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Coplanar waveguide low pass filter based on square complementary split ring resonator with wide rejection

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ABSTRACT

In this paper, we present a novel coplanar waveguide low pass filter (LPF) structure based on the use of square complementary split ring resonators (CSRRs) in order to enhance the performances of a low pass filter. Especially, to enlarge the bandwidth of the LPF, the insertion losses and to increase the rejection of the LPF. The CSRRs are optimised and inserted periodically along the center conductor of the CPW line with a CPW ground integrating stubs permitting to enlarge the bandwidth. The simulation results of this filter show a -3 dB cut-off frequency equal to f_c = 5.28 GHz. The designed filter has a good rejection in the stop band which below -20 dB and presents a good insertion loss in the bandwidth. The proposed filter has been fabricated and tested which give a good agreement between simulation and measurement results, the whole dimensions of the validated filter are 35.48x21.16 mm^2. The originality of this work is the wide rejection band and the miniature dimensions.

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1. INTRODUCTION

Metamaterials, also called “left hand materials”, are artificial periodic structures metallo-dielectric on a scale less than the wavelength which has electromagnetic properties not accessible in nature, namely a permittivity and permeability both negative. The first theory concerning their electromagnetic properties was introduced by the Russian researcher Veselago in 1964 [1]. Since then, this subject has known a long hibernation until 2000, when a first realization practice was proposed by the American researcher D. Smith [2]. The most important caracteristic of this structure is the possibility to control or to modify the permittivity and permeability of the material to get a behaviour adjusted to a particular application. Since, metamaterials [3-6] become a large field which attract many researchers over the world, they allow to work in many applications and to optimize performances of microwave devices, particularly in terms of miniaturization of circuit and the introduction of new properties (large rejection, dual band filters, suppression of the spurious harmonic.

Thanks to these left-handed materials, which use square split ring resonators (SRR) and complementary split ring resonators (CSRRS) [7, 8], it may be possible to design compact microstrip low pass filters, stop band filters and band pass filters for microwave frequency uses, etc. The basic cell of these resonators have very small dimensions compared to the guided wavelength. It is accepted that the limit of homogeneity is fixed at sizes less than λg/4. In this work, we will present a new low-pass filter using CSRR metamaterial structures to improve new performances such as miniaturization, a good rejection and also the suppression of parasitic higher order harmonics

2. CSRR CELL THEORY

The use of CSRR-based metamaterials in this paper is to promote miniaturization and improvement of rejection band for the low pass filter bandwidth [9, 10]. The CSRRs are formed by parallel combinations of inductors (s) and capacitors (C), with the LC circuit electromagnetically coupled to the host transmission line. The equivalent circuit model for the CSRRs loaded by the transmission lines and its relevant values of inductors and capacitors can be calculated using the methods described in [11, 12]. At resonance, the CSRR provides negative effective permittivity and produces a clean rejection stop band. Figure 1 shows the geometry of the CSRR cell structure unit with its equivalent lumped model. The transmission frequency of each CSRR coupled to the transmission line is given by:

$$f = \frac{1}{\left(2\pi\sqrt{LC[C_c + C]}\right)} \tag{1}$$

(a) (b)

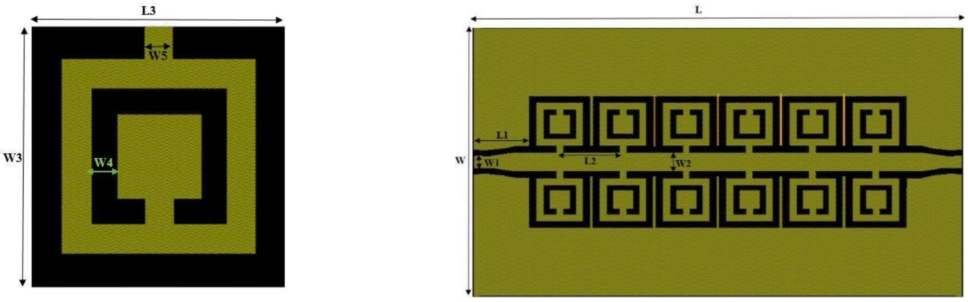
Figure 1. (a) Geometry of a CSRR unit cell, (b) Lumped-element equivalent circuit of the CSRR

The resonant frequency of CSRR can be tuned by adjusting its loop length, split space, loop thickness and spacing between concentric loops. Several publications [13-19] show that for the filter structures, CSRR can considerably reduce the size of the filter while maintaining very high stop band attenuation. In addition, the periodic integration of these resonators with complementary split rings on a coplanar waveguide (CPW) have several design advantages compared to conventional microstrip technology, e.g. the easy realization of shunts and the possibility of mounting active and passive localized components [20-24]. in this paper, we will present a new configuration of a CPW low-pass filter loaded with six CSRRs periodically etched along the center conducto which will permit to enlarge the bandwidth and the rejection band. Such filter is a suitable for UWB applications [25].

