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A C band diplexer incorporating the novel substrate integrated waveguide

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Abstract

A C band planar microwave diplexer in the new emerging technology substrate integrated waveguide (SIW) is based on two-channel filters, a power divider, and three SIW microstrip transitions for input or output purposes. It is conceived under two designs, the first is such that the two-channel filters are perpendicular the second they are linear. Using 3D simulator HFSS, a C band SIW diplexer is investigated in this paper. Channel 1 has a centre frequency of 5.27 GHz, with a bandwidth from 5.20 to 5.33 GHz, and channel filter 2 has a centre frequency of 5.80 GHz, with a bandwidth from 5.76 to 5.84 GHz. The maximal insertion loss of channel 2 is −6.42 dB, while it is −4.62 dB for channel 1. The return loss is less than −10.5 dB for channel 2 and less than −11.8 dB for channel 1.

Keywords: Substrate integrated waveguide, C band, filter, diplexer, HFSS;

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1. Introduction

Great interest and special effort have been directed to the development of different types of waveguide diplexers for different applications. However, the manufacturing of the rectangular waveguide structure (Guglielmi et al., 2001; Jia et al., 2016; Shen et al., 2016) is rather expensive because of the bulky size and non-planar form. This contributes to the difficulty to integrate with other planar circuits. To overcome this problem, a new technique of designing a millimetre-wave circuit, which is called substrate integrated waveguide (SIW), has been introduced. This waveguide is composed of two parallel rows of metallic posts inserted in a plated substrate to realise bilateral edge walls. The distance between the posts and their diameter is chosen as demonstrated in Hao et al. (2005) and Xu et al. (2005). Integrated transitions can be designed on the same substrate compatible with planar structures such as microstrip (Deslandes, 2010; Deslandes & Wu, 2002, 2003; Venanzoni et al., 2019).

SIW structure can be fabricated by using any standard process including low-cost PCB techniques and have small and compact size circuits. SIW components are covered by metal surfaces on both sides of a substrate which contributes to having low insertion loss, low radiation loss, and insensitivity to outside interference. Numerous microwave and millimetre-wave components such as filters (Guglielmi et al., 2001), six ports (Xu et al., 2005), and diplexers (Hao et al., 2005) have been converted from metallic waveguides to SIW circuits. Waveguide diplexers (Deslandes & Wu, 2002) are widely applied to all kinds of electronic and communication systems such as base stations of mobile communications. Their applications are used in these systems to discriminate between wanted and unwanted signal frequencies. Diplexers are essential structures in front-end systems to separate transmit and receive bands. In this work, we analysed the square diplexer (Hao et al., 2005) in the C band, conceived another longitudinal diplexer in the same band, and compared frequency responses.

1.1. Purpose of study

The goal of the paper is to demonstrate the design and optimisation of a diplexer operating within the frequency range of 4.5–6.5 GHz. The study aims to compare the frequency responses of two duplexers designed in the same frequency band, the first one being such that the two channels are perpendicular in the second they are aligned. As shown in Figure 5, the SIW diplexer is equivalent to a conventional rectangular waveguide filled with dielectric, and therefore the diplexer topology (Parment et al., 2017) illustrated, is conceived and optimised just by using the width of the equivalent waveguide. The input ports of both channel filters are simply connected to a waveguide T-junction, which then serves as a power divider.

2. Materials and methods

2.1. Development of planar SIW diplexer

The channel filters (Guglielmi et al., 2001; Jia et al., 2016; Shen et al., 2016) of the diplexer can thus be realised by a series of connected waveguide cavities (resonators), coupled to one another by small apertures (irises). The diplexer is then constructed by connecting each channel filter to a waveguide T-junction. In this paper, based on the studies in Hao et al. (2005) and Xu et al. (2005), a planar microwave bandpass filter (Guglielmi et al., 2001) is designed on the SIW technique. The SIW is an interesting low-cost, low-loss planar technology (Xu et al., 2005). The different components designed in SIW can be integrated with the same substrate using conical micro-strip transitions (Deslandes & Wu, 2002, 2003; Hao et al., 2005). In this application (Hao et al., 2005) a Chebyshev filter (Figure 1) is presented and designed for millimetre-wave applications. Initially, it was designated from the equivalent rectangular waveguide based on the same substrate then the transformations using equations (Venanzoni et al., 2019) make it possible to design the filter in SIW technology, such that the lateral walls are based on metal cylinders (Deslandes, 2010). Iris waveguide bandpass filters are realised using SIW technology in Deslandes (2010) and Venanzoni et al. (2019).

