# A Novel DP-EBG Structure for Low-pass Filter of Wide Stopband

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**Abstract**— In this letter, a novel dual planar electromagnetic bandgap (DP-EBG) microstrip low-pass filter structure is investigated. The presented structure is realized by superposing two different one-dimensional (1-D) electromagnetic bandgap (EBG) structures which have different center frequency of the stopband into a coupled dual-plane configuration. Both simulation and experimental results have verified that only two cells of the proposed structure are enough for the measured −20 dB stopband from 3.7 GHz to 14 GHz with a excellent low-pass performance in a small circuit area. Since this novel design demonstrates superior low-pass filtering functionality, we expect this novel structure is widely used for wideband monolithic circuit applications.

## 1. INTRODUCTION

The electromagnetic bandgap (EBG) structure is a frequency-selective structure capable of restricting the electromagnetic waves along one or more directions within a certain frequency band. Due to the bandgap that can filter out the unwanted signals, the EBG structures have been widely used in antennas, filters, couplers, high-speed circuits, etc. [1–4]. Therefore, the investigation of EBG structures have attracted much attention recently.

In modern telecommunication systems, high-performance microwave circuits with compact size, low insertion loss, steep rejection, and wide stopband are widely required. In [5], a compact tapered planar EBG structure is proposed for achieving wide stopband and flat passband, in comparison with traditional planar EBG structure, the new structure obtained a relative fractional bandwidth of 93.7% in the stopband below −20 dB. In [6], An interleaved electromagnetic bandgap (EBG) structure is investigated to be with a compact size and wide stop-band bandwidth for suppressing power/ground noise in power distribution networks, the interleaved EBG structure achieve substantial improvements on the bandwidth of 51.1% compared with the conventional EBG structure. Several researchers have focused on achieving compact design and wide frequency stopband using multilayered planar techniques, such as [7–10]. For example, T. Akalin [7] has proposed a dual-planar EBG microstrip low-pass filter, but this require large size and has a limitation in compact microstrip circuit applications.

In this paper, we introduce a novel dual planar electromagnetic bandgap (DP-EBG) structure which is achieved with a combination of two one-dimensional (1-D) EBG structures having different center frequencies of the stopband, namely the elliptical dumbbell defected ground structure (ED-DGS) and the microstrip line type electromagnetic bandgap (ML-EBG) structure. A low-pass filter using two cells of the proposed DP-EBG structure demonstrate a rejection of below −20 dB in the range from 3.7 GHz to 14 GHz and negligible insertion loss in the passband. As compared to previous research on EBG low-pass filters, the proposed structure achieves better performance with a ultra-wide stopband and a significant reduction in physical size.

## 2. NOVEL DP-EBG MICROSTRIP LOW-PASS FILTER STRUCTURE

The ordinary filters can be achieved with the microstrip line type electromagnetic bandgap (ML-EBG) structure which consists of the conductor ground plane and periodic patches inserted in the microstrip line on the top plane, as shown in Fig. 1. Since it is designed to satisfy the Bragg reflection condition [11], the period $d$ equals half of guided wavelength at center frequency of the stopband.

It is simple to use the ML-EBG structure for the design of the microstrip filters, but this structure is not compact in physical size for low-frequency band applications since it is designed to satisfy the Bragg reflection condition. In order to provide more evident stopband characteristic and decreese the circuit layout size, a rectangular dumbbell defected ground structure (DGS) unit was proposed in [12]. The DGS filters not only provide deeper stopband but also decrease the physical dimensions when compared with a conventional ML-EBG filter due to its highly-resonant characteristics [12]. However, it is experimentally found that the passband performance of the DGS with only one or a few unit lattices is not good [13]. Hence, if we superpose the ML-EBG structure and the DGS section into a double-plane configuration, in which two types of EBG cells are too strongly coupled to probably remove above mentioned shortages, this compact configuration may be expected to realize better stopband and low-pass performance than that of any single type EBG structure and could be used as a new good low-pass filter.

Based on this idea, we propose a novel compact dual planar electromagnetic bandgap (DP-EBG) microstrip filter as shown in Fig. 2, in which a ML-EBG structure is overlapped on a elliptical dumbbell defected ground structure (ED-DGS). In Fig. 2, each rectangular patch etched on the microstrip line together with its underlying ED-DGS located on the ground plane can be treated as a unit cell, so this novel DP-EBG filter consists of two cells. we simulated a ML-EBG unit cell on a common ground and a common microstrip on a ED-DGS unit cell in addition to the proposed filter structure shown in Fig. 2 using a F4B substrate with 0.8-mm thick and a dielectric constant of 2.65 by Anosoft HFSS. The linewidth $w$ for all models is chosen to be the characteristic impedance of $50\,\Omega$ microstrip line.The ED-DGS cell in the proposed DP-EBG filter is designed for 5.42 GHz resonant frequency, and the ML-EBG structure is designed for 7 GHz Bragg condition so the period of the lattice ($d$) is set as 13.4 mm. Also, other structural dimensions are calculated and shown in Table 1.

