Filtering Power Divider with Ultra-Wide Stopband and Wideband Low Radiation Loss Using Substrate-Integrated Defected Ground Structure

Changxuan Han, *Graduate Student Member, IEEE* and Xun Luo, *Senior Member, IEEE*

***Abstract*—In this report, a substrate-integrated defected ground structure (SIDGS) resonant cell is proposed. Such SIDGS resonant cell can not only introduce an ultra-wide stopband for spurious suppression, but also achieve low radiation loss in a wideband, which can be easily implemented in passive circuits with high performance. To verify this mechanism, a filtering power divider using the folded stepped-impedance scheme is developed. Here, two coupled SIDGS resonant cells are cascaded at the output ports of power divider to achieve a filtering response with ultra-wide band harmonic suppression. The fabricated filtering power divider is operated at 2.87 GHz (i.e., the passband center frequency f_0) with a 3-dB fractional bandwidth (FBW) of 23%, which exhibits the 28 dB attenuation upper-stopband with a low radiation loss even up to 25 GHz (i.e., 8.71f_0).**

***Index Terms*—Filtering power divider (FPD), high isolation, low radiation loss, substrate-integrated defected ground structure (SIDGS), ultra-wide stopband.**

I. Introduction

WITH the ever-developing demands of complex microwave circuits and systems, passive components with wideband interference suppression are developed rapidly. As a key component in modern wireless communication systems, the power divider with filtering function and wide stopband has drawn great attentions recently. In [1], the substrate-integrated waveguide (SIW) is proposed for the power divider design with low radiation loss, which suffers from the narrow stopband. To extend the stopband bandwidth, the lowpass filter [2], stepped-impedance resonators (SIR) [3], and defected ground structure (DGS) [4] are proposed. However, the stopband performances of these methods are limited by the restriction of fabrication techniques. Recently, slow-wave DGS resonator [5] is presented to further enhance the stopband performance, such resonators can not only allocate the intrinsic fundamental resonance, but also introduce an ultra-wide stopband with high rejection level. Nevertheless, high radiation makes conventional DGS hard to be integrated in passive circuits. Therefore, the design of filtering power divider with ultra-wide stopband and low radiation loss for flexible integration still remains a great challenge.

In this report, a novel substrate-integrated defected ground structure (SIDGS) resonant cell is proposed. Such SIDGS resonant cell is consisted of a DGS resonator integrated between two substrate layers, where a bottom grounded plane and surrounding metal-vias are introduced as an integrated package. Therefore, this SIDGS resonant cell can not only reserve the harmonic suppression characteristic of the DGS resonator, but also be easily integrated in passive circuits for the suppressed radiation. Based on the proposed SIDGS resonant cell, a filtering power divider (FPD) with ultra-wide stopband and low radiation loss is design and fabricated. Good agreement between simulation and measurement is achieved.

The authors are with the Center for Integrated Circuits, University of Electronic Science and Technology of China, Chengdu 611731, China.

II. Schematic And Operation

A. Substrate-Integrated Defected Ground Structure

Fig. 1 depicts the configuration of the proposed FPD. Two pairs of coupling SIDGS resonance cells are cascaded on the output arms of a Wilkinson power divider while the microstrip T-stubs act as feed lines. A C-shape etched defect is located on the ground I, which is integrated between two substrate layers. Besides, a bottom grounded plane and surrounding metal-vias are introduced as a package. With such implementation, the proposed SIDGS resonance cell is similar to a λ/2 stepped-impedance resonator with two grounded ends [6].

The electric and magnetic fields of conventional DGS are distributed in an open space, which leads to a large electromagnetic radiation[7]. Such radiation leads to an extra passband insertion loss and electromagnetic interference. For the SIDGS structure, the electric fields are mainly restricted in a quasi-cavity by ground II and metal-vias. With such characteristics, the SIDGS can not only effectively reduce the radiation loss compared to the conventional DGS, but also be convenient for integrated passive circuits.

