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REGULAR ARTICLE

A Novel Low Pass Filter (LPF) Configuration Utilizing Square Complementary Split Ring Resonators

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This paper introduces a novel CPW-LPF architecture utilizing square CSRR on an economical FR4 substrate, aimed at enhancing the efficacy of the low-pass filter. The technique employed involves the implementation of regularly loaded metamaterial structures. The CSRRs are systematically optimized and periodically integrated along the central conductor of the CPW line, which features a CPW ground with stubs to enhance bandwidth. Simulation results for this filter indicate a cutoff frequency of – 4.45 dB, corresponding to $f_c = 5.66$ GHz. The engineered filter has a stopband rejection of less than – 20 dB and demonstrates minimal insertion loss inside the passband. The suggested filter has been evaluated using various electromagnetic solvers, yielding strong concordance between the two simulation outcomes. The resulting structure is appropriate for multiple application standards, including WIFI, WiMAX, LTE, and DCS. The final low pass filter has compact dimensions, measuring $20 \times 7.8 \times 1.6$ mm^3 in volume. The uniqueness of this work lies in its extensive rejection band. The suggested filter is economical and readily compatible with both passive and active components.

Keywords: CPW, LFP, CSRR, Stopband, Rejection

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1. INTRODUCTION

Metamaterials are man-made periodic structures with electromagnetic properties that are inaccessible to the naked eye, such as negative permittivity and permeability. These structures are metal-lo-dielectric and scale below the wavelength. Russian scholar Veselago initially proposed a theory on their electromagnetic properties in 1964 [1]. After that, the topic went into hibernation until American scholar D. Smith presented the first realization practice in 2000 [2]. The capacity to regulate or alter the material's permittivity and permeability to obtain a behavior tailored to a certain application is the most crucial feature of this structure. Metamaterials have emerged as a promising area of study, drawing researchers from all over the globe. These materials have various potential uses, including improving the efficiency of microwave devices through reduced size of circuits [3-6]. This research aims to design low pass, band pass, and band cut filters using SRR and CSRRS [7, 8]. The substrate will be a cheap FR4 with a relative dielectric constant of 4.4, tangential losses of 0.025, and a thickness of 1.6 mm. Several applications and communication protocols are catered to by the suggested filters, which are designed in microstrip and coplanar technology. Filters are simple, passive devices that may separate signals of different frequencies or perhaps eliminate them entirely. They are sometimes linked to passive circuits. Amplifiers, oscillators, and mixers are active circuits that also make use of them. Numerous technologies exist, each with its own set of benefits and drawbacks. Size, electrical performance, and production cost are the three main considerations when selecting a micro-wave filter technology. In a given telecoms system, the relative weight of these factors will vary. Consequently, the application calls for a compromise between these three factors. One or more dielectric substrates, metalized strips, and ground planes make up planar technologies. There are two types of propagation modes: TEM and quasi-TEM. These technologies are the most popular choices for microwave filtering due to their adaptable designs and easy interconnection.

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2. CSRR CELL THEORY

Compactness and exploration of passband rejection band are the goals of this paper's employment of CSRR-based metamaterials [9, 10]. The LC circuit is fixed to the host transmission line, and CSRRs are created by connecting inductors (s) and capacitors (C) in parallel. The techniques outlined in [11, 12] can be used to determine the equivalent circuit model for transmission line-loaded CSRRs, as well as the pertinent values of inductances and capacitors. At resonance, the CSRR creates a clean rejection stopband and a negative effective permittivity. The CSRR unit cell layout and its lumped ECM are shown in Fig. 1.

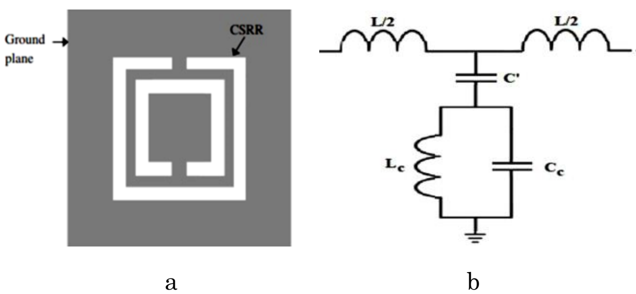


Fig. 1 – (a) ThenCSRR cell layout, (b) lumped EC model

Loop length, spacing, thickness, and concentric loop spacing can be adjusted to modify the CSRR's resonant frequency. Reducing the filter size for filter structures while preserving very good stopband attenuation is achieved using CSRRs, according to several papers [13–19]. Several design benefits, such as facile shunting and the flexibility to install active and passive localized components, are available when these resonators are periodically integrated with complementary split rings on a CPW instead of standard microstrip technology. To achieve a broader passband and rejection band, this study introduces a new design of CPW LPFs that are loaded with six CSRRs carved regularly along the center conductor. This kind of filter works well for ultra-wideband uses.

