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# A Novel Configuration of a Reconfigurable Planar BandPass Filter For Wireless Power Transfer

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**Abstract.** This paper presents the design and analysis of a novel microstrip bandpass filter (BPF) using square split ring resonators (SRRs) as resonating elements. The proposed filter architecture comprises a modified microstrip line section coupled to microstrip lines on either side, with an integrated SRR positioned centrally. The SRR elements are strategically designed and optimized to achieve the desired frequency response. The filter is fabricated on an FR-4 substrate with a thickness of 1.6 mm, a dielectric constant of 4.4, and a loss tangent of 0.025. It features a compact size of 9x26.3mm<sup>2</sup>. This study will initially present the simulation results of the designed filter. Subsequently, the filter will be transformed into a tuneable configuration. one approche will be investigated a reconfigurable structure where the variable capacitance is varied to adjust the bandwidth while maintaining the filter's physical dimensions, The integration of capacitance enables dynamic tuning capabilities for the bandpass filter. This design represents a significant advancement in filter technology, with promising applications in next-generation communication systems that require high levels of flexibility and performance. This filter is designed for wireless power transmission and is compatible with applications operating in the vicinity of 2.4GHz to 2.5GHz.

## 1 Introduction

Microwave filters are integral components in many high-performance microwave systems. They function as frequency-selective elements, enabling the differentiation of multiple communication signals based on their electrical frequencies [1]. Modern communication systems, rapidly evolving with wireless technology, necessitate high-performance microwave bandpass filters (BPF) to ensure optimal operation [2-3]. Microstrip bandpass filters (BPFs) are widely employed in various applications, particularly in RF wireless communications, to effectively suppress unwanted interference signals. This capability stems from their inherent ability to attenuate harmonic frequencies [4-6]. Ring resonators are widely utilized in the design of bandpass filters. Various configurations of ring resonators have been proposed for this application [7-9]. Metamaterials, engineered with intricate artificial structures, exhibit extraordinary properties, including negative permittivity and permeability. Their evolution, marked by Vassalage's 1968 theoretical work and Pendry's 1999 introduction of the split ring resonator, has paved the way for innovative RF filtering techniques [10-11]. Reconfigurable filters are valuable for wireless applications operating across diverse frequency bands. They offer the ability to function at various frequencies with a single design, effectively emulating the performance of multiple filters without increasing the overall size. This makes them a compelling choice for portable devices. [12-13]. Variable capacitance can be integrated into bandpass filters using several methods: the first is Varactors: These voltage-controlled diodes offer variable

capacitance, making them popular in radio frequency and microwave circuits. the second is Mechanical variable capacitors: Adjusting the physical distance between the capacitor plates changes the capacitance, However, their larger size and slower switching speed limit their use in high-frequency applications. MEMS (Micro-Electro-Mechanical Systems): These tiny devices use miniature mechanical components to precisely and rapidly adjust capacitance. While offering superior performance, they tend to be more expensive [14].

Reconfigurable bandpass filters are essential in rectennas for efficient electromagnetic-to-electrical energy conversion, achieved through impedance matching and interference reduction.

The block diagram of a rectenna system is illustrated in Fig1

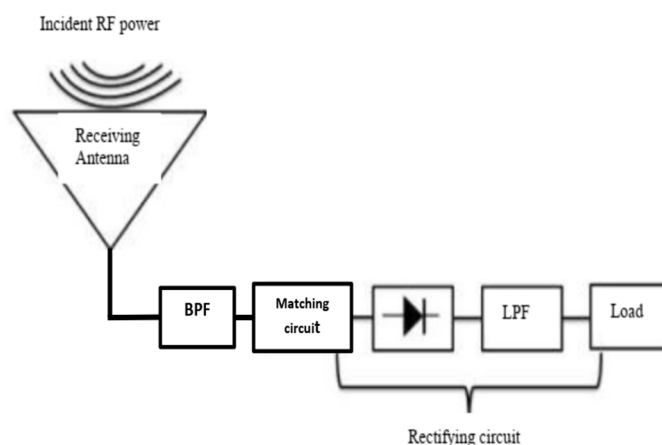
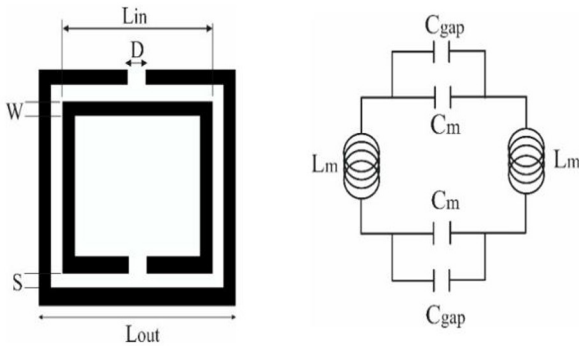


