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# Substrate integrated waveguide filter showing improved stopband performance and fractional bandwidth using different input/output topologies

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**Abstract.** In this work bandpass filter based on SIW technology with an adequate fractional bandwidth as well as refinement in the stopband performance is presented. Its application lies with the receiver filter working in the Ka band used mainly in the ground terminal for satellite communication.. Additionally analysis of divergent input/output arrangement is also demonstrated. Three SIW filter having a varying passband from 19.2GHz -21.2GHz depending on the input/output are synthesized on a planar substrate having height of 0.508mm RT/duroid 6002 using periodically arranged metal via holes through a regulated PCB process .Simulated outputs has a in-band insertion loss 0.9dB and the improved stopband attenuation within the frequency range of 29.5GHz – 31GHz is around 45 dB . It is observed that the experimented results coincide completely with the results simulated in HFSS/CST.

## 1. Introduction

The EM spectrum is heavily crowded with wireless signal and interferences and therefore requires components or circuits that would provide the selection/rejection of the desired signals. Conventionally non-planar metallic waveguide having an advantage of high power carrying capacity ,high quality factor and low loss is most desirably considered even though it has disadvantage of being bulky and very expensive. Whereas Planar structures are preferred usually for low frequency applications because of high loss involved and the inability to carry high power [1-2]. Therefore in order to achieve the benefits of both simple transmission lines utilizing the planar technology and rectangular waveguide which is a non planar technique it lead to the development of an integrated technology Substrate Integrated Circuit (SIC) that are planar, low cost and low profile like the MIC planar structures as well as having the advantage of high power carrying capability and high Qu factor similar to conventional metallic waveguide.



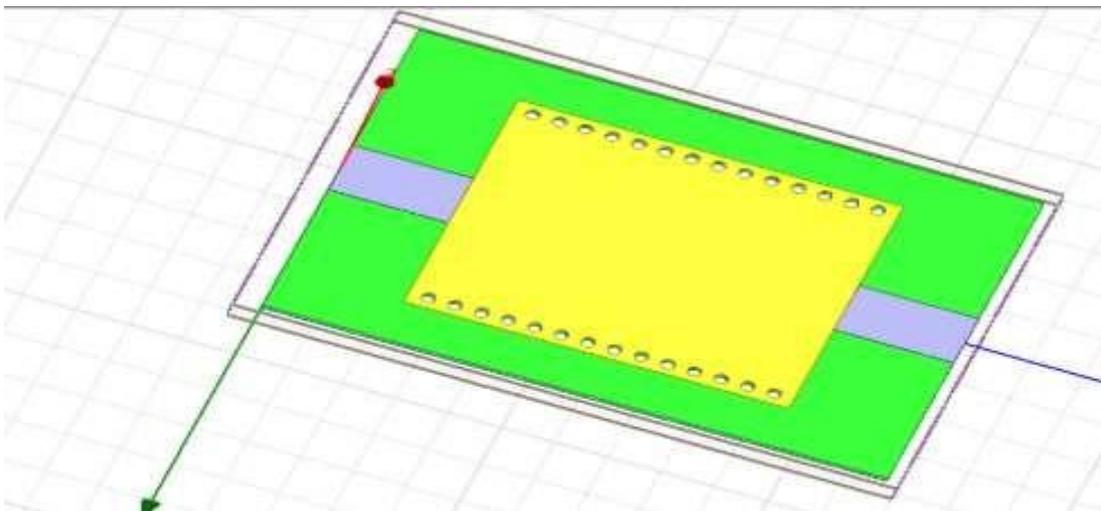
Principle of operation of substrate integrated circuits is to build a virtual channel within the substrate through which the waves can propagate. Two different techniques involved in SIC First: usage of metallic via holes which creates a boundary along the entire structure. Second: usage of different substrate permittivity which leads to total internal reflection due to which the Electromagnetic waves get confined within the virtually created channel. SIW technology is one of the arrangements of SIC with linear periodic arrays/metallic via holes. SIW technology is introduced in many microwave and very high frequency wave components including both active and passive circuits/components as well as antennas.

SIW filter is best component for a receiver filter in the satellite ground terminals in a Ka band. The filter should be able to provide a low-lying insertion loss within the passband frequency range as well as improved stop band performance.