3. DESIGN PROCEDURE

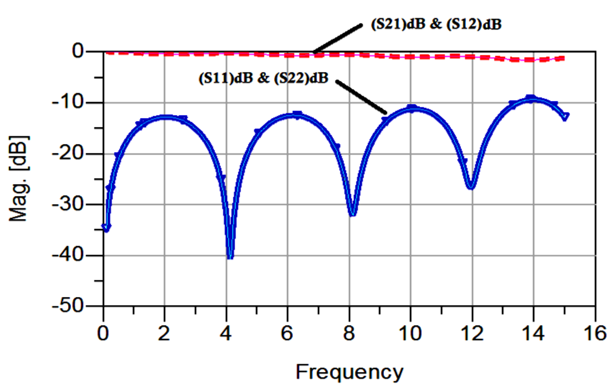


Fig. 2 – The S parameters of the 50 Ohm line versus frequency

Two CSRR cells were connected to the 50 Ohm characteristic impedance line after its certification, as depicted in the picture below:

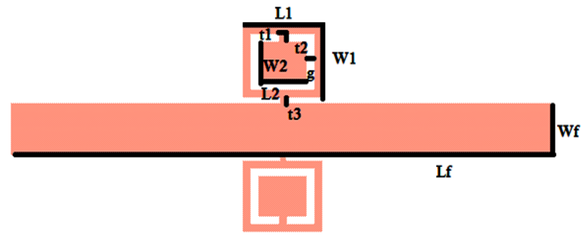


Fig. 3 – The structure of the 50 Ohm line associated with two CSRR cells

The dimensions of this structure are shown in the following table:

Table 1 – Optimized dimensions

Parameters	Value in mm
L_f	20
W_f	2
t_1	0.3
t_2	0.3
t_3	0.2
L_1	2.96
W_1	2.7
L_2	1.77
W_2	1.5
g	0.3

The simulation results of this circuit indicate a low-pass filter characteristic with a cut-off frequency of around 4.45 GHz, exhibiting a passband with an adaption band below – 10 dB, while the frequency range beyond the cut-off frequency demonstrates inadequate rejection. To expand the rejection band and enhance attenuation, one effective strategy is the application of periodicity in CSRR cells, which significantly improves the attenuated band while preserving optimal band-width performance.

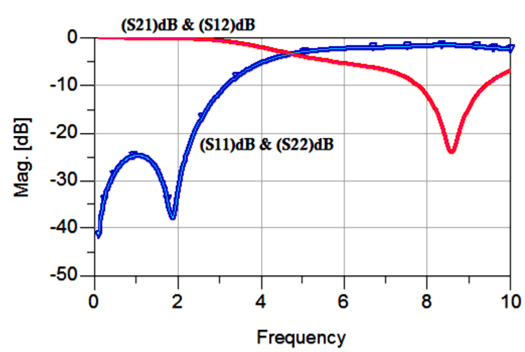


Fig. 4 – The results of the propounded LPF model

Based on the periodicity of the CSRR cells and employing a series of optimizations regarding the number of cells and parametric research (refer to Fig. 5) on the intercellular distance, we confirmed the configuration of a LPF in microstrip technology. The dimensions of the cells and the 50 Ohm impedance transmission line stayed consistent with the previously studied configuration.

