Substrate Integrated Waveguide Bandpass Filter with Complementary Split Ring Resonator at 2.45 GHz

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***Abstract*— Interferences between two applications should be avoided by using a filter. At present, the miniaturized filter is one of the requirement besides good quality and low insertion loss. The sixteenth-mode substrate integrated waveguide (SMSIW) is proposed by using a complementary split-ring resonator (CSRR) to fulfill miniaturized of filter. The filter design used two of sixteenth-mode SIW (SMSIW) that reduced 15/16 of the circular regular SIW. The frequency center filter design is at 2.5 GHz. The simulation result shows insertion loss value at 0.2 dB and return loss value at 29 dB, while for the measurement result gives insertion loss value at 0.7 dB and return loss value at more than 15 dB. It shows the measurement results give good value with the simulation results.**

Keywords*— *bandpass filter, complementary split ring resonator, microstrip filter, sixteenth-mode SIW

I. Introduction

The modern wireless communication not only requires high performance filters and low-cost fabrication but also needs the compact dimensions of filter. Therefore, many researches were developed using methods to get the compact dimensions, one of which is split ring resonators (SRRs) besides using high permittivity [1] or coupled resonator [2]. SRRs was introduced by Pendry et al [3] in 1999 and it has interested greatly among researchers in electromagnetics communities. The SRR could be applied as the synthesis of metamaterials with negative effective permeability and left-handedness (LH). In 2004, Falcone et al introduced a duality argument, a complementary split-ring resonators (CSRRs) as new metamaterial resonators. CSRRs structure have been proven effectively to evince negative permitivity. The signal propagation is blocked around their resonance frequency [4]. The integration of CSRR and SIW structure can improve the performance of filter [5, 6] besides using defected ground structure (DGS) [7]. For the first time, SIW was introduced by Deslandes el al in 2001 [8, 9]. SIW could be implemented for microwave components.

SIW has gained interest because of its several pre-eminence such as high-quality factor, low-loss, compact, simple integration with other planar circuits such as antenna, amplifier, mixer and so on in one substrate. SIW can be implemented to antennas, filters, couplers, transition, mixers, amplifier and so on. The performance such as dimensions and bandwidth are also important when we design SIW structure. The improvement of the compact SIW structure with various waveguide topologies has recently been performed using the substrate-integrated folded waveguide (SIFW) for realization bandpass filter as presented in [10]. A metal septum between dual layer substrate permit folding of the waveguide width that minimizes the dimension by a factor of more than two at the expense of slightly larger losses. Besides SIFW, the half-mode SIW (HMSIW) also can minimize dimensions of nearly 50% as a common SIW [11].

The implementation CSRR to the SIW filters structure gives the improvement of filter such as the insertion loss and return loss value either can minimize SIW filter as presented in [12]. By utilizing CSSR array loaded at HMSIW structure, a miniaturized bandpass filter is achieved [13]. While in [14, 15], a quarter-mode SIW (QMSIW) and an eighth-mode SIW (EMSIW) is used by combining low temperature con-fired ceramic (LTCC) to minimize of wideband bandpass filter. The EMSIW also can be used to reduce the dimensions of filter by a factor 7/8 as shown in [16].

This paper presents sixteenth-mode SIW (SMSIW) loaded with CSRR such as shown in [17] for designing bandpass filter for short range device (SRD) application. The SRD frequency application is 2.4 – 2.483 GHz. Usually at the lower frequency need a wide bandpass filter dimension rather than at the higher frequency but by using SMSIW and CSSR method the dimension more 15/16 compact than common SIW filter.

II. Circular Waveguide and Sixteenth Mode Subtrate Integrated Waveguide

A. Circular Waveguide

Firstly, we observe a circular waveguide with an inner radius a, as shown in Figure 1. This metal pipe supports transversal electric (TE) and transversal magnetic (TM) waveguide modes. The cylindrical coordinates are appropriate with the cylindrical geometry itself.

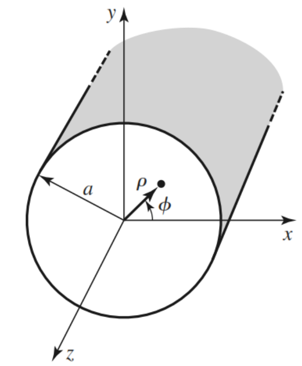


Fig. 1. Geometry of circular waveguide. [18]

The cutoff frequency for TM mode is

$$f_{c_{nm}} = \frac{k_c}{2\pi\sqrt{\mu\varepsilon}} = \frac{p_{nm}}{2\pi a\sqrt{\mu\varepsilon}} \qquad (1)$$

where the several values of p_{nm} are shown in Table 1.

