Wideband Bandpass Filter Design combining Substrate Integrated Waveguide and Complementary Split Ring Resonator

Naima Benmostefa*, Mohammmed. Feham
STIC Laboratory, University of Tlemcen, Algeria
Email: benmostefanaima@yahoo.fr

***Abstract*-This paper presents a compact substrate integrated waveguide (SIW) bandpass filter (BPF) as a candidate for use in wide bandwidth (X-Ku) bands applications. The proposed filter is constructed by the association of bowtie resonators on the SIW structure and Complementary Split Ring Resonators (CSRR), which has successfully led to a compact size and a wide bandwidth. The designed filter is very much compact in size, with dimensions (27*14)mm^2, using a substrate with a relative permittivity of 2.2 and a thickness of 0.245mm. The filters are designed and simulated using HFSS and the results exhibit a return loss less than -15dB and an insertion loss approaching to 0dB over the band (8-18) GHz.**

***Index Terms*- Bandpass filter, SIW, CSRR, Impedance matching, Taper, Wideband**

I. INTRODUCTION

Rectangular Waveguides (RWG) are used in microwave systems due to their high quality-factor and high power handling capability. Their integration with planar circuits requires efficient 3D transitions. Therefor, Substrate Integrated Waveguide (SIW) has been proposed in the last years, as the planar version of the conventional RWG. The SIW is fabricated by using two periodic rows of metallic vias connecting the top and bottom ground planes of a dielectric substrate, allowing in this way an easy integration with planar circuits [1]. The SIW technology can be applied in many microwave and millimeter wave applications, such as traditional structures of filters, couplers, dividers… [2-7].

In this Study, we are interested by bandpass filters. Several papers in the literature are related to these devices, some of them [8-10] developed narrowband filters and others [11-14] conceived wideband filters. The most useful and complete study of wideband filters is presented in the paper [14], but the designed SIW-BPF is efficient just in the band (9-15)GHz. To extend this band, we optimized the filter dimensions and used adequate tapers for impedance matching to 50Ω microstrip line. The analysis of the optimized structure shows wide bandwidth beetween 8 GHz and 18 GHz, called (X-Ku) band. Then by coupling CSRRs to this SIW-BPF, its returnloss is more improved.

So, in this paper, we show the efficiency and the applicability of our SIW-BPF structure. The rest of this paper is organized as follows. In Section 2, we present the basic SIW structure, matching by tapers. Section 3 shows the wideband BPF design. Section 4 describes the performance of the SIW-BPF coupling to CSRRs. Finally, we draw our conclusion in the last Section 5.

II. SUBSTRATE INTEGRATED WAVEGUIDE

The SIW is fabricated by using two periodic rows of metallic vias connecting the top and bottom ground planes of a dielectric substrate of RT/Duroid 5880 with a relative permittivity of 2.2 and a thickness of 0.245 mm, allowing in this way an easy integration with planar microwave circuits. The Figure 1 shows a SIW structure matched to 50Ω mictrostrip lines by tapers. The parameters used to design this device are the diameter “d” of the metalized vias, the space period “p” of vias, the distance “a” between two rows of vias, the dielectric substrate thickness “h”, the lengths (L_1, L_2, L_3) and the widths (w_1, w_2, w_3) of the microtrip line, the taper and the SIW, respectively.

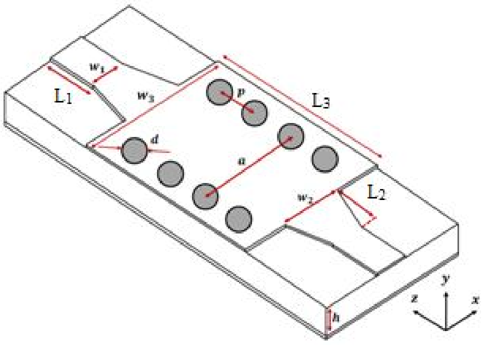

Fig.1. Basic SIW structure matched by tapers

Starting from a RWG with dimensions (W_g, h), filled with a dielectric of permittivity ε_r, having a cut-off frequency of the dominant mode TE_{10} around 10.5GHz. Empirical equations are then used for determining the SIW parameters giving the same characteristics of the fundamental mode propagating and having the same height and the same dielectric. Then we deduce the SIW parameters as the width "a", the diameter "d" of the metalized vias and the space period "p" of vias, given by the following equations (1-6). The period "p" should be kept low to reduce leakage losses between adjacent vias.

$$a = w_g + \frac{d^2}{0.95p} \quad (1)$$

$$d < \lambda_g / 5 \quad (2)$$

$$P < 2d \quad (3)$$

$$\lambda_g = \frac{\lambda}{\sqrt{1 - \left(\frac{\lambda}{\lambda_c}\right)^2}} \quad (4)$$

$$\lambda = \frac{c_0}{\sqrt{\varepsilon_r} f} \quad (5)$$

$$\lambda_c = 2a \quad (6)$$

Where λ is the space wavelength, λ_c is the cut-off wavelenght of the dominant TE_{10} mode, c_0 is the speed of light, f is the operating frequency and ε_r is the dielectric permittivity.

