

# Compact Substrate Integrated Plasmonic Waveguide Bandpass Filter with Wide Stopband

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**ABSTRACT** - This work presents a compact bandpass filter (BPF) based on substrate integrated waveguide (SIW) and the trident-shaped compact spoof surface plasmon polariton (SSPP) structure. In the proposed design, the lower cutoff frequency is primarily determined by the SIW dimensions, while the upper cutoff frequency is determined by integrating trident-shaped SSPP grooves on the top metal plane. SIWs and SSPPs exhibit low and high cutoff responses, respectively, which can be combined for filtering functionalities. The passbands can be flexibly selected by varying the geometric parameters of the SIW and SSPP to adjust the lower and upper frequencies independently. The filter operates from 3.81 to 5.31 GHz, with a center frequency of 4.56 GHz and an FBW of 32.89%. It achieves an insertion loss of 0.56 dB at the center frequency, a return loss is greater than 12 dB across the passband, and a stopband rejection from 5.43 GHz to 10.06 GHz at 25 dB. It is highly suitable for C-band wireless applications.

**Key Words:** Substrate Integrated Waveguide (SIW), Spoof Surface Plasmon Polariton (SSPP), trident-shaped groove, Bandpass filter (BPF), and compact design.

## 1. INTRODUCTION

Microwave band-pass filters (BPFs) play a crucial role in modern wireless communication systems, where the need for high-performance microwave and millimeter-wave components is continuously increasing. Substrate Integrated Waveguide (SIW) is a new type of planar transmission line that combines the positive attributes offered by metallic rectangular waveguides and traditional printed circuit boards, including low attenuation loss, minimal EM radiation losses, and decreased area. Due to these fundamental features, SIW filters become more attractive choices for various millimeter and microwave frequency band circuits [1]. These filters are responsible for selecting desired frequency bands and suppressing unwanted signals during transmission and reception. Among various technologies, Substrate Integrated Waveguide (SIW) has become a preferred choice for designing microwave components because it overcomes many limitations associated with conventional waveguides. SIW-based filters offer advantages such as low insertion loss, excellent electromagnetic shielding, and easy integration with planar circuits [2]. However, a major drawback of conventional SIW filters is their relatively large physical size, which limits their use in

compact and highly integrated systems [3]. To address this issue, researchers have introduced band-pass filters that combine SIW with spoof surface plasmon polaritons (SSPPs), including designs with trident-shaped complementary grooves [4]. SSPPs are artificially engineered electromagnetic surface waves that propagate along metal-dielectric interfaces at microwave frequencies. By incorporating periodic sub-wavelength structures on metallic surfaces inspired by the principle of surface plasmon polaritons (SPPs), SSPPs enable strong field confinement and improved control over wave propagation [5]. Due to these properties, hybrid SIW-SSPP filter designs have gained attention, as they provide wideband performance and allow independent tuning of lower and upper stopband frequencies. In addition, compact narrowband BPFs designed using both SIW and SSPP techniques are suitable for high-frequency applications such as the Ka-band, where impedance matching is often achieved using tapered transitions between microstrip lines and waveguide structures. This combination provides separate tuning of the lower and upper stopband frequencies [6]. A compact narrow-band BPF designed for Ka-band applications uses both SSPPs and SIW structures, with a sharp funnel-shaped taper connecting the microstrip lines to ensure proper impedance matching [7]. Compact microwave filters with high selectivity can be designed by combining Substrate Integrated Waveguide (SIW) structures with spoof surface plasmon polaritons (SSPPs). This integration improves control over wave propagation by modifying characteristics while also enhancing field confinement [8]. As a result, the overall circuit size is reduced without degrading performance [9]. In SIW-SSPP band-pass filters, efficient transmission within the desired frequency range and strong rejection outside the band are achieved through proper transition design between microstrip and SIW sections [10]. The use of periodic subwavelength corrugations enables SSPP modes, which shorten the effective guided wavelength and contribute directly to miniaturization [11].