The initial steps of the design of these Chebyshev filters are performed in a similar method to that of conventional rectangular waveguide iris filters (Deslandes & Wu, 2003). Iris walls (Figure 1) with finite thickness t, in this topology have two parameters di and li (i = 1, 2, n) respectively window width and distance between two irises, to be determined and optimised. The circuit is designated on a height substrate H = 0.5 mm, its dielectric constant εr = 3, its loss tangent tanδ = 0.001, the dimensions of the metal cylinders constituting the walls of the SIW in the plane E, are the diameter d = 0.5 mm, and the space between two cylinders adjacent p = 1 mm. Figure 2 shows the electromagnetic field distribution of the TE10 mode guided in the SIW band pass filter with taper adaptation (Deslandes, 2010; Moallemizadeh et al., 2020; Parment et al., 2017) using 3D FEM simulator HFSS (2005) while an optimisation procedure was followed to meet the desired specifications.

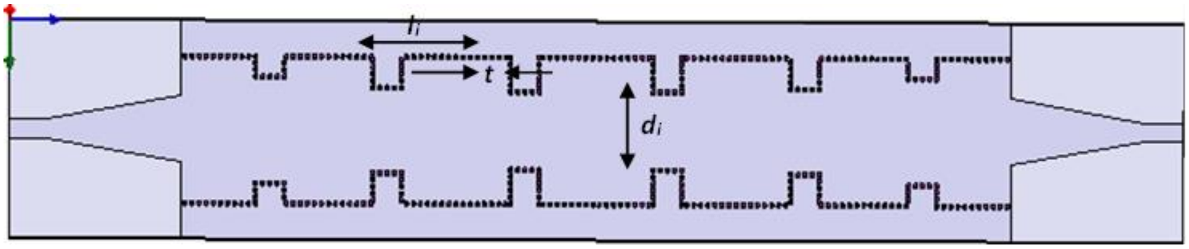


Figure 1

SIW Filter (Hao et al., 2005)

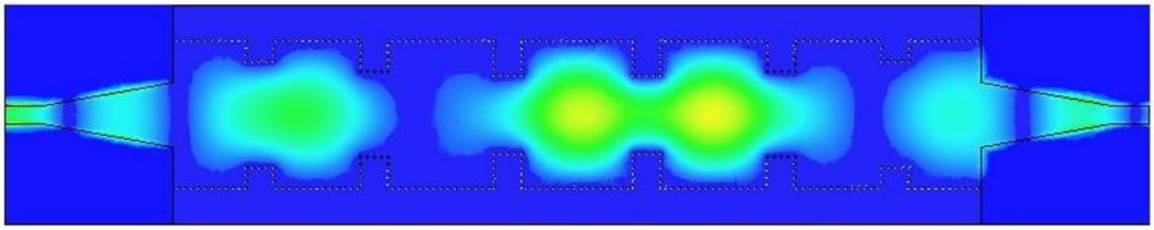
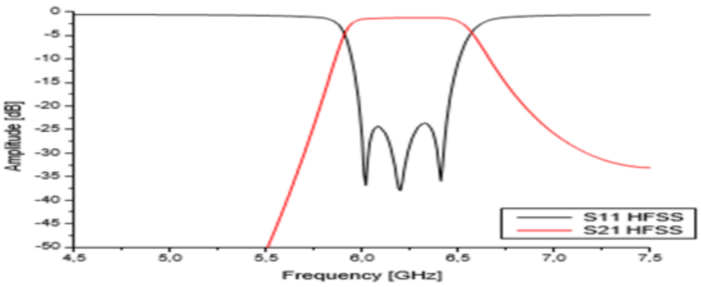


