

PERFORMANCE ANALYSIS OF X-BAND SIW FILTENNA USING A TRANSVERSE SLOT

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Abstract : Integrated filtering and radiation structures are the results of advancements in RF front-end engineering that meet the design requirements of compactness, low insertion loss, and high performance for radar, satellite, and defense communication technologies. In traditional RF systems, the antenna and filtering elements are designed separately, resulting in increased insertion loss, larger systems, and higher design and implementation complexity. To streamline the design and fabrication of such systems, the research describes the design and implementation of an integrated SIW filter and antenna in a compact integrated sub-band system operating at the X-band. The SIW bandpass filter was the first component developed and was designed and optimized for a specific application that required a narrowband filter at X-band with good return and insertion loss performance. Second, a transverse slot was added to the top metallic layer to radiate from the filter while maintaining its filtering function. The design was then evaluated by analyzing the S-parameters, matching condition, and radiation properties of the proposed design. Furthermore, the reconfigurability of the system is discussed. Simulation results obtained using CST Studio Suite demonstrated that the proposed X-band SIW filtenna achieves compact integration of filtering and radiation functionalities with acceptable return loss, VSWR, and gain performance. This design can be implemented in microwave front end system applications like radar, satellite communication systems, and defense electronics.

IndexTerms - Substrate Integrated Waveguide (SIW), Bandpass Filter, Filtenna, Transverse Slot, Reconfigurable Antenna, RF front-end

I. INTRODUCTION

RF front-end modules for wireless communication, radar, satellite communication systems are expected to have small form factor and power consumption along with minimum insertion loss. In traditional front-end architectures, filter and antenna are realized as discrete modules which results in larger circuit footprint and additional insertion loss due to transition between filter and antenna. All these drawbacks severely limits their application potentials in size and power constrained applications like IoT devices, satellite communications systems, defense systems.

Substrate Integrated Waveguide (SIW) has emerged as a potential planar transmission line which can mimic the properties of traditional rectangular waveguide into a conventional dielectric substrate. The waveguide sidewalls are created by the metallic via-hole arrays, support dominant TE₁₀ mode propagation and offer low-loss and high-Q characteristic that are also PCB manufacturing friendly [1][2][3]

Filtenna's basically merge the filtering and radiating characteristics into a single component without the need for external filter and antenna transitions which also bring along their unwanted insertion loss. There have been several researches on SIW based filtennas at 5G mid-band[7], 6G mmWave band [1], dual-mode cavity filtenna[9]. But the compact designs of SIW filtennas at X-band with high-Q-factor is still under research because of their numerous applications at radar, satellite communications system and defense electronics.

We have designed and analyzed X-band substrate integrated waveguide (SIW) bandpass filter and filtenna with transverse slot. The key contributions of this work include: (i) systematic SIW design considering via diameter, pitch, and iris coupling optimization for X-band operation; (ii) parametric analysis demonstrating the effect of resonator dimensions and iris widths on bandwidth, resonant frequency, and insertion loss; (iii) integration of the SIW filter with a transverse slot antenna to form a compact filtenna structure, validated through full-wave simulation using CST Studio Suite; and (iv) to add power divider using stub to add reconfigurable switch for antenna and filter separately.

II. SIW DESIGN FUNDAMENTALS

The SIW is formed by two parallel rows of metallic vias connecting the top and bottom copper layers of a dielectric substrate. The structure supports the TE₁₀ mode analogously to the formation of a rectangular waveguide. The effective width of the SIW, accounting for radiation leakage through the via fence[11][13], is

$$W_{eff} = W_{siw} - \frac{d^2}{0.95p} \quad (2.1)$$

where W_{siw} is the physical SIW width, d the via diameter, and p the via pitch. To suppress leakage while maintaining fabricability, the design constraints $d < p/2$ and $p < \lambda_0/5$ must be satisfied. The guided wavelength inside the SIW is

$$\lambda_g = \frac{\lambda_0}{\sqrt{1 - \left(\frac{f_c}{f}\right)^2}} \quad (2.2)$$

The design of the proposed filter includes the key features of a bandpass filter and uses the substrate-integrated-waveguide (SIW) technology. It is 62.5 mm long and 16.5 mm wide. The SIW sidewalls in this design use arrays of metallic vias. The vias are 0.6 mm in diameter, pitched every 0.9 mm, and designed to create confinement of the electromagnetic fields in the structure while limiting the loss in the SIW. The inductive irises are 6 mm wide and placed symmetrically to control the coupling between adjacent resonators. The Rogers 3003 substrate, 1.52 mm thick, provides the design with low loss in dielectric and good performance in the microwave range.

