# A New Microstrip Diplexer Using Open-Loop Resonators

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***Abstract*— In this paper, a new microstrip diplexer using open loop resonators with compact size and high isolation is designed and fabricated for the WLANs (IEEE 802.11b/g at 2.4 GHz and IEEE 802.11a at 5.2 GHz) applications. The diplexer is formed by two dual-mode band pass filters (BPFs) using an asymmetric fork-form feed line and two open loop resonators. The diplexer has less than 3 dB insertion loss and the isolation between the two channels is more than 25 dB. Furthermore, the proposed diplexer shows several transmission zeros beside the pass bands which improves the selectivity of the BPFs and thus improves the isolation between lower and upper channel filters and achieves a significant attenuation of the undesired harmonics. The electrical performances of the diplexer are investigated numerically by using Momentum integrated in ADS Agilent and CST microwave software. Good agreement between the simulation and measurement results is achieved.**

***Index Terms*—** Diplexer, isolation, open-loop resonators, selectivity, transmission zeros.

## I. INTRODUCTION

Diplexer is a key component in many microwave communication system, including wireless communications system, Radar systems, cellular phones and satellite communications systems. Known as a passive three-port device that allow to an antenna to be shared by a transmitter and a receiver operating in different frequency bands. Otherwise it route the signal from the transmitter to the antenna and from the antenna to the receiver [1]. Diplexers were widely studied in the early 1960's by Matthaei et al. [2]-[3] and Wendel [4].

In the context of modern wireless system communication, and with the fast growth of the wireless communication technology the new developed wireless local area networks (WLANs) standards (IEEE 802.11b/g at 2.4 GHz and IEEE 802.11a at 5.2 GHz) becomes a new and attractive standard technology. The development and the multiplication of standards require the use of multiple frequency bands each dedicated to an application. Thus, diplexers with high isolation, low loss, low

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cost and compact size are increasingly requested to operate in multi-service and multi-bands mobile communication systems which have become more popular.

In the past, several methods to design diplexers have been proposed in literature [5]-[6]-[7]. The most popular structures used, generally combine two band pass filters (BPFs) such as the cross coupled stepped impedance resonators [5], the miniaturized open-loop resonator [6], square ring resonators [7] or two periodic filter structures with open-circuited stubs used to achieve a wide-band diplexer for multiple-frequency applications [8]. However, such structures present many disadvantages like high insertion loss, a poor isolation between the bands and large size.

In this article, a novel microstrip diplexer with good band pass responses, used for applications in modern multi-service communication systems is proposed. The proposed diplexer is formed from two selective band pass filters using open loop resonators, in order to achieve high performances and compact size with attenuation of the unwanted spurious resonant frequencies, using printed circuit technology. The first open loop resonator operates at 2.4 GHz while the second one operates at 5.2 GHz, the whole circuit is formed by coupling the two open loop resonators to an asymmetric microstrip fork-form feed line and two end-open L-shaped feed lines. The microstrip diplexer is initially designed and simulated by using the Momentum integrated in ADS from Agilent technologies [9] and verified with another simulator CST microwave studio [10], then fabricated to confirm the simulation results.

This paper is organized as follow; firstly, we will describe the methodology design using open loop resonator theory. Secondly, the simulated results of the circuit under different coupling spacing between the resonators and the feed lines will be given. Then, the S-parameters response with ADS are presented and compared with simulation results given by CST microwave software and the last section of this paper describes the measurement results.

## II. FORMULATION

Microstrip open-loop resonators with annular or square configuration have been used widely in the design of filters, diplexers, mixers and antennas [11]. Recently, thanks to its compact and small size, the microstrip open loop resonators were used in the design of filters and diplexers [12]-[13].

Consider the open loop resonator obtained by folding a straight-line resonator as shown in fig. 1. Because of the open configuration and the presence of capacitance due to the microstrip gap between the open ends, the field analysis based on electromagnetic field theory is complicated. However, the behavior of the open loop resonator can be deduced by analogy to that of the straight-line resonator.

