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A Compact Dual-Metal-Plane Highpass Filter Using Hybrid Microstrip/DGS

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Abstract—A novel and compact highpass filter (HPF) is proposed in this article. This filter is based on a hybrid-coupled dual-metal-plane microstrip/DGS (defected ground structure) on a single-layer substrate. The resonator etched in the grounding plane shows a wide-band dual-mode resonant response within the desired high-pass frequency band, and is composed of a modified U-shaped slot resonator embedded with an L-shaped slot. The wideband highpass filtering performance is achieved by the dual-mode resonator at the bottom of single-layer substrate coupled broadside to the top microstrip stubs. Simulated results from the electromagnetic (EM) analysis software and measured results from a vector network analyzer (VNA) show a good agreement, and an excellent performance with nearly 40 dB attenuation at the lower stopband has also been obtained across an ultra-wide highpass range. A designed and fabricated prototype filter, having a 3-dB cutoff frequency (f_c) of 5.9 GHz, shows an ultra-wide highpass range, i.e., from 5.9 to 15.52 GHz, and exhibits the highest pass-band frequency up to $2.6f_c$. The printed circuit board (PCB) area of the implemented filter is approximately 0.086 $\lambda_g \times 0.13\lambda_g$, λ_g being the guided wavelength at f_c.

1. INTRODUCTION

In RF/microwave wireless applications, high-pass filters (HPFs) are important circuit elements, while conventional procedures of implementing the HPFs often utilize distributed units or quasi-lumped elements, which require grounded via-holes. As a result, these methods might lead to fabrication problems and also require large PCB sizes [1]. Recently, some new HPFs using various physical structures and design methods have been reported successively [2–10]. A new approach to designing a maximally flat Butterworth HPF, which transforms an open-circuited series stub to short-circuited shunt stub, has been extensively investigated in [2]. An elliptic-function response HPF based on SIR in coplanar waveguide (CPW) technology has also been researched in [3]. A 6th-order pseudo HPF using balanced double-sided parallel-strip lines, for which the width of the dielectric layer is equal to the width of the conducting strips, has been described in detail in [4]. A concept of very simple planar HPFs using a microstrip with a short-circuited edge has been extended to the millimeter-wave filters with passbands beginning in the K and Ka bands, which has been reported in [5]. In [6–8], the complementary split ring resonator (CSRR) is used to design and implement the various HPFs. In [9], complementary spiral resonators (CSRs) are applied to design the HPF. In [10], a CPW periodically loaded with split ring resonators (SRRs) and shunt connected elements can be applied to design the HPF. Generally, the pass-band frequency ranges of HPFs above-overviewed are basically up to $2{\sim}3f_c$.

In this paper, a modified U-shaped slot resonator embedded with an L-shaped slot is used to generate an ultra-wide dual-mode resonant property within the desired high-pass frequency band and is broadside coupled to the top microstrip stubs for the proposed HPF. Generally, the dual-mode (or

