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Low-Loss, Compact DS-OCSRR Shaped DGS Loaded HMSIW Band Pass Filter with High Fractional Bandwidth

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ABSTARCT

Based on the slots and Defected Ground Structure (DGS) technology, Half Mode SIW filter is developed with wide bandwidth. The high pass HMSIW is transformed to band pass filter by means of embedding slots on the microstrip line. To improve the return loss profile of the filter, Double Slit Octagonal Complementary Split Ring Resonator shaped DGS is utilized. The working version is made on a 1.6 mm-thick RT Duroid 5880 board. The simulation outputs and measured results are mutually consistent. The filter is centered at 6.82 GHz. It possesses wide passband from 4.76 GHz to 8.87 GHz with a fractional bandwidth of 60.26 %. It is of size 0.86 λ_g x 0.37 λ_g, where λ_g is calculated at 6.82 GHz. Applications involving C band satellite communication can benefit from the specified low-loss wideband filter.

Keywords: C band; Band pass filter; HMSIW; Defected ground structure; Slots; Satellite communication

NOMENCLATURE

CST	: Computer Simulation Technology
DGS	: Defected Ground Structure
DS-OCSRR	: Double Slit Octagonal Complementary Split Ring Resonator
FBW	: Fractional Bandwidth
HMSIW	: Half Mode Substrate Integrated Waveguide
SIW	: Substrate Integrated Waveguide
TZ	: Transmission Zero

1. INTRODUCTION

High performance microwave filters have become indispensable in RF front end satellite communication in recent decades due to the growing customer base driven by technological advancements. Rectangular waveguides can be used in the development of microwave components. They can handle high power; however, they are difficult to integrate with planar structures. As a result, planar transmission lines like microstrip, co-planar waveguide are used to design and develop microwave components. Even though they are lightweight and low cost, their quality factor is relatively low.

SIW[1], an exciting invention, incorporates the merits of both planar and non-planar transmission lines. It is made by combining a few rows of post walls on the sides of a dielectric-filled waveguide, in which top and bottom are covered with copper claddings. It possesses high pass filter characteristics[2]. Its advantages include a lightweight design, cost-effectiveness, minimal loss, and a large power handling capacity. This technology is ideal to design and develop next generation millimeter and microwave components. Numerous components like antenna, filters, filtennas, power dividers are developed using SIW technology[3-8]. Further miniaturization can be achieved using Half Mode SIW, Quarter Mode SIW, Folded SIW etc., Slots embedded in the microstrip line alters the line inductance and capacitance leading to the change in the field distribution. DGS refers to any defect introduced in the bottom layer which alters the return path of the current distribution. These defects can be either periodic or non-periodic structures. DGS can be employed in several shapes such as dumb -bell, Square, interdigital, split ring resonator shaped etc.,[9]

A 28 GHz SIW filter was developed using through glass vias method[10]. The size of the filter is 0.37 $\lambda_g \times 0.12\ \lambda_g$. Ruchi, *et al.*[11] developed a reconfigurable SIW filter utilizing open-loop ring resonators on the top of the cavity. A notched SIW filter was developed using SRR and DGS[12]. However, these filters are larger in size, exhibit high loss and low FBW. Hence, to address these issues, we developed a HMSIW filter with high FBW and low loss. Slots and DGS are used in this research to construct a wide band HMSIW filter. In the second section, the development of filter design is described. The particulars of geometric configuration are discussed in the third section. Results are briefly presented in the fourth section and the work is concluded in the fifth section.

2. FILTER DESIGN

2.1 Stage A

Figure 1 highlights the HMSIW filter's development. The HMSIW structure is initially designed to have a 5 GHz cut-off frequency. TE_{10} mode is the structure's dominant mode. The via diameter and pitch are selected such that they are λ_g/5 and 2d, respectively[13], where λ_g is the guided wavelength and d is the via diameter.

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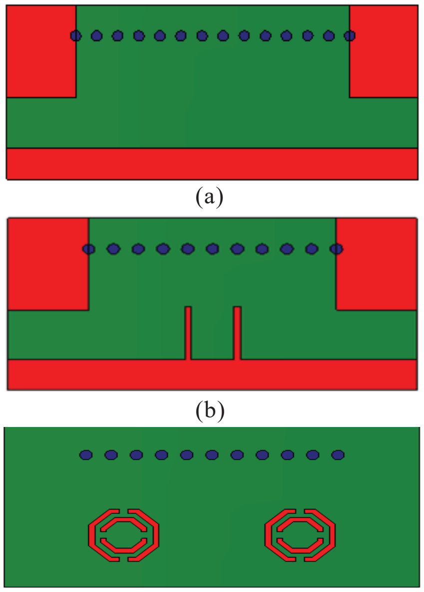


Figure 1: Evolution of the wideband HMSIW filter (a) HMSIW structure; (b) Slots in the top plane; and (c) DGS in bottom plane.