Fig.1. The block diagram of a rectenna system [15]

This study investigates planar bandpass filters with reconfigurable bandwidth, achieved by dynamically adjusting the amplitude of variable amplitude split-ring resonators (SRRs) without altering the filter's dimensions. This approach aims to improve the flexibility and adaptability of RF filtering structures for applications in wireless communication, sensor networks, radar, and other adaptive RF technologies

## 2 SRR theory

The square split-ring resonator (SRR) is a widely studied design in the scientific community. It consists of two square metallic loops facing each other with a gap between them, resembling two squares separated by a space. For a visual representation, refer to the diagrams in [16] which illustrate the structure of a square SRR and its equivalent circuit model.



**Fig2.**Geometry of the square SRR (a) unit cell; (b) equivalent circuit [17]

$$f_0 = \frac{1}{2\pi\sqrt{L_m(C_m+C_{gap})}} \approx \frac{1}{2\pi\sqrt{L_m C_m}} \quad (1)$$

The inductance “ $L_m$ ” of each ring can be obtained as,

$$L_m = \frac{\mu_0 S}{W} [L_{out} + L_{in}] \quad (2)$$

Where the capacitance “ $C_m$ ” representing the space between the inner and outer rings, is defined as

$$C_m = \frac{A\epsilon_0\epsilon_r W(2L_{out}+2L_{in}-D)}{2S} \quad (3)$$

## 3 Design procedure and result discussion

### 3.1, BPF based on SRR structure

ADS simulations were performed to determine the frequency response of the structures. The presence of electromagnetic coupling is evidenced by two dominant resonance frequencies, which deviate from the single resonance frequency expected in the uncoupled case. The coupling coefficient between resonators  $i$  and  $j$  is subsequently derived from these simulated responses [1].

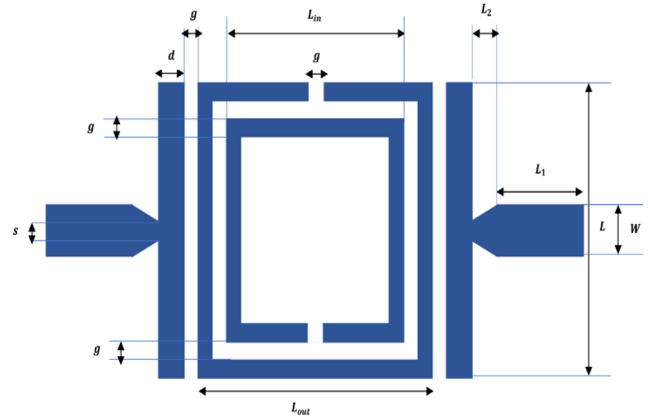
$$M_i M_j = \pm(f_{01}^2 - f_{02}^2)(f_{01}^2 + f_{02}^2) \quad (4)$$

Where  $f_{01}$  and  $f_{02}$  represent the resonant frequencies of the even and odd modes. The external quality factor, denoted as  $Q_e$  may be calculated using the following equation:

$$Q_e = \frac{f_0}{\Delta f} \quad (5)$$

Where  $f_0$  shows resonance frequency and  $\Delta f$  is bandwidth of resonator.

The geometric configuration parameters of the proposed BPF are depicted in Fig. 3



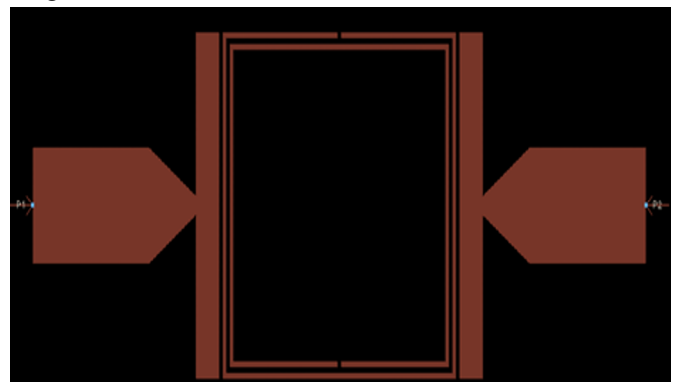
**Fig.3.** Geometry of the proposed bandpass filter [8]

The table (1) displays the various optimized parameters Geometry of the proposed BPF [8].

