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A Novel Triple-Band Bandpass Filter Based on Equilateral Triangle Substrate Integrated Waveguide

Sheng Zhang, Jia Yu Rao, Jun Jie Cheng, Jia Sheng Hong and Fa Lin Liu

A novel compact triple-mode triple-band bandpass filter (TB-BPF) based on equilateral triangle substrate integrated waveguide is first proposed. The first passband response is achieved by the fundamental modes of the first and third cavity. To obtain the second and third passband, a new posts perturbation method is proposed. And based on it, the perturbed TM_{101} and TM_{201} mode of the second cavity can couple with TM_{102} modes of first and third cavities via inductive window, respectively. By adjusting the width of the inductive window, the second and third passband can be achieved. Source-load coupling and Complementary Split-Ring Resonators (CSRRs) are introduced to produce transmission zeros (TZs). Total eight TZs are obtained, which highly improve the performance of the out-of-band. Finally, a TB-BPF is designed, fabricated and measured. The simulated and measured results show good agreement.

Introduction: Substrate Integrated Waveguide (SIW) technology has been successfully applied to design filters due to high quality factor, easy fabrication and integration [1-2]. Recently, multi-mode SIW technology causes a lot of attentions to design multi-band BPFs [3-7]. However, most of them are focused on wideband or dual-band BPFs, only few works studying on Triple Band-BPF (TB-BPF) using SIW technology [3-5]. In [3], a wideband fourth order filter is proposed based on post-loaded electric coupling structure in single-layered substrate integrated waveguide with enhanced coupling. A synthesis technology is proposed to design a dual-band and a triple-band filter in [3], but the sizes of the filters are large. In [5], a compact triple-mode TB-BPF with two perturbed square cavity resonators is proposed, but the whole performance is poor. Multi-layer LTCC technology is utilized to design miniaturized TB-BPFs in [6], however, the whole performance is not well and costs much.

In this paper, a new post perturbation method is first proposed to design a new three-order single-layer triple-mode TB-BPF. The first passband is achieved by the TM_{101} modes of the first and third cavities. In [5-7], additional metal posts, which always locate in all cavities, are usually used to cause "mode shifting". But in this design, an array of posts are just locate in center of the second cavity to produce perturbation. The perturbation shift TM_{101} to higher frequency while TM_{201} nearly invariable. Based on the perturbation characteristics, the TM_{101} and TM_{201} mode of the second cavity are utilized to couple with TM_{102} modes of the first and third cavities, respectively. Then the second and third passband are obtained. To improve the frequency selectivity, source-load coupling and Complementary Split-Ring Resonators (CSRRs) are introduced. Finally, to verify the design, a filter prototype with center frequencies operating at 5.55 GHz, 7.50GHz, and 8.60GHz is fabricated and tested. Good agreement between simulated and measured results is obtained.

Method Analysis: Fig.1 shows the geometry of the proposed perturbation resonator. The resonator consists of *a* equilateral triangle SIW cavity with side length of L and a row of posts perturbation with diameter of d in the middle of the structure. The electric field distributions of the first three resonant modes are shown in Fig.2. It can be found that the TM_{101} and TM_{102} mode are changed greatly while TM_{201} changed a little due to the perturbation. The strength of the perturbation is determined by the parameter L_2 as shown in Fig.3, where TM_{101}^2, TM_{102}^2, TM_{201}^2 are the perturbed modes of the second cavity, and $TM_{102}^{1,3}$ are the TM_{102} modes of the first and third cavities. In Fig.3, as the length of L_1 decreasing, the TM_{101} mode frequency increases rapidly and becomes close to the TM_{201} mode. Thus, the second passband can be created by adjusting the parameter L_1 appropriately. In addition, the third-passband can be achieved between TM_{102}^2 and $TM_{102}^{1,3}$ mode.

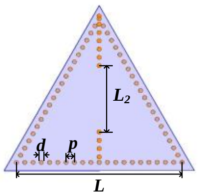

Fig. 1 *Geometry of proposed perturbed resonator*

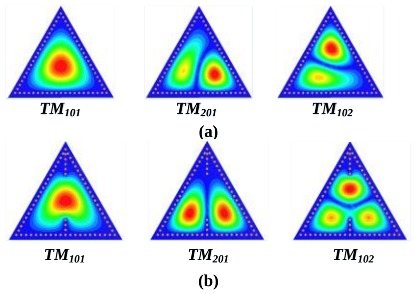

Fig. 2 *Electric field distribution of different resonant modes, (a) without posts perturbation (b) with posts perturbation*

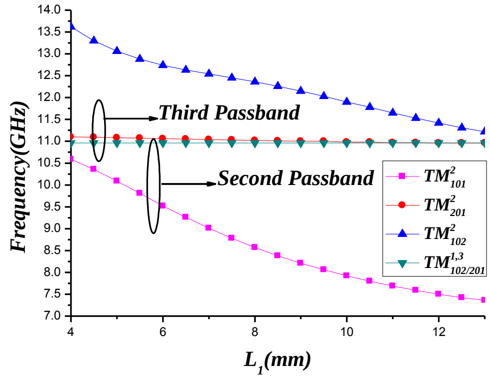

Fig. 3 *Variation in coupling strength as a function of L_2.*

Filter Design: To prove the above assumption, a filter prototype without source-loading coupling and CSRR is designed firstly as shown in Fig.4. By adjusting the widths of the inductive windows (L_1, L_2), the expected coupling results can be obtained as shown in Fig.5. It can be found that if TZs can be introduced in transition stopbands and upper stopband, a TB-BPF can be obtained.