The design of the filter was based on a half wavelength of about 9 mm. The length of the resonators was set to a practical value of 10.5 mm to account for the fringes of the fields and the irises. This consideration also accounts for the short interruptions in the structure caused by the irises and the vias, which also, of course, interrupt the structure. The SIW resonators are about half a wavelength resonators. The coupling between the resonators is set by the irises and, therefore, controls the filter's performance. These designs are set so that the filter is at the desired performance for a target X-band of frequencies.

III. DESIGN METHODOLOGY

3.1 X-Band Filter Design

The substrate footprint has an outer dimension of 62.5 mm × 16.5 mm of guided wavelength at 9.78 GHz. The via radius and pitch remained identical at 0.3 mm and 0.9 mm, respectively, ensuring consistent fabrication constraints. The dimensions of the iris and the lengths of the resonator are proportionally scaled to preserve the desired fractional bandwidth of approximately 14%.

3.2 X-Band SIW Filtenna Configuration

In the initial slot-integrated design, a transverse slot was incorporated into the top copper layer of the final SIW resonator within the X-band filter, while maintaining both Port 1 and Port 2. This two-port configuration primarily serves as a slot-loaded bandpass filter, facilitating the examination of the impact of slot integration on filter performance. The presence of Port 2 permits the analysis of transmission characteristics through the S_{11} and S_{21} parameters. Meanwhile, the introduction of the slot results in minor alterations in the resonant frequency and insertion loss due to slight energy leakage from the structure.

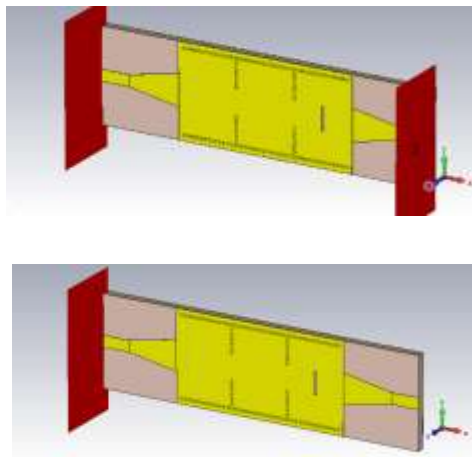


Figure 1 Filter and Filtenna with Transverse Slot

For the next filtenna configuration, Port 2 is removed, and the transverse slot replaces the output port as the radiating element. In this one-port configuration, the structure operates as an integrated filtenna, where the guided electromagnetic energy is redirected toward the radiation through the slot. This eliminates the need for a connection between the antenna and external filter, which reduces the insertion loss, shrinks the PCB, and places bandpass selectivity directly into the antenna response. The slot dimensioning was optimized to establish good impedance matching and suitable radiation at the desired X-band frequency of 9.78 GHz.

IV. RECONFIGURABLE SWITCHING ANALYSIS

Reconfigurable RF structures are integral to modern wireless and radar systems, simplifying the integration of multiple functions into a single, compact device. In the proposed X-band substrate-integrated waveguide (SIW) filtenna, reconfigurability is achieved through the use of a power divider in conjunction with switch elements, which are modeled as equivalent RLC circuits of a PIN diode. This arrangement allows the structure to operate selectively as either a bandpass filter or a radiating antenna, depending on the switching condition.

The power divider functions as a distribution network. It divides the input power into two parts: one part is used for the filter path. The other part is directed to the antenna path. By changing the switch states, the input signal can be sent to the path based on the required mode.

PIN diodes are often used as microwave switches in RF applications. They are used because they can switch fast and are easy to integrate with RF circuits. In the simulation, the PIN diode was represented using RLC parts to model its ON and OFF states. When the PIN diode is ON, it acts like a series circuit with low resistance. This allows the RF signals to pass through the path. When it is OFF, it acts like a circuit with resistance. This blocks the signal from passing through the path. This reconfigurable mechanism enhances the device's flexibility by integrating filtering and radiating operations into a single substrate integrated waveguide (SIW) platform.

