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A High Pass Filter Based on Half Mode Substrate Integrated Waveguide Technology for cm Waves

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Abstract—In this paper, we present a high pass filter based on half mode substrate integrated waveguide HMSIW technology dedicated to the transmission of microwave signals range from 6 GHz to 18 GHz. Taper is used for microstripe to SIW transition. We designed SIW line transmission using CST and HFSS simulators on a Rogers RT5880 substrate with dielectric constant of 2.2 and thickness of 0.508 mm, and we used the half mode technique for miniaturizing the filter size and achieving a size reduction about of 50%. The fabricated filter size is $60 \times 12\,\mathrm{mm}^2$. The lower measured return loss is about -51 dB. We compared the simulation results with measurement ones for validating our proposal. Good agreement between CST, HFSS and measurement results is observed.

1. INTRODUCTION

In recent years, the development of microwave components is towards minimized weight, reduced size, and increased reliability with low cost. Among the most used components in modern telecommunications systems are filters, antenna, power divider, and couplers [1, 2]. Rectangular waveguide is considered an effective transmission line, and it is among the most used components in microwave systems. However, due to its voluminous structure, it is difficult to integrate it into planar structures. To solve this problem, scientists have been working on the development of Substrate Integrated Waveguide (SIW) technology, which has become an emerging technology for telecommunications systems [3, 4]. The SIW technology is used for the design and manufacture of various components serving microwave systems with low cost, compact size, and high quality factor Q such as antipodal antenna [5], leaky wave antenna [6], bandpass filter [7], and power divider [8]. The half mode substrate integrates waveguide HMSIW based on modification of the SIW structure by reducing the waveguide width and the surface area of the metallic plans nearly half compared with the SIW, and it shows similar propagation characteristic to the SIW and smaller size. Several SIW filters based on half mode have been proposed since their introduction [9], and the problems were in the size of the component, the losses, and the cost. In this work, we propose a high pass filter based on HMSIW for solving those problems. The results achieved were satisfactory in terms of component size, losses, and cost. The organization of this paper is as follows. First, we present rules and design method by calculating the width of dielectric filled waveguide DFW and SIW width, and we use taper for microstrip to SIW transition. After that, we present simulation results of the HMSIW high-pass filter, then we present the experimental results of the high pass filter. Finally, we end our work by conclusion. We used CST and HFSS simulators to design and optimize our structures and PCB process for manufacturing.

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2. SIW HIGH PASS FILTER DESIGN

The main problem in SIW circuit design is related to losses. It is necessary to make the right choice of the substrate and also the value of diameter "d" of the metal vias and the distance "p" between two successive via centers. To design a good SIW structure, you must adhere to certain design rules [10]. For dielectric filled waveguide DFW, the dimension "a_d" of the waveguide is calculated by Equation (1) where ε_r is the relative dielectric constant of the dielectric that fills the waveguide, and "a" is the long dimension of the rectangular waveguide [1].

$$a_d = \frac{a}{\sqrt{\varepsilon_r}} \tag{1}$$

By working at the same cut-off frequency, the main design equation of a SIW is given by Equation (2) [11].

$$a_d = W_{siw} \left\{ \xi_1 + \frac{\xi_2}{\frac{p}{d} + \frac{\xi_1 + \xi_2 - \xi_3}{\xi_3 - \xi_1}} \right\} \tag{2}$$

where:

$$\xi_1 = 1.0198 + \frac{0.3465}{\frac{W_{siw}}{p} - 1.0684} \tag{2a}$$

$$\xi_2 = -0.1183 - \frac{1.2729}{\frac{W_{siw}}{p} - 1.2010} \tag{2b}$$

$$\xi_3 = -0.1183 - \frac{1.2729}{\frac{W_{siw}}{p} - 1.2010} \tag{2c}$$

The other SIW design parameters are defined by the following equations:

$$d < \frac{\lambda_g}{5} \tag{3}$$

$$p < d \times 2 \tag{4}$$

where λ_g is the guided wavelength.

