Lowpass Filter Design Based on Microstrip Meander Line with HDGS

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Abstract – A microstrip meander line with a single H-shaped Defected Ground Structure (HDGS) is employed to design a novel compact lowpass filter with sharp roll off and wide stop band. Two parametric studies were conducted to analyze the sensitivity of the HDGS position and the size effects on the filter response. The design is fabricated to have a 6 GHz cutoff frequency using Rogers TMM 10i substrate, with an area of 7.6 x 6 mm^2. The measured results are in a good agreement with simulation prediction.

Index Terms – Defected ground structures, compact filter, lowpass filter and microstrip meander line.

I. INTRODUCTION

Lowpass filters are widely used in various wireless communication systems; they take important roles in many microwave integrated circuits and monolithic microwave integrated circuits. Lowpass filters with compact design, superior performance and low cost are highly desired to incorporate in innovative microwave systems. There have been several variations to the state-of-art microstrip line structure, such as meandering the transmission line [1-7], defecting the ground plane structure [8-28]; to enhance the behavior of the lowpass filter.

Defecting the ground plane structure of a microstrip line has been popular for more than a decade. A defect etched in the ground plane rejects certain frequency bands by suppressing the surface wave based on its geometry and position. There have been many geometrical Defected Ground Structures (DGS), such as dumbbell [12-15], circular [16], elliptical [17-18], Complementary Slot Ring Resonator (CSRR) [5, 19-21], U-shaped [22-23], H-shaped [24-25]; where each shape has its merits. In designing lowpass filters using DGS shapes, two or more DGS's are used in order to attain good frequency response, such as low insertion loss, sharp cutoff transition and wide stop band.

In this paper, instead of using a straight microstrip line with multiple DGS, a meander microstrip line is used with a single H-shaped Defected Ground Structure (HDGS), to design a compact lowpass filter with a superior performance. The proposed meander line filter

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with a single DGS is compact and is characterized by very low insertion loss in the passband, a steep roll-off transition and a wide stopband. A parametric study of the effects of size and position sensitivity of the HDGS are investigated. The filter is measured and compared with simulation results.

II. CONFIGURATION AND CHARACTERISTICS OF THE LOWPASS FILTER

The proposed lowpass filter is depicted in Fig. 1, where a meandered 50-Ω line is printed on top of the dielectric layer surface and an HDGS etched in the ground plane. It is to be noted that in this design, the center of the HDGS is positioned exactly beneath the center of the meander line (L/2, W/2). The meander line parameters are illustrated in Fig. 1 (a), which are the meander spacing (l_1 and l_2), the meander line length (L) and the meander line width (D). The HDGS parameters are illustrated in the inset of Fig. 1 (b), which are the slot width (a), the slot gap (g) and the side lengths (b_1 and b_2). These parameters have prime influence on the performance of the filter. Therefore, the meander line and the H-defect parameters must be carefully chosen in order to achieve the satisfactory filter performance.

Using Agilent Advanced Design System (ADS) software, the proposed lowpass filter is simulated and results are plotted in Fig. 2. The lowpass filter is designed to operate at a cutoff frequency 6 GHz. It is worth mentioning that the area of the HDGS plays a dominant role in determining the cutoff frequency of the filter. The pass band ripples are less than 0.5 dB; the flatness in the pass band is affected by the dimensions of the slot width (a) and the slot gap (g). The meander line inhabits slow wave effect causing a wide stop band with high attenuation level [1, 7]. The stop band of the simulated S_{21} response maintains its attenuation level below -20 dB from 6.5 GHz to 10.7 GHz and below -10 dB from 6.25 GHz to 22.1 GHz, demonstrating a wide stop band as well as high rejection level, which reaches -68 dB at 10 GHz.

