*Progress In Electromagnetics Research C, Vol. 62, 1–10, 2016*

# Flat-Passband Substrate Integrated Waveguide Filter with Resistive Couplings

**Bin Gao, Lin-Sheng Wu*, and Jun-Fa Mao**

**Abstract**—A lossy filter with resistive coupling is proposed based on substrate integrated waveguide (SIW) resonators, where nonresonating nodes are not required to simplify the realization. The sensitivity analysis of $S$-parameter to the resistive coupling coefficient is carried out to determine the parameters of coupling structure and mounted resistors. When resistive couplings are added to the structure, the measured 0.2-dB passband bandwidth increases from 198 to 256 MHz, compared with the case without resistive couplings. At a sacrifice on the additional insertion loss of 1.1 dB, the passband flatness and selectivity are improved significantly. The lossy SIW filter can provide a smaller in-band insertion loss than the microstrip counterparts, because the unloaded $Q$-factor of SIW resonators is higher than that of microstrip resonators. Moreover, a simpler topology and a less insertion loss are obtained in the proposed resistively coupled SIW filter than those of the lossy filter synthesized with lossy coupling matrix. Excellent agreement between the simulated and measured results is achieved to demonstrate our idea.

## 1. INTRODUCTION

Filter is one of the most important elements in various microwave systems for radar and communication applications. Filter design has to deal with particular electrical specifications and constraints that also concern its weight and cost. The conventional synthesis procedure is based on the assumption of low-loss or even lossless networks [1]. This is approximately satisfied with high-$Q$ resonators. However, the miniaturization and integration may cause significant degradation of unloaded $Q$-factors of microwave resonators, which bring some disadvantages, such as high insertion and reflection losses in passband, rounding effect of bandedges, and degraded frequency selectivity within transition bands.

In order to overcome the issues in ideal lossless design of low-$Q$ filters, several new techniques are proposed recently. The predistortion technique [1, 2] can improve flatness and selectivity of filters obviously by reflecting more power in the middle passband, which causes its in-band return loss significantly worsened. These filters should usually be cooperated with circulators or isolators.

Another method is proposed in [3, 4] to apply nonuniform-$Q$ resonators for lossy filter design. Based on the utilization of resonators with different prescribed unloaded $Q$-factors, the method can easily be implemented. In this way, the coupling topology obtained with conventional synthesis method can still be utilized for modified lossy filters. And the resonators which introduce the relatively higher power dissipation especially to the edges of passband should have higher $Q$-factor. If the required $Q$-factors cannot be accurately implemented due to some practical limitations, the achieved passband will still be uneven.

In [3], the resistive coupling was first introduced into the lossy filter design. The cross coupling structure with chip resistor was adopted. The matrix synthesis approach with resistive coupling

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*Received 15 November 2015, Accepted 26 January 2016, Scheduled 1 February 2016*

* Corresponding author: Lin-Sheng Wu (wallish@sjtu.edu.cn).

The authors are with the Key Laboratory of Ministry of Education of Design and EMC of High-Speed Electronic Systems, Shanghai Jiao Tong University, China.

coefficients is developed in [5, 6]. By attenuating both the transmission and reflection coefficients of an ideal lossless filter, a lossy coupling matrix can be synthesized. However, the required coupling scheme is much more complicated than that for conventionally designed filter, especially for the cases of asymmetric and higher-order responses.

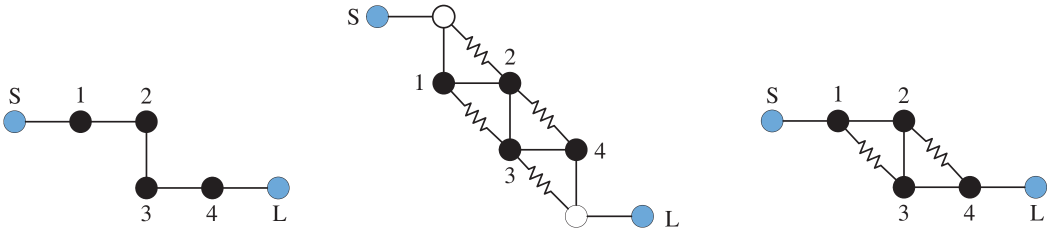
As described in [7], the resistive couplings between resonators are more responsible for the filter response other than the resistive couplings located between the nonresonating node and resonator. Thus, the resistive couplings and nonresonating nodes can be removed to simplify the design of microstrip hairpin filter. However, the relatively low unloaded $Q$-factor of microstrip resonators makes the insertion loss deteriorated significantly.