In this paper, an SIW-SSPP-based band-pass filter incorporating a trident-shaped groove is developed. The proposed groove structure allows precise control of the upper cut-off frequency without increasing the SSPPs height ( $h1$ ). The operating characteristics are mainly governed by the groove width ( $L5$ ) and slot depth ( $S5$ ), which influence the behavior of the SSPP mode. A parametric study is

performed to optimize these parameters. The final design achieves compact size, low insertion loss, improved return loss, and strong suppression in the stopband, making it suitable for applications in the C-band frequency ranges.

## 2. DESIGN METHODOLOGY

### 2.1 Design of classical SIW filter

The stated work starts with designing the classical SIW at required structural dimensions as plotted in Fig. 1.

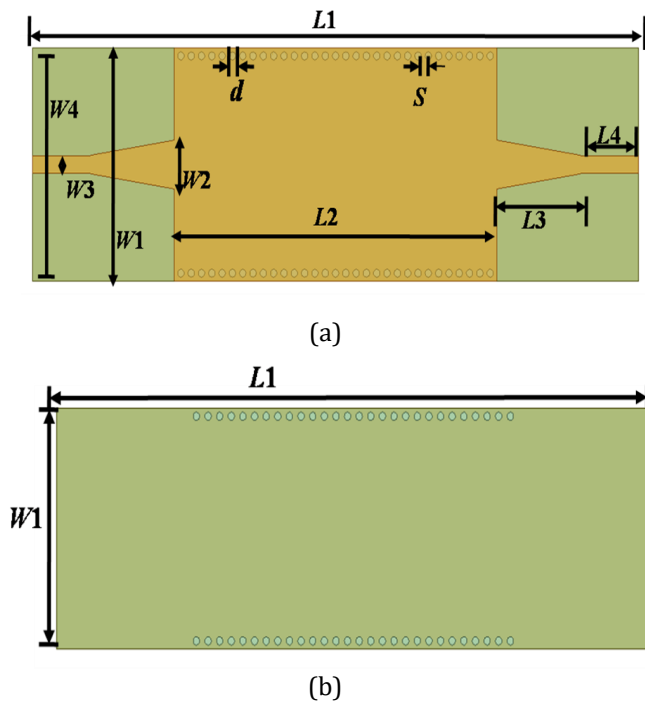


Fig. 1. The layout of the SIW filter (a) top layer (b) bottom layer

The standard SIW structure's electrical performance is similar to that of a classical waveguide. Equations (1), (2), and (3) in [2]–[3] are used to calculate the geometrical variables and cutoff frequency of the SIW structure.

$$f_{cT E_{0,5,0}} = \frac{c_0}{2\sqrt{\epsilon_r}} \left( W_{SIW} - \frac{4d^2}{0.95s} \right) \quad (1)$$

$$W_{eff} = W_{SIW} - \frac{d^2}{0.95s} \quad (2)$$

$$L_{eff} = L_{SIW} - \frac{d^2}{0.95s} \quad (3)$$

From above, (1), (2), and (3)  $c_0$  are the light velocity in free space  $W_{SIW}$  and  $L_{SIW}$  represent the SIW width and length  $W_{eff}$  and  $L_{eff}$  define the SIW effective width and length.  $d$  is the copper via diameter, and  $S$  is the periodic space between vias. The standard SIW filter is defined in Fig. 1, and the employed precise measurements of the filter are tabulated in Table 1.