$$\lambda_g = \frac{2\pi}{\sqrt{\frac{(2\pi f)^2 \varepsilon_r}{c^2} - \left(\frac{\pi}{a}\right)^2}} \tag{5}$$

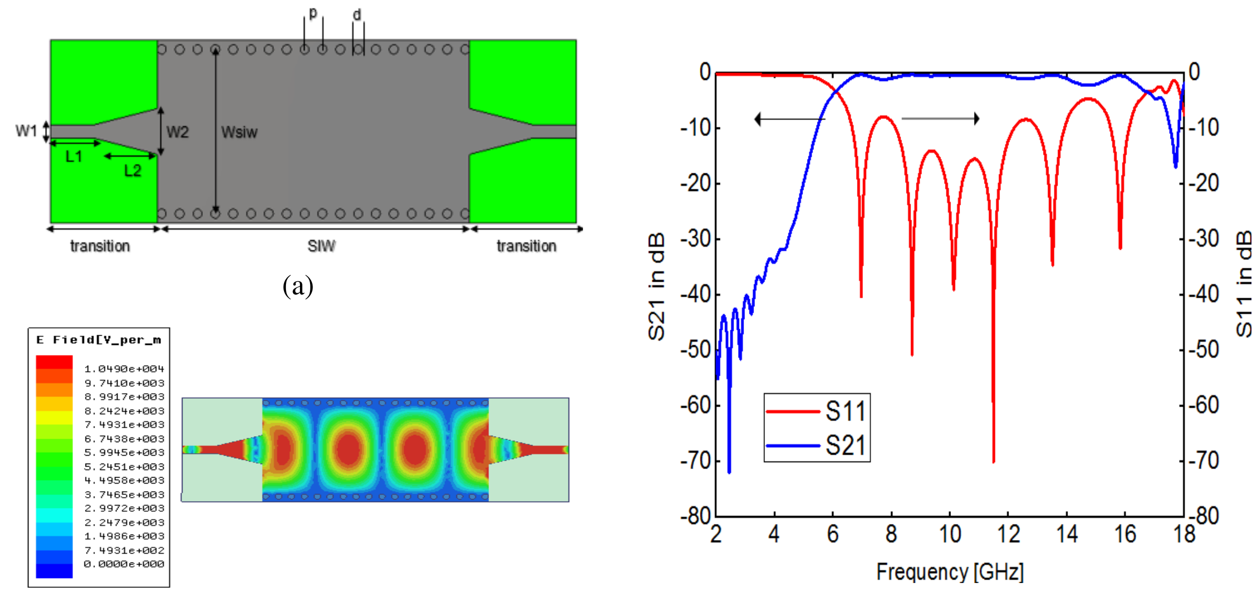
The transition between the micro-ribbon line and the substrate integrated waveguide requires the calculation of the output impedances Z_{pi} from the input impedance, which is equal to $50\,\Omega$. The Impedance is calculated using Equation (6) [1].

$$Z_{pi} = Z_{TE} \frac{\pi^2 h}{8 W_{siw}} \tag{6}$$

Z_{TE} represents the wave impedance for the TE_{10} mode, and it is given by Equation (7).

$$Z_{TE} = j\omega \frac{\mu'}{\beta} = \sqrt{\frac{\mu}{\varepsilon_r}} \times \frac{\lambda_g}{\lambda} \tag{7}$$

Using the CST we designed a SIW high pass filter to reject frequencies that are less than 6 GHz on a Rogers 5880 based substrate having a loss tangent approximately 0.018, a relative permittivity of 2.2, a thickness h of 0.508 mm, and the thickness of the conductor equal to 0.05 mm. The geometry of the SIW high pass filter configuration is shown in Figure 1(a).



