A MINIATURIZED LOWPASS/BANDPASS FILTER US-ING DOUBLE ARROW HEAD DEFECTED GROUND STRUCTURE WITH CENTERED ETCHED ELLIPSE

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Abstract—A new double arrow head defected ground structure (DGS) with centered etched ellipse is proposed for designing a multilayer low pass filter (LPF) with wide rejection band and low insertion loss in the stop-band. The prototype LPF consists of three double arrow head DGS with centered etched ellipse in the ground plane and compensated capacitor on the top layer of a $30 \times 40 \, \text{mm}^2$ Roger RT/Duroid5880 substrate having relative permittivity (ε_r) of 2.2 and thickness of 0.78 mm. The cutoff frequency is equal to 1.07 GHz. The prototype LPF is then realized as multilayer structure to enhance the filter response and reduce its size. The size reduction of the proposed multi-layer LPF is about 26% more than the conventional one. The proposed filter has been fabricated and measured. Good agreement is achieved between the simulated and measured results. The filter presents the advantages of compact size; low insertion loss and high out-band suppression. Finally, the multilayer LPF is transformed to band pass filter (BPF) using J-inverter method.

1. INTRODUCTION

Microwave filters are one of the most important components in modern telecommunication systems [1–4]. Microwave filters are the basic building blocks used for frequency selectivity in the development of various wireless systems that operate at frequency ranges above 300 MHz. Filters block play a key role in effectively transmitting the desired signals in certain pass-band regions while attenuating all the undesired signals in the remaining band-stop regions [5]. Minimum

insertion loss, high selectivity, and compactness are very necessary requirements to ensure optimal filter performance. Continually improving filter performance along with size compactness are both considered as challenging constraints, which must be faced when designing planar filters. Defected ground structures have gained much interest in the fabrication of microwave and millimeter wave filters. The idea of the DGS is realized by etching a slot in the ground plane. The DGS slot disturbs the current flow in the ground plane and in turn causes a periodic perturbation of the characteristic impedance, which causes band gap characteristics over certain frequency bands. This disturbance affects the value of the capacitance and inductance of the transmission line [2–4] and thus suppresses spurious response in the LPF.

In this paper, a new design for a LPF is investigated. The proposed filter has a cutoff frequency of 1.07 GHz. The performance and size of the proposed filter has been enhanced by introducing the multilayer technique [3]. Furthermore, a parametric study involving the effect of changing the coupling distance between the DGS elements on the filter response has been conducted. The transformation form LPF to BPF is also presented.

2. PROPOSED DOUBLE ARROW HEAD WITH CENTERED ETCHED ELLIPSE SINGLE ELEMENT STRUCTURE

The idea of using the arrow head DGS structure is used in this work [5]. Fig. 1 shows the geometry of a single DGS element that consists of double arrow heads with etched ellipse at the center of each head, connected together using a rectangular slot. The single DGS element is involved in the design of the prototype LPF introduced in this work.
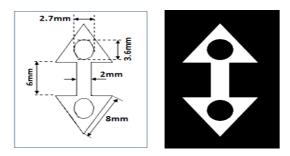

Figure 1. Geometry of the single element for the proposed DGS LPF.

The proposed LPF is designed on a Roger RT/Duroid5880 dielectric substrate of surface area equals to $30 \times 40 \, \text{mm}^2$, having a dielectric constant of 2.2 and a thickness of 0.78 mm as shown in Fig. 2. The DGS element is slotted in the ground plane of the dielectric substrate, while a 50-Ω microstrip line of width 2.421 mm and a compensated capacitor is constructed on its top layer. The S-parameters results of the proposed LPF are generated using Ansoft HFSS [6] and shown in Fig. 3. A cutoff frequency of 1.07 GHz together with an attenuation
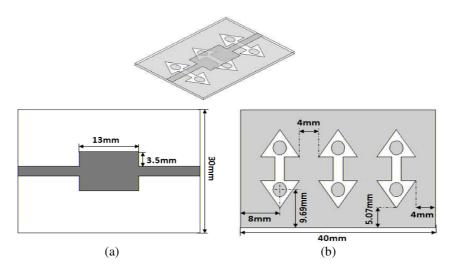

Figure 2. Schematic diagram of the prototype LPF (a) top layer and (b) bottom layer.
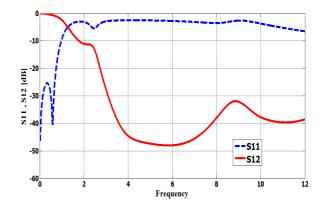

Figure 3. S-parameters results for the proposed LPF.

level of -48 dB at 6 GHz can be observed from the data provided in
Fig. 3. A rejection band of 9 GHz can be realized at an attenuation
level of 20 dB starting from 2.7 GHz to 12 GHz. To achieve more size
reduction and maintain the filter performance, further investigation
was added to the prototype filter.