On the other hand, a substrate integrated waveguide (SIW), as an intermediate guiding-wave structure, provides a good trade-off between miniaturization, $Q$-factor, cost and integration [8, 9]. An SIW cavity is the implementation of waveguide structure in planar substrates by means of metallic via arrays between two ground planes. In [10], a predistorted filter is designed with SIW resonators which have an unloaded $Q$-factor of 500, and it achieves passband flatness equivalent to its counterparts with the $Q$-factor of 2000. Based on SIW technology, the filter in [11] realizes transmission zeros in in-line topology by frequency-dependent couplings. A three-pole Chebyshev SIW filter is designed by the lossy matrix synthesis in [12], but the configuration is complicated with two additional nonresonating nodes and three surface mounted resistors.

In this paper, a lossy SIW filter with resistive coupling is proposed to achieve flat passband and simple coupling scheme. The filter structure has only two resistive couplings between resonators, avoiding resistive couplings between the resonators and nonresonating nodes. Based on SIW cavity resonators, the lossy filter has smaller insertion loss than its counterparts with microstrip lines. Through the sensitivity analysis of $S$-parameters to the resistive coupling coefficient, the parameters of the resistive couplings can be confirmed. From the results, it can be seen that the measured data agree well with the simulated ones.

## 2. ANALYSIS AND DESIGN

At first, a four-pole Chebyshev filter is designed with SIW resonators for the first reference. This reference filter is centered at $f_0 = 5.0$ GHz with a 250 MHz bandwidth. The in-band return loss is set to 20 dB. The SIW resonators are fabricated on a Taconic TLY-5A substrate having a height of 40 mil. The permittivity is $\varepsilon_r = 2.17$ and its loss tangent $\tan\delta = 0.0009$. The copper layer is 35-μm thick and the surface roughness 0.3 μm. With this substrate, the unloaded $Q$-factor of SIW resonator is around 490. The coupling matrix $M_1$ is synthesized by the conventional method [13] of ideal lossless cases in Eq. (1), and the coupling topology is given in Fig. 1(a). The filter can be structured as an inline network. The synthesized results of the reference SIW filter are shown in Fig. 2. Its synthesized passband is centered at 5.0 GHz with a 0.2-dB bandwidth of 208 MHz, and its minimum insertion loss is 0.84 dB, due to the



(a) (b) (c)

**Figure 1.** Coupling topology: (a) the reference SIW filter; (b) the lossy SIW filter synthesized with lossy matrix synthesis; (c) the lossy SIW filter with resistive couplings.

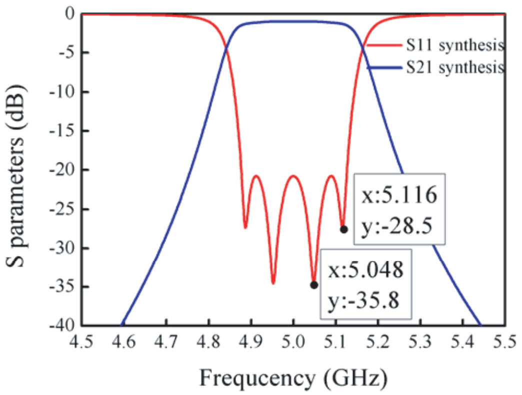


**Figure 2.** Synthesized results of the reference SIW filter with lossy coupling matrix.

finite $Q$-factor.

$$M_1 = \begin{bmatrix} 0 & 1.035 & 0 & 0 & 0 & 0 \\ 1.035 & -0.041i & 0.911 & 0 & 0 & 0 \\ 0 & 0.911 & -0.041i & 0.700 & 0 & 0 \\ 0 & 0 & 0.700 & -0.041i & 0.911 & 0 \\ 0 & 0 & 0 & 0.911 & -0.041i & 1.035 \\ 0 & 0 & 0 & 0 & 1.035 & 0 \end{bmatrix} \tag{1}$$

A lossy SIW filter synthesized with lossy coupling matrix is designed as the second reference filter. Similarly, this filter is centered at $f_0 = 5.0\,\text{GHz}$ with a 250 MHz bandwidth. The in-band return loss is 20 dB. The lossy coupling matrix $M_2$ is synthesized in Eq. (2) with the scaling factor $k_s = k_l = 0.333$ [6], and the coupling topology is given in Fig. 1(b).

$$M_2 = \begin{bmatrix} -0.018i & 0.340 & -0.018i & 0 & 0 & 0 \\ 0.340 & -0.078i & 0.907 & 0.037i & 0 & 0 \\ -0.018i & 0.907 & -0.096i & 0.702 & 0.037i & 0 \\ 0 & 0.037i & 0.702 & -0.096i & 0.907 & -0.018i \\ 0 & 0 & 0.037i & 0.907 & -0.078i & 0.340 \\ 0 & 0 & 0 & -0.018i & 0.340 & -0.018i \end{bmatrix} \tag{2}$$

