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Design of compact microstrip bandpass filter using square DMS slots for Wi-Fi and bluetooth applications

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ABSTRACT

This paper presents the design of a compact bandpass filter based on two identical rectangular resonators and is implemented on microstrip technology for Wi-Fi and bluetoothapplications. To reduce the size of the filter, the defected microstrip structure (DMS) technique is proposed. This technique consists of etching slots in the rectangular resonator, which results in a change in the line properties and increase of the effective inductance and capacitance. This feature is used for miniaturization. The designed filter has a compact size (6.82x8.3) mm² with a low insertion loss of -0.1 dB and a good return loss of -36 dB. The simulation results are realized using the (computer simulation technology) CST Microwave software.

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1. INTRODUCTION

The rapid evolution of wireless communications systems like Wi-Fi and bluetoothapplications increases the demand for the design of radio frequency (RF) filters having a low insertion loss, good matching level, compact size, and good selectivity [1]. A bandpass filter is one of the most important devices in the wireless communications systems, which can filter out the noise or reduce the interference of the external signals that could affect the quality or the performance of any communication system. Its conception is directly related to the performance and the type of desired application [2].

The real challenge that the researchers now face is thus obtaining bandpass filters that are characterized by their excellent matching level, low insertion loss, small size, and ease of fabrication. For this, several research works have proposed techniques to reduce filter size while keeping good performances, such as open-loop ring resonators [3-6], parallel-coupled lines [7-11], stepped-impedance resonator (SIR) [12, 13] and defected ground structure (DGS) [14-17].

The defected microstrip structure (DMS) is one of the most techniques used to reduce the filter size due to its easy design, makes it with high compactness, high-quality factor, and more easily integrated with other RF devices. This technique is realized by etching slots in the microstrip line, which disturb the current distribution. Therefore, the effective inductance and capacitance of the micro-strip line are changed. This change affects the resonance characteristics in the frequency response. However, these characteristics can be used to design compact microwave components [18-23].

In this paper, a compact microstrip bandpass filter based on two identical rectangular resonators using the DMS technique has been presented, which is a continuation of another work [24, 25]. The design procedure follows two main steps. The first is to etch square DMS slots on a conventional rectangular resonator which can be controlled to reduce the resonator size. Whereas the second step consists in associating of two identical modified resonators to determine the performances of the filter in terms of bandwidth, matching level and insertion loss. The proposed compact bandpass filter is simulated, optimized and implemented on an RT6010 substrate with a dielectric constant of 10.2, a thickness of 1.27 mm and a tangent loss of 0.0023, it has a very small size of (6.82x8.3) mm^2 with low insertion loss (-0.1 dB) and good matching level (-36 dB). The simulation results are carried out using the CST Microwave software.

The paper organization is given as follows. In section 1, the background, related works, and novelty of this paper are described. In section 2.1, the proposed rectangular resonator geometry and its characteristics are presented. Then, square-shaped DMS is integrated into the resonator to reduce its size with good unloaded quality factor and in section 2.2; we associate two identical rectangular resonators for designing a compact bandpass filter with good electrical performances. In section 3, a conclusion is made to show the finding and benefits of the proposed bandpass filter design.

2. COMPACT BANDPASS FILTER DESIGN AND MINIATURIZATION

The main objective of this work is to design a compact bandpass filter for wireless communication applications (Wi-Fi and Bluetooth) by using modified rectangular resonator. The bandpass filter is designed by using RT6010 substrate and it is simulated using CST tool. The desired filter is estimated to have a compact size of (6.82x8.3) mm^2, with better electrical performances meeting the specifications Table 1.