W_{HM} is the width of the HMSIW structure, W_{SIW} is the SIW width, a_{eff} is the effective width of dielectric filled waveguide, a is the width of the waveguide, p is the pitch, ε_r is the permittivity of the substrate, c is light velocity and f_{c10} is the cutoff frequency. Eqn. (1-4) are followed for the design of HMSIW:

$$W_{HM} = \frac{1}{2} * W_{SIW} \quad (1)$$

$$W_{SIW} = a_{eff} + \frac{d^2}{0.95 * p} \quad (2)$$

$$a_{eff} = \frac{a}{\sqrt{\varepsilon_r}} \quad (3)$$

$$a = \frac{c}{2 f_{c10}} \quad (4)$$

2.2 Stage B

A pair of slots of length L_x=5.2 mm and width W_x=0.5 mm is engraved on the top plane. The slots are separated by 3.5 mm. The microstrip line's current transmission is disrupted and more TZs are produced by the slots implanted in the upper layer. Thus, the high pass nature of the HMSIW is converted into band pass filter.

2.3 Stage C

To enhance the impedance matching, two double slit octagonal split ring resonator-shaped DGS are employed at the base of the filter. The DGS are placed 8 mm apart. DGS can be etched in periodic or aperiodic fashion on the ground surface of the RF or microwave component. It eventually changes the transmission line inductance and capacitance resulting in improved characteristics. Radius of the loop enclosed by octagon is represented by the 'R,' split gap by 'x,' the ring width by 'y' and the ring spacing by 'z'. DS-OCSRR is shown in Fig. 2.

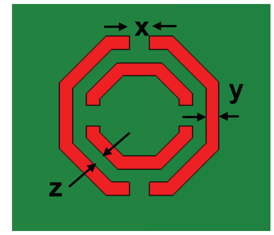


Figure 2. DS-OCSRR shaped DGS.

3. GEOMETRICAL CONFIGURATION

Figure 3 shows the geometrical depiction of the suggested filter. The following are the optimum parameters (all in mm): L=33, W=16.88, L_{HM}=20, W_{HM}=11.5, p=2, d=1, W_m=4.9, L_x=5.2, W_x=0.5, G_1=3.5, G_2=8.46, R=3, x=0.5, y=0.5, z=0.5.

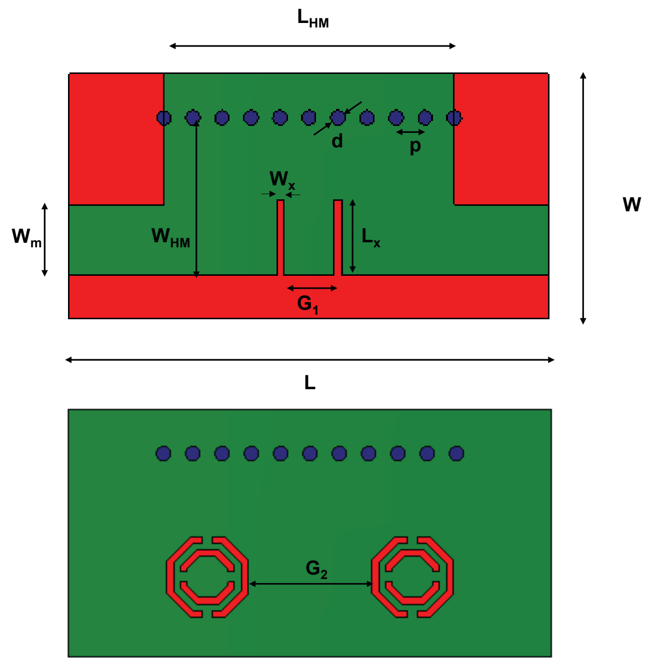


Figure 3. Geometric configuration (top and bottom view).

4. RESULTS AND DISCUSSION

4.1 Stage A

The electric field distribution at 6 GHz (f > f_c) of HMSIW structure is shown in Fig. 4. It is obvious that for frequencies greater than the cutoff frequency the signal propagates from one port to the other. S-parameters are depicted in Fig. 5. For frequencies higher than 5 GHz, the S_{11} offers greater than 15 dB and the S_{21} is nearly 0 dB. Consequently, the HMSIW structure offers a 5 GHz cut-off frequency and displays high pass nature. Transmission Zero (TZ_1) occurs at 3 GHz with an attenuation of 24 dB

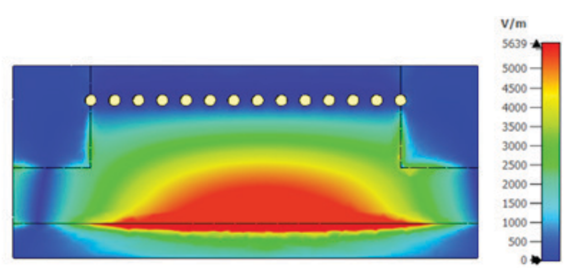


Figure 4. Electric field distribution of HMSIW structure for 6 GHz (f>f_c).