B. Filtering Power Divider Design

To verify the aforementioned characteristics, a filtering power divider operating at 2.87 GHz with a 3-dB FBW of 23% is designed based on the SIDGS resonant cell. The design tools ADS, CST Microwave Studio, and dielectric substrate Rogers 4003C (i.e., $\varepsilon_r = 3.55$, $h_1 = 0.203$ mm, and $h_2 = 0.303$ mm) are used. Such FPD is composed of two filtering parts and a stepped-impedance Wilkinson power divider. Here, a pair of SIDGS resonant cells and T-stubs constitute the filtering part. The coupling coefficient k for the required frequency response can be obtained by adjusting the distance d_1 and d_2 between the two SIDGS cells. Meanwhile, the demanded external quality factor Q_e is determined by the width w_1 of the T-stub. Besides, a λ/4 open stub is added on the T-stub to generate a transmission zero at upper stopband, which

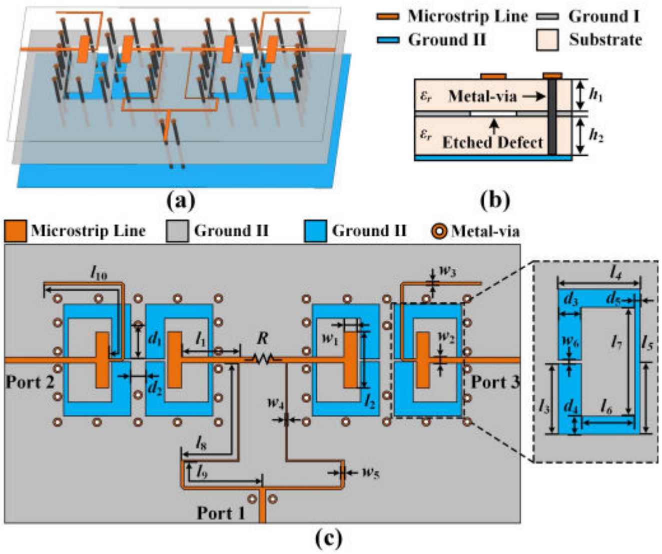

Fig. 1. Configuration of the proposed FPD in (a) 3D view, (b) Layer schematic diagram, and (c) Top view.

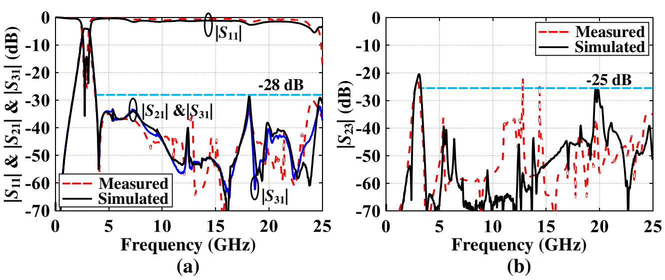

Fig. 2. Measured and simulated results of the proposed filtering power divider. (a) $|S_{11}|$, $|S_{21}|$, and $|S_{31}|$. (b) $|S_{23}|$.

could improve the passband selectivity. Then, the stepped-impedance scheme is utilized for Wilkinson power divider design to achieve good impedance matching with compact size. Moreover, the isolated resistor is optimized as 180 Ω to enhance the output-isolation.

III. Fabrication and Measurement

Based on the principles mentioned above, a FPD operating at 2.87 GHz with 3-dB FBW of 23% is fabricated. The prototype exhibits a compact core-circuit size of 29.8 mm by 14.9 mm (i.e., $0.46\lambda_g$ by $0.23\lambda_g$, where the λ_g is the microstrip guided wavelength at 2.87 GHz). The measured results depicted in Fig. 2 are performed using the network analyzer over the frequency range from 0.01 to 25 GHz. The measured minimal passband insertion loss is 1.1 dB, excluding 3 dB division loss. Meanwhile, the proposed FPD could achieve an ultra-wide upper stopband up to 25 GHz (i.e., $8.71f_0$) with a rejection level greater than 28 dB. Besides, a transmission zero is created at 4.05 GHz to improve the passband selectivity. The in-band isolation greater than 20 dB is measured with the utilization of a 180 Ω resistor R. The performance summary and comparison with state-of-the-arts FPD are shown in Table I, which reveal that the proposed

