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REGULAR ARTICLE

Design of a Split Ring Resonators-Based Band Pass Filter with Triple Pass Band Characteristics for Wireless Communication Systems

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Metamaterial technology indeed holds great promise for enhancing wireless communication, especially in the development of advanced filters and devices. The use of metamaterials for filter design is an exciting and promising area of research, driven by their exceptional properties and potential for revolutionizing various technological applications. In fact, Metamaterials can be engineered to exhibit unique electromagnetic properties, allowing for precise control of the filtering characteristics. This enables designers to create filters with sharp passbands and stopbands, as well as customizable cutoff frequencies. Besides, Metamaterials can be used to miniaturize filters, making them suitable for compact and portable devices. This is especially valuable for applications with size constraints, such as mobile phones and wearable technology. Moreover, Metamaterials provide the flexibility to design filters with adjustable bandwidth. In this paper, a triple-bandpass printed filter using split-ring resonators is designed and simulated. The proposed filter is composed of two split-ring arrays loaded on the transmission line. It is printed on a Rogers RT/duroid 6010/6010LM (tm) substrate. The proposed BPF has a small size (14×16 mm^2) and high selectivity. The simulation result exhibit three passbands centered at 3.15 GHz, 6.27 GHz and 9.31 GHz, respectively with required return loss and insertion loss characteristics. The simulation studies are carried out with HFSS software and its electrical equivalent circuit model (ECM) is designed using ADS tool. The results obtained using HFSS is in well agreement with ECM results.

Keywords: Pass-band filter, Metamaterial, Resonator, Split ring resonators, Wireless communication system, Radar.

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1. INTRODUCTION

Wireless communication systems are infrastructure and technologies that enable the transmission of information, data, and signals without the need for physical wired connections. These systems utilize wireless technologies such as radio waves, microwave, infrared, or other wireless mediums to transmit and receive data between devices [1]. Pass-band filters are integral components in wireless communication systems. They serve multiple functions and are crucial for tasks such as signal conditioning, interference rejection, frequency selectivity, and regulatory compliance. By shaping the transmitted and received signals according to the system's specific requirements, these filters play a pivotal role in ensuring efficient and reliable communication. Through their functions, pass band filters help to optimize the quality and integrity of wireless communication signals.

To enhance the electrical performance within the available bandwidth and minimize the space occupied by the filters, researchers have explored various innovative approaches [2-5]. These approaches aim to improve the filter's performance while reducing its physical footprint [6-7]. Metamaterial filters offer several advantages over traditional filters. They can be engineered to have extremely narrow bandwidths, high selectivity, and low insertion loss. Metamaterial filters can achieve a high Q-factor, which indicates a narrow bandwidth and high selectivity. This is beneficial for reducing interference and improving signal quality. Besides, Metamaterials enable the design of filters that can operate across multiple frequency bands or achieve wideband filtering, making them versatile for various applications. Moreover, it can be reconfigured to change their filtering characteristics in response to variable communication needs. This adaptability is essential for dynamic communication environments. In addition, it can be employed to create non-reciprocal filters that allow signals to pass in one direction while blocking them in the opposite direction. This property is useful for isolators and circulators in RF and microwave systems. Furthermore,

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Metamaterials can be used to design filters that can absorb or redirect electromagnetic waves, contributing to the development of stealth technology and radar-absorbing materials.

Many designs of printed filters based on split ring resonators (SRR) are available in the literature [8-15]. In this study, the aim was to design a triple band-pass filter based on split ring resonators to better meet the requirements of wireless communication system like Wi-Fi, Cellular Networks, satellite communication, and others. Authors of Ref. [8] introduced a band-stop filter operating in the microwave frequency range, which utilizes a rectangular split-ring resonator (RSRR). This filter merges the properties of a traditional microstrip band stop filter with those of a metamaterial featuring negative permittivity. The design of this structure focuses on the frequency band between 1 GHz and 4 GHz, employing a substrate material with a relatively high dielectric constant ($\varepsilon_r = 10.2$), specifically RO3210, and low tangential losses ($\mathrm{tg}\delta = 0.003$). Authors of Ref. [9] have proposed a metamaterial filter for THz application. The filter is suggested and its effectiveness is confirmed within the frequency range of 0.5 to 3.0 terahertz (THz). The proposed filter demonstrates a transmission peak of 94.3 % at the resonant frequency of 1.43 THz when tested with samples at room temperature. In [10], a filter-based pair of symmetrical split ring metamaterial resonators (SSRRs) is reported. These resonators have identical square shapes but different dimensions and exhibit negative permittivity ($\mu < 0$). They are connected through a metallic line and are etched onto the top surface of a substrate made of Rogers material (RO4003) with specific physical properties, including a dielectric constant of 3.55 and a tangential loss of 0.0027. The two SSRRs are linked to two microstrip feed lines that are tailored to achieve a 50 Ω impedance. Longqin et al. [11] proposed a flexible metamaterial filter operating in the terahertz (THz) range. The filter is constructed using cross-shaped metamaterial patterns on a substrate of polydimethylsiloxanes (PDMS). These FTM filters are designed as band-stop filters, offering the capability to selectively control the resonant frequency. Consequently, they offer a tunable transmission channel over a wide frequency span within the sub-THz spectrum.