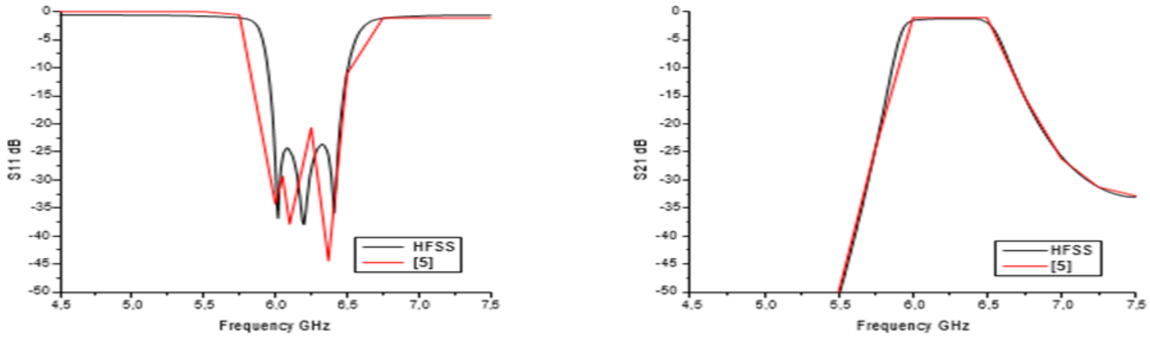
Figure 2

TE10 Electric Field Magnitude in SIW Filter

The frequency responses of the scattering parameters of S11 and S21 are shown in Figure 3a. Figure 3b shows the comparison of the frequency response obtained by Hao et al. (2005) and by electromagnetic simulation with the HFSS simulator (Figure 3a). It can be seen that a return loss of less than −24.69 dB and an insertion loss of about 1.25 dB is achieved in the pass-band from 5.97 to 6.50 GHz.



(a)



(b)

Figure 3

(a) Simulated Parameters Sij of SIW Filter. (b) Comparison of HFSS Simulated Parameters Sij and Hao et al. (2005)

Diplexers are devices used in RF and microwave systems to combine two disjoint-band signals from separate channels into a single signal and project it onto a common port. They are generally synthesised by combining a set of channel filters with a power-distribution network (Figure 4) (Moallemizadeh et al., 2020). Signals of frequencies F1 and F2 enter the system and with a power divider, each channel filter selects its corresponding signal to pass through to the output.

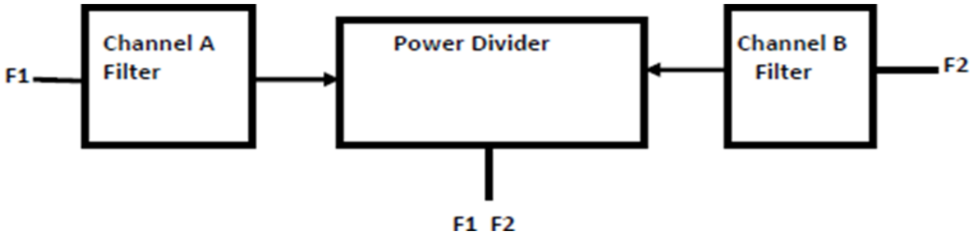
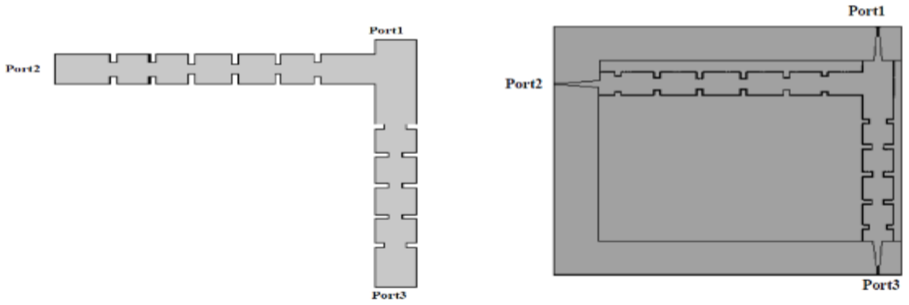


Figure 4

Schematic of Diplexer Configuration

3. Results

The geometrical parameters filter has been adjusted using Hao et al. (2005), then the diplexer has been configured after some optimisations (Figure 5), consists of two channels of SIW filters and three planar transitions (Deslandes, 2010; Deslandes & Wu, 2002; Hao et al., 2005).



(a) (b)

Figure 5

SIW Filters: (a) Waveguide Diplexer. (b) SIW Diplexer

We have analysed this structure using the 3D simulator HFSS (2005) taking frequency responses in Figure 6. Figure 7 represents the comparison between the transmission and reflection coefficients S21, S31, and S11 obtained in Hao et al. (2005) and following the simulation.

