NOVEL SUPER-COMPACT STOPBAND FILTAR WITH GROUNDED PATCH RESONATORS

Vasa Radonić, Vesna Crnojević-Bengin

Faculty of Technical Sciences, University of Novi Sad, Serbia

Abstract: *In this paper, novel metamaterial unit cells based on the square grounded patch are proposed and applied in the microstrip filter design. To illustrate the potentials of the proposed unit cells, a novel compact stopband microstrip filter is proposed, based on the grounded patch resonators embedded in the microstrip line. Characteristics of the proposed filter are compared with state-of-the-art stopband filters of similar type in terms of size, performance and fabrication complexity. The fabricated fourth-order filter has overall dimension of* $0.52\lambda_g$ *x* $0.13\lambda_g$*, 10dB fractional bandwidth equal to 35% at 4.36GHz, and insertion loss of more than -30dB in the stopband, and it outperforms all previously published stopband filters of that type.*

Key Words: ***stopband filtar, patch resonator, metamaterial***

1. INTRODUCTION

In the last decade, development of artificial structures which exhibit unusual electromagnetic properties, received a significant attention. Such structures, called metamaterials, consist of unit cells with subwavelength dimensions. By a proper choice of the type and geometrical arrangement of the unit cells, the effective permittivity and permeability can be made arbitrarily small or large, or even negative.

One of the main research directions in the field of metamaterials is based on application of split-ring resonator, SRR, which provides negative permeability at microwave frequencies. Essentially, SRR behaves as an LC resonant tank which exhibits filtering properties at resonance, when properly polarized. Although having a very narrow frequency range with negative permeability and relatively high insertion loss, the configurations that use SRR have drawn a lot of attention, [1-4]. In microstrip architecture, negative permeability is achieved when SRR is placed next to the microstrip line, [5]. Such structure is a single negative medium and exhibits stop band characteristic in the vicinity of the resonant frequency of SRR. However, in fabrication of SRR-based circuits, a special attention has to be paid to the resolution, i.e. to the fabrication of narrow conductive lines on small spacings which form an SRR.

In this paper, novel metamaterial microstrip unit cell are presented, where SRR is replaced with much simpler unit cell - a grounded square patch resonator shown in Fig. 1. Grounded patch was initially proposed by D. Sievenpiper in electromagnetic bandgap (EBG) structures, in the design of two-dimensional metamaterials, [6], but are seldom used in microstrip applications. The main feature of EBG structures is the suppression of surface wave propagation, which increases the antenna gain and reduces the unwanted back radiation. Recently, microstrip applications of grounded patch grabbed attention, [7]. In this paper, microstrip applications of grounded patch were proposed in the design of stopband filter. Influences of different arrangements in regard to microstrip line were analyzed. Using the proposed unit cell, the fourth-order stopband filter is designed which outperforms all similar existing solutions in terms of fractional bandwidth, size and fabrication complexity.

2. MICROSTRIP IMPLEMENTATIONS

A typical unit cell of the single-negative metamaterial consists of a microstrip loaded with SRR, [8]. Due to negative permeability at the resonant frequency of the ring, such unit cells exhibit notch behavior. The similar unit cell which uses grounded patch instead of the SRR, was proposed in [9], Fig. 2(a). The fabrication of the grounded patch is less sensitive to dimension tolerances, since it does not require narrow lines on small spacing such as SRR. In order to enhance the coupling between the patch and the microstrip, we propose to embed the grounded patch in the microstrip, [9-10], Fig 2(b). 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 100μm x 100μm. 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. Conductor losses were modeled using bulk conductivity for copper. Simulations were performed using EMSight, full-wave simulator from Microwave Office. The overall size of all unit cells is 5mm x 5mm. Simulated responses of all structures are shown in Fig. 3, where microstrip loaded with SRR and SRR embedded in the microstrip are included in comparison.

In the case of resonators placed next to the microstrip, the grounded patch exhibits much stronger rejection at resonance, but its resonant frequency is significantly higher than that of SRR. However, when unit cells are embedded in the microstrip, resonant frequency of the grounded patch decreases while its high rejection is preserved and even enhanced. Although the embedded SRR exhibits the lowest resonant frequency of all (i.e. the highest potential for miniaturization), its rejection level is insufficient for filtering applications. Furthermore, the grounded patch exhibits second resonance at approximately three times the first resonant frequency. According to these results, it is very clear that the grounded patch embedded in microstrip is suitable for the design the stopband filters with extended passband region.