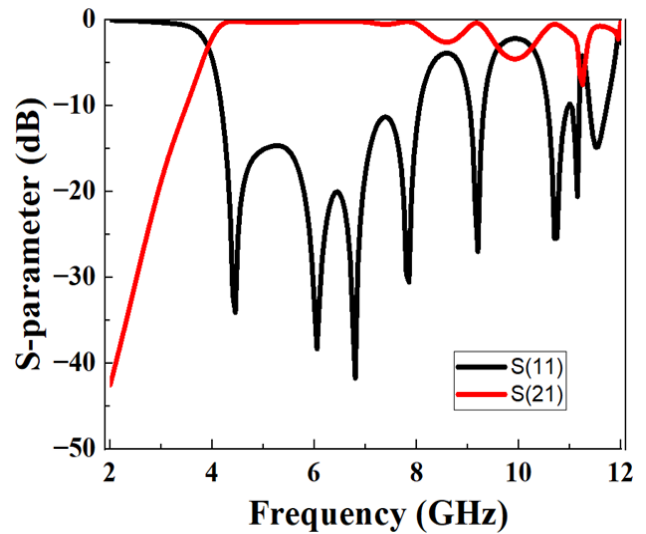


Fig. 2. Simulated output of SIW filter

The simulated S-parameters output of the filter is defined in Fig. 2;

it indicates the passband starting frequency value of 3.81 GHz,

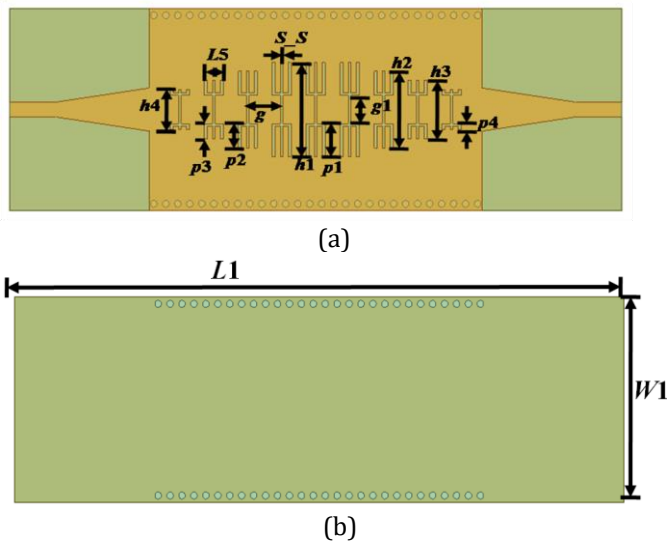
having good return and insertion losses over the entire operating frequency of the passband.

Table 1. Dimensions of SIW filter

Variable	Value (mm)	Variable	Value (mm)
Substrate width ( $W1$ )	30	Substrate length ( $L1$ )	94
Tapered transition width ( $W2$ )	6.3	Filter length ( $L2$ )	50
Feed width ( $W3$ )	2.3	Tapered transition length ( $L3$ )	13
Filter effective width ( $W4$ )	13.6	Feed length ( $L4$ )	9
Space between vias ( $S$ )	1.6	Via diameter ( $d$ )	1

### 2.2 Design approach of proposed SIW-SSPP-based bandpass filter

In order to achieve the bandpass experience at the C-band frequency range, the microwave bandpass filter is designed using both SIW and SSPPs, as shown in Fig. 3. This is achieved by integrating trident-shaped groove grooves. Due to the high and low pass characteristics of both SIW and SSPPs, when a periodic arrangement of SSPP grooves is inserted into a standard SIW filter, the bandpass response is realized as a result of a bandpass filter.