This integration reduces hardware complexity, minimizes interconnection losses, and improves compactness, making it particularly suitable for X-band RF front-end applications.

Table 1 RLC Values of Reconfigurable Switches

Frequency Band	State	Resistance (R)	Inductance (L)	Capacitance (C)
X-Band	ON	10 Ω	0.4 nH	-
	OFF	3 kΩ	0.4 nH	0.015 pF

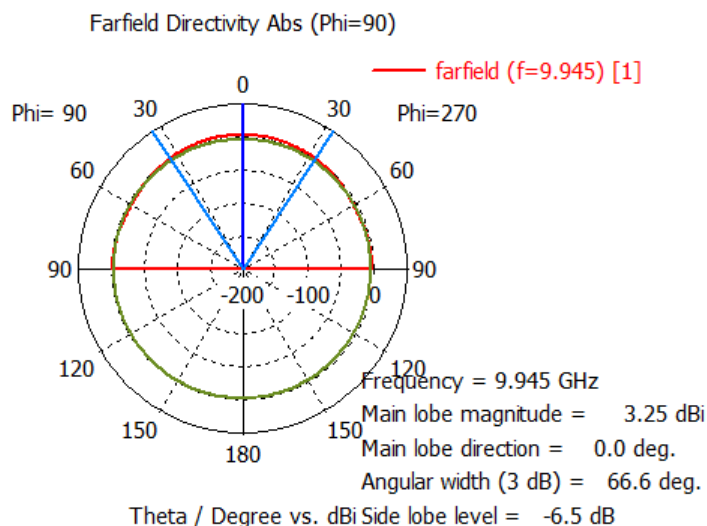
V.SIMULATION RESULTS AND DISCUSSION

5.1 X-Band SIW Filter and Filtenna Analysis

The proposed X-band substrate-integrated waveguide (SIW) structure was examined through three progressive stages: a standalone SIW bandpass filter, a slot-integrated filter, and a one-port filtenna configuration. Initially, a standalone SIW filter was designed and simulated to achieve the desired narrowband X-band response, characterized by suitable return loss, insertion loss, and bandwidth performance. The simulation results showed good impedance matching and effective frequency selectivity at the desired resonance frequency.

Next, a transverse slot was introduced on the top metallic layer while retaining both the input and output ports. In this two-port slot-integrated configuration, the structure continued to function as a filter, with only minor changes in the resonant frequency and S-parameters caused by the slot loading effect. The added slot slightly altered the electromagnetic field distribution and introduced partial radiation while maintaining the main bandpass characteristics.

In the final stage, Port 2 is removed to convert the slot-integrated filter into a one-port filtenna. This change in structure modified the termination condition and effective electrical length, leading to a shift in the resonant frequency. The resulting filtenna achieved an acceptable return loss, a VSWR below 2, and a satisfactory gain, demonstrating the successful integration of filtering and radiating functions within a single compact design.



