

Band-Pass Filter with Coupled Corrugations and Plated through Holes for C and X Band Applications

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ABSTRACT: A miniaturized microstrip band-pass filter (BPF) with coupled corrugations and plated through holes (PTHs) in the source-load coupling path is designed and fabricated. The proposed filter provides a wide passband at 8.2 GHz. The surface current distributions of the proposed filter are depicted to verify its performance. The proposed filter indicates that the insertion loss is 1.1 dB, and the peak return loss is 36.27 dB at 10 GHz. The proposed filter operates in the wide range of 6.5–10 GHz, which covers both C and X band applications, such as satellite communications, military, and radar systems. The compact size, wide passband, low insertion loss, and high attenuation levels in the stopbands are some of the features of the proposed filter. In addition, the simulated results are validated using measurements.

1. INTRODUCTION

Microwave filters play an important role in various aspects of modern communication systems, and there has been an emerging emphasis on the development of miniaturized, wide-band, and advanced microwave systems. There is a demand for compact and high-performance band-pass filters. Recently, an array of metallized vias has been adopted [1] to design high-performance filters because of its low cost, light weight, compactness, high Q-factor, and easy integration with planar microwave circuits in various filter designs [2–5].

In [6], undesired radiations that affect band-pass filter performance are eliminated using metallized vias. Additionally, grounded via holes in conventional substrates are very suitable for realizing resonators that occupy less space than conventional waveguides [7] and effectively reduce the insertion loss by eliminating the surface waves of the filter [8].

Next, corrugations were introduced to suppress multi-spurious radiations in the stopband in [9] and [10]. Furthermore, corrugated coupled microstrip lines were introduced as building blocks for constructing parallel coupled-line filters, which also discussed that a corrugated coupled section is shorter than that of a flat line section with the frequency response having effective harmonic suppressions in [11]. Thus, plated through holes (PTHs) can be used to effectively suppress the in-band radiation, whereas the corrugated coupled lines can be used to suppress the out-of-band radiation.

This paper presents a compact microstrip band-pass filter operating at 8.2 GHz using coupled corrugations and PTH in the source-load path. The proposed filter comprises a corrugated

coupled feed path that couples the signal from the input source port to the output load port and a central rectangular cavity to introduce a pair of transmission zeros. All unwanted radiation from the filters is eliminated by an array of metallized vias distributed throughout the proposed band-pass filter structure.

2. DESIGN AND ANALYSIS

2.1. Geometry of the Band-Pass Filter with PTH

Figure 1 shows the geometry of the proposed band-pass filter with coupled corrugations and plated-through holes. The corrugations in the coupling path from the source to the load effectively suppress multi-spurious radiation in the stopband, whereas the array of metallized vias eliminates the undesired radiation in the filter. The specifications of the designed filter include a center frequency (f_0) of 8.2 GHz with 3-dB fractional bandwidth (Δ) of 43%. The filter is designed on an FR4 substrate with a dielectric constant $\epsilon_r = 4.3$, loss tangent $\tan \delta = 0.0025$ and thickness of 1.6 mm. The proposed band-pass filter is simulated using Computer Simulation Technology (CST) Microwave Studio.

2.2. Evolution of the Proposed BPF

The BPF design was designed to evaluate the miniaturization offered by the proposed filter stage. The evolution of the BPF is shown in Figure 2. In the first stage, the BPF consists of a symmetric L-shaped feed path that couples the signal from the source port to the load port, a pair of symmetric inverted L-shaped coupling paths, and a center rectangular coupling patch. The inter spacing of each structure was set to 0.2 mm. The filter provides a band-pass response at 11.72 GHz with an insertion