In SIW technology, the components are fed by 50Ω microstrip line. The integration between them can be made by a taper transition, which realizes the impedance matching between the impedance of the feeding line and the impedance of the SIW component. The taper is used to have maximum coupling between SIW-BPF and external microstrip line. There are some studies [15, 16] that provide an appropriate treatment for the taper transition. Due the difficult of analytical treatment, computational optimization is used to determine the optimum dimensions of the taper.

Finally, the optimum dimensions of the structure (figure1) are presented in Table 1 and the layout of this structure is shown on figure 2. This structure was analyzed by HFSS and its response is given on figure 3, where we can see a return loss S11 higher then -2.3dB and an insertion loss S21 less then -15dB over the band (8-20)GHz.

Table 1: Parameters of the proposed SIW

Parameters	a	p	D	h	L_1
Values (mm)	9.6	0.765	0.5	0.245	4.18
Parameters	L_2	L_3	W_1	W_2	W_3
Values (mm)	3.82	10.63	0.74	1.91	13.09

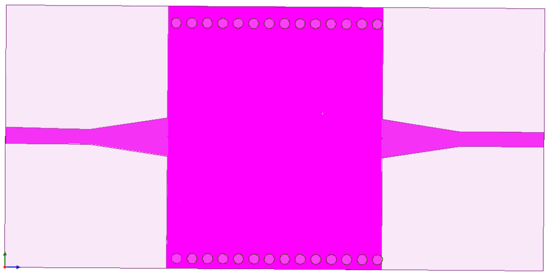

Fig.2. Layout of SIW Structure

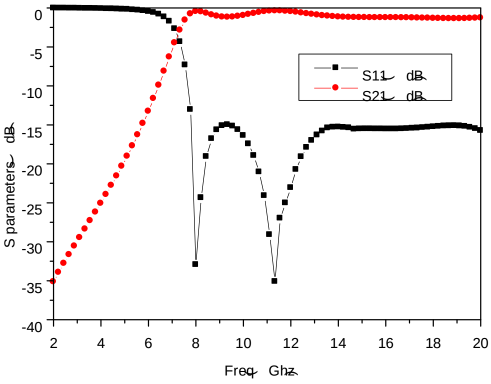

Fig.3. Simulated S11 and S21 responses of the SIW structure

III. THE PROPOSED SIW-BPF DESIGN

The design of the proposed SIW-BPF was built using SIW cavity with microstrip ends as shown in Figure 2. We have made semi-circular slots of radius r to obtain a bowtie resonator, as shown in figure 4. Then parametric sweeps were done on the semi-circular slots diameter r to get the desired filter response. The high performances of this filter was obtained with r= 2.5 mm, as shown in figure 5. The return loss is kept less then -13.5dB and the insertion loss is close to 0dB over the band (8-18)GHz.

