

A Novel Design of Microstrip CSRR Low-Pass Filter with Enhanced Performance for Wireless Communication

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Abstract—In this work, we present the design and implementation of a microwave microstrip low-pass filter using a Complementary Split Ring Resonator (CSRR) structure. The filter was optimized and analyzed using the Method of Moments (MoM). The final prototype is mounted on an FR4 substrate, featuring a relative permittivity of 4.4, a thickness of 1.6 mm, and a loss tangent of 0.025. The overall dimensions of the structure are 44.6 mm × 11.3 mm. The proposed low-pass filter is suitable for integration with RF circuits. The originality of the final design lies in its compact size and ease of integration with both passive and active microwave circuits.

Index Terms—Microstrip Low-Pass Filter, Complementary Split Ring Resonator (CSRR), Wireless Communication, Harmonic Suppression, Metamaterial Filters.

I. INTRODUCTION

Metamaterials, and specifically Split Ring Resonators (SRRs), have emerged as promising solutions for designing miniaturized and high-performance RF components. These structures exhibit unique left-handed properties, enabling advanced control over electromagnetic waves, making them ideal for applications in modern RF systems [1]–[5]. Complementary SRRs (CSRRs), in particular, enhance these properties, allowing the design of compact low-pass filters with improved frequency selectivity and harmonic suppression [6]–[11]. This work focuses on the design and implementation of a novel microstrip SRR-based low-pass filter for wireless communication applications. Mounted on an FR4 substrate, the filter leverages the benefits of CSRRs to achieve superior harmonic suppression and compactness.

The following sections describe the design of a new planar low-pass filter structure based on CSRR resonators. The filter design was optimized and simulated using the electromagnetic solver ADS from Keysight, and the results demonstrate significant improvements in efficiency and suitability for wireless communication systems.

II. DESIGN OF A LOW-PASS FILTER (LPF) BASED ON CSRR

In this work, two distinct designs of low-pass filters (LPFs) are proposed, both utilizing Complementary Split Ring Resonators (CSRR) integrated into a microstrip structure. The designs were modeled and optimized using ADS (Advanced Design System), a widely used electromagnetic simulation tool, ensuring accurate and reliable performance evaluation.

A. Theoretical Background of CSRRs

A CSRR structure can be represented using the lumped-element electrical circuit, as shown in Fig. 1. This model captures the essential electromagnetic behavior of the CSRR by incorporating key parameters such as the line capacitance (C_l), the fringing capacitance of the gap (C_f), and the series capacitance (C_s). The inductance of the host line (L) and the resonant tank formed by L_c and C_c govern the resonance behavior of the structure. [1]

The effective series capacitance (C_s) and total capacitance (C) of the circuit are given by:

$$C_s = 2C_f + C_{par} \quad (1)$$

$$C = \frac{C_{par}(2C_f + C_{par})}{C_f} \quad (2)$$

where $C_{par} = C_l + C_f$. These equations highlight the role of distributed capacitances in defining the filtering properties of the CSRR. The resonance is determined by the interaction between L_c and C_c , which forms the resonant tank circuit.

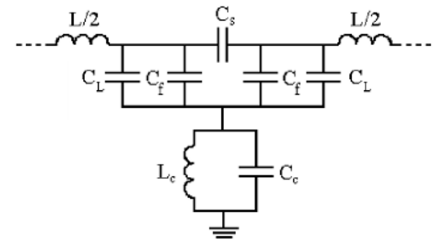


Fig. 1: Equivalent lumped-element circuit model of a CSRR-based transmission line.

B. Two-Resonator Filter Design and Analysis

The two-resonator low-pass filter design incorporates a compact structure with two CSRR resonators, measuring 28.49 mm in length and 11.3 mm in width, as shown in Fig. 2. The identical dimensions of the resonators and input/output ports (Port 1 and Port 2) ensure symmetry and uniform performance. This configuration is well-suited for applications requiring minimal space while maintaining effective harmonic suppression. The S-parameter analysis in Fig. 3 shows strong performance, with good input impedance matching (S_{11}) and low insertion loss (S_{21}) of -1.090 dB at 2.8 GHz. Outside the passband, (S_{21}) drops below -20 dB, confirming efficient low-pass behavior and robust harmonic suppression.