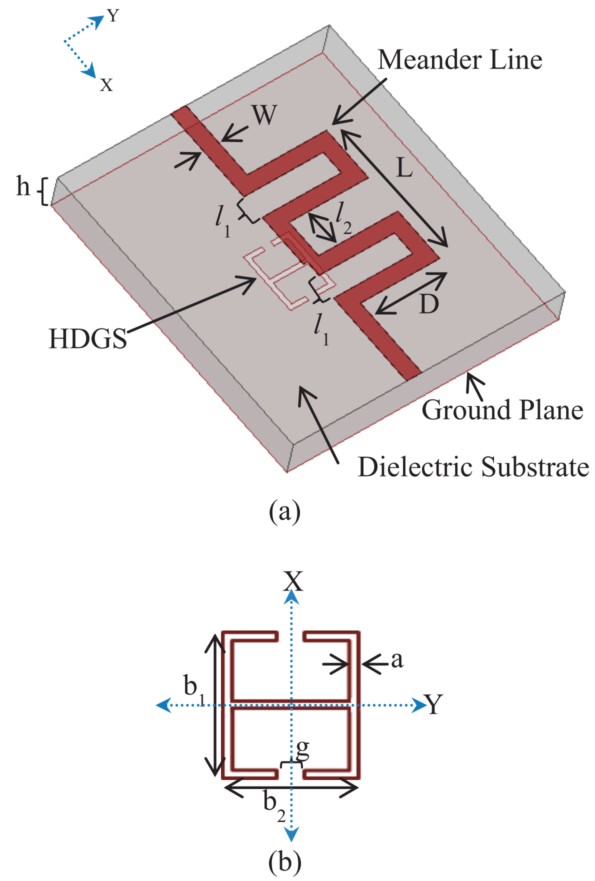


Fig. 1. Geometry of the proposed lowpass filter: (a) meander line and (b) HDGS.

The substrate is designed using Rogers TMM 10i™ with dielectric constant ε_r=9.8 and thickness h=0.508 mm. The conductor strip has 50 Ω characteristic impedance given by the width W=0.5 mm. Intensive simulations were conducted to optimize the filter parameters to achieve a superior lowpass filter response in terms of flat pass band, sharp roll-off transition and wide stop band with high attenuation level. The geometric dimensions of the meander line as well as the dimensions of the H-shaped ground defect are tabulated in Table 1. These dimensions bring the filter length to 0.39 of the effective electrical wavelength at the cutoff frequency, which denotes the compactness of the proposed lowpass filter size.

Table 1: The design parameters of the proposed lowpass filter in millimeter

L	l_1	l_2	D	a	b_1	b_2	g
7.6	1.55	2.5	5.5	0.3	4	3	0.6

In the design procedure of the proposed filter, dimensions of the HDGS are first obtained to set the cutoff frequency at 6 GHz. The meander spacing (l_1 and l_2) and the meander line width (D) are then optimized to reach a superior lowpass filter performance.

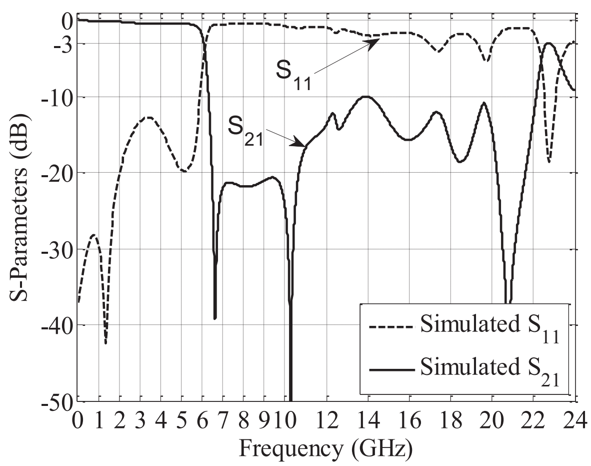


Fig. 2. The response of the proposed lowpass filter; S_{21} (solid line) and S_{11} (dashed line).

Figure 3 illustrates the performance of the meander line LPF, compared with the straight line based filter with one DGS. It is to be observed that the proposed meander line performs better in all aspects with a flat pass band, a steep transition region, a wide stop band and a high attenuation level in the stop band. The superiority of the performance of the proposed filter justifies the replacement of the straight line by meander line. It is worth noting that the straight line design can have better filter response if the number of DGS's are increased to two or more [19-22, 25], but this would be at the expense of more filter size.

