Analysis of Metamaterial Unit Cells Based on Grounded Patch

Vasa Radonić, Vesna Crnojević-Bengin, Branka Jokanović[1]

Abstract – **In this paper unit cells based on the square grounded patch resonator are employed in microstrip configurations. Influence of geometrical parameters on performances is analyzed and compared with similar configurations which use split-ring resonators. Guidelines for stop-band filter design are given through analysis of proposed unit cells on different substrates. As it is represented, unit cell based on the ground patch shows better potential for design of wide stopband filters then SRR.**

Keywords – **Metamaterial, Unit cell, Patch resonator, Split-Ring Resonator.**

I. 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 parameters of metamaterials (such as 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], [2], [3], [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 spacing which form an SRR.

In this paper, novel metamaterial microstrip implementations are presented, where SRR is replaced with much simpler unit cell-a grounded square patch shown in Fig. 1. Such unit cells were first proposed in the design of two-dimensional metamaterials, i.e. high-impedance surfaces, [6], but are seldom used in micros trip applications. Fundamental properties of 2D metamaterials unit cell, called mushroom structure, and their applications are investigated in [7]. In this paper, microstrip unit cells based on the grounded patch are compared to similar structures that use SRR. Influence of different geometrical parameters on performances is analyzed, as well as the high-frequency limit of operation of both unit cells, since lower microwave bands are becoming more and more occupied and new solutions are sought for wireless communication systems of the next generation which will use higher frequencies. Guidelines for stop-band filter design are given through analysis of proposed unit cells on different substrates.

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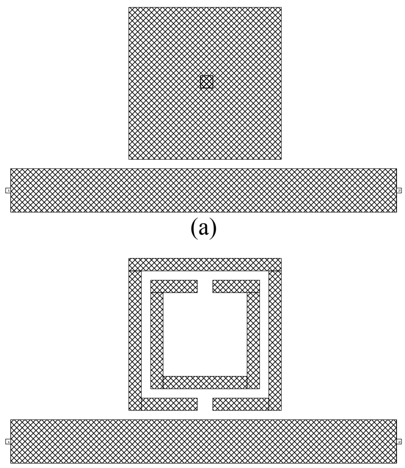
Fig.1. Grounded square patch

II. MICROSTRIP LINE LOADED WITH THE GROUNDED PATCH / SRR

Microstrip lines loaded with the grounded patch and SRR are shown in Fig.2a and Fig.2b, respectively. To enhance the coupling, distance between the unit cells and the microstrip line, as well as the distance between the concentric rings of the SRR are chosen to be the minimal achievable in standard PCB technology, i.e. equal to 100μm. The circuits are realized on a 1.27mm thick Taconic CεR-10 substrate, with ε_r=9.8 and dielectric loss tangent equal to 0.0035. Conductor losses are modeled using bulk conductivity for copper. In order to increase the inductance of unit cell, dimension of SRR lines and patch via also have minimal width, equal to 100μm. All simulations were performed using EMSight, full-wave simulator from Microwave Office.



(a)

(b)

Fig. 2. Microstrip loaded with (a) grounded patch resonator, (b) SRR

TABLE 1

SIMULATION RESULTS FOR MICROSTRIP LOADED WITH GROUNDED PATCH WITH SIZE *a*

***a* [mm]**	**4.9**	**3.1**	**2.5**	**2.1**	**1.5**	**1.1**	**0.7**	**0.3**
f_{s1} [GHz]	3.12	4.68	5.59	6.4	8.24	9.61	13.5	16.5
B_{-3db} [MHz]	114	222	316	446.2	681	985	1200	458
B_{-10} [MHz]	37.5	78.8	109	147.9	236	344	379	na
s_{21} [db]	-34.4	-42.1	-49.5	-26.6	-28.6	-30.4	-36.4	-52.9

TABLE 2

SIMULATION RESULTS FOR MICROSTRIP LOADED WITH SRR WITH OUTER RING DIMENSION *a*

***a* [mm]**	**4.9**	**3.1**	**2.5**	**2.1**	**1.5**	**1.1**	**0.7**
f_{s1} [GHz]	2.32	3.96	5.19	6.41	9.93	12.95	16.7
B_{-3db} [MHz]	39.5	59.8	68.3	-5.19	na	na	na
B_{-10} [MHz]	na	na	na	na	na	na	na
s_{21} [dB]	-7.79	-8.68	-8	-5.19	-2.03	-2.77	-2.58

