Super-Compact Stop Band Filter Based on the Grounded Hilbert Patch Resonator

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Abstract

In this paper, a novel super-compact stop band filter is presented based on the grounded Hilbert patch resonator embedded in the microstrip. Characteristics of the proposed filter are compared with state-of-the-art stop band filters of similar type in terms of size, performances and fabrication complexity. The proposed fourth-order filter has overall dimensions of $0.47\lambda_g$ x $0.12\lambda_g$, 10 dB fractional bandwidth equal to 30 % at 4.43 GHz, and insertion loss of more than -30 dB in the stop band. To the best of the authors' knowledge, the proposed filter outperforms all previously published metamaterial-based planar stop band filters.

1. Introduction

Stop band filters are important building elements in modern communication systems, especially in power amplifiers, antenna systems and mixers. Several stop band configurations have been proposed in recent years which use planar technology, due to small size and ease of integration of the resulting circuit. In this paper we focused on planar metamaterial-based stop band filters, inherently characterized with small size. A number of solutions have recently been published based on the concept of single-negative metamaterials, i.e. on split-ring resonators (SRR), [1]-[3]. SRR-based unit cells offer great potential for miniaturization of microwave filters. However, in fabrication of SRR, a special attention has to be paid to the resolution, i.e. to the fabrication of narrow conductive lines on small spacing which form an SRR. The metamaterial microstrip structure, where SRR is replaced with a different particle - a grounded square patch resonator, was proposed in [4]. The grounded square patch was initially proposed in the design of high-impedance surfaces, but was not used in microstrip applications. Recently, the grounded patch resonator embedded in the microstrip line was used for the design of a compact fourth-order stop band filter with high level of signal rejection and extended pass band region between the first and the second stop band, [4].

Due to their inherent space-filling property, the application of fractal curves allows the design of very long lines on finite substrate areas, and has already resulted in several highly miniaturized microwave passive devices, including some metamaterial structures [5]-[6]. In this paper, a novel single-negative metamaterial unit cell based on the grounded Hilbert patch resonator embedded in the microstrip line is proposed. Using the proposed unit cell, a super-compact highly selective stop band filter of the fourth order was designed and compared to state-of-the-art stop band filters available in the literature.

2. Single-negative unit cell based on the grounded Hilbert patch resonator

The proposed unit cell consists of a grounded Hilbert patch embedded in the microstrip line, Fig. 1, where s denotes the gap between the microstrip line and the resonator, a is length of the side of the patch, w is line width of the ring, and d denotes side dimensions of square via positioned in the center of the patch. Dimensions w_H and g_H denote the line width and spacing of the Hilbert fractal patch, respectively. The initial values used in simulations were: a=2.9 mm, w_H=0.5 mm and g_H =0.3 mm. In order to enhance the coupling between the patch and the microstrip, the width of the microstrip line around the patch as well as the spacing between the line and the patch are set to minimal values achievable in standard PCB technology, i.e. to 100μm. Via is modeled with a square cross section equal to 100 x 100 μm.

Simulated responses of the proposed unit cell are also shown in Fig. 1, where square patch embedded in the microstrip, SRR embedded in the microstrip and microstrip loaded with SRR are included in comparison. All circuits were realized on a 1.27 mm thick Taconic CεR-10 substrate, with ε_r=9.8 and dielectric loss tangent equal to 0.0035. Simulations were performed using EMSight, full-wave simulator in Microwave Office. Distances between the unit cells and the microstrip line, as well as the distance between the concentric rings and width of the SRR are chosen to be equal to 100 μm. The overall size of SRR and all patches is 2.9 x 2.9 mm.

A grounded patch like SRR exhibit notch behavior when it's properly polarized. The conventional grounded patch exhibits much stronger rejection at resonance, but its resonant frequency is significantly higher than that of SRR. However, when SRR is embedded in the microstrip, its rejection level is insufficient for filtering applications. Hilbert patch embedded in the microstrip exhibits almost the same resonant frequency as SRR and has stronger rejection in the stop band. Furthermore, the grounded patch exhibits second resonance at approximately three times the first resonant frequency. According to these results, it is clear that the grounded Hilbert patch embedded in the microstrip is the most suitable for the design of stop band filters with extended pass band region and higher suppression in the stop band.

3. Filter configuration

Based on the proposed grounded Hilbert patch embedded in the microstrip, super compact highly selective stop band filter of the fourth order was designed. Layout of the proposed filter is shown in Fig. 2 for outer dimensions of the patches equal to 2.9 x 2.9 mm. All unit cells are identical, and no time-consuming optimization is needed in the process of filter design. The spacing between patches and the microstrip are equal to 0.1 mm and size of all vias is 0.1 x 0.1 mm. The overall filter dimensions are 12.9 x 3.3 mm, i.e. approximately $0.47\lambda_g$ x $0.12\lambda_g$, where λ_g is the guided wavelength. Simulated response of the filter is shown in Fig. 2. The filter exhibits 10 dB fractional bandwidth equal to 30 % at 4.43GHz, with the rejection of more than 30 dB and the maximal reflection coefficient around 1 dB in the stop band.

