototype development with a normalized \(\Omega c\) equal one, \(FBW\) is the fractional bandwidth of bandpass filter. \(J_{j,j+1}\) are the distinctive feature admittances of \(J\)-inverters and \(Y_0\) is the characteristic admittance of the terminating lines.

The distinctive feature impedances of coupled line microstrip resonators are calculated in order to realize the \(J\)-inverters obtained above

\[
(Z_{0e})_{j,j+1} = \frac{1}{Y_0} \left[ 1 + \frac{J_{j,j+1}}{Y_0} + \left( \frac{J_{j,j+1}}{Y_0} \right)^2 \right] \quad j = 0 \text{ to } n \quad (17)
\]

\[
(Z_{0o})_{j,j+1} = \frac{1}{Y_0} \left[ 1 - \frac{J_{j,j+1}}{Y_0} + \left( \frac{J_{j,j+1}}{Y_0} \right)^2 \right] \quad j = 0 \text{ to } n \quad (18)
\]

The actual lengths of each coupled line section are then determined by

\[
l_j = \frac{\lambda_0}{4(\sqrt{(\varepsilon_r)_j} \times (\varepsilon_m)_j)^{1/2}} - \Delta l_j \quad (19)
\]

where \(\Delta l_j\) is the equivalent length of microstrip open end
3. Filter Design and Implementation

I. Introduction

An iterative design process that starts with the design constraints and initial values that refer to the expressions in the closed form described above. The centre frequencies of the passband are 2.6 GHz for the 1st band and 6 GHz for the 2nd band, can be used in a wide variety of wireless communication applications such as WiMax and 802 IEEE Standard application.

II. Design specification

The proposed diplexere filters have several specifications such as thickness, dielectric constant … etc as shown in Table 1.

<table>
<thead>
<tr>
<th>Specifications</th>
<th>proposed design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials (Substrate)</td>
<td>Roger (RO4350)</td>
</tr>
<tr>
<td>TanD</td>
<td>0.0037</td>
</tr>
<tr>
<td>Dielectric constant</td>
<td>3.7</td>
</tr>
<tr>
<td>Thickness (mm)</td>
<td>1.524</td>
</tr>
</tbody>
</table>

By using the prototype calculations and expressions from 14 to 19, in section one, the even and odd impedance of each coupled line of 3 order filter are obtained as listed in Table 2. The coupling coefficient for 0.1 dB ripple also calculated to get the circuits parameters.

<table>
<thead>
<tr>
<th>N</th>
<th>For 2.6 GHz</th>
<th>For 6 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$Z_{0n}$</td>
<td>$Z_{oe}$</td>
</tr>
<tr>
<td>1</td>
<td>0.59</td>
<td>97.1</td>
</tr>
<tr>
<td>2</td>
<td>0.87</td>
<td>132.5</td>
</tr>
<tr>
<td>3</td>
<td>0.39</td>
<td>97.1</td>
</tr>
</tbody>
</table>

Both such Even and odd mode transmission line impedance are submitted in ADS to LineCalc package along with the values of the parameters. The length, width, and spacing value between the resonators are then modified, the values are given in Table 3.

It could be attention that the design of dual bandpass filter using the coupled line technology is used half-wavelength line resonator. They are arranged to get the best resonator along half of their wavelength this parallel arrangement provides a relatively large coupling for a given spacing.

This filter structure is particularly convenient between the resonators and thus for the construction of filters with a wider bandwidth compared to the structure for the final coupled microstrip filters described in the previous.
Fabricated PSCs are carefully connected to Anritsu Wiltron MS4642B Vector Network Analyzer - 10 MHz to 20 GHz for the measurement. After the preparation of all the requirements for experimental testing, the first prototype filter of (RO4350) is connected with the MS4642B network analyser to measured the four parameters $S_{11}, S_{21}, S_{31}$ and $S_{23}$. After complete the measurement, a comparission between the simulation and experimental result is done as shown in Figure 4.