3. MULTILAYER LPF WITH WIDE REJECTION BAND

The multilayer technique is proposed in this work to enhance the filter
response and at the same time achieve more size reduction relative to
the prototype configuration shown in Fig. 2 [3]. Thus, a multilayer
LPF is realized by replacing the compensated capacitor on the top
layer of the substrate with one of the bottom elliptical slotted arrow
head DGS elements. Fig. 4 shows the schematic diagram of both, top
and bottom layers. A total size reduction of 26% was gained compared
to the conventional LPF shown in Fig. 2. The new total dimension
of the dielectric substrate is 26×34 mm^2. A further investigation
was considered to confirm, which final design should be fabricated and
measured. Hence, a circular slot was introduced in the arrow heads,
having a radius of 1.8 mm and the computed scattering parameters
were compared to that generated using the elliptical slots and shown in
Fig. 5. One can notice from the comparison provided in Fig. 5 that the
rejection band has slightly decreased using the circular slot relative to
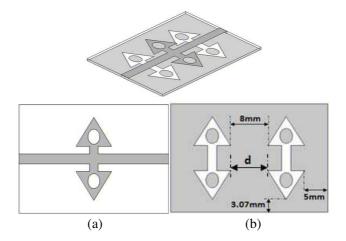the elliptical one. On the other hand, the level of the pass-band region

(a)   (b)

Figure 4. Schematic diagram of the multilayer LPF (a) top layer and
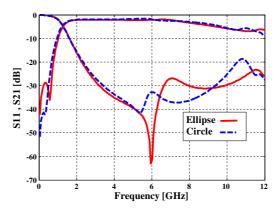(b) bottom layer.

Figure 5. Comparison between the S-parameters results for circular and elliptical slots.
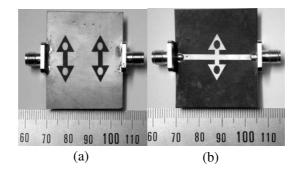

Figure 6. Fabricated DGS-LPF, (a) bottom view and (b) top view.

was reduced to -35 dB relative to the -29 dB used by the elliptical slot. Thus, the proposed multilayer LPF for the elliptical slot configuration was fabricated and measured as shown in Fig. 6. The simulated and measured S-parameters of the multilayer LPF are shown in Fig. 7. Good agreement between the simulated and measured results can be observed. Based on the simulated results, one can realize that the filter exhibits lower insertion loss in the stop band with a sharper transition from the pass-band to the stop band relative to the performance of the prototype LPF. A parametric study involving the effect of changing the coupling distance between the double arrow heads is constructed, which in turn result in affecting the ripples level in the pass-band of the proposed LPF. As shown in Table 1, one can realize that at $d = 8$ mm the ripple level in the pass-band region reaches a minimum value of -29 dB.
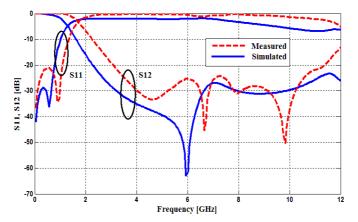
Figure 7. Measured and simulated S-parameters results for the multilayer LPF.

Table 1. Effect of changing the coupling distance on the ripple level in the pass-band region.

Coupling distance d [mm]	Ripple level in pass-band [dB]	Size [mm^2]
1	-22.43	26×34
2	-24.30	26×34
3	-24.52	26×34
4	-26.57	26×34
5	-23.38	26×34
6	-26.37	26×34
7	-26.43	26×34
8	-27.55	26×34
9	-27.41	26×36
10	-27.19	26×36

4. ELECTRIC FIELD DISTRIBUTION

As a way of verifying the performance of the proposed multilayered LPF, near field distribution has been computed as shown in Fig. 8. The electric field was computed at two frequencies, one in the stop-band region and the other in the pass-band region. At the frequency of 1 GHz, one can realize that the electric field is almost concentrated in
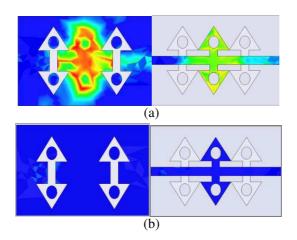
(a)

(b)

Figure 8. Electric field distribution within the multilayer LPF at (a) $f_0 = 1\,\text{GHz}$ and (b) $f_0 = 4\,\text{GHz}$.

the region between the two arrow head DGS slots in the ground plane and the one arrow head printed on the top layer. On the other hand, at the frequency of 4 GHz; the electric field distribution is almost zero in the arrow head DGS slots, which operates in the stop-band region.

