A Compact Triple-Mode Bandpass HMSIW Filter

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Abstract—A simple method for designing a triple-mode bandpass filter is presented in this paper. Triple-mode is achieved by using half-mode substrate integrated waveguide (HMSIW) cavity. Three perturbation metal vias were introduced for shifting resonant modes. The resonant frequencies of these modes can be adjusted by the location and the diameter of perturbation vias properly. In order to improve the out-of-band rejection, the CPW-to-SIW transition was added. A triple-mode HMSIW filter with the center frequency of 13 GHz was designed and fabricated. The measured fractional bandwidth is 35% with a transmission zero located at 20.4 GHz. Good agreement is observed between simulation and measurement.

1. INTRODUCTION

In recent years, bandpass filters have been explosively developed as a key component of modern communication and sensor systems. In order to make the filters more compact, additional modes should be generated by the traditional resonator. Triple-mode filter which hold three resonances in one structure is one kind of multi-mode filters that has been studied. This kind of filters achieves high performance in response selectivity while keeping the size compact. Generally speaking, traditional waveguide triple-mode filters are difficult to integrate with planar circuit and to fabricate [1]. Afterwards, some compact microstrip triple-mode filters were proposed [2]. The planar structure is easily integrable with planar technology, while it has higher conductor loss and lower power capability.

The substrated integrated waveguide (SIW) and half-mode substrate integrated waveguide (HMSIW) have been proved to have high $Q$-factor, high power capability and low cost [3, 4]. Different methods were investigated to design SIW bandpass filter, such as inverter-coupled resonator [5], combined with the concept of defected ground structures (DGS) [6]. In [7] a dualband bandpass SIW filter using perturbation vias were proposed. However, the size of SIW cavity can still be half reduced by using the HMSIW resonator which has a similar field distribution. This structure has been exploited to design bandpass filters in recent years [8–10], while seldom have any papers been reported in realizing triple-mode filters using a single HMSIW resonator.

In this article, an easy way to design a triple-mode bandpass HMSIW filter has been investigated. Three simple perturbation vias were used in a HMSIW cavity for mode shifting. Two modes shifted to the other resonant mode by modifying the diameters and position of two perturbation vias, and the other via had a similar function to tune the mode frequency. A CPW-to-SIW transition was introduced to improve the out-of-band performance. At the end, a design example is given to demonstrate the presented structure. A triple-mode bandpass filter is designed and fabricated using HMSIW cavity, and the results agree well with the simulated one.
2. FILTER DESIGN

2.1. HMSIW Resonator

Figure 1 shows the structure evolution of the square SIW and HMSIW cavity. The HMSIW resonator is realized by cutting the square SIW along the diagonal of the cavity. The open side of the HMSIW is approximately equivalent to magnetic wall, and the array of metallic via-holes approximates the electric boundary. The space between the metallic vias is $p$, and the diameter of the via is $d$. These two parameters are always set to the condition of $d/p \geq 0.5$ and $d/\lambda_0 \leq 0.1$ [11]. HMSIW keeps similar propagation characteristics to that of the traditional SIW resonator while the size of the structure reduces nearly 50% [4].

![Figure 1. Evolution of the (a) square SIW and (b) HMSIW cavity.](image)

![Figure 2. Simulated S-parameter of the HMSIW resonator.](image)

The resonant frequencies of the resonant modes of a square SIW cavity are calculated as the following formula

$$f_{m0n} = \frac{c_0}{2\sqrt{\varepsilon_r}} \sqrt{\left(\frac{m}{c_{\text{eff}}}\right)^2 + \left(\frac{n}{c_{\text{eff}}}\right)^2}$$

(1)

where $c_0$ is the speed of light in free space and $c_{\text{eff}}$ the equivalent width of rectangle cavity.

$$c_{\text{eff}} = c - \frac{d^2}{0.95p}$$

(2)

$C$ is the width of SIW cavity, $d$ the diameter of SIW via-holes, and $p$ the space between two vias. As the size of the HMSIW is determined, the central frequency of the filter is basically settled.

2.2. Triple-Mode Filter Design

Figure 2 depicts the resonant frequencies of the HMSIW resonator. The resonant frequencies for the HMSIW are at 7.5 GHz, 13 GHz and 15 GHz, and the corresponding modes are $TE_{101}$, $TE_{201}/TE_{102}$ and $TE_{202}$, indicated in Figure 2 within the curve. In order to demonstrate the differences among these resonant modes clearly, the electric field distributions at different resonant modes of the HMSIW resonator are shown in Figure 3.