(b) (c)

Figure 1. (a) Geometry of the SIW high pass filter configuration. (b) Distribution of the electric field at the frequency of 11.5 GHz. (c) Transmission coefficient and return loss of high pass filter. The optimized parameters values of the proposed filter are given in mm such as: $W_1 = 1.5$, $W_2 = 5.0$, $L_1 = 5.0$, $L_2 = 7.5$, $W_{siw} = 18$, $p = 1.8$, $d = 0.9$.

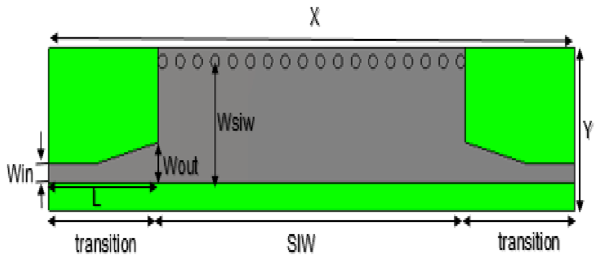
The technique used for obtaining the optimized parameters is the study parametric (parameters sweep) using CST software. The simulated S_{11} and S_{21} of the proposed filter are shown in the Figure 1(c). We observe that the filtering band ranges from 6 to 18 GHz, and the filter rejects the frequency under 6 GHz with an transmission coefficient about of -0.5 dB with the appearance of many peaks with the best reaching -70 dB at the frequency of 11.8 GHz. The rejection is very good under 6 GHz, and it reached -72 dB around the frequency of 2.2 GHz. From this analysis, we can say that this SIW filter is functional to transmit cm waves that range from 6 to 18 GHz. As we show in Figure 1(b) we can notice that the electric field is well delimited and distributed in the whole SIW high pass filter, and its dominant mode is TE_{10}.

3. HALF MODE SIW HIGH PASS FILTER DESIGN

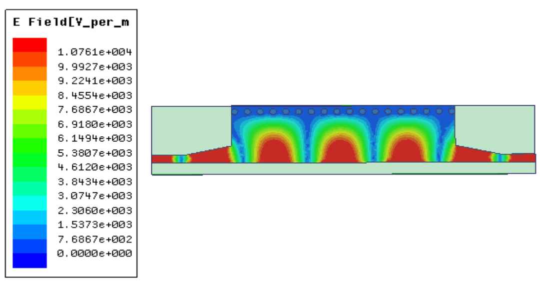
For the half-mode SIW filter, simply modify the previous structure by eliminating one-half and keep the other half. We use the parametric study by CST software for optimizing the filter performance. The HMSIW high pass filter structure is shown in Figure 2(a). From Figure 2(c), we observe that the filter less passes the frequency above 6 GHz and eliminates the frequency under 6 GHz with a transmission coefficient about -0.5 dB. We also observe the appearance of many resonance frequencies under -10 dB with the best reaching -55 dB at the frequency of 6.8 GHz. The rejection is good under 6 GHz, and it reached -44 dB at the frequency of 3.9. We notice that the filter did not lose its performance when we used the half-mode technique. We observe from distribution of the electric of the frequency of 6.1 GHz in the HMSIW, shown in Figure 2(b), that the dominant mode is approximately half of the TE_{10}, and it is well located in the HMSIW.