As illustrated by the coupling matrix in Eq. (3) and the coupling topology in Fig. 1(c), two resistive couplings are introduced into the SIW filter to enhance passband flatness and frequency selectivity with simple realization. One resistive coupling is inserted between the first and third resonators while the other resistive coupling is connected with the other two resonators.

$$M_2 = \begin{bmatrix} 0 & 1.035 & 0 & 0 & 0 & 0 \\ 1.035 & -0.041i - |m_{13}|\,i & 0.911 & m_{13}i & 0 & 0 \\ 0 & 0.911 & -0.041i - |m_{24}|\,i & 0.700 & m_{24}i & 0 \\ 0 & m_{13}i & 0.700 & -0.041i - |m_{13}|\,i & 0.911 & 0 \\ 0 & 0 & m_{24}i & 0.911 & -0.041i - |m_{24}|\,i & 1.035 \\ 0 & 0 & 0 & 0 & 1.035 & 0 \end{bmatrix} \tag{3}$$

For simplification, the coupling topology is assumed with symmetric configuration, i.e., $m_{13} = m_{24}$. The value of $m_{13}$ should be determined to achieve good flatness in the passband. By choosing some in-band sampling frequencies, a flat passband will be obtained in the case that the variation of their transmission amplitudes is minimized, and the $|S_{21}|$ variation of these samplings is lower than a threshold.

Since the filter has a symmetric response, the reflection zeros of the designed reference SIW filter in the upper half passband are chosen as two sampling frequencies, i.e., 5.048 and 5.116 GHz, as shown in Fig. 2. The synthesized results of $|S_{21}|$ are plotted in Fig. 3. $|S_{21}|$ of the sampling frequencies with the finite unloaded $Q$-factor of SIW resonator are calculated to be $a_1 = 0.9072$ and $a_2 = 0.8799$.

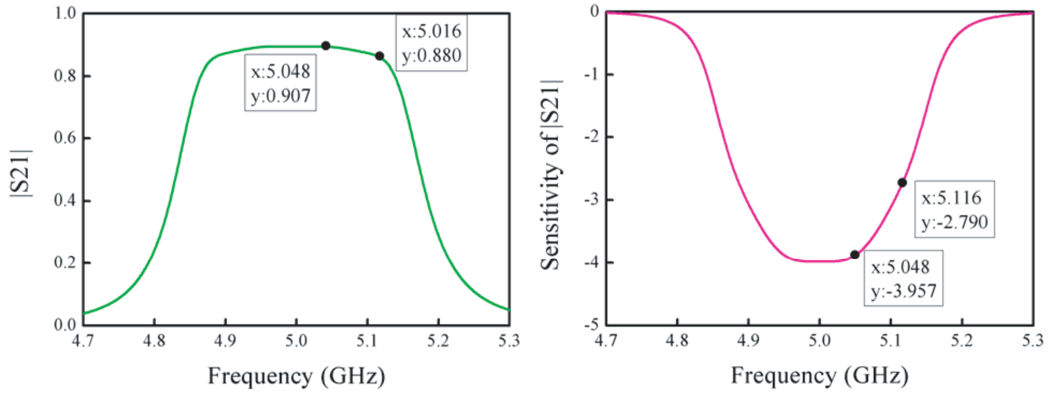


**Figure 3.** Synthesized results of $|S_{21}|$ and the sensitivity of $|S_{21}|$ to the resistive coupling $m_{13}$ of the reference SIW filter.

The sensitivity analysis of $|S_{21}|$ to the resistive coupling $m_{13}$ is carried out. The sensitivity can be calculated by

$$k = \partial |S_{21}| / \partial m_{13} \tag{4}$$

$$S_{21} = -2j\mathbf{A}^{-1}_{N+2,1}, \quad \mathbf{A} = -j\mathbf{R} - s\mathbf{U} + \mathbf{M} \tag{5}$$

$$s = \frac{j}{FBW}\left(\frac{f}{f_0} - \frac{f_0}{f}\right) \tag{6}$$

where $FBW$ is the fractional bandwidth, $\mathbf{R}$ an $(N+2)\times(N+2)$ zero matrix except for $R_{11} = R_{N+2,N+2} = 1$, and $\mathbf{U}$ an $(N+2)\times(N+2)$ identity matrix except for $U_{11} = U_{N+2,N+2} = 0$. The sensitivity of $|S_{21}|$ to the resistive coupling coefficient $m_{13}$ is also provided in Fig. 3 as a function of frequency. The sensitivities at the two sampling frequencies are obtained to be $k_1 = -3.957$ and $k_2 = -2.790$ with the transmission magnitudes of $a_1 = 0.907$ and $a_2 = 0.880$, respectively. Based on the first-order approximation, we have

