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A New Compact Coupled Circular Ring Band-Pass Filter Structure for ISM Band Application

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Abstract. This work presents a compact bandpass filter BPF designed using coupled circular ring resonators implemented with microstrip technology. The key feature of the proposed design lies in the circular ring resonator, which primarily employs capacitive coupling to achieve resonance. The filter is mounted on an RO4003C substrate with a thickness of 1.52 mm, a dielectric constant of 3.38, and a loss tangent of 0.0027. It operates at a center frequency of 5.72 GHz with a bandwidth of 693 MHz, offering low insertion loss and effective suppression of unwanted signals outside the passband. The filter's performance was verified through simulations carried out using two distinct electromagnetic solvers. Thanks to its compact structure, flexible design, and outstanding performance, this BPF marks a significant improvement in microwave filter technology and shows great promise for use in next-generation wireless communication systems, wireless power transfer, and 5.8 GHz rectenna arrays for RF energy harvesting.

1 Introduction

In recent years, the growing advancement of telecommunication technologies has led to a significant rise in the demand for devices with specialized functions, such as antennas, power combiners/splitters, and filters. Numerous researches have been proposed and carried out to fulfill the demand by upgrading the existing technology implemented in current devices. Among so many devices, filter is one of the most essential devices widely used in wireless applications. The capability in handling higher frequency region with low loss transmission is one of capabilities which should be inherent in the device. Bandpass filters play a crucial role in this function, allowing desired frequency components to pass through while efficiently suppressing unwanted interference [1–2].
Microstrip technology has become a leading choice for filter design in communication front-end systems due to its planar form, compact size, resilience to manufacturing tolerances, and excellent consistency in performance [3–5]. Among filter topologies, coupled circular rings are frequently employed in bandpass filter designs. Arrays of microstrip ring resonators enable selective, compact, flexible, and low-cost filters that are well-suited to a broad spectrum of communications and signal processing uses. As a result, many researchers have investigated various ring resonator configurations to further advance filter characteristics [6–8].
Metamaterials engineered structures with extraordinary electromagnetic properties like negative permittivity and permeability have transformed RF filtering techniques. Since Veselago's theoretical proposal in 1968 and Pendry's creation of the SRR in 1999, the field of metamaterials has enabled new approaches to filter design [7–11].

Figure 1 presents the block diagram of a rectenna system, in which bandpass filters play a crucial role in converting electromagnetic energy into electrical energy. The efficiency of this conversion hinges on proper impedance matching and the ability to suppress undesirable interference [12].

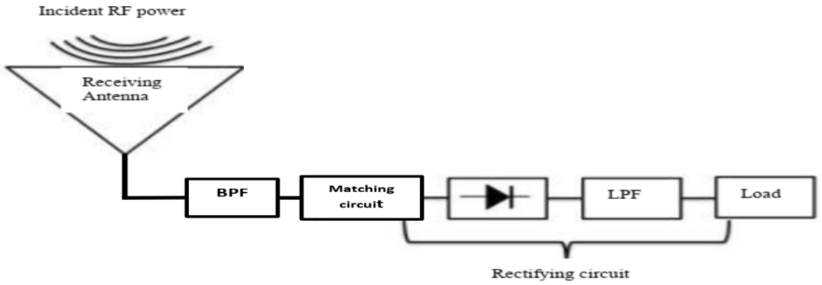


Fig.1. The block diagram of a rectenna system [12]

The rectenna is a highly efficient energy harvesting circuit where every component has a specialized role. Energy capture begins with a tuned antenna that converts RF waves into an AC signal. To maximize the usable power, a bandpass filter immediately selects the desired frequency band, suppressing interference. Power transfer efficiency is then guaranteed by an impedance matching network that links the antenna to the core of the system: the rectifier. The rectifier, which often uses low-threshold Schottky diodes, converts the high-frequency AC into pulsed DC. The final stage is a low-pass filter that eliminates signal ripples, providing clean, stable DC power ready for storage or use in the load.

We present the design and optimization of a compact BPF utilizing coupled circular ring resonators. To guarantee accuracy and maximize performance, the filter's geometry was meticulously refined using parametric sweeps across two different electromagnetic solvers. The result is a filter with a small footprint that boasts excellent performance metrics (low insertion loss and high return loss). This advancement in planar filter technology is ideal for adaptive RF systems in applications like radar and sensor networks, thanks to its inherent compactness, flexibility, and potential for tunability.