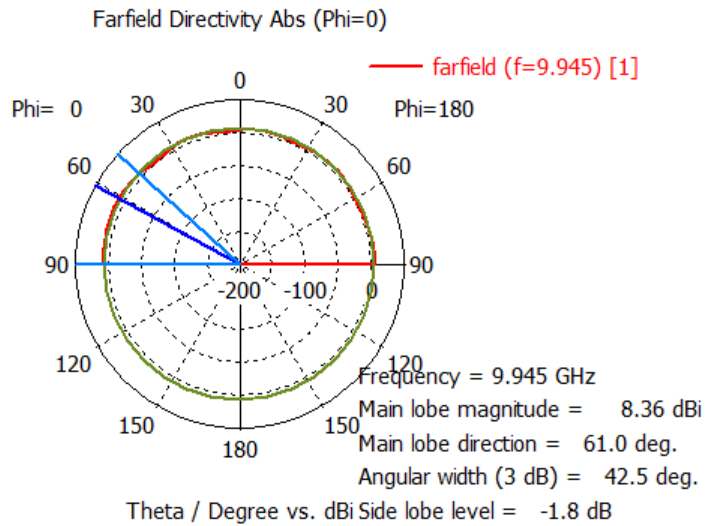


Figure 2 2D-Farfield Plot at Phi=0 and Phi=90

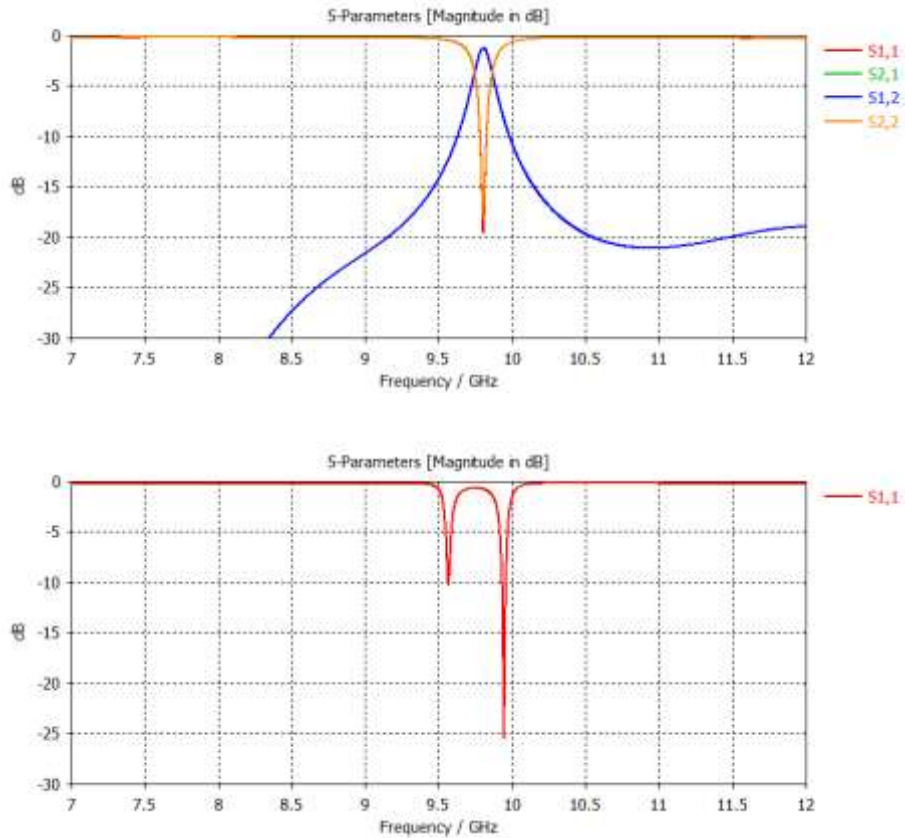


Figure 3 S-Paramater of Filter and Filtenna using slot

Table 2 Output Comparison of Filter and Filtenna

Parameter	Filter	With Port 2 (Filter + Slot)	Without Port 2 (Filtenna)
Function	Filtering unwanted frequency	Filtering analysis with slot loading	Radiation + filtering
Resonant Frequency	9.78 GHz	9.78 GHz	9.94 GHz
Return Loss (S ₁₁)	-19.5 dB	-19.5 dB	-25 dB
Insertion Loss (S ₂₁)	-1 dB	-1.5 dB	-

VSWR	-	-	1.1
Gain	-	-	6.1 dBi
Radiation	-	Minimal	Enabled

5.2 Reconfigurable Switching Analysis

When the filter branch switch is turned on and the antenna branch switch is turned off, the device functions like a bandpass filter. It does not emit much radiation. When the filter branch switch is turned off and the antenna branch switch is turned on, the signal goes to the transverse slot, which causes the antenna to emit radiation. The filter branch switch and the antenna branch switch are important because they show it is possible to put radio frequency functions into one small substrate integrated waveguide platform the filter branch switch and the antenna branch switch make this possible.