Figure 4 shows the studied HMSIW cavity with three metallic perturbation vias. One of the metallic vias is located at the symmetry axis of the HMSIW cavity with a diameter $r$ and the other two located at the blue gap of the mode $TE_{202}$ shown in Figure 3(c) with a diameter $R$.

One of the perturbation vias located at the symmetry axis of the HMSIW cavity has little effect on the $TE_{201}/TE_{102}$ mode since the electric field is weak at that location, while it affects the resonant modes $TE_{101}$ and $TE_{202}$ as the perturbation via approximates the electric wall. The size of the cavity
Figure 3. Electric field distribution of (a) TE\(_{101}\) mode, (b) TE\(_{201}/TE_{102}\) mode, (c) TE\(_{202}\) mode.

Figure 4. Configuration of the HMSIW resonator.

Figure 5. Simulated \(S_{21}\) with different perturbation vias, (a) radius \(R\), (b) position \(d_1\).

will be equal to a decrement of the resonant mode TE\(_{101}\) and an increment of TE\(_{202}\) mode as \(d_1\) increases. By employing this characteristic, the lower and higher modes will be under control. Since the resonant frequency of the SIW cavity is given in Equation (1), the variation of the cavity size will lead to a movement of the resonant frequency.

Similar to parameter \(d_1\), the increase of parameter \(r\) will tune the resonant frequencies of TE\(_{101}\) and TE\(_{202}\) modes while having little effect on the frequency of TE\(_{102}/TE_{201}\) modes. Figure 5 plots the simulated \(S\)-parameters by changing parameters \(d_1\) and \(r\) of the perturbation vias.

In order to tune the resonant frequency of TE\(_{101}\) mode to the desired frequency, we add two more perturbation vias located in the gap of mode TE\(_{202}\). The change of diameter \(R\) or position \(d_2\) will have a notable impact on the TE\(_{101}\) and TE\(_{201}/TE_{102}\) modes while the TE\(_{202}\) mode keeps unchanged.

As a conclusion, these three vias located at the particular position can shift TE\(_{101}\) and TE\(_{202}\) mode resonant frequencies or TE\(_{101}\) and TE\(_{201}/TE_{102}\) mode resonant frequencies, whereas the other resonant frequency will keep unchanged.
3. EXPERIMENT RESULTS

A triple-mode bandpass filter has been designed and fabricated following the previous analysis. The substrate used for the bandpass filter is Rogers RT/Duroid 5880 with a relative permittivity of 2.2 and thickness of 0.787 mm. As depicted in Figure 6, the dimensions of the filter are $l = 4$ mm, $s = 0.4$ mm, $w = 2.34$ mm, $R = 0.8$ mm, $r = 0.6$ mm, $d_1 = 1.34$ mm, $d_2 = 1$ mm. Figure 6 shows a photograph of the fabricated filter.

![Photograph of the fabricated filter.](image)

The simulated and measured results of the proposed filter are shown in Figure 7. It is obvious that the central frequency is about 13 GHz. The measured insertion loss is about 2.5 dB, and the measured return loss is lower than 10 dB. Some discrepancies between the simulated and measured ones are mainly attributed to the fabrication inaccuracy and extra SMA connector loss. In addition, there is a transmission zero located at 20.4 GHz due to the introduction of the CPW-to-SIW transition, which brings in the source-load coupling. The additional transmission zero improves the out-of-band rejection of the designed filter [12].

![Simulated and measured results.](image)

4. CONCLUSION

In this paper, an easy way to design a single-cavity HMSIW triple-mode filter has been investigated. Metallic perturbation vias are introduced to shift the resonant modes. By moving the position and changing the size of the perturbation vias, the size of the cavity will be equal to a decrement. Two of the resonant frequencies can be adjusted as the perturbation vias approximates the electric wall which will lead to a variation of the equivalent cavity size, while the other resonant frequency keeps unchanged since the electric field is weak at that particular location. By using CPW-to-SIW transition, out of band rejection performance can be further improved. A triple-mode bandpass HMSIW filter with the proposed element has been fabricated to validate the synthesis technique, and the measured result shows a good agreement with the simulated performances.
REFERENCES