2 Microstrip Circular Ring Resonator Theory

In the theoretical section of this research, we will outline fundamental relationships that allow for the calculation of key dimensions and parameters crucial for the design of the proposed filter. The fig 2 illustrates the geometry of the microstrip circular ring resonator circuit,

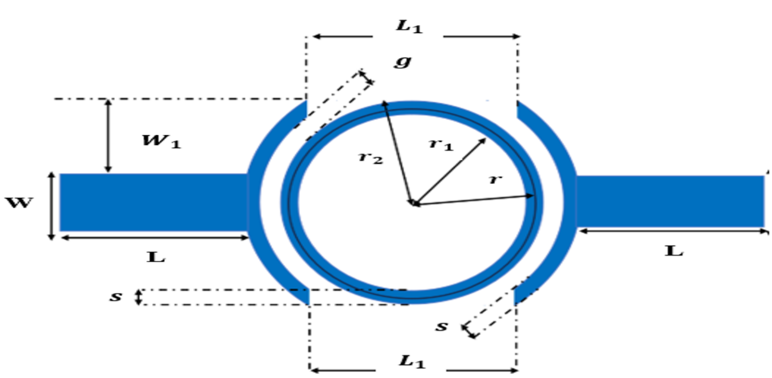


Fig.2. The geometry of the microstrip circular ring resonator circuit

For the PCB substrate height h, we assume the common condition w/h > 1. Under this assumption, the line width w can be determined by iteratively solving the coupled Equations (1) and (2)[11]:

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}(1+\frac{12h}{W})^{-1/2} \quad (1)$$

$$Z_0 = \frac{120\pi}{\sqrt{\varepsilon_{eff}}\left[\frac{W}{h}+1.393+\frac{2}{3}\ln(\frac{W}{h}+1.444)\right]} \quad (2)$$

For the ring resonator, the fundamental principle is that its mean circumference (2πr) must be equal to an integer multiple of the guided wavelength (λ_g), meaning:

$$2\pi r = n\lambda_g \quad (3)$$

Typically, the dominant mode of the operation is chosen, for which n = 1, The guided wavelength λ_g is computed as [11]:

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{eff}}} = \frac{C}{f_r\sqrt{\varepsilon_{eff}}}$$

(4)

where c represents the speed of light, f_r is the resonant frequency of the microstrip circular ring resonator structure, and ε_{eff} is its effective permittivity.

The feed lines positioned to the left and right of the ring are designed with a length L equal to:

$$L = \frac{\lambda_g}{4} \quad (5)$$

Now, combining (3) and (4), the mean radius of the ring follows as[11]:

$$r = \frac{C}{2\pi f_r\sqrt{\varepsilon_{eff}}} \quad (6)$$

The inner and outer radii of the ring are set to:

$$r_1 = r - \frac{W}{2} \quad (7)$$

$$r_2 = r + \frac{W}{2} \quad (8)$$

where *W* represents the microstrip line width (for both the feed line and the ring), as determined by (1) and (2)

The table “(1)” displays the various optimized parameters Geometry of the proposed BPF.

Table 1. Values of the different parameters of the BPF

Parameters	Values (mm)
W	3
W_1	4.15
L	4.85
L_1	7.3
r_1	5
r_2	5.5
g	0.5
s	0.5

3 design procedure and results discussion

3.1 Design by ADVANCED DESIGN SYSTEM (ADS)

The proposed BPF structure features a modified microstrip line connected to 50Ω microstrip lines at both ends, with a centrally located microstrip circular ring resonator. This optimized design prioritizes simplicity, thus reducing manufacturing complexity, and achieves a compact size of 11.25x22.46mm².

The layout of the BPF, implemented using Agilent's ADS software, is illustrated in the Fig.3.

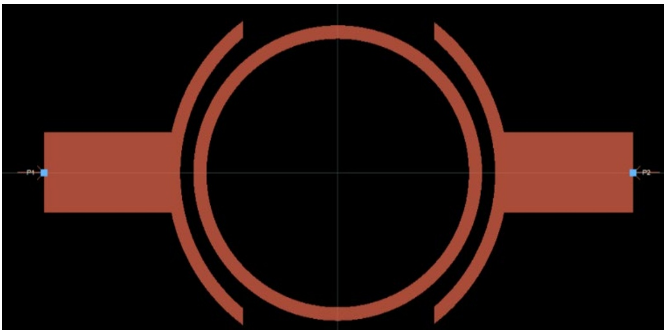


Fig.3. Layout of BPF by using ADS

Simulation results show that the BPF achieves good performance at its 5.72 GHz center frequency, exhibiting a return loss of 20 dB and an insertion loss of 1.7 dB, which are typical characteristics of bandpass filtering. Characterized by its compact dimensions and low passband insertion loss, this filter also achieves a good rejection level of -20 dB at 5.72 GHz. The total bandwidth attained is around 693 MHz.

The Fig. 4 illustrates the simulated S-parameters of the proposed BPF

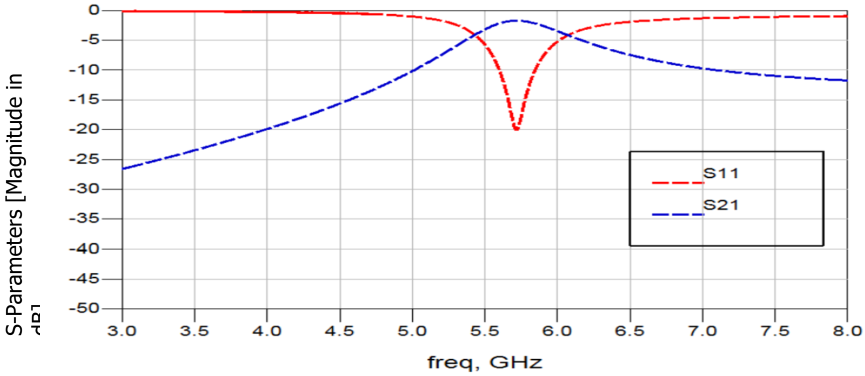


Fig.4. S-parameters versus frequency of the designed filter BPF by using ADS

3.2 Design by another electromagnetic solver

For the purpose of validating the S-parameter results generated by ADS, an additional study was performed using a different electromagnetic solver.