Adequate stop band attenuation should be achieved to suppress the power into the receiver [3]. In order to achieve the low-lying insertion loss within the required passband frequency. In this designed SIW filter we create four cavities which are enough to attain the receiver filter selectivity. The greater challenge is to achieve stopband attenuation for which large number of discontinuities are required for generating the needed coupling because of very less resonators present in the filter. Such discontinuities is observed as impedance inverter for a low frequency range wherein at high frequency large quantity of the generated power is transported across these created SIW cavities that are coupled and which presides in low stop band attenuation even much before the initialization of the resonating frequency after the first order. Many different techniques were introduced in order to improve the stop band attenuation of conventional metallic waveguide utilizing the E plane discontinuities which is extremely difficult to realize for SIW filter.

Therefore, in SIW filter [4-5] the generation of transmission zeros is used to improve the stop band attenuation and the selectivity. These generated transmission zeros however are not far from the passband due to the low profile structure. Another approach is usage of separate modes to create different path flow for the flow of energy.

In this paper the generation of transmission zeros is achieved due to composite coupling of the leading order modes for improving the stop band performance.



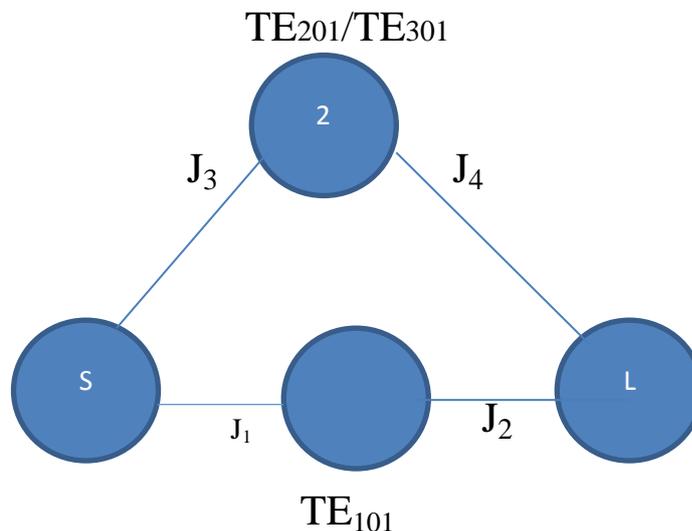
**Figure 1.** Structure Of SIW

## 2. Filter Design

Figure 1 represents the amplified SIW cavity within which  $TE_{m0n}$ . ( $m$  represents odd number and  $n$  represents positive integer) mode is elevated because of the symmetry obtained towards the width direction. This cavity is elevated using two microstrip lines of  $50\Omega$  impedance. The low profile SIW cavity is depicted in figure (b) where the required circuit elements are acquired using the equation as shown :

$$W = \frac{f_1}{B} \left( \frac{f}{f_1} - \frac{f_1}{f} \right) \quad (1)$$

Where  $f_1$  is center frequency and  $B$  is absolute bandwidth of pass band generated due to the second order resonant mode. The dominant mode  $TE_{101}$  provided the required passband for the designed SIW filter [6]. The cavities where the transmission zeros are located could be finely adjusted by either modifying the breadth of the SIW cavity having a slight impact on the desired pass band or by altering the location of the different input/output designed using microstrip lines. If the distance between the input or output microstrip lines are less, the transmission zeros generated are closer to the pass band response as this causes the coupling across the created source/load and generated  $TE_{201}$  resonant mode increases.



**Figure 2.** Circuitry representing the generated SIW cavity

Regarding the frequency responses inclusive of the reflection zero created by the basic mode  $TE_{101}$  and the generated second order  $TE_{301}/TE_{201}$  mode, the designed coupling matrix is

$$M = \begin{vmatrix} b_3 & J_1 & J_2 & 0 \\ J_1 & b_1 & 0 & J_2 \\ J_3 & 0 & b_2 & J_4 \\ 0 & J_2 & J_4 & b_4 \end{vmatrix}$$

$J_1$  and  $J_2$  are normalized coupled coefficients across the source/load and the generated TE101 mode, whereas  $J_3$  and  $J_4$  are the normalized coupled coefficients across the source/load together with the generated TE201/TE301 modes .

