Super-compact stopband filter based on grounded patch resonator

Vasa Radonić, Vesna Crnojević-Bengin

In this letter, a novel compact stopband microstrip filter is proposed, based on the grounded patch resonator 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.

Introduction: 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]. In this letter, a novel single-negative microstrip metamaterial unit cell based on the grounded patch resonator is presented. The square grounded patch was initially proposed in the design of high-impedance surfaces, [4], but is seldom used in microstrip applications. 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.

Unit cell: A typical unit cell of the single-negative metamaterial consists of a microstrip loaded with SRR, [5]. Due to negative permeability at the resonant frequency of the ring, such unit cells exhibit notch behaviour. In this letter, we first propose a similar unit cell which uses grounded patch instead of the SRR, Fig. 1(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, Fig 1(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 100 μm. Via is modelled with a square cross section equal to 100x100 μm. Simulated responses of all structures are shown in Fig. 2, where SRR embedded in the microstrip is 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.

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 modelled using bulk conductivity for copper. Simulations were performed using EMSight, full-wave simulator from Microwave Office. The overall size of all unit cells is 5x5 mm.

Filter configuration: 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. 3 for outer dimension of the patches equal to 3.3x3.3 mm. 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 0.1 mm and size of all vias is 0.1x0.1 mm. The overall filter dimensions are 14.5x3.7 mm, 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. 4, 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% 10 dB fractional bandwidth centered at 4.36 GHz with the rejection of more than 30 dB and the maximal reflection coefficient around 1 dB in the stopband. The second stopband appears at approximately 10 GHz.

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 10 dB 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.

Filter 1a, [1], 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 1b. The response of Filter 1b is similar to the proposed one in terms of fractional bandwidth (33%), Q-factor (3.083) and rejection in the stopband (-45 dB). 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 1b 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%.

Conclusion: An analysis and comparison of recently published metamaterial-based 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.

Authors' affiliations:

V. Radonić and V. Crnojević-Bengin (Faculty of Technical Sciences, Trg Dositeja Obradovića 6, Novi Sad, Serbia, e-mail: vasarad@uns.ac.rs, bengin@uns.ac.rs)

References

[1] OZNAZI, V., and ERTRUK, V.B.: 'A Comparative investigation of SRR- and CSRR- based bandreject filters: simulations, experiments, and discussion,' Microw. Opt. Technol. Lett., Vol. 50, No. 2, pp. 519-523, February 2008

[2] GARCIA-GARCIA, J., BONACHE, J., GIL, I., MARTIN, F., MARQUES, R., FALCONE, F., LOPEREGI, T., LASO, M.A.G., and SOROLLA, M.: 'Comparison of electromagnetic band gap and split-ring resonator microstrip lines as stop band structures,' Microw. Opt. Technol. Lett. , Vol. 44, No. 4, pp. 376-379, February 2005

[3] WU, R., AMARI, S., and ROSENBEG, U.: 'New cross-coupled microstrip band reject filters," IEEE MTT-S International Microwave Symposium, Vol.3, pp. 1597-1600, 2004

[4] SIEVENPIPER, D., YHANG, L., BROAS, R.F.J., ALEXOPULOUS, N., and YABLANOVIITCH, E.: 'High-impedance electromagnetic surfaces with a forbidden frequency band,' IEEE Tranc. Microw. Theory Tech., Vol.47, No.11, November 1999

[5] GARCIA-GARCIA, J., MARTIN, F., BEANA, J. D., Marques, R., JELINEK., L.: 'On the resonances and polarizabilities of split rings resonators' Jouran of Applied Physics 98, 033103, pp. 1-9, August 2005

Table captions:

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

Figure captions:

Fig. 1. (a) Microstrip loaded with the ground patch resonator. (b) Proposed resonator: grounded patch embedded in the microstrip.

Fig. 2. 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.

