Ziyu ZHOU, Gang DONG, Xinqing LEI, Zhangming ZHU, 2025. Miniaturized diplexer with wide-stopband based on half-mode substrate integrated waveguide. *Frontiers of Information Technology & Electronic Engineering,* 26(7):1237-1242. https://doi.org/10.1631/FITEE.2400944

# Miniaturized diplexer with wide-stopband based on half-mode substrate integrated waveguide



**Key words:** Diplexer; Substrate integrated waveguide (SIW); Miniaturization; Half-mode; Wide-stopband; Intrinsic modes; Suppression technique

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# Motivation

1. Due to the significant impact on wireless communication systems, the trend in diplexer design focuses on wide-stopband performance, high isolation, low insertion loss, and miniaturization.

2. In a conventional design, T-junctions are used in diplexers to separate two passbands. Many studies aim to minimize the circuit size by eliminating T-junctions. Nevertheless, both multi-layer technology and folded SIW increase the design complexity and manufacturing costs.

3. Building on the topology that combines DMR and SMRs, various techniques have been implemented to achieve wide-stopband SIW diplexers without T-junctions. However, in these studies, since the $TE_{202}$ mode in the SMRs is not completely suppressed, the boundary of the stopband is limited to around $2f_1$.

# Main idea

1. Using half-mode substrate integrated rectangular cavities (HMSIRCs) as DMR and SMRs overcomes the limitations of SMRs on the miniaturization and wide-stopband performance.

2. The $TE_{202}$ mode is effectively eliminated from SMRs as the specific even modes in HMSIRC are not excited due to magnetic walls in the symmetry plane. The $TE_{102}$ mode is suppressed. Therefore, the diplexer can obtain a wider stopband only through second-order resonance.

3. The usage of HMSIRCs, coupled with a reduced number of resonators, further minimizes the circuit size.

# Method

1. To eliminate T-junctions, the diplexer combines a dual-mode resonator (DMR) with single-mode resonators (SMRs). The employment of HMSIW technology breaks through the limitations of SMRs on miniaturization.



