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Novel Dual-band SIW Filter Using Quad mode Cavity

Sambaiah Pelluri*, Anmol Jain, and M.V. Kartikeyan

Department of Electronics and Communication Engineering, Indian Institute of Technology, Roorkee - 247 667, India
**E-mail: sambaiah439@gmail.com*

ABSTRACT

A dual-band bandpass substrate integrated waveguide (SIW) filter is proposed using a quad-mode cavity in this paper. First two degenerative modes (TE_{102} and TE_{201}) with via perturbation give the first passband. The second passband is realised by using higher modes (side and diagonal modes of TE_{202}) which are obtained by putting square slot at the center of the cavity. The square slot increases the frequency ratio of the center frequencies of first and second passbands. Moreover, orthogonal feed-lines are used in the proposed design to increase transmission zeros (TZs) which helps to improve the selectivity and out-of-band rejection of the filter. Designed and fabricated a dual-band filter prototype using a single layer printed circuit board (PCB) technology, size is only 19 mm × 19 mm. The insertion losses are 2.1 dB and 2.4 dB, and fractional bandwidths of 3.40 per cent and 2.00 per cent at 11.00 and 15.58 GHz, respectively. The measurement results show close agreement with the simulation results.

Keywords: SIW, Dual-band; Bandpass filter; Quad-mode cavity; Perturbation

1. INTRODUCTION

Due to rapid growth in wireless communication technology, modern communication systems require dual-band microwave filters which are compact, cost-effective, high performance and easy to fabricate. There are many technologies to design microwave filters. SIW is one of it and get more attention due to less losses, high Q-factor, low cost and high power handling capability. SIW is a planar structure which is synthesised by PCB technology with an array of metallic vias to form side walls of the waveguide[1]. A very few designs of a dual-band SIW filter were reported. In[2], square cavities are coupled using a single mode to get dual-band response. Also, different size miniaturisation approaches like defected ground structure (DGS)[3], complementary split ring resonator (CSRR)[4] are used for dual-band SIW filters. In[5], dual-band operation is achieved by introducing transmission zero in the passband, using a dual mode cavity. A few multimode SIW filters have been designed[6-9]. However, very few papers discussed the dual-band filter design using the multimode in the SIW cavity.

In this paper, a quad-mode cavity is used to design a dual-band SIW bandpass filter. The first two degenerative modes are TE_{102} and TE_{201}, used to get the first passband with via perturbation. The square slot at the center of the cavity gives side and diagonal modes of TE_{202} which constitute the second passband and increases the frequency ratio of the center frequencies of two passbands. In addition, orthogonal feed-lines are adopted in the proposed design to increase finite frequency TZs to improve the selectivity and out-of-band rejection of the filter.

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2. FILTER DESIGN

2.1 Filter Structure

The configuration of the proposed dual-band bandpass SIW filter is as shown in Fig. 1. The proposed structure consists of a quad-mode SIW cavity. The multi-mode cavities reduce the number of required resonators for the design. So, overall filter size becomes compact. Here, vias are used to perturb degenerative modes and a square slot at center improves frequency ratio of the center frequencies of the passbands. In this design, the orthogonal input/output feed lines are used to provide bypass coupling to increase TZs. Coplanar waveguide topology is used as SIW-microstrip transition in this filter for good impedance matching.

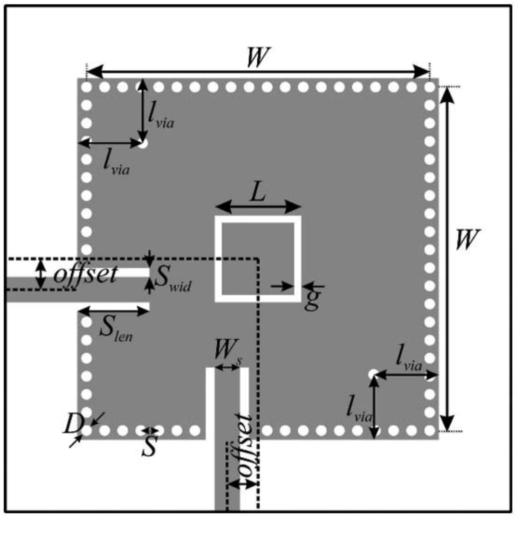

Figure 1. The configuration of the proposed quad-mode SIW based dual bandpass filter.