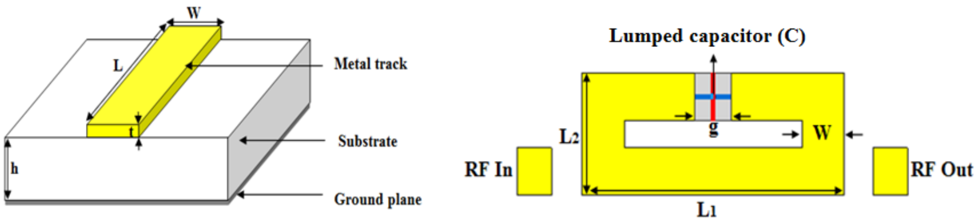
Table 1. Specifications of the desiredfilter

Parameters	Values
Center frequency (f_0)	2.4 GHz
Bandwidth (BW)	300 MHz
Matching level (S_{11})	<-15 dB
Insertion loss (S_{21})	>-0.5 dB

2.1. The conventional rectangular resonator characteristics

The geometry of the conventional rectangular resonator [24] consists of five microstrip line sections closed by a lumped capacitor (1.15 pF) and implemented on a dielectric substrate RT6010 with thickness h=1.27 mm and relative permittivity ε_r=10.2, as shown in Figure 1. This resonator operates at 2.4 GHz with an unloaded quality factor of around 128.55. This value is in the interval values corresponding to microstrip filters [25]. All the dimensions of the conventional rectangular resonator are summarized in Table 2.

To reduce the size of this conventional resonator, a simple square DMS slot is integrated into microstrip line section L_1 (Figure 2 (a)). The integration of the square slot (DMS) impacts the resonance frequency which has shifted from 2.4 to 2.18 GHz (Figure 2 (b)). To find the frequency fixed in the specifications (2.4 GHz), we proceed to an adjustment of "L_1" and "a", thus leading to a reduction in the dimensions of the resonator.



(a) (b)

Figure 1. (a) Microstrip technology, (b) Configuration of the conventional rectangular resonator

At the fixed resonance frequency, and by varying "a" and "L_1", we analyze the unloaded quality factorQ_0, which can be used to measure the loss of the resonant circuit. Q_0 is obtained from the frequency response of the circuit (Figure 2 (a)) using (1-2) [1]:

$$Q_0 = \frac{Q}{1-S_{21}} \tag{1}$$

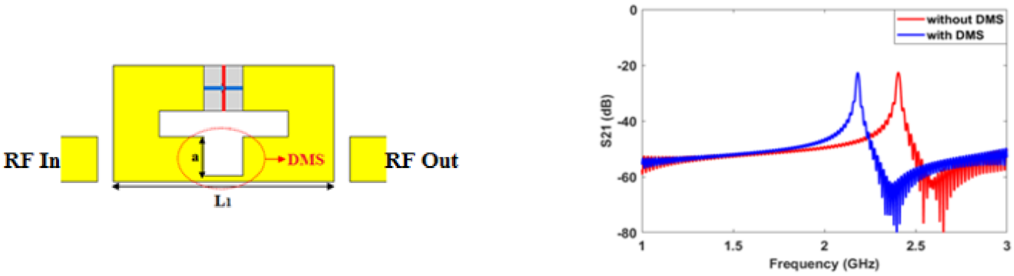
$$Q = \frac{f_0}{BW} \tag{2}$$

with q the loaded quality factor, S_{21} is the insertion loss at the resonance frequency f_0 and BW is the bandwidth.

For each couple of “a” and “L_1”, while the resonant frequency is fixed at 2.4 GHz, Q_0 is calculated. Table 3 summarizes obtained results. From the analysis of the results in the Table 3, and by making a compromise between the size of the resonator and Q_0, the best compromise is obtained for the iteration 4 with the best Q_0 and a reduced size.

