Enhanced Performance of Substrate Integrated Waveguide Bandstop Filter using Circular and Radial Cavity Resonator

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Abstract—Circular and Radial SIW cavity resonators are proposed to enhance the performance of SIW bandstop filter. Prior to this research work, rectangular cavity resonator was used to produce bandstop response. The design of the circular and radial SIW bandstop filters are done by directly coupling circular and radial cavity resonators to the SIW line. The SIW bandstop filters are designed to operate at X-band and implemented on Rogers RO4350 substrate with a thickness of 0.508mm. Simulated and measured results show good bandstop responses and thus useful in microwave bandstop filter design.

Keyword—Bandstop Filter, Substrate Integrated Waveguide, Cavity Resonator, Stopband Bandwidth

I. INTRODUCTION

Bandstop filter plays an important role in attenuating unwanted signal in microwave communication systems. The current trend of miniaturization and integration leads towards the use of planar transmission lines such as microstrip and stripline rather than conventional waveguide [1]. Defected ground structure has been used on microstrip filter to design a bandstop filter [2]. Defected microstrip structure has been used to design bandstop filter [3]. Recently, defected microstrip structure and defected ground structure are utilized to produce miniaturized dual-band bandstop filters [4]. Uniplanar double spiral resonant cells bandstop filter has been shown to have a high rejection but has been designed for broad stopband [5]. Substrate integrated waveguide was first proposed by Pilote, Flanik and Zaki with the title of waveguide filter having a layered dielectric structure [6]. Substrate integrated waveguide has the advantages of low insertion loss, high Q-factor and can be implemented in planar form. SIW is formed by two periodic rows of metallic via hole on a dielectric substrate [7].

Only a few research papers on bandstop filters were done using SIW technique. A multiple SIW bandstop filter had been designed by transversal coupling network [8]. SIW cavity resonator separated by unity impedance inverters had been used to design a single bandstop filter [9]. Further to that, a single bandstop filter had been designed by directly coupling three cavity resonators to SIW line [10]. Even and odd predistortion technique was presented to design a SIW bandstop filter [11]. Another design had used an impedance inverter network connected across a two-port network SIW bandpass filter to function as a bandstop filter [12]. Bandstop filter has also been designed based on a dual-band bandstop filter topology [13].

Prior to this research, only rectangular cavity resonator structure was used in the design of SIW bandstop filter while SIW circular cavity filter had been used for bandpass filter design [14-15]. In this paper, circular and radial cavity resonators are design incorporated for the bandstop filters. The bandstop filters are designed by coupling SIW cavity resonators to a SIW line to produce broad passband and bandstop response. However, the rectangular cavity resonator bandstop filter is also fabricated for comparison.

II. SIW BANDSTOP FILTER DESIGN

A. Substrate Integrated Waveguide Transmission line design

SIW line functions as a waveguide in transmitting the input signal to the load. In SIW structure, only TE_{M0} modes can be excited and extracted in the structure, thus, TM modes do not exist in the SIW structure [16]. The lower passband cutoff frequency for the SIW line is the corresponding resonant frequency \( f_c \). Therefore, effective width of the SIW line \( W_{eff} \) can be determined [7] by:

\[
 f_c(TE_{10}) = \frac{c}{2\sqrt{\varepsilon_r}} \left( W - \frac{d^2}{0.95 \cdot p} \right)^{-1}
\]
where $W$ is the width of the SIW line, $d$ is the diameter of the metallic via holes and $p$ is the spacing between the via holes.

The diameter $d$ and the spacing between the via holes $p$ are determined by using a set of design rules for the substrate integrated waveguide [16-18] given as:

\[
d < p < 2d \quad \text{(3)}
\]

\[
d < \lambda_c / 5 \quad \text{(4)}
\]

\[
p / \lambda_c < 0.25 \quad \text{(5)}
\]

where $\lambda_c$ is the cutoff wavelength and $\lambda_g$ is the guide wavelength.

The bandstop filters are designed to operate at X-band. So, a lower resonant frequency for the SIW line is preferred to obtain a good passband response along the band. 6GHz is the selected resonant frequency and the $W_{\text{eff}}$ length of 13.06mm is obtained.

B. Coupling of the cavity resonator to SIW line

The coupled position of the resonator to SIW line is determined to get strong electric field intensity coupling between cavity resonator and SIW line. The position of the resonator is placed at 19.59mm from the input of the SIW line to the centre of the cavity resonator. The input width of the cavity resonator for the three designs is set at 8.3mm which is the adequate width for the three designs to operate and function.

C. Configuration of the resonators

For the rectangular cavity resonator, there are two critical parameters which are the width, represented by $a$ and the length, represented by $b$ that affect the bandstop response. While for the circular cavity resonator, the two critical parameters are the radius and the length of the circle represented by $r$ and $l$ respectively that affect the bandstop response. As for the radial cavity resonator, there are three parameters, the span degree, the radius and the coupling length of the radial represented by $rd$, $r$ and $l$ respectively. Fig. 1, Fig. 2 and Fig. 3 show the configuration of the rectangular, circular and radial cavity resonator SIW bandstop filter design.

\[
W_{\text{eff}} = W - \frac{d^2}{0.95 \cdot p} \quad \text{(2)}
\]
III. SIMULATION RESULTS

The simulations are carried out to investigate the performance produced by each resonator. These are done by varying the value of one parameter while the rest of the dimensions are being kept constant. The analyses of the performances are based on the centre stopband frequency, 3dB stopband bandwidth, attenuation and average insertion loss. 3dB stopband bandwidth is a crucial parameter for any bandstop filter design [19].

