# Compact Bandpass Filters with Bandwidth Control using Defected Ground Structure (DGS)

**Sajjad Ur Rehman, Abdel Fattah A. Sheta, and Majeed A. S. Alkanhal**

Department of Electrical Engineering
King Saud University, P.O.Box 800, Riyadh 11421, Kingdom of Saudi Arabia
engr.sajjadrehman@gmail.com, asheta@ksu.edu.sa, majeed@ksu.edu.sa

***Abstract*** **—**This paper presents new compact microstrip bandpass filters with bandwidth control by employing DGS resonators. The proposed bandpass filters consists of two coupled DGS resonators with a microstrip excitation. The bandwidth can be controlled by choosing the coupling structure between the two DGS resonators. The wider bandwidth can be achieved by adding a strip conductor between the two DGS resonators. However, the narrow bandwidth can be obtained by etching a slot in the strip conductor placed between the DGS resonators. The widths of the strip conductor and the etched slot control the filter bandwidth. Fractional bandwidth (*FBW*) from about 2.5% or less to more than 22% can be achieved by this design approach. The concept has been validated through the design and implementation of two filters with *FBW* of 6% and 12.9%. Measurements agree well with theoretical results.

***Index Terms*** **—** Bandpass filter, DGS filter, microstrip filters.

## I. INTRODUCTION

Recent advances in wireless communications demand high performance and compact RF subsystems. Almost all wireless communication systems require compact microwave filters, which can suppress unwanted out-of-band signals. The inherent advantages of defected ground structures (DGS) make it one of the most important techniques to meet compact high performance microwave filters. DGS is an etched periodic or non-periodic cascaded configuration defect in the ground of microstrip and coplanar lines. DGS disturbs the shield current distribution in the ground plane. This disturbance will change the characteristics of a transmission line such as line capacitance and inductance [1]. DGS have interesting properties such as size miniaturization, suppression of surface waves and arbitrary stop bands [2-4]. Since DGS cells have inherently resonant properties, many of them have been used in filtering circuits to improve the stop and pass band characteristics [5].

Many filters have been investigated which controls the center frequency and bandwidth [5-11]. DGS based patterns that can be considered the dual of the open-loop microstrip resonators is proposed in [5] and used to design coupled resonator filters with different external coupling arrangements. The same concept has also been used to design a multilayer coupled resonator DGS filter [6]. This approach introduces various coupling mechanisms to achieve a wider class of filtering functions. Dual-band bandpass filters featuring compact size and flexible frequency choice are demonstrated in [7] using resonators based on slotted ground structures. Two resonators based on slotted ground structures form the basis of the filter design. The resonators allow the back-to-back and face-to-face embedding configuration, hence, greatly reduces the physical size of the filters. The work reported in [8] proposed bandpass filter design based on coupled DGS and microstrip resonators. The combination of DGS and microstrip resonators allows use of the top and bottom side of the microwave substrate, therefore the resonators can partially overlap and desired coupling coefficient can be achieved. In [9],

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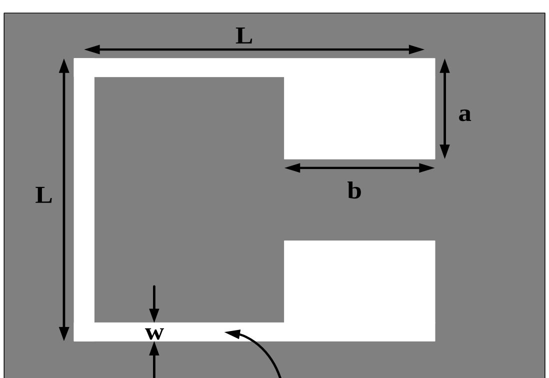
second and third order bandpass filters have been designed for fractional bandwidth from 7% to 17% through various feeding arrangements. In [10], a study of some planar microwave bandpass filters composed of defected ground resonators using electric and magnetic coupling are proposed. The proposed DGS microstrip resonator presented in [11] has the resonant and anti-resonant characteristic that is very similar to those of a SAW resonator or a FBAR.