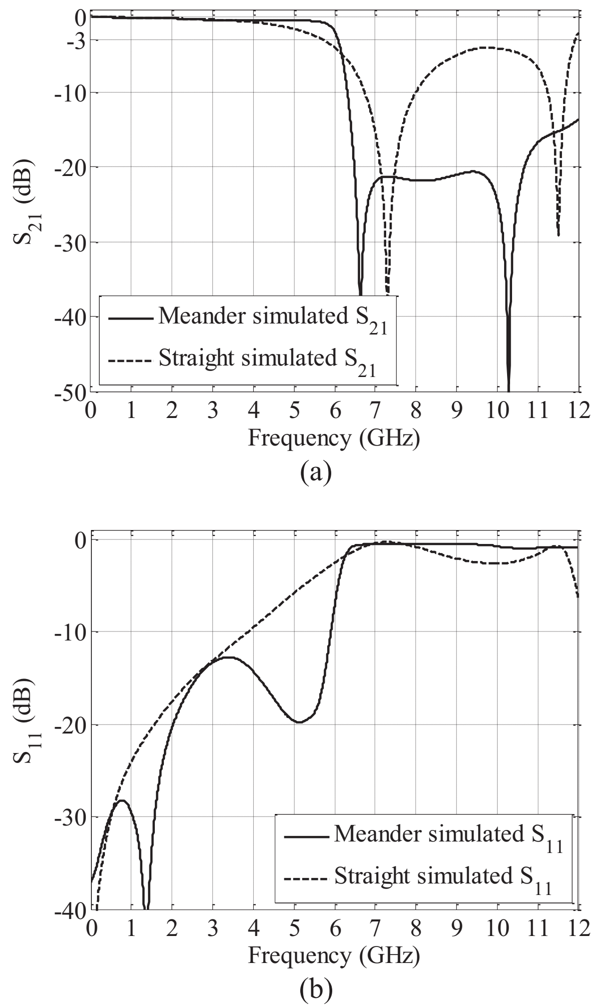


Fig. 3. S-parameters simulation comparison between the proposed lowpass filter (solid line) and the straight line design (dashed line): (a) S_{21} and (b) S_{11}.

III. PARAMETERIC STUDY

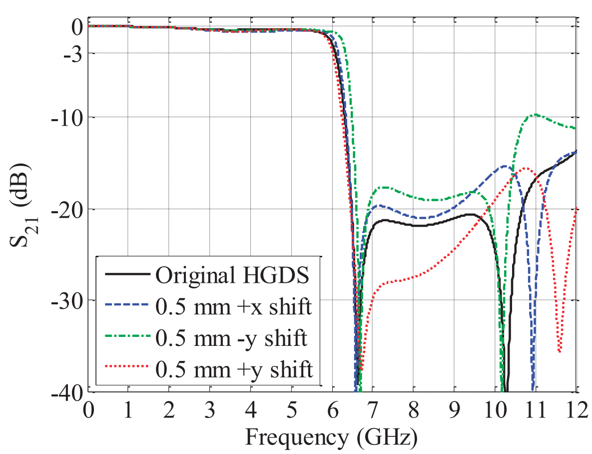
The performance of the presented lowpass filter underwent two parametric studies. First an investigation is carried out to learn more about how sensitive the positioning of the H-defect in the ground plane relative to the meander structure. This will give a measure of how tolerant the filter design to any miss-alignment in the positioning of the HDGS during fabrication. A second study is conducted to understand the result of having a different-sized HDGS on the filter response.