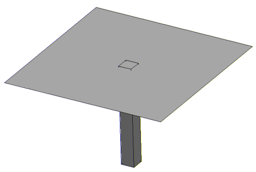
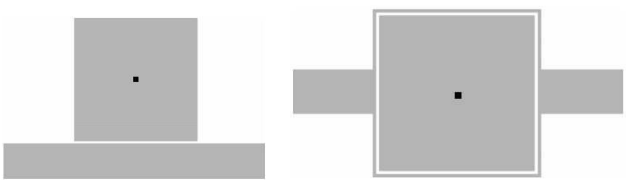


Fig.1. *Grounded square patch resonator.*



(a) (b)

Fig. 2. (*a) Microstrip loaded with the ground patch resonator, (b) Proposed resonator: grounded patch embedded in the microstrip.*

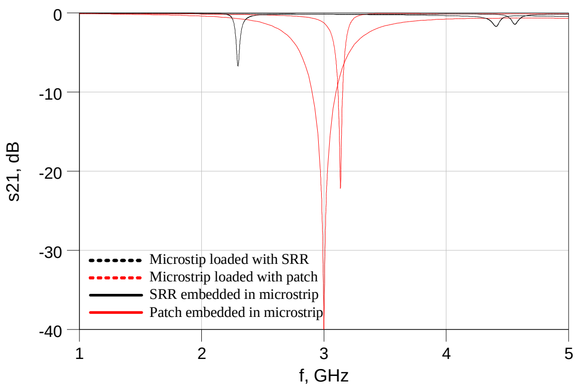


Fig. 3. *Comparison of the simulation results for four different unit cells: microstrip loaded with SRR, microstrip loaded with grounded patch, SRR embedded in microstrip, and grounded patch embedded in microstrip.*

3. STOPBAND FILTER DESIGN

Stopband filters are important building elements in modern communication systems, especially in power amplifiers, antenna systems and mixers. Several stopband 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 focus on metamaterial-based planar stopband filters, inherently characterized by a 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].

Based of the proposed ground patch embedded in the microstrip, super compact high selectivity stopband filter of the fourth order was designed, fabricated and measured. Layout of the filter is shown in Fig. 4 for optimized outer dimension of the patches equal to 3.3mm x 3.3mm. All unit cells are identical, and no time-consuming optimization is needed in the process of filter design. All spacings between patches and the microstrip are equal to 0.1mm and size of all vias is 0.1mm x 0.1mm. The overall filter dimensions are 14.5mm x 3.7mm, i.e. approximately $0.52\lambda_g$ x $0.13\lambda_g$, where λ_g is the guided wavelength. Simulated and measured responses of the filter are compared in Fig. 5, while the photograph of the fabricated prototype is shown in the inset. A good agreement can be observed, except for some ripples at the stopband edges, which result from the manufacturing tolerances. The filter exhibits 35% 10dB fractional bandwidth centered at 4.36GHz with the rejection of more than 30dB and the maximal reflection coefficient around 1dB in the stopband. The second stopband appears at approximately 10GHz.

The proposed filter is compared with recently published stopband filters based on different configurations of SRR, [1]-[3]. The characteristic parameters for these filters are summarized in the Table I, where f_c denotes central frequency, *FBW* is 10dB fractional bandwidth and $s_{21\text{-}0}$ is rejection in the stopband, *Q* is the loaded quality factor, and s_{21L} and s_{21R} are insertion losses in the passbands on the left and the right side of the stopband, respectively. *Q* is defined as the ratio of the central frequency and the 10dB bandwidth. In references [1]-[3], the authors did not provide exacted values of *Q*-factor and insertion losses in the passbands. Those values are obtained from measured responses presented in the papers. Table I also gives order of different filters, and their overall dimensions and chip area in terms of guided wavelengths.

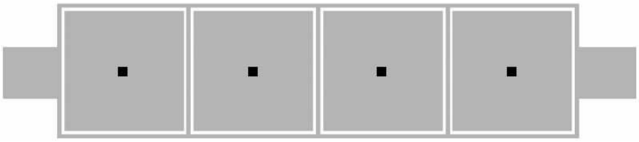


Fig. 4. *Layout of the proposed stopband filter of the fourth order.*

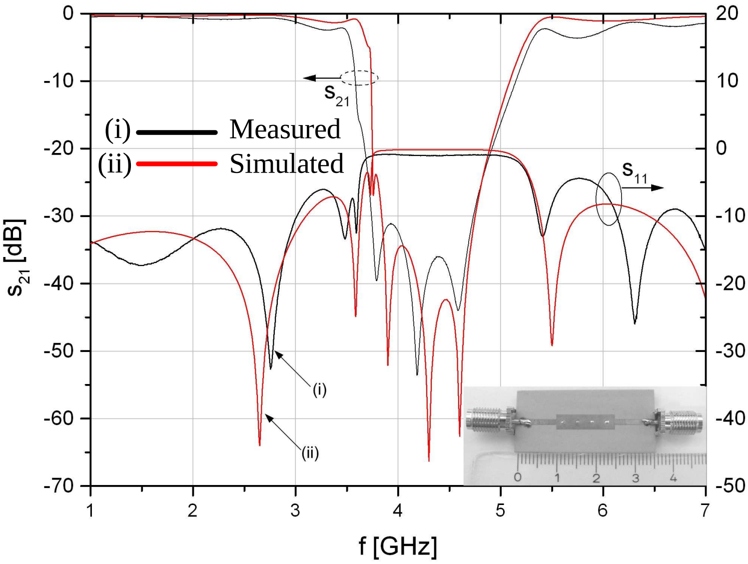


Fig. 5. *Simulated and measured responses of the proposed stopband filter. Photograph of the fabricated circuit is shown in the inset.*