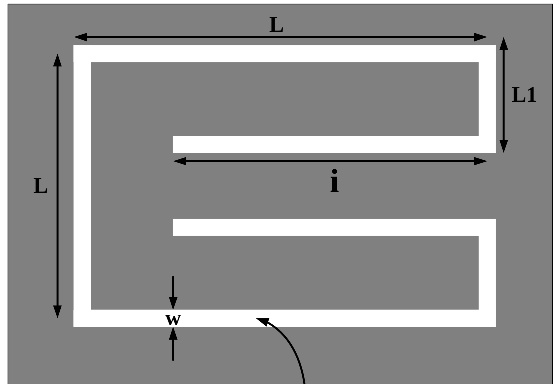
In this paper, we propose new compact microstrip bandpass filters based on coupled DGS resonators. A strip conductor placed between the DGS resonator and etched slot in this strip conductor adjust the coupling between the resonators and then the filter bandwidth. The bandwidth of the proposed filter is controlled by changing the slot and strip widths. The proposed DGS resonator is presented in Section II where in the effect of the resonator size on the resonator resonance frequency is discussed. Bandpass filters based on coupled DGS resonators are investigated in Section III followed by concluding remarks in Section IV.

## II. DGS RESONATORS

In the past years, various slotted ground resonators were proposed such as open-loop DGS resonators [5, 7], dumbbell [12], spiral [13], H-shaped [14], and cross-H shaped [15]. The proposed DGS resonators shown in Figs. 1(b) and 1(c) are developed from the conventional DGS resonator shown in Fig. 1(a) [7]. The self resonance frequency ($f_0$) of the resonator depends on its physical dimensions.



(a)



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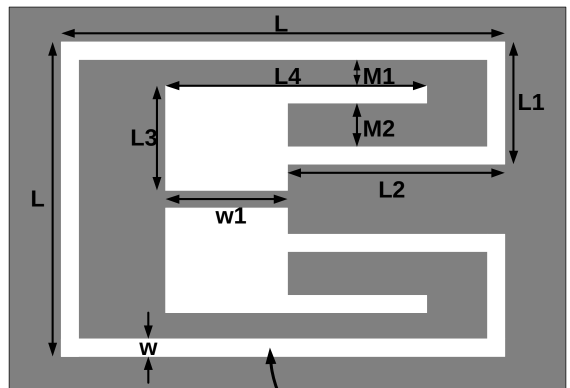
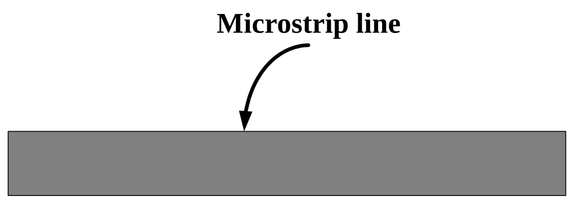


(c)



(d)

Fig. 1. Schematic layout of various DGS resonators: (a) backside of the DGS resonator proposed in [7], (b) backside of our proposed DGS resonator, Type A, (c) backside of our proposed DGS resonator, Type B, (d) front side of the DGS resonators.

All resonators are excited by 50 Ω microstrip line shown in Fig. 1(d). Duroid material with 2.2 dielectric constant and 0.78mm thickness is used. The length $L$ of the square cell is 10mm and $W$ is 0.5mm for all three resonators. $a$ and $b$ in Fig. 1(a) are 4mm and 5mm, respectively. $L1$ is 4mm and $i$ is 8mm for resonator in Fig. 1(b). Whereas, $L1$ is

4mm, *L2* is 5.5mm, *L3* is 3.5mm, *L4* is 6mm, *M1* is 0.9 mm, *M2* is 1.6mm, and *W1* is 2.5mm for the proposed resonator shown in Fig. 1(c). For the same square size $L \times L$ the structure shown in Fig. 1(c) is the most compact structure (i.e the lowest resonance frequency) compared to those shown in Figs. 1(a) and 1(b). Based on the dimensions mentioned above, the simulated $S_{21}$ of the three configurations is shown in Fig. 2. It can be shown that the resonance frequency is reduced from 2.92 GHz for the structure in Fig. 1(a) to 2.37 GHz and 1.8GHz for the structures given in Figs. 1(b) and 1(c), respectively. For this reason, the filter analyzed and designed in this paper is based on the structure given in Fig. 1(c).