## 2.1 Design Equations

Here the transmission zeros are generated far away from the pass band therefore not able to interfere with the transmission poles of the filter [7]. We achieve a chebyshev response in the pass band.

The important parameter to be considered in the design of the SIW cavity are:

1. width of the SIW cavity  $a_1$
2.  $d_1$  diameter of via holes and
3.  $p_1$  spacing between the vias .

The frequency of the passband can be determined using

$$f_0 = \frac{c}{2\sqrt{\epsilon_r}} \sqrt{\frac{1}{a_{1eff}^2} + \frac{1}{L_{eff}^2}} \quad (2)$$

$$a_{1eff} = a_1 - \frac{a_1^2}{0.95p_1} \quad (3)$$

$$a_{1eff} = a_1 - \frac{a_1^2}{0.95p_1} \quad (4)$$

Conditions necessary to design SIW :

$$p_1 \leq d_1 \quad (5)$$

$$p_1 / \lambda_c < 0.25 \quad (6)$$

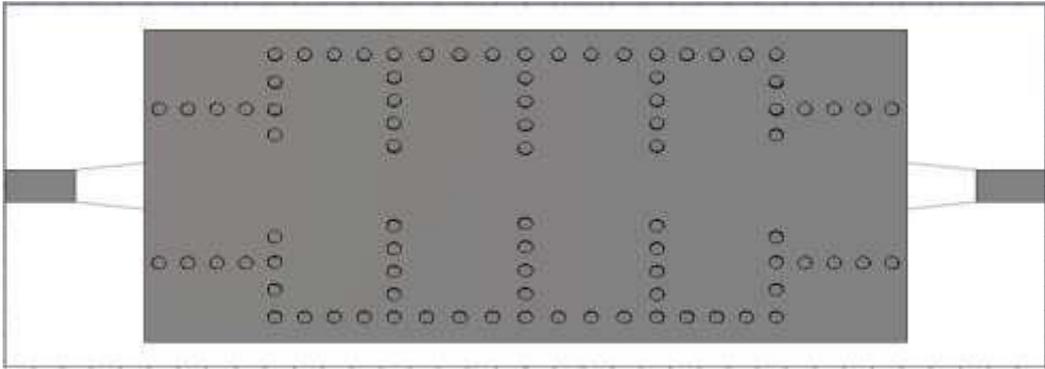
$$a_1 / k < 1 \times 10^{-4} \quad (7)$$

$$p_1 / \lambda_c > 0.05 \quad (8)$$

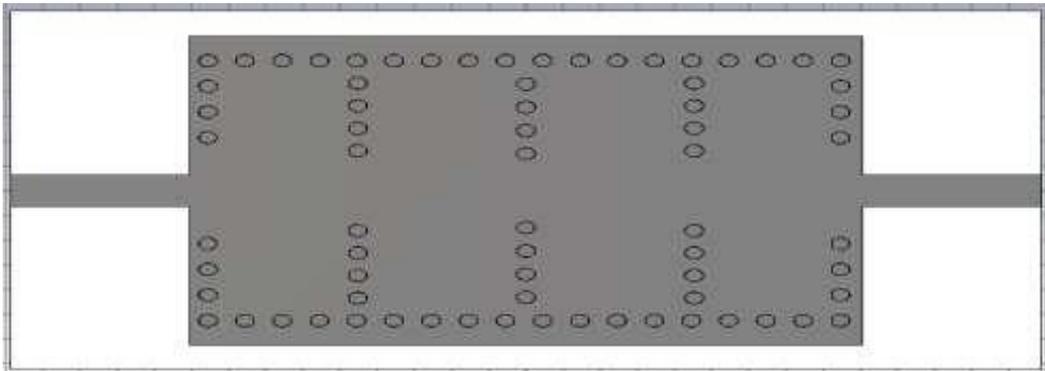
For the created SIW cavity the location of transmission zeros could be modified in [8] by altering the breadth of the created SIW cavity . Another approach to regulate the transmission zeros is by varying the location of the designed input/output microstrip lines . Immediately after the elevated SIW cavity is attained , finally the a bit more regulation could be attained by varying the SIW parameters in order to achieve very good results .