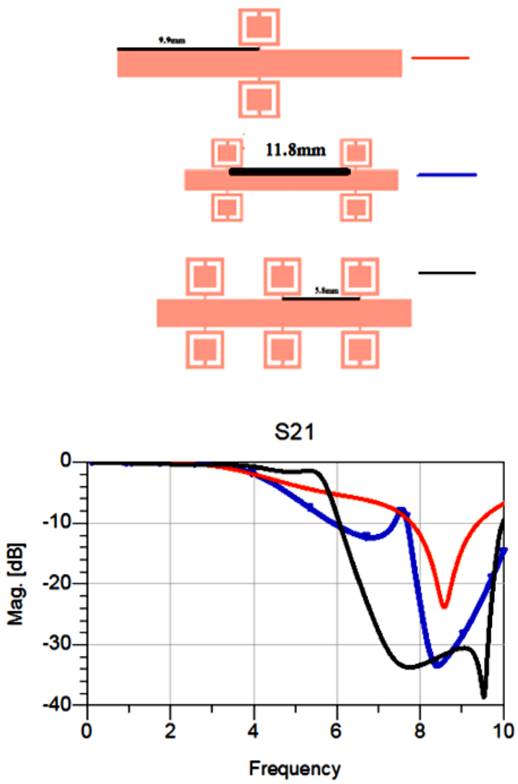


Fig. 5 – The S parameters of the LPF for each number of CSRR cells

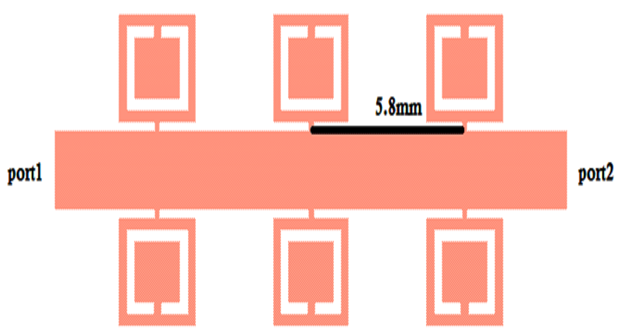


Fig. 6 – The structure of the proposed microstrip low-pass filter

With 6 CSRR cells, we get a substantial attenuation with a coefficient that is largely below – 20 dB, according to the parametric study's simulation results (Fig. 7). This suggests that the number of CSRR cells plays a significant role in improving the attenuation band and extending the bandwidth. Figure 6 illustrates the results of the filtering structure simulation, which reveal that the low-pass filter has a cut-off frequency of 5.66 GHz, a broad rejection band, and a significant attenuation up to 10 GHz.

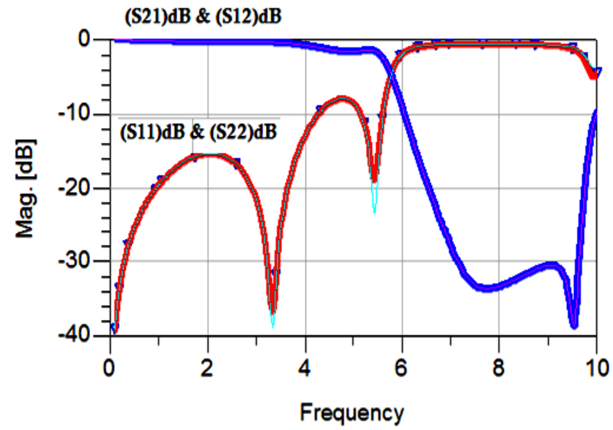


Fig. 7 – The S parameters of the Low-pass filter

To validate the modeling on Momentum and the resulting simulations, we executed the modeling on an alternative three-dimensional electromagnetic simulation software, CST. It is noteworthy that we can delineate the structure in three dimensions utilizing a finite ground plane and an alternative way of meshing and numerical computation known as the Finite Integration Technique (FIT). The simulation results of ADS and CST, as illustrated in the picture below, are in substantial concordance.