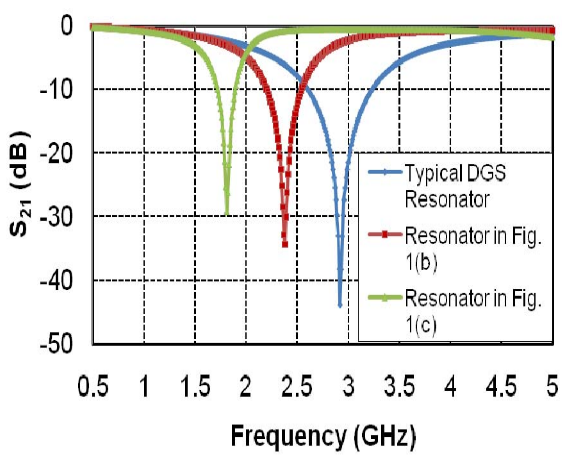



Fig. 2. Simulated $S_{21}$ of the three resonators shown in Figs 1(a), 1(b), and 1(c).

The resonant frequency $f_0$ of the proposed resonator in Fig. 1(c) is determined by the width and the length *L* of the DGS cell. Scaling up and down the physical size of the DGS cell can control the resonance frequency $f_0$. Denoting *L'* as the new lengths compared to the dimensions given above. *L'* represents all the lengths including *L, L1, L2, and L4.* The resonator resonance frequency is inversely proportional to the cell size *L'*. Figure 3 shows the simulation $f_0$ for different values of *L'*. It is seen that by increasing *L'* by 1mm (*L'*+1), $f_0$ is reduced to 1.42 GHz. While decreasing the *L'* by 2mm (*L'*-2), $f_0$ is increased to 3.62 GHz. The result shown in Fig. 3 is helpful in designing a filter with a specific center frequency.

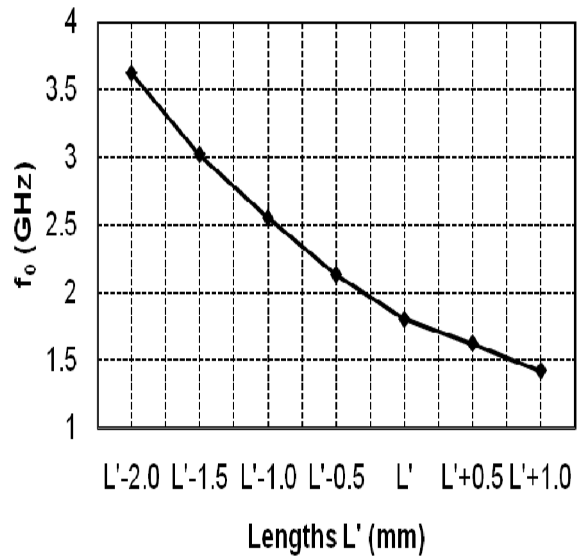
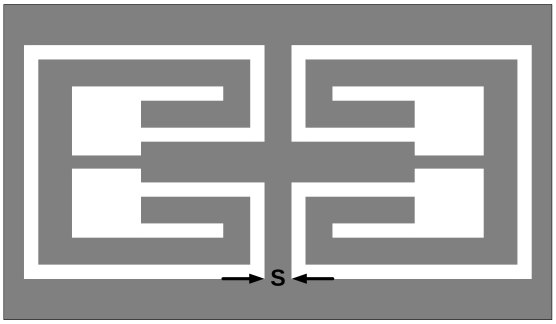


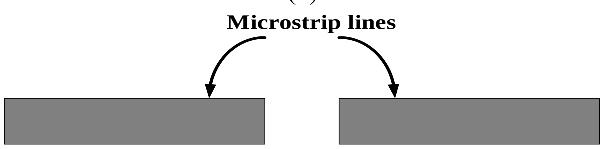

Fig. 3. Resonator resonance frequency ($f_0$ )against its cell size. *L'* represents the lengths *L, L1, L2, L3,* and *L4* of the resonator shown in Fig. 1(c).

