Mediterranean Smart Cities Conference (MSCC 2024)
2-4 May, 2024, Martil, Morocco

A New Design of a Microstrip BandPass Filter based on SRR Structure

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Abstract*— This paper presents the design and analysis of a novel Bandpass Filter (BPF) design realized in microstrip technology using square split ring resonators (SRR) as resonators. The BPF structure consists of modified microstrip line connected to 50Ω microstrip line on both sides and SRR which has been added and located in the center of the proposed design. The SRR elements are used and optimized to achieve the desired frequency response. The filter is mounted on an FR-4 substrate having a thickness of 1.6 mm, a dielectric constant of 4.4 and loss tangent of 0.025. The circuit is designed to operate central frequency of 3.48 GHz and has a bandwidth of 780 MHz. This circuit is designed and simulated by using two electromagnetic solvers based on different physical methods, which show a low insertion loss in the whole band pass and has a good rejection. The simulation results demonstrate also the effectiveness of the SRR based bandpass filter in achieving the desired performance characteristics, making it a promising candidate for wireless communication and RF signal processing applications. And Through this study we will contribute to the development of a compact microstrip bandpass filter with superior electrical performance.

Keywords— BPF; SRR; Metamaterial; Microstrip

I. INTRODUCTION

Wireless technology's evolution is presently steered by the demands for high data rates and the need for communication partners' mobility. Electromagnetic waves operate at various carrier frequencies, allocated within frequency slots, and subsequently mix in the wireless channel (open air). For effective communication, transmitter and receiver devices must select

electromagnetic waves at specific frequencies for exchange. The bandpass filter facilitates this selection process by allowing desired signals to pass through without loss, while rejecting unwanted signals [1].

The utilization of ring resonators is widespread in the design of bandpass filters. the use of the SRR cell in filter implementation enables the creation of selective, compact, flexible, and cost-effective filters, making it an important choice for many communication and signal processing applications. Different configurations of ring resonators have been suggested for this purpose [2-5].

Metamaterials are engineered materials with dimensions much smaller than the wavelength of the signals they interact with. Rather than relying on their basic components, they derive distinctive electromagnetic wave propagation properties from their structural design. Within the electromagnetic field, these artificial materials are characterized by two effective constitutive parameters: effective permittivity and permeability. These parameters describe how metamaterial structures respond to magnetic and electric fields [6-10].

The main objective of this study is to develop a novel compact microstrip bandpass filter with superior electrical performance. To accomplish this, the split ring resonator is employed and integrated into the structural design. In order to achieve the desired return loss, favorable insertion loss, and minimal size for the proposed design, multiple parameters were adjusted and optimized using two electromagnetic solvers.

II. CHARACTERISTICS OF A CONVENTIONAL SQUARE SRR

The conventional Square SRR is considered as one of the most common configuration that have been studied and analyzed by researchers, it comprises two square-shaped rings separated by a gap, positioned opposite each other. “Fig. 1(a) and (b)” illustrate the schematic diagram of a Square SRR along with its equivalent circuit model [11-13], respectively.

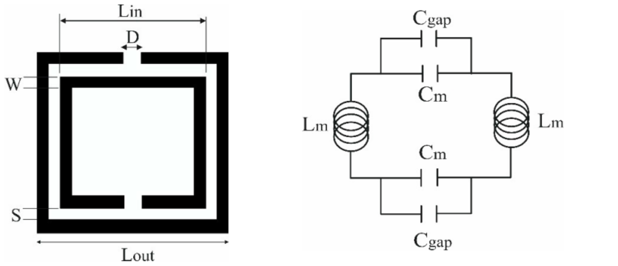


Figure 1. Geometry of the square SRR (a) unit cell; (b) equivalent circuit [14].