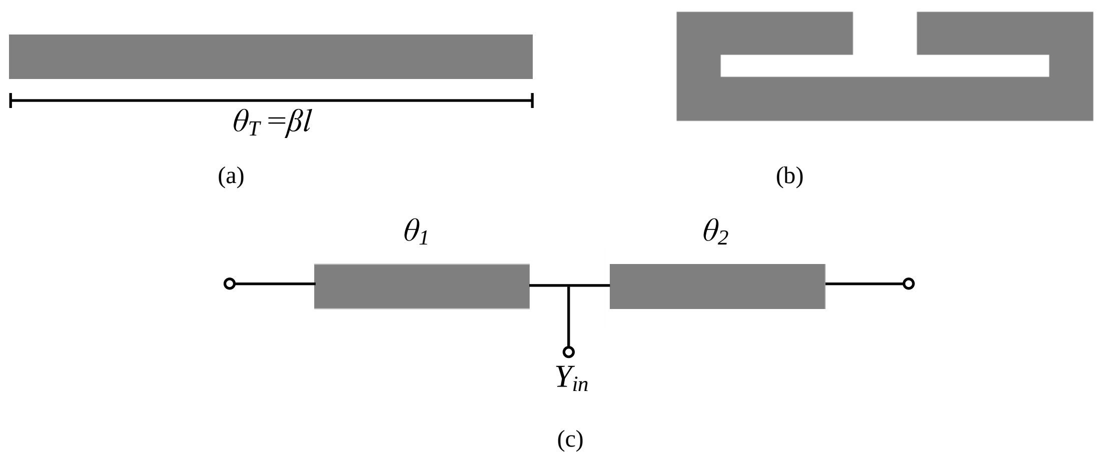


Fig. 1. (a) Straight-line resonator (b) The open loop resonator (c) Equivalent circuit of the straight-line resonator used to calculate the input admittance from any point within its length.

In its equivalent circuit depicted in Fig. 1.c, $\theta_T = \theta_1 + \theta_2$ represents the total electrical length of the resonator while $\theta_1$, $\theta_2$ are the electrical lengths of the short and the long paths of the resonator.

Assuming a lossless transmission in the open circuit, the expression of the input impedance can be given by the equation (1) [14].

$$Z_{in} = \frac{Z_0}{j \tan g(\theta)} \tag{1}$$

Where $Z_{in}$, $Z_0$ and $\theta$ are the input impedance, the characteristic impedance and the electrical length of the transmission line respectively.

From the Fig1.c the input admittance can be written as:

$$Y_{in} = Y_{in1} + Y_{in2} \tag{2}$$

$$Y_{in} = \frac{1}{Z_{in1}} + \frac{1}{Z_{in2}} = \frac{1}{\dfrac{Z_0}{j \tan g(\theta_1)}} + \frac{1}{\dfrac{Z_0}{j \tan g(\theta_2)}} \tag{3}$$

$$Y_{in} = jY_0(\tan(\theta_1) + \tan(\theta_2)) = jY_0 \frac{\sin(\theta_T)}{\cos(\theta_1)\cos(\theta_2)} \tag{4}$$

$Y_{in}$ is the input admittance from any point within its length given by the equation (5).

$$Y_{in} = jY_0(\tan(\theta_1) + \tan(\theta_2)) = jY_0 \frac{\sin(\theta_T)}{\cos(\theta_1)\cos(\theta_2)} \tag{5}$$

A standing wave can be maintained in the resonator when $Y_{in} = 0$, otherwise the resonances occur at: $\theta_T = n\,\pi$ or $l = n\lambda/2$. Fig. 2 presents the voltage distribution in the straight-line resonator at the fundamental frequency and the second harmonic (n=1, 2). We conclude that the voltage attains a maximum since the open ends of the resonator force the current to be zero. Also the voltage pass by a zero when $Y_{in} = \infty$ (or $Z_{in} = 0$), this occurs at the first resonant frequency when ($\theta_1 = \theta_2 = \pi/2$) and at