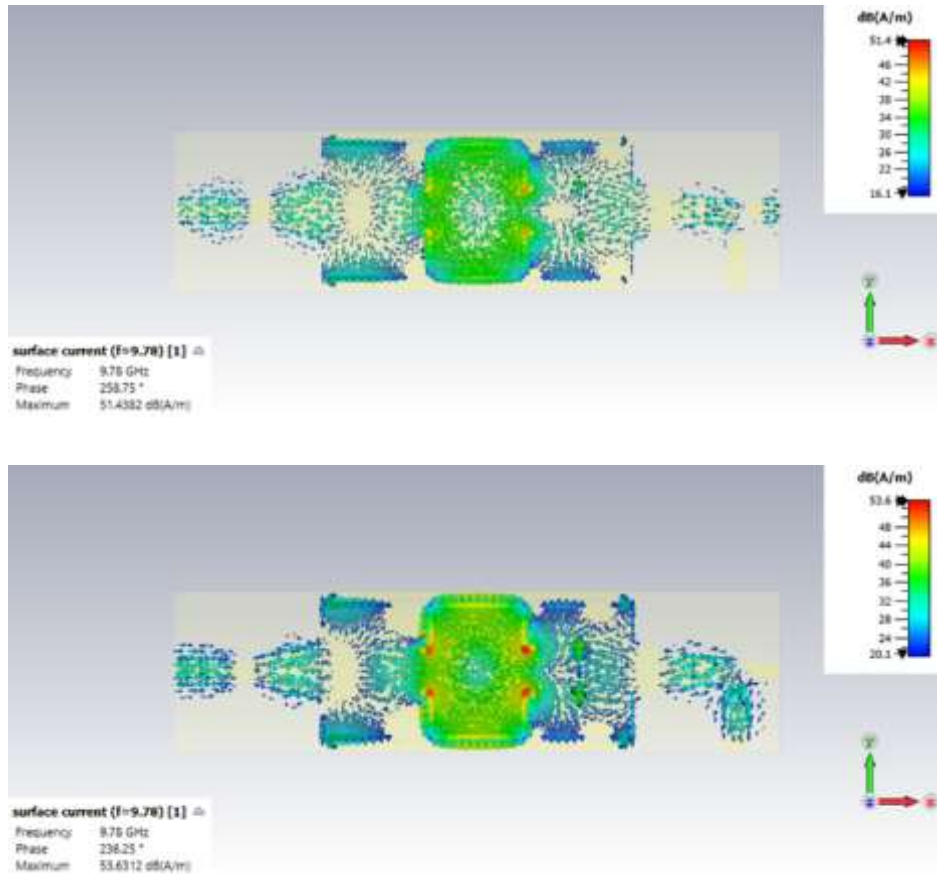


Figure 4 Surface Current Distribution of Reconfigurable Filter and Antenna

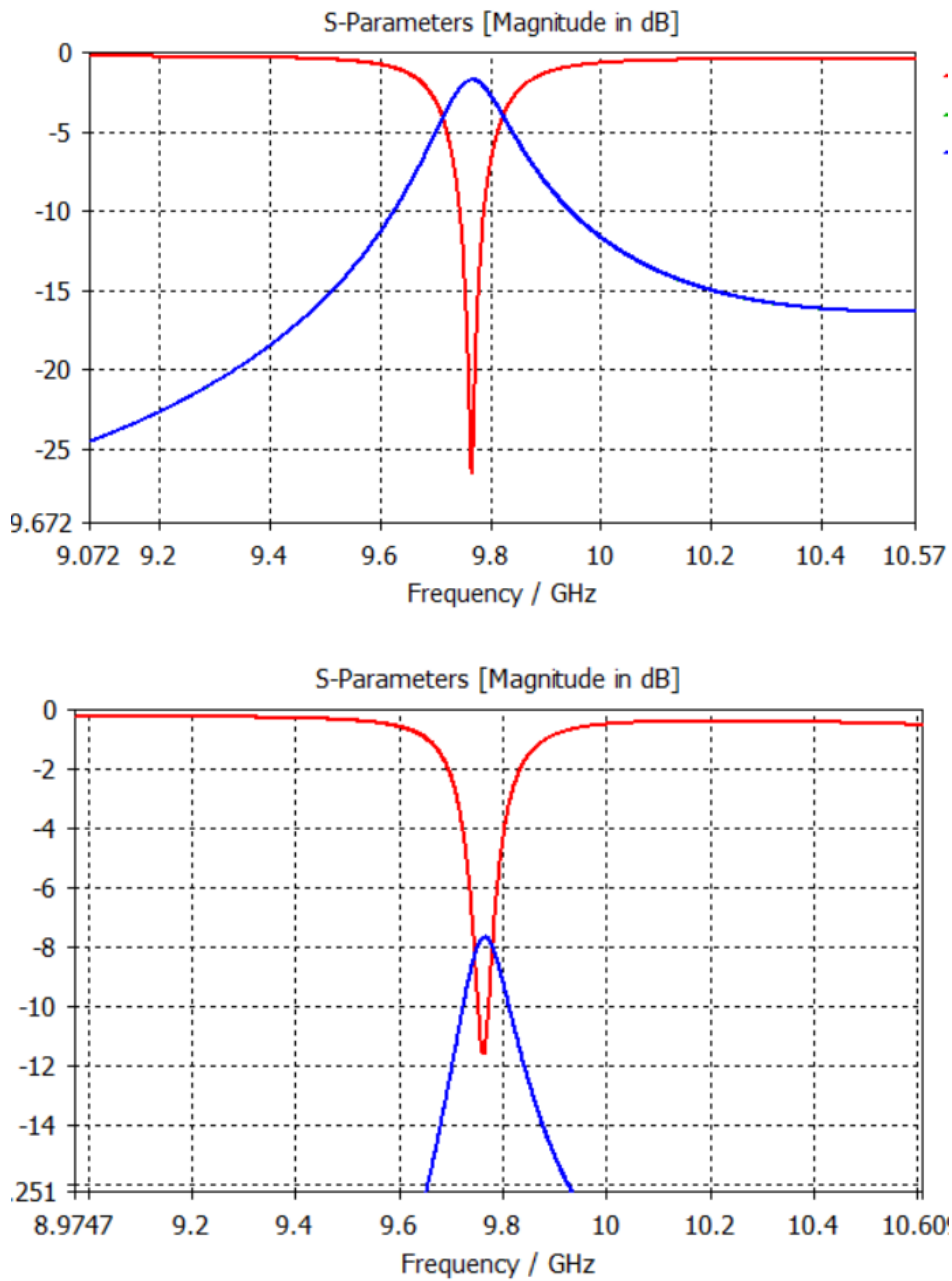


Figure 5 S-Parameter of Reconfigurable Filter and Antenna

VI. COMPARISON WITH PRIOR WORK

Table III compares the proposed design with recent SIW filter and filtenna designs reported in the literature. The proposed structure achieves competitive return and insertion losses across dual bands, with the advantage of integrating both filtering and radiation in a single compact planar layout on a low-cost Rogers 3003 substrate.

Table 3 Comparison with Prior SIW Filter/Filtenna Designs

Ref.	Topology	Band	S ₁₁ (dB)	S ₂₁ (dB)	Q-Factor
[1]	SIW Dual-Mode	13.1–13.6 GHz	-10	Not Available	Not Available
[2]	HMSIW Cross-Coupled	5 GHz	-20	-1.22	Not Available
[5]	SIW-CSRR BPF	2.36–3.88 GHz	-11	-1.5	Not Available

Ref.	Topology	Band	S ₁₁ (dB)	S ₂₁ (dB)	Q-Factor
[8]	T-W-I SIW BPF	Ku-Band	-6	-1.5	Not Available
This Work	SIW Filtenna	X-Band	-25	-	-
This Work	SIW Filter	X-Band	-19.5	-1	~65
This Work	Reconfigurable Filter	X-Band	-26	-2	~65
This work	Reconfigurable Antenna	X-Band	-11.8	-	-

VII CONCLUSION

This research involves the design along with the simulation and study of an X-band SIW-based bandpass filter and filtenna on a Rogers RT Duroid 3003 substrate. The design included the systematic optimization of resonator dimensions via parameters, iris coupling, and microstrip-to-SIW transition to facilitate efficient operation within the X-band. The simulated SIW filter showed effective filtering with an adequate return and insertion loss with an acceptable narrowband performance at the desired frequency of resonance.

To create the filtenna, which is a combination of filtering and antenna, a transverse slot was added to the SIW filter, making it a compact design. The slot-loaded design was studied in both 2-port and 1-port configurations to study the effects of loading the slot, the radiating slot on the changes of resonance, and to study the radiation. The proposed filtenna demonstrated reasonable performance for the X-band in terms of impedance matching, VSWR, and gain.

In addition, a reconfigurable switching configuration using a power divider and PIN diode equivalent RLC model was studied to enable selective operation as either a filter or antenna. Overall, the proposed SIW filtenna provides a compact, low-loss, and functionally flexible RF front-end solution for applications such as radar, satellite communications, and defense systems.