$$m_{13} = m_{24} = \frac{a_1 - a_2}{k_2 - k_1} = 0.0234 \tag{7}$$

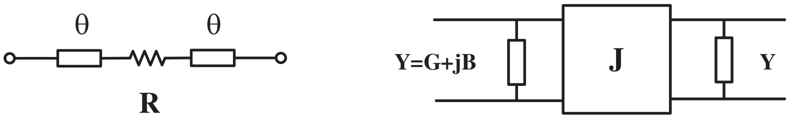
The resistive coupling can be realized by the circuit shown in Fig. 4(a), which is equivalent to the complex admittance inverter shown in Fig. 4(b). The transmission matrices of circuits in Figs. 4(b) and 4(a) are given by

$$[ABCD] = \begin{bmatrix} 1 & 0 \\ Y & 1 \end{bmatrix} \cdot \begin{bmatrix} 0 & \pm\frac{j}{J} \\ \pm jJ & 0 \end{bmatrix} \cdot \begin{bmatrix} 1 & 0 \\ Y & 1 \end{bmatrix} = \begin{bmatrix} j\frac{Y}{J} & \frac{j}{J} \\ j\frac{Y^2}{J} + jJ & j\frac{Y}{J} \end{bmatrix} \tag{8}$$

$$\begin{aligned} [ABCD] &= \begin{bmatrix} \cos\theta & jZ_0\sin\theta \\ \frac{j\sin\theta}{Z_0} & \cos\theta \end{bmatrix} \cdot \begin{bmatrix} 1 & R \\ 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} \cos\theta & jZ_0\sin\theta \\ \frac{j\sin\theta}{Z_0} & \cos\theta \end{bmatrix} \\ &= \begin{bmatrix} \cos 2\theta + j\frac{R\sin 2\theta}{2Z_0} & \frac{R(1+\cos 2\theta)}{2} + jZ_0\sin 2\theta \\ \frac{R(\cos 2\theta - 1)}{2Z_0^2} + j\frac{\sin 2\theta}{Z_0} & \cos 2\theta + j\frac{R\sin 2\theta}{2Z_0} \end{bmatrix} \end{aligned} \tag{9}$$

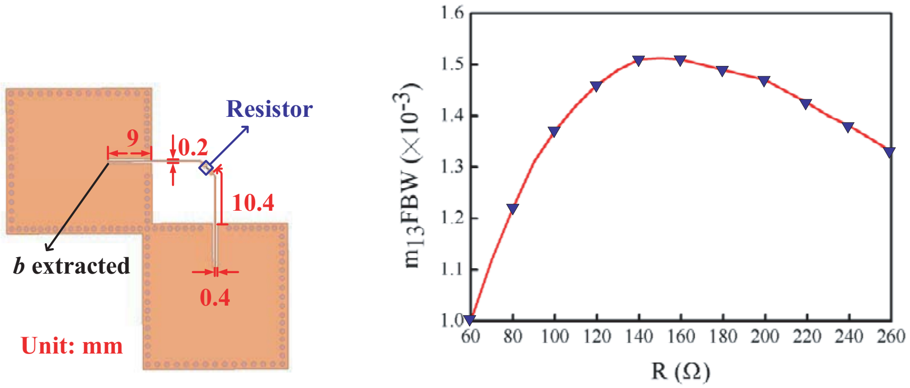
where $R$ is the resistance value of surface mounted resistor, and $\theta$ and $Z_0$ are the electrical length and characteristic impedance of the transmission line connecting the resistor with an SIW cavity, respectively. Then, the expression of $J$ can be derived as

$$J = \frac{4Z_0\sin 2\theta}{(R + R\cos 2\theta)^2 + 4Z_0^2\sin^2 2\theta} + j\frac{2R(1+\cos 2\theta)}{(R + R\cos 2\theta)^2 + 4Z_0^2\sin^2 2\theta} \tag{10}$$



(a) (b)

**Figure 4.** Resistive coupling structure: (a) the circuit to be realized; and (b) the equivalent circuit.



(a) (b)

**Figure 5.** (a) Layout of extracting the value of the susceptance slope parameter $b$; (b) the value of $J$ as the function of $R$.