Figure 8a and b, respectively, show magnitude surface plots of the electromagnetic field propagating in the complete structure as microwave signals of (a) 5.42 GHz and (b) 5.84 GHz are excited into the common port. As can be seen in Figure 8, the 5.42 GHz signal is only permitted to propagate through channel A, and the 5.84 GHz signal can only propagate through channel B.

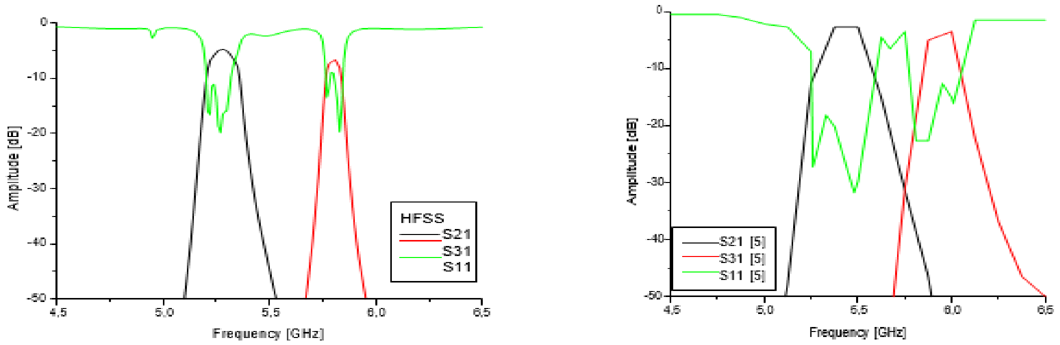


Figure 6

Sij Coefficients of Square SIW Diplexer (HFSS) and Hao et al. (2005)

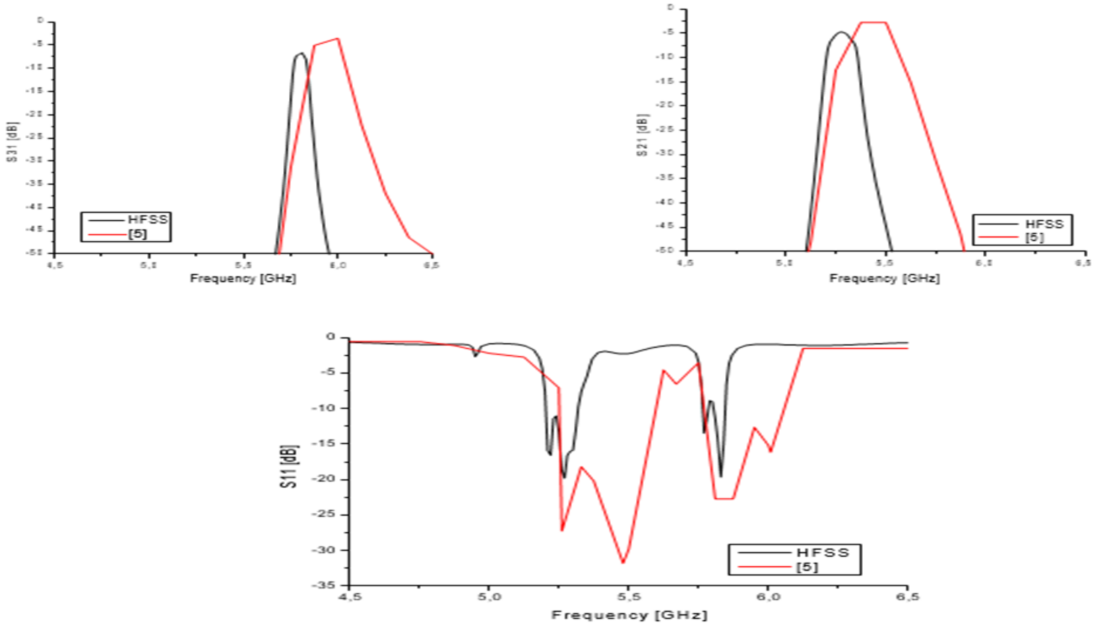


Figure 7

Comparison of Simulated Coefficients Sij of SIW Diplexer and Hao et al. (2005)

