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Design and Fabrication of a Compact SIW Diplexer in C-Band

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Abstract: In this paper, a compact 6.8/7.6 GHz diplexer is provided with the help of substrate integrated waveguide (SIW) structures. The use of this structure is for satellite communication systems. The designed diplexer includes a T-junction. In addition, our structure consists of two SIW filters of the type of bandpass. The relative bandwidth of the upper channel is 3.3% at the center frequency of 7.6 GHz and its lower channel is 3.7% at the center frequency of 6.8 GHz. The proposed diplexer offers a great benefit in terms of size decrease. In addition, it displays an optimal insertion loss. While giving the low return loss. Ultimately, the designed structure displays ideal rates of isolation and rejection. The diplexer incorporates a planar form and can be simply integrated with to the integrated circuits of the microwave. The insertion and return losses are 1.8 dB and 15d B in the lower band and they are 1.9 dB and 17 dB in the upper band. Simulations have been implemented with CST Microwave Studio. The Diplexer is completely built into a standard printed circuit board (PCB) procedure. A very favorable compromise is reached among the results of the construction and the measurement, which is the evidence of the proposed method.

Keywords: Substrate Integrated Waveguide (SIW), Band Pass Filter, Diplexer.

1 Introduction

IN general, a substrate integrated waveguide (SIW) is a flat structure that filled with dielectric. Its form is similar to rectangular waveguide. While being associated with the category of substrate integrated circuits (SICs). SIW is a famous method for achieving a swap solution between the waveguide and planar structures. It is made using common techniques such as PCB, low-temperature ceramic co-fired (LTCC), and so forth. Among the benefits of SIW are: high-quality factor and gain, flat structure, low cost, easy construction, low radiation loss rates and so on. Diplexers are the needed elements in the world of modern technology. They usually consist of two bandpass filters. Diplexers are usually used to separate two different RF signals. Recently, SIW structures make a great contribution to the creation of diplexers.

Basically, diplexers have several constructional topologies. SIW diplexers are provided with a branch port forms which has an angle of 90° among the two output ports [1]. The SIW diplexers type of T-junction is provided with an angle of 180° between two output ports [2-4]. Diplexers using a circulator instead of T-junction, with an angle of 120° between the output ports [5]. Y-type SIW diplexers using curved microstrip ports [6, 7]. SIW diplexers using a square dual mode cavity as a joint resonator that presenting the T-junction [8]. Diplexers with port orientation backward diplexer [9].

A compact SIW diplexer is provided in this paper. The use of this structure is for the C-band satellite communication antennas. The proposed diplexer in this paper is the type of T-junction. Also, the designed structure has two fourth-order SIW filters. The used filters are the type of bandpass. Compared to other articles, the proposed diplexer offers important benefits in terms of size reduction, the simplicity of fabrication, and low cost. In the beginning, a brief preface to the subject of the discussion will be described (Section 2). Then the components of the proposed diplexer are explained (Section 3). The simulation and measurement results of the SIW filters are reported. Finally, by testing and measuring the fabricated prototype, the validity of the proposed method is verified (Section 4).

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2 Diplexer Idea

The basic design of the SIW diplexer in CST software is shown in Fig.1. In this structure, the T-junction through the transition lines is linked to fourth order SIW filters. Basically, fourth order SIW filters are used to obtain high isolation. The components are implemented in a standard PCB procedure on the Rogers RO4003. The substrate thickness is 0.508 mm. The dielectric constant of the substrate is $\varepsilon_r = 3.38$. The loss tangent of the substrate is $\tan\delta = 0.0027$. All vias of left and right side filters should be drilled with diameters of 0.5 mm and 0.4 mm respectively. While the diameters of the central vias on the left and right side filters are 0.7 mm and 0.6 mm, respectively.

3 Elements Design

In the discussion below, the extension of two filters and a T-junction is reported.

3.1 Design Fourth-Order SIW Filter

The SIW filter configuration is depicted in Fig. 2. The SIW filter coupling diagram is presented in Fig. 3.