3. DESIGN PROCEDURE BY USING ELECTROMAGNETIC SOLVERS

We started the design of the proposed low pass filter based on metamaterials by studying the basic cell of the CSRR structure. Firstly, the CSRR is tuned to the resonant frequency by adjusting its loop length, split space, loop thickness and spacing between concentric loops, which will allow the matching input impedance of the filter to the desired frequency band. Secondly, we etched periodically six resonators with complementary split rings of the CPW transmission line as shown in Figure 2. After several series of optimization using the numerical methods of meshing integrated in electromagnetic solver which is the moment method, we have validated the proposed CPW LPF into simulation. Figure 2 illustrate the geometry of the low-pass filter (a) and of the CSRR unit cell (b). The optimized dimensions are presented in Table 1.

The final topology of the CPW low pass filter is printed on an FR4 substrate having a thickness of 1.6 mm, a dielectric permittivity Ɛr = 4.4 and a loss tangent tanδ = 0.025. The proposed filter using periodic structures of CSRR is simulated by using an electromagnetic solver. Figure 3 shows the S parameters of the final filter optimized. As shown in Figure 3. We have obtained a low pass filter having a wide bandwidth with a cut-off frequency at -3 dB equal to 5.28 GHz. This frequency can be tuned to achieve a low pass filter by adjusting the dimensions and values of capacitance and inductance when we transform lumped elements to distributed elements. The simulation results of this filter show a good insertion loss around which is arround -0.5 dB, a very wide rejection band until 9 GHz and a rejection under -20 dB. This rejection is due to the insertion of periodic optimised square complementary split ring resonator shapes.



(a) (b)

Figure 2. (a) The topology of CSRR unit cell, (b) Topology of the proposed CPW LPF using CSRR periodic cells

Table 1. Dimensions of the proposed CPW LPW structure

Parameters	Values (mm)
L	35.48
W	21.16
L1	4
L2	4.11
L3	4.4
W1	1
W2	1.5
W3	3.9
W4	0.44
W5	0.5

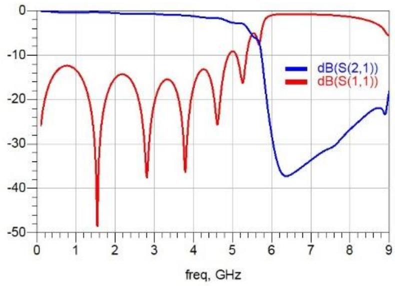


Figure 3. The S parameters of the proposed LPF structure versus frequency

Before the fabrication and in order to be sure about the LPF modelisation, we have conducted the same study and simulation using another electromagnetic solver based on 3D modelisation and another meshing method based on Finite Integral technique. The structure was simulated by using the same dimensions on an FR4 substrate. The geometry of this filter is illustrated in the Figure 4. Figure 5, show good concordance between the both EM solvers, the first one is a 2D method and the second one is using 3D modelisation. As shwon in Figure 5, we have got a good agreement between simulation results by using the both electromagnetic solver which validate the proposed CPW low pass filter into simulation.The design is verified also with the simulation of current distributions at a frequency in the bandwidth and an other one in the rejected band, so we have launched a simulation at two frequencies one at2 GHz and one at 7 GHz. The current distribution presented in Figure 6 illustrates the flow of current density in the bandwidth and an attenuation of current density in the rejection band from port 1 to port 2 which confirms that the filter behaves correctly in the whole frequency band.

