

# Engineering of the metamaterial-based cut-band filter

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**Abstract** Metamaterial-based cut-band filters are realized by combining either split-ring resonators (SRRs) close to a microstrip line or complementary split-ring resonators under this line. Indeed, their use reduces the size of conventional microwave filters. The study of this paper focuses on the influence of the association of different arrays of SRR especially on the bandwidth of the cut-band filter.

## 1 Introduction

In recently, many people have focused on filter design with split-ring resonator (SRR) or improved SRR structures [1, 2]. The split-ring resonators presented by Pendry can exhibit negative permeability [3] and are used to realize left-handed materials (LHMs) with a negative index [4–7]. The SRRs are composed by concentric rings cut made with nonmagnetic metal such as copper. When SRRs are excited by magnetic field, their real part of permeability can be highly positive to negative close to their resonance frequency. This resonance frequency is narrow band which can be explained by analogy to LC resonator, where the inductance  $L$  is the length of the ring and the capacitance  $C$  is the size of the cut. Through their properties, the SRRs are used to reduce the size of microwave filter [8]. But, these new filters are also narrow band. However, the periodicity and the size of the SRR are often constants. The

position and the width of the cut-band filter depend of the size and the number of SRR. The association of SRRs with different sizes can increase the bandwidth of the filter.

## 2 Cut-band filter with constant SRR

Before associated many arrays of SRR, the behavior of a cut-band filter made with constants resonators is first reminded. All the calculations are made with a finite element software HFSS from Ansoft. For instance, a microstrip line combined with seven split-ring resonators of 5 mm placed every 5.5 mm on each side of it gives a filter which rejection is located at 4.9 GHz (Fig. 1). This frequency can be retrieved by knowing the size of the SRR and the permittivity and thickness of the substrate. In our case, the substrate is a 1.6-mm-thickness FR4. By increasing the number of SRR placed along the microstrip line, the band rejection is deeper [8]. Moreover, if the size of the rings increases, the resonance frequency decreases as expected (Fig. 2). Indeed, the value of the inductance increases and the frequency is inversely proportional to this value.

## 3 Association of different arrays of SRR

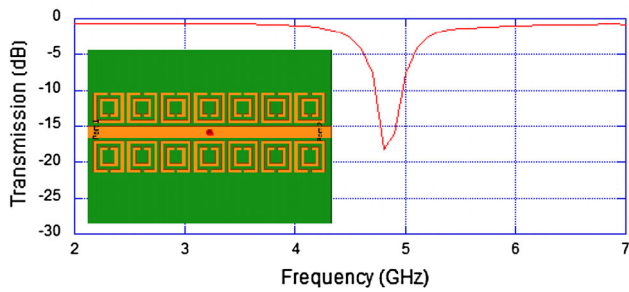
To understand the influence of each array of SRR, only three different arrays are used. The external size of these SRR equals 4.5, 5 and 5.5 mm, respectively.

For the first combination, only the two external SRRs of the array are changed. In one side, the SRRs are replaced by smaller ones and on the other side by biggest ones. As shown in Fig. 3, the three rejections can be observed and are located at 5.6, 4.8 and 4.3 GHz which correspond to the

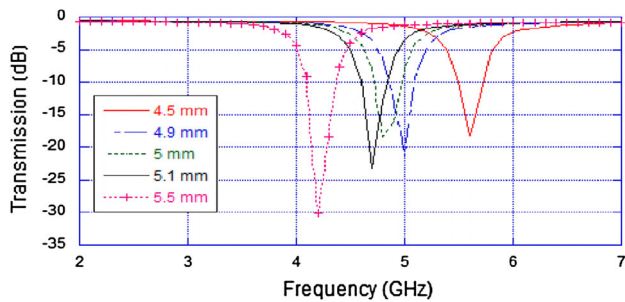
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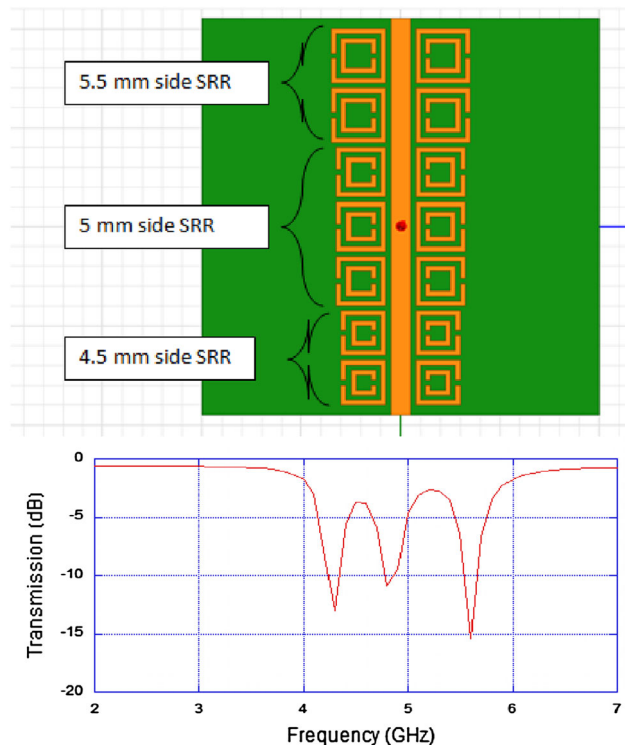
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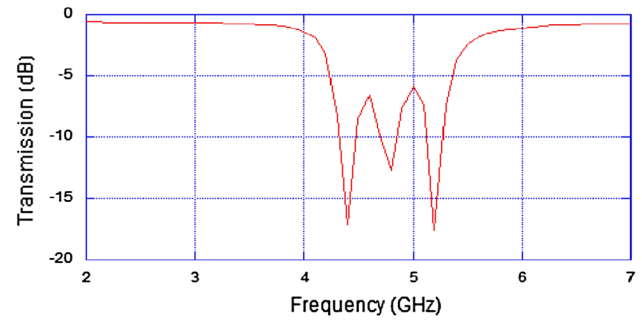
**Fig. 1** Transmission spectrum of a microstrip line associated with seven SRRs