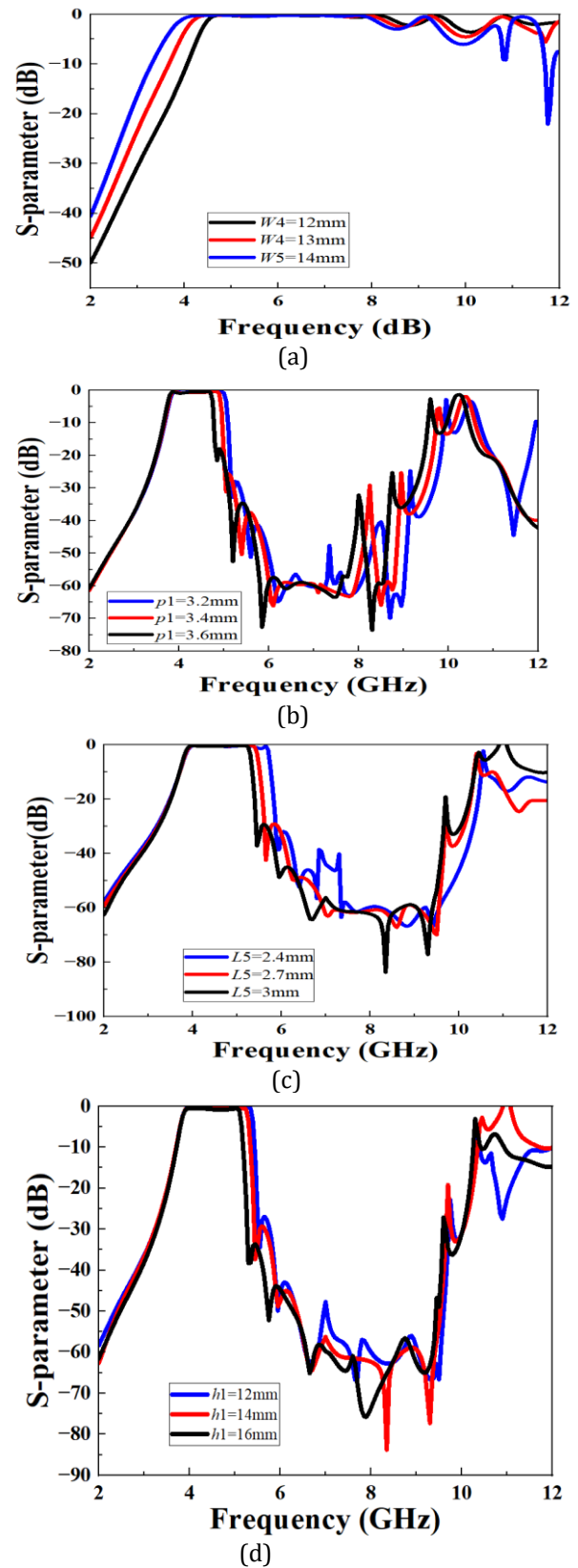


**Fig. 3.** Configuration of proposed SIW-SSPP bandpass filter (a) Top view (b) Bottom view

According to Fig. 3, the optimized dimensions for the SSPP are considered as  $h_1=14\text{mm}$ ,  $h_2=11.7\text{mm}$ ,  $h_3=9.4\text{mm}$ ,  $h_4=7\text{mm}$ ,  $L_5=2.8\text{mm}$ ,  $g=5.1\text{mm}$ ,  $p_1=4\text{mm}$ ,  $p_2=2.85\text{mm}$ ,  $p_3=1\text{mm}$ ,  $p_4=2.85\text{mm}$ ,  $S_S=0.3\text{mm}$ , and  $g_1=3\text{mm}$ .

### 2.3 Parametric Analysis

To achieve the desired passband frequency response, the proposed filter's physical dimensions are changed. First, it is found that changing the SIW effective width ( $W_4$ ) can change the lower passband frequency range, as shown in Fig. 4 (a), with various SIW effective width ( $W_4$ ) values. It is evident that the cut-off frequency falls as the effective width of SIW rises and vice versa. By adding the high-pass and low-pass features of SIW and SSPPs, a compact wideband bandpass filter is realized. The passband exhibits the passband range from 3.81 to 5.31 GHz. Further, the parametric study is performed to understand the impact of the structure's physical dimensions on the filter response. Now, parametric studies are conducted to evaluate the impact of trident-shaped groove dimensions on the frequency response of the filter. First, it is noted that the lower cut-off frequency value of the passband is independently controlled by the width of the SIW ( $W_4$ ). The upper cut-off frequency value of the passband is controlled by the height of the SSPP groove ( $h_1$ ), as illustrated in fig. 3(a). For instance, raising the  $W_4$  from 12 mm to 14 mm, the frequency shifts from 3.73 GHz to 9.88 GHz, as illustrated in fig. 4(a). Similarly, raising the  $h_1$  value from 12 mm to 16 mm moves the frequency from 3.83 GHz to 5.39 GHz, as illustrated in fig. 4(b). For example, increasing the  $L_5$  value from 2.4 mm to 3 mm, the frequency value moves down from 3.84 to 5.71 GHz as depicted in fig. 4(c). If the  $p_1$  value is rising from 3.2 mm to 3.6 mm, the frequency value moves down from 3.77 to 5.04 GHz, as depicted in Fig. 4(d).