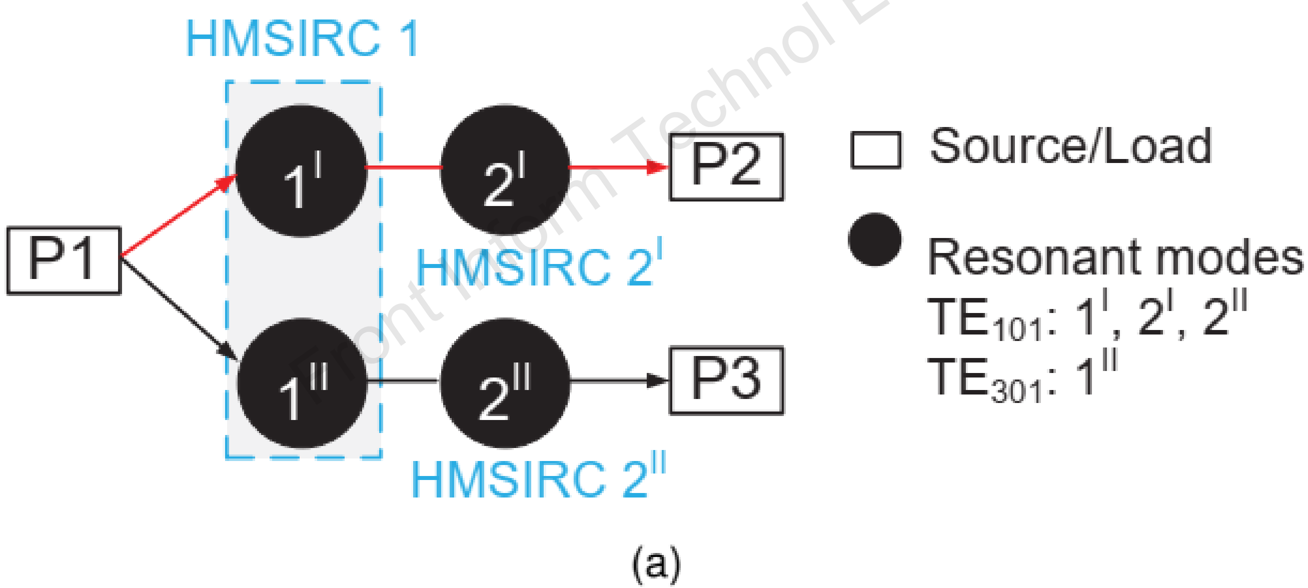


**Fig. 2 Proposed SIW diplexer based on HMSIRCs: (a) coupling topology**

# Method

2. To achieve wide-stopband, the third mode in DMR and the second mode in SMRs should be suppressed. The second mode in SMRs is the $TE_{102}$ mode. Due to the inhibition of the $TE_{102}$ mode in SMRs, the first unsuppressed mode in SMRs is the $TE_{301}$ mode, which specifies the stopband boundary of the diplexer. Consequently, the stopband of the proposed diplexer can be extended to $2.236f_1$ at most.



**Table 1** Cases of higher-order mode characteristics of half-mode substrate-integrated rectangular cavity (HMSIRC) with different $W/L$ values

| | Case 1 [1, 1.633] | Case 2 [1.633, 2.828] | Case 3 [2.828, +∞) |
|---|---|---|---|
| 1st mode | $TE_{101}$ | $TE_{101}$ | $TE_{101}$ |
| 2nd mode | $TE_{102}$ | $TE_{301}$ | $TE_{301}$ |
| 3rd mode | $TE_{301}$ | $TE_{102}$ | $TE_{501}$ |
| $f_2^r/f_1^r$ | [1.581, 1.784] | [1.374, 1.784] | (1, 1.374] |
| $f_3^r/f_1^r$ | [1.784, 2.236] | [1.172, 1.837] | (1, 1.914] |

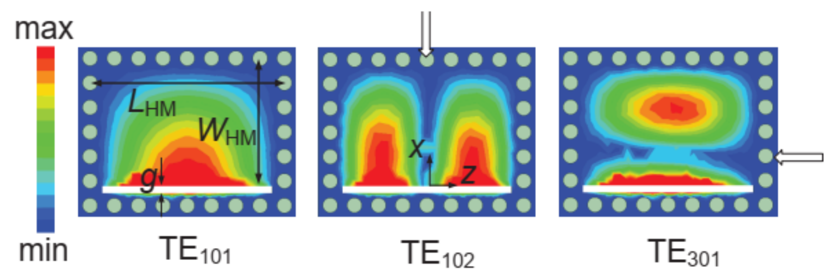


**Fig. 1** Electric field magnitude distributions of $TE_{101}$, $TE_{102}$, and $TE_{301}$ modes in a half-mode substrate-integrated rectangular cavity (HMSIRC). $W_{HM}$ and $L_{HM}$ denote the width and length of the HMSIRC, $g$ is the width of the gap on the metal layer