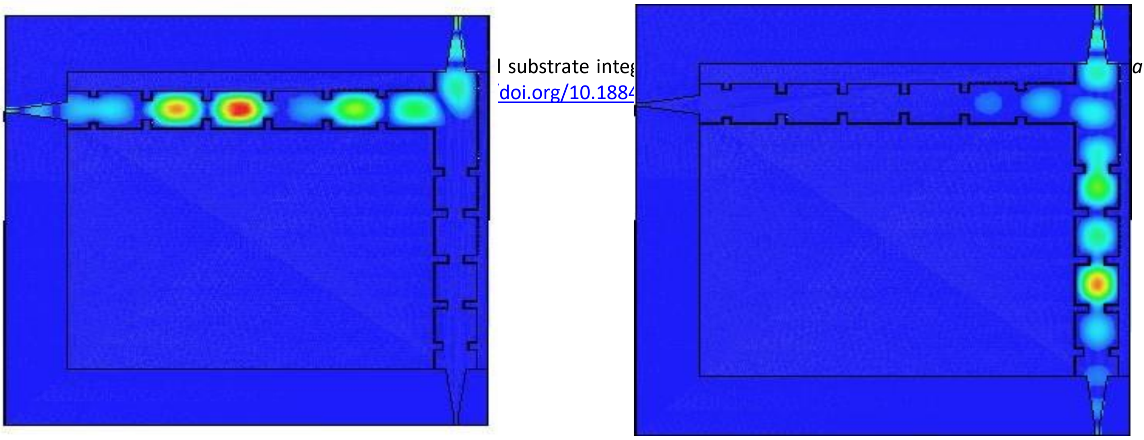
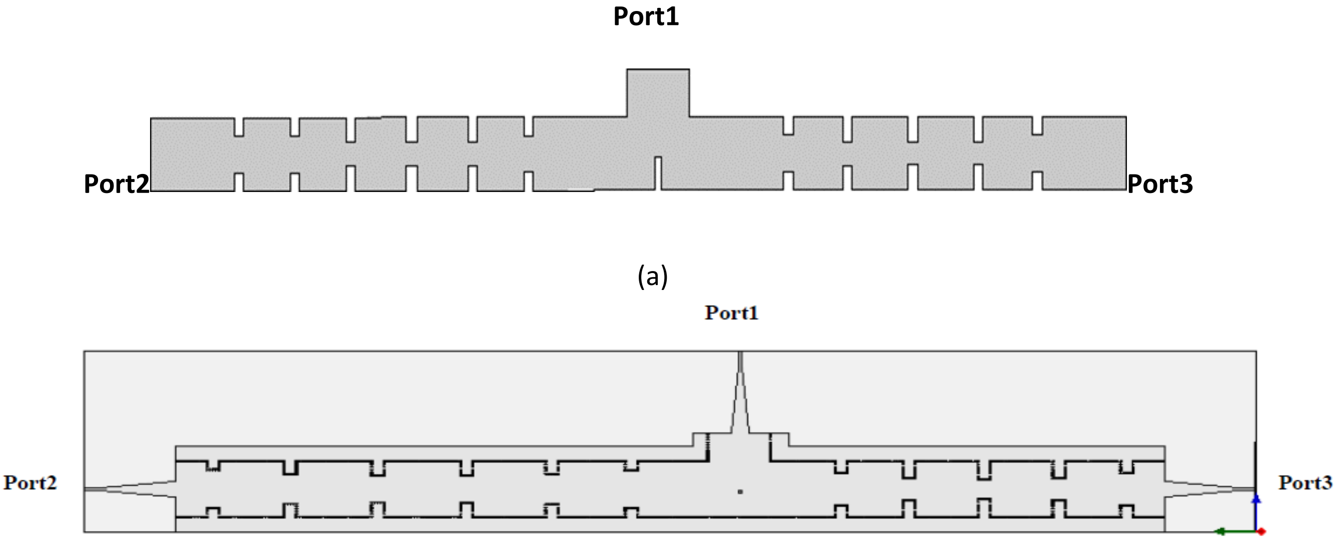

(a) (b)

Figure 8

Magnitude Surface Plots of the Electromagnetic Field. (a) F = 5.42 GHz (b) F = 5.84 GHz

Figure 8a is a TE10 electric field magnitude of S21, and Figure 8b is a TE10 electric field magnitude of S31in square SIW diplexer.