TABLE 3

MICROSTRIP LINES LOADED WITH GROUNDED PATCH / SRR WITH SIZE *a* SIMULATED ON DIFFERENT SUBSTRATES

Taconic C*ε*R-10 substrate; *h*=1.27mm ε_r=9.8 tg*δ*=0.0035										
***a* [mm]**	**0.7**		**1.1**		**2.1**		**3.1**		**4.9**	
UC Type	**SRR**	**Patch**	**SRR**	**Patch**	**SRR**	**Patch**	**SRR**	**Patch**	**SRR**	**Patch**
f_{r1} [GHz]	16.7	13.5	12.95	9.61	6.41	6.4	3.96	4.68	2.32	3.12
s_{21} [db]	-2.58	-36.4	-2.77	-30.4	-5.19	-26.6	-8.68	-42.1	-7.79	-34.44
B_{-3db} [MHz]	na	1200	na	985	68	446.2	59.8	222	39.5	114
Taconic RF-60A ORCER substrate; *h*=0.64mm ε_r=6.15 tg*δ*=0.0038										
***a* [mm]**	**0.7**		**1.1**		**2.1**		**3.1**		**4.9**	
UC Type	**SRR**	**Patch**	**SRR**	**Patch**	**SRR**	**Patch**	**SRR**	**Patch**	**SRR**	**Patch**
f_{r1} [GHz]	17.3	17.3	12.2	16.3	12.2	13.7	5.02	6.93	3	4.46
s_{21} [db]	-1.05	-1.13	-3.36	-12.3	-3.36	-19.8	-5.23	-12.3	-4.33	-9.98
B_{-3db} [MHz]	nd	nd	43.8	1000	43.8	510	62.5	132.5	30.6	74.6
Taconic TLE substrate; *h*=0.96mm ε_r=2.95 tg*δ*=0.0028										
***a* [mm]**	**1.5**		**1.7**		**2.1**		**3.1**		**4.9**	
UC Type	**SRR**	**Patch**	**SRR**	**Patch**	**SRR**	**Patch**	**SRR**	**Patch**	**SRR**	**Patch**
f_{r1} [GHz]	15.6	15	14.05	13.85	10.7	11.7	6.65	8.52	3.91	5.65
s_{21} [db]	-7.06	-24.5	-4.04	-30.3	-4.55	-32.5	-6	-27.9	-7.15	-25.4
B_{-3db} [MHz]	220	1470	90.5	1289	76	998	74.8	532	64.4	227
Taconic TLT substrate; *h*=3.18mm ε_r=2.5 tg*δ*=0.0006										
***a* [mm]**	**0.7**		**1.5**		**2.5**		**4.9**		**5.5**	
UC Type	**SRR**	**Patch**	**SRR**	**Patch**	**SRR**	**Patch**	**SRR**	**Patch**	**SRR**	**Patch**
f_{r1} [GHz]	18	12.4	13.3	8.39	8.89	6.19	3.91	3.93	3.73	3.61
s_{21} [db]	-15.6	-24.9	-2.41	-39.3	-4.77	-47.5	-14.7	-49	-15.2	-45.7
B_{-3db} [MHz]	580	3080	na	2618	56	1180	367	650	302	520

To investigate the influence of the patch/SRR size to the performances, outer dimension of the patch and the ring, a, were varied. Tables 1 and 2 show simulation results for both structures, where f_{s1} denotes first resonant frequency, s_{21} is insertion loss at f_{s1}, B_{-3dB} and B_{-10dB} are 3dB and 10dB bandwidths, respectively. Unlike the grounded patch, it is not possible to design SRR with *a*<0.7mm, due to its specific shape.

It can be seen that at lower frequencies (approximately below 6.4GHz), SRR presents a better solution when miniaturization is the main concern. However, SRR suppresses signals in the vicinity of resonance in much lesser extent than the grounded patch. This is also visible in Fig. 3, where simulation results for a wider frequency range for both structures with *a*= 4.9mm are compared. In the case of higher-frequencies, grounded patch results in more than two times smaller unit cells than SRR (for example, grounded patch at 16.5GHz is only 0.3mm wide while SRR is 0.7mm). In the same time, stronger signal rejection of the grounded patch in comparison to SRR is preserved. Another difference between the grounded patch and SRR also visible in Fig. 3 is that the ratio between first two harmonics: in the case of the grounded patch this ratio is approximately equal to 3, while it is only 2 for the SRR.