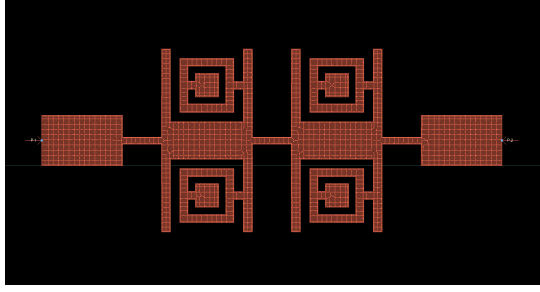


Fig. 2: Layout of the resonator CSRR-Based Low-Pass Filter Design.

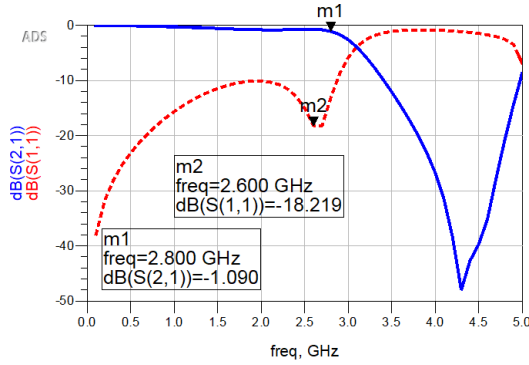


Fig. 3: Frequency Response (S_{11} and S_{21}) versus frequency.

C. The proposed Low-Pass Filter design

To improve the rejection and performance of the LPF, additional resonators were integrated, followed by extensive parametric and optimization studies. The resulting four-resonator CSRR-based LPF, with dimensions of 44.57 mm $\times$ 11.3 mm, demonstrates enhanced performance, as shown in Fig. 4. The design maintains identical resonator sizes and symmetrical input/output ports for consistent operation.

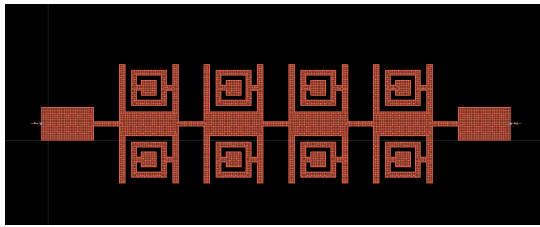


Fig. 4: Layout of the Four-Resonator CSRR-Based Low-Pass Filter Design.

Simulation results (Fig. 5) show improved filtering characteristics, with S_{11} reaching **-18.131 dB** at **2.575 GHz**, indicating excellent impedance matching, and S_{21} achieving a cutoff frequency of **2.92 GHz**. The final LPF circuit demonstrates sharper roll-off and superior harmonic suppression compared to the first LPF structure.

III. CONCLUSION

This study presents the design and optimization of compact low-pass filters (LPFs) based on Complementary Split Ring Resonator (CSRR) structures for wireless communication

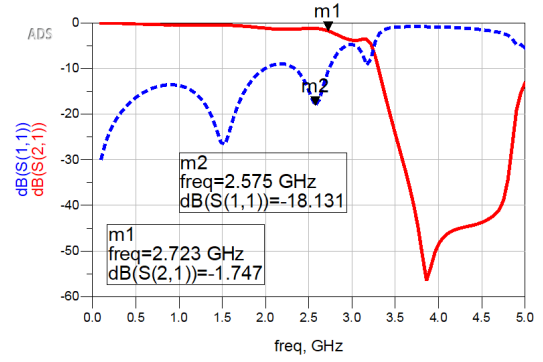


Fig. 5: Frequency Response (S_{11} and S_{21}) versus frequency of the final periodic LPF structure.

applications. The design was optimized using the Method of Moments (MoM), known for its efficiency in handling planar structures. The resulting LPF exhibits a well-matched input impedance for minimal signal reflection, low insertion loss in the passband to maintain signal integrity, and high attenuation in the rejection band to suppress unwanted harmonics and noise. Its miniature size makes it highly suitable for integration into compact microwave devices, supporting compatibility with IoT devices, wireless modules, and next-generation RF systems.

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