The proposed filter has been compared with five recently published stop band filters based on metamaterials, [1]-[4]. The characteristic parameters for these filters are summarized in the Table I, where f_c denotes central frequency, *FBW* is 10 dB fractional bandwidth and $s_{21\text{-}0}$ is rejection in the stop band. Table I also gives order of different filters, and their overall dimensions and chip area in terms of guided wavelengths.

Filter 1 proposed in [1], is basically a microstrip loaded with SRRs on both sides. Although the filter is of the sixth order, its footprint is seven times larger than the one of the proposed filter. Furthermore, it exhibits a narrow stop band equal to 3.6%. Filter 2, [2], uses the same configuration as the previous one, but with carefully optimized dimensions of the SRRs: The size of each pair of SRRs is slightly increased in each section of the filter, to create a wider stop band, equal to 17%. Eight unit cells are used, resulting in eleven times larger footprint than in the case of the proposed filter. An alternative to obtain a stop band characteristic is to use complementary SRRs etched in the ground plane, below the microstrip, Filter 3, [1]. The response of Filter 3 is similar to the proposed one in terms of fractional bandwidth and rejection in the stop band. However, to achieve such response, the filter needs to use 8 unit cells, resulting in the total footprint more than two times larger than in the proposed case. Furthermore, Filter 3 exhibits lossy response above the higher stop band edge and requires more complicated fabrication procedure in which etching is performed on both sides of the substrate, requiring highly accurate alignment of two conductive layers. Filter 4 is characterized by the smallest bandwidth and rejection in the stop band of all filters. Furthermore, its footprint is quite large. By using the Hilbert grounded patch instead of the square patch, [4], Filter 5, length of filter is reduced for 9.6% and its width for 8.3%, without affecting its performances. The response of Filter 5 is similar to the proposed one. Nevertheless, its footprint is 16.5% larger that the proposed one.

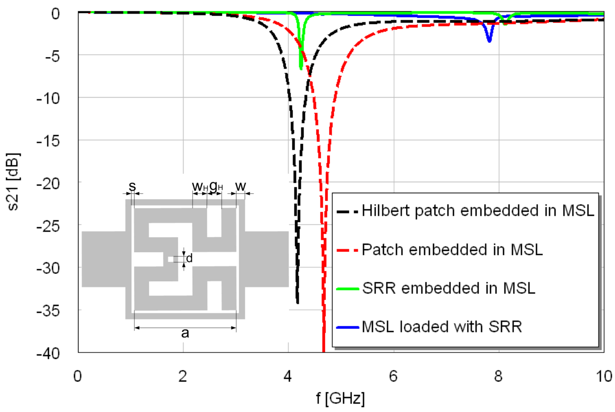

Fig. 1. Comparison of the simulation results for four different unit cells. Layout of the proposed unit cell is shown in the inset.

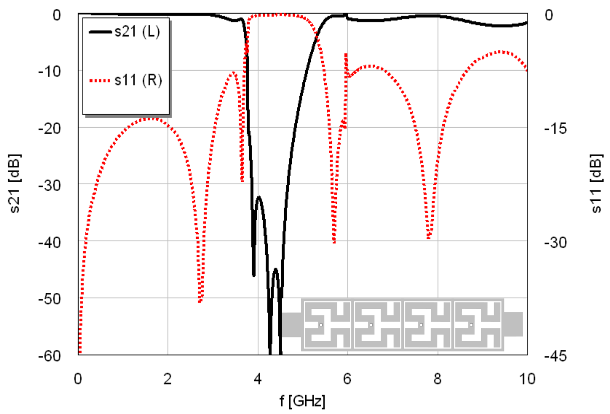

Fig. 2. Simulated response of the proposed stop band filter. Layout of the proposed stopband filter is shown in the inset.

Table I. Comparison of the characteristics of the proposed filter and other metamaterial-based stop band filters.

Type of unit cell	**Proposed filter**	**Filter1 [1]**	**Filter2 [2]**	**Filter 3 [1]**	**Filter 4 [3]**	**Filter 5 [4]**
***f_c* [GHz]**	4.43	9.25	4.5	9.25	2.44	4.36
***BW* [MHz]**	1330	≈333	760	3000	60	1360
***FBW* [%]**	30	3.6	17	33	2.45	35
s_{21-0} [dB]	-32	-35	-25	-45	-20	-30
***Dimensions* [mm]**	12.9x3.3	19.5x7.75	39.3x9.97	19.5x3	23.7x23.7	3.7x14.5
***Dimensions* [λ_g]**	0.47x0.12	1x0.4	1.6x0.4	1x0.15	0.5x0.5	0.52x0.13
***Chip area*, [100*λ_gxλ_g]**	5.64	40	64	15	25	6.76
Filter order	4	6	8	6	4	4

4. Conclusion

A novel unit cell based on the grounded Hilbert patch embedded in the microstrip has been proposed in this paper. To demonstrate the applicability of the proposed unit cell, super compact stop band filter was designed. The footprint of the fourth-order filter is equal to $0.47\lambda_g$ x $0.12\lambda_g$, where λ_g is the guided wavelength. The proposed filter operates at 4.43 GHz and exhibits 10 dB fractional bandwidth equal to 30%, signal rejection level higher than 30 dB, and an extended pass band region up to 10 GHz. The advantages of the proposed filter are shown through comparison with recently published metamaterial-based planar stop band filters. Additional miniaturization can be obtained by changing line-to-spacing ratio or order of the Hilbert curve.

References

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