TABLE I. VALUE OF P_{NM} FOR TM MODES OF A CIRCULAR WAVEGUIDE [18].

n	p_{n1}	p_{n2}	p_{n3}
0	2.405	5.520	8.654
1	3.832	7.016	10.174
2	5.135	8.417	11.620

For the TM modes of the circular waveguide, the lowest cut-off frequency for TM_{01} mode, with $p_{01} = 2.405$.

B. *Sixteen Substrate Integrated Waveguide (SMSIW)*

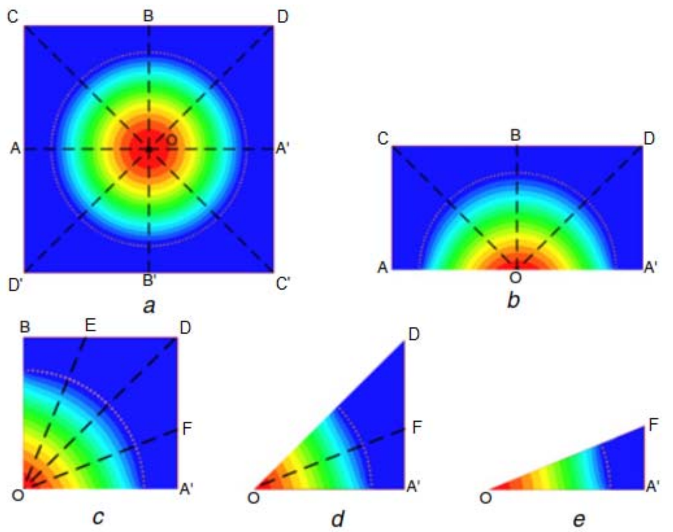


Fig. 2. Simulated electric field distribution with perfect magnetic walls of (a) Common Circular SIW, (b) HMSIW, (c) QMSIW, (d) EMSIW, (e) SMSIW. [17]

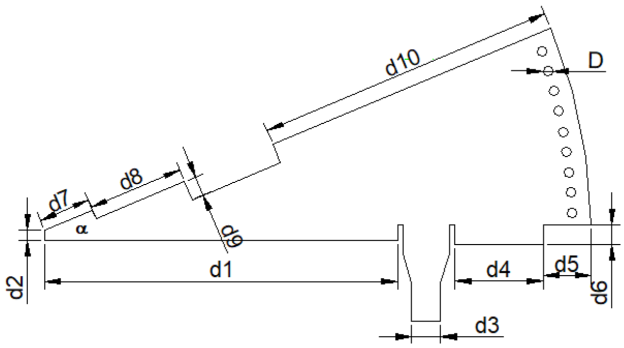
The magnitude of electric field distribution of the TM_{010} mode in a common SIW circular cavity, HMSIW, EMSIW, and SMSIW is shown in Figure 2. By bisecting the common SIW circular cavity in Figure 2(a) with another fictional magnetic wall, from A to A', the HMSIW is generated as referred to Figure 2(b). It means the dimensions of the HMSIW is a half of the common SIW circular cavity. As well as the QMSIW is realized by cutting the dimensions HMSIW along fictional magnetic wall from O to B, as shown in Figure 2(c). If the dimensions of QMSIW cuts with another fictional magnetic wall from O to D, the EMSIW will be achieved, as referred to Figure 2(d). The SMSIW is obtained by half-reduction of EMSIW along fictional magnetic wall from O to F, as referred to Figure 2(e). Hence, the SMSIW can be reduced 93.75% compared with common SIW cavity, without changes its resonant frequency. Hence the SMSIW can be applied design for compact microwave component such as a filter.

