Multilayer Tapered U-shape EBG Low Pass Filter

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Abstract. *In this paper a Multi-layered U-shaped Electromagnetic Band Gap (EBG) low pass filter is proposed. A design for prominent stop band characteristics with minimized ripples is presented, while maintaining the filter pass-band performance. By properly designing and integrating the tapering techniques with the low pass filter, the proposed structure exhibit superior pass band and stop band characteristics. By designing the microstrip line in U-shape the circuit area is reduced significantly and due to this shape the pass band ripples are suppressed to a large extent. Since the design is multi-layered, no structure is designed at the ground plane so the problem of distortion of ground plane structure while packaging is resolved. The measured results indicate that the proposed structure achieves significantly improved band characteristics with minimum distortion.*

Keywords: Multilayer, Tapered U-shape, Low Pass Filter, Microstrip Line, Electromagnetic Band Gap

1. Introduction

A Microwave filter is a two port network used to control the frequency response at a certain point in a microwave system [1]. More specifically a low pass filter is a filter that passes low frequency signals but attenuates signals with frequencies higher than cut off frequency as shown in Fig.1.

In this paper a multi-layered U-shaped electromagnetic band gap (EBG) low pass filter which works at 2.5 GHz is proposed. A design for prominent stop band characteristics with minimized ripples is presented, while maintaining the filter pass-band performance. By properly designing and integrating the tapering techniques with the low pass filter, the proposed structure exhibit superior pass band and stop band characteristics. By designing the microstrip line in U-shape the circuit area is reduced significantly and due to this shape the pass band ripples are suppressed to a large extent. Since the design is multi-layered, no structure is designed at the ground plane so the problem of distortion of ground plane structure while packaging is resolved.

In a traditional straight one-dimensional (1-D) EBG microstrip structure [2], a good stopband performance is usually obtained by increasing the number or the size of EBG cells, thus resulting in an increase in the circuit area. These EBG structures have cells in a single plane. They are a compromise between good filtering performance and compact physical size. The problem above was well addressed by introducing multiple bends in the MLIN giving rise to an EBG filter structure with an excellent rejection band in a relatively small physical size [3].

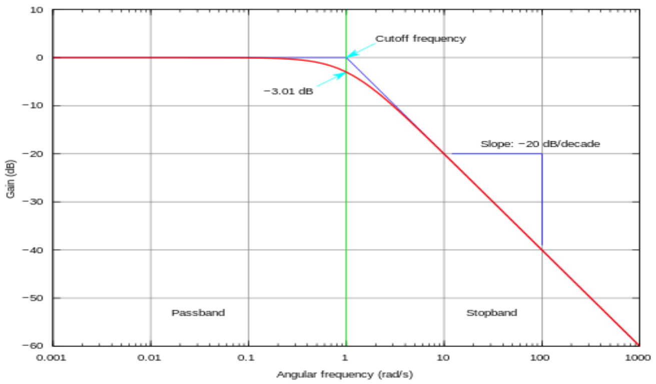

Fig. 1 Response of low pass filter

In this paper, a novel high-performance compact DP-EBG (Dual Planar-EBG) micro strip low-pass filter structure with U-shaped MLIN geometry is proposed and implemented. With the unique U-shaped geometry of the MLIN and the DP-EBG configuration with a reduction in the width of the MLIN, as well as the adopted Chebyshev tapering distribution, the proposed filter structure demonstrates a high selectivity, a low ripple level in the passband.

2. Electromagnetic Band Gap Structures (EBG)

The Electromagnetic Band Gap (EBG) structure has been a term widely accepted today to call the artificial periodic structure that prohibits the propagation of electromagnetic waves in certain frequency bands at microwave or millimeter wave frequencies. These periodic structures were originally proposed at optical frequencies and are known as a photonic band gap (PBG) structure or photonic crystal (PC). Analogous to crystals where periodic arrays of atoms produce band gaps in which the propagation of photon is prohibited, an artificial periodic structure is comprised of periodic macroscopic cells. These periodic structures are scalable over a wide frequency range in the electromagnetic spectrum. Due to their scalability, research has progressed into the range of microwave and millimeter wave, infrared [5]. It has been widely applied as the substrate of planar microwave circuits such as patch antennas to suppress the surface waves, and power amplifiers to reduce the harmonics [6].The unique feature of EBG structures is the existence of the band gap where electromagnetic waves are not allowed to propagate. They have been widely applied to the substrate of microwave circuits such as patch antennas and power amplifiers to improve their performance. The only trade off of planar EBG structures is that they are not able to control the propagation of waves in the entire 3-D space. Nevertheless, planar EBG structures have attracted much attention because of their prominent stopband characteristic, their ease of fabrication, and their compatibility with monolithic circuits. With the superior filtering functionality associated with the band gap, planar EBG structures are employed in the design of high-performance microstrip low-pass filters.