Designing this way begins. Initially, the coupling matrix for the quasi-elliptic characteristic of the suitable fourth-order filter is specified with a return loss of 15 dB. Coupling matrixes are obtained using (1) or the following formula [10]:

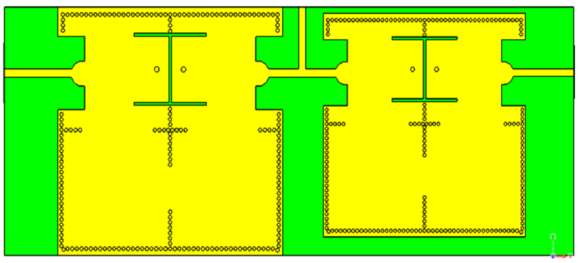


Fig. 1 Image of SIW diplexer in CST software.

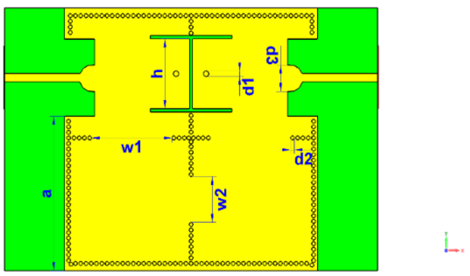


Fig. 2 The configuration of the fourth order SIW filter.

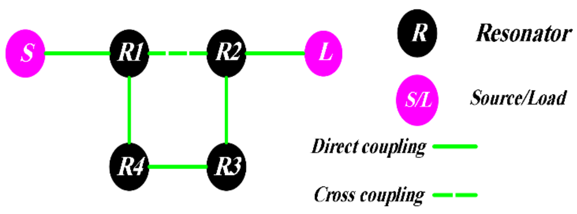


Fig. 3 Coupling diagram of the SIW filter.

$$K_{ij} = K_{ji} = \frac{f_j^2 - f_i^2}{f_j^2 + f_i^2} \tag{1}$$

By using this relation, the coupling matrix is obtained in the form of the matrix (2).

$$K_{ij} = \begin{bmatrix} 0 & -0.04 & 0 & 0.2 \\ -0.04 & 0 & 0.2 & 0 \\ 0 & 0.2 & 0 & 0.05 \\ 0.200 & 0 & 0.050 & 0 \end{bmatrix} \tag{2}$$

The coupling coefficients K_{12} and K_{21} are equal, while their signs are negative. The presence of negative sign displays the transmission zero attendance after the passband at a frequency of 7.2 GHz. It is visible in Fig.5. The filter central frequency occurs at $f_0 = 6.8$ GHz and the bandwidth of the filter is $BW = 0.23$ GHz. By applying these values and using (3), the generalized coupling matrix [11] is obtained as the matrix (4).

$$M_{ij} = K_{ij} \times \frac{f_0}{BW} = K_{ij} \times \frac{6.8}{0.23} = K_{ij} \times 29.6 \tag{3}$$

$$M_{ij} = \begin{bmatrix} 0 & 1.6 & 0 & 0 & 0 & 0 \\ 1.6 & 0 & -1.2 & 0 & 5.9 & 0 \\ 0 & -1.2 & 0 & 5.9 & 0 & 1.6 \\ 0 & 0 & 5.90 & 0 & 1.500 & 0 \\ 0 & 5.9 & 0 & 1.50 & 0 & 0 \\ 0 & 0 & 1.6 & 0 & 0 & 0 \end{bmatrix} \tag{4}$$

Then the sizes belonging to the square cavity are estimated. For this purpose, the dimensions of the iris are corrected. This setting helps to achieve optimal coupling coefficients. In fact, this is a necessary condition for full wave simulation belonging to the coupled cavities. Finally, the dimensions of the cavities should be adjusted. The purpose of this action is to compensate for the resonance displacement created by the irises [12-16].

The quality factor of the structure Q_{ext1} is obtained from (5). In which $\Delta f_{\pm 90}$ means the bandwidth in which phase change is equal to ± 90 [10].

$$Q_{ext1} = \frac{f_0}{\Delta f_{\mp 90}} = 71.9 \tag{5}$$

Also, using (6), which represents the bandwidth ratio [10], $Q_{ext2} = 80.85$ is obtained.

$$\frac{BW_1}{BW_2} = \frac{Q_{ext2}}{Q_{ext1}} \cdot \frac{f_{01}}{f_{02}} \tag{6}$$

In Fig. 4, the electric field pattern is drawn.

The design is relatively straightforward. In Table 1, the dimensions of the fourth-order SIW filters are classified.

Figs. 5 and 6 respectively provide the frequency responses of the left and right side filters in the CST software.