A. Sensitivity study

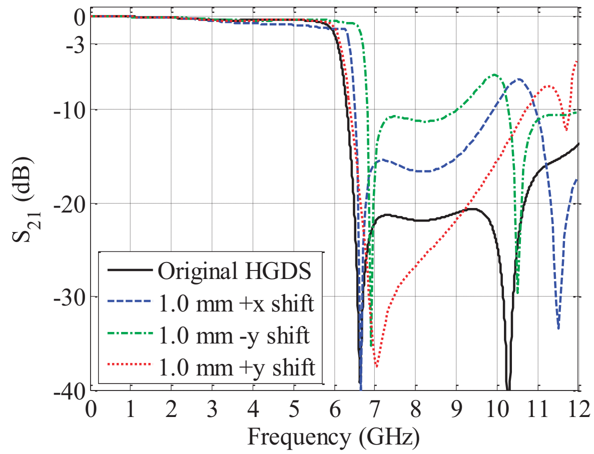
To verify the role of positioning the HDGS relative to the meander line, this test is performed. The study is based on shifting the HDGS position relative to the meander line, in other words keeping all parameters fixed except the position of the HDGS relative to the meander line. The study results are then compared to the original design. This study consists of six tests, where in each test the HDGS is displaced from the original design position, where the center of the HDGS is positioned exactly beneath the center of the meander line (L/2, W/2) by a specified amount in a specified direction.

Six tests have been carried out by shifting the HDGS 0.5 mm in the +x-direction, 0.5 mm in the ±y-direction, 1.0 mm in the +x-direction and 1.0 mm in the ±y-direction. The simulated S_{21} of each test is compared with the original proposed design as shown in Fig. 4. It is observed that the attenuation level and the width of the stop band are affected by the position of the HDGS relative to the meander line structure. Also, the cutoff frequency of the filter is shifted to higher values compared to the proposed operating cutoff frequency.

In case of any miss-alignment in fabrication, it can be argued that the filter performance is satisfactory with shift up to 1.0 mm in the +y-direction (33.3% of b_2), 0.5 mm in the –y-direction (16.7% of b_2), and 0.5 mm in the + or – x-direction (12.5% of b_1).



(a)



(b)

Fig. 4. Comparison of simulated S_{21} between the original proposed low-pass filter design (solid line) and spatial sensitivity test cases: (a) 0.5-mm displacements in HGDS designs and (b) 1.0-mm displacements in HGDS designs.

B. Scaling study

To underline the significance of the size of the HDGS etched in the ground plane, a scaling study is carried out. The study is based on re-simulating the proposed design, keeping all parameters fixed except for the size of the HDGS. This study consists of four tests, where in each test the HDGS is scaled by a specified factor. These four tests are scaling the H-shaped defect by 0.8, 0.9, 1.1 and 1.2. All simulation responses are compared to the original proposed design.

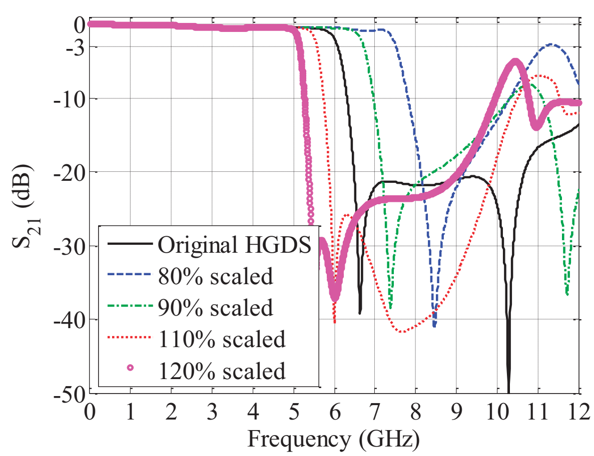
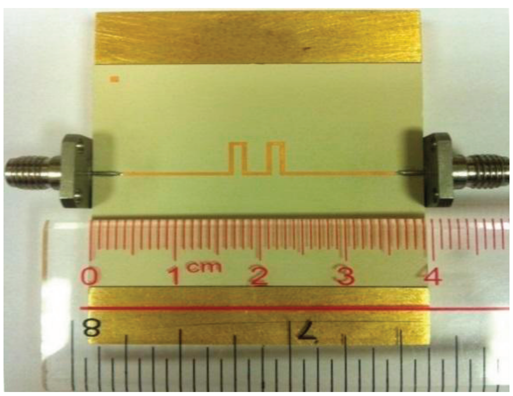


Fig. 5. The S_{21} simulations of the original proposed design (solid line) and all 4 cases of the scaling study.