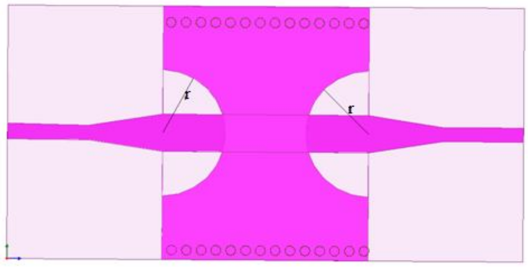

Fig.4. Layout of SIW-BPF structure with semi-circular slots of radius r

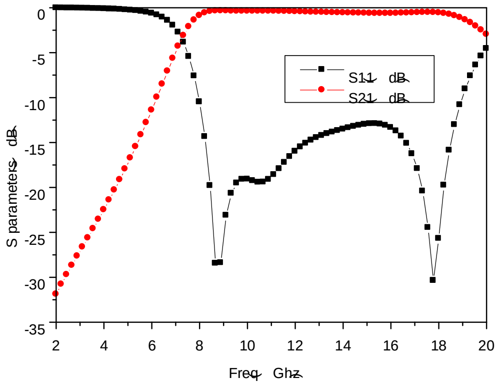

Fig.5. Simulated S11 and S21 responses of the proposed SIW-BPF with r = 2.5mm

IV. SIW-BPF COUPLING TO CSRRS

The complementary split rings resonators (CSRRs) are new type of planar resonators introduced to miniaturize microwave devices, implemented in planar technology. CSRRs with small electrical size are useful resonators to implement bandpass filters with wide bandwidth and high performances [17-19]. We have observed firstly, the influence of a CSRR cell, centered in the ground plane, then we have cascaded other cells with the same dimensions. Since CSRRs are etched in centre of the bottom layer, and they are mainly excited by the electric field induced by the SIW (as for TE_{10} mode), this coupling can be modeled by connecting the SIW capacitance to the CSRRs. Then if we alter the geometric parameters of the CSRR cell and the number of cells, the SIW-BPF response is completely modified. Therefore to keep the same response (figure 5) of the filter, the number and the dimensions of CSRR cell have been slightly adjusted. As shown in Figure 6, we have cascaded two CSRRs with 1.8mm for the outer circle diameter and 1mm for the inner circle diameter, to achieve the required bandwidth.

Figure 6 shows the Layout of a SIW with CSSRs etched in the ground plane. Let us now analyze the CSSRs loaded SIW. Since CSRRs are etched in the bottom layer and they are mainly excited by the electric field induced by the SIW (as for TE_{10} mode), this coupling can be modeled by connecting the SIW capacitance to the CSRRs.

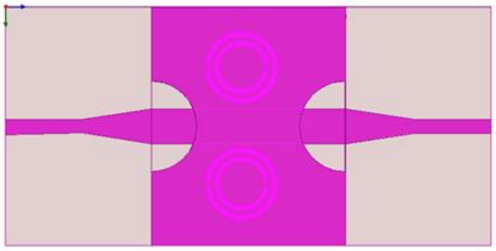

Fig.6.a. Layout top view of SIW-BPF coupling to CSRRs

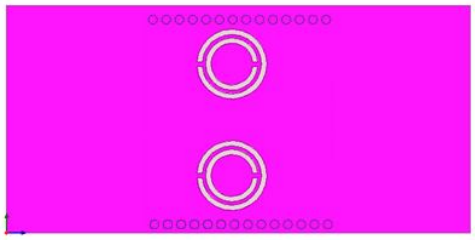

Fig.6.b. Layout bottom view of SIW-BPF coupling to CSRRs

The simulated S-parameters of this structure are presented in Figure 7, where it can be clearly found that this filter exhibits similar characteristics as Figure 5, with lower returnloss (less then -15dB) over the band (8-18)GHz.

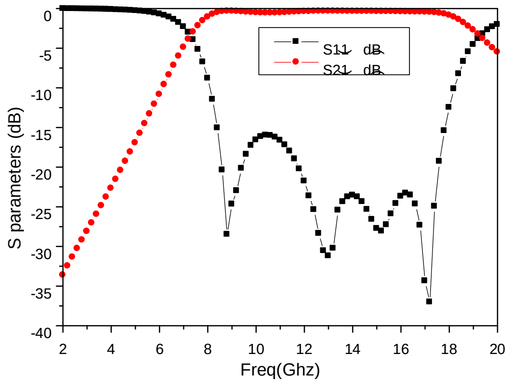

Fig.7. Simulated S11 and S21 responses of the proposed SIW-BPF coupling to CSRRs

V. CONCLUSION

This paper is focused on the design of compact substrate integrated waveguide (SIW) bandpass filters (BPF) as candidate for use in wide bandwidth (X-Ku) bands applications. Two semi-circular slots have been embedded in the SIW-BPF structure from the input and the output sides, to achieve the desired response in the band (8-18)GHz. Then, to improve the return loss in this frequency band, we have coupled two CSRR cells with appropriate dimensions, to the SIW-BPF. Finally, the proposed SIW-BPF is small size (27*14)mm^2, low profile and showing interesting results in the desired wideband, with high performances of return loss and insertion loss parameters. This study can be extended to design filters at millimeter frequency ranges.

REFERENCES

[1] K. Wu, D. Deslandes and Y. Cassivi, «The substrate integrated circuits- A new concept for high-frequency electronics and optoelectronics», Proceedings of 6th International Conference on Telecommunications in Modern Satellite, Cable and Broadcasting Service, Telskis 2003,Nis, Serbia and Montenegro, Oct. 2003.

[2] X. P. Chen, K. Wu, «Substrate Integrated Waveguide Filter», IEEE Microwave Magazine, vol. 15, no. 5, Jul.-Aug. 2014, pp. 108-116.

[3] Rui Cai, Wenxuan Jiang, Yuan Zhou, Peng Chen and Xutao Yu, « Substrate integrated waveguide slot array antenna for vehicle-mounted continuous wave radar », 2017 IEEE International Conference on Computational Electromagnetics (ICCEM), Kumamoto, Japan, March 2017.