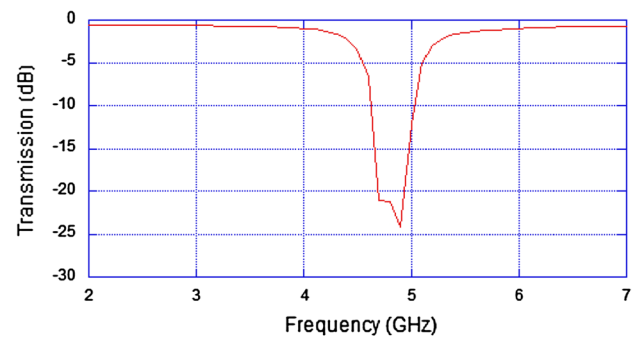
**Fig. 2** Comparison between five structures with constant size of SRRs from 4.5 mm side to 5.5 mm side



**Fig. 3** Up design of the structure with mixed sizes of SRR. Down transmission spectrum of the microstrip line associated with three arrays of SRRs: 4.5, 5 and 5.5 mm



**Fig. 4** Transmission spectrum of a microstrip line associated with three arrays of SRRs which size is 4.7, 5 and 5.3 mm



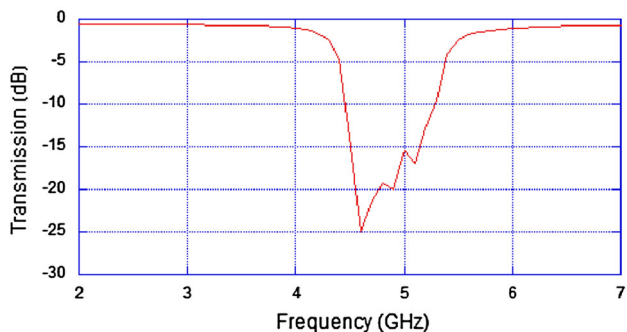
**Fig. 5** Transmission spectrum of the structure with three arrays of SRRs which size is, respectively, 4.9, 5 and 5.1 mm

size of the SRR equals to 4.5, 5 and 5.5 mm, respectively. These values are close to those obtained for constant structure. The small shift frequency is due to the coupling between the different sizes of SRRs. However, if the bandwidth is now larger than for constant structures, we can notice that the rejection only reaches about  $-12$  dB. This could be easily explained by the small number of constant SRR. Moreover, the rejections are too distant from each other. Therefore, the transmission level between the rejections equals almost  $-3$  dB which is not expected for a cut-band filter.