It is seen that when the length of transmission line is not equal to half wavelength, the inverter admittance and resulted coupling coefficient will be complex. In order to obtain the required resistive coupling coefficient, the resistance should satisfy the following equation.

$$\mathrm{Im}\,(J)=\frac{2R\,(1+\cos 2\theta)}{R^2\,(1+\cos 2\theta)^2+4Z_0^2\sin^2 2\theta}=bm_{13}FBW \tag{11}$$

where $b$ is the susceptance slope parameter of the SIW resonator, which can be extracted at the tapped location as shown in Fig. 5(a) with the full-wave simulator, ANSYS HFSS. It is obtained that $b = 2.5\,\mathrm{S}$ in our design. Fig. 5(b) shows the resistive coupling coefficient $m_{13}$ as the function of resistance $R$, where $\theta = 153°$ and $Z_0 = 160\,\Omega$. The resistive coupling coefficient at first increases with $R$ to a maximum value and then shows decreasing trend. When a resistive coupling coefficient $m_{13}$ is synthesized, the required value of $R$ can be solved by

$$R=\frac{1\pm\sqrt{1-4Z_0^2b^2m_{13}^2FBW^2\sin^2 2\theta}}{bm_{13}FBW\,(1+\cos 2\theta)} \tag{12}$$

It is also found that when the length of transmission line is accurately equal to half wavelength, the resistance is simplified to be

$$R=1/(m_{13}bFBW) \tag{13}$$

The resistance is selected to $R = 90\,\Omega$ as the initial value in our design.

## 3. RESULTS AND DISCUSSION

### 3.1. Reference SIW Filter

The first reference filter is implemented as an inline network with its layout and fabricated prototype shown in Fig. 6. It consists of four SIW cavities, and each of them only connects with the adjacent cavities or input/output feeding lines. It is measured by a vector network analyzer, Agilent E5071C. The synthesized, simulated and measured responses are plotted in Fig. 7 for comparison. Table 1

**Table 1.** Coparison of the synthesized, simulated and measured results of the reference filter.

| | Central Frequency (GHz) | Minimum Insertion Loss (dB) | 0.2-dB Bandwidth (MHz) | In-Band Return Loss (dB) |
|---|---|---|---|---|
| Synthesized | 5.00 | 0.84 | 208 | 20.0 |
| Simulated | 5.00 | 0.88 | 199 | 19.2 |
| Measured | 4.98 | 1.04 | 198 | 18.9 |

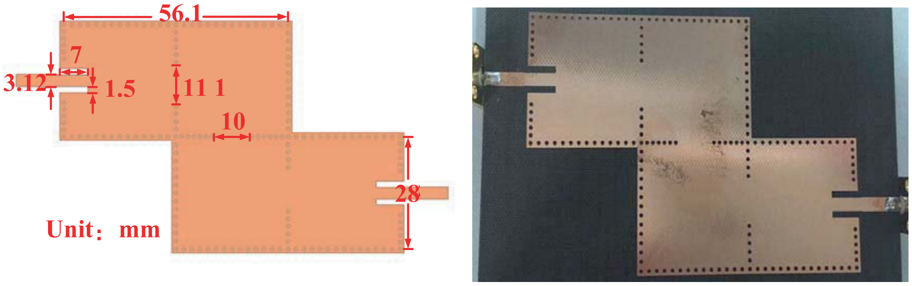


**Figure 6.** Layout and photo of the reference SIW filter designed with the conventional synthesis method.

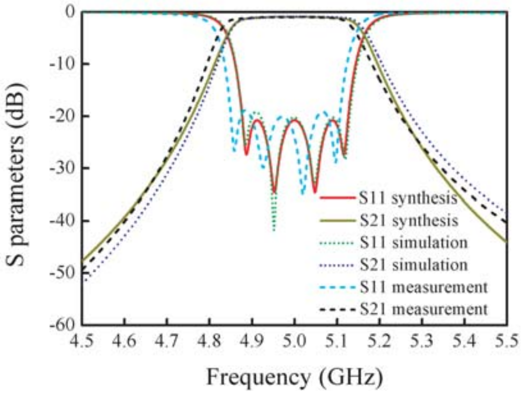


**Figure 7.** Synthesized, simulated and measured responses of the reference SIW filter prototype.

summarizes the critical parameters of the synthesized, simulated and measured responses. It is seen that they are in good consistency. The measured passband is centered at 4.98 GHz, and the bandwidth with the insertion loss varying within 0.2 dB is 198 MHz. The central frequency and 0.2-dB fractional bandwidth are 5.00 GHz and 199 MHz in simulation, respectively. The frequency shift is mainly due to the tolerance of substrate permittivity and fabrication. The measured minimum insertion loss is 1.04 dB, and the in-band return loss is better than 18.9 dB, while the simulated minimum insertion loss is 0.88 dB, and the in-band return loss is better than 19.2 dB. The additional measured insertion loss of about 0.16 dB is introduced by the SMA connectors in measurement.