[4] Xiong Zou, Fang-Zhi Geng, Yong Li and Yi Leng, « Phase Inverters Based on Substrate Integrated Waveguide», IEEE Microwave and Wireless Components Letters, Volume 27, Issue 3, March 2017, pp. 227-229.

[5] Zhang Cheng Hao and Fang Fang Kong, «Developing high performance Q-band planar filters using the multilayered substrate integrated waveguide technique», Microwave and Optical Technology Letters, Volume 59, Issue 3, March 2017, pp. 698-703.

[6] Peng Chu et al., «Dual-Mode Substrate Integrated Waveguide Filter With Flexible Response», IEEE Transactions on Microwave Theory and Techniques, Volume 65, Issue 3, March 2017, pp. 824-830.

[7] B. Rahali and M. Feham, «Coupler, Power Divider and Circulator in V-Band Subtrate Integrated Waveguide Technology», International Journal on Computational Sciences & Applications (IJCSA) Vol.3, No.6, December 2013, pp. 63-72.

[8] Chun-Xia Zhou, Chuan-Ming Zhu and Wen Wu, «Tunable Dual-Band Filter Based on Stub-Capacitor-Loaded Half-Mode Substrate Integrated Waveguide», IEEE Transactions

on Microwave Theory and Techniques, Volume 65, Issue 1, Jan. 2017, pp. 147-155.

[9] L. Tan, ZQ. Xu, Z. Chen and S. Huang, «A Multilayer T-Septum Substrate Integrated Waveguide Filter», Journal Electromagnetics, Volume 37, Issue 4, 2017, pp. 203-211.

[10] M. L. Fong, M. Rafiee, H. Y. Cha and M. S. Aftanasar, «Improved Low Cost Substrate Integrated Waveguide Symmetrical Window Bandpass Filter», 9th International Conference on Robotic, Vision, Signal Processing and Power Applications. Lecture Notes in Electrical Engineering, vol. 398, Springer, Singapore, pp. 587-597.

[11] AO. Nwajana, A. Dainkeh and KSK. Yeo, «Substrate Integrated Waveguide (SIW) Bandpass Filter with Novel Microstrip-CPW-SIW Input Coupling», Journal of Microwaves, Optoelectronics and Electromagnetic Applications, Vol. 16, No. 2, June 2017, pp. 393-402.

[12] Srikar, D. Behera and Santanu Kumar, «Design of Compact Half Mode Substrate Integrated Waveguide Band Pass Filters for X-Band and Ku Band Applications», International Conference on Wireless Communications Signal Processing and Networking (WiSPNET), SSN College of Engineering, Chennai, India, March 2017.

[13] Zhang X., J. Xu, Z. Yu, and Y. Dong, «Microstrip wide band-pass filter based on substrate integrated waveguide (SIW)», Proceedings of IEEE International Symposium on Microwave, Antenna, Propagation, and EMC Technologies for Wireless Communications, Hangzhou, China, Aug. 2007.

[14] Aya N. Alkhafaji, Ali J. Salim, and Jawad K. Ali, «Compact Substrate Integrated Waveguide BPF for Wideband Communication Applications», PIERS Proceedings, Prague, Czech Republic, Jul. 2015, pp. 135-139.

[15] Ricardo Caranicola Caleffo, «New Design Procedure to Determine the Taper Transition for Impedance Matching Between Microstrip Line and SIW Component», Journal of microwaves, Optoelectronics and Electromagnetic Applications, Vol. 15, No. 3, September 2015, pp. 247-260.

[16] Dominic Deslandes, «Design Equations for Tapered Microstrip-to-Substrate Integrated Waveguide Transitions», Microwave Symposium Digest, IEEE MTT-S International, 2010, pp. 704-707.

[17] Hao Zhang, Wei Kang and Wen Wu, «Differential substrate integrated waveguide bandpass filter with improved common-mode suppression utilising complementary split-ring resonators», Electronics Letters, Volume 53, Issue 7, March 2017, pp. 508-510.

[18] M. T. Passia, M. Nitas and T. V. Yioultsis, «A fully planar antenna for millimeter-wave and 5G communications based on a new CSRR-enhanced substrate-integrated waveguide », 2017 International Workshop on Antenna Technology: Small Antennas, Innovative Structures, and Applications (iWAT), Athens, Greece, March 2017.

[19] N. Benmostefa, M. Meliani, M. Feham, H. Ouslimani, «Metamaterials Form Miniature Bandstop Filters», Microwaves & RF, February 2013, pp. 64-68.