The insertion loss in the passbands of 6.8 GHz and 7.6 GHz filters are near to 1.8 dB and 1.9 dB, respectively. The return loss is 15 dB in the lower band, while it is 17 dB in the upper band. In addition, the 6.8 GHz filter stopband isolation in the 7.6 GHz filter passband is about 23 dB. Transmission zero is located in 7.2 GHz. It presents a great rejection rate in the inverse channel band.

3.2 T-Junction

The proposed structure in this paper is formed by joining two fourth-order bandpass SIW filters via a middle T-junction. Typically, the attendance of the T - junction changes the response of the filters from optimal to undesirable. So some necessary predictions should be taken. The T-junction is considered in accordance with Fig. 7.

4 Implementation of the Diplexer

Our desirable diplexer comes from a compound of described elements in the previous section. The entire structure of the diplexer is depicted in Fig. 8. General port or port 3 is above. Port 1 or 6.8 GHz is on the left side. Port 2 or 7.6 GHz is on the right side.

The simulated frequency response results of the designed diplexer by the CST software is shown in Fig. 9.

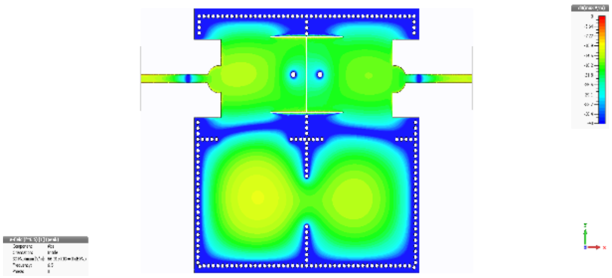


Fig. 4 Electric field pattern in CST software.

Table 1 The fourth-order SIW filter dimensions.

Filter [GHz]	d_1 [mm]	d_2 [mm]	d_3 [mm]	w_1 [mm]	w_2 [mm]	h [mm]	a [mm]
6.8	0.7	0.5	3.3	10.7	5.8	8.8	19.4
7.6	0.6	0.4	2.9	9.6	5.2	7.9	17.5

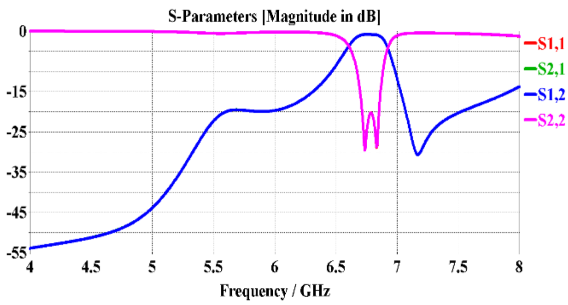


Fig. 5 Simulated results of the left side SIW filter in CST software.

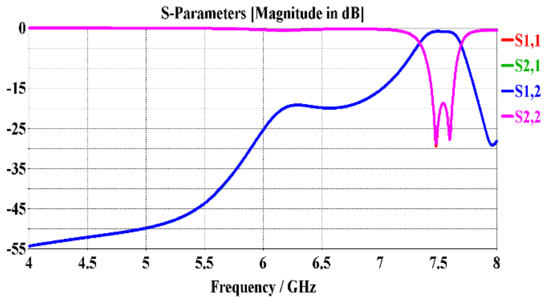


Fig. 6 Simulated results on the right side SIW filter in CST software.

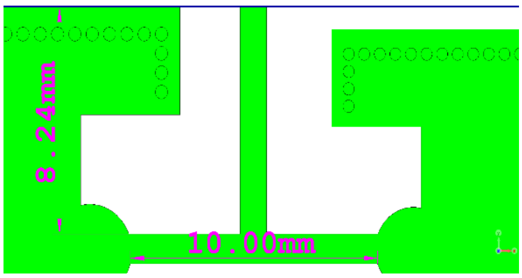


Fig. 7 The T-junction.

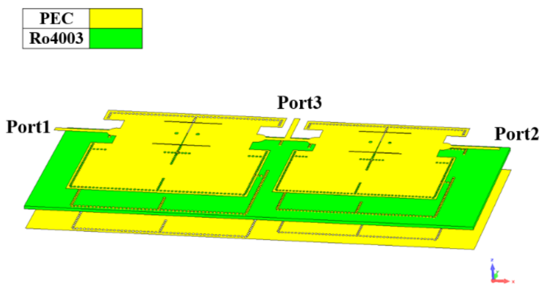


Fig. 8 Complete configuration of SIW diplexer in CST software.