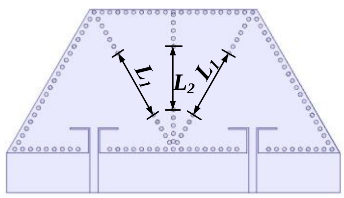

Fig.4 *Structure of the Triple-band BPF without source-load coupling and CSRRs.*

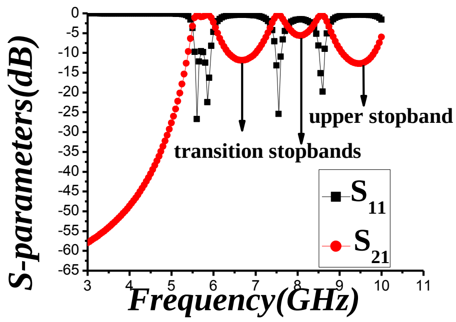

Fig.5 *S-parameters corresponding to L_1=11.61mm, L_2=8.96mm.*

This can be fulfilled by introducing source-load coupling and etching CSRRs as depicted in Fig.6. Its coupling scheme is depicted in Fig.7, where A and B represent the TM_{101} mode and TM_{102} mode of the first and third cavity, A', B' represent TM_{101} mode and TM_{201} mode of the second cavity, respectively. These modes are coupled from source to load via three separate paths. Hence, three paths for the triple-band response can be easily designed and realized, independently.

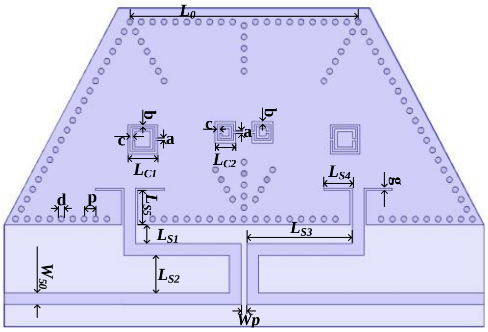

Fig.6 *Structure of the triple-band BPF.*

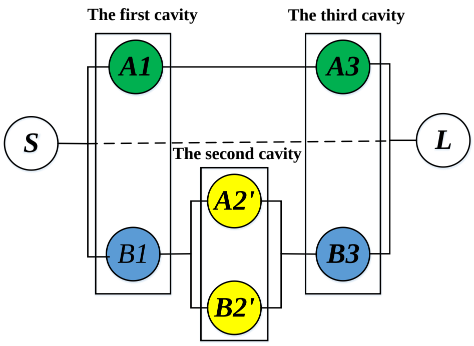

Fig.7 *Coupling scheme of the triple-band BPF.*

Filter Design: Based on the above study, a TB-BPF is designed and fabricated, which is depicted in Fig.8. The substrate used in this paper is the RT/duroid6006, with ε_r=6.15, $\tan\delta$=0.0019 and thickness *h*= *0.635mm*.The I/O feed lines are 50 Ω microstrip line. The final dimensions are as follows (all in mm): *d=0.5, p=1,* W_{50}*=1.02,* L_{S1}*=1.65,* L_{S2}*=3.31,* L_{S3}*=9.24,* L_{S4}*=2.29,* L_{S5}*=3.0,* L_{C1}*=2.58,* L_{C2}*=1.84,* L_1*=8.50,* L_2*=7.47,* W_P*=0.5, g=0.2, a=0.2, b=0.2, c=0.2.*

The measured and the simulated results are shown in Fig.9 simultaneously. The three passbands of the measured results are centered at 5.55GHz, 7.50GHz, and 8.60GHz, with fractional 3 dB bandwidths of 310MHz, 390MHz and 400MHz, respectively. The measured minimum insertion losses of the three passbands are 1.39, 1.33, and 1.53 dB, respectively. The measured return losses are above 14 dB for the three passbands. Some slight differences between the simulated and measured results may be attributed to the fabrication to tolerance and assembly errors in the design. In addition, total eight TZs are obtained due to the source-load coupling and the feature of CSRRs, which highly improve the frequencies selectivity. Among them, TZ_4 and TZ_7 are attributed to CSRRs, and others are referred to source-loading coupling.

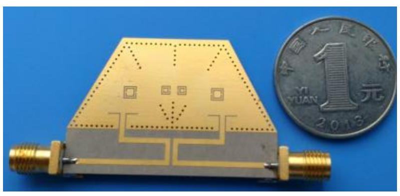

Fig.8 *Photograph of the fabricated triple-band BPF.*

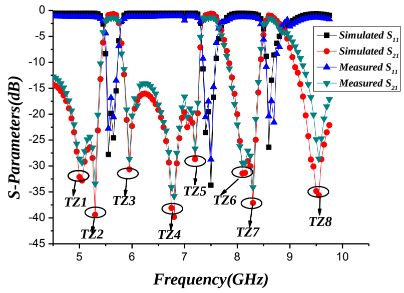

Fig.9 *Simulated and measured S-parameters of the triple-band BPF.*

Conclusion: A new post perturbation method is proposed firstly in this letter. Then a compact TB-BPF based on equilateral triangle SIW is designed based on it. The first-passband is achieved by the fundamental modes of the first and third cavity. The second and third passband are created due to the perturbation. Among which, the second-passband is achieved by the TM^{2}_{101} mode and $TM^{1,3}_{102}$ modes, the third passband is obtained by the TM^{2}_{201} mode and $TM^{1,3}_{102}$ modes. Source-load coupling and CSRRs are utilized to produce TZs in the transition stopbands and upper stopband, which eight TZs are obtained. Finally, a filter prototype is fabricated and tested. The simulated and measured results are in good agreement with each other.

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