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Dumbbell Perturbed Half Mode Substrate Integrated Waveguide (HMSIW) Band-Pass Filter

J. Kundu[1], S. Moitra[2] and P. S. Bhowmik[3]
[1]Department. of Electronics and Communication Engineering, NSHM Knowledge Campus, Durgapur, India
Jhuma.kundu@gmail.com
[2]Department of Electronics and Communication Engineering, Dr. B C Roy Engineering College, Durgapur, India
[3]Department of Electrical Engineering, National Institute of Technology, Durgapur, India
souravmoitra25@yahoo.in, pshowmik@gmail.com

***Abstract*—This article presents a design of a dumbbell slotted Half Mode Substrate Integrated Waveguide (HMSIW) filter with Band-pass property over a substrate with dielectric constant of 3.2 and material thickness of 0.792mm. Wideband operational capability in the entire Ku band has been established using array of etched dumbbell slots over the metallic surfaces of the HMSIW structure. Control on the major filter parameters like Insertion Loss and Transmission Bandwidth has been achieved using slots in upper as well as lower metallic layer (Ground plane). Effect of variation of gaps between successive slots has also been studied and presented with appropriate details. The effectiveness of our proposed design is that, it can be modified for operation in other frequency bands also by simply changing the parameters of the dumbbell-slots. The filter discovers applications in various Ku band operations.**

***Index Terms*— Substrate Integrated Waveguide (SIW), Dumbbell-Slot Array, Half Mode SIW, System-on-Substrate (SoS), Ku-band.**

I. INTRODUCTION

In recent years, renewed interests have been mooted on the design of the wireless components and systems as new applications for millimeter waves. Substrate-integrated waveguide (SIW) technology is a promising technique in this domain for the development of microwave and millimeter-wave circuits and components. Transmission parameters of SIW closely resemble with the conventional rectangular waveguides mode of propagation and electromagnetic modes inside both SIW and waveguides are similar in nature. However, unlike metallic waveguides, solid dielectric material is inserted between the metallic layers in SIW. This results more compact layout with greater power handling capability. This type of waveguide known as laminated waveguide has been proposed for the foremost time in 1994 [1]. Since then, several components based on the SIW technology have been proposed over the past several years for operation in the microwave and millimeter wave region which include several filters [2], couplers [3], oscillators [4], slot array antennas [5], six-port circuits [6], and circulators [7].

In SIW, the lateral surfaces of the sandwiched dielectric must also be covered for its operation similar to that of metallic waveguides. This can be implemented by inserting a metallic vias with a connection at the top and bottom metallic surfaces as shown in Fig. 1.

The classical rectangular waveguide filters are bulky, heavy, high cost, and also difficult to integrate with planar

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circuits, being three-dimensional (3-D) structures. Whereas, with SIW technology, a complete circuit can be fabricated in planar form using a standard printed circuit board or other planar processing techniques. The coplanar circuits include planar circuitry, transitions with microstrip lines and coplanar waveguides, rectangular waveguides, active components and antennas). Thus, SIW technology represents an attractive alternative to conventional metallic waveguides for low-cost, low-loss, and high-density integration of microwave and millimeter-wave components and subsystems.
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II. HMSIW FILTER DESIGN

The design of SIW structures is the first step toward the efficient design of the complete SIW components. Several issues are to be considered while designing an SIW, that include the operation bandwidth, radiation leakage, dielectric and conductor losses. Traditional metallic rectangular waveguide bandpass filters such as *E*-plane filter [8, 9], *H*-plane filter [10], and fin-line filter [11] have been widely used in microwave and millimetre-wave systems because of their good qualities of low insertion loss and high power handling capacity. Here we started with a basic half mode SIW filter. Structure of the basic SIW and HMSIW filter is shown in Fig. 2.
The important factors affecting the transmission characteristics of SIW and HMSIW components are diameter of the holes or post diameter d, pitch or gap between the holes b, the spacing between the centres of two rows W_{eff} and the space between the end points of the two metallic via rows, W. The pitch b has to be small to reduce the leakage loss among adjacent vias. It has been found that the post diameter d is also subject to the power loss phenomena. Hence the ratio d/b is considered to be more critical than the pitch length as the post diameter and the pitch length are related to each other. The equivalent width is the effective width of the SIW and may be obtained by the following expression.

$$W_{eff} = W - d - \frac{d^2}{(0.95)(b)} \qquad (1)$$

This relation is very useful for investigate and design various SIW components with the help of W_{eff} of the SIW. The cut-off frequency of the SIW structures can be defined as [14]

$$f_c = \frac{c}{2W_{eff} \times \sqrt{\epsilon_r}} \qquad (2)$$

where, c is the velocity of light in vacuum. The SIW cannot support TM modes but the TE modes are found to propagate through them due to the nature of the structure. Fig 2 shows basic HMSIW structure with its important dimensions as designed using above relations. The HMSIW filter without any dumbbell-slots and its Scattering parameters have been shown in Fig 3 and Fig 4 respectively.