![Configuration of radial cavity resonator SIW bandstop filter](image)

**Fig. 3** Configuration of radial cavity resonator SIW bandstop filter

**TABLE I**

Frequency response of variation of $a$ for rectangular cavity resonator with dimensions $b=9\text{mm}$, $c=8.3\text{mm}$, and $d=13.06\text{mm}$

<table>
<thead>
<tr>
<th>$a$(mm)</th>
<th>Center Stopband Frequency (GHz)</th>
<th>3dB Stopband Bandwidth (MHz)</th>
<th>Attenuation (dB)</th>
<th>Average insertion loss (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.06</td>
<td>9.75</td>
<td>559</td>
<td>-18.7</td>
<td>-1.2</td>
</tr>
<tr>
<td>13.06</td>
<td>9.27</td>
<td>511</td>
<td>-18.0</td>
<td>-1.2</td>
</tr>
<tr>
<td>15.06</td>
<td>8.99</td>
<td>498</td>
<td>-17.7</td>
<td>-1.3</td>
</tr>
</tbody>
</table>

![Frequency response of variation of $a$ for rectangular cavity resonator with dimensions $b=9\text{mm}$, $c=8.3\text{mm}$, and $d=13.06\text{mm}$](image)

**Fig. 4** Frequency response of variation of $a$ for rectangular cavity resonator with dimensions $b=9\text{mm}$, $c=8.3\text{mm}$, and $d=13.06\text{mm}$.  

The graphs show the frequency response of the filter for different values of $a$. The centre stopband frequencies are 9.75 GHz, 9.27 GHz, and 8.99 GHz for $a=11.06$, $a=13.06$, and $a=15.06$ mm, respectively. The 3dB stopband bandwidths are 559 MHz, 511 MHz, and 498 MHz, respectively. The attenuation is consistently around -17.7 dB, and the average insertion loss is below 1.3 dB, indicating good performance for the filter design.
Table II

<table>
<thead>
<tr>
<th>$b$ (mm)</th>
<th>Center Stopband Frequency (GHz)</th>
<th>3dB Stopband Bandwidth (MHz)</th>
<th>Attenuation (dB)</th>
<th>Average insertion loss (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>10.10</td>
<td>664</td>
<td>-17.5</td>
<td>-1.3</td>
</tr>
<tr>
<td>9</td>
<td>9.27</td>
<td>511</td>
<td>-18.0</td>
<td>-1.2</td>
</tr>
<tr>
<td>11</td>
<td>8.62</td>
<td>397</td>
<td>-13.9</td>
<td>-1.4</td>
</tr>
</tbody>
</table>

For the rectangular cavity resonator, the width $a$ and length $b$ are investigated and the results are shown in Fig. 4, Fig. 5, Table I and Table II. The results show that an increase in the width $a$ resulted in a decrease in the centre stopband frequency, stopband bandwidth and attenuation. Similarly, the increase in the length $b$ indicates a decrease in the centre stopband frequency and stopband bandwidth but not the attenuation. There is peak attenuation at certain length, in this case at 9mm.

Table III

<table>
<thead>
<tr>
<th>Radius $r$ (mm)</th>
<th>Center Stopband Frequency (GHz)</th>
<th>3dB Stopband Bandwidth (MHz)</th>
<th>Attenuation (dB)</th>
<th>Average insertion loss (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.7</td>
<td>8.78</td>
<td>434</td>
<td>-15.4</td>
<td>-1.3</td>
</tr>
<tr>
<td>6.2</td>
<td>9.22</td>
<td>450</td>
<td>-17.4</td>
<td>-1.3</td>
</tr>
<tr>
<td>5.7</td>
<td>9.72</td>
<td>477</td>
<td>-17.1</td>
<td>-1.3</td>
</tr>
</tbody>
</table>
For the circular cavity resonator, radius $r$ and length $l$ are investigated and the results are shown in Fig. 6, Fig. 7, Table III and Table IV. The results show that an increase in the radius $r$ and length $l$ resulted in a decrease in the centre stopband frequency, stopband bandwidth and attenuation. Parameter $r$ has the most effect on the centre stopband frequency so it has to be determined first in each design. However the length $l$ has the most effect in stopband bandwidth, so it can be used to optimize the bandstop response.