The proposed filter consists of two sets of resonators which are placed on the transmission line. Each set is composed of three identical rings. These resonators are placed on a substrate called "Rogers RT/duroid 6010/6010LM (tm)" with a dielectric constant of $\varepsilon_r = 10.2$. The main objective of this work is to improve the performance of the bandpass filter in terms of bandwidth, adaptation, and resonant frequency while reducing its size. The proposed filter operates at 3.16 GHz, 6.32 GHz and 9.37 GHz with a small size of (14 × 16) mm^2, and offers attractive return loss and insertion loss characteristics.

2. SIMULATION RESULTS AND DISCUSSION

The pass-band filter is constructed using a transmission line connected to two 50Ω input/output ports (Figure 1). It's placed on a substrate with dimensions of (14 × 16) mm^2, specifically made from the Rogers RT/duroid 6010/6010LM (tm) material. This material has a dielectric constant of $\varepsilon_r = 10.2$, a thickness of $h = 0.4$ mm, and a tangent loss of 0.0023. On the other side of the substrate, there is a ground plane. To improve the filter's performance, six identical square ring resonators (SRRs) are incorporated in two rows surrounding the transmission line. These resonators demonstrate a magnetic response resulting from the artificial magnetic dipole moments generated by the rings. The resonator structure is depicted in Fig. 1, with dimensions $L_r = 4$ mm, $W_r = 1$ mm, and $g = 0.5$ mm.

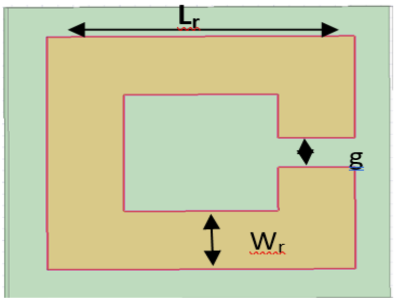
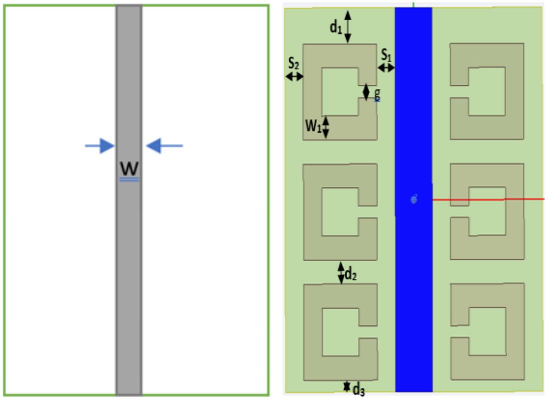


Fig. 1 – Geometry of the Square SRR

The schematic views of the pass-band filter with SRR resonator are given in Fig. 2, where the different dimensions are given in the Table 1.



(a) (b)

Fig. 2 – Schematic views of the pass- band filter: (a) without SRR; (b) with SRR resonator

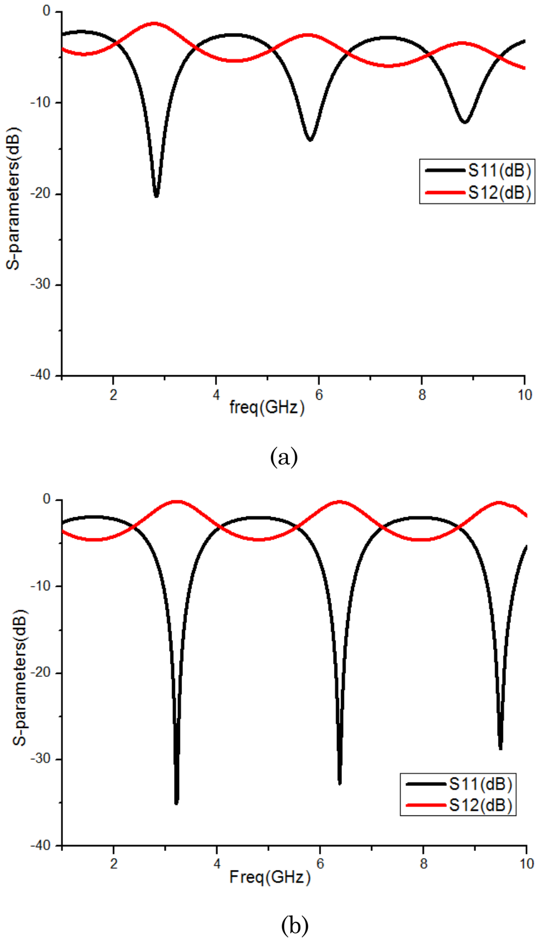
The design and analysis of the pass-band filter are performed using HFSS software. Fig. 3 displays the simulation results of the reflection coefficient (S_{11}) and transmission coefficient (S_{21}) as a function of frequency for the proposed pass-band filter. The plot reveals that the filter exhibits resonance at 3.15 GHz, 6.27 GHz and 9.31 GHz. Table 1 shows a list of the appropriate dimensions for the proposed pass-band filter.