In this design, via diameter is considered as 0.6mm and distance between the centres of two consecutive vias has been taken as 1.2mm. The S-parameters as shown in Fig. 4, clearly indicates the response of a high-pass filter operable in Ku-band. The filter has its lower cut-off at 12GHz with a tolerable insertion loss (less than 1dB) at the pass-band.

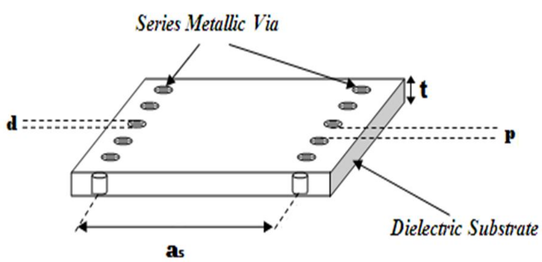


Fig.1. Basic SIW structure with metallic vias

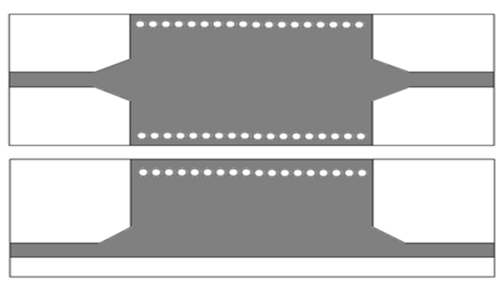
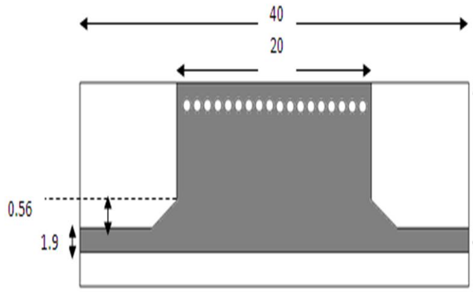


Fig.2. Basic SIW and HMSIW Filter structure

To modify this into a band pass filter we considered effect of several techniques, each of which leads us to stop at a particular frequency band as per our requirement. For this purpose, we propose a dumbbell-slot etched on the surface of the PEC. The DMS slot resonator is formed by a section of HMSIW which acts as a quasi-TEM mode transmission line resonator. It is short circuited at one end and open circuited at the other. The electrical



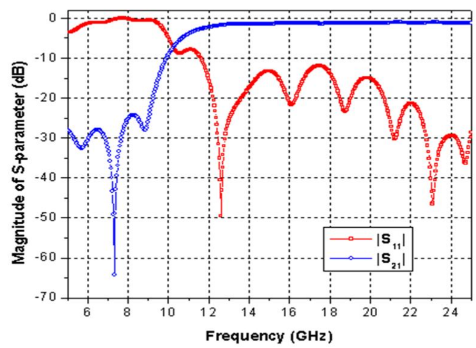


Fig. 3. Basic HMSIW Filter (All dimensions are in mm)

Fig. 4. S11 & S21 of Simple HMSIW Filter without T-slot

length of the resonators is related to the stop band as a function of quarter-wave length long slot with respect to the centre frequency of the stop band which has to be created. The insertion loss and the ripple properties are controlled by the external quality factor Q_e which is given by the following relation.

$$Q_e = 2Q_l = \left(\frac{2f_0}{\Delta f_{-3dB}}\right) \qquad (3)$$

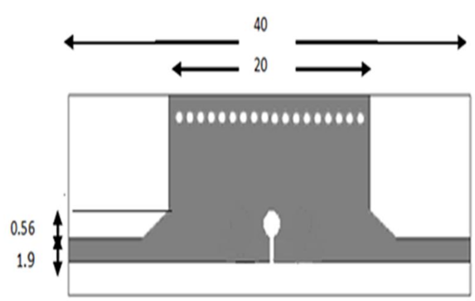
Single dumbbell-slot filter and its observed S-parameters have been shown in Fig. 5 and Fig. 6 respectively.

As observed by introduction of a single dumbbell -slot over the PEC, the band-stop characteristic is obtained but with high insertion loss. An array of three dumbbell -slots (Fig. 7) has been introduced (only at the top surface) to minimize the insertion loss as well as to obtain better transmission characteristics at the desired pass band as well as to obtain as increased bandwidth covering full Ku band (Fig. 9). However, the pass-band suffers from a relatively high insertion loss of around 3.5dB towards higher cut-off frequency. It is to be mentioned in this regard that the insertion loss also depends on the relative dielectric constant of the material chosen.

Mutual coupling between successive resonators may be adjusted by alterations of the length and width of the slots. Here the resonators are coupled to each other and the central frequency peak point of a single resonator is split into two distinct peaks. The coupling coefficient of the two adjacent resonators can be obtained from the simulated scattering parameters of the two resonators which is given by [12-13]

$$k = \frac{f^2{}_U - f^2{}_L}{f^2{}_U + f^2{}_L} \qquad (4)$$

Where f_U and f_L are the upper and lower resonating frequency of the dumbbell slot resonators. Increased slot width will increase the coupling and also the separation of the two resonant peaks and vice versa.