## III. BANDPASS DGS FILTER

Bandpass filter can be designed by cascading several bandpass resonators and adjusting the coupling between these resonators to achieve a specific bandwidth. The coupling between the resonators is controlled by the strip conductor width *S* separating the two resonators as shown in Fig. 4(a). The effect of the strip thickness *S* on the fractional bandwidth (*FBW*) is shown in Fig. 5. It can be seen that as *S* increases, the bandwidths decreases. In other words, increasing *S* between the two resonators will decrease coupling and so decrease the bandwidth. The *FBW* that can be obtained using this structure is limited from about 13% to 23%. Figure 6 shows the simulated frequency response of two filters designed for *S*=0.1mm and *S*=0.5mm. The structure is simulated using IE3D package. The same dimensions presented in the above section are used in this case (*L* = 10mm, *L1* = 4mm, *L2* = 5.5mm, *L3* = 3.5mm, *L4* = 6mm, *W1* = 2.5mm, *M1* = 0.9mm, and *M2* = 1.6mm).




(a)




(b)

Fig. 4. (a) Schematics of backside of BPF, (b) front side of BPF.

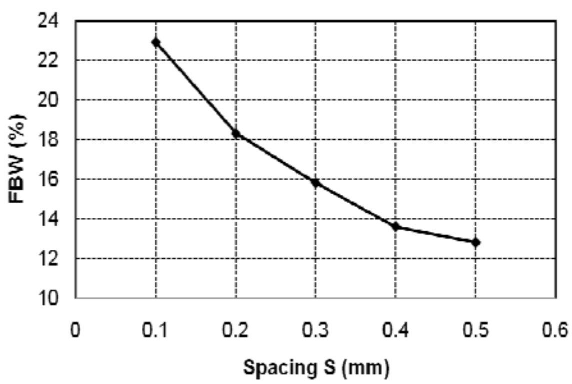



Fig. 5. Computed fractional bandwidths (*FBW*) for different spacing *S*.

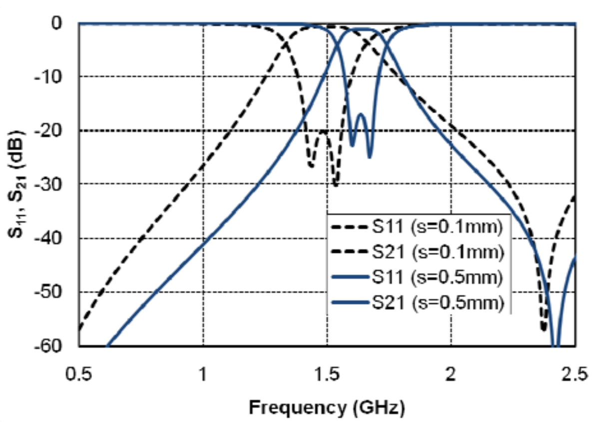
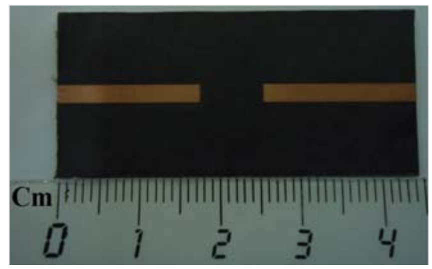
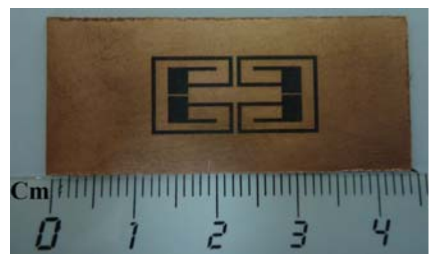



Fig. 6. Simulated frequency responses for different spacing *S*.