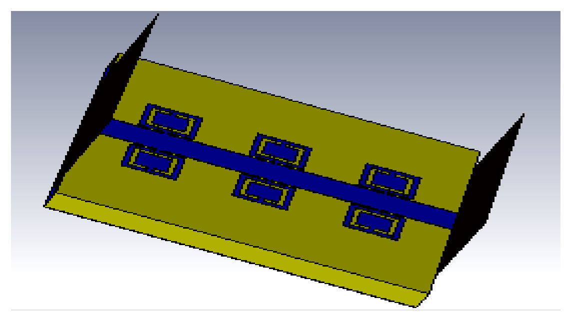


Fig. 8 – The proposed low pass filter modeled on CST-MW

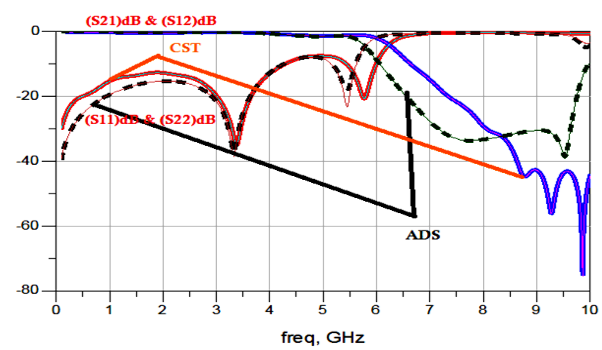
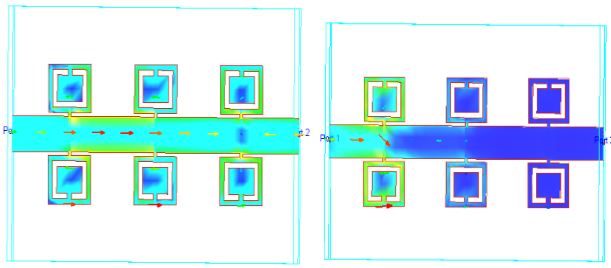


Fig. 9 – Comparison of simulation results on ADS and CST of the proposed filter structure

To comprehensively analyze the behavior of this filter construction, a simulation was conducted to evaluate the surface currents in both the passband and reject band. Figs. 4-8 demonstrate that the filter transmits the signal at 3.4 GHz while significantly attenuating and obstructing the signal at 8.35 GHz, which falls inside the rejected band. The final structure is compatible with several application standards, including WIFI, WiMAX, LTE, and DCS. The final low pass filter possesses compact dimensions with a volume of $20 \times 7.8 \times 1.6$ mm^3.



a b

Fig. 10 – The current density for a frequency in the passband (a) 3.4 GHz and in the attenuated band (b) 8.35 GHz

4. CONCLUSION

This work presents novel coplanar waveguide low-pass filter architecture. The method employed involves the application of regularly loaded metamaterial structures. The metamaterial cell was optimized and verified prior to the validation of the optimal filter circuit. Following the modeling of the suggested and optimized low-pass filter (LPF), we conducted simulations and tests on the filter circuit, enabling us to validate its performance in the passband with a cut-off frequency of 5.227 GHz and in the rejection band with significant attenuation extending up to 20 GHz. The results con-firm the efficacy of this filter for various microwave applications. The innovation of this work is in the pro-posed filter's affordability and its seamless interaction with both passive and active components. Additional benefits are the extensive rejection bandwidth and the compact size. This approach can incorporate tuned components such as varactors and PIN diodes to develop a reconfigurable filter capable of operating in several frequency bands suitable for low microwave power levels.

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Нова конфігурація низькочастотного фільтра (LPF) на основі квадратних додаткових розщеплених кільцевих резонаторів (CSRR)

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У даній роботі запропоновано нову архітектуру низькочастотного фільтра (LPF) на основі КВП (CPW) із використанням квадратних додаткових розщеплених кільцевих резонаторів (CSRR) на економічній підкладці FR4, що спрямована на підвищення ефективності роботи фільтра. Запропонована методика базується на використанні регулярно навантажених метаматеріальних структур. CSRR-структури оптимізовано та періодично інтегровано вздовж центрального провідника лінії CPW, при цьому наземний шар CPW має шунтуючі виступи для розширення смуги пропускання. Результати моделювання показали частоту зрізу на рівні – 4,45 дБ при f_c = 5,66 ГГц. Спроєктований фільтр характеризується пригніченням у смузі затримки нижче – 20 дБ та мінімальними втратами в смузі пропускання. Оцінка фільтра проводилась за допомогою різних електромагнітних симуляторів, і отримані результати продемонстрували високий ступінь узгодженості між ними. Запропонована структура відповідає вимогам численних стандартів, таких як WiFi, WiMAX, LTE та DCS. Фінальна реалізація фільтра має компактні габарити: 20 × 7,8 × 1,6 мм^3. Особливість цієї розробки полягає у розширеній смузі відсічення, що вирізняє її серед аналогів. Фільтр є економічно вигідним та сумісним як з пасивними, так і з активними компонентами.

Ключові слова: КВП (CPW), Низькочастотний фільтр (LPF), CSRR, Смуга затримки, Пригнічення.