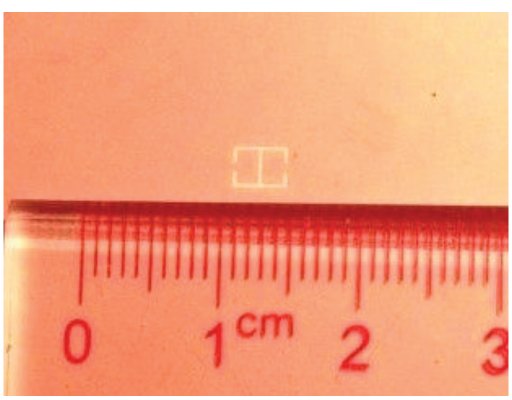
Figure 5 shows the result of the study, where it is deduced that the cutoff frequency of the lowpass filter is affected by the size of the HDGS. It is realized that the larger the HDGS is, the lower the cutoff frequency is and vice versa. It is important to mention that the conducted tests did not include optimizing of the filter parameters for each case; it was merely scaling of the HDGS.

IV. EXPERIMENTAL RESULTS

The lowpass filter presented in this paper is fabricated, where the meander line structure is implemented on a Rogers TMM 10i substrate with dielectric constant ε_r=9.8 and thickness h=0.508 mm. These are the same design parameters used in all of the simulations in this paper. Figure 6 (a) and (b) illustrate photographs of the top layer and the HDGS layer of the fabricated filter, respectively. The miniature size of the meander structure is evident as well as the HDGS size.



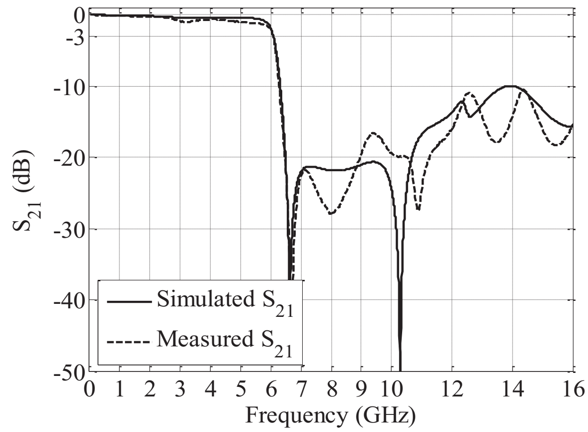
(a)



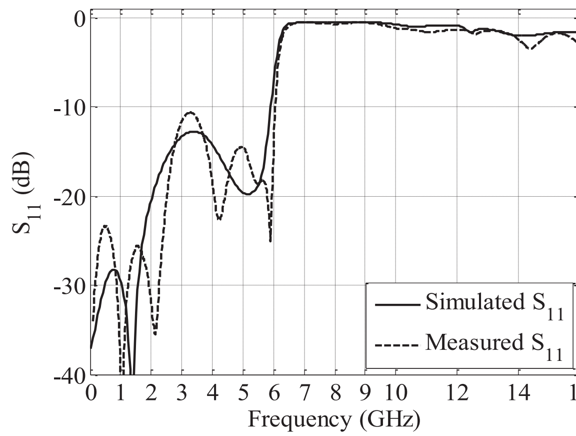
(b)

Fig. 6. Photographs of the measured low-pass filter: (a) the top layer and (b) the HDGS layer.

The manufactured lowpass filter response was measured by a vector network analyzer and results of the measurements are compared with the simulation predictions as shown in Fig. 7. These measurements show a good agreement with simulation results.



(a)



(b)

Fig. 7. S-parameters comparison between the simulated design (solid line) and the fabricated filter (dashed line): (a) S_{21} and (b) S_{11}.