The filter with *S*=0.5 mm is fabricated and tested using Anritsu 37396C Network Analyzer. The photographs of the top and bottom sides are shown in Fig. 7. The universal test fixture (Gigalane) is used to allow accurate measurements without soldering. The filter bandwidth is about 210 MHz centered at 1.63 GHz. A little shift in the center frequency with respect to Fig. 3 is observed since the resonator arrangement in Fig. 1(c) is slightly different on that used in the cascading form in Fig. 4 (a).




(a)




(b)

Fig. 7. Photographs of the bandpass filter (a) front side of the filter, (b) back side of the filter.

Figure 8 shows the measured and simulated frequency response of the filter. Very good matching is observed in both simulations and measurements. The simulated and measured insertion losses are 1 dB and 1.4 dB, respectively.

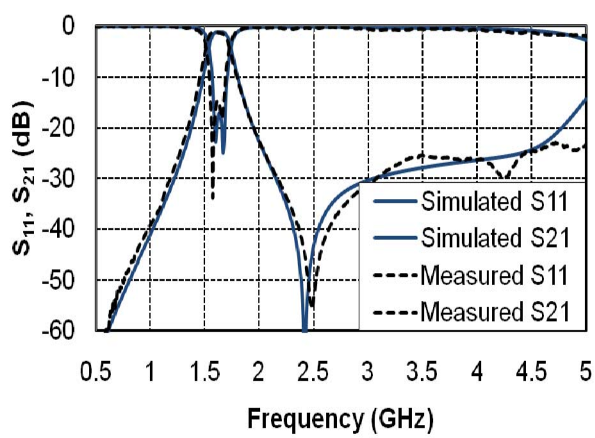



Fig. 8. Simulated and measured results of BPF with space *S*=0.5mm.

### A. Effect of slot etched in the coupled conductor strip

As shown in Fig. 5, filter *FBW* from 13% to 23% can be achieved by a coupled conductor strip of width from 0.5 mm to 0.1 mm, respectively. However, narrower bandwidth can be achieved by etching a slot of width *d* in the coupling strip as shown in Fig. 9.

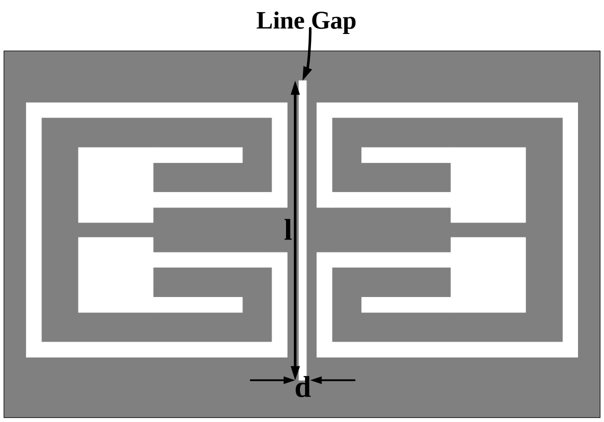



Fig. 9. Schematics of backside of BPF with etched slot of width *d* in the coupled conductor strip.

The strip conductor width is fixed to be 0.5 mm. The effect of the slot width on the *FBW* is shown in Fig. 10. It can be seen that the *FBW* decreases as the slot width increases. *FBW* of about 2.5% can be reached as the slot width *d* =0.4 mm. Figure 11 shows the simulated frequency response of two filters for *d*=0 mm and *d*=0.4 mm. The length *l* of the etched slot is 11mm in all the cases. The same physical dimensions of the resonator discussed in the previous sections are used.