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

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:

$$C_m = \frac{A\varepsilon_0\varepsilon_r W(2L_{out} + 2L_{in} - D)}{2S} \quad (3)$$

III. DESIGN PROCEDURE AND RESULTS DISCUSSION

To ensure appropriate dimensions for the Bandpass Filter (BPF), the design of the SRR-based BPF starts by treating the SRR structure as a standard microstrip line deployed on a dielectric substrate. Figure 2, illustrates the SRR structure as a component of the BPF, comprising two truncated rings of non-magnetic metal conductor. The SRR structure, which has a square shape, is deployed on a FR-4 dielectric substrate.The wavelength λ_d for the desired working frequency of the BPF can be derived simply from the wavelength in free space λ_0 using “(4)”

$$\lambda_d = \frac{\lambda_0}{\sqrt{\varepsilon_{r,eff}}} \quad (4)$$

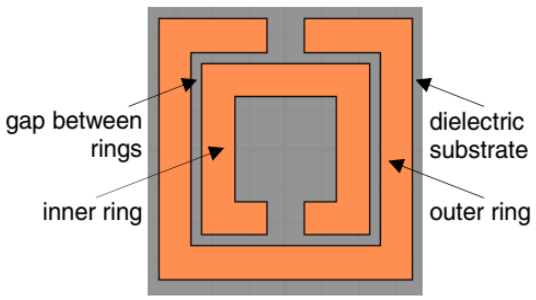


Figure 2. Structure of SRR takes a square shaped as an element of BPF [15].

Where $\varepsilon_{r,eff}$ is the relative permittivity effective of dielectric substrate which is given in “(5)” [16].

$$\varepsilon_{r,eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}[1 + \frac{12}{u}]^{-\frac{1}{2}} \quad (5)$$

where ε_r is the relative permittivity of dielectric substrate and u denotes the ratio between width of transmission line (W) and thickness of dielectric substrate (h) as expressed in “(6)”, with A is given in“(7)” [17].

$$u = \frac{W}{h} = \frac{8e^A}{e^{2A} - 2} \quad (6)$$

$$A = \frac{Z_0}{60}[\frac{\varepsilon_r}{2}]^{\frac{1}{2}} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1}[0.23 + \frac{0.11}{\varepsilon_r}] \quad (7)$$

The length of the outer ring of the square SRR (a) can be theoretically calculated using equation (8).

$$a = \frac{0.5\lambda_d + g}{4} + \omega \quad (8)$$

Here, g represents the space between the ends of the ring, and ω denotes the width of the outer ring of the square SRR. The length of the inner ring of the square SRR is adaptable to meet the specified criteria, depending on the gap between the outer and inner rings of the SRR.

A compact and miniaturized microstrip BPF was built by using square SRR unit cell. Due to its relatively low cost, the proposed circuit is printed on FR-4 substrate. This substrate is characterized by a relative permittivity of 4.4, a loss tangent of 0.025, and a thickness h=1.6 mm. he geometric configuration parameters of the proposed bandpass filter (BPF), which utilizes a square Split Ring Resonator, are depicted in “Fig. 3”.

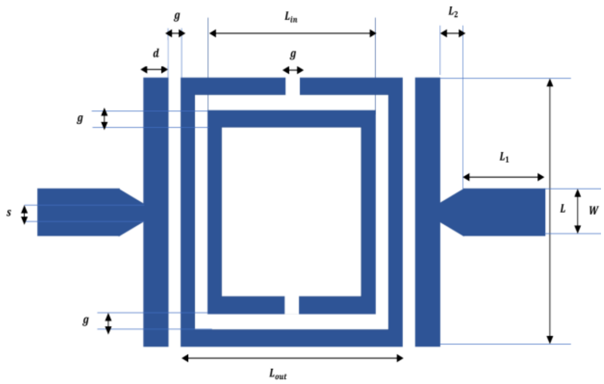


Figure 3. Geometry of the proposed bandpass filter

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

TABLE I. VALUES OF THE DIFFERENT PARAMETETRS OF THE BPF

Parameters	Values (mm)
Lout	9
Lin	8.4
L1	5.5

L_2	2
L	9
W	3
d	1
s	0.5
g	0.15

A. *Design by ADVANCED DESIGN SYSTEM (ADS)*

The BPF structure consists of modified microstrip line connected to 50Ω microstrip line on both sides and SRR which has been added and located in the center of the proposed design. And the optimized BPF circuit is designed to be very simple, which helps to minimize manufacturing complexity. It features a compact size of 9x26.3mm².

