

Compact differential bandpass filter using onesixth mode and novel onethird mode triangular SIW resonators

Sheng Zhang¹, Xue-Dong Fu^{1a)}, Jun-Jie Cheng¹, Fa-Lin Liu², and Jia-Sheng Hong³

¹ School of Information and Control Engineering, China University of Mining and Technology, Xu Zhou, 221116, China
² Department of Electronic Engineering and Information Science, University of Science and Technology of China, Hefei, 230027, China
³ Department of Electrical, Electronic and Computer Engineering, Heriot-Watt University, Edinburgh EH14 4AS, UK
a) fxd0721@cumt.edu.cn

Abstract: In this letter, a novel one-third mode triangular substrate integrated waveguide resonator (OTMTSIWR) is presented firstly. Compared with the conventional OTMTSIWR, this novel resonator has a lower resonant frequency (f_0) and acceptable unloaded quality (Q_u) to suppress the common-mode (CM) signals, while has more flexibilities to design balanced coupled topology structures. The novel OTMTSIWR and one-sixth mode triangular SIW resonator (OSMTSIWR) can be creatively cascaded together to further reduce filter size. To validate the properties of the novel OTMTSIWR and the above idea, a compact differential bandpass filter (BPF) with a size reduction over 87% is proposed. The filter can produce symmetrical frequency response with one transmission zero (TZ) on each side of the differential-mode (DM) passband by using cross-coupling technology. Meanwhile, good CM suppression is implemented in the DM passband. The measured results are in good agreement with the simulated ones.

Keywords: novel OTMTSIWR, differential BPF, cross-coupling

Classification: Microwave and millimeter-wave devices, circuits, and modules

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1 Introduction

With the development of modern communication system, environmental noise and electromagnetic interference are becoming more serious. Compared with the single ended signal unbalanced circuit, the balance circuit has a good immunity to those adverse signals [1]. Therefore, the differential BPF research is attracting more attentions [2]. Meanwhile, the SIW with its high quality factor, low cost and high power capacity has been widely studied in the filter designs [3, 4, 5, 6, 7, 8, 9]. In recent years, some differential BPFs based on SIW resonators have been designed in [6, 7, 8]. In [6], an approach to design differential BPF on SIW is presented and the proposed filter with centre frequency 13.45 GHz has better selectivity, but it has a larger size of $1.29 \times 1.94 \lambda_g^2$. A differential filter in [7] is designed to reduce size using half-mode SIW (HMSIW) resonators. However, only one TZ is generated in the filter. In [8], a differential BPF based on folded HMSIW resonators is designed to further reduce the filter size, but the fabrication process is costly and complicated. The OTMTSIWR is presented to reduce the resonator size in [9], but for its irregularity, it is not suitable to design differential BPF. In a word, the miniaturized differential BPF based on SIW resonator is becoming a challenging topic.

In this letter, a novel OTMTSIWR is presented, which has a lower f_0 to suppress the CM signals and maintains acceptable Q_u . And the novel OTMTSIWR and OSMTSIWR are creatively cascaded together to further reduce filter size. Based on the above idea, a compact differential BPF is proposed by using cross-

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coupling technology, which is realized by a pair of half wavelength microstriplines (MLs). Compared with the proposed filter in [6], the filter size is reduced over 87%. One TZ is implemented on each side of the DM passband, which highly improve the selectivity. In addition, the proposed BPF can easily achieve the CM suppression level below -26.2 dB in the DM passband. The measured results agree well with the simulated ones.

2 Novel OTMTSIWR analysis

The electric field distribution in the triangular SIW resonator (TSIWR) is shown in Fig. 1(a). By cutting along the virtual magnetic walls (the dotted lines), the conventional OTMTSIWR [9] and OSMTSIWR can be obtained, respectively, which are shown in Fig. 1(b) and 1(c). Comparing the electric field distributions of TSIWR, OTMTSIWR and OSMTSIWR, the electric field distribution is almost kept unchanged. The OTMTSIWR and OSMTSIWR can reduce the resonator size by 66.7% and 83.3%, respectively. When the electric field distribution in the SIW resonator is odd-symmetric with respect to symmetrical plane, the electrical field could be in the statuses of out-of-phase under CM operation and in-phase under DM operation [6]. So the OTMTSIWR at the TM_{201} mode can be used to suppress CM signals, as shown in Fig. 2(a). However, the TM_{102} mode and TM_{201} mode are a pair of degenerate mode, which is shown in Fig. 2(b). Only when the two modes are separated can the differential filter be designed using OTMTSIWRs at TM_{201} mode. On the other hand, in order to suppress the CM signals ideally, two or more OTMTSIWRs should be used. Due to the irregularity of the OTMTSIWR, two or more OTMTSIWRs are hardly cascaded together to design balanced structures in a single plane. As a result, the conventional OTMTSIWR is not suitable for differential filter design. At the same time, to the OSMTSIWR, the electric field distributions at all resonant modes are not odd-symmetric, so a differential filter can't be designed only using it. However, the OSMTSIWR can be improved part of a differential BPF to reduce the filter size.



Fig. 1. The electric field distributions at TM_{101} mode.