(i) Microstip loaded with SRR
(ii) Microstrip loaded with grounded patch
(iii) SRR embedded in microstrip
(iv) Grounded patch embedded in microstrip

Fig. 3. Layout of the proposed stopband filter of the fourth order

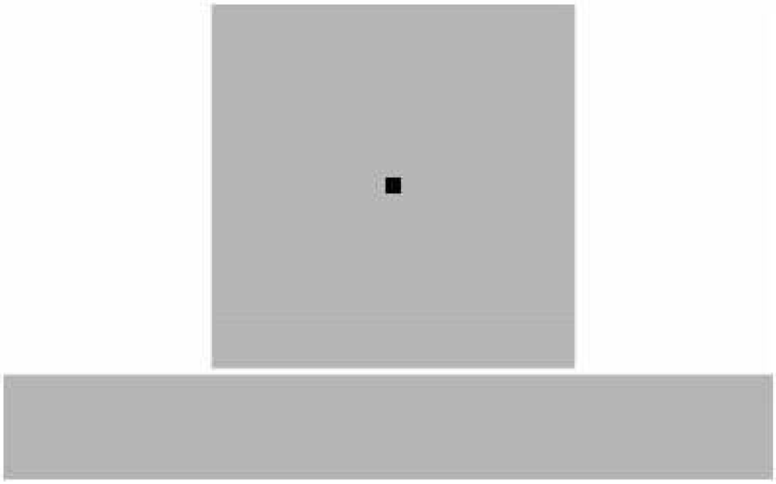
Fig. 4. Simulated and measured responses of the proposed stopband filter. Photograph of the fabricated circuit is shown in the inset.

(i) Measured
(ii) Simulated

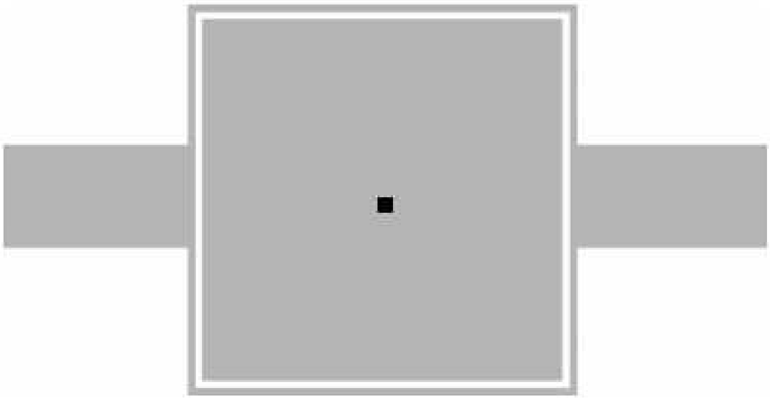
Table I

	Proposed Filter	Filter 1	Filter 2	Filter 1b	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
$s_{21\text{-}0}$, 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, 100*λ_gxλ_g	6.76	40	64	15	25
Filter order	4	6	8	6	4

Figure 1



(a)



(b)