The plot indicates that the filter exhibits resonance at three central frequencies of 3.15 GHz, 6.27 GHz and 9.31 GHz respectively, with low insertion loss and high levels of rejection. This makes it suitable for use in various applications such as wireless communication systems, radar systems, and satellite communication systems. To achieve a more thorough evaluation of the pass-band filter's performance, it is crucial to consider VSWR (Voltage Standing Wave Ratio) as a significant metric [4]. VSWR enables the assessment of the filter's capability to effectively transmit frequencies within the desired bandwidth. The evolution of VSWR as a function of frequency for the proposed band-pass filter is depicted in Fig. 4.

The VSWR values at the resonance frequencies are equal to 1, indicating a good impedance match and efficient transmission of signals within the three passbands of the filter.

Table 1. Dimensions of MTM BPF

Filter parameters	Value
S_1	1 mm
d_1	1.5 mm
d_2	1 mm
S_2	1 mm
W_1	1 mm
d_3	0.5 mm
W	2 mm



(a)

(b)

Fig. 3 – Simulated S_{11} and S_{12} parameters of the pass-band filter: (a) without SRR; (b) with SRR

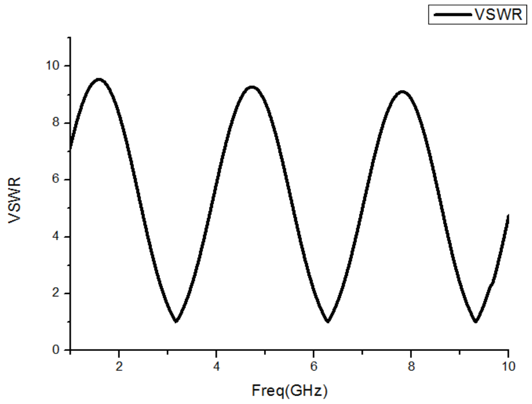


Fig. 4 – VSWR of proposed pass-band filter versus frequency

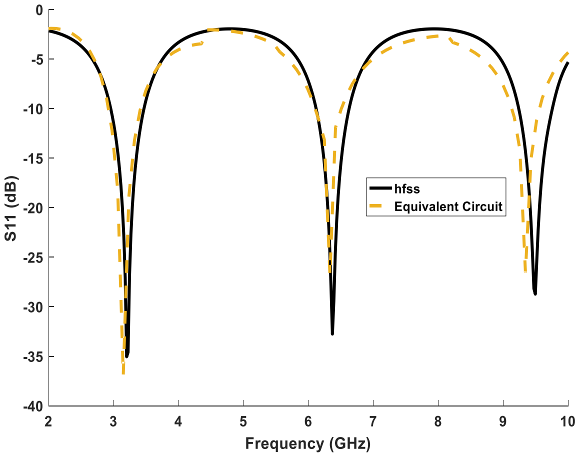


Fig. 6 – Comparison of reflection coefficient results between HFSS and ADS (equivalent circuit)

Table 2 – Comparison between ADS and HFSS

S_{11} Results	Resonance frequency (GHz)	Resonance peak (dB)	Supported Frequency bands
Equivalent Circuit	3.14, 6.27, 9.29	– 37, – 26.87, – 26.57	S-band, C-band, X-band
HFSS	3.15, 6.27, 9.31	– 39, – 43, – 48	S-band, C-band, X-band

In order to validate the HFSS results, a supplementary simulation was conducted utilizing the Agilent ADS software. Fig. 5 illustrates the equivalent circuit of the pass-band filter generated by the ADS simulator. Table 2 covered by the proposed filter in both HFSS and ADS, with simulation results depicted in Fig. 6. According to provides a comparison of various frequency bands Fig. 6, a good agreement between the results of electromagnetic simulation (HFSS) and equivalent circuit (ADS) is obtained for the proposed band-pass filter.

3. CONCLUSION

In this paper, a metamaterial band pass filter based on split ring resonators loaded on the microstrip transmission line is presented. The implemented structure shows triple pass bands satisfying the requirements of insertion and return losses. Two resonator arrays are placed on the transmission line. Each array consisted of three identical rings. The Simulation results of the proposed pass-band filter is demonstrated by the good agreement in terms of reflection and transmission coefficients. It's offers three operating bandwidths with minimum return loss and high levels of rejection. The equivalent circuit model (ECM) is also investigated to understand the working insight of the proposed BPF model. Considering these characteristics, the proposed band-pass filter makes it valid for different applications such as wireless communication systems, radar systems, and satellite communication systems.