V. CONCLUSION

In this paper, we present a compact superior lowpass filter comprising a meander line structure on top of a 0.508-mm Rogers TMM 10i substrate and a single H-shaped defect etched in the ground plane. The effect of the proposed meander line is compared with the straight line design. The comparison proves the superiority of the proposed design in terms of the filter criteria, such as a flat response in the pass band, a steep roll-off in the transition region and a wide stop band with high attenuation level staying below -10 dB from 6.25 GHz to 22.1 GHz. The operating cutoff frequency of the lowpass filter at 6 GHz is affected by the position and size of the HDGS. Two parametric studies were administered to investigate the effects of the position sensitivity of the HDGS relative to the meander line, as well as the size of the HDGS. The position sensitivity study shows that the proposed design can tolerate miss-alignment of the HDGS position up to 1.0 mm in the +y-direction (33.3% of b_2), 0.5 mm in the –y-direction (16.7% of b_2) and 0.5 mm in the + or – x-direction (12.5% of b_1). The scaling study presented the general relationship between the size of the HDGS and the filter cutoff frequency as inversely proportional. Scaling of the HDGS also affects the stop band response, and hence, further optimization is required to obtain satisfactory results. The presented lowpass filter design is simulated, fabricated and measured, where measurements show a good agreement with simulation results.

REFERENCES

[1] C. K. Wu, H. S. Wu, and C. K. C. Tzuang, "Electric-magnetic-electric slow-wave microstrip line and bandpass filter of compressed size," *IEEE Microwave Theory and Techniques*, vol. 50, no. 8, 1996-2004, August 2002.

[2] P. Vincent, J. Culver, and S. Eason, "Meandered line microstrip filter with suppression of harmonic passband response," *Microwave Symposium Digest, IEEE MTT-S International*, vol. 3, 1905-1908, 2003.

[3] G. Y. Su, C. N. Chan, U. L. Tam, and K. W. Tam, "Compact microstrip lowpass filter using a meander-line structure," *Microwave and Optical Technology Letters*, vol. 48, no. 7, 1339-1341, 2006.

[4] H. Liu, R. H. Knoechel, and K. F. Schuenemann, "Miniaturized bandstop filter using meander spurline and capacitively loaded stubs," *ETRI Journal*, vol. 29, n. 5, 614-618, 2007.

[5] G. L. Wu, W. Mu, X. W. Dai, and Y. C. Jiao, "Design of novel dual-band bandpass filter with microstrip meander-loop resonator and CSRR DGS," *Progress In Electromagnetics Research, PIER 78*, 17-24, 2008.

[6] M. Naser-Moghadasi, M. Alamolhoda, and B. Rahmati, "Spurious response suppression in hairpin filter using DMS integrated in filter structure," *Progress In Electromagnetics Research C*, vol. 18, 221-229, 2011.

[7] E. Metlevskis and R. Martavicius, "Computer models of meander slow-wave system with additional shields," *Electronics and Electrical Engineering*, vol. 119, no. 3, 2012.

[8] C. Kim, J. Park, D. Ahn, and J. Lim, "A novel 1-D periodic defected ground structure for planar circuits," *IEEE Microwave and Guided Wave Letters*, vol. 10, no. 4, 2000.

[9] L. H. Weng, Y. C. Guo, X. W. Shi, and X. Q. Chen, "An overview on defected ground structure," *Progress In Electromagnetics Research B*, vol. 7, 173-189, 2008.

[10] J. Xiao, S. Ma, and Y. Li, "A novel h-shaped microstrip resonator and its design to filter using defected ground structure," *High Density Microsystem Design and Packaging and Component Failure Analysis, Conference*, *2005.*

[11] H. Liu, Z. Li, and X. Sun, "Compact defected ground structure in microstrip technology," *Electronics Letters*, vol. 41, 132-134, 2005.

[12] H. Liu, Z. Li, X. Sun, and J. Mao, "Harmonic suppression with photonic bandgap and defected ground structure for a microstrip patch antenna," *IEEE Microwave and Wireless Components Letters*, vol. 15, 55-56, 2005.