4. RESULTS COMPARISON

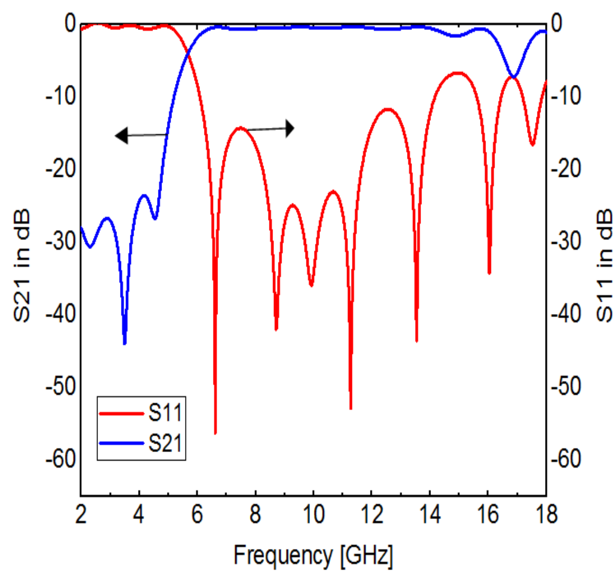
Figure 3 presents the comparisons between CST Studio and Ansoft HFSS simulation results of transmission coefficient and return loss. HFSS simulator based on the finite element method and CST Microwave studio uses FIT (finite integration technique, a relative of FDTD) for its transient solver.



(a)

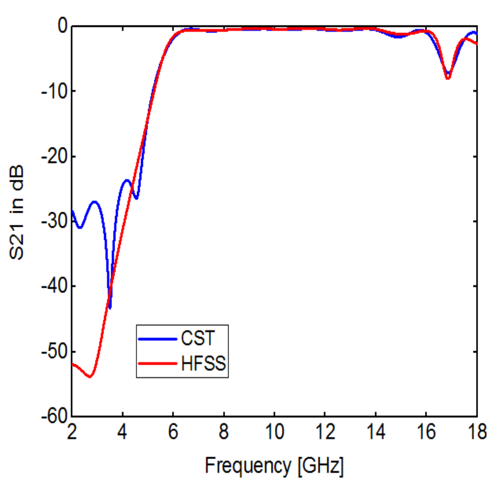


(b)

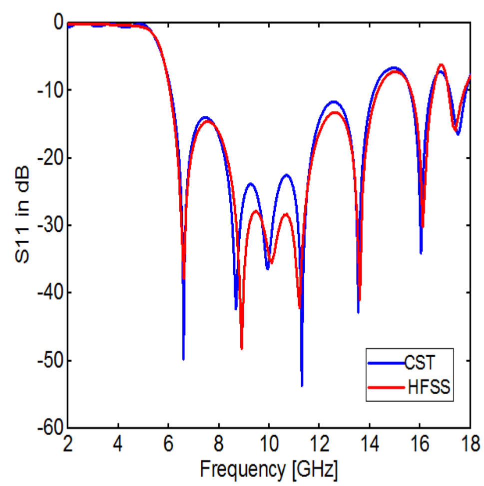


(c)

Figure 2. (a) Structure of HMSIW high pass filter. (b) Distribution of the electric field at the frequency of 6.1 GHz. (c) Transmission coefficient and return loss of HMSIW filter. The optimized parameters of the HMSIW high pass filter are set such as: $W_{in} = 1.5$, $W_{out} = 2.5$, $L = 12.5$, $X = 60$, $Y = 12$, $W_{siw} = 9$.



(a)



(b)

Figure 3. (a) Transmission coefficient and return loss of HMSIW filter. (b) Transmission coefficient and return loss of HMSIW filter.

From Figure 3, it is shown excellent results are obtained. The simulation results show a good agreement of the cut-off frequency. We observe a good agreement in the functional band that ranging from 6 to 18 GHz also we obtained a good agreement in resonances frequencies. It can also be noted that we have an agreement in the rejection under 6 GHz.

