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Compact Balanced UWB BPF Based on HMSIW and D-DGS

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Abstract—A compact balanced UWB bandpass filter (BPF) is proposed in this paper, which is based on the half-mode substrate integrated waveguide (HMSIW) and the differential defected ground structure (D-DGS). Using the HMSIW, the filter can achieve compact size, wide passband and good compatibility. Two D-DGS cells are employed to provide good suppression for the common-mode (CM) noise, while they have small effect on the performance of differential-mode (DM) signals. To validate the design theory, a microstrip balanced UWB BPF is designed, fabricated and measured to meet compact size, low insertion loss, good return loss as well as proper bandwidth. The predicted results are compared with measured data and show reasonable agreement.

1. INTRODUCTION

Balanced circuits are important to modern communication systems development. Their abilities in reducing noise, crosstalk and electromagnetic interference (EMI) are very good. In practical circuits, common-mode noise still interferes with differential signal path, which will degrade the signal integrity of a high speed circuit system [1–8]. The balanced bandpass filters (BPFs) are effective in removing the common-mode noises but still keep good signal integrity performance for the differential signals in their passbands [9–16].

Many structures have been proposed in previous researches for building balanced filters. Some balanced filters based on branch-line structures were presented in [9, 14, 15], which obtained good common-mode suppression in the passband and high selectivity for the differential mode but relatively high insertion loss. In addition, differential filters were constructed in [10, 11] by taking advantage of the parallel-coupled lines which had some limitations for the special structures. Some balanced filters [12, 13] aim at UWB applications, but their sizes are relatively large. In [16], a differential filter was proposed, but the structure was too complex.

In this study, a half-mode substrate integrated waveguide (HMSIW) structure and a differential defected ground structure (D-DGS) are utilized to develop an UWB balanced BPF. By employing D-DGS, the proposed filter can realize ultra-wide passband performance with fractional bandwidth of 113%. Moreover, the common-mode noise is efficiently suppressed under 15 dB, and good signal quality for the differential components is maintained. Good differential-mode and common-mode responses are achieved as demonstrated in both simulation and measurement.

2. DESIGN AND ANALYSIS OF PROPOSED FILTER

2.1. Characteristics of HMSIW-DGS

Figure 1(a) shows the HMSIW structure with etching DGS on the ground plane. HMSIW can achieve high-pass characteristic, and DGS has the characteristic in low pass. The size of HMSIW is nearly half

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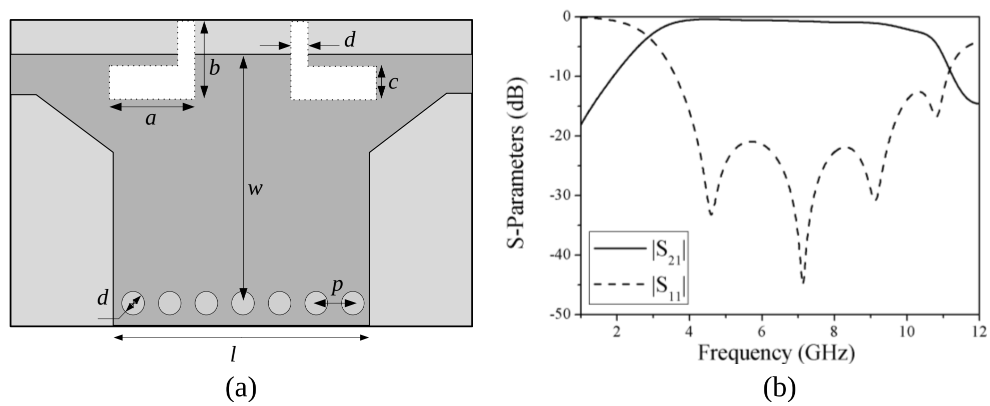

Figure 1. (a) Layout schematic and (b) simulated frequency responses of HMSIW with DGS.

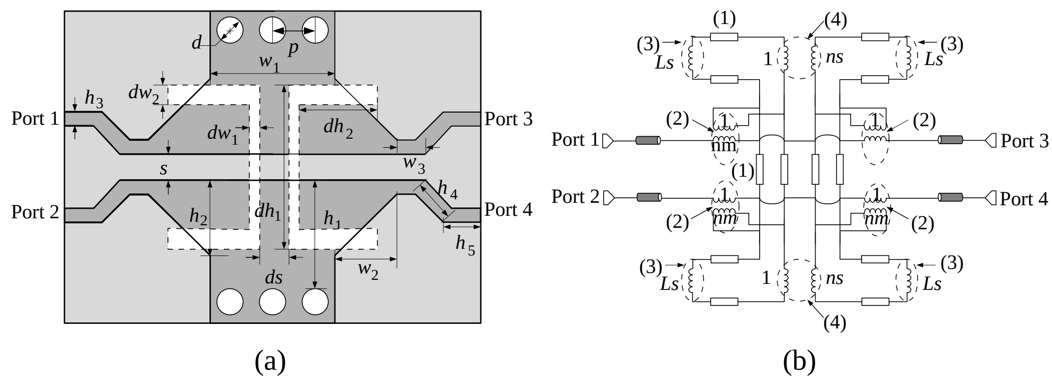

Figure 2. Layout schematic of (a) proposed balanced UWB bandpass filter and (b) equivalent circuit.