2.2 Quad-mode SIW Cavity

The center frequency of the passband is responsible for determining the size of a multi-mode SIW cavity. Initially, we select the two degenerate modes of the filter i.e TE_{m0n} and TE_{p0q} and then use the following design equation to calculate the resonant frequency for the cavity[5]

$$f_0 = \frac{c}{2\sqrt{\mu_r \varepsilon_r}} \sqrt{\left(\frac{m}{W_{eff}}\right)^2 + \left(\frac{n}{L_{eff}}\right)^2} \tag{1}$$

$$= \frac{c}{2\sqrt{\mu_r \varepsilon_r}} \sqrt{\left(\frac{p}{W_{eff}}\right)^2 + \left(\frac{q}{L_{eff}}\right)^2} \tag{2}$$

where W_{eff} and L_{eff} are the equivalent width and length of the SIW cavity and are equal, represented by W for the square SIW cavity. The initial dimensions of the square SIW cavity can be found using Eqns (1) and (2).

The proposed square SIW cavity is realised on 0.25 mm thickness RT/Duroid 5880 substrate with dielectric constant 2.2. The geometrical parameters of the square SIW cavity are W=19 mm, the diameter of the vias D=0.6 mm and pitch between the vias S=1 mm at first passband 12.15 GHz using TE_{102} and TE_{201}.

Resonant characteristics of the quad-mode cavity structure are studied by using high-frequency structural simulator (HFSS) Eigenmode simulator. The first six modes of the square cavity are TE_{101}, TE_{102}, TE_{201}, TE_{202}, TE_{103} and TE_{301} at 8.98, 12.15, 12.15, 15.37, 17.19 and 17.19 GHz, respectively. The square slot etched at the center and on top of the SIW cavity. This shows the same effect on both TE_{102} and TE_{201}. As shown in Fig. 2(a) and 2(c), this square slot increases the current distribution path of TE_{102} and TE_{201}. Therefore, the resonant frequency is decreased to 11.07 GHz. Due to the square slot, next higher order modes are diagonal TE_{202} and side TE_{202} at 15.16 and 16.14 GHz, respectively, which forms the second passband.

In the proposed design, TE_{102} and TE_{201} are the degenerate modes. As we know that, degenerate modes coincide with each other and only one resonant peak can be seen. In this structure, a pair of diagonal vias is placed for perturbation. As a result, the degenerate modes split and gives the first passband. A pair of diagonal vias helps to enhance the coupling between degenerative modes. Therefore, the modes are TE_{102}, TE_{201}, diagonal $TE_{202,}$ and side TE_{202} at 11.07, 11.55, 15.16 and 16.14 GHz, respectively, are used in this design. The electric field distributions of TE_{102}, TE_{201}, diagonal $TE_{202,}$ and side TE_{202} are as shown in Figs. 3(a)-3(d), respectively.

The coupling scheme for the proposed design is depicted in Fig.4. The first two degenerative modes are TE_{102} and TE_{201}, used to get the first passband. Next higher order modes are diagonal TE_{202} and side TE_{202}, used for the second passband. The bypass coupling between source-load increases TZs to increase selectivity.

2.3 Second Order Dual-band SIW Filter

The proposed filter structure is as shown in Fig. 1 the proposed design has orthogonal I/O feed lines. The deviation of I/O feeding lines from the central axis of the cavity is denoted with variable *offset*. Fig. 5 shows the variation of S_{21} with respect to *offset*. If *offset* is zero and cavity has no square slot, the first passband is due to TE_{102} and TE_{201} at 12.15 and 12.8 GHz, respectively, and the second passband is given by