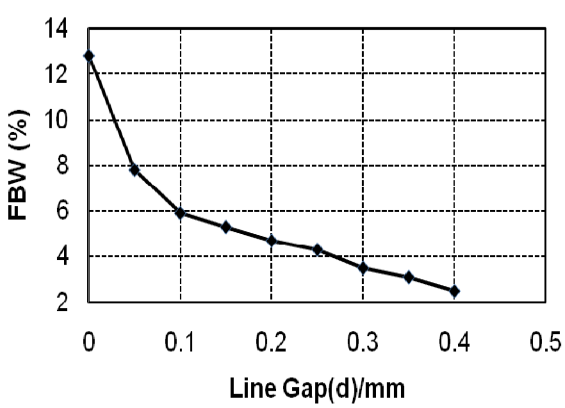



Fig. 10. Computed *FBW* for different slot widths *d*.

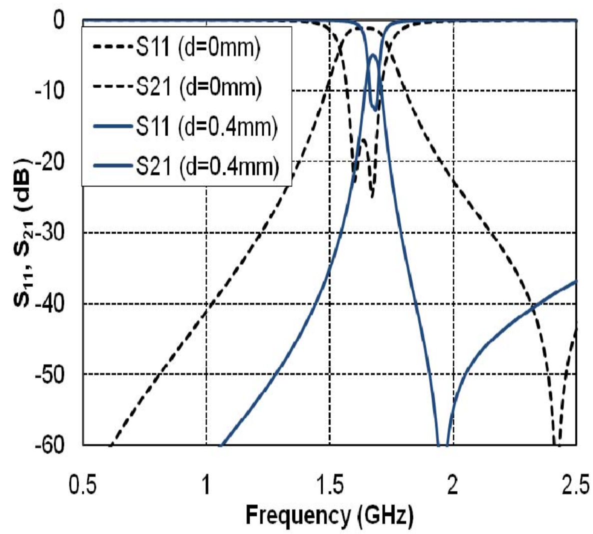



Fig. 11. Simulated frequency responses for different line gap width *d*.

As mentioned in Fig.10, to achieve about 6% *FBW* the slot width *d* should be 0.1mm and length *l* is 11mm. The coupled conductor strip width *S* is 0.5mm. For experimental validation a BPF with *d*=0.1mm, *l*=11mm, and *S*=0.5mm is fabricated and tested. The back-side photograph of the fabricated filter is shown in Fig. 12. The experimental results are compared with the simulations as shown in Fig. 13.

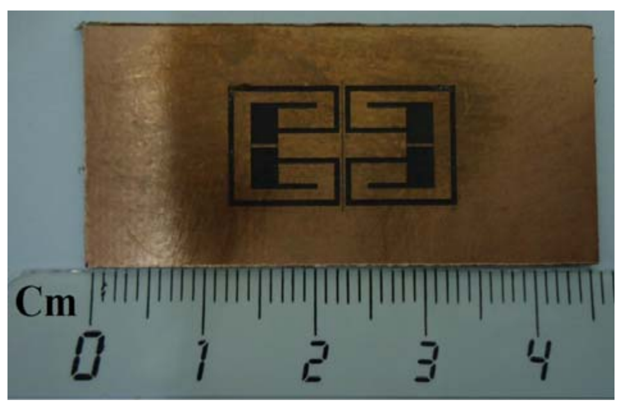
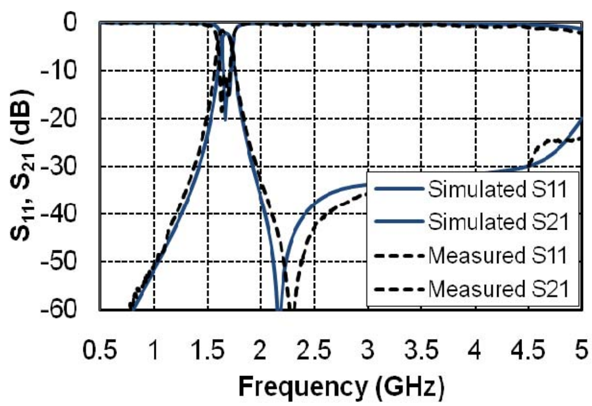



Fig. 12. Photograph of back side of the fabricated bandpass filter (*S*=0.5mm, *d*=0.1mm).