of a SIW structure, and the attenuation is less than that of SIW. Due to the inherent relationship of the SIW and HMSIW, we can obtain [17]:

$$w_{ff,HMSIW} = w_{eff,SIW}/2 + \Delta w \tag{1}$$

where Δw is shown in (2)

$$\frac{\Delta w}{h} = \left(0.05 + \frac{0.30}{\varepsilon_r}\right) \ln\left(0.79\frac{w_{eff,SIW}/2}{h^3} + \frac{104w_{eff,SIW}/2 - 216}{h^2} + \frac{38}{h} + 2.77\right) \tag{2}$$

The cut-off frequency of quasi-$\text{TE}_{0.5,0}$ mode of dielectric rectangular waveguide is given by

$$f_{c,TE_{0.5,0}} = \frac{c}{4\sqrt{\varepsilon_r}w_{eff,HMSIW}} \tag{3}$$

With Ansoft's High Frequency Structure Simulator (HFSS) software, the S-parameters of the HMSIW-DGS is simulated and investigated. The HMSIW and DGS can be highly integrated together, which will realize small size and UWB performance, as shown in Figure 1(b).

2.2. Design of the Proposed Balance Filter Structure

Figure 2(a) depicts the proposed balanced filter using the characteristic of HMSIW-DGS. The designed filter consists of two HMSIW structures as the differential lines and etching the two U-shaped DGSs as the D-DGS on the ground plane. Figure 2(b) shows that the equivalent circuit of the proposed balanced UWB BPF is divided into four following components. (1) Slit as a transmission line model. (2) Electromagnetic coupling between microstrip line and slit as an ideal transformer, and nm is the turn ratio of the ideal transformer. (3) Short-end of slit as inductance, and L_s is the equivalent inductance. (4) Electromagnetic coupling between slits as an ideal transformer, and n_s is the turn ratio of the ideal transformer [18].

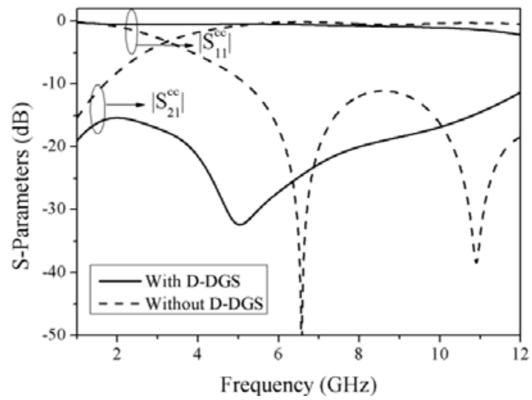

Figure 3. The frequency responses of HMSIW with and without D-DGS.

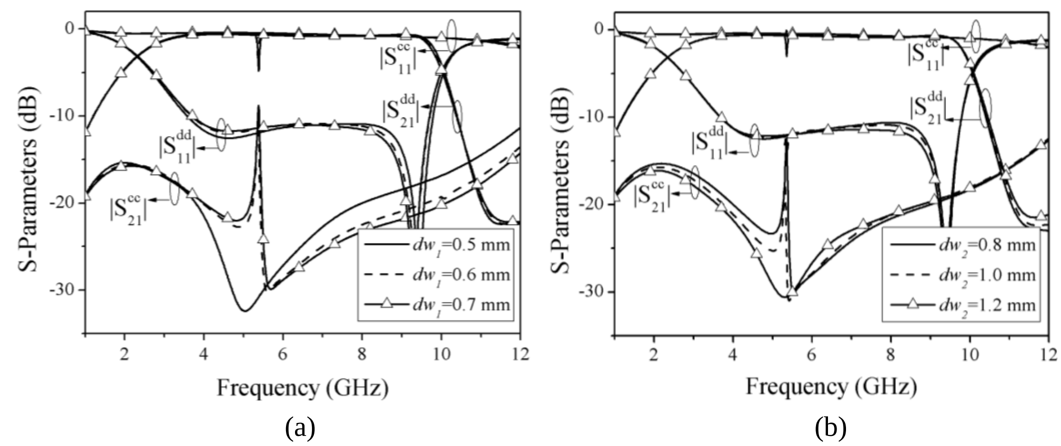

Figure 4. Simulated S-parameters of common-mode for different values of (a) dw_1 and (b) dw_2.