[13] M. Salehi, A. Motevasselian, A. Tavakoli, and T. Heidari, "Mutual coupling reduction of microstrip antennas using defected ground structure," *10th IEEE International Conference on Communication Systems*, 1-5, 2006.

[14] S. H. Zainud-Deen, M. E. S. Badr, E. El-Deen, K. H. Awadalla, and H. A. Sharshar, "Microstrip antenna with defected ground plane structure as a sensor for landmines detection," *Progress In Electromagnetics Research B*, vol. 4, 27-39, 2008.

[15] F. Y. Zulkifli, E. T. Rahardjo, and D. Hartanto, "Radiation properties enhancement of triangular patch microstrip antenna array using hexagonal defected ground structure," *Progress In Electromagnetic Research M*, vol. 5, 101-109, 2008.

[16] B. T. Tan, S. T. Chew, M. S. Leong, and B. L. Ooi, "A modified micrstrip circular patch resonator filter," *IEEE Microwave and Wireless Components Letters*, vol. 12, no. 7, 252-254, 2002.

[17] R. Dehdasht-Heydari and M. Naser-Moghadasi, "Introduction of a novel technique for the reduction of cross polarization of rectangular microstrip patch antenna with elliptical DGS," *Journal of Electromagnetic Waves and Applications*, vol. 22,

no. 8-9, 1214-1222, 2008.

[18] X. Q. Chen, L. X. Wang, L. H. Weng, and X. W. Shi, "Compact low pass filter using novel elliptic shape DGS," *Microwave and Optical Technology Letters*, vol. 51, no. 4, 1088-1091, 2009.

[19] J. Zhang, B. Cui, S. Lin, and X. W. Sun, "Sharp-rejection low-pass filter with controllable transmission zero using complementary split ring resonators (CSRRS)," *Progress In Electromagnetic Research, PIER 69*, 219-226, 2007.

[20] S. S. Karthikeyan and R. S. Kshetrimauim, "Compact wideband bandpass filter using open slot split ring resonator and CMRC," *Progress In Electromagntics Research Letters*, vol. 10, 39-48, 2009.

[21] G. E. Al-Omair, S. F. Moahmoud, and A. S. Al-Zayed, "Lowpass and bandpass filter design based on DGS with complementary split ring resonators," *Applied Computational Electromagnetics Society Journal*, vol. 26, no. 11, 907-914, 2011.

[22] S. W. Ting and K. W. Tam, "Miniaturized microstrip lowpass filter with wide stopband using double equilateral u-shaped defected ground structure," *Microwave and Wireless Components Letters*, vol. 16, no. 5, 240-242, 2006.

[23] D. H. Bi and Z. Y. Yu, "Study of dual stopbands UWB antenna with u-slot and v-slot DGS," *Journal of Electromagnetic Waves and Applications*, vol. 22, no. 17-18, 2335-2346, 2008.

[24] H. W. Lui, "Design of a miniaturized HTS mictrostrip resonator with slotted ground plane," *J. of Active and Passive Electronic Devices*, vol. 4, 257-280, 2009.

[25] A. Boutejdar, S. Amari, A. Elsherbini, A. S. Omar, "A novel lowpass filter with ultra-wide stopband and improved q-factor performance using h-defected ground structure (DGS)," *IEEE Antennas and Propagation Society International Symposium*, 1545-1548, 2007.

[26] L. Maloratsky, "Using modified microstrip lines to improve circuit performance," *High Frequency Electronics*, March 2011.

[27] A. Boutejdar, A. Sherbini, W. Ali, S. Fouad, L. Ahmed, and A. Omar, "Design of compact microstrip lowpass filters using coupled half-circle defected ground structures," *IEEE Antennas and Propagation Society International Symposium*, 2008.

[28] M. H. Al Sharkawy, D. A. El-Aziz, and E. G. Mahmoud, "A miniaturized lowpass/bandpass filter using double arrow head defected ground structure with centered etched ellipse," *Progress In Electromagnetics Research Letters*, vol. 24, 99-107, 2011.

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