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the second resonance when ($\theta1 = \pi/2$ and $\theta_2 = 3\pi/2$). So it's important to know when the voltage is null because the resonator cannot be excited by the feed line at these points. [15]

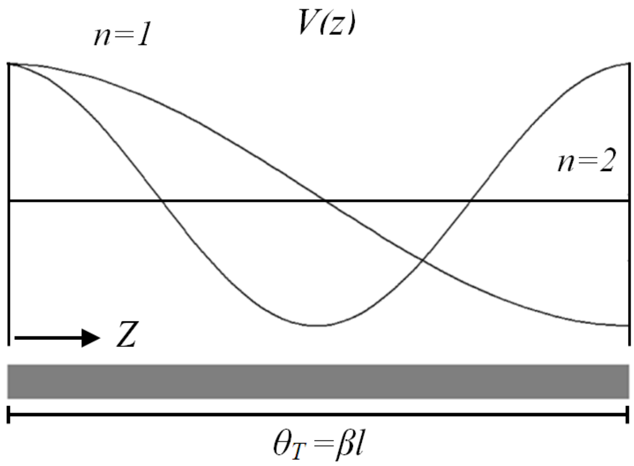


Fig. 2.Voltage distribution in a straight-line resonator.

Many approaches are possible to design a diplexer based on different filter configurations such as low pass and high pass filters, two band pass filters or band pass and band stop filters [16]. In our case the construction of the proposed diplexer begins by the design of two BPFs operating at 2.4/5.2 GHz respectively. The transmit filter (Tx) is the filter operate in the 2.4 GHz and the filter centered at 5.2 GHz is denoted receive filter (Rx).

The full-wave electromagnetic simulator ADS is used in the first time to characterize the frequency response of the diplexer and in order to verify its electrical performances, CST-MW is used to design and to simulate the circuit.

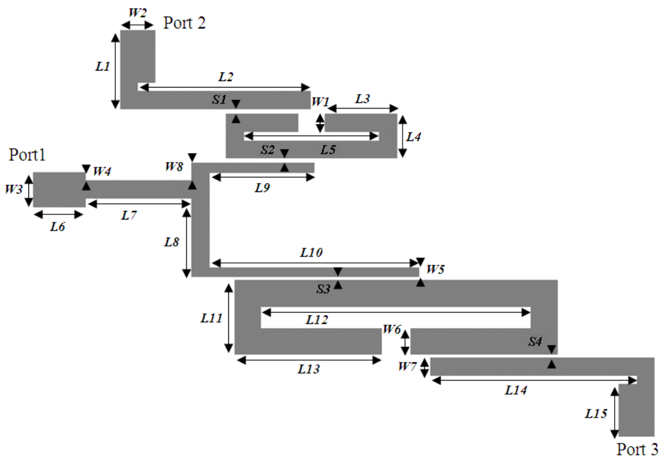


Fig.3. Physical structure and dimensions of the diplexer.

Fig.3 shows the structure of the proposed microstrip open-loop diplexer. Port 1 represents the input port connected to the antenna, while the port 2 and 3 represent the output of the receiver filter and the input of the transmitter filter respectively.

The proposed diplexer is mainly composed of two band-pass filters with open-loop resonators designed for WLANs applications at 2.4/5.2 GHz. In this geometry, two end-open L-shaped feed lines for the input and the output of diplexer are placed in close proximity to each resonator; the common port is connected directly to an asymmetric microstrip fork-form feed line coupled to the two resonators. To connect the Tx and the Rx filters, the T-junction remains the most used, however diplexers with the T-junction configuration are too large. The coupled-junction represents a good alternative not only to reduce the diplexer size but also to obtain better insertion loss and rejection performances.

The dimensions of the asymmetric microstrip fork-form feed line, the open loop resonators and the I/O ports should be selected carefully and adjusted by a full wave electromagnetic analysis to improve the performances of the diplexer. In order to obtain a high isolation between the two channels the input impedance seen into the Tx filter is infinite when the Rx filter is operated, and vice versa for Tx [17]-[18], so two band pass with high selectivity provides the possibility to design with high isolation a microstrip diplexer.