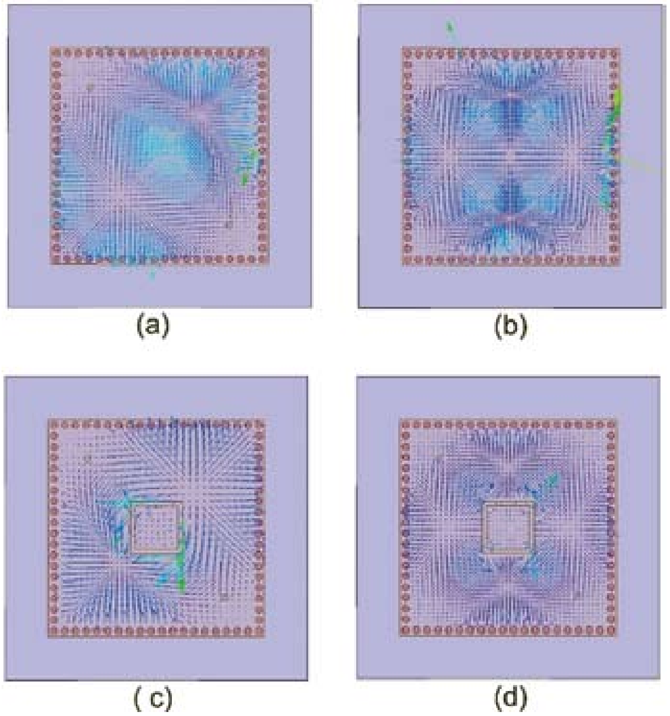

Figure 2. Surface current distribution of the square SIW cavity (a) TE_{102} mode, (b) side TE_{202} mode, (c) TE_{102} mode with a square slot, and (d) side TE_{202} mode with the square slot.

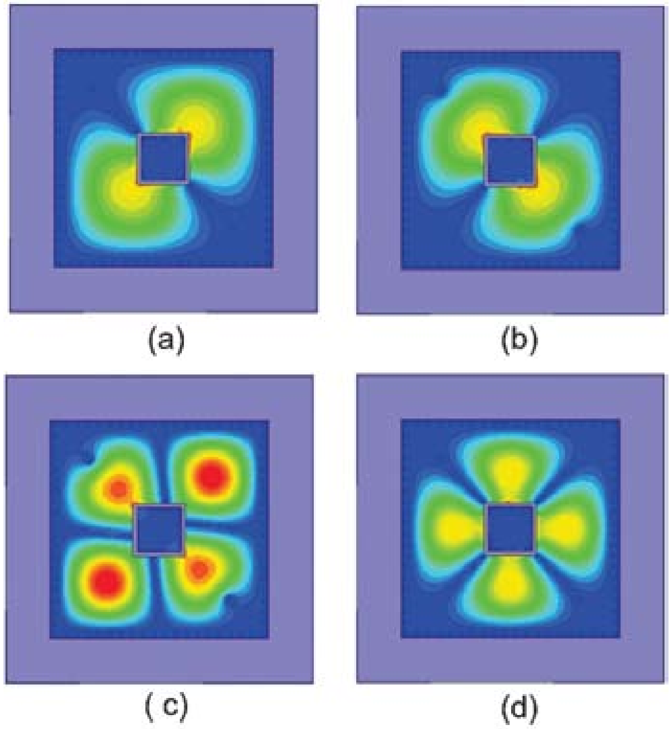

Figure 3. Electric vector field distribution of the square SIW cavity with diagonal vias and square slot (a) TE_{102} mode, (b) TE_{201} mode, (c) diagonal TE_{202} mode, and (d) side TE_{202} mode.

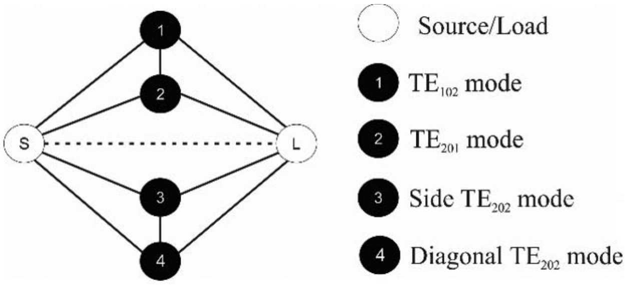

Figure 4. Coupling scheme.