### 3.2. Lossy Filter Synthesized with Lossy Coupling Matrix

Figure 8 shows the layout and photo of the reference filter synthesized with lossy coupling matrix, where four resistive couplings are introduced. The synthesized, simulated and measured responses are compared in Fig. 9(a) and Table 2. In measurement, this filter presents an insertion-loss variation of 0.2 dB within 244 MHz. The minimum insertion loss is 3.06 dB, and the return loss is better than

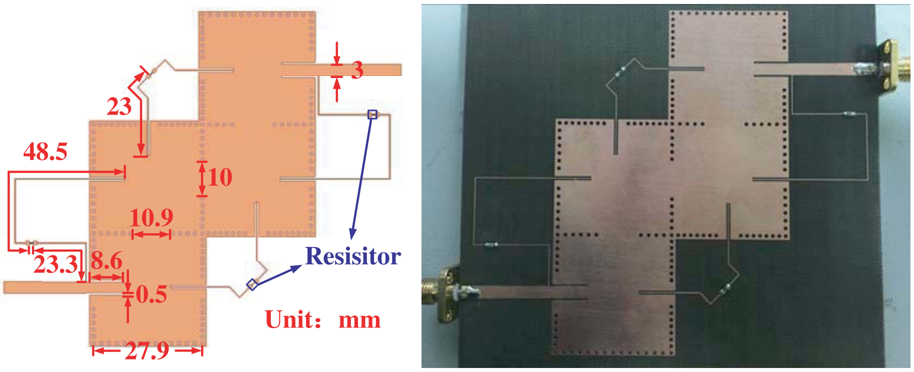
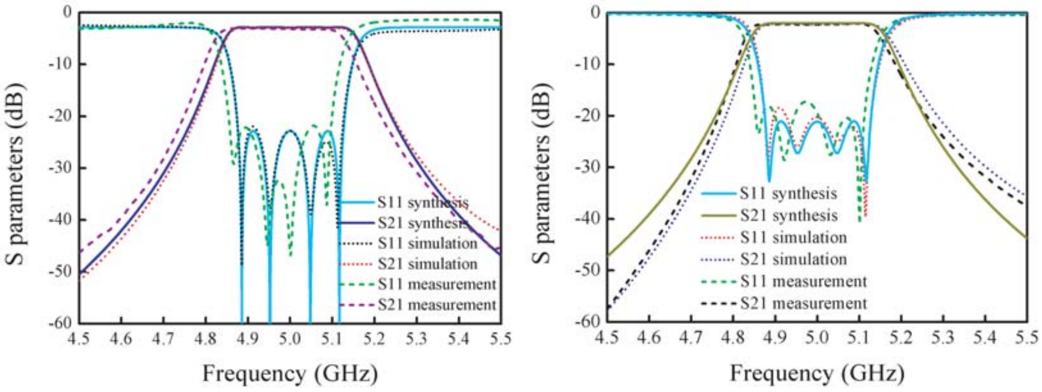


**Figure 8.** Layout and photo of the SIW filter synthesized with lossy coupling matrix.



(a) (b)

**Figure 9.** Comparison of synthesized, simulated and measured results (a) the reference lossy SIW filter synthesized with lossy coupling matrix; (b) the proposed lossy SIW filter with resistive couplings.

**Table 2.** Coparison of the synthesized, simulated and measured results of the lossy filter synthesized with lossy coupling matrix.

| | Central Frequency (GHz) | Minimum Insertion Loss (dB) | 0.2-dB Bandwidth (MHz) | In-Band Return Loss (dB) |
|---|---|---|---|---|
| Synthesized | 5.00 | 2.84 | 266 | 22.84 |
| Simulated | 5.00 | 2.88 | 254 | 21.95 |
| Measured | 4.98 | 3.06 | 244 | 21.82 |

21.82 dB. However, the insertion loss and in-band return loss are 2.88 and 21.95 dB, and the 0.2-dB bandwidth is 254 MHz in the simulated results. The measured flatness is slightly degraded when compared with the theoretical result.

### 3.3. Proposed Resistively Coupled SIW Filter

The structure and fabricated prototype shown in Fig. 10 is the proposed lossy SIW filter with resistive couplings. Each resistive coupling structure consists of a surface mounted resistor, two sections of transmission lines and two square pads with 1-mm side length. It is fabricated on the same substrate as those in Section 2.