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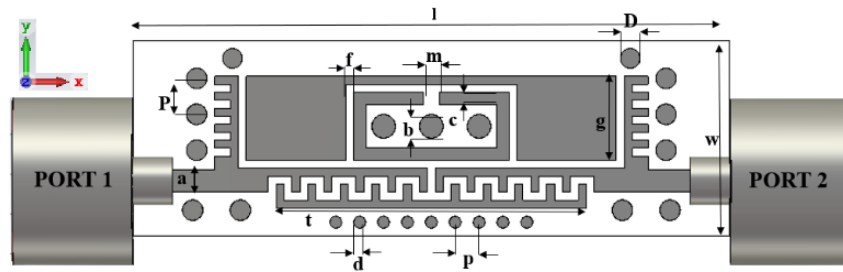


FIGURE 1. Geometry of proposed band-pass filter (BPF) with coupled corrugations and plated through holes ($l = 15$ mm, $w = 4.9$ mm, $d = 0.3$ mm, $p = 0.6$ mm, $D = 0.52$ mm, $P = 1$ mm, $k = 0.2$ mm, $a = 0.76$ mm, $b = 0.6$ mm, $c = 0.3$ mm, $g = 1.9$ mm, $f = 0.2$ mm, $m = 0.4$ mm, $t = 7.8$ mm).

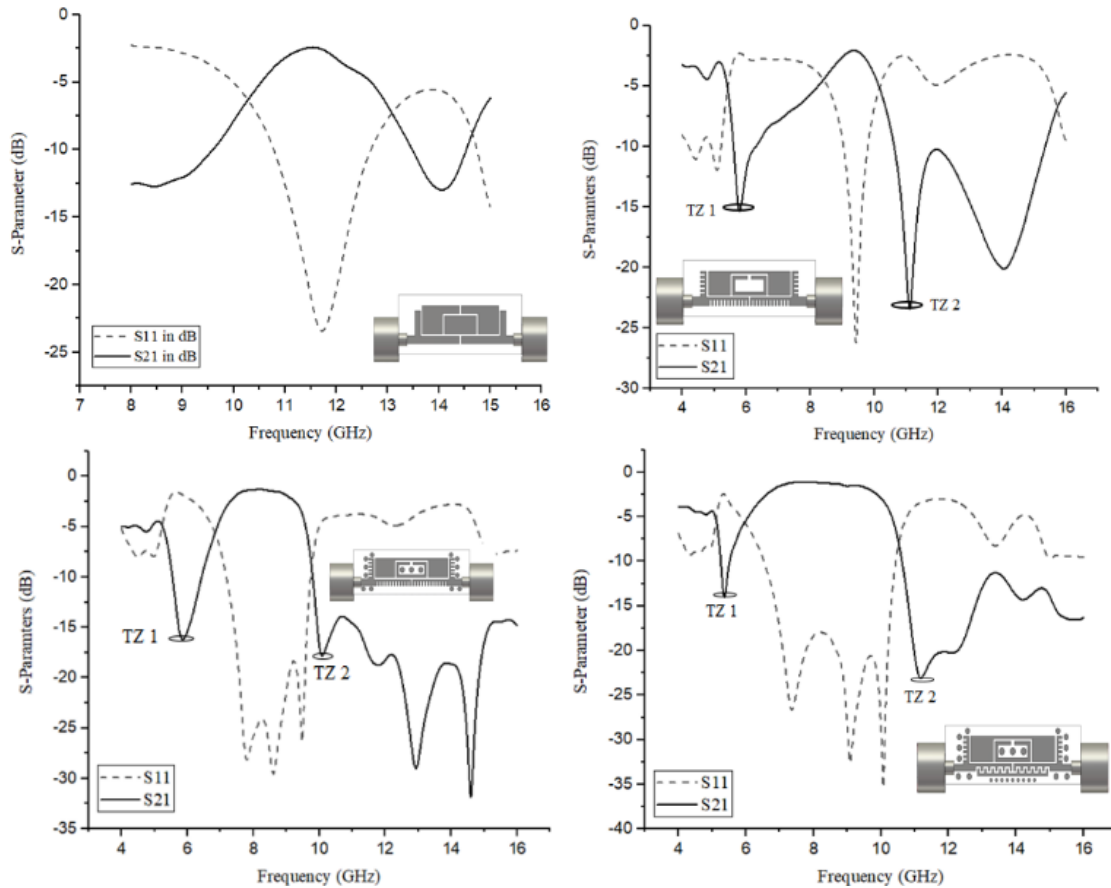


FIGURE 2. Evolution of the proposed miniaturized BPF in each stage with its reflection (S_{11}) and transmission (S_{21}) characteristics.