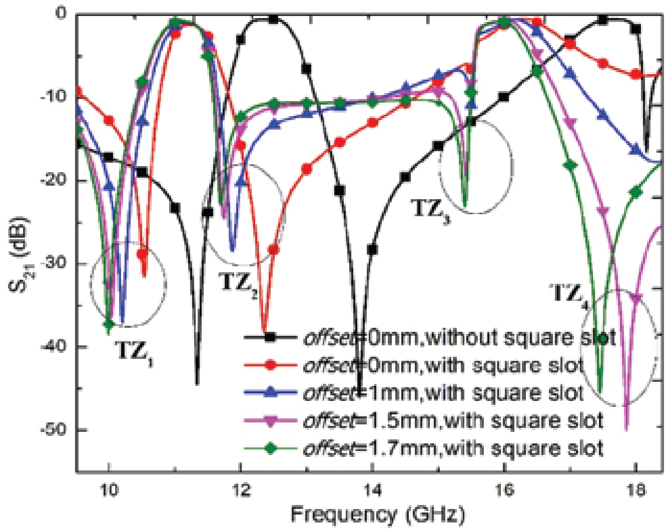

Figure 5. Simulated $|S_{21}|$ with different *offset* positions of I/O feed lines.

TE_{103} and TE_{301} at 17.19 and 17.9 GHz, respectively. In this case, the response has three finite TZs because of no source-load coupling.

If *offset* is zero and cavity has a square slot, the first passband is shifted down to 11.07 GHz. This is due to the change of current distribution path of TE_{102}/TE_{201} by square slot, is as shown in Fig. 2(a) and 2(c). With square slot, the TE_{103} mode is changed as side TE_{202} mode. As shown Fig. 2(b) and 2(d), the square slot doesn't change the current distribution of diagonal TE_{202} but it has shown more effect on side TE_{202}, shifted the resonant frequency down. Therefore, diagonal TE_{202} and side TE_{202} constitutes the second passband. In this case also, the response has shown three TZs due to no source-load coupling. If offset is provided to I/O feed lines, fourth TZ is occurring at upper stopband of the second passband. As shown in Fig. 5, fourth TZ is moving close to passband when *offset* is increased which improves source-load coupling.

As shown in Fig. 5, the proposed structure gives four transmission zeros. The first transmission zero (TZ_1) is due to the opposite phase and equal coupling to each mode (TE_{102} and TE_{201})[10]. The second transmission zero (TZ_2) is between the passbands, generated due to the inductive behaviour of one of the modes of the first passband (either TE_{102} or TE_{201}) and the capacitive behaviour of one of the modes of the second passband (either side or diagonal mode of TE_{202}). Therefore, passed signals from these resonant modes have a 180° phase difference[11]. The third transmission zero (TZ_3) is due to opposite phase and equal coupling to each mode (side and diagonal of TE_{202} mode). Fourth transmission zero (TZ_4) is due to cross-coupling between source and load[10].

Figure 6 shows the effect of l_{via} on the S_{21} response. Here, a pair of diagonal vias is used to give perturbation to degenerative modes. If l_{via} increases, the first passband bandwidth increases due to more coupling between degenerative modes. At the same time, diagonal TE_{202} mode frequency is shifted towards side TE_{202}, results in second passband bandwidth decreases.

The effect of square slot length L on $|S_{21}|$ is as shown in Fig. 7. As shown in Fig. 3, the square slot effects the current distribution of TE_{102}, TE_{201} and side TE_{202} modes. If square slot length L increases, the frequency of TE_{102} and TE_{201} decreases and increases two passbands center frequency ratio. The second passband bandwidth can be tuned without affecting first passband bandwidth by changing square slot length. Therefore, the optimum values are taken for *offset*, $l_{via,}$ and L to get the required response from Figs. 5-7.