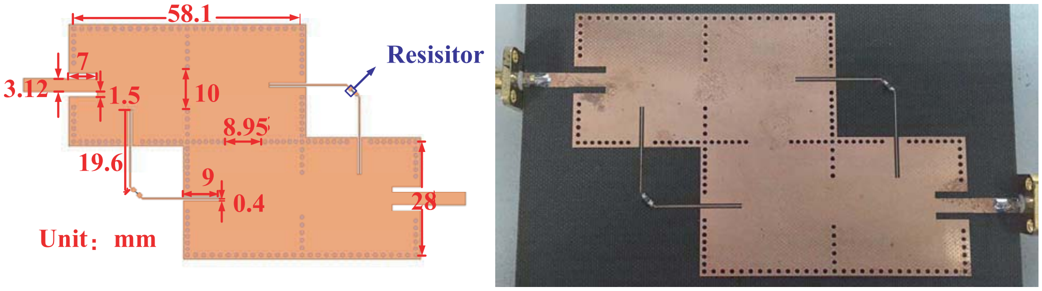


**Figure 10.** Layout and photo of the proposed lossy SIW filter with resistive couplings for flat passband.

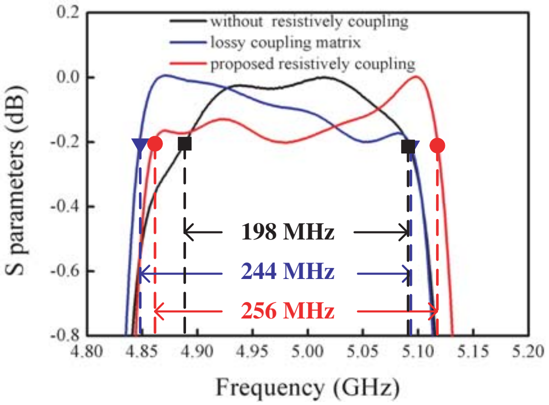


**Figure 11.** Measured normalized transmission coefficients of the two reference SIW filters and the proposed resistively coupled SIW filter.

The comparison of synthesized, simulated and measured responses is plotted in Fig. 9(b) and summarized in Table 3. Its measured passband is centered at 4.99 GHz with a 0.2-dB bandwidth of 256 MHz, while its central frequency and 0.2-dB fractional bandwidth are 5.00 GHz and 257 MHz in simulation, respectively. The simulated minimum insertion loss is 2.05 dB, and its in-band return loss is better than 18.4 dB. The measured insertion loss is 0.1 dB higher than the simulated one. The return loss is also degraded by 1.1 dB in measurement.

The normalized transmission coefficients and measured results of the reference SIW filter, lossy filter synthesized with lossy coupling matrix and the proposed resistively coupling filter are compared in Fig. 11 and Table 4. With insertion loss increased from 0.98 to 3.06 dB, the 0.2-dB bandwidth of the SIW filter synthesized with lossy coupling matrix is improved by 23.2%. By using resistive couplings, the 0.2-dB bandwidth of the proposed lossy SIW filter is broadened from 198 to 256 MHz, i.e., 29.3% improvement of the flat passband, at the cost of increasing the minimum insertion loss by only 1.1 dB when compared with the reference SIW filter. The insertion loss of the proposed resistively coupled filter is 2.10 dB, less than that of 3.06 dB of the lossy SIW filter synthesized with lossy coupling matrix, while their 0.2-dB bandwidths are comparable. And the realization of our proposed filter is more simplified because of avoiding two resistive couplings and two resistors. For the proposed resistively coupled filter, the transmission magnitude of the upper bandedge is a little higher than that of the lower bandedge, as shown in Fig. 11. This is mainly due to the parasitic real part of the coupling coefficient provided by the resistive coupling structure, since the length of transmission lines is not just equal to half wavelength.

Moreover, the lossy filter realized with microstrip resonators in [7] has an insertion loss of 3.1 dB with the larger *FBW* of 21% while our proposed lossy SIW filter with simplified resistive couplings has a lower insertion loss of 2.15 dB for a smaller *FBW* of 5%. Thus, the SIW filter is more applicable to provide a flat passband with low insertion loss especially for narrow-band applications, compared with the microstrip counterparts.