# Major results

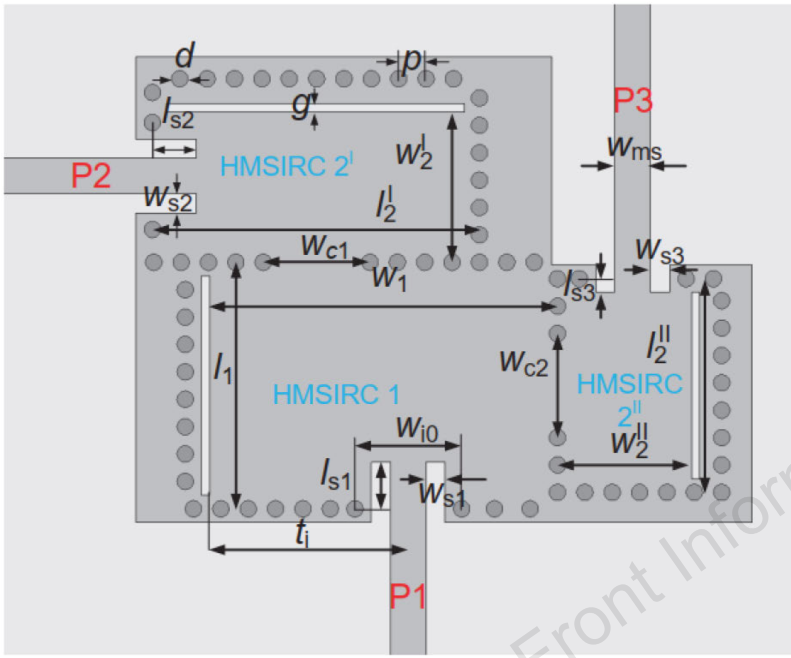


Fig. 2 (b) Geometric configuration

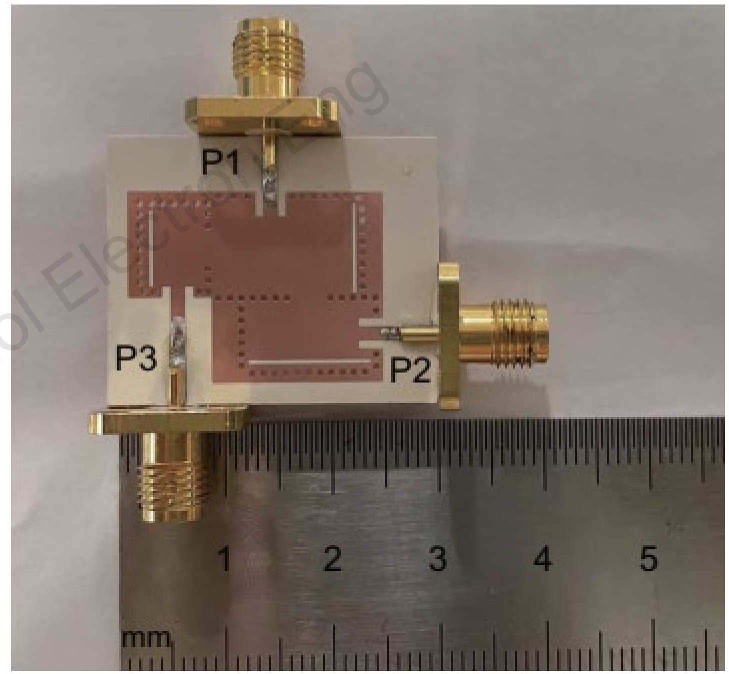


Fig. 5 Photograph of the fabricated prototype

# Major results

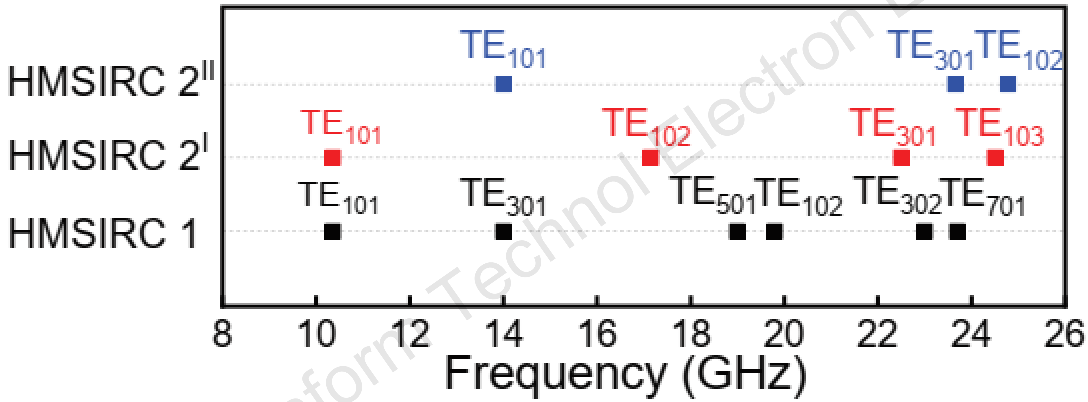


**Fig. 7 Frequency spectrum of the initial resonances for the HMSIRCs in the proposed diplexer**

# Major results

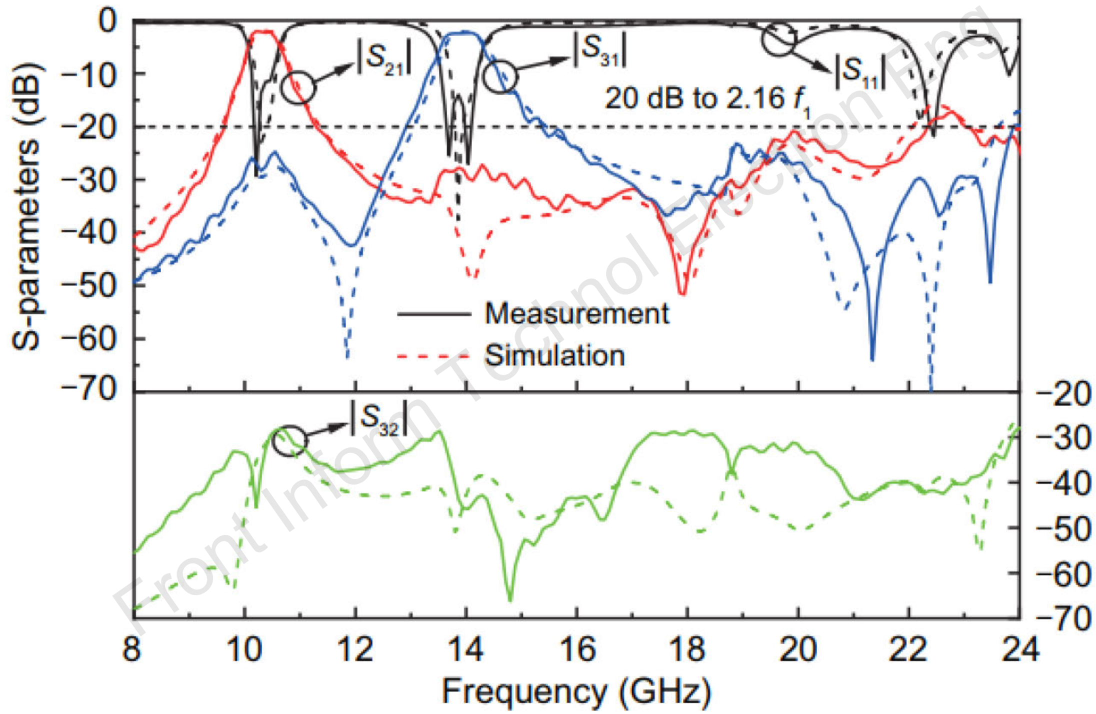


**Fig. 4 Comparison between the simulation and measurement results of the proposed diplexer**

# Major results

**Table 3 Comparison with other reported SIW diplexers**

| Reference | Order | $f_1/f_2$ (GHz) | -3 dB bandwidth/ FBW (%) | Isolation (dB) | Rejection/ Stopband | IL (dB) | Size ($\lambda_g^2$) |
|---|---|---|---|---|---|---|---|
| Zhou et al. (2018a) | 3/3 | 12/14 | 4.9/5.65 | 27 | 20 dB/1.45$f_1$ | 1.34/1.41 | 2.77 |
| Iqbal et al. (2019) | 2/2 | 10.5/13.5 | 3.71/1.7 | 42 | 20 dB/2$f_1$ | 0.8/1.35 | 2.78 |
| Zhou and Wu (2021) | 3/3 | 3.5/5 | 4/3.2 | 45.8 | 20 dB/1.7$f_1$ | 2.77/2.55 | 1.62 |