**Fig. 4.** Simulated outputs of proposed SSPPs using various values (a) Horizontal width ( $W_4$ ), (b) Height of grooves ( $h_1$ ), (c) Horizontal groove length ( $L_5$ ), (d) Vertical length of groove ( $p_1$ )

Fig. 4 tells that the effect of physical variable values of SSPPs' trident-shaped grooves inserted on the upper plane of the device on the transmission characteristics of the standard microwave bandpass filter and their simulated results. As a result, it is evident that the passband upper edge can be readily moved by simply changing the SSPPs trident-shaped groove variables, primarily vertical groove length ( $p1$ ), the horizontal groove length ( $L5$ ), and groove length ( $h1$ ), as shown in Fig. 4.

### 3. SIMULATION OUTPUT AND DISCUSSION

The Rogers RT/Duroid 5880 substrate, which has a thickness of 0.508 mm and a relative permittivity of 2.2, is used to develop and simulate a microwave bandpass filter for C-band services. Fig. 5 defines the proposed bandpass filter simulated output. By altering the physical parameters of the SIW and SSPP structures, the passband's frequency range can be changed in relation to the bandwidth requirement. The bandpass filter is more compact in size, and the structure's final footprint is  $1.05 \lambda_g \times 1.88 \lambda_g$  not including the feedline, where  $\lambda_g$  is the guided wavelength, which is considered at the center frequency. The simulated performance parameters of the proposed filter are defined in Fig. 5, and the range of the passband of the proposed filter is 3.81 GHz to 5.31 GHz, having a center frequency of 4.56 GHz. In an SIW-SSPP-based filter, the higher-order modes may be slightly active beyond the passband. Moreover, compared proposed filter performance with earlier published work, which is tabulated in Table 2.

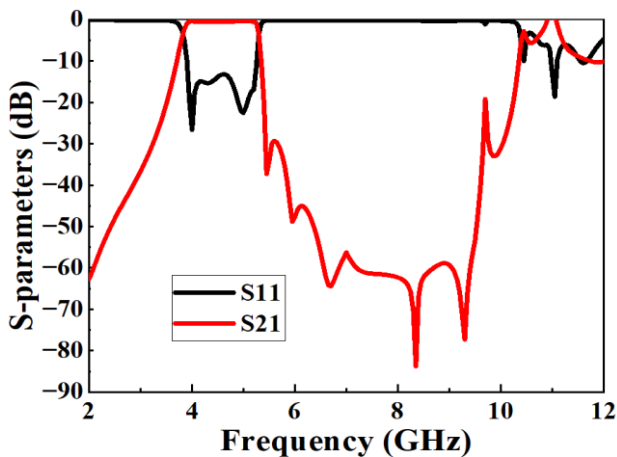


Fig. 5. The simulated output of the proposed filter

Table 2: Performance Comparison of Proposed and Existing Filters

Ref. No.	Unit type	FBW (%)	RL (dB)	IL (dB)	Size (Length X Width) ( $\lambda_g$ )
[5]	SIW	44.0	12	2	2.96 X 0.86
[7]	SIW-SSPP	57.5	>10	<1	10.3 X 0.74
[8]	SIW-SSPP	46.8	>10	<1.08	1.63 X 0.74
[10]	SIW-SSPP	44	>12	2	4.57 X 0.91
[11]	SIW-SSPP	32.0	9.42	2.0	1.17 X 0.59
<b>This work</b>	<b>SIW-SSPP</b>	<b>32.89</b>	<b>&gt;12</b>	<b>0.56</b>	<b>1.05 X 1.88</b>