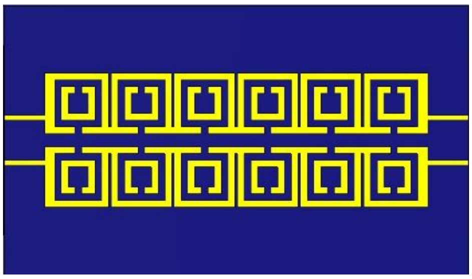


Figure 4. Topology of the proposed 3D CPW LPF structure designed by another EM Solver

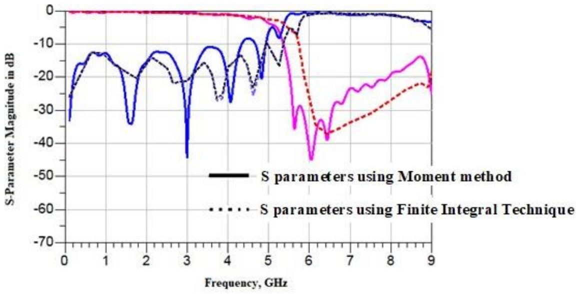
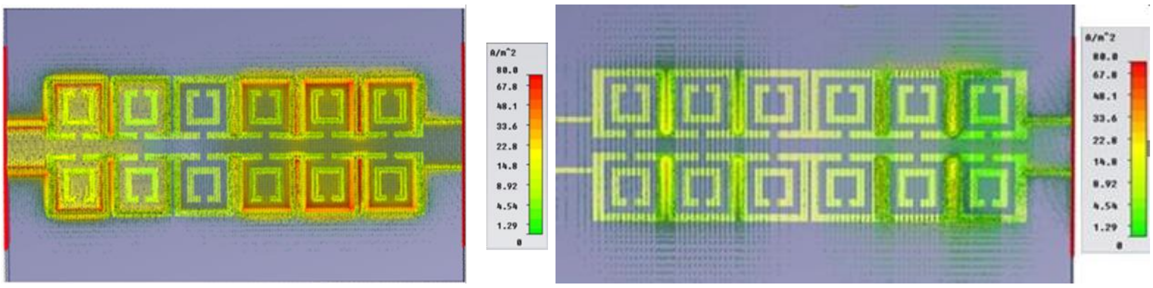


Figure 5. S parameters Comparison results of the proposed CPW LPF by using Two EM solvers



(a) (b)

Figure 6. The current distribution at; (a) 2 GHz and (b) 7 GHz

4. FABRICATION AND MEASUREMENT

After the validation of the proposed filter into simulation, we have achieved the fabrication of the CPW final low pass filter structure as depicted in Figure 7. The fabrication was done by using LPKF laser machine. As show in the following figure, we can see that we have a good precision into achievement. After the calibration of the vector network analyser, by using 3.5 mm calibration Kit we have obtained the Transmission and reflection coefficients versus frequency until 20 GHz. The measurement results confirm the simulated results and present a wide rejection until 20 GHz.

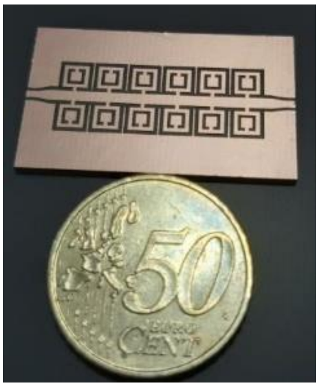
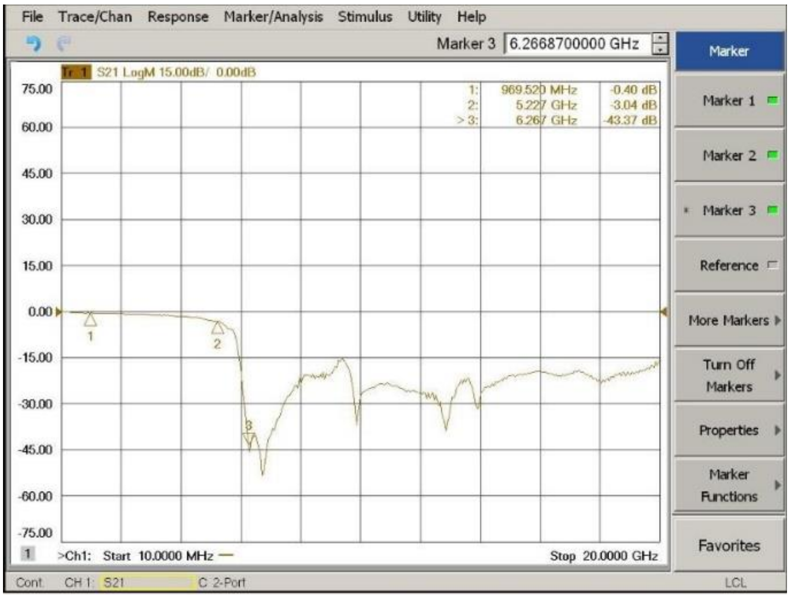