Traditionally in straight EBG microstrip structure, a good stop band performance is obtained either by increasing the number or the size of EBG cells, thus increasing the circuit area. The above problem was well solved by introducing multiple bends in the microstrip line giving rise to an EBG filter structure with a relatively small physical size and an excellent rejection band.

3. Tapering Techniques

Tapering techniques are effective for eliminating ripples in the passband caused by the periodicity in an EBG microstrip structure. In some tapered EBG microstrip structures, tapering techniques are applied by directly adopting tapering functions (such as Hamming tapering function and Kaiser tapering function) to modify the dimension of the periodic elements. The other approach to taper EBG structures is based on low side lobe array theory including Binomial array, Dolph–Tschebyscheff array (Chebyshev array), and Taylor array. The significant effects of Binomial and Chebyshev distribution on the passband performance of an EBG microstrip structure have been shown by Karmakar *et al.* [7]. For a 1-D planar EBG microstrip structure with a single column of *m* circles etched in the ground plane of a microstrip line, the distribution of the dimension of the circle follows the following expression:

$$b_i = b_c . T(z_i) \qquad (1)$$

When tapering functions are applied, and

$$b_i = b_c . a_i \qquad (2)$$

When low side lobe array theory is applied. is an integer with a range from 1 to $m/2$ in the case that *m* is an even number and from $1(m+1)/2$ to in the case that *m* is an odd number. b_i is the radius (or the area) of the *i*th circle, b_c is the radius (or the area) of the central circle. In (1), is the tapering function, and z_i is the normalized distance between the center of the *i*th circle and the center point of the structure that can be determined by the following expression:

$$z_i = (2d_i/L_t) \qquad (3)$$

Where d_i is the distance between the center of the *i*th circle and the center point of the microstrip line and L_t is the total length of the EBG microstrip structure. In (2), a_i is the *i*th coefficient in the array. In the case that *m* is even, the central circle does not exist but it is used to determine the dimension of the circle when employing tapering functions. Whereas when the low side lobe array theory is applied, the two circles at the center are regarded as central circles in the calculation [3].

Chebyshev array is a compromise between uniform and Binomial array. Its coefficients are related to Tschebyscheff polynomial that satisfies the recurrence relations expressed as follows:

$$T_m(z) = z.\, T_{m-1}(z) - [(1-z^2)\{1-[T_{m-1}(z)]\}]^{1/2} \qquad (4)$$

$$T_m(z) = 2z.T_{m-1}(z) - T_{m-2}(z) \qquad (5)$$

Where $T_1(z) = 1$. Letting $z \equiv \cos\Theta$, $T_m(z)$ is expressed as

$$T_m(z) = \cos(n.\Theta) = \cos[m.\mathrm{arcos}(z)] \qquad (6)$$

To determine the coefficients in Binomial and Chebyshev array, the element number is set to six. For Chebyshev array, the major-to-minor lobe ratio is fixed at 25 dB. Table 1 shows the corresponding values of every tapering function and the normalized coefficients of the arrays.

Table 1 Value of Tapering Functions and Normalized Coefficient

Type	**$T(z_1)$**	**$T(z_2)$**	**$T(z_3)$**
Bartlett	0.82	0.46	0.09
Blackman	0.87	0.27	0.01
Connes	0.94	0.49	0.03
Cosine	0.96	0.66	0.14
Gaussian	0.98	0.86	0.66
Hamming	0.93	0.48	0.10
Hanning	0.92	0.43	0.02
Welch	0.97	0.70	0.17
Kaiser	0.94	0.58	0.16
Type	a_1	a_2	a_3
Binomial	1	0.50	0.10
Chebyshev	1	0.73	0.39

The area of the circle is tapered according to (1) or (2) where the filling factor (r/a_1) of the central circle is set to be 0.25.