The D-DGS is kept symmetrical to the central line of the two differential lines. From experimental demonstrations, it can be found that the D-DGS has the ability to avoid the common-mode noise. As shown in Figure 3, the common-mode noise of the HMSIW is highly suppressed with D-DGS. The return current of differential-mode is relatively small through the ground caused by the D-DGS, while the D-DGS will have serious effect on the common-mode signal because the return current will pass through the ground.

By simulation demonstrations, it can be found that the dimensions of the D-DGS have effect on the common-mode $|S_{21}|$ while they are independent of the differential-mode signals. As shown in Figure 4(a), the suppression of CM noises is improved when dw_1 decreases. On the contrary, the CM noises become stronger with decreasing dw_2, as given in Figure 4(b).

3. IMPLEMENTATION AND RESULT

The balanced UWB BPF has been designed on a substrate RT/Duroid 5880 with a dielectric constant of 2.2, a thickness of 1 mm and a loss tangent of 0.0009. The structural parameters for the proposed filter circuit are illustrated in Figure 2(a): $h_1 = 10\,\text{mm}$, $h_2 = 7\,\text{mm}$, $h_3 = 3\,\text{mm}$, $h_4 = 7\,\text{mm}$, $h_5 = 2.5\,\text{mm}$, $w_1 = 5.3\,\text{mm}$, $w_2 = 4\,\text{mm}$, $w_3 = 2.2\,\text{mm}$, $s = 0.4\,\text{mm}$, $d = 0.9\,\text{mm}$, $p = 1.8$ mm, $dh_1 = 13\,\text{mm}$, $dh_2 = 5\,\text{mm}$, $dw_1 = 0.5\,\text{mm}$, $dw_2 = 1.2\,\text{mm}$, $d_s = 5\,\text{mm}$. Figure 5 shows photographs of the fabricated balanced UWB bandpass filter based on HMSIW and D-DGS. The overall size is only $28.4 \times 24.6\,\text{mm}^2$. The measurement of S-parameters was accomplished by an Agilent N5230A network analyzer. The good property of the presented structure is shown by simulation and measurement.

Figure 6 presents the simulated and measured results of the fabricated filter. It can be seen that a wide differential-mode passband is achieved in the frequency range of 2.19–9.97 GHz, which is approximately equivalent to 110% fractional bandwidth, while the largest differential-mode insert loss

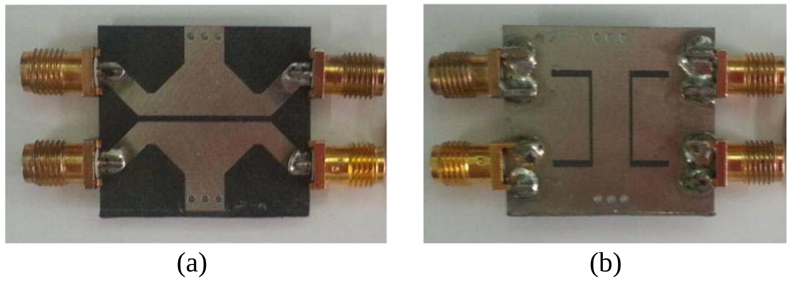

Figure 5. Photographs for (a) top view and (b) bottom view of the proposed balanced filter.

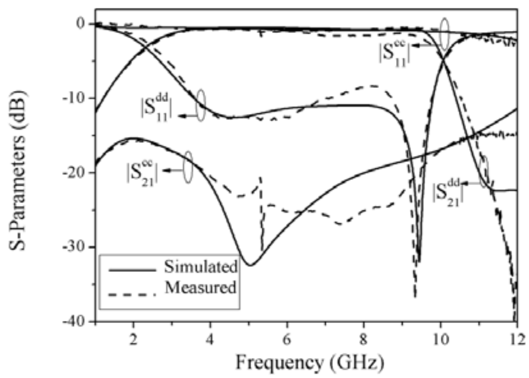

Figure 6. The comparison result of simulated and measured S-parameters.

Table 1. Comparison with some recently reported UWB balanced BPFs.

	f_0 (GHz)	Size ($\lambda_0 \times \lambda_0$)	3 dB FBW	$\|S_{21}^{dd}\|$ @ passband	$\|S_{21}^{cc}\|$ @ passband
Ref. [11]	6.85	1.01×1.01	110%	< 2.05 dB	> 15 dB
Ref. [12]	6.85	1.10×1.60	135%	< 1.0 dB	> 10 dB
Ref. [13]	6.85	0.64×0.64	111%	< 1.75 dB	> 13 dB
This work	6.85	0.65×0.56	113%	< 1.63 dB	> 15 dB

is less than 1.0 dB across the passband according to the simulations and is less than 1.63 dB within the pass-band of the measured result. It is also shown that the common-mode signals suppression of the proposed filter is greater than 15.3 dB from simulations and 15 dB in the measurements across the whole investigated band.