loss of 2.56 dB and a 3-dB bandwidth of 0.9 GHz. The second stage design includes a corrugated structure of 0.5 mm tooth depth in the symmetric L-shaped coupling path and a rectangular cavity of width 3.3 mm at the center to create a pair of Transmission Zeros (TZs) in the BPF response. The filter provides a band-pass response at 9.4 GHz with an insertion loss of 2.1 dB and 3-dB bandwidth of 0.9 GHz. A pair of TZs was obtained at $0.6f_0$ and $1.2f_0$.

In the third stage design, with the same filter configurations as mentioned earlier, metallized vias are drilled into the substrate in the structure of the modified filter. The vias are introduced to arrest unwanted radiation in the proposed BPF structure. The filter provides a wide band-pass response at a center frequency of 8.2 GHz with a reduced insertion loss of 1.3 dB

and a wider 3-dB bandwidth of 2.2 GHz. In addition, a pair of TZs is obtained at $0.7f_0$ and $1.2f_0$. The fourth stage design incorporates an array of metallized vias drilled into the substrate below the corrugated coupling path to arrest the undesired radiation from the filter. The filter provides a wide band-pass response at a center frequency of 8.2 GHz with a reduced insertion loss of 1 dB and a wider 3-dB bandwidth of 3.54 GHz. In addition, a pair of TZs is obtained at $0.7f_0$ and $1.4f_0$.

2.3. Analysis of Parametric Sweep

A study of varying some parameters in the design of the proposed band-pass filter is performed, which is tabulated in Table 1. When the diameter (D) of the metallized vias is increased

TABLE 1. Parametric sweep results.

Varying Parameters	Dimensions (mm)	Varying Results
Diameter of via (D)	0.26	IL = 1.1 dB
	0.52	IL = 3.0 dB
	1	IL > 3.0 dB
Perturbation length (m)	0.4	BW = 3.5 GHz
	1.4	BW < 3.5 GHz
	2.4	BW < 3 GHz

Note: IL: Insertion Loss; BW: Bandwidth.

from 0.26 to 1 mm, the effective insertion loss of the proposed filter tends to increase to 3 dB or even more. In addition, when the perturbation length (m) of the center rectangular cavity is varied, the overall bandwidth of the proposed filter decreases from 3.5 GHz with some spurious radiation in the pass band. Hence, in-band radiation is eliminated by choosing the diameter of the via as 0.26 dB with a wideband bandwidth of 3.5 GHz by having the perturbation length of $m = 2.4$ mm. With these parametric studies, the performance of the band-pass filter can be achieved as desired.

Corrugations are introduced in the coupling path of the band-pass filter to suppress spurious emissions in the stopband and improve the bandwidth of the proposed filter [12]. In addition, an array of metallized vias is introduced around the filter to arrest the undesired radiation from the sharp edges and corners of the microstrip corrugated coupled path.

2.4. Theoretical Analysis

The proposed BPF follows the fundamental or center frequency (f_0) equation given by (1), using the length (l) of the resonator from source to load and the effective dielectric constant (ϵ_{eff}) of the substrate.

$$f_0 = \frac{c}{2l\sqrt{\epsilon_{eff}}} \quad (1)$$

According to the theory of corrugation in [13] and [14], the dimensions of the corrugated path are obtained, which include teeth width $t_w = 0.2$ mm, tooth pitch $t_p = 0.4$ mm, and tooth depth $t_d = 0.5$ mm at the centre frequency and are given by (2) and (3),

$$\frac{t_w}{\lambda_0} \leq 0.1 \quad (2)$$

$$\frac{t_w}{t_p} \geq 0.5 \quad (3)$$

where λ_0 is the free space wavelength. With these specifications, the proposed filter is designed and fabricated and proves its validation for the theory.