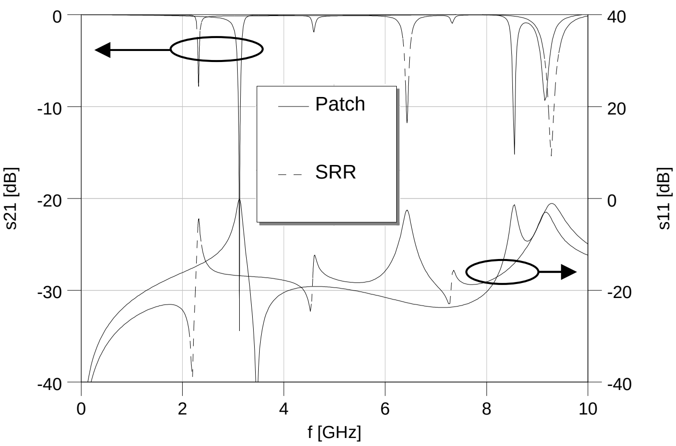


Fig. 3. Simulation results for microstrip lines loaded with grounded patch and SRR with outer dimensions a= 4.9mm

A. Influence of substrate characteristics to unit cell performances

Since capacitance and inductance of the proposed unit cells significantly depend on the characteristics of the substrate used, a number of different materials has been analyzed in this section. Detailed results for unit cells with grounded patch and SRR with different size are presented in Table 3. In the same table, characteristics of the used substrates can be found.

It can be seen that for all substrates, a frequency exists up to which SRR allows higher miniaturization. Of course, this frequency depends on the substrate characteristics and varies from 3.6GHz to 17.3GHz for substrates used in comparison. However, advantages of the grounded patch such as stronger suppression in the vicinity of resonance and wider stopband exist on all substrates. This makes grounded patch much more suitable for the design of wide stopband filters than SRR, while the actual substrate should be chosen according to particular specifications.

III. Grounded Patch / SRR Embedded in the Microstrip Line

In order to reduce the overall dimensions of the structure and to increase the coupling between microstrip line and the unit cell, a novel configuration shown in Fig. 4 is used, where the grounded patch is embedded in microstrip line. Simulation results for both structures with different size of the patch and the ring, a, are shown in Tables 4 and 5, respectively. It should be noted that SRR embedded in the microstrip exhibits very small insertion loss at resonance, and therefore 3dB bandwidth could not be measured. For that reason, simulation results for the second harmonic (f_{s2} and s_{21_2}) are also presented in Table 5. Simulation results for both structures with *a*= 4.9mm are compared in Fig. 5 for a wider frequency range.

Embedding unit cells in the microstrip resulted in significant improvement of performances of the configuration that uses grounded patch: resonant frequency is reduced in all cases and suppression of the signals around resonance is significantly increased. On the other hand, performances of the configuration with SRR are considerably degraded: suppression at resonance is unacceptably low, and the structure is no longer advantageous in terms of miniaturization.