A good agreement can generally be observed between the simulated and measured results. The deviations of the measurements from the simulations are attributed to the fabrication tolerance as well as SMA connectors. A comparison of the performance of the proposed filter with the other reported balanced BPFs is listed in Table 1. It can be seen that the proposed filter outperforms the others in terms of DM/CM responses and size.

4. CONCLUSION

A novel balanced UWB bandpass filter is proposed and designed. The total circuit configuration is compact and simple. The D-DGS underneath the symmetrical HMSIW transmissions lines is easy to suppress the common-mode noise and achieve differential-mode bandpass performances. Good agreement between the simulation and measurement results demonstrates the validity of the design.

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REFERENCES

1. Viallon, C., G. Meneghin, and T. Parra, "NMOS device optimization for the design of a W-band double-balanced resistive mixer," *IEEE Microwave and Wireless Components Letters*, Vol. 24, 637–639, 2014.
2. Wei, H.-C., C.-L. Hsiao, and R.-M. Weng, "A broadband low power high isolation double-balanced subharmonic mixer for 4G applications," *Progress In Electromagnetics Research*, Vol. 138, 143–155, 2013.
3. Tang, X. and K. Mouthaan, "Design of large bandwidth phase shifters using common mode all-pass networks," *IEEE Microwave and Wireless Components Letters*, Vol. 22, 55–57, 2012.
4. Guo, J., Z. Xu, C. Qian, and W. Dou, "Design of a microstrip balanced mixer for satellite communication," *Progress In Electromagnetics Research*, Vol. 115, 289–301, 2011.
5. Chiu, L., Q. Xue, and C. H. Chan, "Dual-fed patch antenna with distorted patch mode for balanced circuits," *IET Microwaves, Antennas & Propagation*, Vol. 4, 809–816, 2010.
6. Niu, J. X. and X. L. Zhou, "Analysis of balanced composite right/left handed structure based on different dimensions of complementary split ring resonators," *Progress In Electromagnetics Research*, Vol. 74, 341–351, 2007.
7. Liao, C. F., Y. J. Chan, and Y. C. Chiang, "2.4 GHz monolithic microwave mixer with lumped balanced circuits," *Microwave and Optical Technology Letters*, Vol. 17, 357–359, 1998.
8. Gunton, D. J., "Microwave balanced-mixer circuits using combline directional couplers," *Electronics Letters*, Vol. 12, 204–205, 1976.
9. Li, L., J. Bao, J.-J. Du, and Y.-M. Wang, "Differential wideband bandpass filters with enhanced common-mode suppression using internal coupling technique," *IEEE Microwave and Wireless Components Letters*, Vol. 24, 300–302, 2014.
10. Wu, X.-H., Q.-X. Chu, and L.-L. Qiu, "Differential wideband bandpass filter with high-selectivity and common-mode suppression," *IEEE Microwave and Wireless Components Letters*, Vol. 23, 644–646, 2013.
11. Wang, X.-H., Q. Xue, and W.-W. Choi, "A novel ultra-wideband differential filter based on double-sided parallel-strip line," *IEEE Microwave and Wireless Components Letters*, Vol. 20, 471–473, 2010.
12. Zhu, H. T., W. J. Feng, W. Q. Che, and Q. Xue, "Ultra-wideband differential bandpass filter based on transversal signal-interference concept," *Electronics Letters*, Vol. 47, 1033–1035, 2011.
13. Wang, X.-H., H. Zhang, and B.-Z. Wang, "A novel ultra-wideband differential filter based on microstrip line structures," *IEEE Microwave and Wireless Components Letters*, Vol. 23, 128–130, 2013.
14. Wu, S. M., C. T. Kuo, and C. H. Chen, "Very compact full differential bandpass filter with transformer integrated using integrated passive device technology," *Progress In Electromagnetics Research*, Vol. 113, 251–267, 2011.
15. Wu, C.-H., C.-H. Wang, and C. H. Chen, "Novel balanced coupled-line bandpass filters with common-mode noise suppression," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 55, 287–295, 2007.
16. Wu, S.-M., R.-F. Hsu, and P. H. Yu, "Signal integrity and electromagnetic broadband packaging model extraction of full differential bandpass filter on IPD with BGA packaging," *Progress In Electromagnetics Research*, Vol. 141, 201–217, 2013.
17. Lai, Q., C. Fumeaux, W. Hong, and R. Vahldieck, "Characterization of the propagation properties of the half-mode substrate integrated waveguide," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 57, 1996–2004, 2009.
18. Matsumoto, K., Y. Toyota, K. Iokibe, and R. Koga, "Development of equivalent circuit model with transmission line model for designing filters formed on printed circuit boards," *2010 IEEE International Symposium on Electromagnetic Compatibility (EMC)*, 289–294, 2010.