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

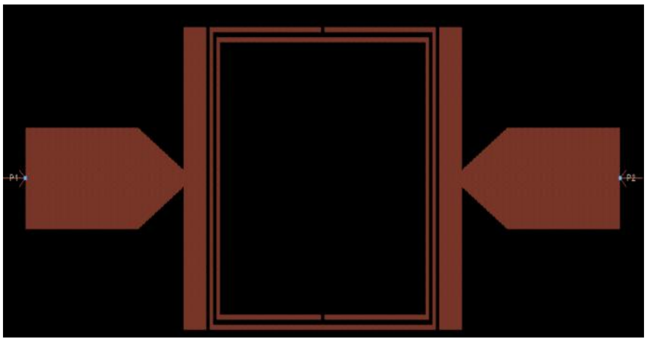


Figure 4. Layout of BPF by using ADS

The simulation results indicate a behavior characteristic of bandpass filtering at the central frequency of 3.48 GHz,

the BPF has return loss of 20.667dB and insertion loss of 1.187dB , it’s has a compact size, and low insertion loss in the pass-band. The filter is also having a good rejection of -35 dB at the 5 GHz. The total band bass obtain is about 780 MHz

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

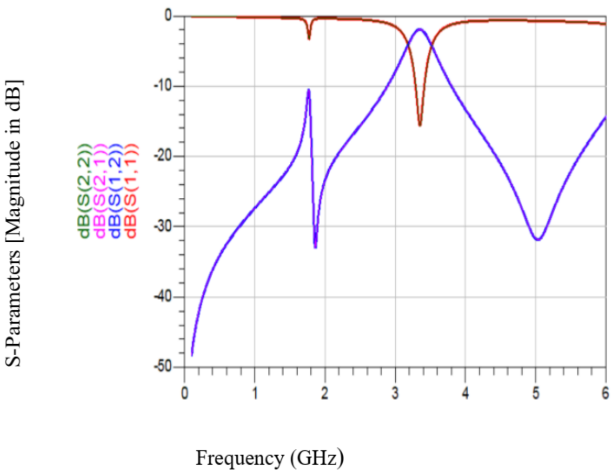


Figure 5. S-parameters versus frequency of the designed filter BPF by using ADS

B. *Design by another electromagnetic solver*

To validate the simulated results obtained from ADS in term of S-parameters, another study is conducted by using another electromagnetic solver.

The “Fig. 6” illustrates the layout of BPF using another electromagnetic solver.

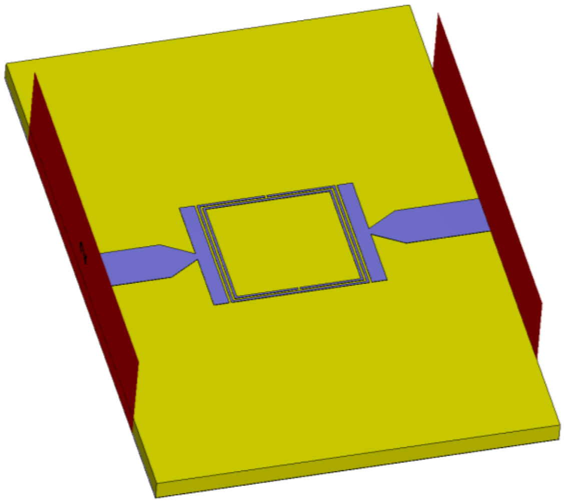


Figure 6. Layout of BPF by usign another electromagnetic solver.

As shown in “Fig. 7” a nearly identical simulation results were obtained by using both of two electromagnetic solvers which validate the obtained results into simulation.