| | 4/4 | 3.5/5.5 | 3.43/2.55 | 27.6 | 20 dB/2.05$f_1$ | 3.41/3.4 | 1.136 |
| Xie et al. (2020) | 2/2 | 10/12.25 | 4/3.2 | 20 | 24 dB/1.79$f_1$ | 2.05/1.65 | 2.34 |
| | 2/2 | 8/12 | 3.43/2.55 | 20 | 20 dB/2.05$f_1$ | 1.84/2.88 | 1.54 |
| Ma et al. (2023) | 3/3 | 12/14 | 2.04/2.44 | 22 | 20 dB/1.32$f_1$ | 2.51/2.19 | 3.47 |
| | 3/3 | 12/14 | 3.73/3.99 | 47 | 20 dB/2.02$f_1$ | 1.39/1.37 | 3.62 |
| Liu et al. (2023) | 4/4 | 34.95/36.44 | 1.73/1.39 | 28.9 | 20 dB/2.37$f_1$ | 4.24/5.1 | 12.6 |
| This work | 2/2 | 10.34/13.9 | 5.7/5.83 | 28.1 | 20 dB/2.16$f_1$ | 2.03/2.33 | 1.363 |

# Conclusions

1. A planar SIW diplexer is proposed based on HMSIW technology, featuring a wide-stopband and a small circuit size.

2. The dimensions of the diplexer are 22.5 mm × 17 mm ($1.343\lambda_g \times 1.015\lambda_g$). The measured stopband extends to $2.16f_1$ with a rejection of more than 20 dB.

3. A second-order prototype based on $TE_{101}$/$TE_{301}$ DMR is designed and fabricated, covering a wide range of frequency ratios.

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