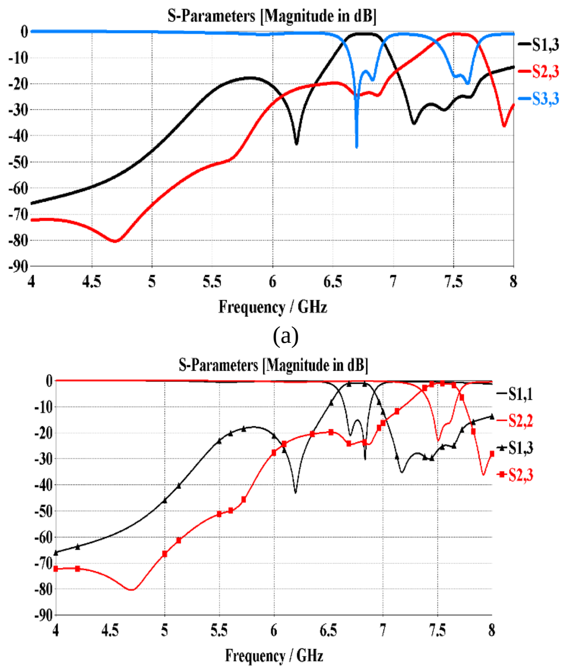


Fig. 9 Simulated results of 6.8 GHz/7.6 GHz single mode diplexer; a) S_{13}, S_{23} & S_{33} and b) S_{11}, S_{22}, S_{13} & S_{23}.

The response is essentially similar to the characteristics of the filters (see Figs. 5 and 6). The equivalent circuit of the proposed SIW diplexer structure with full details is evident in Fig.10.

The fabricated model of the suggested diplexer is illustrated in Fig. 11.

The obtained results of the measurement are shown in Fig. 12. As it is seen, an excellent agreement is got between the results of the simulation and the measurement (Figs. 9 and 12). The comparison between the proposed SIW diplexer specification and other presented diplexers in the articles is evident in Table 2.

5 Conclusion

A compact SIW diplexer is presented that used in C-band satellite communication antenna. This diplexer consists of three main parts: 1. T-junction 2. SIW filter on the left. 3. SIW filter on the right. One of the important parameters of the system is the isolation between the receiver and transmitter at frequencies of 6.8 GHz and 7.6 GHz, respectively. In the lower band (6.8 GHz), return loss is 15 dB, with a 1.8 dB insertion loss, while the bandwidth is 0.25 GHz. In the upper band (7.6 GHz), return loss is 17 dB, with a 1.9 dB insertion loss, while the bandwidth is 0.25 GHz. The design of the diplexer and its components are described in detail. Simulations have been implemented with CST software. The proposed diplexer offers a great benefit in terms of size decrease. In addition, it displays an optimal insertion loss. While giving the low return loss. Ultimately, the designed structure displays ideal rates of isolation and rejection. The structure is designed and manufactured in a single-layer PCB procedure. Construction and simulation results are so similar, which confirms the correctness of the method. Finally, the features of the diplexer can be mentioned as the ideal isolation of 23 dB at 7.6 GHz.

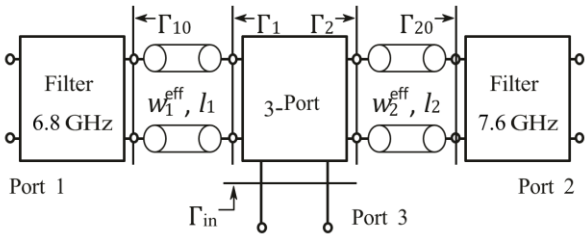
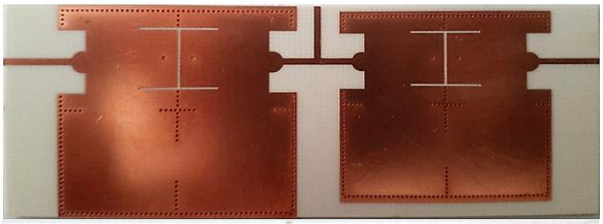
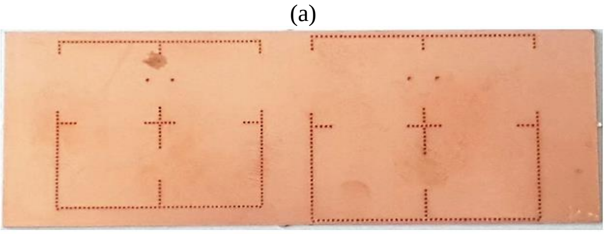


Fig. 10 Simulated results of the left side SIW filter in CST software.