For the radial cavity resonator, degree $rd$ and length $l$ are investigated and the results are shown in Fig. 8, Table V. The results show that an increase in the degree $rd$ and length $l$ resulted in a decrease in the centre stopband frequency, stopband bandwidth and attenuation. Parameter $rd$ has the most effect on the centre stopband frequency so it has to be determined first in each design. However the length $l$ has the most effect in stopband bandwidth, so it can be used to optimize the bandstop response.
For the radial cavity resonator, the radius $r$, degree of radius $rd$ and length $l$ are investigated and the results are shown in Fig. 8, Fig. 9, Fig. 10, Table 5, Table 6 and Table 7. The increase of radius $r$ and degree $rd$ result in a decrease in the centre stopband frequency and stopband bandwidth, while an increase in the length $l$ gives an increase in the centre stopband frequency and stopband bandwidth. Radius, $r$ is the most crucial parameter as it has the most influence in the bandstop response. The degree $rd$ can be used to control the centre stopband frequency as it influences the centre stopband frequency without much effect on stopband bandwidth and attenuation. The length $l$ can be used to control stopband bandwidth without much effect on centre stopband frequency.

**TABLE VI**

Frequency response of variation of radius of radial cavity resonator with dimension $rd=90^\circ$, $l=6mm$, and $W_{eff1}=8.3mm$

<table>
<thead>
<tr>
<th>Radius $r$ (mm)</th>
<th>Center Stopband Frequency (GHz)</th>
<th>3dB Stopband Bandwidth (MHz)</th>
<th>Attenuation (dB)</th>
<th>Average insertion loss (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.7</td>
<td>9.26</td>
<td>507</td>
<td>-18.5</td>
<td>-1.3</td>
</tr>
<tr>
<td>15.2</td>
<td>9.09</td>
<td>459</td>
<td>-17.2</td>
<td>-1.3</td>
</tr>
<tr>
<td>15.7</td>
<td>8.80</td>
<td>425</td>
<td>-15.4</td>
<td>-1.3</td>
</tr>
</tbody>
</table>
TABLE VII
Frequency response of variation of centre of radial cavity resonator with dimension \(\theta_d=90^\circ\), \(r=14.7\text{mm}\), and \(W_{\text{eff}1}=8.3\text{mm}\)

<table>
<thead>
<tr>
<th>Separation of the center of radius / (mm)</th>
<th>Center Stopband Frequency (GHz)</th>
<th>3dB Stopband Bandwidth (MHz)</th>
<th>Attenuation (dB)</th>
<th>Average insertion loss (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>9.26</td>
<td>507</td>
<td>-18.5</td>
<td>-1.3</td>
</tr>
<tr>
<td>5.5</td>
<td>9.23</td>
<td>464</td>
<td>-17.7</td>
<td>-1.3</td>
</tr>
<tr>
<td>5</td>
<td>9.23</td>
<td>402</td>
<td>-16.3</td>
<td>-1.3</td>
</tr>
</tbody>
</table>

IV. MEASUREMENT RESULTS

The rectangular, circular and radial cavity resonator SIW bandstop filters are fabricated on RO4350 substrate using standard PCB process to verify the simulation results. The substrate relative permittivity constant is 3.48 with 0.5mm thickness and has a loss tangent of 0.0037. The diameter of the metallic holes is 0.5mm. The separation between the metallic holes is 0.3mm. Figure 11, Figure 12 and Figure 13 show the fabricated rectangular, circular and radial SIW bandstop filter respectively.
Figure 14, Figure 15 and Figure 16 show the comparison between simulated and measured frequency response. The results show that there is a shift in the centre stopband frequency for all the three designs. The frequency shifts for the three designs are around 400MHz. The shift is mainly caused by the variation of dielectric permittivity between simulated and fabricated substrate. The increase in insertion loss and attenuation for both simulated and measured reveals the correlation between the two parameters. Thus, the simulation and measured results are in agreement with each other. The insertion loss is mostly caused by the transition loss from microstrip line to SIW.
TABLE VIII
Comparison between simulated and measured rectangular, circular and radial cavity resonator SIW bandstop filter

<table>
<thead>
<tr>
<th>Resonator</th>
<th>Simulation</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Centre stopband frequency (GHz)</td>
<td>Attenuation</td>
</tr>
<tr>
<td>Rectangular</td>
<td>9.27</td>
<td>-18.0</td>
</tr>
<tr>
<td>Circular</td>
<td>9.72</td>
<td>-17.4</td>
</tr>
<tr>
<td>Radial</td>
<td>9.26</td>
<td>-18.5</td>
</tr>
</tbody>
</table>

V. CONCLUSION
The circular and radial cavity resonators SIW bandstop filters are introduced in this paper. Both cavity resonators are able to produce the bandstop response. Comparing to rectangular cavity resonator, circular cavity resonator shows a better 3 dB stopband bandwidth response while radial cavity resonator shows a slightly improvement in the attenuation and the 3 dB stopband bandwidth. Frequency shift is observed between the simulated and measured results. The shift of the centre stopband frequency for the three designs is towards the lower stopband frequency. This research clearly shows that the rectangular cavity resonator, the circular cavity resonator and the radial cavity resonator SIW bandstop filters can be developed. They demonstrate good performance as bandstop filters at X-Band but each of their optimization has to be compromised.

ACKNOWLEDGMENT
I would like to thank UTeM and Exploratory Research Grant Scheme (ERGS) for their sponsorship on this research.

REFERENCES