## 2.2 Input/Output Arrangements

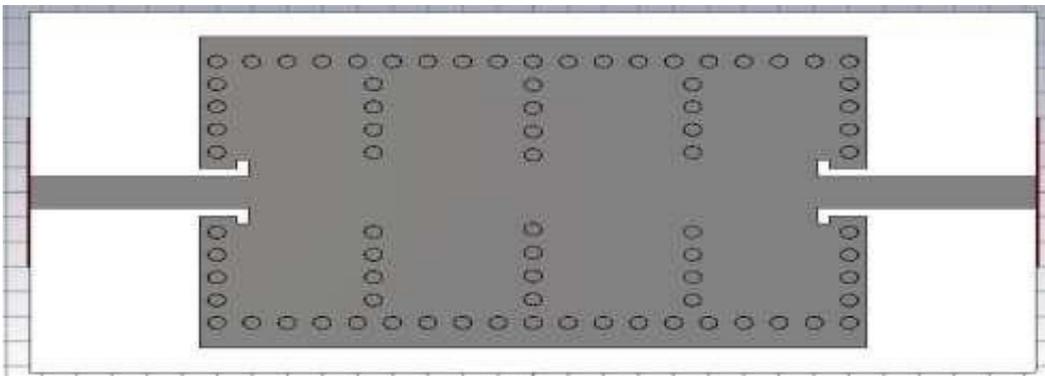
With this procedure we designed a chebyshev SIW filter having four SIW cavities [9]. Two different topologies of input/output lines is considered for the design of the SIW filter and is designed on a planar RTduroid 6002 substrate with thickness of 0.508mm and periodically arranged array of metal via holes having a radius of 0.25mm.



**Figure. 3.** SIW filter with tapered transition using microstrip lines



**Figure. 4.** SIW filter with microstrip lines

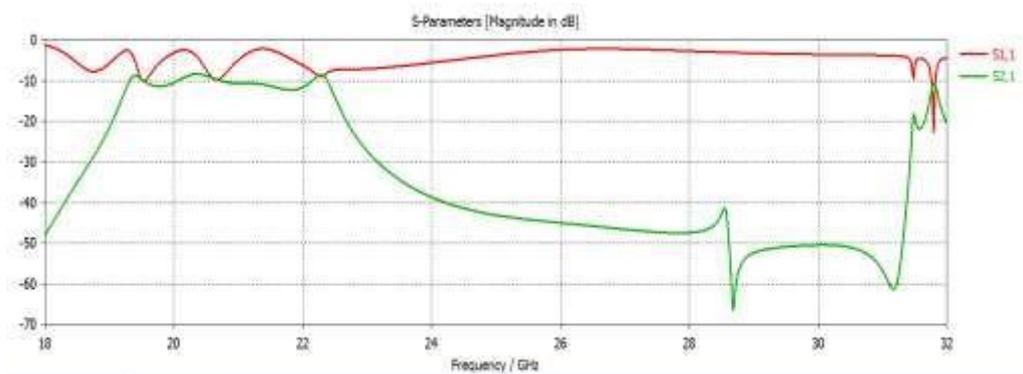


**Figure. 5.** SIW filter with microstrip lines using L slot coupling

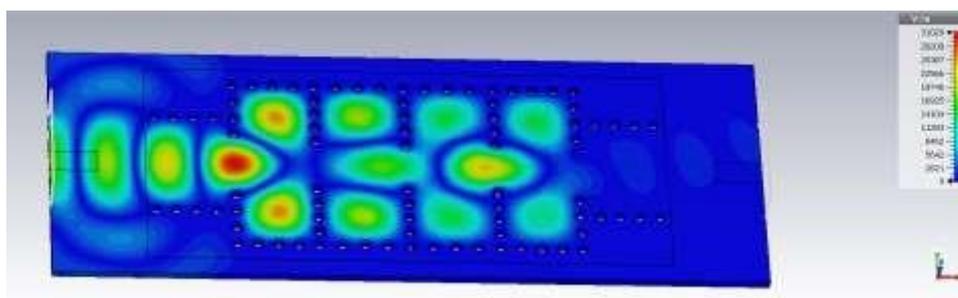
**Table 1.** Dimension of the three different topologies SIW filter

