Design and characterization of tapered transition and inductive window filter based on Substrate Integrated Waveguide technology (SIW)

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Abstract

Microstrip tapered transition and inductive band-pass filter around 5 GHz, using Substrate Integrated Waveguide technology (SIW) are studied in this paper. All the structures are designed with Finite Element Method (FEM) and fabricated on a single substrate of Epoxy FR4 using a standard PCB process. The return loss of the proposed filter is better than 20 dB.

The measured results for all the structures investigated show a good agreement with the simulation results.

Keywords: *Substrate Integrated Waveguide (SIW), Band-pass Filter, Transition, Via-Holes, SIW-Microstrip Technology.*

1. Introduction

In recent years, a new waveguide technology called the substrate integrated waveguide (SIW) has been introduced in many microwave communication systems, such as Wireless Local Area Networks (WLAN). This technology has been successfully used to design microwave and millimeter-wave filters which are widely exploited extensively as a key block in modern communication systems [1]-[4].

The traditional rectangular waveguide technologies are used in various microwave and millimeter-wave communication systems, especially communication satellites, earth stations, and wireless base-stations, due to their high Q values and high power capability. However, they are expensive to fabricate, voluminous and do not integrate with planar structures in electronic systems. Microstrip lines, on the other hand, are easy and not expensive to fabricate, but are not low loss radiation and not shielded.

SIW components take the advantages of low radiation loss, high Q- factor and high power in systems. Additionally, they have a small size compared to the corresponding conventional rectangular waveguide components. They are constructed by metal filled via-hole arrays in substrate and grounded planes which can be easily interconnected with other elements of the system on a single substrate plat form without tuning, this system can be miniaturised into small package called the system in package SIP which has a small size and a low cost [5]. A schematic view of an integrated waveguide is shown in Fig. 1.

In this paper, the finite element method (FEM) based on a commercial software package "HFSS" has been applied to the analysis of the SIW structures. Firstly we propose C-band SIW microstrip line with tapered transition, and then we focus on the design of SIW inductive window filter around 5GHz. The designs of these structures are fabricated by using a low cost printed circuit board (PCB) technology and measured by means of a Vector network analyser (HP8720C).

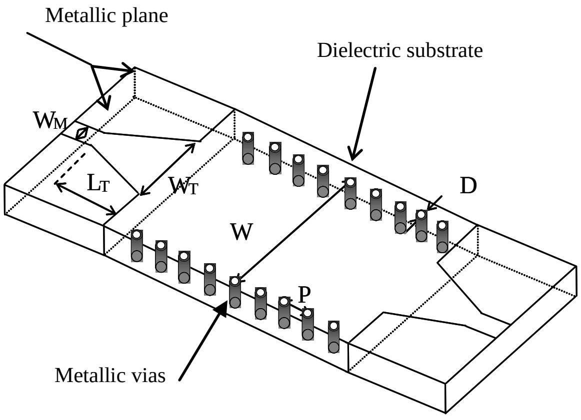


Fig. 1 Topology of the substrate Integrated Waveguide

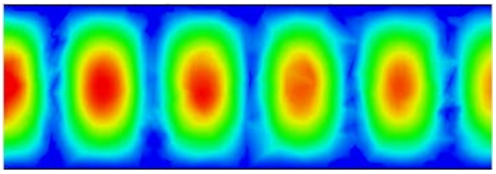
2. Substrate Integrated Waveguide resonator cavity

A substrate-integrated waveguide (SIW) is made of metallic via arrays in the substrate between top and bottom metal layer replacing the two metal sidewalls.

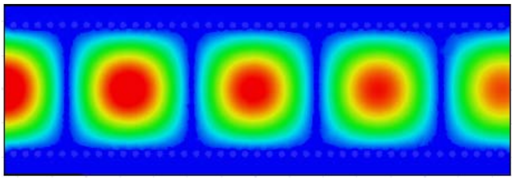
The propagation properties of the mode in the SIW are very similar to the electromagnetic field distribution of TE_{10}-like mode in a conventional metallic rectangular waveguide (RWG).

In order to compare the electromagnetic field distribution in SIW and rectangular waveguide RWG, we take the diameter of the metallic via D = 1 mm and the period of the vias P = 1.8 mm. The distance between the rows of the centres of via is W = 19 mm. The top, middle, bottom and sidewall metallizations are all copper and the dielectric material is FR4 substrate with $\varepsilon_r = 4.4, \tan\delta = 0.02$.

Fig. 2 shows the cross-sectional view field distribution of dielectric waveguide and SIW without transitions at 5.5 GHz.



a) Rectangular waveguide



b) SIW without transitions

Fig.2 Electric fields distributions in rectangular waveguide and SIW.

We observe that the dominant mode of the SIW resembles the TE_{10} mode of conventional waveguide. The maximum field is present at the middle of the guide.