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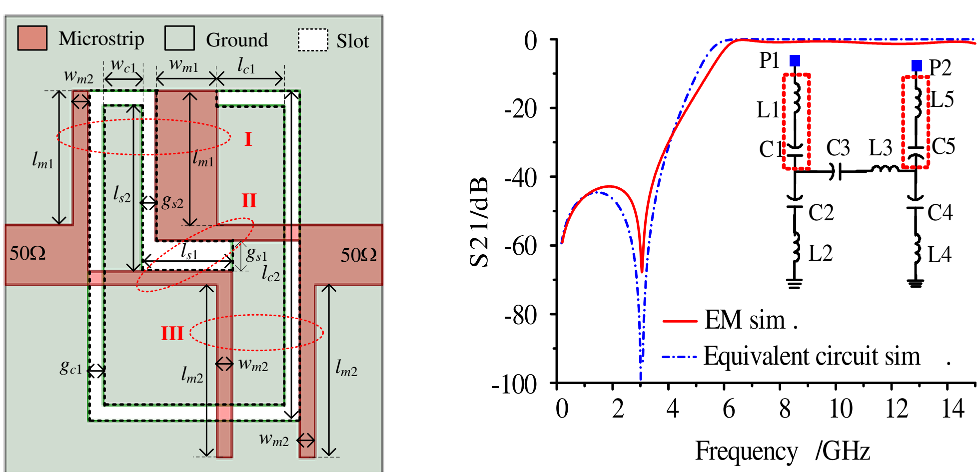
multi-mode) resonant characteristics have been extensively applied to design UWB BPF and dual-band (or multi-band) filters [11–13]. However, they are rarely used to implement the HPF. The designed miniature HPF does not require any via-hole, which often leads to some fabrication problems. The hybrid DGS exhibiting dual-mode resonant characteristic is obtained by etching slots in the ground plane of the microstrip lines. With the help of the three pairs of top microstrip parallel-coupled sections, the lower frequency attenuation for the bandstop and the upper pass-band transmission response have been achieved. This circuit is designed on 0.254 mm dielectric substrate with relative dielectric constant 2.2. In addition, the dimensions of the fabricated high-pass filter are approximately 4.9 mm×3.2 mm ($\approx 0.086\lambda_g \times 0.13\lambda_g$), where λ_g is the guided wavelength at the 3-dB cutoff frequency f_c in the substrate.

2. PROPOSED DUAL-MODE RESONATOR AND HPF

In Figure 1(a), a novel and simple configuration of the demonstrated HPF using a dual-mode resonator is shown with some key dimensions defined. The top microstrip input/output signal transmission paths, including two pairs of coupled stubs and a pair of coupled main transmission lines, generate the transmission zero (TZ) near the DC operating point, as these microstrip coupled gaps are equivalent to the lumped capacitance with blocking DC property. Additionally, the two-dimensional (2-D) view shown in Figure 1(a) also describes the relative position relation between top microstrip lines and bottom combined DGS resonator on the single-layer substrate. In Figure 1(b), the approximate equivalent circuit of the proposed filter, a pseudo third-order lumped element model, is inserted in the response. The lumped elements in red-dash boxes, L1C1 and L5C5, are used to model the parasitic effects in the filter. The lumped elements, L2C2 and L4C4, model the input/output microstrip/proposed DGS, as shown in the area I and III of Figure 1(a), while the lumped elements, L3C3, model the interactive effect, as shown in area II of Figure 1(a). The equivalent element values shown in Figure 1(b) have been achieved by curve fitting the lumped response with the one from the full-wave EM simulation. It is clearly seen that both transmission responses agree well with each other.

In Figure 1, the modified U-shaped slot resonator embedded with an L-shaped slot at the bottom of the substrate is used to create an ultra-wide dual-mode resonant response. Based on the following original physical dimensions, i.e., $w_{m1} = 0.8$ mm, $w_{m2} = 0.2$ mm, $l_{m1} = 1.8$ mm, $l_{m2} = 2.3$ mm, $l_{c2} = 4.4$ mm, $g_{s1} = 0.4$ mm, $g_{s2} = 0.2$ mm, $g_{c1} = 0.2$ mm, the other four geometrical variables l_{s1}, l_{s2}, l_{c1} and w_{c1} have been further investigated in this design. The dual-mode characteristics of the proposed resonator are shown in Figure 2 as the above-mentioned four parameters are varied. As shown in Figure 2(a), the two resonant peaks will move down to a lower frequency as the two variables l_{s1} and



(a) (b)

Figure 1. The proposed filter. (a) Configuration of the combined resonator and HPF/ (b) Equivalent circuit and its transmission response. ($L1 = 0.122$ nH, $C1 = 0.568$ pF, $L2 = 1.086$ nH, $C2 = 2.5$ pF, $L3 = 0.422$ nH, $C3 = 0.33$ pF, $L4 = 1.1$ nH, $C4 = 2.5$ pF, $L5 = 0.122$ nH, $C5 = 0.62$ pF).