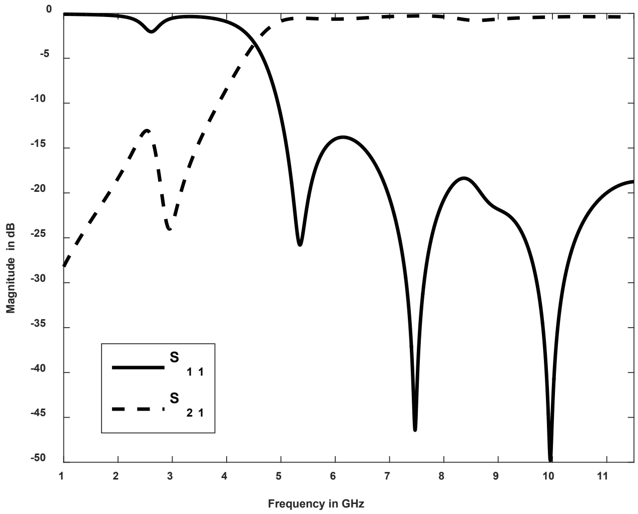


Figure 5. S-parameters of HMSIW structure.

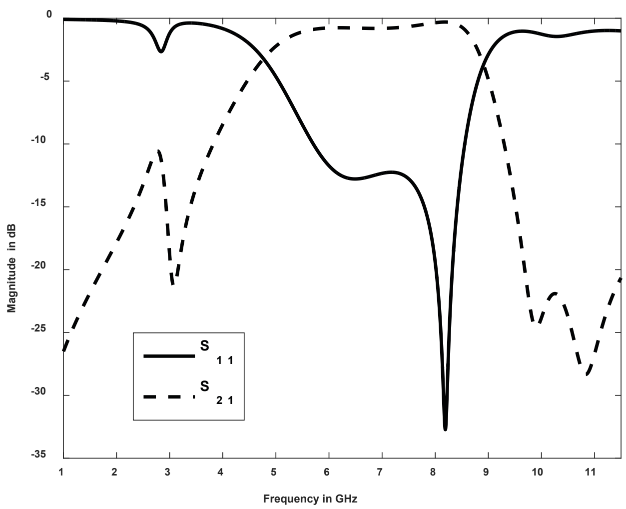


Figure 6. S-parameters of slots loaded HMSIW structure.

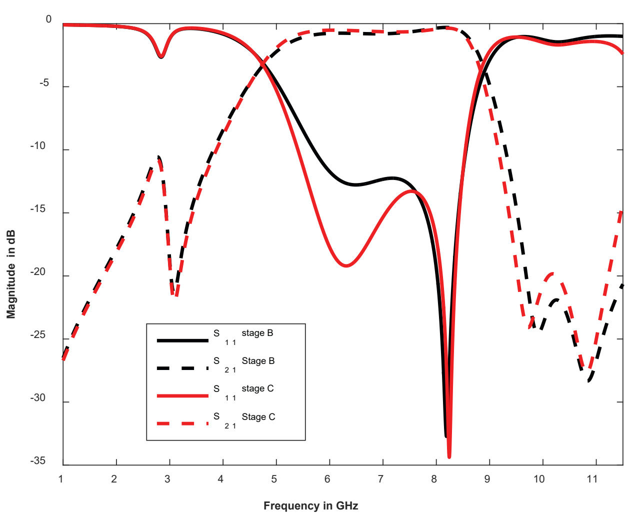


Figure 7. Comparison of stage B and stage C.

4.2 Stage B

The Scattering coefficients of the slots loaded HMSIW filter is shown in Fig. 6.

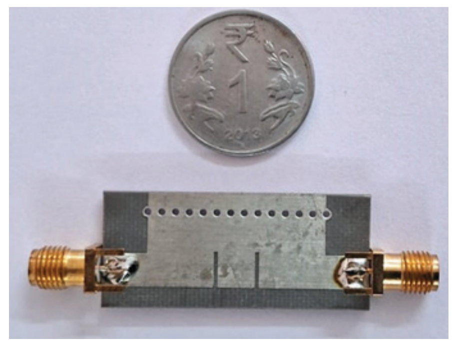
The slots embedded in the top layer distracts the current transmission in the HMSIW structure and creates addition TZs (TZ_2 and TZ_3) at 9.9 GHz and 10.8 GHz with an attenuation of 24.6 dB and 28.3 dB respectively. TZ_1 attenuation becomes 21 dB at 3 GHz due to the coupling between the slots. The high pass filtering response of the HMSIW is now converted into band pass response.