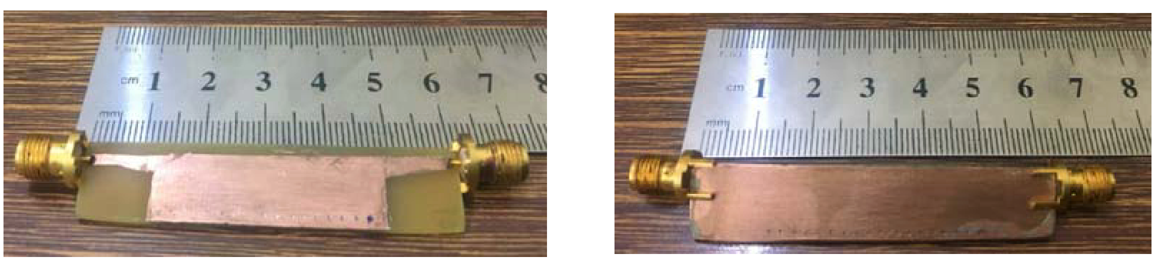
5. EXPERIMENTAL RESULTS

To validate the simulation results, the proposed half-mode SIW high pass-filter is fabricated and measured using PCB process by ProtoMat S103 and R&S ZVA 40 Vector Network Analyzer as shown in Figure 4. Figure 5 shows pictures of the fabricated half-mode SIW high pass-filter prototype. The measured return loss and insertion loss are shown in Figure 6 compared with the simulation results obtained by CST simulator.

From Figure 6 we notice a good agreement between simulation and experimental results of the

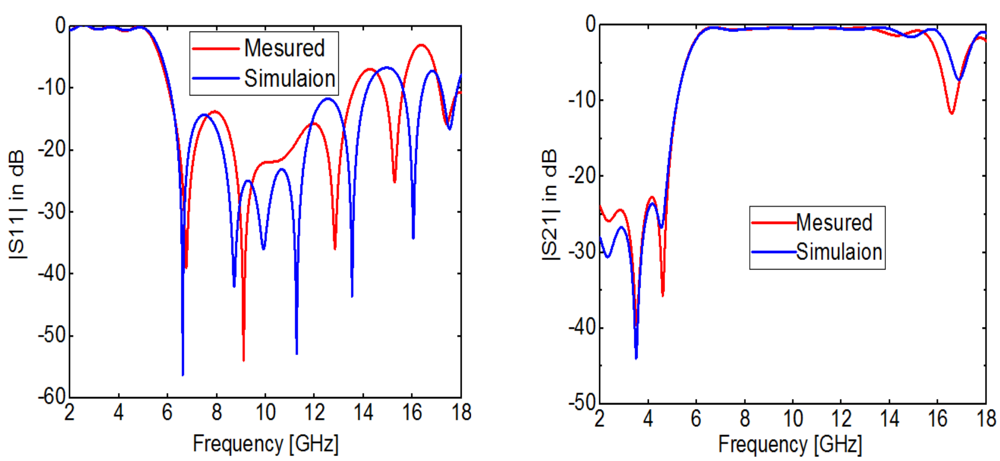
(a) (b)

Figure 4. (a) ProtoMat S103. (b) NAV ZVA 40.



(a) (b)

Figure 5. The photograph of the fabricated HMSIW high pass filter.



(a) (b)

Figure 6. (a) Return loss of the HMSIW high pass filter. (b) Transmission coefficient of the HMSIW high pass filter.

operational frequency range from 6 GHz to 18 GHz. In the measured curve plotted in Figure 6 we notice a reflection coefficient S_{11} below -10 dB in all band which ranges from 6 to 18 GHz with the appearance of several resonance frequencies with the best reaching -51 dB at the frequency of 9 GHz. The measured insertion loss is shown in Figure 6, and it is approximately -1 dB. Good rejection is observed under 6 GHz, and it is below -22 dB from 2 to 6 GHz.

6. CONCLUSION

In this work, a SIW high pass filter is designed, fabricated, and measured used for transmitting cm wave from 6 to 18 GHz, and the design method is discussed. Good agreement is observed between simulation and measurement results. The lower measured return loss is about -50 dB at 9 GHz. The HMSIW filter has a size reduction of 50% compared to a similar SIW filter. This type of filter is easy for integration with other planar circuits compared to using a conventional waveguide, and it is suitable for Wlan, WiMAX, radar, and satcom applications. The corresponding study to design a SIW band pass filter from this SIW high pass filter will be presented soon.

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