The design parameters of the proposed diplexer structure shown in fig. 3 were optimized by using ADS.

L1= 4.5, L2= 9.89, L3= 4.12, L4= 2.54, L5= 7.8, L6= 3, L7= 6.08, L8 = 4.49, L9= 6, L10= 12, L11= 4.27, L12=15.5, L13= 8.4, L14= 11.82, L15= 3, W1= 1, W2= 2, W3= 2, W4= 0.5, W5= 0.5, W6= 1.5, W7=1,W8= 1, S1= 0.3, S2= 0.3, S3= 0.2, S4= 0.2 (All in mm).

The external $Q_e$ defined by the equation (8) can express the coupling between the L-shape coupling arm and the open loop resonator.

$$Q_L = \frac{1}{\frac{2}{Q_e}+\frac{1}{Q_0}} = \frac{f_0}{(\Delta f)_{3dB}} \tag{6}$$

$$Q_0 = \frac{Q_L}{(1-10^{-L/20})} \tag{7}$$

$$Q_e = \frac{2Q_0Q_L}{(Q_0-Q_L)} \tag{8}$$

Where the $Q_0$ is the unloaded Q of the open loop resonator, calculated from the equation (7), with $f_0$ is the resonant frequency, $(\Delta f)_{3dB}$ is the – 3 dB bandwidth of the pass band, L is the insertion loss in decibel and $Q_L$ is the loaded Q obtained by the equation (6) [12].

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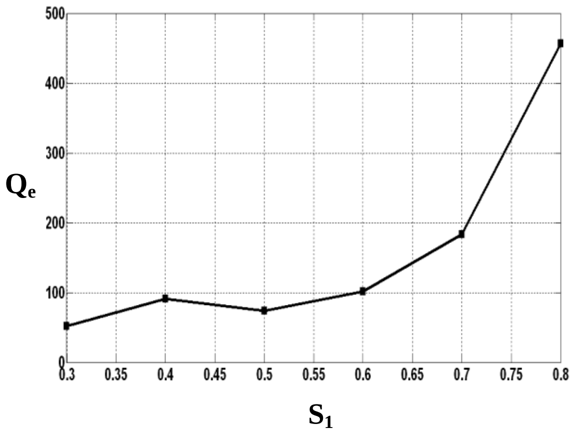
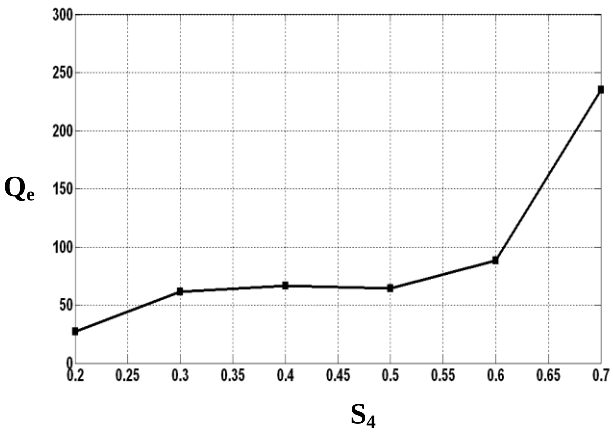
The external $Q_e$ for different values of $S_1$ and $S_4$ parameters are shown in Fig. 4. These simulated tests are introduced to improve the return loss ($S_{11}$) in the pass band and to obtain a good coupling degree between the L arm and the open loop resonators.

It's shown that the insertion losses and the bandwidth of the higher band pass filter decreases when $S_1$ changes between 0.75 mm and 0.3 mm while all the other dimensions are kept constant. Increasing the $S_4$ from 0.2 mm to 0.7 mm produces the same impact on the insertion loss and the bandwidth of the lower band pass filter. Then, a higher insertion loss and a narrow bandwidth are obtained for a higher external $Q_e$, so to design a band pass filter with a wide stop band and a low insertion loss, the open loop resonator should have a low external $Q_e$. Otherwise, the coupling periphery between the resonator and the L shape feed line should be increased.