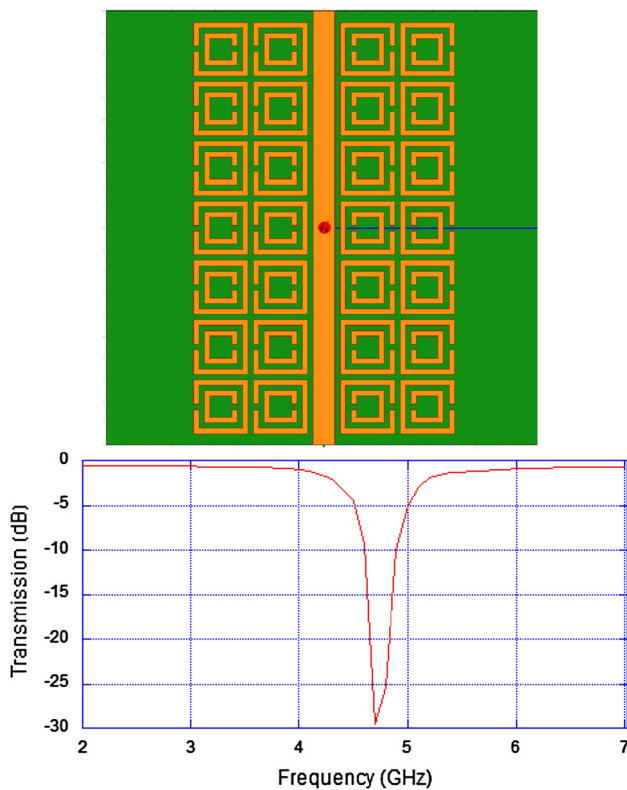
In order to approximate the resonance frequencies, the SRR now have sizes closer to each other. For instance, the two SRRs placed at each extremity equal 4.7 and 5.3 mm and the three SRRs placed in the middle remain at the size of 5 mm. These sizes are willingly chosen to illustrate the influence of these parameters on the filter (Fig. 4).

If the size of the SRR used for the three arrays is closer, the rejections would be closer too and the total bandwidth will be increased.

In the following configuration, the 3 arrays of SRRs have sizes, respectively, equal to 4.9, 5 and 5.1 mm (Fig. 5). The resonance frequencies are slightly split, and the rejection is still below  $-20$  dB. But the bandwidth has decreased.



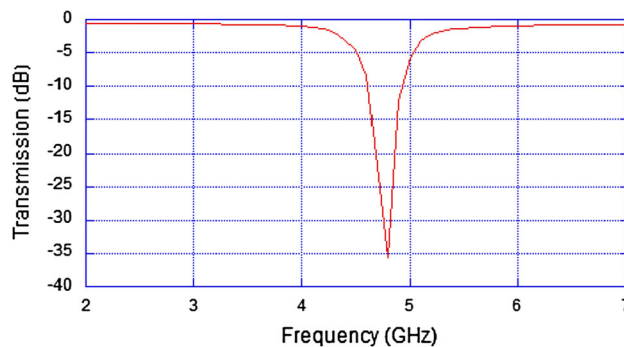
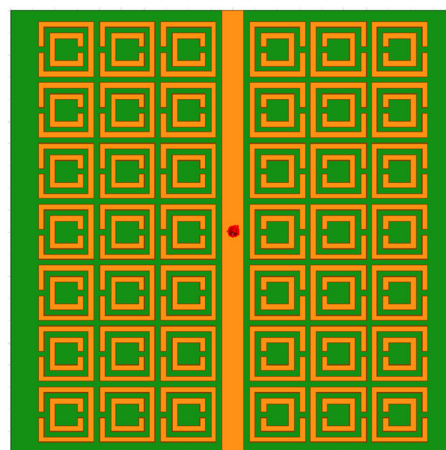
**Fig. 6** Transmission spectrum of the structure with ramping size of the seven SRRs, from 4.7 to 5.3 mm



**Fig. 7** Microstrip line loaded with two rows of 5-mm-side SRR from each side of the line. Up design. Down transmission spectrum

A solution to increase the bandwidth is to vary progressively the size of the SRR. In the following configuration, each SRR has different size. The external size of the seven SRRs equals, from the left to the right of the microstrip line, 4.7, 4.8, 4.9, 5, 5.1, 5.2 and 5.3 mm.

The answer of this configuration is the large bandwidth (Fig. 6). Indeed, the bandwidth of the filter with uniform 5-mm-side SRR is 200 MHz, whereas with the SRR progressively variable, the bandwidth reaches 1 GHz at -10 dB.



**Fig. 8** Microstrip line loaded with three rows of 5-mm-side SRR from each side of the line. Up design. Down transmission spectrum

As against, if the variation of the size of each SRR is too abrupt, while the resonant frequencies deviate giving a greater bandwidth but with a very low level of rejection.

One way to increase the depth of the bandwidth without increasing the length of the line is to add other arrays of SRR on each side of the line. To understand this phenomenon, the array is now constituted by constant 5 mm size of SRR. If the structure is composed of two rows of SRR, the resulting coupling is stronger and deeper bandwidth (Fig. 7). By adding another row, the transmission level reaches -35 dB (Fig. 8).

For a wideband metamaterial cut-band filter, it suffices to progressively vary the size of the SRR and coupled them with other rows.

### 4 Conclusions

To broad the bandwidth of a filter made with the association of SRR with a microstrip line, different arrays of SRR could be used. A rejection peak appears for each array. The level of this peak depends on the number of coupled SRR. If the size of the SRR used in each arrays varies a little, the rejection peaks become closer and increase the bandwidth of the filter.

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