Fig. 2. The electric field distributions in OTMTSIWR.

By cutting along the dotted lines (OA, OB and OC), the novel OTMTSIWR is presented. As shown in Fig. 3, comparing the electric field distributions at three typical modes in this novel resonator, the TM_{201} mode is odd symmetric, so this





novel resonator can be used to design differential filter. And it can be known from Fig. 4 that compared with the conventional resonator, the novel resonator has a lower f_0 to suppress CM signals. Meanwhile, it maintains acceptable Q_u , which is still larger than 174 when *a* is smaller than 15 mm. In addition, two novel resonators can easily cascaded to suppress CM signals by sharing an electrical wall, so it has more flexibilities to design balanced coupled topology structures.



Fig. 3. The electric field distributions in novel OTMTSIWR.



Fig. 4. Different f_0 and Q_u for different length a.

3 Filter design

According to the above analysis, the novel OTMTSIWR can be irreplaceable part of a differential BPF to suppress the CM signals and the OSMTSIWR can be reformative part to further reduce the filter size. A compact differential BPF based on OSMTSIWRs and novel OTMTSIWRs is proposed and optimized by utilizing cross-coupling technology, which is shown in Fig. 5. The *RT/duroid 6006*, with $\epsilon_r = 6.15$, $tan \delta = 0.0019$ and thickness h = 0.635 mm, is applied for all the simulations and fabrication in this paper. The proposed filter are realized by using the TM_{201} mode in the cascaded novel OTMTSIWRs (R2, R3) and the TM_{101} mode in four OSMTSIWRs (R1, R1', R4 and R4'). S (S') and L (L') stand for the I/O feed lines. The coplanar waveguides are used as conversion structures between the feed



Fig. 5. (a) The configuration of the proposed filter. (b) Coupling topology structure.



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lines and four OSMTSIWRs, respectively. The solid line indicates the positive coupling, which is realized by the magnetic coupling windows between R2 and R3. The dotted lines indicate the negative coupling, which is implemented by the gap coupling between the cascaded R1(R1'), R2 and R3, R4(R4'), respectively.

The second coupling path is realized by a pair of half wavelength MLs, which are connected with R1(R1') and R4(R4') directly, respectively. Because the ML length is half wavelength, the property of the second coupling path is same with the coupling property between the two MLs. Based on the approach proposed in [10], the coupling coefficient between the two MLs can be obtained by adding the electric wall and magnetic wall on the symmetrical plane, respectively. Fig. 6 depicts the influence of different coupling length k_3 on the coupling coefficient, while the pitch $k_2 = 0.1$ mm is kept unchanged. It shows that when the k_3 is in the range of 0 to 0.7 mm, the coupling coefficients are negative and namely, the second coupling path's property is mainly negative.



Fig. 6. (a) Different coupling coefficients for different k_3 . (b) The second coupling path.

According to the symmetry of the proposed filter, a perfect electric wall would appear along the symmetrical plane under DM operation, thus the half bisection topology can be obtained, as shown in Fig. 7. With the negative coupling between R1 and R4, the cross-coupling is implemented, which could generate one TZ on each side of the DM passband. The final optimized dimensions are shown as follows (all in mm): $a_1 = 24$, $b_1 = 7$, $a_2 = 8.2$, $b_2 = 4.7$, $w_1 = 1.02$, a = 1.5, $l_1 = 1.1$, g = 0.1, $g_1 = 0.3$, $g_2 = 0.2$, k = 2.8, $k_1 = 4.7$, $k_2 = 0.1$, $k_3 = 0.2$, $l_2 = 4.1$, d = 0.5, s = 0.8.



Fig. 7. Half bisection topology of the proposed filter.

The measured and simulated results are shown in Fig. 8. The measured centre frequency is 9.09 GHz with a 3-dB bandwidth of 68 MHz under DM operation. The measured in-band return loss S_{11} is below -18.2 dB, and the minimum insertion loss S_{21} is less than -2.1 dB. Two TZs generated by cross-coupling can also be





observed at 8.57 and 9.29 GHz with attenuation of 45.8 dB and 35.7 dB, respectively. And the measured return loss $|S_{11}|$ is less than 0.6 dB from 8 GHz to 10.4 GHz under CM operation, and the CM suppression level is less than -26.2 dB in the DM passband. The measured results agree well with the simulated ones. The filter size is measured to be $0.42 \times 0.78\lambda_g^2$. Compared with the proposed filter in [6], this filter size reduces over 87%.



Fig. 8. (a) The measured and simulated results of the filter. (b) Photograph of the filter

4 Conclusion

In this letter, a novel OTMTSIWR is presented firstly. Compared with the conventional OTMTSIWR, this novel resonator has a lower f_0 and acceptable Q_u to implement the CM suppression. The OSMTSIWR and novel OTMTSIWR are cascaded firstly to further reduce size. Then a differential BPF with symmetric frequency response is proposed. Compared with the proposed filter in [6], this filter size is reduced over 87%. By utilizing cross-coupling technology, one TZ is implemented on each side of the DM passband. Meanwhile, good CM suppression is implemented. In short, the proposed filter has excellent DM selectivity, good CM suppression and compact size.

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