III. DESIGN OF BANDPASS FILTER

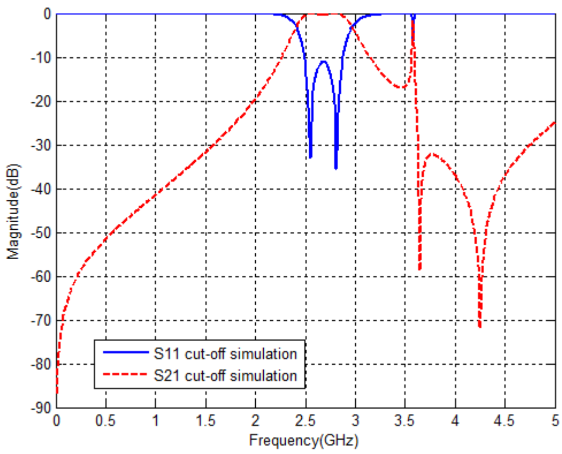
A. *Sixteenth Mode Substrate Integrated Wavaguide Circular Cavity*

The bandpass filter is designed by using Rogers RT/Duroid 5880 substrate. It has a dielectric constant (ε_r) of 2.2, thickness 1.575 mm and loss tangent (tan δ) 0.0004. In order to make the SMSIW circular cavity, it can be equivalent to common metallic cavity the condition of $D/dp \geq 0.5$ and $D/\lambda_0 \leq 0.1$. It is to ensure minimum leakage of energy, where D is the diameter of metallic holes, d_p is the distance between two adjacent metallic holes and λ_0 is the free space wavelength.

Figure 3(a) shown the structure for SMSIW circular cavity with an angel $\alpha = 22.5°$ and radius $a = 27.4$ mm. Frequency cut-off can be achieved by equation (1).While Figure 3(b) shows the simulation result of frequency cut-off SMSIW circular cavity. Actually the insertion loss, S_{21} and the return loss, S_{11} have good value but the frequency requirement is not suitable with SRD application, and the spurious response occurs at the transmission parameter.



(a)

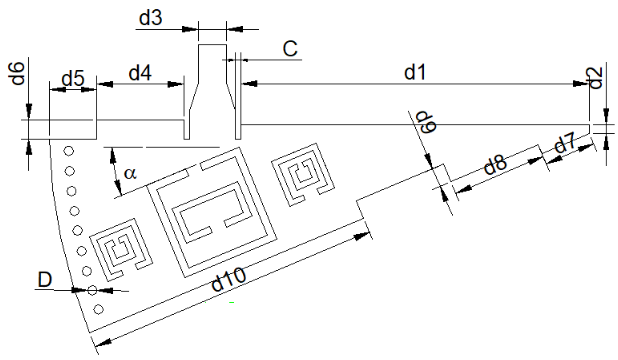


(b)

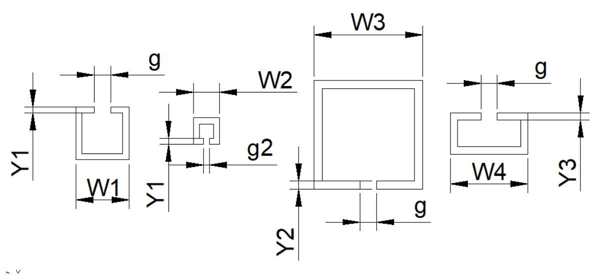
Fig. 3. (a) Proposed design structure of SMSIW, (b) Simulation result of SMSIW circular cavity.

B. *Complementary Split Ring Resonator*

Figure 4(a) shows the design of the SMSIW with CSRR. Bandpass filter uses three coupled CSRR that is etching at the top layer. While the detail of parameter CSRR is shown in Figure 4(b).



(a)



(b)

Fig. 4. (a) Design of proposed CSRR-loaded SMSIW (b) Dimension parameter of CSRR.

The parameter values of design are given in Table 2, to fulfil the specification of the bandpass filter for SRD application, which works at 2.4 – 2.483 GHz. The specification was achieved by optimization performed the full-wave electromagnetic simulator-Ansys HFSS v15.

TABLE II. DIMENSION OF BANDPASS FILTER WITH SMSIW CSSR (ALL PARAMETER IN MM)

	Size		*Size*		*Size*
d1	18.4	d8	5	W4	3.78
d2	0.5	d9	1	g	0.8
d3	1.5	d10	15.6	g2	0.7
d4	4.6	D	0.6	Y1	0.3
d5	1.9	W1	2.58	Y2	0.4
d6	1	W2	1.28	Y3	0.35
d7	2.75	W3	5.28		

IV. RESULT AND DISCUSSION

The prototype of bandpass filter is shown in Figure 5. The slot of CSRR are etched at copper layer at the top layer while the bottom layer is a ground layer. The bandpass filter has the symmetrical configuration with two port. The impedance of each port is 50 Ω.