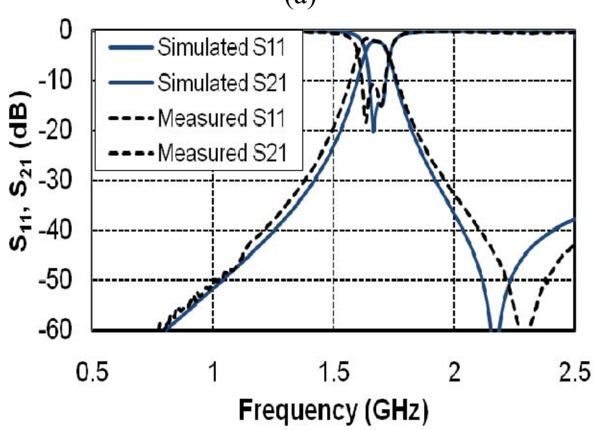
The results of the two fabricated filters with coupled conductor strip width *S*=0.5mm are summarized in Table 1. The measured fractional bandwidths (*FBW*) are 13% for the filter with no etched slot and 6.5% with etched slot of width = 0.1 mm in the conductor strip.

Table 1: Performance of the filters (*S*=0.5)

| | ***S*=0.5mm *d*=0mm** | ***S*=0.5mm, *d*=0.1mm** |
|---|---|---|
| **Simulated** | 12.5 % | 6 % |
| **Measured** | 13 % | 6.5 % |
| **Simulated $f_o$** | 1.61 GHz | 1.67 GHz |
| **Measured $f_o$** | 1.63 GHz | 1.67 GHz |
| **Simulated Insertion** | 1.0 dB | 2.3 dB |
| **Measured Insertion** | 1.46 dB | 2.1 dB |




(a)




(b)

Fig. 13. Simulated and measured results of BPF with slot width *d*=0.1mm, (a) wide range plot, (b) narrow range plot.

## IV. CONCLUSION

New compact DGS resonators are proposed and used to design bandpass filter with fractional bandwidth from about 2.5% to 23%. The DGS resonators are placed back-to-back and coupled with a conductor strip. It has been shown that the width of the strip-conductor controls the filter bandwidth by controlling the coupling between the resonators. Etching a slot in the coupled strip reduces the filter bandwidth more. Two bandpass filters with fractional bandwidth of 6%, and 13% have been designed and fabricated. The simulated and measured results of the proposed bandpass filter exhibit good agreement.

## ACKNOWLEDGMENT

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**Sajjad Ur Rehman** graduated from Engineering Dept., Iqra University Pakistan in 2006. He worked as a lecturer at the Iqra University (Peshawar Campus) Electrical Engineering Dept., during 2007-2008. Currently, Engr. Sajjad Ur Rehman is M.Sc. student and research assistant at the Electrical Engineering Department, King Saud University, Saudi Arabia. His research interests include microstrip filters and reconfigurable RF filters.

**Abdel Fattah Sheta** graduated from the Communications and Electro-Physics Dept., Alexandria University, Egypt in 1985. He received the M.Sc. degree in Electrical Engineering, Cairo University, in 1991. In 1996, he received the Ph.D. degree in Microwave Circuits Analysis and Design from ENST, Université de Bretagne Occidentale, France. During 1996-1998, he worked as a researcher at the National Telecommunication Institute, Cairo, Egypt. In 1998, he joined Electrical Engineering Department, Fayoum University. Currently, Dr. Sheta is a Professor at EE Department, King Saud University, Saudi Arabia. His current research interests include reconfigurable RF systems, UWB systems, microstrip antennas, microstrip filters, and planar and uniplanar MIC's and MMIC's.

**Majeed Majeed A. S. Alkanhal** received the B.S. and M.S. degrees from King Saud University, Riyadh, Saudi Arabia, in 1984 and 1986, respectively, and the Ph.D. degree from Syracuse University, Syracuse, NY, in 1994, all in Electrical Engineering. He is presently a Professor and Chairman of the Electrical Engineering Department at King Saud University, Riyadh, Saudi Arabia. His research interests are in antennas and propagation, computational electromagnetics, and microwave engineering.