	Filter (3)	Filter (4)	Filter (5)	Microstrip Lines	
$w_{io}$	4.09mm	4.26mm	4.26mm	$w_{ms}$	1.28mm
$w_{12}$	3.17mm	3.17mm	3.22mm	$h$	0.508mm
$w_{23}$	2.99mm	2.99mm	2.99mm	$\epsilon_r$	2.94mm
$l_1$	4.11mm	4.03mm	4.03mm	$\tan\delta$	0.0012
$l_2$	4.54mm	4.52mm	10.5mm		
$a_1$	10.5mm	10.5mm			
$a_{io}$	6.16mm				
$l_t$	2.4mm				
$w_t$	1.86mm				
$w_{slot}$			2.56mm		

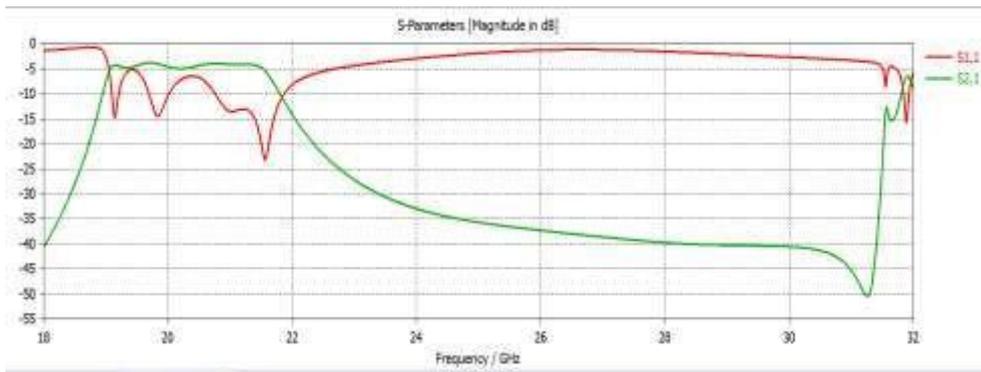
**3. Simulated Results**



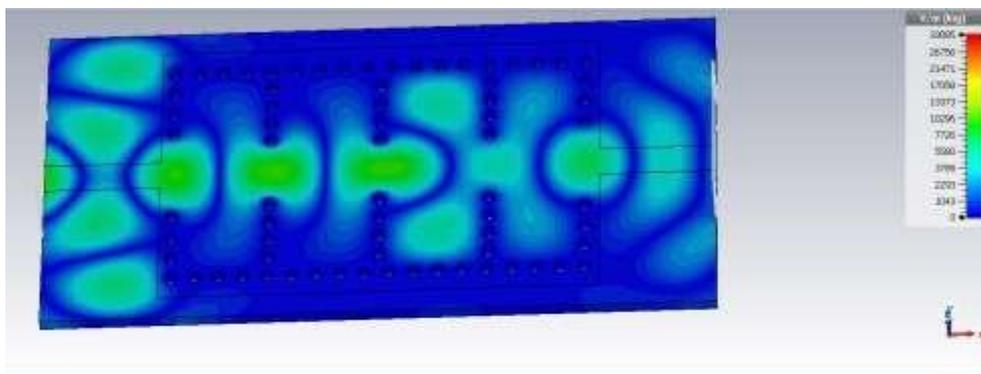
**Figure 6.**  $S_{11}$  for the Filter shown in Fig 3



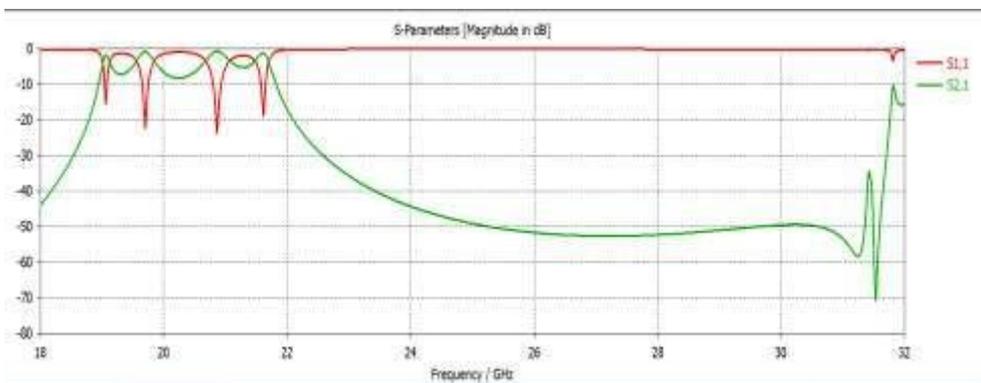
**Figure 7.** Electric Field Distribution