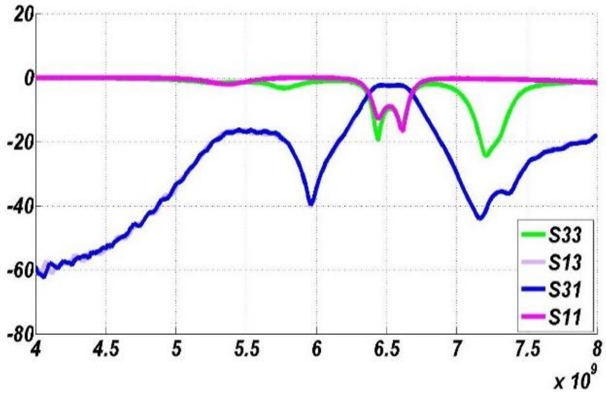


(a)

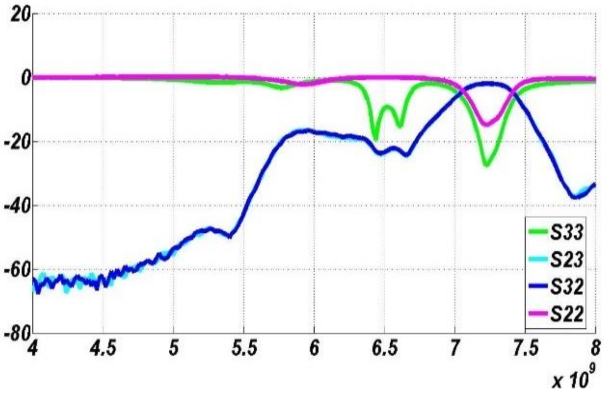


(b)

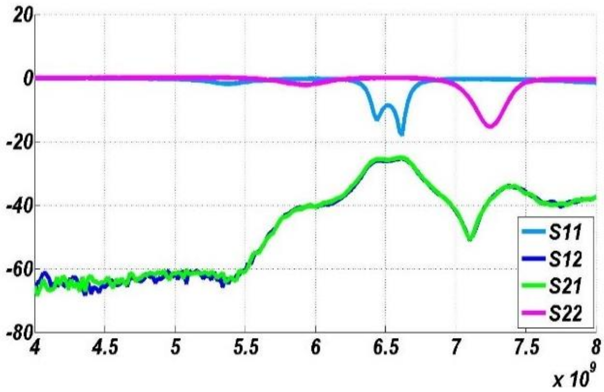
Fig. 11 The photo of the fabricated diplexer; a) The image of the top view and b) The image of the bottom view.



(a)



(b)



(c)

Fig. 12 Frequency response results from measurement of the fabricated SIW diplexer; a) S_{33}, S_{13}, S_{31} & S_{11}, b) S_{33}, S_{23}, S_{32} & S_{22}, and c) S_{11}, S_{12}, S_{21} & S_{22}.

Table 2 Comparisons between articles and suggested diplexer.

References	Size	Insertion Loss [dB]	Return Loss [dB]	Rejection [dB]	Isolation [dB]
[1]	$2.71\lambda_0\times3.35\lambda_0\times0.009\lambda_0$	2.6/3.2	12.5/17.5	55dB@5.42GHz/55dB@5.96GHz	53
[3]	$2.04\lambda_0\times0.65\lambda_0\times0.053\lambda_0$	1.6/2.1	10/10	42dB@9.50GHz/37dB@10.50GHz	35
[17]	$1.44\lambda_0\times0.98\lambda_0\times0.022\lambda_0$	2.2/2.4	17.5/17.5	22dB@7.75GHz/22dB@8.25GHz	–
[18]	$0.27\lambda_0\times0.22\lambda_0\times0.008\lambda_0$ (With regardless of microstrip feeds)	1.6/2.3	12.9/12.9	43dB@4.66GHz/28dB@5.80GHz	32
In This Study	$1.6\lambda_0\times0.72\lambda_0\times0.01\lambda_0$	1.8/1.9	15.0/17.0	23.7dB@6.80GHz/24.9dB@7.60GHz	23

While λ_0 is the free space wavelength. Its function is at the central frequency of the first channel.