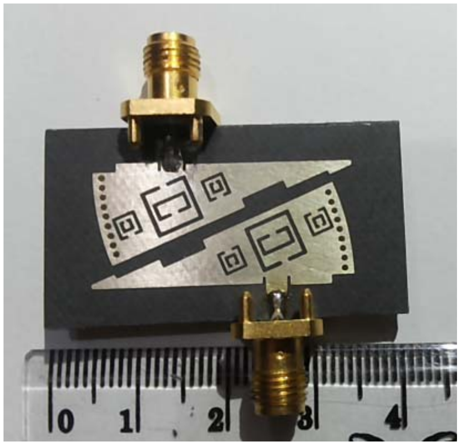


Fig. 5. Prototype of the SMSIW with CSRR.

The fabricated SMSIW bandpass filter with CSRR is measured by using Vector Network Analyzer, Anritsu MS 2026A. Figure 6 shows the comparison of the simulation and measurement results. The dash lines are the simulation results while the solid lines are the measurement. The insertion loss value for the simulation is 0.2 dB and it occur the degradation to 0.5 dB when fabricated. The return loss value is 29 dB for the simulation results and decrease to 17 dB when fabricated. The simulation and the measurement results quite precise as shown by achieving idle values for frequency center and the range of bandpass. Table 3 shows the resume of simulation and fabrication bandpass filter with SMSIW circular cavity.

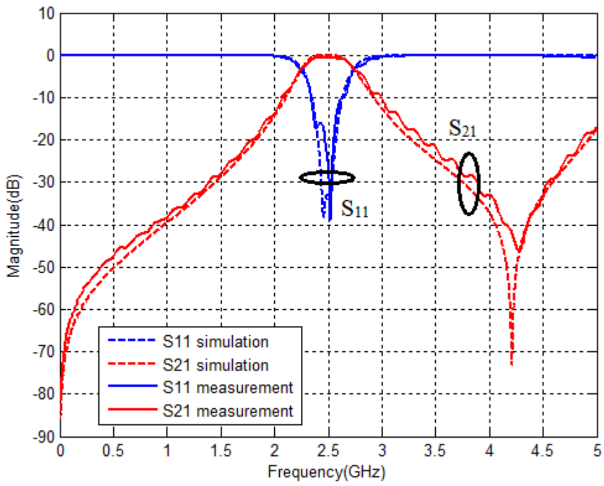


Fig. 6. Simulation and measurement results of SMSIW circular cavity.

TABLE III. COMPARISON BETWEEN SIMULATION AND MEASUREMENT RESULTS OF SMSIW CIRCULAR CAVITY

Parameter	*Simulation*	*Measurement*
Pass Band	2.4 – 2.6 GHz	2.4 – 2.6 GHz
Frequency center	2.5 GHz	2.5 GHz
Bandwidth	200 MHz	200 MHz
Insertion loss	0.2 dB	0.7 dB
Return loss	29 dB	17 dB

The overall dimensions of fabricated of SMSIW circular cavity with CSRR has dimension 33.4 mm × 21.85 mm × 1.575 mm include two port for microstrip feed lines. While for excluding the two port, it has dimension 28.6 mm × 13.86 mm × 1.575 mm which is equivalent to $0.2383\lambda_0 \times 0.1155\lambda_0 \times 0.0131\lambda_0$.

V. CONCLUSION

The reduction dimensions of bandpass filter by using SMSIW with CSRR is achieved 93.75%. The simulation and measurement results gives the insertion loss values below 1 dB and the return loss values more than 15 dB. The little bit of discrepancy between simulation and measurement is mostly due to changes of parameter design when the layout design is converted to fabricate, but the overall results give recommendation for microwave applications.

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REFERENCES

[1] D. W. Astuti, Juwanto and M. Alaydrus, "A Bandpass Filter Based on Square Open Loop Resonators at 2.45 GHz" in 2013 IEEE 3rd International Conference on Instrument, Communications, Information Technology and Biomedical Engineering., pp. 147-151.

[2] M. Alaydrus, D. Widiastuti and T. Yulianto, "Designing Cross-Coupled Bandpass Filters with Transmission Zeros in Lossy Microstrip" in 2013 IEEE 5th Int. Conf. on Information Technology and Electrical Engineering, pp. 1-4.

[3] J. B. Pendry, A. J. Holden, D. J. Robbins, and W. J. Stewart, "Magnetism from conductors and enhanced nonlinear phenomena," IEEE Trans. Microw. Theory Tech., vol. 47, no. 11, pp. 2075–2084, Nov. 1999.