Table 2. Dimensions of the conventional rectangular resonator

Parameters	Values (mm)
W	1.17
L_1	7.285
L_2	3
G	1



(a) (b)

Figure 2. (a) Square slot DMS configuration, (b) Simulated S_{21} (dB) of the proposed resonator with and without DMS

Table 3. The parametric study of “a”and“L_1”

Iteration	a (mm)	Size L_1xL_2 (mm²)	Q_0
1	0.2	(7.175x3)	114.52
2	0.4	7.05x3	127.83
3	0.6	6.85x3	133.69
4	0.8	6.45x3	134.31
5	0.99	5.7x3	129.90

2.2. Bandpass filter based on two identical rectangular resonators

To obtain a band pass filter for Wi-Fi and bluetooth applications with two transmission zeros, good matching level (S_{11}<-15 dB) and low insertion loss (S_{21}>-1 dB), with a bandwidth about 300 MHz, an optimal configuration of filter based on microstrip technology is proposed Figure 3. This structure consists of two identical coupled rectangular resonators separated by the distance “S”, and connected with two feed lines (50 Ω). These resonators are implemented on a RT6010 substratewith a thickness of 1.27 mm, a dielectric constant of 10.2and tangent loss of 0.0023. The optimal feed line location (d = 3.01 mm) can be estimated by [1]:

$$d = \frac{2(L_1+L_2)}{\pi} sin^{-1}\left(\sqrt{\frac{\pi}{2Q_e}}\right) \tag{3}$$

$$Q_e = \frac{g_0 g_1}{FBW} = 6.74 \tag{4}$$

where $Q_e$is the external quality factor, $g_0 = 1$ and $g_1 = 0.8431$ are the normalized values of a Chebyshev 0.1 dB and FBW is the relative bandwidth (0.125).

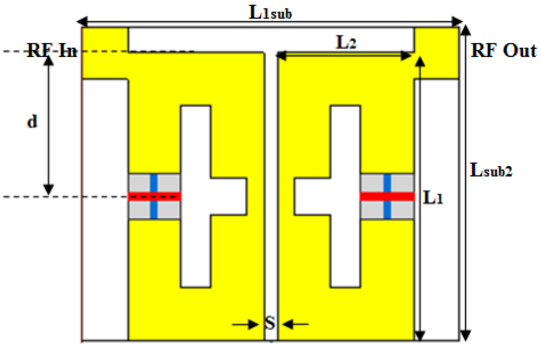


Figure 3. Layout of proposed band pass filter

In order to get the optimal distance between the rectangular resonators, a parametric study of “S” is presented in Figures 4 and 5. This study based on the coupling between theresonators that constitute the bandpass filter. When twostrictly identical resonators are placed side by side, theresonance modes of each of them are disturbed. Thisperturbation that corresponds to the coupling depends on the inter-resonators distance “S”.

Table 4 shows variations of the return loss, insertion loss and bandwidth with the change of the distance S. From this table, we can see that the bandwidth can be decreased by increasing the inter-resonator space "S", at the same time, the level of the insertion loss decrease, so, the best performance in terms of adaptation, insertion loss and bandwidth is obtained for S = 0.3 mm.

Figure 6 demonstrates the final results of the proposed bandpass filter in terms of matching level S11, insertion loss S21, and bandwidth. It is observed that the proposed filter provides bandwidth equals 300 MHz at a center frequency of 2.4 GHz, and a matching level S11 of -36 dB. The corresponding insertion loss S21 is equal to -0.1 dB. The two transmission zeros are visible at the frequencies, 2.05 GHz and 2.7 GHz, which indicates a sharp cut before and after the bandwidth.