3. RESULTS AND DISCUSSIONS

The miniaturized BPF with PTH provides a bandwidth of 5 GHz at -10 dB reference level as shown in Figure 3, ensuring that the proposed filter is suitable for various high-performance

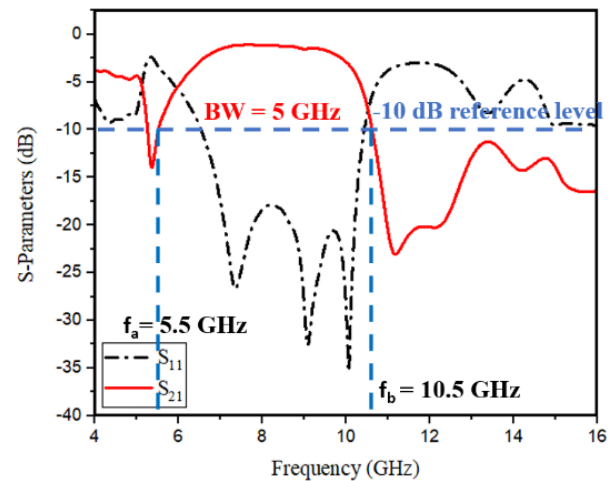


FIGURE 3. Transmission characteristics with 5 GHz bandwidth at -10 dB reference level; f_a and f_b — Lower and Upper Cut-off Frequency.

systems [15]. The surface current distribution of the proposed band-pass filter is shown in Figure 4. The surface current is an electric current induced by an applied electromagnetic field. The electric field pushes the charges around. There is a shift in the charges around the atoms. When the charges are displaced as mentioned, the material is said to be polarized. Resonant arms with high-surface current densities are denoted by red, and those with low-surface current densities are denoted by blue. It can be observed from the figure that the high-density current is distributed through the corrugated coupled line and also through the center rectangular cavity. Moreover, because the metallized vias arrest undesired radiation, a very low-density current is observed on each via.

The group delay of the proposed BPF is shown in Figure 5. The group delay lies within 1.5 nS throughout the passband, and when the out-of-band transition occurs, the group delay peaks up to 5.8 nS, ensuring the high selectivity [16] of the proposed BPF.

The simulated S_{21} and S_{11} of the proposed band-pass filter with PTH and coupled corrugations are observed such that the insertion loss (S_{21}) is 1.1 dB for the bandwidth of 6.5–10 GHz. The worst return loss (S_{11}) within the passband is 17 dB at 8.2 GHz and with a peak return loss of 36 dB at 10 GHz. The fractional bandwidth (Δ) of the proposed filter is 43% which covers a part of the C and X band frequency ranges.

The proposed filter also ensures a pair of transmission zeros of 15 dB at 4.8 GHz and 25 dB at 11.2 GHz. The selectivity of the filter is improved by these transmission zeros around the passband, which are obtained by introducing a rectangular cavity in the center of the filter with perturbation $m = 0.4$ mm. It is observed that there is a reduction in in-band radiation throughout the 3-dB bandwidth of the S_{21} response curve. In addition, there is a trade-off between the number of transmission zeros and the insertion loss of the proposed band-pass filter.

A prototype of the proposed band-pass filter is fabricated, as shown in Figure 7, with a miniaturized dimension of 15 mm (length) \times 4.9 mm (width) \times 1.67 mm (height). A comparison of the measured and simulated insertion losses of the proposed