Thus, the initial dimensions of SIW resonator cavity can be determined by the conventional resonant frequency formula of metallic waveguide resonator, where the length and width of the conventional dielectric waveguide cavity: L_G and W_G, should be replaced by the equivalent width and length of the SIW cavity, L and W, because of the presence of vias sidewall.

So, an SIW cavity can be designed by using the following relations [6]:

$$L = L_G - \frac{D^2}{0.95.P} \tag{1}$$

$$W = W_G - \frac{D^2}{0.95P} \tag{2}$$

In equations (1) and (2), the parameters D and P are the diameter and the period of via holes respectively.

3. A design of proposed transition

In order to combine SIW and microstrip technologies, SIW-microstrip transitions are very required [7]-[8]. Tapered transition shown in Fig. 1 has been studied.

This kind of transition consists of a tapered microstrip line section that connects a 50 microstrip line and the integrated waveguide. The taper is used to transform the quasi-TEM mode of the microstrip line into the TE_{10} mode in the waveguide.

It is known that the propagation constant of the TE_{10} mode is only related to the width “W” .Therefore, the height or the thickness “b” of the waveguide can be reduced without much influence on the TE_{10} mode propagation, thus allowing its integration into a thin substrate that could reduce the radiation loss of the microstrip line.

The design of this transition is very critical and important in order to have a good performance. The optimisation of the transition is obtained by varying the dimension (L_T, W_T) of the tapered geometry (Fig.1).

This structure is fabricated on a substrate FR4 ($\varepsilon_r = 4.4, \tan\delta = 0.02$), the distance between the rows of the centres of via is w = 19 mm, the diameter of the metallic via is D = 1 mm and the period of the vias P = 1.8 mm. The width of tapered W_T is 5.82 mm, its length is L_T = 22 mm. The transitions have been realized using PCB process (fig. 3).

Fig. 3 A Photograph of the manufactured SIW- microstrip line with tapered transitions

This line is simulated by using HFSS, including the two SMA connector’s influences. The simulated results and the measured results are compared in Fig. 4.

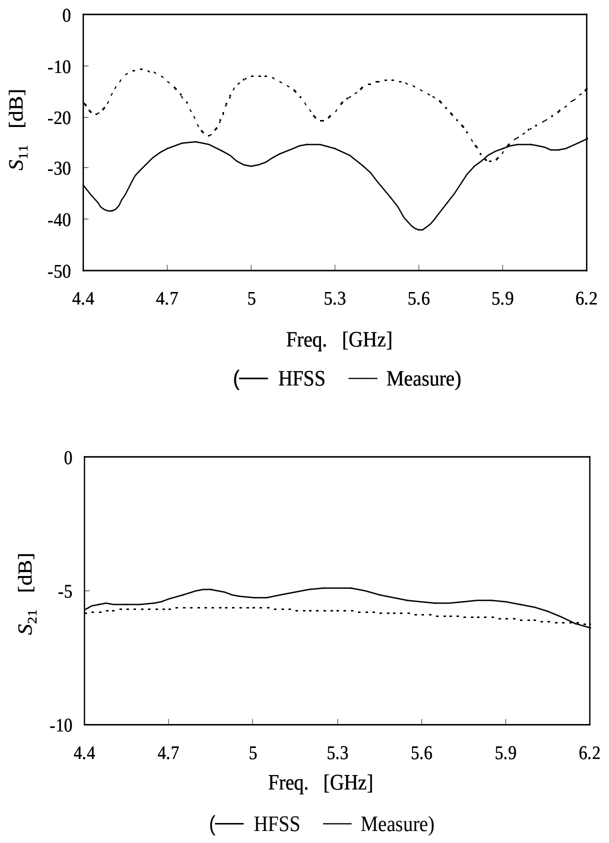


Fig. 4 Return and insertion losses for SIW-microstrip tapered transition

4. A design of SIW filter

4.1 Filter Configuration

Fig.5 Shows the proposed design of filter, this filter includes two microstrip tapered transitions and four SIW resonators cavities.

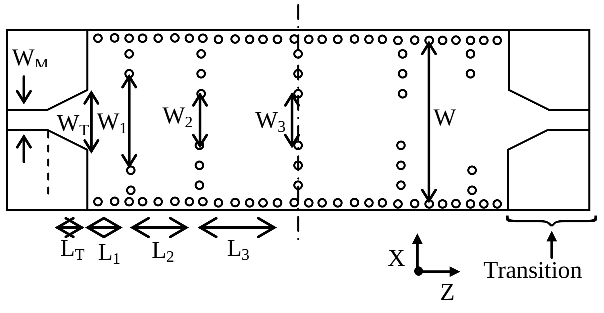


Fig. 5 Geometry of microwave SIW filter

Since the field distribution of mode in SIW has dispersion characteristics similar to the mode of the conventional dielectric waveguide, the design of the proposed SIW band-pass filter, makes use of the same design method for a dielectric waveguide filter. The filter can be designed according to the specifications [9]-[10]. The equivalent circuit of band-pass filter is given by Fig.6.