Table I. Comparison of the characteristics of the proposed filter and other recently published metamaterial-based microstrip stopband filters

	Proposed Filter	**Filter [1]a**	**Filter [2]**	**Filter [1]b**	**Filter [3]**
***f_c*, GHz**	4.36	9.25	4.5	9.25	2.44
***BW*, MHz**	1360	≈333	760	3000	60
***FBW*, %**	35	3.6	17	33	2.45
Q	3.206	27.78	5.92	3.083	40.67
s_{21-0}, dB	-30dB	-35dB	-25dB	-45dB	-20dB
s_{21L}, dB	-0.77	-0.3	-0.67	-1.33	-0.603
s_{21R}, dB	-1.15	-0.3	-1	-6.67	-0.862
***Dimensions*, mm**	3.7x14.5	19.5x7.75	39.3x9.97	19.5x3	23.7x23.7
***Dimensions*, λ_g**	0.52x0.13	1X0.4	0.4x1.6	1x0.15	0.5x0.5
***Chip area*, 100λ_gxλ_g**	6.76	40	64	15	25
Filter order	4	6	8	6	4

Filter [1]a, is basically a microstrip loaded with SRRs on both sides. Although the filter is of the sixth order and has high *Q*-factor, it exhibits a very narrow stopband equal to 3.6%. Furthermore, its footprint is seven times larger than that of the proposed filter. 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 stopband, equal to 17%. Eights unit cells are used, resulting in almost ten times larger footprint than in the case of the proposed filter. An alternative to obtaining a stopband characteristic is to use complementary SRRs etched in the ground plane, [1], below the microstrip instead of SRRs positioned next to the line, Filter [1]b. The response of Filter [1]b is similar to the proposed one in terms of fractional bandwidth (33%), Q-factor (3.083) and rejection in the stopband (-45dB). However, to achieve such response the filter needs to employ 8 unit cells, resulting in the total footprint more than two times larger than in the proposed case. Furthermore, Filter [1]b exhibits lossy response above the higher stopband edge. It also 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 [3] is characterized by the smallest length of all, slightly smaller than that of the proposed filter, and the highest quality factor. However, its footprint is quite large. Although Filter [3] is of the fourth order, it exhibits a very narrow stopband, equal to 2.45%.

The proposed filter is also compared with recently published non metamaterials stopband filters, [11]-[14]. The characteristic parameters for these filters are summarized in the Table II, where f_c denotes central frequency, FBW is 10dB fractional bandwidth, $s_{21\text{-}0}$ is rejection in the stopband and Q is the loaded quality factor that is defined as the ratio of the central frequency and the 10dB bandwidth. Table II also gives order of different filters, and their overall dimensions and chip area in terms of guided wavelengths.

Filter [11] is a wideband second order filter based on meander lines. Although the filter has ultra wide bandwidth, it has low Q-factor and footprint that is more that free time larger then the proposed filter and exhibits lossy response above the higher stopband edge. Filter [12] is a basically microstrip line loaded with split-ring and grounded T-resonator. The filter is very compact, slightly smaller than that of the proposed filter, and has the highest quality factor. However, filter has very narrow band with small insertion losses equal to -15dB in the stopband. Filter proposed in [13] is characterized by the smallest size of all and exhibits extremely wide stopband, equal to 123%. However, Filter [13] has smooth transition and exhibits lossy response above the higher stopband edge. Filter [14] is third order filter based on steep-impedance two-section stubs. The response of this filter is similar to the proposed one in terms of fractional bandwidth (37%), but it has smaller Q-factor. Furthermore, its footprint is two times larger than that of the proposed filter.