Then, in order to characterize the proposed DP-EBG microstrip filter experimentally, we fabricated this structure and its $S$-parameters were measured to validate the simulation results. Fig. 3 shows the fabricated structure, which has a F4B substrate ($2.65\varepsilon_r$ and 0.8 mm thickness).

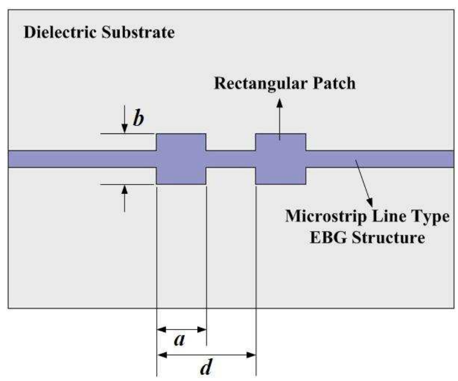



Figure 1: Front view of the ordinary filter using ML-EBG structure which is built up on the microstrip line.

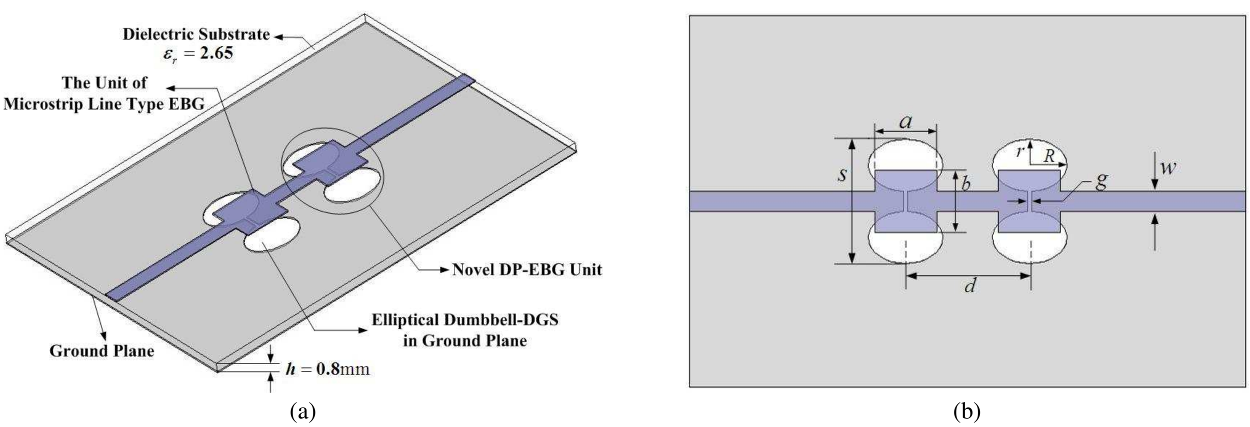
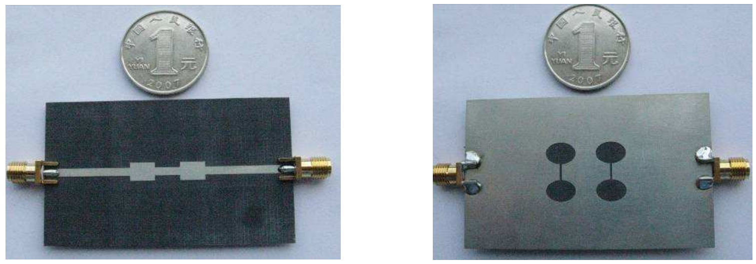



Figure 2: Schematic of the novel DP-EBG microstrip structure. (a) 3-D view. (b) Top view.

Table 1: Novel DP-EBG microstrip structure specifications, where the axial ratio: $R/r$ is assigned to be 10/7.

| Parameters | $w$ | $a$ | $b$ | $R$ | $r$ | $g$ | $s$ |
|---|---|---|---|---|---|---|---|
| Value (mm) | 2.2 | 6.7 | 5 | 4 | 2.8 | 0.5 | 15.4 |



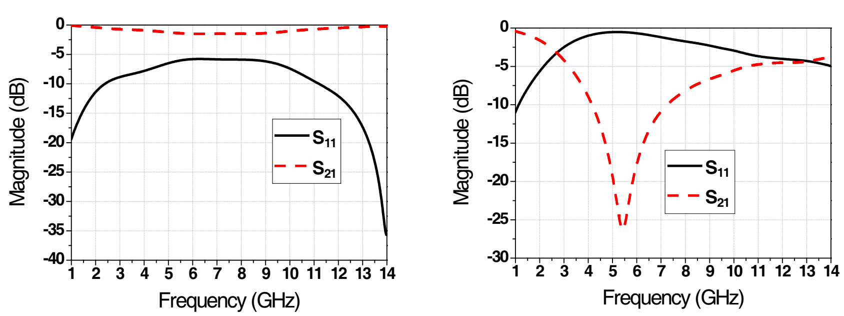
(a) (b)

Figure 3: Manufactured prototype of the novel DP-EBG microstrip structure. (a) Top view. (b) Bottom view.