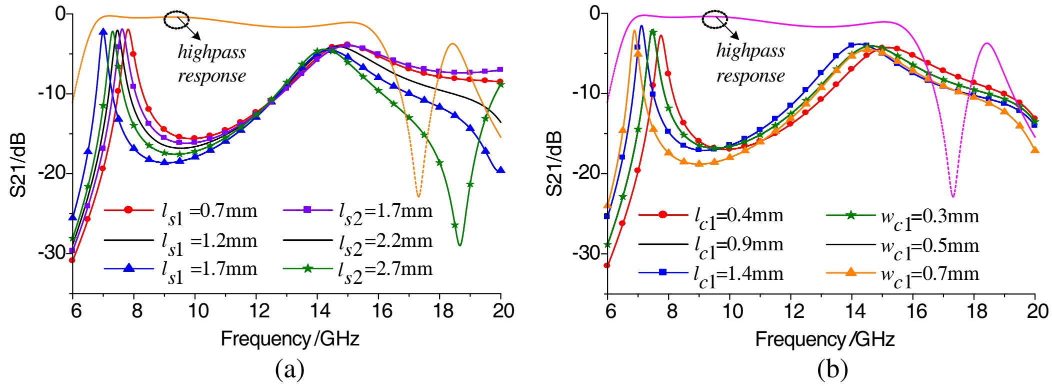


Figure 2. Weakly coupled responses of the proposed resonator within the high-pass range for various parameters and dimensions. (a) Dimensions variation of L-shaped DGS ($l_{c1} = 0.9$ mm and $w_{c1} = 0.5$ mm), and (b) Dimensions variation of DGS ($l_{s1} = 1.2$ mm and $l_{s2} = 2.2$ mm).

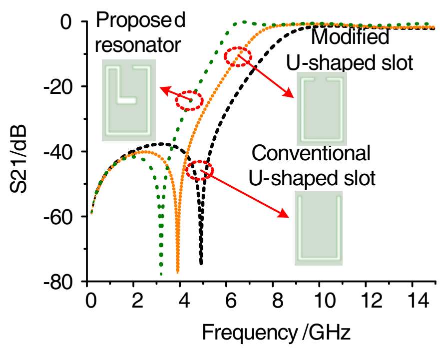


Figure 3. Various responses for different resonators with an identical microstrip structure shown in Figure 1(a) (White areas represent slot lines).

l_{s2} increase. Similarly, Figure 2(b) shows that the two resonant peaks will also move down to a lower frequency as the two variables l_{c1} and w_{c1} increase. In addition, there are the two transmission zeros observed in Figure 2, which are distributed at the lower and upper sides of two resonant peaks. This result also explains the reason why the second transmission zero within the stopband of the proposed HPF from approximately $\lambda_g/8$ of the proposed U-shaped slot is located near 3.5 GHz, and there is a parasitic pass-band attenuation around 18.0 GHz. Making use of the hybrid broadside couplings between the top microstrip coupled-line sections and the bottom dual-mode hybrid U-shaped slot embedded with L-shaped slot, an excellent high-pass response will be obtained, which is also shown in Figure 2. In addition, the different responses of various ground-plane resonators, including the conventional U-shaped slot, the modified U-shaped slot and the proposed combined DGS resonator, are shown in Figure 3. Obviously, the proposed composite ground-plane resonator is more compact than other two resonators for the same design specifications, e.g., 3-dB cut-off frequency and transmission zero.

To demonstrate the possibility of implementing high-selective HPFs with the proposed hybrid microstrip/DGS, a third-order HPF, with a pass band ripple of 0.1 dB, a minimum stop band insertion loss of 40 dB, and a 3-dB cut-off frequency of 6.0 GHz, was designed and fabricated. The original simple design formula can be obtained from [1], based on the low-pass prototype to high-pass transformation. Also, the design methodology and procedure can be described similar to that in [3].