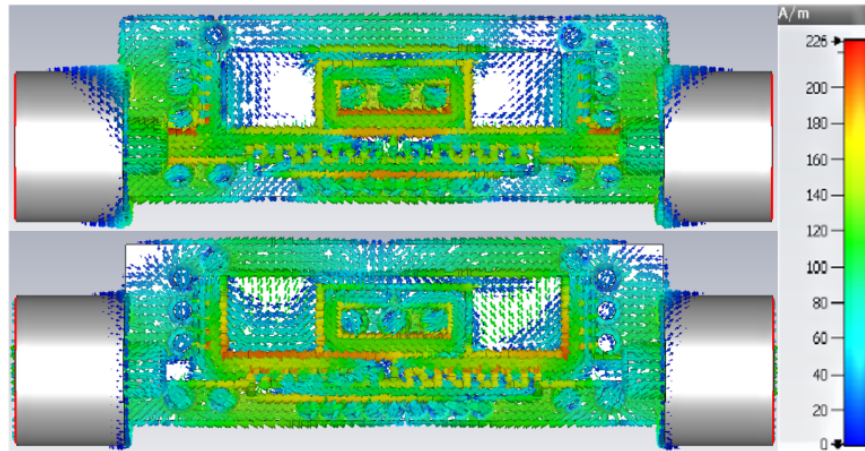


FIGURE 4. Simulated surface current distributions of proposed filter at 8.2 GHz in the rectangular resonator (top) and in the coupled corrugation path (bottom).

TABLE 2. Performance comparison with other BPFs.

Reference	CFs (GHz)	ILs (dB)	Δ (%)	Size (mm ²)	Miniaturization Methodology
[1]	10.19	1.58	5.6	214 × 214	Mixed Mode Cavities and folded TE method
[4]	3.55	1.4	14.3	15.9 × 25.9	SIW and Interdigital filter
[6]	6.97	2.28	3.61	15.06 × 15.06	Triple mode ridge SIW
[17]	3.07	2.77	16.28	47.8 × 48.6	Half-mode SIW and Multimode resonator
[18]	4.5	2.2	20	2.1 × 1.32	Circular SIW with mixed coupling topology
[19]	10	2.3	10	14.8 × 10.8	Integrated Passive Device
[20]	11.51	1.42	6.78	23.46 × 14.6	SIW and Microstrip line resonators
This work	8.2	1.1	43	15 × 4.9	SIW and Coupled Corrugations

CFs: Center Frequencies; ILs: Insertion Losses; Δ : Fractional Bandwidth.

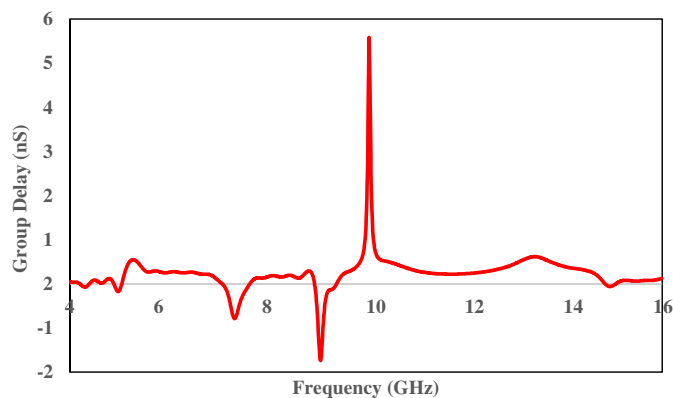


FIGURE 5. Group delay characteristics of the BPF.

filter is shown in Figure 6. The filter provides a wide bandwidth of 6.5–10 GHz with a 10 dB reference level of return loss. In addition, a comparison of the simulated and the measured return losses of the filter is depicted in Figure 7. A wider bandwidth is achieved with reduced insertion loss and maximum return loss, as simulated, and the small deviation in the measurements is attributed to the connector and fabrication losses. Hence, the measured results are in agreement with the simulated results.

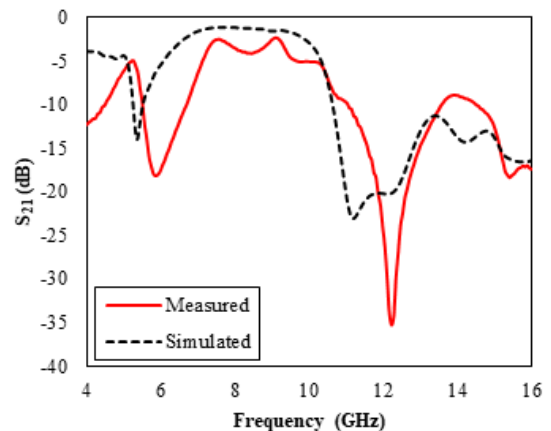


FIGURE 6. Comparison of simulated and measured insertion losses of the proposed band-pass filter.