5. TRANSFORMATION OF LPF TO BPF USING J-INVERTER METHOD

Figure 9 shows the geometry of the proposed BPF using J-inverter method [7–9]. The proposed BPF consists of the two double arrow head with centered etched ellipse DGS in the ground plane and a 50-Ω microstrip line printed on top of the substrate with a width of 2.421 mm from both sides. The microstrip line is then connected through radial edges with a high impedance microstrip line of width 0.921 mm as shown in Fig. 9. The high impedance microstrip line is connected to an elliptical microstrip patch with a rectangular gap of width 0.15 mm at the center of the top layer. The proposed BPF exhibits a center frequency of 1.95 GHz. The Roger RT/Duroid 5880 substrate used before in this paper for the LPF is being used again for realizing the BPF. Fig. 10 represents the frequency response of the BPF, having a pass-band region from 1.87 GHz to 2.1 GHz at the 20 dB attenuation level.
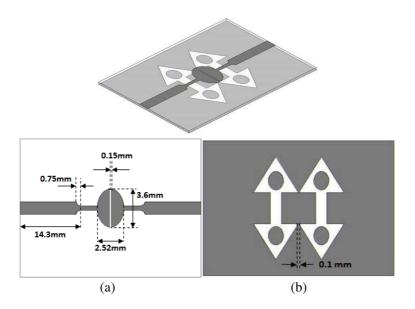
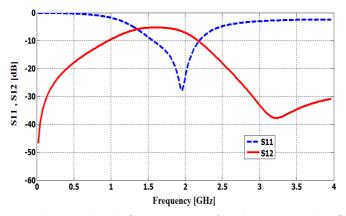**Figure 9.** The geometry of the proposed BPF, (a) top view and (b) bottom view.

Figure 10. The simulated S-parameters for the proposed DGS BPF.

6. CONCLUSIONS

This paper has proposed a new double arrow head with centered etched ellipse DGS structure used for designing a LPF. The multilayer technique is introduced to reduce the filter size and enhance the rejection band response compared to the prototype LPF. A size reduction of 26% was achieved resulting in a more compact LPF when

compared to the previous design. The multilayer LPF is fabricated and good agreement is obtained between the simulated and measured results. The filter exhibits interesting characteristics in terms of compactness, return loss, insertion loss, and selectivity. Moreover, an electric field analysis was performed on the proposed LPF. The proposed LPF is then transformed to BPF using J-inverter technique.

REFERENCES

1. Boutejdar, A., A. Sherbini, S. Amari, and A. S. Omar, "A new technique to double the reject band of a low-pass filter by employing coupled C-open-loop resonators as defected ground," *Asia Pacific Microwave Conference*, Yokohama, Japan, 2006.

2. Lim, J. S., C. S. Kim, T. Y. Lee, D. Ahn, and Nam, "Design of low pass filters using defected ground structure and compensated microstrip line," *Electronic Letters*, Vol. 38, 1357–1358, 2002.

3. Boutejdar, A. and A. S. Omar, "A miniature 5.2-GHz band stop microstrip filter using multilayer technique and coupled octagonal defected ground structure," *Microwave and Optical Technology Letters*, Vol. 51, 2810–2813, 2009.

4. Ahn, D., J. Park, C. Kim, J. Kim, Y. Qian, and T. Itoh, "A design of the low-pass filter using the novel microstrip defected ground structure," *IEEE Trans. Microwave Theory Tech.*, Vol. 49, 86–93, 2001.

5. Rahman, A., A. Boutejdar, A. K. Verma, G. Nadim, and A. S. Omar, "Improved circle model for DGS based lowpass filter," *IEEE Antennas and Propagation Symposium*, Vol. 1, 998–1001, 2004.

6. http://www.ansoft.com/products/hf/hfss/.

7. Awida, M., A. Boutejdar, A. Safwat, H. El-Hennawy, and A. Omar, "Multi-bandpass filters using multi-armed open loop resonators with direct feed," *IEEE MTT-S International Microwave Symposium*, Honolulu, Hawaii, June 2007.

8. Li, M., L. Haiwen, A. Boutejdar, W. Shuxin, and F. Tong, "Novel microstrip bandpass filter with slotted hexagonal resonators and capacitive loading," *Proc. 38th EUMC*, Amsterdam, The Netherlands, October 2008.

9. Al Sharkawy, M. H., A. Boutejdar, F. Alhefnawi, and O. Luxor, "Improvement of compactness of lowpass/bandpass filter using a new electromagnetic coupled crescent defected ground structure resonators," *Applied Computational Electromagnetics Society (ACES) Journal*, Vol. 25, No. 7, July 2010.