Table II. Comparison of the characteristics of the proposed filter and other recently published non metamaterial stopband filters

	Proposed Filter	**Filter [11]**	**Filter [12]**	**Filter [13]**	**Filter [14]**
f_c, GHz	4.36	2.5	1.425	1.5	3
***BW*, MHz**	1360	3000	27	1840	1110
***FBW*, %**	35	120	1.9	123	37
Q	3.206	0.83	52.78	0.82	2.7
$s_{21\text{-}0}$, dB	-30	-25	-15	-30	-46
***Dimensions*, mm**	3.7x14.5	26.4x32.4	23.4x19.3	4.3x58.1	53x14.8
***Dimensions*, λ_g**	0.52x0.13	0.4x0.5	0.232x0.19	0.04x0.53	0.767x0.21
***Chip area*, $100\lambda_g x\lambda_g$**	6.76	20	4.408	2.12	16.413
Filter order	4	2	1	1	3

4. CONCLUSION

An analysis and comparison of recently published microstrip stopband filters has been carried out in this work. A novel unit cell has been proposed based on the grounded patch embedded in the microstrip. To demonstrate the applicability of the proposed unit cell, super compact stop-band filter of the fourth-order was designed, fabricated and measured. It operates at 4.36 GHz and exhibits 10 dB fractional bandwidth of 35%, signal rejection level higher than 30 dB, and an extended passband region between the first and the second stopband. Apart from its performances, the advantage of the proposed filter over other similar configurations, is its very compact size: the footprint of the fourth-order filter is equal to $0.52\lambda_g x 0.13\lambda_g$, where λ_g is the guided wavelength.

4. REFERENCES

[1] V. Oznazi and V. B. Ertrurk: "A Comparative investigation of SRR- and CSRR- based bandreject filters: simulations, experiments, and discussion," *Microwave and Optical Technology Letter*, Vol. 50, No. 2, pp. 519-523, February 2008.
[2] J. Garcia-Garcia, J. Bonache, I. Gill, F. Martin, R. Marques, F. Falcone, T. Loperegi, M. A. G. Laso and M. Sorolla: "Comparison of electromagnetic band gap and split-ring resonator microstrip lines as stop band structures," *Microwave and Optical Technology Letter*, Vol. 44, No. 4, pp. 376-379, February 2005.
[3] R. Wu, S. Amari and U. Rosenberg: "New cross-coupled microstrip bandreject filters," *IEEE MTT-S International Microwave Symposium*, Vol. 3, pp. 1597-1600, 2004.
[4] V. Crnojević-Bengin, V. Radonić, and B. Jokanović, "Left-handed microstrip lines with multiple complementary split-ring and spiral resonators," *Microwave and Optical Technology Letter*, Vol. 49, No. 6, pp.1391-1395, June 2007.
[5] V. Radonić, B. Jokanović and V. Crnojević-Bengin: "Different approaches to the design of metamaterials," *Microwave Review,* Vol. 13, No. 2, pp. 2-7, December 2007.
[6] D. Sievenpiper, L. Yhang, R. F. J. Broas, N. Alexopulous, E. Yablanovitch: "High-impedance electromagnetic surfaces with a forbidden frequency band," *IEEE Transaction of Microwave Theory and Techniques*, Vol.47, No.11, November 1999.
[7] J. G. Lee and J. H. Lee: "Parallel coupled bandstop filter using double negative coupled transmission line" *Microwave and Optical Technology Letter,* Vol. 17, No. 4, April 2007.
[8] J. Garcia-Garcia, F. Martin, J. D. Beana, R. Marques and L. Jelinek: „On the resonances and polarizabilities of split rings resonators," *Jouran of Applied Physics 98*, 033103, pp. 1-9, August 2005.
[9] V. Radonić, V. Crnojević-Bengin and B. Jokanović, „Novel unit cell based on the grounded patch for filter applications," *Mediterranean Microwave Symposium MMS 2008*, Damaskus, Syria, 14-16 Oktober 2008.
[10] V. Radonić and V. Crnojević-Bengin: "Super-compact stopband filter based on grounded patch resonator," *Electronic letters,* Vol. 46, No. 2, pp. 146-147, January 2010.
[11] M. K. Mandal, K. Divyabramhan and S. Sanyal: "Design of compact wide-band bandstop filters with sharpe rejection characteristics," *Microwave and Optical Technology Letter*, Vol. 50, No. 5, pp. 1244-1248, March 2008.
[12] D. C. Rebenaque, F. Q. Pereira, J. L. G. Tornero, J. P. Garcia and A. A. Melcon: "Two simple implementations of transversal filters with coupling between non-resonant nodes," *IEEE MTT-S International microwave symposium*, Vol. 2, pp. 957-960, 2005.
[13] M. K. Mandal, V. K. Velidi, S. Sanyal and A. Bhattacharya: "Design of ultra-wideband bandstop filter with three transmission zeros," *Microwave and Optical Technology Letter,* Vol. 50, No. 11, pp. 2955-2957, August 2008.
[14] C.-W. Hsue, Y.-J. Chen and Y.-H. Tsai: "Design of bandstop filters using discrete-time notch filter, two-section stub and frequency-scaling method," *Microwave and Optical Technology Letter,* Vol. 49, No. 5, pp. 1098-1101, March 2007.