REFERENCES

- [1] S. Javadi, B. Rezaee, and W. Bösch, "SIW Dual Mode Compact Filtenna for 6G Technology," in *Proc. IEEE Future Networks World Forum (FNWF)*, 2025.
- [2] Q. Liu and L. Zhu, "Design of Cross-Coupled Bandpass Filters with Flexible Coupling via Half-Mode Substrate-Integrated Waveguide," *International Journal of RF and Microwave Computer-Aided Engineering*, vol. 34, Art. no. 3897878, pp. 1–13, 2024.
- [3] X. Wang, Y. Li, H. Li, Z.-Y. Zong, and W. Wu, "Compact Single- and Dual-Band Band-Pass Filters Employing Mixed Eighth-Mode SIW and Microstrip Line Resonators," *IET Microwaves, Antennas & Propagation*, vol. 17, pp. 190–199, 2023.
- [4] R. Li, Y. He, C. Song, and W. Li, "A SIW-Based High Gain Wideband Filtering Antenna for 5G mmWave Application," in *Proc. IEEE Asia-Pacific Conference on Antennas and Propagation (APCAP)*, 2024.
- [5] J. Haidi and A. Munir, "Performance Characteristics of SIW-Based BPF with Square-Shaped CSRR Incorporation," in *Proc. IEEE APS/USNC-URSI*, 2023, pp. 799–800.
- [6] V. Alagumurugesan *et al.*, "Design and Analysis of a Slotted Rectangular Patch Antenna for Dual-Band Radar Applications in C and X Bands," in *Proc. International Conference on Communication, Computing and Electronics Systems (ICCES)*, 2024, pp. 88–93.
- [7] Z. El Ouali *et al.*, "Design, Simulation, and Fabrication of a Cheap Low-Profile Filtenna for 5G Mid-Band Applications," in *Proc. IEEE Future Networks World Forum (FNWF)*, 2024, pp. 254–259.
- [8] J. K. Paul, S. Moitra, and P. S. Bhowmik, "Control of Insertion Loss in SIW Band-Pass Filter Using New Tapered Waveguide Iris Technique," *Electrica*, vol. 24, no. 1, pp. 256–264, 2024.
- [9] A. Altyinnikov *et al.*, "Design of a Compact Unified SIW Cavity Filtenna Module for Antenna Array Application," *Micromachines*, vol. 16, no. 3, p. 285, 2025.
- [10] S. Wang, J. Liu, and X. Zhang, "Bandwidth-Controllable Third-Order Band Pass Filter Based on Substrate-Integrated Waveguide (X-Band)," *Micromachines*, vol. 14, no. 7, pp. 1–13, 2023.
- [11] C. Xu, P. Li, B. Peng, C. Gu, and K. Wu, "Dispersion Characteristics of Substrate Integrated Rectangular Waveguide," *IEEE Microwave and Wireless Components Letters*.
- [12] A. O. Nwajana and E. R. Obi, "A Review on SIW and Its Applications to Microwave Components," *Microwave and Wireless Communications*, 2022.
- [13] Deslandes D, Wu K. Review of substrate integrated waveguide circuits and antennas. *IET Microw Antennas Propag*. 2010
- [14] Darling J S, Guruviah V, Dwivedi RP. SIW technology for 5G antenna applications and beyond: A critical review. *Int J Commun Syst*. 2024.
- [15] Michalkiewicz ML, Mariano AA, Dartora CA. Bandpass filter using SIW technology in inductive window topology with low-cost substrate FR-4. *J Microw Optoelectron Electromagn Appl*. 2022.

- [16] Otmani A, Rahali B, Abdeldjelil A, Belkacem H. The design of filter based on substrate integrated waveguide with symmetrical inductive iris. In: Proc Int Symp Signal Image Video Commun.
- [17] Darbandi H, Neshati MH. Input impedance of rectangular substrate integrated waveguide cavity-backed slot antennas. In: Proc ICEE.
- [18] Keltouma N, Mehdi D. Design of substrate integrated waveguide single longitudinal slot antenna. Int J Eng Res Technol (IJERT).
- [19] Gul T, Aslam B. Design and analysis of SIW iris bandpass filters for Ku-band applications. In: Proc Int Conf Emerging Technologies (ICET). 2024.

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