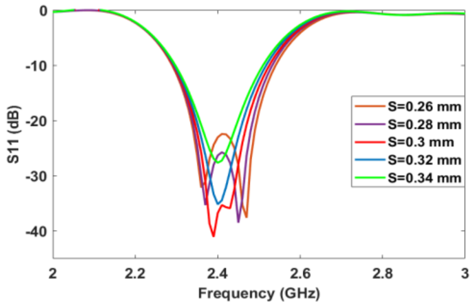


Figure 4. Simulated results of reflexion lossfor different values of S

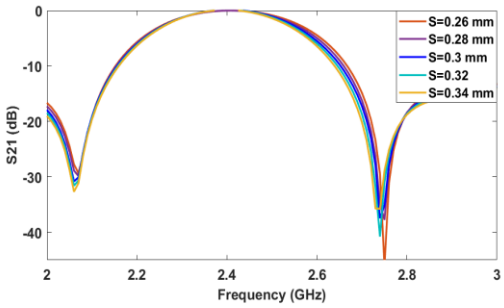


Figure 5. Simulated results of insertion loss for different values of S

Table 4. The parametric study of S

S (mm)	S_{11} (dB)	S_{21} (dB)	BW (GHz)
0.26	-23	-0.15	0.323
0.28	-26.32	-0.12	0.311
0.3	-36.75	-0.1	0.3
0.32	-35.16	-0.1	0.29
0.34	-27364	-0.11	0.28

To validate the filter performances, the current distribution is examined. Figure 7 shows the current distributions for the designed filter at 2.4 GHz (bandwidth) and 4 GHz (bandstop). From the analysis of Figure 7, it can be seen that the current shows maximum distribution at 2.4 GHz and a minimum distribution at 4 GHz. This means that the designed filter offers total transmission in bandwidth and total reflexion in bandstop. The performance of the proposed bandpass filter is summarized in Table 4 with other reported works for comparison. It can be seen from Table 5 that the proposed filter has a very small size (6.82x8.3) mm² with good performances than those reported in the literature.

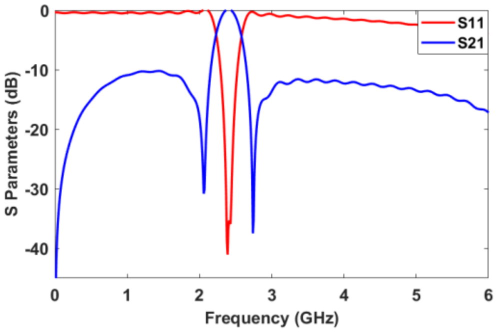
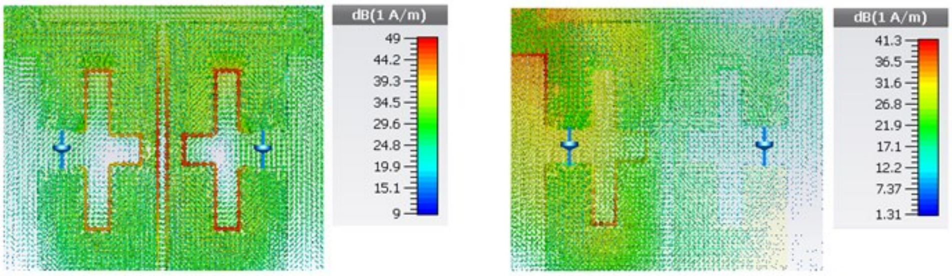


Figure 6. S parameters for proposed DMS filter



(a) (b)

Figure 7. Current distribution at: (a) 2.4 GHz and (b) 4 GHz

Table 5. Performance comparison with previous works

Ref	f_0 (GHz)	BW (GHz)	Insertion loss (dB)	Size(mm²)
[6]	2.4	0.29	0.23	9.4x23.1
[25]	2.4	0.3	0.01	7.485x8.18
[26]	2.4	0.12	0.91	22x22
[27]	2.4	0.07	0.32	18x18
This work	2.4	0.3	0.1	6.82x8.3

3. CONCLUSION

In this paper, a microstrip bandpass filter using the modified rectangular resonator has been presented. The modified rectangular resonator based on the DMS slot offers advantages of simple topology, miniature size, and a good unloaded quality factor (134.31). The designed filter demonstrates enhanced passband behavior with a center frequency of 2.40 GHz and bandwidth fixed at 300 MHz. This filter is characterized by a good matching level of -36 dB and a very low insertion loss of -0.1 dB. Two transmission zeros are located at 2.05 GHz and 2.7 GHz. This obtained results show that this filter provides a reasonable matching level and insertion loss as well as offering overall filter dimensions of 6.82×8.3 mm² which makes the proposed filter very desirable for bluetoothand Wi-Fi applications.

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