**Table 3: The length, width, and spacing value between the resonators**

<table>
<thead>
<tr>
<th>N</th>
<th>Width (mm)</th>
<th>Space (mm)</th>
<th>Length (mm)</th>
<th>Width (mm)</th>
<th>Space (mm)</th>
<th>Length (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.8</td>
<td>0.13</td>
<td>17</td>
<td>2.5</td>
<td>0.3</td>
<td>7</td>
</tr>
<tr>
<td>2</td>
<td>2.5</td>
<td>0.3</td>
<td>15</td>
<td>3.5</td>
<td>1.3</td>
<td>6.2</td>
</tr>
<tr>
<td>3</td>
<td>1.8</td>
<td>0.13</td>
<td>17</td>
<td>2.5</td>
<td>0.3</td>
<td>7</td>
</tr>
</tbody>
</table>

**Figure 4: A comparison between the simulation and experimental result**

The presented study in this thesis is contrasted with related activities in this field as outlined in the Table 4, it can be noticed that there is the high response of this prototype filter compared with the previous study. The response obtained in this study indicate there is an improvement of several parameter such as the return loss, insertion loss and isolation as shown in the table above, instead of small band rejection and mainly large size
Table 4: Comparison of results with previously published researches

<table>
<thead>
<tr>
<th>Ref.</th>
<th>FC1 GHz</th>
<th>FC2 GHz</th>
<th>IL1</th>
<th>IL2</th>
<th>RL1</th>
<th>RL2</th>
<th>Isolation</th>
<th>Size (mm*mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[4]</td>
<td>2.6</td>
<td>6.0</td>
<td>0.6</td>
<td>0.9</td>
<td>&gt;10</td>
<td>&gt;10</td>
<td>13</td>
<td>25.7×22.3</td>
</tr>
<tr>
<td>[13]</td>
<td>1.8</td>
<td>2.45</td>
<td>2.2</td>
<td>1.8</td>
<td>17</td>
<td>16</td>
<td>21</td>
<td>20.0×52.0</td>
</tr>
<tr>
<td>[6]</td>
<td>2.95</td>
<td>4.92</td>
<td>1.43</td>
<td>1.47</td>
<td>16</td>
<td>18</td>
<td>&gt;40</td>
<td>17.7×11.0</td>
</tr>
<tr>
<td>[8]</td>
<td>8.3</td>
<td>10</td>
<td>1.8</td>
<td>1.9</td>
<td>10</td>
<td>10</td>
<td>26.6</td>
<td>15.1×2.6</td>
</tr>
<tr>
<td>[14]</td>
<td>2.4</td>
<td>5.2</td>
<td>1.94</td>
<td>2.55</td>
<td>10.8</td>
<td>12</td>
<td>25</td>
<td>35×23.16</td>
</tr>
<tr>
<td>[15]</td>
<td>2.4</td>
<td>2.6</td>
<td>2.24</td>
<td>3.17</td>
<td>12.4</td>
<td>17.86</td>
<td>15</td>
<td>134×68.47</td>
</tr>
<tr>
<td>[16]</td>
<td>1.8</td>
<td>2.45</td>
<td>2.05</td>
<td>2.15</td>
<td>15</td>
<td>15</td>
<td>25</td>
<td>50×53</td>
</tr>
<tr>
<td>[17]</td>
<td>2.36</td>
<td>5.17</td>
<td>2.3</td>
<td>2.8</td>
<td>-</td>
<td>-</td>
<td>18</td>
<td>61.8×34.7</td>
</tr>
<tr>
<td>This work</td>
<td>2.6</td>
<td>6</td>
<td>0.5</td>
<td>2</td>
<td>16</td>
<td>25</td>
<td>23</td>
<td>14×75</td>
</tr>
</tbody>
</table>

4. Conclusions

The results obtained by simulation and implementation in this work are of fundamental importance and interest in the field of design of dual-band microstrip filter using coupled-line. The main issues are as a proposed microstrip diplexer has been designed and manufactured using coupled line stepped impedance resonator operated at 2.6 and 6 GHz for WiMAX and wireless applications respectively. The proposed design has been manufactured in PCBway and Fastturn companies in China and tested in the ministry of science and technology in Iraq. The insertion losses at the first and second resonance frequencies are 0.8 dB and 0.9 dB, with return loss of 17 dB and 25 dB respectively.

5. References

[6] Q. Li, Y. Zhang, and C. T. M. Wu,