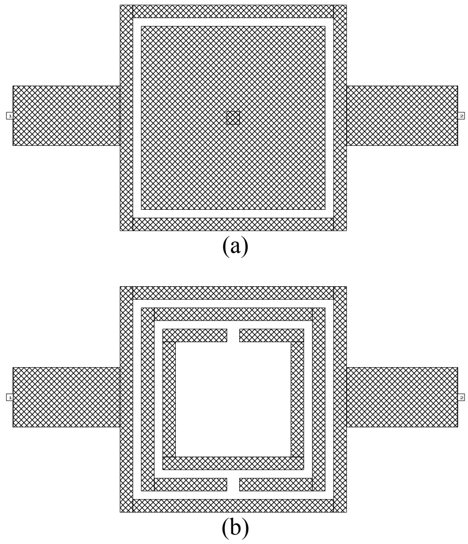


Fig. 4. (a) Grounded patch resonator and (b) SRR embedded in the microstrip line

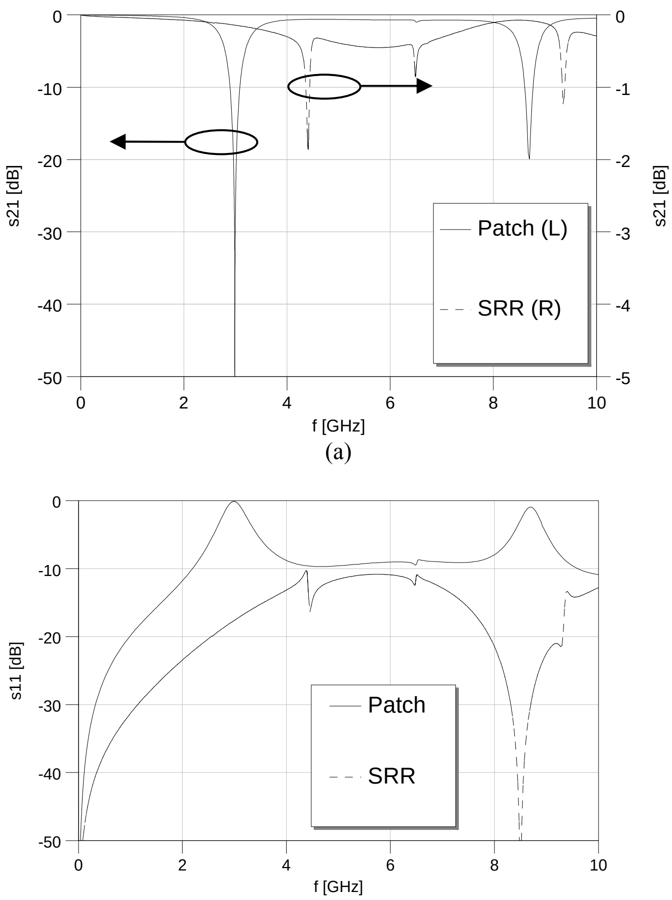


Fig. 5. Simulation results for grounded patch / SRR with *a*= 4.9mm, embedded in the microstrip: (a) transmission coefficient (b) reflection coefficient

TABLE 4
GROUNDED PATCH WITH SIZE *a* EMBEDDED IN THE MICROSTRIP

***a* [mm]**	**4.9**	**3.1**	**2.5**	**2.1**	**1.5**	**1.1**	**0.7**	**0.3**
f_{s1} [GHz]	2.99	4.43	5.28	6.05	7.77	9.16	13.2	16.5
B_{-3db} [MHz]	572	1190	1725	2255	3166	3776	5680	555.7
B_{-10} [MHz]	189.4	365	502	644	1000	1285	1557	1785
s_{21} [db]	-52.6	-50.3	-49.8	-50.5	-54	-55.7	-55.6	-54.6

TABLE 5
SRR EMBEDDED IN THE MICROSTRIP

***a* [mm]**	**4.9**	**3.1**	**2.5**	**2.1**	**1.5**	**1.1**	**0.7**
f_{s1} [GHz]	4.41	4.3	5.54	6.83	10.4	13.8	16.52
f_{s2} [GHz]	6.5	7.26	9.26	10.5	16.5	17.5	21.1
s_{21_1} [dB]	-1.86	-0.225	-0.416	-0.628	-0.845	-1.69	-8.46
s_{21-2} [dB]	-0.86	-3.64	-4.15	-7.21	-10.5	-8.01	-21.1

IV. CONCLUSION

Unit cells based on grounded patch and SRR in two geometrical arrangements (next to the microstrip and embedded in the microstrip) are presented and compared. Influence of geometrical parameters on performances of the unit cells is analyzed, as well as influence of substrate material. All obtained results are based only on simulations.

In the case of unit cells positioned next to the microstrip, SRR exhibits higher potential for miniaturization up to a certain frequency, which depends on the substrate characteristics and varies from 3.6GHz to 17.3GHz for substrates used in comparison. However, SRR suppresses signals in the vicinity of resonance in much lesser extent than the grounded patch. In the case of higher frequencies, grounded patch results in more compact unit cells, while in the same time, its stronger signal rejection and wider stop-band in comparison to SRR are preserved.

Embedding grounded patch in the microstrip results in reduction of its resonant frequency and in increased signal suppression. On the other hand, such embedding significantly degrades performances of SRR: suppression at resonance is unacceptably low, and the structure is no longer advantageous in terms of miniaturization.

It can be concluded that unit cells based on the grounded patch are much more suitable for the design of wide stopband filters then those that utilize SRR, while the actual substrate to be used should be chosen according to particular specifications.

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