**Table 3.** Coparison of the synthesized, simulated and measured results of the resistively coupled lossy filter.

| | Central Frequency (GHz) | Minimum Insertion Loss (dB) | 0.2-dB Bandwidth (MHz) | In-Band Return Loss (dB) |
|---|---|---|---|---|
| Synthesized | 5.00 | 2.01 | 255 | 20.0 |
| Simulated | 5.00 | 2.05 | 257 | 18.4 |
| Measured | 4.99 | 2.10 | 256 | 17.3 |

**Table 4.** Comparison of the measured results of the two reference SIW filters and the proposed resistively coupled SIW filter.

| | Central Frequency (GHz) | Minimum Insertion Loss (dB) | 0.2-dB Bandwidth (MHz) | In-Band Return Loss (dB) |
|---|---|---|---|---|
| Reference | 4.98 | 0.98 | 198 | 18.9 |
| Lossy | 4.98 | 3.06 | 244 | 21.8 |
| Proposed | 4.99 | 2.10 | 256 | 17.3 |

## 4. CONCLUSION

A lossy SIW filter with two resistive couplings is proposed to improve the passband flatness and frequency selectivity. The resistive couplings between SIW cavities are constructed with surface mounted resistors and planar transmission lines, avoiding the introduction of other resistive couplings between the nonresonating nodes and SIW cavities. The design and realization are simplified, and smaller additional insertion loss is introduced, in comparison with the filter designed with the synthesis method of lossy coupling matrix. The proposed lossy SIW filter has a lower in-band insertion loss with a narrower bandwidth than the microstrip counterparts. Excellent agreement has been observed among the synthesized, simulated and measured results.

## ACKNOWLEDGMENT

This work is supported by the National Natural Science Foundation of China under Grants 61370008 and 61361166010.

## REFERENCES

1. Cameron, R. J., C. M. Kudsia, and R. R. Mansour, *Microwave Filter for Communication Systems: Fundamentals, Design, and Applications*, Wiley, Hoboken, NJ, USA, 2007.
2. Williams, A. E., W. G. Bush, and R. R. Bonetti, "Predistortion techniques for multicoupled resonator," *IEEE Trans. Microw. Theory Tech.*, Vol. 33, No. 5, 402–408, May 1985.
3. Guyette, A. C., I. C. Hunter, and R. D. Pollard, "The design of microwave bandpass filters using resonators with nonuniform $Q$," *IEEE Trans. Microw. Theory Tech.*, Vol. 54, No. 11, 3914–3922, Nov. 2006.
4. Meng, M., I. C. Hunter, and J. D. Rhodes, "The design of parallel connected filter networks with nonuniform $Q$ resonators," *IEEE Trans. Microw. Theory Tech.*, Vol. 62, No. 1, 372–381, Jan. 2013.
5. Miraftab, V. and M. Yu, "Generalized lossy microwave filter coupling matrix synthesis and design using mixed technologies," *IEEE Trans. Microw. Theory Tech.*, Vol. 56, No. 12, 3016–3027, Dec. 2008.

6. Miraftab, V. and M. Yu, "Advanced coupling matrix and admittance function synthesis techniques for dissipative microwave filters," *IEEE Trans. Microw. Theory Tech.*, Vol. 57, No. 10, 2429–2438, Oct. 2009.
7. Basti, A., A. perigaud, S. Bila, S. Verdeyme, L. Estagerie, and H. Leblond, "Design of microstrip lossy filters for receivers in satellite transponders," *IEEE Trans. Microw. Theory Tech.*, Vol. 62, No. 9, 0018–9480, Sep. 2014.
8. Chen, X.-P. and K. Wu, "Substrate integrated waveguide filters: Design techniques and structure innovations," *IEEE Microw. Magazine*, Vol. 15, No. 6, 121–133, Sep. 2014.
9. Wu, L.-S., X.-L. Zhou, L. Zhou, W.-Y. Yin, and J.-F. Mao, "A substrate integrated evanescent-mode waveguide filter with nonresonating node in low temperature co-fired ceramic," *IEEE Trans. Microw. Theory Tech.*, Vol. 58, No. 10, 2654–2662, Oct. 2010.
10. Mira, F., J. Mateu, and M. Bozzi, "Substrate integrated waveguide predistorted filter at 20 GHz," *IET Microw. Antennas Propag.*, Vol. 5, No. 8, 928–933, Jan. 2011.
11. Jedrzejewski, A., N. Leszczynska, L. Szydlowski, and M. Mrozowski, "Zero-pole approach to computer aided design of in-line SIW filters with transmission zeros," *Progress In Electromagnetics Research*, Vol. 131, 517–533, 2012.
12. Szydlowski, L., A. Lamecki, and M. Mrozowski, "Design of microwave lossy filter based on substrate integrated waveguide (SIW)," *IEEE Microw. Wireless Compon. Lett.*, Vol. 21, No. 5, 249–251, May 2011.
13. Cameron, R. J., "General coupling matrix synthesis methods for Chebyshev filtering functions," *IEEE Trans. Microw. Theory Techn.*, Vol. 47, No. 4, 433–442, Apr. 1999.