TABLE I
Comparison of State-of-the-Art Power Dividers

Ref.	Tech.*	f_0 (GHz)	IL** (dB)	Stopband Rejection	Passband Isolation	Stopband Isolation	Radiation Loss
[6]	SIW	4.82	2	N/A	N/A	N/A	Low
[7]	Microstrip	0.9	1.6	>20 dB up to $11.1f_0$	>23 dB	N/A	High
[10]	Microstrip	2.02	1.0	>40 dB up to $4.55f_0$	>22 dB	>22 dB up to $4.41f_0$	High
[19]	DGS	2.31	1.2	>30 dB up to $8.66f_0$	>17 dB	>28 dB up to $8.66f_0$	High
This work	**SIDGS**	**2.87**	**1.0**	**>28 dB up to $8.71f_0$**	**>20 dB**	**>25 dB up to $8.71f_0$**	**Low**

*: Technology. **: Insertion loss.

FPD shows competitive merits of the insertion loss, stopband performance, isolation, and radiation loss.

IV. Conclusion

In this report, a SIDGS resonant cell is proposed for high performance integrated system design. Compared to the convectional DGS, such SIDGS can not only introduce a wide stopband performance, but also reduce the radiation loss in a wideband. Based on the proposed SIDGS resonant cell, an FPD with low insertion loss, ultra-wide band harmonic suppression, and low radiation loss is developed. With such good performances, the proposed SIDGS resonant cell is attractive for integrated circuits and systems with wideband spurious suppression.

Receiving the IEEE MTT-S Undergraduate/Pregraduate Scholarship has inspired me to develop the study on the mm-wave integrated circuit. It will also encourage me in the future study. I had received the undergraduate degree with the invaluable guidance of Prof. dr. Xun Luo at University of Electronic Science and Technology of China (UESTC). It is my honor to pursue the Ph.D's degree at the UESTC under supervision of Prof. dr. Xun Luo.

References

[1] X. Wang, X.-W. Zhu, L. Tian, P. Liu, W. Hong, and A. Zhu, "Design and experiment of filtering power divider based on shielded HM-SIW/QMSIW technology for 5G wireless applications," in *IEEE Access*, vol. 7, pp. 72411–72419, Jun. 2019.

[2] W.-M. Chau. K.-W. Hsu, and W.-H. Tu, "Filter-based Wilkinson power divider," *IEEE Microw. Wireless Compon. Lett.*, vol. 24, no. 4, pp. 239–241, Apr. 2014.

[3] P. Cheong, K.-I. Lai, and K.-W. Tam, "Compact Wilkinson power divider with simultaneous bandpass response and harmonic suppression," in *IEEE MTT-S Int. Microwave Sym. Dig.*, Anaheim, CA, USA, May 2010, pp. 1588–1591.

[4] D. Ahn, J.-S. Park, C.-S. Kim, J. Kim, Y. Qian, and T. Itoh, "A design of the low-pass filter using the novel microstrip defected ground structure," *IEEE Trans. Microw. Theory Tech.*, vol. 49, no. 1, pp. 86–93, Jan. 2001.

[5] L. Fan, H. Qian, B. Yang, G. Wang, and X. Luo, "Filtering power divider with wide stopband using open-stub loaded coupled-line and hybrid microstrip T-stub/DGS cell," in *IEEE MTT-S Int. Microwave Sym. Dig.*, Philadelphia, PA, USA, Jun. 2018, pp. 1–4.

[6] X. Luo, J.-G. Ma, and E.-P. Li, "Hybrid microstrip/DGS cell for filter design," *IEEE Microw. Wireless Compon. Lett.*, vol. 21, no. 10, pp. 528–530, Oct. 2011.

[7] Y. Rao, H. J. Qian, B. Yang, R. Gómez-García, and X. Luo, "Dual-band bandpass filter and filtering power divider with ultra-wide upper stopband using hybrid microstrip/DGS dual-resonance cells," in *IEEE Access*, vol. 8, pp. 23624–23637, Jan. 2020.