Figure 2

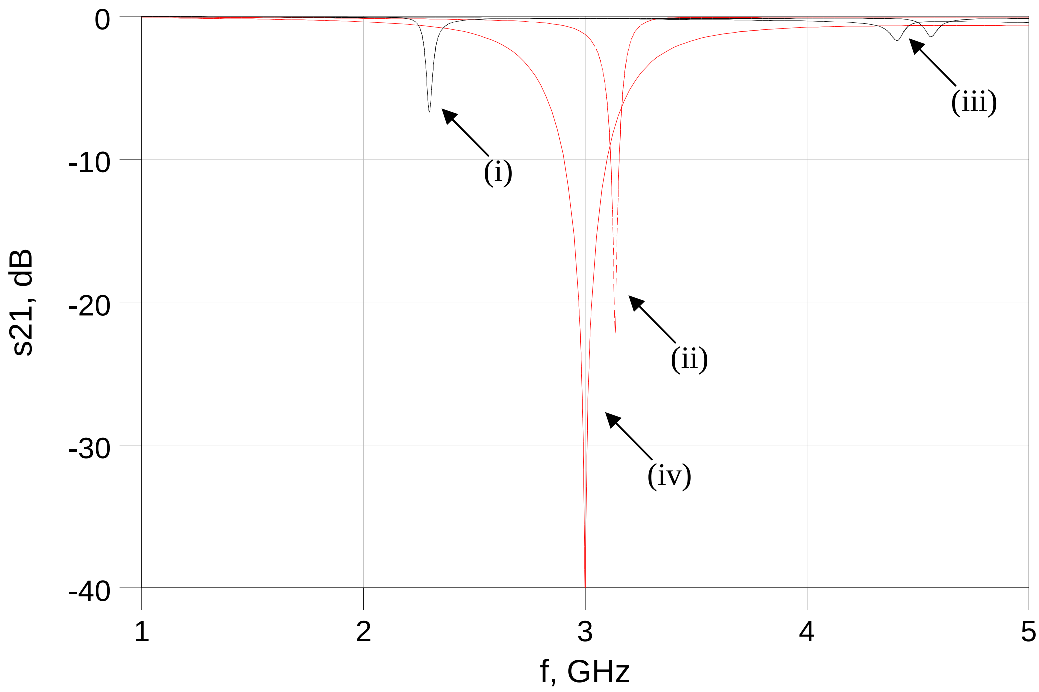


Figure 3

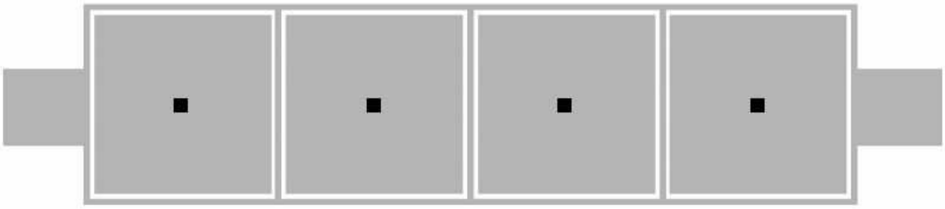
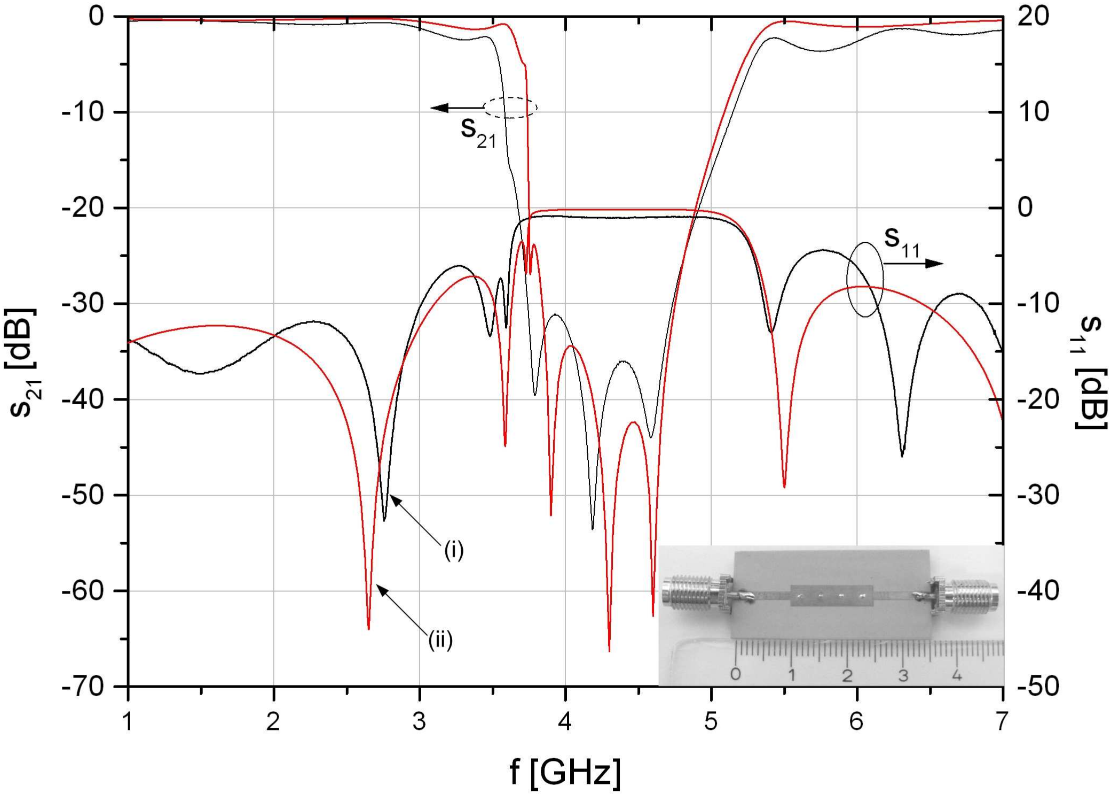


Figure 4


s21 [dB]
s11 [dB]
f [GHz]
s21
s11
(i)
(ii)
0
-10
-20
-30
-40
-50
-60
-70
20
10
0
-10
-20
-30
-40
-50
1
2
3
4
5
6
7