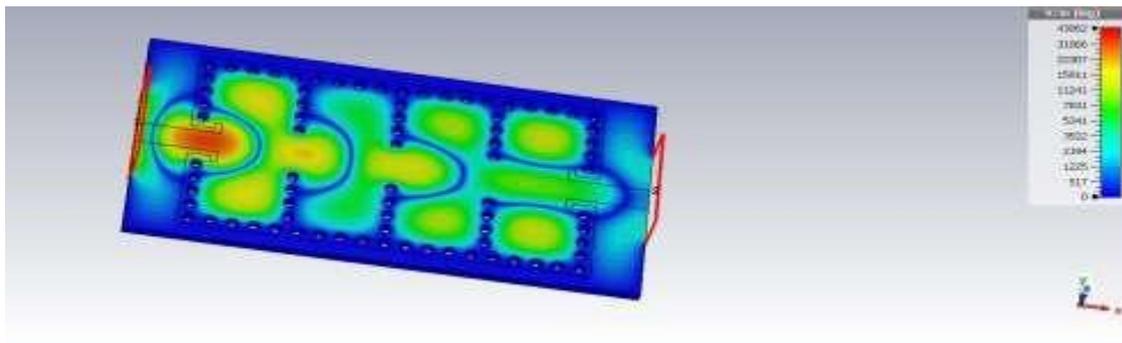
**Figure 8.**  $S_{11}$  for the Filter shown in Fig 4



**Figure 9.** Electric Field Distribution



**Figure 10.**  $S_{11}$  for the Filter shown in Fig 4



**Figure 11.** Electric Field Distribution

#### 4. Analysis

The filter designed in Fig. 3 has a very low insertion loss within the passband frequency due to the tapered transition at the input/output lines which creates increased loss. The filter in Fig.4 having direct microstrip input/output lines has a very poor stopband performance because of the iris having large discontinuities which leads to large amount of energy transmitted within the stopband. SIW filter shown in Fig.5 where L slots are used for coupling the designed input/output microstrip lines has a very good stopband performance due to the iris having very small discontinuities and therefore very small amount of energy is transferred in the stopband. Usage of L slot coupling causes radiation which reduces the  $Q_u$  factor of the resonator but this has no effect in the insertion loss within the desired passband as there is very little effect  $Q_u$  factor on the insertion loss within the passband for the initial and last resonators compared to the middle placed resonators.

The distribution of the electric field with input power given at port 1 for the SIW filter implemented in Fig. 4 is shown above. It has been observed that the transmission zeros is seen at 31.5 GHz. Similar distribution of the electric field is seen when the input power is given at port 2 cause of the symmetry in the structure.

#### 5. Conclusion

Here we have designed the SIW filter with different input/output arrangements and the effect is observed and measured. Design of the SIW filter is discussed along with the working principle.

Three arrangements of the input/output was considered

- 1) with the tapered transition which had poor in band insertion loss due to the transition between the microstrip lines and the SIW structure which introduced additional losses.
- 2) using direct microstrip input/output lines, where the stopband performance was very poor due to the iris having large discontinuities leading large amount of energy transfer in the stopband.
- 3) using the concept of L slot coupling where we obtained very good stopband performance along with it very less amount of energy was transmitted in the stopband.

The above designed SIW filters are of the fourth order having a desired passband within the range 19.2GHz -21.2GHz are synthesized on a planar substrate RT/duroid 6002 using periodically arranged arrays of metal via holes through a regulated PCB process as shown in Fig 3. It has been observed in-band insertion loss of 0.9dB and attained stopband attenuation within the frequency range of 29.5 -

31.5GHz is found to be 50 dB . The measured results coincide with the simulated results in a perfect manner.

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