Figure 7. The fabricated low pass filter

The Figure 8 illustrates the measure result of the fabricated filter. As illustrated in Figure 8 (a) the S21 measured shows the inserstion loss of -0.4 dB and wide rejection band until 20 GHz. In the other side, Figure 8 (b) presents the S11 measured, it shows a good result in term of return loss which is about -15 dB in the bandwidth. The circuit has a cut-off frequency at -3 db equal to 5,227 GHz. We can conclude that we have a very good agreement between simulation and measurement results.



Marker 3 6.2668700000 GHz

Tr 1 S21 LogM 15.00dB/ 0.00dB

```
  1:   969.520 MHz   -0.40 dB
  2:     5.227 GHz   -3.04 dB
> 3:     6.267 GHz  -43.37 dB
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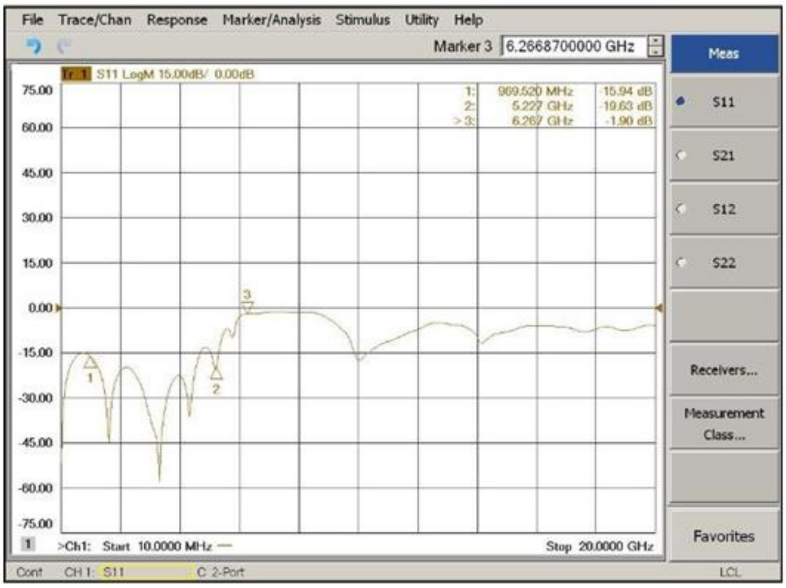
>Ch1: Start 10.0000 MHz — Stop 20.0000 GHz

Cont. CH 1: S21 C 2-Port LCL

(a)



Marker 3 6.2668700000 GHz

Tr 1 S11 LogM 15.00dB/ 0.00dB

```
  1:   969.520 MHz  -15.94 dB
  2:     5.227 GHz  -19.63 dB
> 3:     6.267 GHz   -1.90 dB
```

>Ch1: Start 10.0000 MHz — Stop 20.0000 GHz

Cont. CH 1: S11 C 2-Port LCL

(b)

Figure 8. S11 and S21 mesurement result; (a) S21 parameter, (b) S11 parameter

5. CONCLUSION

In this paper we have designed and fabricated a novel CPW low pass filter structure. The technique used consists of the implementation of metamaterial structures loaded periodically. The metamaterial cell was optimised and validated before the validation of the final filter circuit. Then, the proposed filter is designed, simulated and validated by using differents electromagnetic solvers. After the simulation the proposed and optimised LPF, we have done the fabrication and tested the filter circuit which permit us to validate the behavior of the filter in the bandwidth with a cutoff frequency of 5,227 GHz and in the rejection band with wide frequency band attenuation until 20 GHz. The obtained results permit to validate this filter for many microwave applications, the originality of this work is that the proposed filter is low cost and easy to integrate with passive, active components. Other advantages are the wide rejection band and the miniature dimensions. As perspectives to such work, we can integrate tuned components as varactors, PIN diodes, in order to achieve and to have reconfigurable filter which can function in other frequency bands that are suitable for low levels of microwave power.

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