It is observed that for the performance of tapered EBG structures, the reduction in the ripple level in the passband is commonly proportional to the reduction in the bandwidth and attenuation of the stopband. Nevertheless, the Chebyshev tapered EBG structure exhibits a 4.3-GHz-wide stopband at 10 dB with an attenuation of 24.36 dB, a ripple level of 0.17 dB in the lower passband, and a ripple level of 2.9 dB in the higher passband. Although its stopband performance is not the best, the very low ripple level in the passband enables it to obtain a good trade-off between the ripple level in the passband, and the bandwidth and attenuation of the stopband[5].

4. Design of U-Shape Geometry

Fig 2(a) shows the schematic of a straight EBG micro strip structure with four square patches inserted in the micro strip line at a period of *a.* Fig. 2(b) shows U-shaped MLIN with distance between the two parallel sections is also *a* . Fig. 2(c) shows the schematic of the U-shaped EBG micro strip structure used in the proposed low-pass filter structure. As can be clearly seen it is a combination of the structures in Fig. 2(a) and (b) [8].

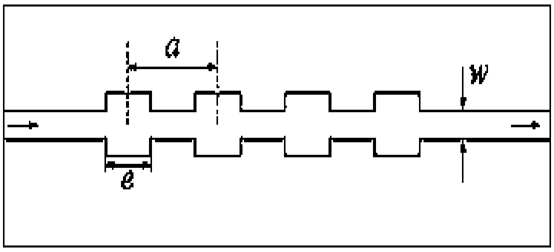

Fig. 2(a) Schematic of a straight EBG microstrip structure

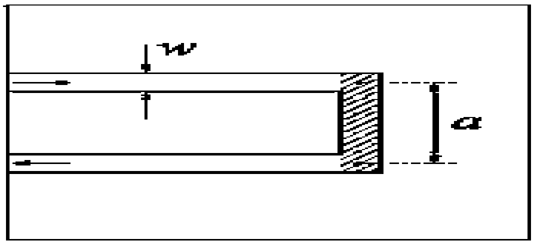

Fig. 2(b) U shape micro strip line

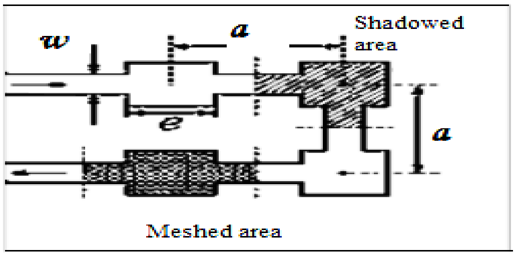

Fig. 2(c) U shape EBG microstrip structure

The straight EBG microstrip structure in Fig. 2(a) satisfies the Bragg reflection condition [3], which is expressed by the following equation:

$$\beta . a = \pi \qquad (7)$$

Where,
β = wavenumber in the substrate material and
a = period of the structure.

The straight EBG microstrip structure of Fig 2(a) is not a conventional microstrip low-pass filter because it is designed to satisfy the Bragg reflection condition.
The edge *e* of the inserted square patch equals half of the period:

$$e = a/2 \qquad (8)$$

As compared to the straight EBG microstrip structure of Fig 2(a), the U-shaped EBG microstrip structure in Fig. 2(c) is more compact in physical size. The resonant frequency is determined by the physical length of the resonator. Since it has only one bend it has a single resonator (shown as shaded region in Fig 2(b)). The relation between the length of the resonator and the resonant frequency is:

$$L = \frac{c}{2 f_r \sqrt{\varepsilon_r}} \qquad (9)$$

Where *L* is the physical length of the resonator. In the U-shaped MLIN of Fig 2(c) there is only one resonator and its length is as short as one EBG period. Due to the absence of a resonator with a length longer than *a,* no resonance is introduced at frequencies lower than f_r.

5. Filter Design

The proposed multi-layered U-shape low pass filter is designed with dielectric constant of 4.4 and substrate height of 1.67mm for a cut off frequency of 2.5GHz.