References

[1] Z. C. Hao, W. Hong, J. X. Chen, X. P. Chen, and K. Wu, "Planar diplexer for microwave integrated circuits," *IEE Proceedings-Microwaves, Antennas and Propagation*, Vol. 152, No. 6, pp. 455–459, Dec. 2005.

[2] H. J. Tang, W. Hong, J. X. Chen, G. Q. Lou, and K. Wu, "Development of millimeter-wave planar diplexers based on complementary characters of dual-mode substrate integrated waveguide filters with circular and elliptic cavities," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 55, No. 4, pp. 776–782, Apr. 2007.

[3] S. Sirci, J. Martinez, J. Vague, and V. Boria, "Substrate integrated. waveguide diplexer based on circular triplet combline filters," *IEEE Microwave and Wireless Components Letters*, Vol. 25, No. 7, pp. 430–432, Jul.2015.

[4] P. Chu, W. Hong, M. Tuo, K-L. Zheng, W. W. Yang, F. Xu, and K. Wu, "Dual-mode substrate integrated waveguide filter with flexible response," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 65, No. 3, pp. 824–830, Mar. 2017.

[5] J. He, K. Gao, and Z. Shao, "A novel compact KA-band high-rejection diplexer based on substrate integrated waveguide," in *IEEE International Conference on Computational Problem-Solving (ICCP)*, pp. 19–21, Oct. 2012.

[6] Z. Kordiboroujeni and J. Bornemann, "Mode matching design of substrate integrated waveguide diplexers," in *IEEE MTT-S International Microwave Symposium Digest (MTT)*, pp. 2–7, 2013.

[7] J. Schorer, J. Bornemann, and U. Rosenberg, "Mode-matching design of substrate mounted waveguide (SMW) components," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 64, No. 8, pp. 776–782, Apr. 2016.

[8] F. Cheng, X. Lin, K. Song, Y. Jiang, and Y. Fan, "Compact diplexer with high isolation using the dual-mode substrate integrated waveguide resonator," *IEEE Microwave and Wireless Components Letters*, Vol. 23, No. 9, pp. 459–461, Sep. 2013.

[9] Z. Kordiboroujeni and J. Bornemann, "K-band backward diplexer in substrate integrated waveguide technology," *Electronics Letters*, Vol. 51, No. 18, pp.1428–1429, Sep. 2015.

[10] J. S. Hong and M. J. Lancaster, *Microstrip Filter for RF/Microwave Applications*. New York: Wiley, 2001, pp. 235–272.

[11] R. J. Cameron, "General coupling matrix synthesis methods for Chebyshev filtering functions," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 47, No. 4, pp. 433–442, Apr. 1999.

[12] R. J. Cameron, C. M. Kudsia, and R. R. Mansour, *Microwave filters for communication systems: Fundamentals, design, and applications.* Hoboken and N. J: Wiley-Interscience, 2007.

[13] R. J. Cameron, "Advanced coupling matrix synthesis techniques for microwave filters," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 51, No. 1, pp. 1–10, Jan. 2003.

[14] A. Ghobadi Rad and J. Soleiman Meiguni, "WLAN substrate integrated waveguide filter with novel negative coupling structure," *Journal of Modeling & Simulation in Electrical & Electronics Engineering (MSEEE)*, Vol. 1, No. 2, pp. 15–18, 2015.

[15] J. Soleiman Meiguni and A. Mazandarani, "Miniaturized impedance inverter 2.4 GHz filter with optimal transmission zeroes," *Microwave and Optical Technology Letters*, Vol. 60, No. 8, pp. 1940–1946, 2018.

[16] F. Khamin-Hamedani and Gh. Karimi, "Dual-band bandpass filter based on coupled complementary hairpin resonators," *Iranian Journal of Electrical and Electronic Engineering (IJEEE)*, Vol. 14, No. 4, pp. 324–329, Dec. 2018.

[17] A. García-Lampérez, M. Salazar-Palma, and S. H. Yeung, "SIW compact diplexer," in *IEEE MTT-S International Microwave Symposium (IMS2014)*, pp. 1–4, 2014.

[18] Y. Dong and T. Itoh, "Substrate integrated waveguide loaded by complementary split-ring resonators for miniaturized diplexer design," *IEEE Microwave and Wireless Components Letters*, Vol. 21, No. 1, pp. 10–12, Jan. 2011.

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