[4] F. Falcone, T. Lopetegi, J. D. Baena, R. Marques, F. Martin, and M. Sorolla, "Effective negative-epsilon stopband microstrip lines based on complementary split ring resonators," IEEE Microw. Wireless Compon. Lett., vol. 14, no. 6, pp. 280–282, Jun. 2004.

[5] W. Che, C. Li, K. Deng, and L. Yang, "A Novel Bandpass Filter Based on Complementary Split Rings Resonators and Substrate Integrated Waveguide," Microwave Optical Technology Letter, vol. 50, no. 3, pp. 699-701, March 2008.

[6] Q. L. Zhang, W. Y. Yin, S. He, and L. S. Wu, "Compact Substrate Integrated Waveguide (SIW) Bandpass Filter with Complementary Split-Ring Resonators (CSRRs)," IEEE Microwave Wireless Compon. Lett., vol. 20, no. 8, pp. 428-428, Augt 2010.

[7] D. W. Astuti, A. Jubaidillah, and M, Alaydrus, "Substrate Integrated Waveguide Bandpass Filter for VSAT Downlink," in 2017 IEEE 15th International Conference on Quality in Research (QiR): International Symposium on Electrical and Computer Engineering., pp. 101-105.

[8] D. Deslandes, K. Wu, "Integrated microstrip and rectangular waveguide in planar form," IEEE Microwave and Wireless Compon. Lett. 2001, Vol. 11, No. 2, pp. 68–70, Feb. 2001.

[9] D. Deslandes, and K. Wu, "Integrated Transition of Coplanar to Rectangular Waveguides," in 2001 IEEE MTT-S International Microwave Sympsoium Digest., Vol. 2, pp 619-622.

[10] N. Grigoropoulos, B. S-Izquierdo, and P. R. Young, "Substrate integrated folded waveguides (SIFW) and filters," IEEE Microwave Wireless Compon. Lett, vol. 15, no. 12, pp. 829-831, Dec. 2005.

[11] Y. Wang, W. Hong, Y. Dong, B. Liu, H. J. Tang, J. C. Chen, X. Yin, and K. Wu, "Half mode substrate integrated waveguide (HMSIW) bandpass filter," IEEE Microw. Wirel. Compon. Lett., vol. 17, no. 4, pp. 265–267, Apr. 2007.

[12] Y. D. Dong, T. Yang, and T. Itoh, "Substrate Integrated Waveguide Loaded by Complementary Split-Ring Resonators and Its Applications to Miniaturized Waveguide Filters," IEEE Trans. on Microw. Theory and Techniques. vol. 57. no. 9, pp 2211-2223. Sept. 2009.

[13] L. Qiang, Q. Sun, W. Zhao, W.-B. Qin, J.-K. Wang, "A Miniaturized Bandpass Filter Based on Half-Mode Substrate Integrated Waveguide Loaded by Complementary Split-Ring Resonators," in 2010 Proc. IEEE International Conference on Ultra-Wideband., vol. 2, pp 1-4.

[14] Z. Xiangjun, G. Yongxin and Wangfei, "Minimization of Wideband LTCC Bandpass Filter Using QMSIW and EMSIW Cavities," in 2015 IEEE MTT-S International Microwave Workshop Series on Advanced Materials and Processes for RF and THz Applications (IMWS-AMP), pp 1-2.

[15] S. Chengtian, D. Yabo, Z. Xiangjun, Z. Yanming, and Z. Yong, "Compact wideband LTCC bandpass filter exploiting eighth-mode SIW loaded with CSRR," Microw. Opt. Technol. Lett., vol. 56, no. 9, pp. 2164–2165, Sept. 2014.

[16] Y. Zhu, "A Source-Load Coupled Bandpass Filter using One-Eight Mode Substrate Integrated Waveguide Cavity," in 2014 XXXIth URSI General Assembly and Scientific Symposium (URSI GASS), pp. 1-4.

[17] A, R. Azad and A. Mohan, "Sixteenth-mode substrate integrated waveguide bandpass filter loaded with complementary split-ring resonator," Electr. Lett., vol. 53, no. 8, pp 546-547, April 2017.

[18] D. M. Pozar, Microwave Engineering. 3rd. ed, New York, USA: Wiley, 2004. pp. 121-130