After discussing the dual-mode characteristic of the modified U-shaped slot resonator embedded with an L-shaped slot and investigating the important physical dimensions, the initial geometric parameters have been calculated by the above-described frequency response characteristic. Taking advantage of optimization and simulation performances from the full-wave EM simulator, the final geometric sizes have been obtained, i.e., $w_{m1} = 0.8\,\mathrm{mm}$, $w_{m2} = 0.2\,\mathrm{mm}$, $l_{m1} = 1.8\,\mathrm{mm}$, $l_{m2} = 2.3\,\mathrm{mm}$, $l_{c1} = 0.9\,\mathrm{mm}$, $l_{c2} = 4.4\,\mathrm{mm}$, $l_{s1} = 1.2\,\mathrm{mm}$, $g_{s1} = 0.4\,\mathrm{mm}$, $l_{s2} = 2.2\,\mathrm{mm}$, $g_{s2} = 0.2\,\mathrm{mm}$, $w_{c1} = 0.5\,\mathrm{mm}$, $g_{c1} = 0.2\,\mathrm{mm}$.

3. FILTER IMPLEMENTATION AND EXPERIMENTAL RESULTS

Based on the above-defined physical dimensions of the designed HPF shown in Figure 1(a), an advanced and miniaturized HPF has been simulated, fabricated, installed and measured. The photographs of implemented filter are given in Figure 4, one of which is the top microstrip structure shown in Figure 4(a), and the other of which is the bottom improved U-shaped slot resonator embedded with an L-shaped slot, also shown in Figure 4(b). The simulation and measurement have been accomplished using the commercially available simulation software and VNA, respectively. Figure 5 shows the simulated and measured insertion loss and return loss of the proposed filter. It can be seen that good agreement between the simulated and measured results has been achieved. Seen from Figure 5, the measured 3-dB cutoff frequency $f_c = 5.9\,\mathrm{GHz}$, and the 3-dB high frequency (HF) pass-band range is from 5.9 to 15.52 GHz, which exhibits the highest pass-band frequency exceeding $2.6f_c$. Within the passband, the measured minimum IL is 0.81 dB at 6.46 GHz while the maximum IL is 2.19 dB at 12.13 GHz. At the same time, there are three transmission poles observed within the passband, i.e., 6.44 GHz, 9.63 GHz and 14.44 GHz, respectively. Also, two transmission zeros (TZs) have been obtained, which are near the DC operating point with an attenuation of $-65.4\,\mathrm{dB}$ at 3.34 GHz. From DC to 3.8 GHz, the transmission attenuation within the stop-band frequency band exceeds 40 dB. In addition, a comparison of our work with some typical references is shown in Table 1, in which f_{pmax}/f_c shown in Table 1 is defined as the ratio between the maximum passband frequency f_{pmax} and 3-dB cutoff frequency f_c.

(a) (b)

Figure 4. Photographs of the implemented HPF. (a) Top microstrip, and (b) bottom improved U-shaped slot resonator embedded with L-shaped slot.

Table 1. Comparison of various HPFs in different works.

Ref.	f_c/GHz at 3-dB	ILmin/dB In the passband	Sizes ($\lambda_g \times \lambda_g$)	f_{pmax}/f_c	ILmin/dB in the stopband
[3]	3.0	N/A	0.092×0.185	2.0	> 40
[7]	1.8	1.3	0.08×0.09	3.0	> 40
[8]	1.74	0.33	N/A	4.5	> 60
[9]	1.5	2.2	0.37 (length)	2.0	> 40
[10]	1.45	2.0	N/A	1.7	> 30
This work	5.9	0.81	0.086×0.13	2.6	> 40

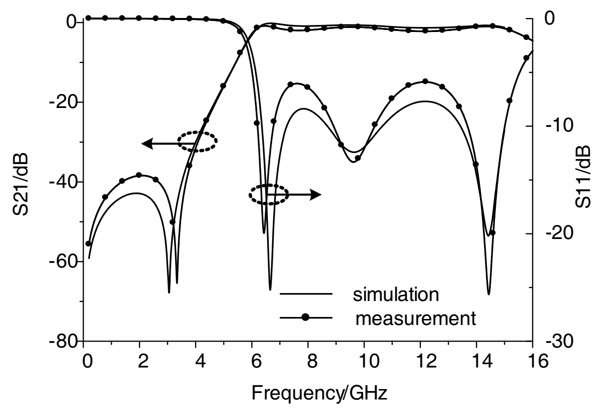


Figure 5. Simulated and measured results of implemented HPF.