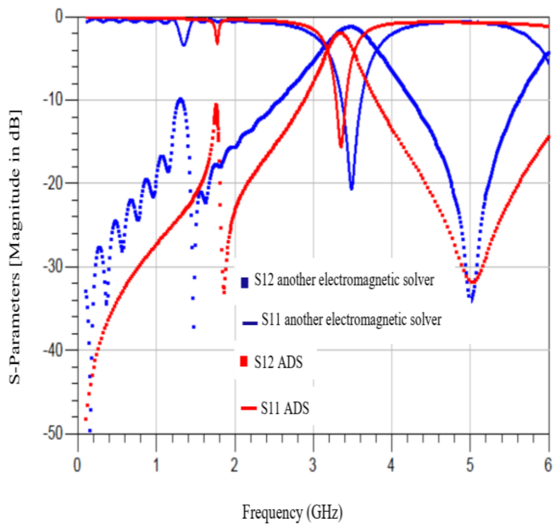


Figure 7. Comparison of the S-parameters results versus frequency response of the proposed BSF

"Fig. 8" illustrates the VSWR value, at the center frequency of 3.48 GHz we notice that the value of VSWR (Voltage Standing Wave Ratio) is equal to 1.24157

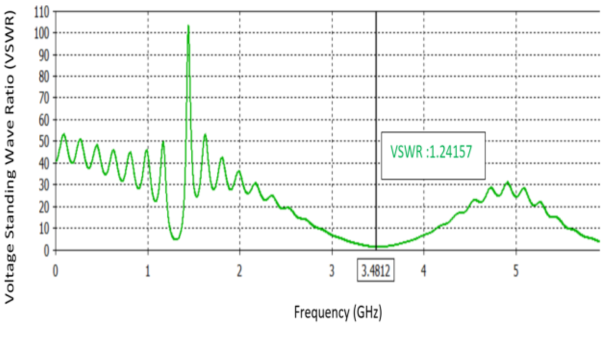
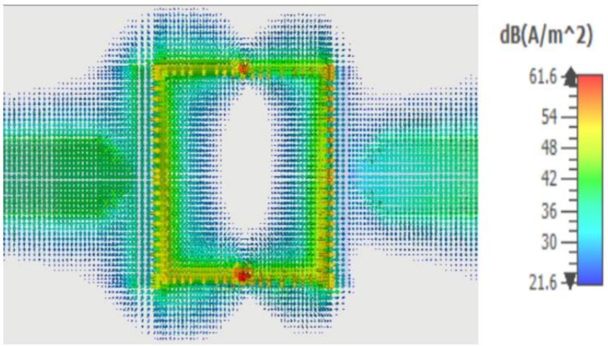


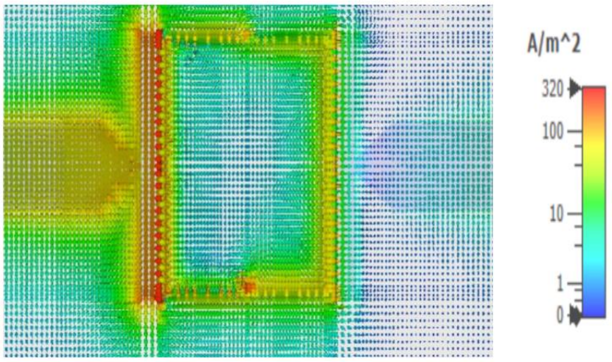
Figure 8. VSWR result

The realization of the BPF gives good performances in terms of insertion loss, return loss and VSWR.

To study the current distribution of the proposed BPF, the "Fig. 9", illustrates two currents distribution, one in the bandwidth at 3.48 GHz (a) and another in the rejected band at 2 GHz (b). The obtained results confirm the operation band of this filter.



(a)



(b)

Figure 9. Presents the current distribution (a) at 3.48 GHz and (b) at 2 GHz

IV. CONCLUSION

This study introduces a novel compact microstrip bandpass filter based on square spilt ring resonators, this filter operates in the bandwidth ranging from 3.1 GHz to 3.88 GHz, with a center frequency of 3.48 GHz. at the center frequency the BPF has return loss of 20.667dB and insertion loss of 1.187dB. this structure is characterized by its compact size, cost effectiveness, and ease of integration with radio frequency circuits. With its specified characteristics, this circuit would indeed be a favorable choice for implementation in modern communication systems.

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