The layout of the Bandpass Filter (BPF), implemented using a different electromagnetic solver, is illustrated in the Fig 5.

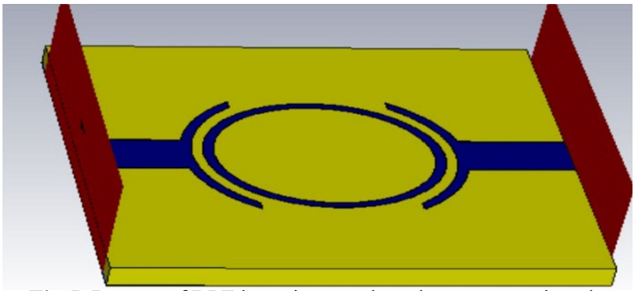


Fig.5. Layout of BPF by using another electromagnetic solver

The near-identical simulation results obtained from the two electromagnetic solvers, as presented in Fig 6, serve to validate the accuracy of the simulation.

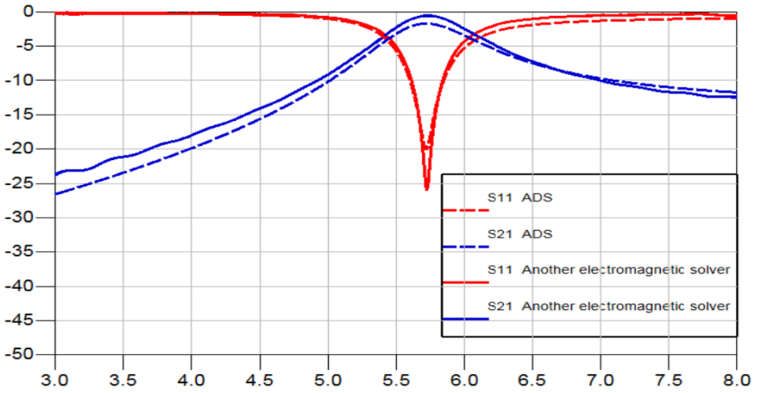
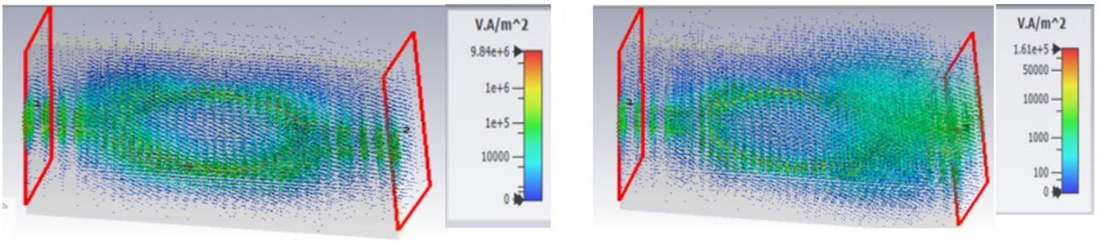


Fig.6. S-parameters versus frequency of the designed BPF by using another electromagnetic solver

The power flow of the proposed BPF is visualized in Fig.7, showing the behavior within the bandwidth at 5.8 GHz (a) and in the rejected band at 4 GHz (b). These illustrations confirm the filter's operating frequency range. At 5.8 GHz: The power flow vectors (indicated by arrows) are clearly directed from one end of the filter to the other.this indicates efficient energy transmission, confirming that the structure allows this frequency to pass through — as expected from a bandpass filter, and at 4 GHz:the power flow is more disturbed, disorganized, or largely reflected or dissipated, This shows that the filter effectively rejects this frequency, confirming its stopband behavior around 4 GHz.



(a) (b)

Fig.7. Presents the power flow (a) at 5. 8 GHz and (b) at 4 GHz

4 Conclusion

This research presents a miniaturized electronic signal filter employing specially designed Coupled Circular Rings. This bandpass filter operates with a 5.39 GHz to 6.09 GHz bandwidth

(5.72 GHz center frequency) and exhibits a return loss of 20 dB and an insertion loss of 1.7 dB at the center frequency. The filter is characterized by its compact size, low cost, and ease of RF circuit integration, This filter has many applications, including, Wireless Local Area Networks (WLANs): For devices operating in the 5.8 GHz ISM band to improve transmission and reception by reducing out-of-band noise and interference from other devices, and a bandpass filter at 5.8 GHz is crucial in a rectenna system designed to harvest energy from radio waves in this frequency band.

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