As mentioned before, a second diplexer (Figure 9) is conceived in the same frequency band based on the same channels A and B being aligned. As expected, the HFSS simulations of this design required optimisation of the entire diplexer to achieve frequency responses (Figure 6). The optimisation was done in HFSS, in the same way as for each filter, combining the optimisation tools integrated into the software and the manual adjustment.



(a)
(b)

Figure 9
Optimisation: (a) Waveguide Diplexer. (b) Longitudinal SIW Diplexer

The HFSS model of this design is presented in Figure 10. Figure 11 represents the comparison between the transmission and reflection coefficients S21, S31, and S11 obtained for the longitudinal SIW diplexer (Figure 10) and the square SIW diplexer (Figure 6).

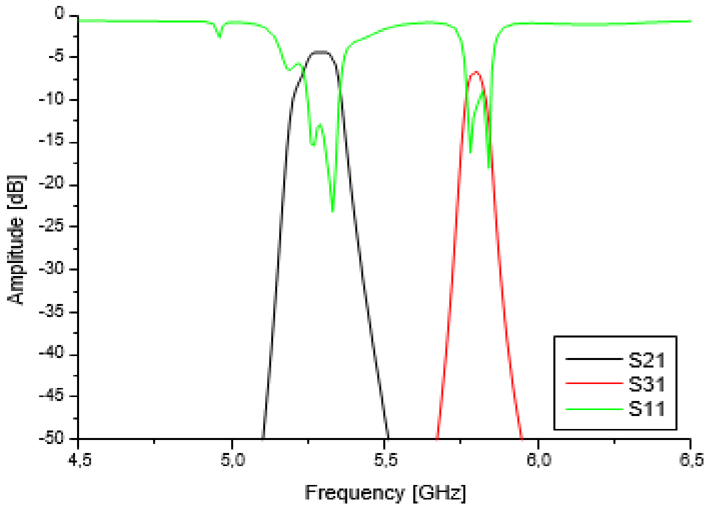


Figure 10

Simulated Coefficients Sij (HFSS) of SIW Longitudinal Diplexer

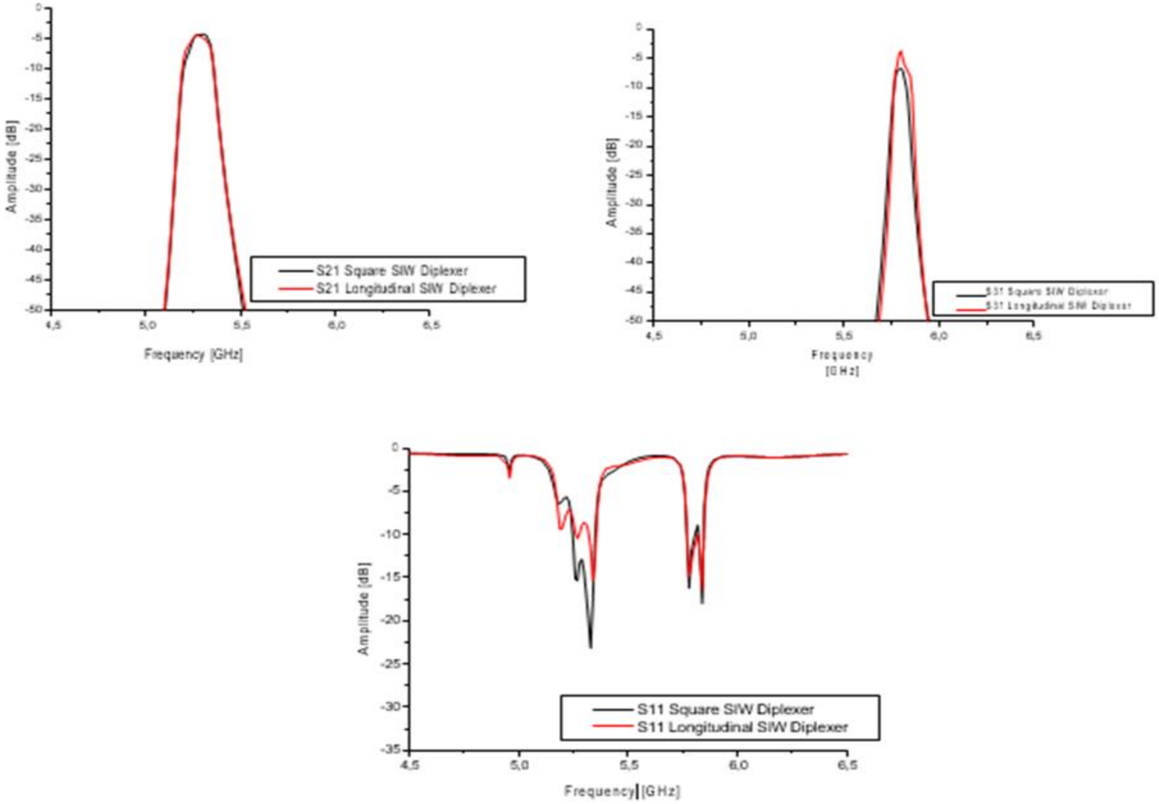


Figure 11

Comparison of Simulated Coefficients Sij of Square and Longitudinal SIW Diplexers

For longitudinal SIW diplexer, Figure 12a and b, respectively, illustrates magnitude surface plots of the electromagnetic field propagating in the complete structure as microwave signals of (a) 5.36 GHz and (b) 5.79 GHz are excited into the common port. Like before, as can be seen in Figure 13, the 5.36 GHz signal is only permitted to propagate through channel A, and the 5.79 GHz signal can only propagate through channel B.