Table 2 lists the comparison of the proposed band-pass filter using coupled corrugations and plated through holes with the state-of-the-art. The proposed filter exhibits a miniaturized design with a lower insertion loss and a wider bandwidth.

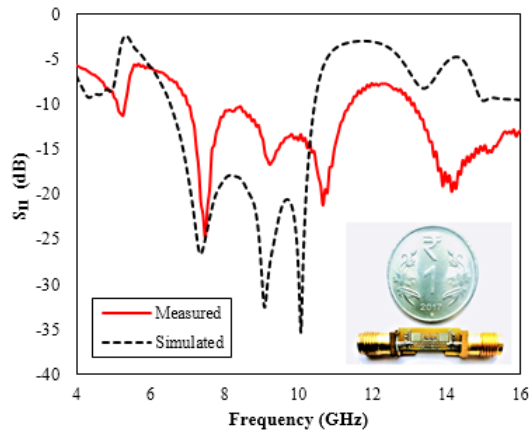


FIGURE 7. Comparison of simulated and measured return losses of the proposed band-pass filter and (inset) Fabricated prototype of the proposed band-pass filter.

4. CONCLUSION

A compact microstrip band-pass filter with a wide bandwidth and low insertion loss using coupled corrugations and plated-through holes is proposed. The proposed filter provides an insertion loss of 1.1 dB, a fractional bandwidth of 43%, high selectivity with a maximum return loss of 17 dB at 8.2 GHz, and a peak loss of 36 dB at 10 GHz. The proposed filter configuration with corrugations and plated-through holes in the coupling path from the source to the load is analyzed and provides a wider bandwidth in the range of 6.5–10 GHz, covering both C- and X-band applications. These features make the proposed filter attractive for satellite and radar systems.