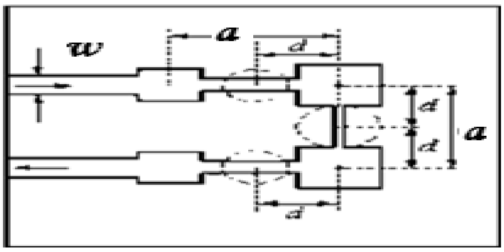

Fig. 3(a) Top view 1 of proposed filter

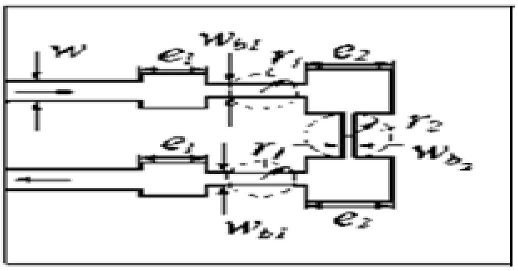

Fig. 3 (b) Top view 2 of proposed filter

On top layer the U- shape microstrip structure as described in Fig. 3(a) and (b) is designed with the following dimensions tabulated in Table2.

Table 2. Parameters of proposed filter

Parameter	Dimension(mm)
a	13.78
w	2.32
e_1	4.89
e_2	6.79
w_{b1}	0.85
w_{b2}	0.32

The proposed low pass filter is then designed as per Fig. 3 and the values mentioned in Table 2. And the pattern thus designed.

On the second layer, by using Chebyshev tapering techniques three circles are etched below the low pass filter design as per the dimensions mentioned in Table 3.

Table 3. Parameters of tapered circles

Parameters	Dimension(mm)
r_1	2.94
r_2	3.45

By using the dimensions of circles mentioned in Table 3 the second layer of the circuit is designed.

The bottom layer which is the ground layer is left as it is, i.e. no pattern is designed on it. By doing so the problem which occurs due to distortion of ground structure because of packaging and handling is finally overcome.

6. Result and Conclusion

The design of the multi-layered U-shaped tapered low pass filter with a cut-off frequency 2.5GHz with low pass structure on the top layer, tapered circles on the middle layer and an empty ground layer is designed and simulated. A photograph of the fabricated band pass filter is shown in Fig.4.

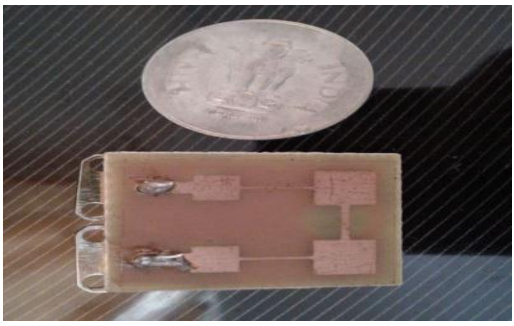

Fig. 4 Hardware of proposed low pass filter

The simulated and measured responses are shown in Fig.9. As can be seen from Fig. 5 the measured response of filter has better gain characteristics than the simulated one. Also the measured response shows that the proposed filter has a much stable pass band from 0 to 2.5 GHz. On comparing the two results it has been verified that the proposed structures are implemented and the measurement results are found to be in good agreement with the simulation results, verifying the excellent stopband and passband performance obtained using the proposed configuration.

With reference to [4] it can be seen that the presented filter has a much stable stop band free from spurious signals. In [4] a double sided PCB is designed, whereas in the present design a multilayered filter is designed. The ground layer of present filter is left as it is, thus the problem which occurs due to distortion of ground structure because of packaging and handling is overcome.

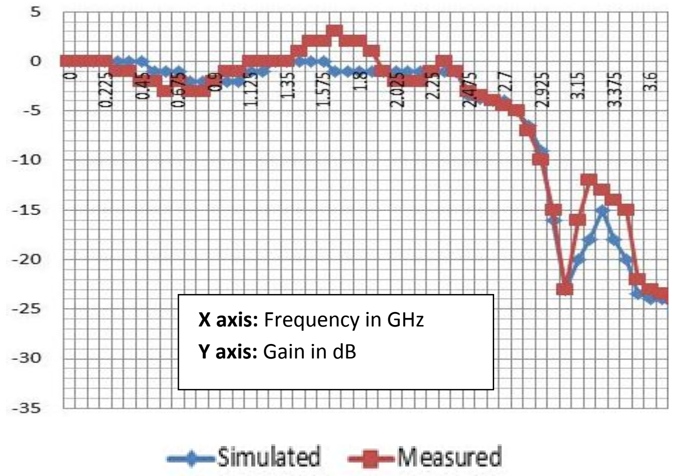

Fig. 5 Simulated v/s measured response

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