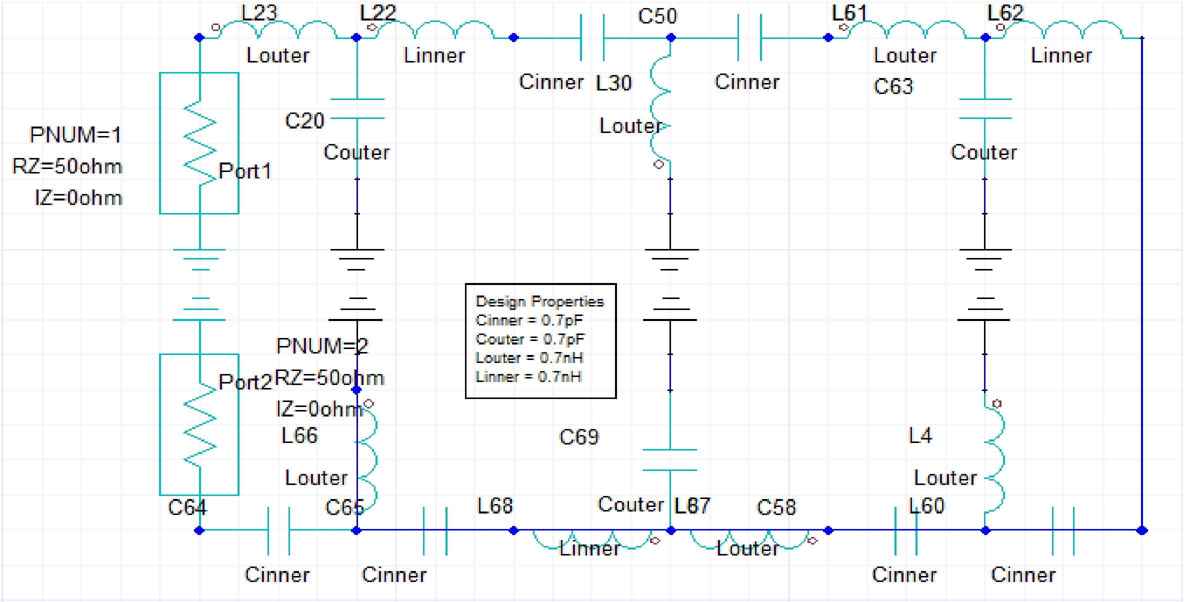


Fig. 5 – The equivalent circuit of the pass-band Filter

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Розробка смугового фільтра на основі розділених кільцевих резонаторів із характеристиками потрійної смуги пропускання для систем бездротового зв'язку

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Технологія метаматеріалів справді має великі перспективи для покращення бездротового зв'язку, особливо в розробці вдосконалених фільтрів і пристроїв. Використання метаматеріалів для проектування фільтрів є перспективнююю сферою досліджень, що обумовлено їх винятковими властивостями та потенціалом для революції в різних технологічних додатках. Насправді метаматеріали можна сконструювати так, щоб демонструвати унікальні електромагнітні властивості, що дозволяє точно контролювати характеристики фільтрації. Це дає змогу розробникам створювати фільтри з чіткими смугами пропускання та смугами зупинки, а також настроюваними частотами зрізу. Крім того, метаматеріали можна використовувати для мініатюризації фільтрів, що робить їх придатними для компактних і портативних пристроїв та особливо цінно для додатків з обмеженнями розміру, таких як мобільні телефони та носима технологія. Крім того, метаматеріали забезпечують гнучкість розробки фільтрів із регульованою смугою пропускання. У цій статті розроблено та змодельовано трисмуговий друкований фільтр із використанням резонаторів з роздільними кільцями. Запропонований фільтр складається з двох матриць розділених кілець, завантажених на лінію передачі. Він надрукований на підкладці Rogers RT/duroid 6010/6010LM (tm). Він має невеликий розмір 14 × 16 мм^2 і високу селективність. Результати моделювання показують три смуги пропускання з центром на частотах 3,15; 6,27 і 9,31 ГГц відповідно з необхідними характеристиками зворотних і внесених втрат. Дослідження моделювання проводяться за допомогою програмного забезпечення HFSS, а його модель еквівалентної електричної схеми розроблена за допомогою інструменту ADS. Результати, отримані з використанням HFSS, добре узгоджуються з результатами ЕСМ.

Ключові слова: Смуговий фільтр, Метаматеріал, Резонатор, Кільцеві резонатори, Система бездротового зв'язку, Радар.