(a)




(b)

Fig. 4. Simulated external $Q_e$ (a) by varying $S_1$ and all the other dimensions are held constant (b) by varying $S_4$ and all the other dimensions are held constant.

In order to reach good band pass behavior with suppression of the unwanted spurious resonant frequencies and with a wide upper stop band, the dimensions of the two open loop resonator and the feed lines are optimized minutely, each resonator have separate operating frequencies with a different spurious peaks, low levels and small bandwidth. Fig. 5 shows that the proposed diplexer has good performances, the 2nd and the 3rd harmonics are drastically attenuated and a good attenuation from the 4 GHz to 20 GHz is obtained.

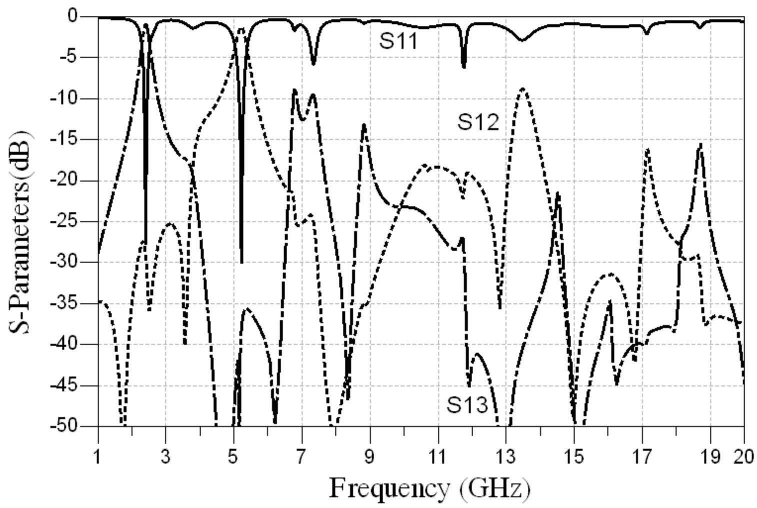
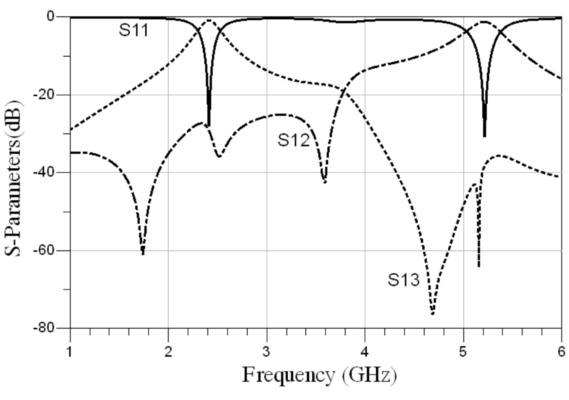



Fig. 5. Simulated frequency response of the proposed diplexer.

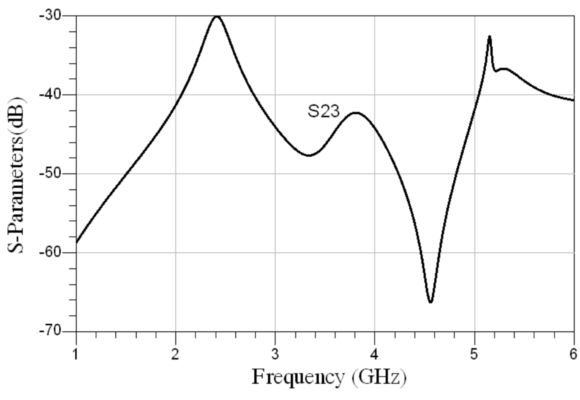
The design approach can be summarized as follow. Firstly, according to the specified center frequency $f_0$ of each filter the length of each open loop resonator is obtained. Once the two band pass filters operating at 2.4 GHz and 5.2 GHz are designed, an asymmetric fork feed line is also designed to form the whole circuit. Then, the $S_1$, $S_4$ and the periphery between the resonators and the feed lines are adjusted based on the simulated tests introduced to improve the insertion losses in the pass band. Finally, the dimensions of the feed lines are slightly balanced to reach a good attenuation in the upper stop band.