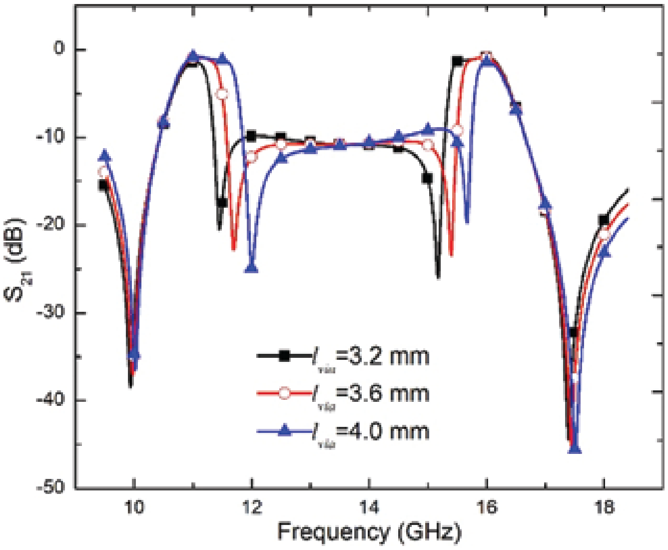

Figure 6. Simulated $|S_{21}|$ with different positions of diagonal vias l_{via}.

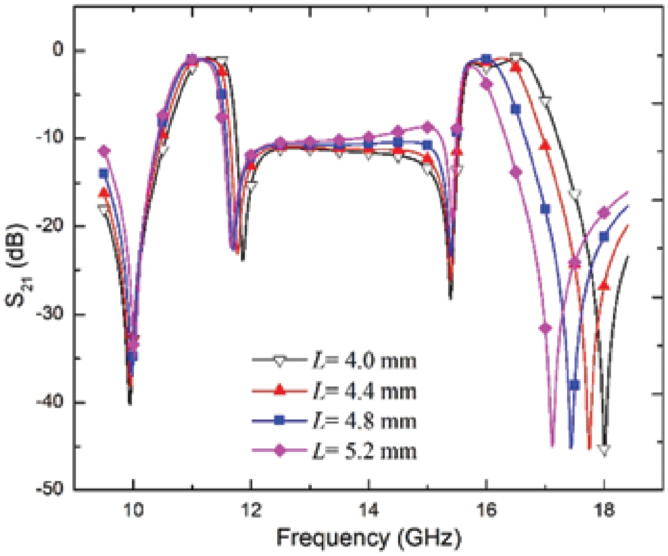

Figure 7. Simulated $|S_{21}|$ with different square slot length L.

3. RESULTS AND DISCUSSION

A quad mode cavity based dual-band SIW bandpass filter with a center square slot has been fabricated using substrate RT/Duroid 5880 with a dielectric constant of 2.2 and a thickness of 0.25 mm, and shown in Fig. 8. The size of the designed filter is 19x19 mm^2. The dimensions in Fig. 1 are obtained as: W=19 mm, W_s=1.4 mm, S_{len}=4 mm, S_{wid}=0.5 mm, l_{via}=3.6 mm, D=0.6 mm, S=1 mm, L=2.4 mm, g=0.4 mm. The measurement results of the proposed dual-band SIW filter has been shown in Fig. 9. It is observed that a pair of transmission zeros for the first band are obtained at 9.86 GHz and 11.55 GHz with center frequency at 11 GHz and a pair of transmission zeros for the second band are obtained at 15.16 GHz and 17.1 GHz with center frequency at 15.58 GHz. Return loss obtained for both the bands is higher than -10 dB. The insertion loss and fractional bandwidth for the first passband are 2.1 dB and 3.4%, respectively. The second passband has 2.4 dB insertion loss and a fractional bandwidth of 2.00%. Therefore it shows good selectivity and stopband performance of the filter. The center frequency ratio of the passbands is 1.41. The measured results have given more insertion loss than simulation. The reason is the losses of SMA connectors and the substrate dielectric loss. The frequency shift in the measured results is due to the variation in dielectric constant and fabrication process. We have used higher modes those are TE_{201}, TE_{102}, and TE_{202} in the proposed design instead of using multiple single mode cavities. It serves us with the benefit of achieving low losses with the reduced size.