REFERENCES

- [1] Jiao, M. R., L. F. Sun, X. Zhao, F. Zhu, W. Yu, P. Chu, K. Zhou, and G. Q. Luo, "Miniaturized dual-mode substrate integrated waveguide bandpass filters with wide stopbands using mixed-mode cavities," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 73, No. 11, 9217–9225, Nov. 2025.
- [2] Ganaraj, P. S., K. Guha, M. Kavicharan, J. Iannacci, M. Donelli, and K. S. Rao, "Design and analysis of piezoelectric MEMS actuator based SIW filter for K/Ka band communication," *Microsystem Technologies*, Vol. 31, 3569–3578, 2025.
- [3] Gupta, A. and A. A. Khan, "Substrate integrated waveguide bandpass filter with wide upper stopband," *AEU – International Journal of Electronics and Communications*, Vol. 191, 155663, 2025.
- [4] Sood, S., V. Niranjana, and V. Sachan, "Miniaturized SIW interdigital bandpass filter with unsymmetrical resonators for 5G," *Sādhanā*, Vol. 50, No. 3, 134, 2025.
- [5] Vinodha, E., "A broadband low profile SIW cavity-backed antenna loaded with hexagonal and rectangular slots for 'X' band application," *Analog Integrated Circuits and Signal Processing*, Vol. 118, No. 2, 307–315, 2024.
- [6] Jiao, M. R., F. Zhu, P. Chu, W. Yu, and G. Q. Luo, "Compact hybrid bandpass filters using substrate-integrated waveguide and stripline resonators," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 72, No. 1, 391–400, Jan. 2024.
- [7] Liu, Q., H. Qian, D.-W. Zhang, K. Gong, and Q.-K. Liu, "Compact highly-selective bandpass filter based on triple-mode ridge substrate integrated waveguide cavity," *IEEE Microwave and Wireless Technology Letters*, Vol. 33, No. 9, 1274–1277, Sep. 2023.
- [8] Liu, X., N. Liu, C. Fan, Y. Liu, Y. Yang, and Z. Zhu, "SIW bandpass filter with wide stopband using harmonic interleaving and orthogonal transmission techniques," *IEEE Transactions on Components, Packaging and Manufacturing Technology*, Vol. 12, No. 11, 1841–1848, Nov. 2022.
- [9] Song, W., Z. Yi, and L. Wang, "Millimeter-wave substrate-integrated corrugation-loaded H-plane horn antenna with beamwidth and back radiation suppression," *IEEE Antennas and Wireless Propagation Letters*, Vol. 22, No. 10, 2402–2406, Oct. 2023.
- [10] Kuo, J.-T., W.-H. Hsu, and W.-T. Huang, "Parallel coupled microstrip filters with suppression of harmonic response," *IEEE Microwave and Wireless Components Letters*, Vol. 12, No. 10, 383–385, Oct. 2002.
- [11] Zhang, X. and F. Xu, "A novel wideband bandpass corrugated substrate integrated waveguide filter combining EBG structure and DGS," in *2021 International Conference on Microwave and Millimeter Wave Technology (ICMMT)*, 1–3, Nanjing, China, 2021.
- [12] Manafi, S., M. A. Al-Tarifi, and D. S. Filipovic, "Isolation improvement techniques for wideband millimeter-wave repeaters," *IEEE Antennas and Wireless Propagation Letters*, Vol. 17, No. 2, 355–358, Feb. 2018.
- [13] Balanis, C. A., *Antenna Theory: Analysis and Design*, John Wiley & Sons, 2016.
- [14] Vala, A. D., A. Patel, K. Mahant, J. Chaudhari, H. Mewada, and E. M. Ali, "Corrugated SIW based bandpass filter for microwave interferometer and ISM band application," *Progress In Electromagnetics Research C*, Vol. 108, 137–146, 2021.
- [15] Wang, L., X. Yao, S. Sun, T. Du, M. Cui, X. Chen, D. Li, X. Bi, L. Qian, C. Li, and Y. Xiong, "Design of a wideband bandpass filter with quarter wavelength triple parallel line," *Microsystem Technologies*, Vol. 31, No. 11, 3351–3359, 2025.
- [16] Malki, M., L. Yang, J.-M. Muñoz-Ferreras, and R. Gómez-García, "All-frequency-two-port-quasi-absorptive planar bandpass filter with quasi-flat group delay and multi-transmission-zero extended stopbands," *IEEE Microwave and Wireless Technology Letters*, Vol. 33, No. 12, 1611–1614, Dec. 2023.
- [17] Xie, W.-B., Y.-H. Ma, D.-W. Wang, C.-H. Yu, Y. Hu, and W.-S. Zhao, "Compact single-and dual-band balanced high-selectivity bandpass filters based on microstrip resonator loaded substrate integrated waveguide," *IEEE Transactions on Electromagnetic Compatibility*, Vol. 67, No. 5, 1629–1633, Oct. 2025.
- [18] Wang, X., N.-Y. Zhong, H. Li, J.-Y. Chu, H. Yang, X.-L. Yang, X.-W. Zhu, and W. Wu, "Miniaturized circular substrate integrated waveguide bandpass filter with flexible mixed coupling and wide stopband rejection," *IEEE Transactions on Circuits and Systems II: Express Briefs*, Vol. 71, No. 8, 3655–3659, Aug. 2024.
- [19] Zhou, C., S. Zhang, S. Fu, W. Wang, and Y. Guo, "Ultracompact bandpass filter with multiple transmission zeros and low insertion loss," *IEEE Transactions on Components, Packaging and Manufacturing Technology*, Vol. 14, No. 7, 1240–1253, Jul. 2024.
- [20] Lin, G. and Y. Dong, "A compact, hybrid siw filter with controllable transmission zeros and high selectivity," *IEEE Transactions on Circuits and Systems II: Express Briefs*, Vol. 69, No. 4, 2051–2055, Apr. 2022.