4.3 Stage C

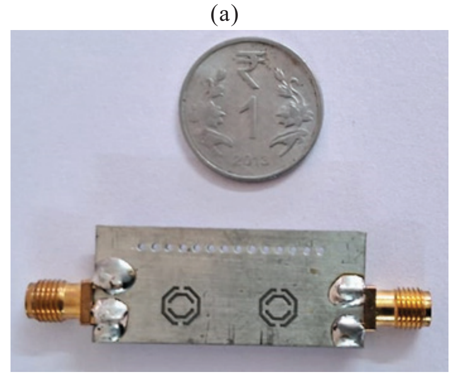
In the proposed structure, incorporation of DGS improves the impedance matching and the S_{11} becomes greater than 15 dB in the pass-through band. There is a slight shift in the TZ_2 and TZ_3 attenuation values. The comparison of the S-parameters of stage B and C is depicted in Fig. 7.

4.4 Fabrication and Experimental Verification

The filter is fabricated using Rogers RT Duroid 5880 substrate of 1.6 mm thickness. It has a permittivity of 2.2 and loss tangent of 0.0009. Simulation is performed using CST



(a)



(b)

Figure 8. Snapshot of the proposed prototype.

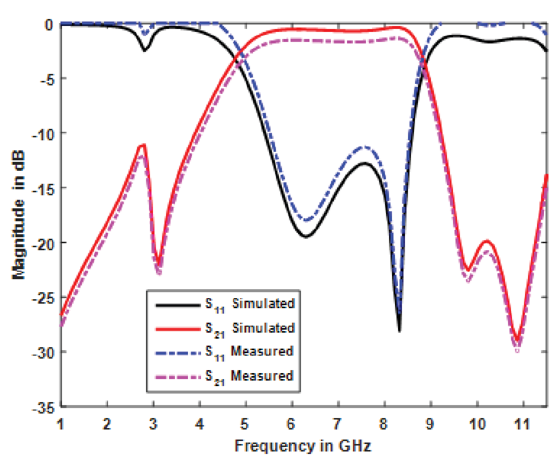


Figure 9. Correlation between simulated and actual outcomes.

Table 1. Comparison with other reported C band filters

References	f_r (GHz)	FBW (%)	RL (dB)	IL (IL)	No of TZs	Electrical size
14	3.7	27	10	<2	4	$0.45\ \lambda_g$ x $0.8\ \lambda_g$
15	3.8	14	14	<2.5	-	NR
16	4.12	38	20	<1	2	$0.59\ \lambda_g$ x $0.36\ \lambda_g$
17	5.84	23.56	45.49	<4.2	-	$0.72\ \lambda_g$ x $0.72\ \lambda_g$
This work	6.82	60.26	15	<1.9	3	$0.86\ \lambda_g$ x $0.37\ \lambda_g$

f_r-Resonant frequency, FBW-Fractional bandwidth, RL- Return loss, IL – Insertion loss, TZ- Transmission zeros, NR- Not Reported

software. An illustration of the manufactured prototype is displayed in Fig. 8. It is experimentally verified with a vector network analyser. The prototype measures an overall size of 33 x 16.88 mm^2. Figure 9 displays the comparison between the measured and software modelled outcomes. The outcomes are consistent except at few frequencies which may be due to fabrication tolerances and connector losses.

The proposed filter is compared with other existing C band filters and is depicted in Table 1. Comparatively, the proposed filter has a wide FBW, low loss and compact in size. The HMSIW filter has a center frequency of 6.82 GHz. S_{11} is more than 15 dB throughout the passband, while the reduction of signal due to component insertion is 1.9 dB. It possesses wide passband from 4.76 GHz to 8.87 GHz with FBW of 60.26 %. It has three TZs at 3 GHz, 9.6 GHz,10.8 GHz with an attenuation of 21 dB, 24 dB and 28 dB, respectively. Thus, the filter has good selectivity, low loss, compact size, good return loss profile, and reduced wide bandwidth.

5. CONCLUSION

In the proposed work, a wideband C-band HMSIW filter is presented. A 50 % miniaturization is achieved using Half mode concept. Considering the benefits of DGS and slots, three TZs are generated in the miniaturized filter structure. The filter, centered at 6.82 GHz, has return loss greater than 15 dB and a 1.9 dB insertion loss in the passband and FBW of 60.26 %. The proposed filter is a promising candidate for C-band satellite communication applications.

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In current contribution, she is responsible for the filter design, simulation, review/analysis of the results, and finalisation of the manuscript.