## 3. NUMERICAL AND MEASUREMENT RESULTS

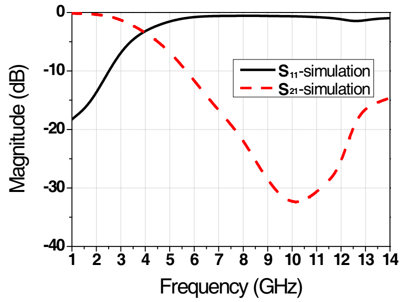
Figure 4 shows the calculated data of the single ML-EBG cell and the single ED-DGS cell. The single ML-EBG cell shows flat transmission characteristics and very low insertion loss without ripples in the passband while the single ED-DGS cell shows a attenuation pole location in the stopband which is wider than that of a single ML-EBG cell, indicating there is a highly-resonant behavior in the ED-DGS. It can be concluded from results shown in Fig. 4 that the DGS unit provide evident stopband characteristics while the ML-EBG cell shows good low-pass performance.

Figure 5 shows $S$-parameters of the proposed DP-EBG microstrip structure consisting of one cell and two cells, It can be seen from the Fig. 5 that the return loss in the lowpass band for the one-unit microstrip structure is not always below $-10$ dB and its corresponding insertion loss is also a little higher than that of the DP-EBG structure including two cells. In Fig. 5(b), the measured data agree well with the simulation results except the difference occurring in the high frequency band which could be attributed to the variation of the actual dielectric constant and the loss tangent. Also, it has been assumed infinite conductivity for the metallic strip and the ground plane in the simulation. The Fig. 5(b) also show that the most important feature of the proposed DP-EBG microstrip filter is about $-20$ dB stopband from 3.7 GHz $\sim$ 14 GHz (In other words, the relative bandwidth is over than 116%) in addition to the negligible insertion loss which is less than 0.5 dB throughout the passband (0 GHz $\sim$ 2 GHz). It is also noted that there are some attenuation pole locations in the stopband which are more deeper than that shown in Fig. 4(b), meaning the resonant behavior of it is more intense than that of the single ED-DGS cell. These favorable results for the proposed DP-EBG filter structure can be explained by the theory introduced in [8] that the longitudinal resonant modes of the ML-EBG structure and the transverse resonant modes of the ED-DGS are strongly coupled through the ED-DGS gap fields so that the passband and stopband characteristics are effectively improved by these multiple resonant modes. Further more, by virtue of the highly-resonant mechanism, this novel DP-EBG filter has relatively wider stopband characteristics and smaller required circuit size than that of other dual planar EBG filters proposed in [9, 10] which satisfies the Bragg reflection condition. Also, this new DP-EBG structure, having only one substrate, is much simpler to be fabricated than that of the EBG filter introduced in [6] which consists of dual attached slabs while the relative stopband bandwidth is also wider. Therefore, it is testified from the experimental results that the DP-EBG microstrip structure proposed in this letter is a new compact low-pass filter with ultra-wide stopband.

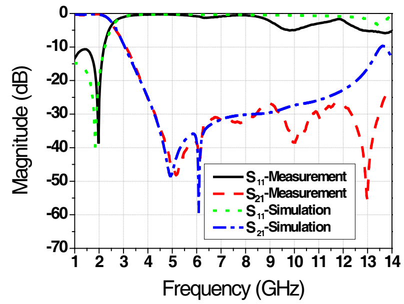



(a) (b)

Figure 4: Simulated results of EBG cells, (a) single ML-EBG cell and (b) single ED-DGS cell.



(a)



(b)

Figure 5: $S$-parameters of the proposed DP-EBG microstrip structure, (a) simulated results of one DP-EBG cell and (b) simulated and measured results of two DP-EBG cells.

## 4. CONCLUSIONS

A novel low-pass filter structure using the DP-EBG configuration is designed and implemented in this paper. Due to the dual planar arrangement of two different EBG structures as well as their unique characteristics, this proposed EBG filter structure obtains a relative fractional bandwidth of more than 116% in the stopband below −20 dB and excellent low-pass performance in a compact physical size. The structure was fabricated and the measured results are in good agreement with the simulation results, verifying the good performance of the proposed structure. Since this novel filter structure is easy to fabricate and shows superior passband and stopband characteristics in a small circuit area, it will be widely applied in various monolithic circuits.

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