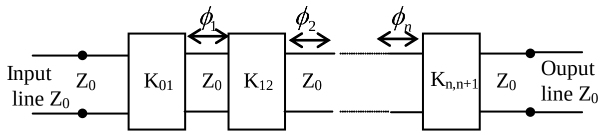


Fig.6 Equivalent circuit of SIW filter

This circuit represents an impedance inverter $K_{n,n+1}$ and a phase shift ϕ_n, the normalized K-inverter values can be calculated as described in [9]-[11] and can be physically realized in terms of discontinuities in a rectangular waveguide using the scattering parameters S_{ij} as follows:

$$K=\sqrt{\frac{1-|S_{11}|}{1+|S_{11}|}} \tag{3}$$

Using this equation, the electrical lengths of the resonators ϕ_i are obtained [11]:

$$\phi_i=\pi-\frac{1}{2}\left(\frac{\pi}{2}-\angle S_{11}\right) \tag{4}$$

$$L_i=\frac{\lambda_g \phi_i}{2\pi} \tag{5}$$

λ_g is the guided wavelength.

4.2 Simulated and experimental results

We designed the proposed SIW filter using the last steps procedure. The initial filter parameters are optimized and given in Table 1.

Table 1: Dimensions of the siw filter

L_i (mm)	5.5	13.6	14.9
W_i (mm)	12.57	10.2	9.6
W_M= 1.4	W_T= 5.8	L_T =21.7	

Each rectangular cavity is created with many rows of via-holes, which have radius of 0.5 mm; the distance between these metallic-vias is set to 1.8 mm. The SIW filter is symmetrical along z axis, it has been fabricated on FR4 substrate ($\varepsilon_r = 4.4, \tan\delta = 0.02$) with a thickness of 0.8 mm.

The filter proposed is done with HFSS using the Finite Element Method (FEM) and fabricated using a standard PCB process (Fig.7) and measured with Vector Network Analyzer. The Fig. 8 shows the comparison between the electromagnetic simulation and the measurements for the input reflection and the transmission, respectively.

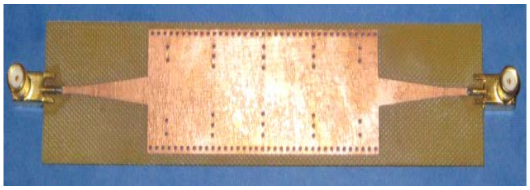


Fig.7 A Photograph of the manufactured SIW filter

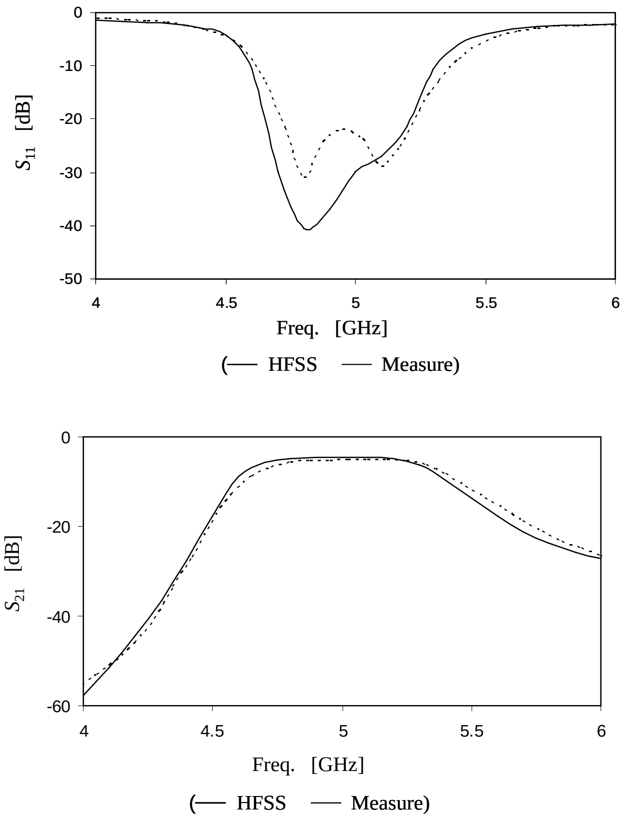


Fig. 8 Return and insertion losses of SIW filter

It can be seen that the agreement is good, the filter has a frequency bandwidth of 750 MHz, the insertion loss around frequency f = 5 GHz is approximately -5 dB the return loss in the pass-band is better than -20 dB.

5. Conclusion

In order to design low cost devices for C band, SIW-microstrip transition and band-pass filter have been treated with HFSS, fabricated and tested. The filter shows a good performance in terms of return and insertion losses. The main characteristics of these kinds of SIW structures are that they have a small size, a high power handling and are easily manufactured.

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