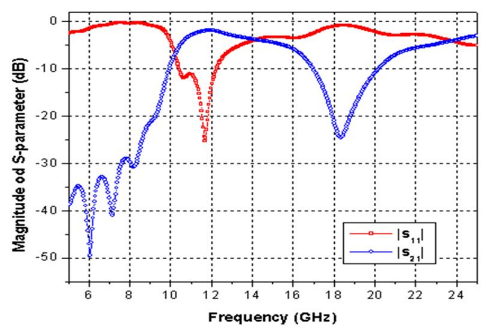


Fig. 5. Single dumbbell-slot HMSIW Filter

Fig. 6. S11 & S21 of Single dumbbell-slot HMSIW Filter

Fig. 10 shows S11 & S21 of double Side dumbbell-slot array HMSIW Filter. In this case the array of T-slots has been etched on both top and bottom surfaces of the metallic layers. This shows a significant improvement of insertion loss in the pass-band (less than 2dB over a frequency band of 12GHz to 16GHz).

The reported method has been further studied and the effect of variation of gaps between the slots S_g has been presented in Fig. 11. It is been observed that S_g is inversely proportional to the transmission bandwidth of the

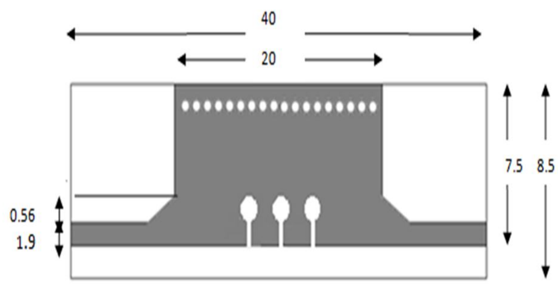


Fig. 7. Single Side dumbbell -slot array HMSIW Filter (All dimensions are in mm)

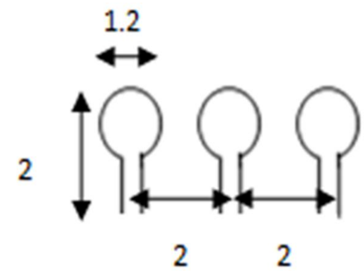


Fig. 8. Structure of dumbbell –slot (All dimensions are in mm)

filter. Control over the insertion loss at the higher cut-off has been achieved by this study. The wide banding effect of the filter can also be achieved by simple varying the slot gaps.

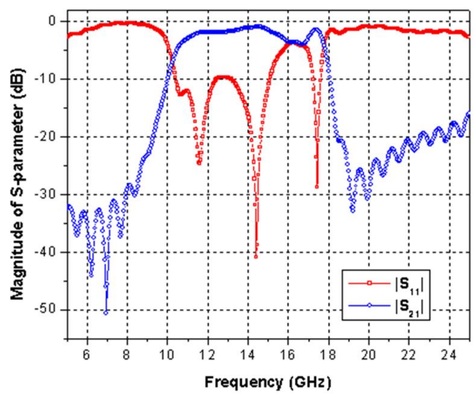


Fig. 9. S11 & S21 of Single Side dumbbell-slot array HMSIW Filter

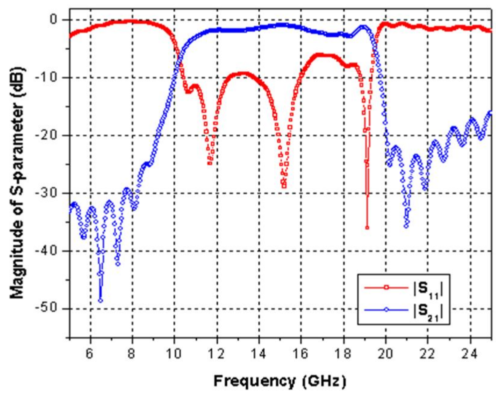


Fig. 10. S11 & S21 of Double Side dumbbell-slot array HMSIW Filter

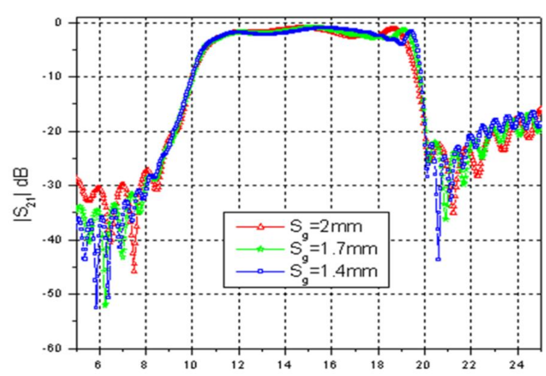


Fig. 11. Variation of S_{21} for different slot gaps S_g

III. CONCLUSIONS

Technique for obtaining band-pass characteristics in a HMSIW has been discussed in this paper. Implementation of array of dumbbell-slots (DMS) has been found to serve the purpose quite effectively. Both single and double sided dumbbell-slot array (both at top and bottom metallic surfaces) are studied and presented with detailed results. Insertion loss, transmission bandwidth and other parameters have been controlled with variation of several slot parameters. The filter operates covering the entire Ku band and hence it is suitable for applications in Ku band radar and remote sensing operations.

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