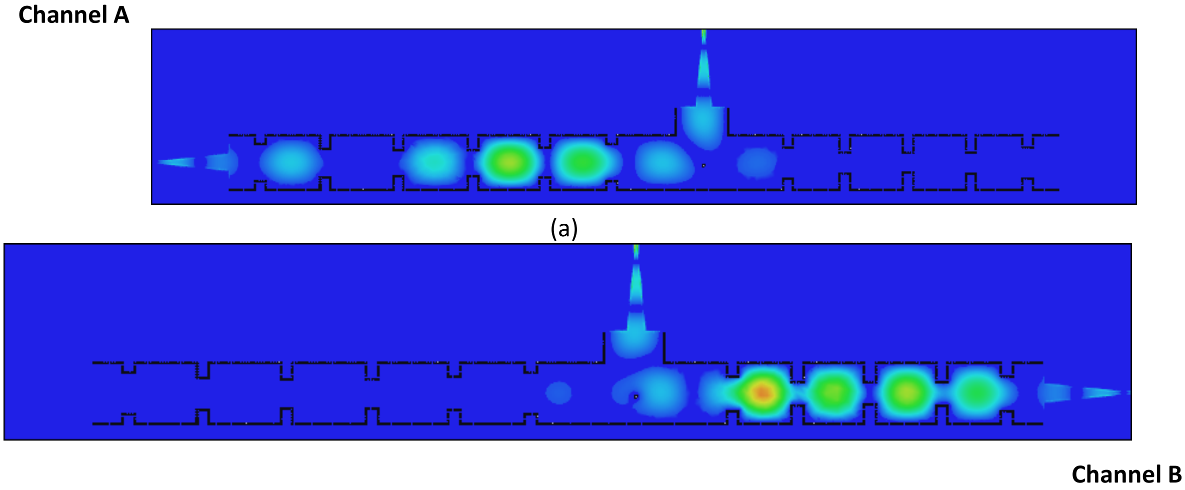


Figure 12

Surface Plots of the Electromagnetic Field. (a) F = 5.36 GHz (b) F = 5.79 GHz

Figure 12a is a TE10 electric field magnitude of S21, while Figure 12b is a TE10 electric field magnitude of S31 in longitudinal SIW diplexer

4. Conclusion

In this paper, a planar microwave C band diplexer based on the SIW technique is presented using two geometries such that the two channels are perpendicular or linear. Channel 1 has a centre frequency of 5.27 GHz, with a bandwidth from 5.20 to 5.33 GHz, and channel filter 2 has a centre frequency of 5.80 GHz, with a bandwidth from 5.76 to 5.84 GHz.

The maximal insertion loss of channel 2 is −6.42 dB, while it is −4.62 dB for channel 1. The return loss is less than −10.5 dB for channel 2 and less than −11.8 dB for channel 1.The simulated results show good channel isolation, moderate insert losses, and small return losses inpassbands for the two designs. The diplexer takes a planar form and can be easily integrated with microwave integrated circuits

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