**Table1.**Values of the different parameters of the BPF

Parameters	Values (mm)
Lout	9
Lin	8.4
L1	5.5
L2	2
L	9
W	3
d	1
s	0.5
g	0.15

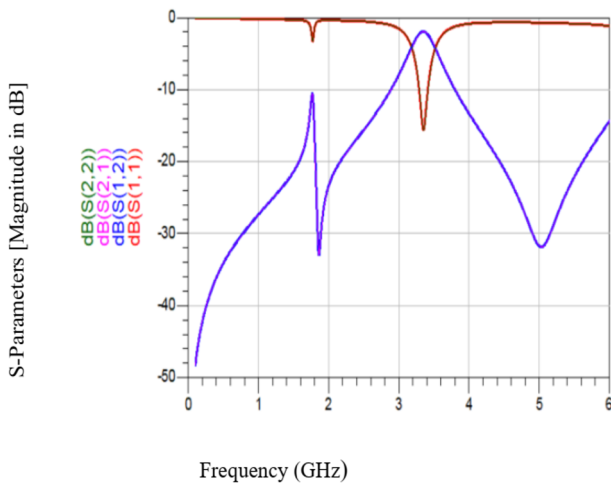
The Fig. 4 illustrates the layout of BPF using ADS from Agilent



**Fig.4.**Layout of BPF by using ADS [11]

The simulated BPF demonstrates good performance at its center frequency of 3.5 GHz, achieving a return loss of 20.67 dB and an insertion loss of 1.19 dB, characteristic of bandpass filtering.

The Fig. 5 illustrates the simulated S-parameters of the proposed BPF



**Fig.5.** S-parameters versus frequency of the designed filter BPF by using ADS [11]

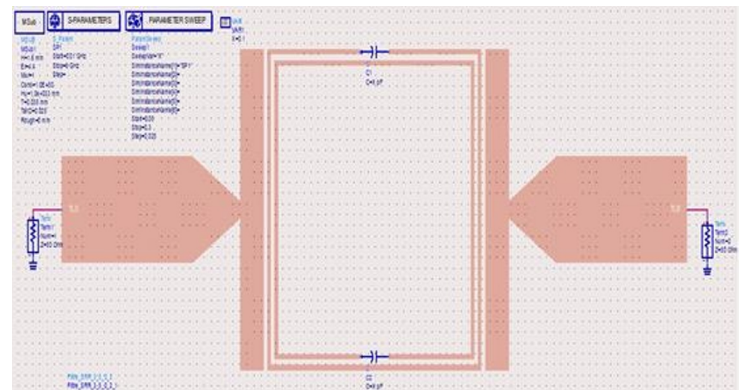
### 3.2, Reconfigurable SRR BPF design using variable capacitors

Capacitance plays a crucial role in shaping the behavior of filter circuits. Because capacitance directly influences circuit impedance, changing its value inevitably alters the filter's frequency response. Considering a bandpass filter, the center frequency and bandwidth are dependent on the values of both capacitances and inductances within the circuit. Consequently, adjusting the capacitance provides a means to shift the center frequency and/or modify the bandwidth. This section details a reconfigurable filtering approach that achieves bandwidth control by varying capacitance while maintaining a fixed filter size.

In this structure, a capacitance has been added and it is varied from 0.05pF to 0.3pF with a step of 0.025 pF using the tools (VAR and Param Sweep).

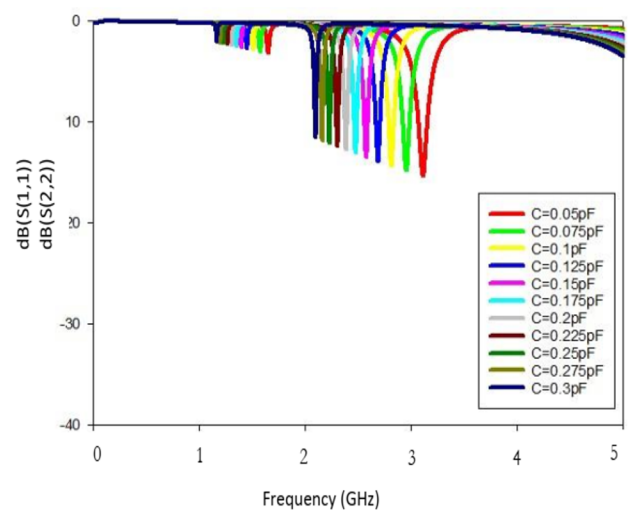
In the original filter, the value of the gap was  $g=0.15\text{mm}$ , but it was changed to  $g=1.2\text{mm}$ , a to accommodate the possibility of integrating a variable capacitor.