4. CONCLUSION

In this article, a novel and miniaturized HPF using an improved U-shaped slot resonator embedded with an L-shaped slot with a dual-mode wideband response has been designed, manufactured, and measured. The ultra-wide passband response has been implemented by the proposed composite DGS, which is coupled broadside to the top microstrip sections. The fabricated HPF has exhibited an ultra-wide passband filtering response up to $2.6f_c$, a return loss with three transmission poles within the passband, and a good stopband attenuation characteristic with two transmission zeros. In addition, the proposed HPF has a very simple geometrical structure and circuit topology. Therefore, the filter is easy designed and implemented via conventional PCB technology. The concept and approach to the HPF proposed in this paper could also be used to implement ultra-wideband bandpass filters, based on the cascade of high- and low-pass filters.

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REFERENCES

1. Hong, J. S. and M. J. Lancaster, *Microstrip Filters for RF/Microwave Applications*, Wiley, New York, 2001.
2. Shoaib, N., I. Shoaib, and S. Shoaib, "A novel approach to transform an open circuit series stub to a short circuit shunt stub for the implementation of high-pass butterworth filter," *Microwave Opt. Technol. Lett.*, Vol. 55, 497–501, 2013.
3. Durán-Sindreu, M., J. Bonache, and F. Martín, "Elliptic high-pass filters with stepped impedance resonators in coplanar waveguide technology," *Microwave Opt. Technol. Lett.*, Vol. 54, 1094–1097, 2012.
4. Misan, S., R. Haviv, D. Ackerman, H. Matzner, and M. Haridim, "A high-pass filter based on modified double-sided parallel-strip lines," *Microwave Opt. Technol. Lett.*, Vol. 51, 2691–2694, 2009.
5. Chramiec, J., M. Kitlinski, and J.-J. Bogdan, "Microstrip line with short-circuited edge as a high-pass filter operating up to millimeter-wave frequencies," *Microwave Opt. Technol. Lett.*, Vol. 49, 2178–2180, 2007.

6. Li, C., K.-Y. Liu, and F. Li, "Design of microstrip highpass filters with complementary split ring resonators," *Electron. Lett.*, Vol. 43, 35–36, 2007.
7. Mondal, P. and A. Chakrabarty, "Compact highpass filter using complementary split ring resonator," *Microwave Opt. Technol. Lett.*, Vol. 49, 2470–2472, 2007.
8. Liu, J.-C., D.-S. Shu, B.-H. Zeng, and D.-C. Chang, "Improved equivalent circuits for complementary split-ring resonator-based high-pass filter with C-shaped couplings," *IET Microw. Antennas Propag.*, Vol. 2, 622–626, 2008.
9. Selga, J., G. Sisó, M. Gil, J. Bonache, and F. Martín, "Microwave circuit miniaturization with complementary spiral resonators-Application to high-pass filters and dual-band components," *Microwave Opt. Technol. Lett.*, Vol. 51, 2741–2745, 2009.
10. Selga, J., M. Gil, F. Aznar, J. Bonache, and F. Martín, "Composite right-left-handed coplanar waveguides loaded with split ring resonators and their application to high-pass filters,," *IET Microw. Antennas Propag.*, Vol. 4, No. 7, 822–827, Jul. 2010.
11. Baik, J.-W., L. Zhu, and Y.-S. Kim, "Dual-mode dual-band bandpass filter using balun structure for single substrate configuration," *IEEE Microw. Wireless Compon. Lett.*, Vol. 20, 613–615, 2010.
12. Luo, S. and L. Zhu, "A novel dual-mode dual-band bandpass filter based on a single ring resonator," *IEEE Microw. Wireless Compon. Lett.*, Vol. 19, 497–499, 2009.
13. Chiou, Y.-C., C.-Y. Wu, and J.-T. Kuo, "New miniaturized dual-mode dual-band ring resonator bandpass filter with microwave C-sections," *IEEE Microw. Wireless Compon. Lett.*, Vol. 20, 67–69, 2010.