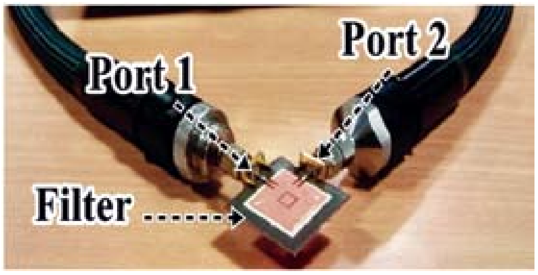

Figure 8. Photographs of the fabricated dual-band filter.

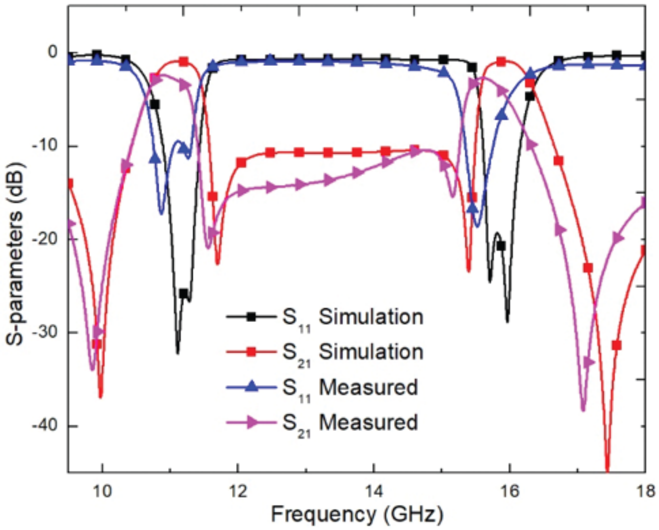

Figure 9. Simulated and measured results of the proposed design.

4. CONCLUSION

In this paper, a quad-mode single-cavity dual band SIW bandpass filter is presented and analysed. The square slot is made on the top layer which reduces cavity size and increases the frequency ratio of the center frequencies of two passbands. An orthogonally aligned input and output feed-line along with the addition of via perturbation, the transmission zeros are generated at the adjacent of the two passbands, and thus greatly improved selectivity of the designed filter and desired sharp out-of-band rejections. Moreover, the structure is realised using a single cavity structure which serves with the advantage of low cost and easy fabrication. Therefore, the proposed bandpass filter has great potential for future high-frequency applications.

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CONTRIBUTORS

Mr Sambaiah Pelluri received BTech in electronics and communication engineering from Vignan's Engineering College, Guntur, India, in 2008, and the MTech in Electronic Design and Technology from National Institute of Technology, Calicut, India, in 2010. He is currently pursuing the PhD with IIT Roorkee, Roorkee, India. His current research interests include developing novel passive components and active devices for microwave and millimeter-wave integrated circuits.
Contribution in the current study, he carried out all design studies to generate the results.

Ms Anmol Jain received BTech in electronics and communication engineering from National Institute of Technology, Hamirpur, India, in 2017. She is currently pursuing the MTech with IIT Roorkee, Roorkee, India. Her research focuses on developing novel passive components for microwave and millimeter-wave integrated circuits.
Contribution in the current study, he did the fabrication and generated the measured results.

Dr M.V. Kartikeyan received MSc in physics, and PhD in electronics engineering from IIT (BHU) Varanasi, Varanasi, India, in 1985 and 1992, respectively. He has been a Full Professor with the Department of Electronics and Communication Engineering, IIT Roorkee, Roorkee, India, since 2009. His current research interests include millimeter/ THz wave engineering (electron cyclotron masers, high power devices, and components), metamaterials and fractals, planar microstrip antennas and filters, MICs, and RF and microwave design with soft computing techniques. Prof. Kartikeyan is a Senior Member of IEEE, Fellow of the IET (UK), Institution of Electronics and Telecommunications Engineers (India), Institution of Engineers (India), and Vacuum Electronic Devices and Applications Society (India).
Contribution in the current study, he guided and scrutinised the results.