The Co-Simulation of Schematic and Layout of the reconfigurable BPF in ADS is shown in Fig.6.



**Fig.6.** The Co-Simulation of Schematic and Layout in ADS

The Fig.7 illustrates Variations of reflection coefficients versus frequency.



**Fig.7.** The S11 and S22 performances of the reconfigurable filter

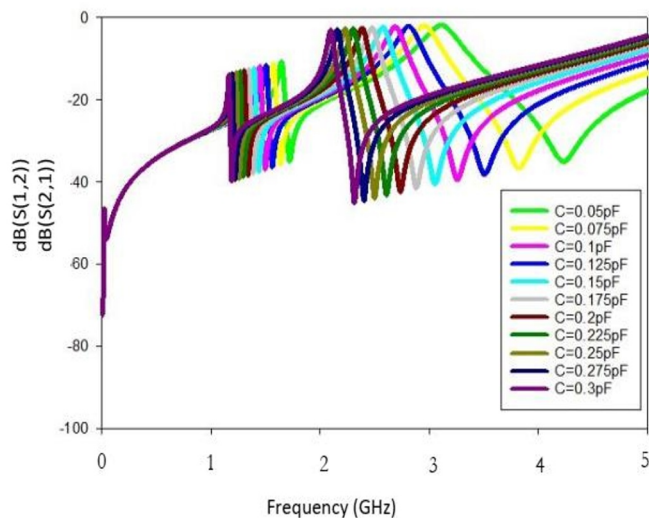
It is observed that as the capacitance (C) increases from 0.05 pF to 0.3 pF, the resonant frequencies shift towards lower values. When C is small, the number of resonances observed in the analyzed frequency band is reduced and Higher C values lead to more resonances, suggesting additional modes or increased coupling.

For  $C=0.05\text{ pF}$  The impedance matching appears to be less optimal, which may indicate higher signal reflection. and for  $C=0.3\text{ pF}$  Lower S11 values (more negative) indicate.that the circuit absorbs more of the incident energy (better impedance matching).

The Fig. 8 depicts how the transmission coefficient (S21 and S12) changes with frequency for various capacitance values (ranging from 0.05 pF to 0.3 pF).

Each curve corresponds to a specific capacitance value.As capacitance increases, the resonance peaks shift.Significant variations are observed between 1 GHz and 4 GHz, suggesting a strong impact of the capacitor on the frequency response.For higher C values, multiple resonance phenomena appear, influencing bandwidth and attenuation.. Adding a variable capacitance directly influences the system's frequency response.The resonance frequency shifts to lower values as C increases, which is expected in resonant circuits.

These results are useful for designing reconfigurable filters, where adjustable capacitance allows modifying the bandwidth and center frequency of the filter.



**Fig.8.** The S21 and S12 performances of the reconfigurable filter

## 4. Conclusion

This study investigated a reconfigurable planar bandpass filter using split-ring resonators (SRRs), achieving reconfigurability through variable capacitance to enable dynamic bandwidth adjustment without altering the filter's size. Simulation and experimental results confirmed the feasibility and performance of this design. This novel filter shows promise for applications demanding flexibility, including wireless communication systems (where reconfigurable filters improve energy efficiency and versatility by adapting to various standards and frequency bands), radar systems, wireless sensor networks, and test and measurement equipment. In conclusion, the integration of SRRs and variable capacitance in reconfigurable bandpass filters represents a significant advancement in microwave technology, providing a flexible and efficient solution for modern communication systems. Reconfigurable bandpass filters around 4.4 GHz and 4.5 GHz are valuable for applications requiring adaptability, such as rectennas, dynamic spectrum access, and multi-band wireless communication devices. By enabling selection of specific bands for transmission or reception, reconfigurable filters simplify the RF front-end design of multi-band devices (e.g., Wi-Fi, 5G, satellite communication), reducing the need for multiple filters.

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