\*\* FBW- Fractional bandwidth, RL- Return loss, IL- Insertion loss

When comparing the proposed work with previously published works, as shown in Table II, our filter provided a very small size and significantly improved return loss and, more importantly, insertion loss compared to the previously published works. Although the standard filter width dimension is slightly larger, the dual-layer construction actually makes it extremely difficult to implement this design

### 4. CONCLUSION

Here, a wideband microwave bandpass filter employing SIW and SSPP topologies, which is applicable to use in various millimeter-wave and microwave band circuits. First, a regular SIW structure is developed and simulated using HFSS software. Then, the parallel-arranged SSPP cuts are inserted into the SIW upper surface in order to experience the wideband bandpass features. The simulated output displayed attenuation and reflection losses of 0.56 dB and >12 dB with a 3 dB FBW of 32.89% at the center frequency of 4.56 GHz. The advised filter is very small in its size when compared to some SSPP-based published bandpass filters, as mentioned in Table II, and the filter has broad stopband rejection at 25 dB from 11.29 to 13.91 GHz as well as adequate passband qualities. At last, the constructed bandpass filter provides merits such as less attenuation loss, good reflection loss, a small footprint, and broad band response (FBW=32.89%). This filter is well matched for C-band services.

**REFERENCES**

- [1] D. Deslandes, K. Wu, "Single-substrate integration technique of planar circuits and waveguide filters." *IEEE Trans. Microw. Theor. Tech.* 51(2), 593–596 (2003).
- [2] Chen, X.P., Wu, K.: Substrate integrated waveguide filter: basic design rules and fundamental structure features. *IEEE Microw. Mag.* 15(5), 108–116 (2014).
- [3] R.S. Sangam, R.S. Kshetrimayum: Approximate design equation for iris width calculation of iris substrate integrated waveguide (SIW) bandpass filters. In: 2017 Twenty-Third National Conference on Communications (NCC), pp. 1–3. IEEE (2017).
- [4] J. B. Pendry, L. Martin-Moreno, and F. J. Garcia-Vidal, "Mimicking surface plasmons with structured surfaces," *Science*, vol. 305, no. 5685, pp. 847–848, Aug. 2004.
- [5] Surface plasmon polariton waveguides with subwavelength confinement L. Yang, P. Li, H. Wang, Z. Li *Chinese Physics B*, 2018.
- [6] D. Zhang, K. Zhang, Q. Wu, T. Jiang, A compact wideband filter based on spoof surface plasmon polaritons with a wide upper rejection band, *IEEE Photon. Techn. Lett.* 32 (2020), 1511–1514, (12).
- [7] Q. Zhang et al., "A Hybrid Circuit for Spoof Surface Plasmons and Spatial Waveguide Modes to Reach Controllable Band-Pass Filters." *Sci. Rep.* 5, 16531 (2015). [8] D. Pan et al., Wideband substrate integrated waveguide chip filter using spoof surface plasmon polariton. *Micromachines*, 13 (8), 1195, (2022).
- [8] Chen, P., et al., Hybrid spoof surface plasmon polariton and substrate integrated waveguide broadband bandpass filter with wide out-of-band rejection, *IEEE Microwave and Wireless Components Letters*, Vol. 28, No. 11, 984-986 (2018).
- [9] D. Zhang, K. Zhang, Q. Wu, T. Jiang, A compact wideband filter based on spoof surface plasmon polaritons with a wide upper rejection band, *IEEE Photon. Techn. Lett.* 32 (2020), 1511–1514, (12).
- [10] P. Chen, L. Li, K. Yang, and Q. Chen, "Hybrid spoof surface plasmon polariton and substrate integrated waveguide broadband bandpass filter with wide out-of-band rejection," *IEEE Microw. Wireless Compon. Lett.*, vol. 28, no. 11, pp. 984–986, Nov. 2018.
- [11] Y. Luo, J. Yu, Y. Cheng, F. Chen, H. Luo, A compact microwave bandpass filter based on spoof surface plasmon polariton and substrate integrated plasmonic waveguide structures, *Appl. Phys. A* 128 (1) (2022).