## III. RESULTS AND DISCUSSION

Fig. 6 shows the simulated results of the proposed diplexer. From which, low insertion loss, high rejection and high isolation can be clearly observed.




(a)




(b)

Fig. 6. S-parameters versus frequency of the proposed diplexer by using ADS (a) the return and insertion (b) the Isolation.

Fig. 6 depicts the optimized and simulated S-parameters with ADS software, we can observe that the band pass insertion loss remains lower than 0.93 dB and 1.3 dB for low and high band respectively, the insertion loss is more than 25 dB in band-stop. The return loss are around 28 dB for transmission channel and 30 dB for the receive one. Moreover the simulated isolation between the two channels is better than 30dB. The diplexer is appropriately designed to suppress the spurious harmonic of the lower band pass filter in the operating range of the second filter. As we can observe the band pass filter operating at 2.4 GHz has a harmonic suppression more than 30 dB up to 6.5 GHz.

Because of the asymmetric feed structure, many transmission zeros can be obtained, The Tx BPF operated at 2.4 GHz has two transmission zeros in the simulation band (1-6 GHz) located at 4.7 GHz and 5.16 GHz, with attenuation of 76 dB and 64 dB, respectively, which improve the band selectivity. Moreover, this filter has a FBW of 8.1 %. The Rx BPF operated at 5.2 GHz has a FBW of 4.46 %. Similarly, the second BPF also has many transmission zeros located at 1.7 GHz, 2.5 GHz and 3.6 GHz, with attenuation of 61 dB, 36 dB and 42 GHz respectively, which are expected to improve the isolation of the proposed diplexer. The location of the transmission zeros can be controlled by the variation of the coupled gap between the feed line and the open loop resonators. In addition, the use of filters with high selectivity explains the good isolation between the two channels.

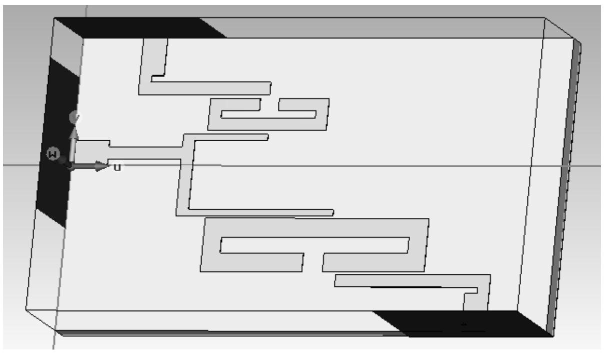


Fig. 7. Layout of the designed microstrip open-loop diplexer with CST-MW.

After investigating the characteristics of the microstrip diplexer for the WLAN applications and in order to verify the electrical performances of the proposed diplexer, CST Microwave Studio were used to design and to simulate the circuit. The frequency responses obtained are similar to the previous simulated results with Momentum integrated in ADS.

Fig. 8 shows the frequency response of the diplexer with CST-MW software, as we can see; the diplexer has an insertion loss of 0.91 dB at the Tx channel and 0.51dB for the Rx channel, the band pass return loss still better than 24 dB in the two frequency bands. In addition, the simulated $S_{32}$ parameter is always better than 34 dB for the range 2.2–2.6 GHz, and is even less than 38 dB from 4.8 to 5.4 GHz. The simulated 3 dB FBWs are 16.46 % at 2.37GHz and 8.79 % at 5.13GHz respectively.

Furthermore, the proposed diplexer shows several transmission zeros beside the pass bands which improves the selectivity of the BPFs. Thus better isolation between the two BPFs and a wide stop band can be obtained.

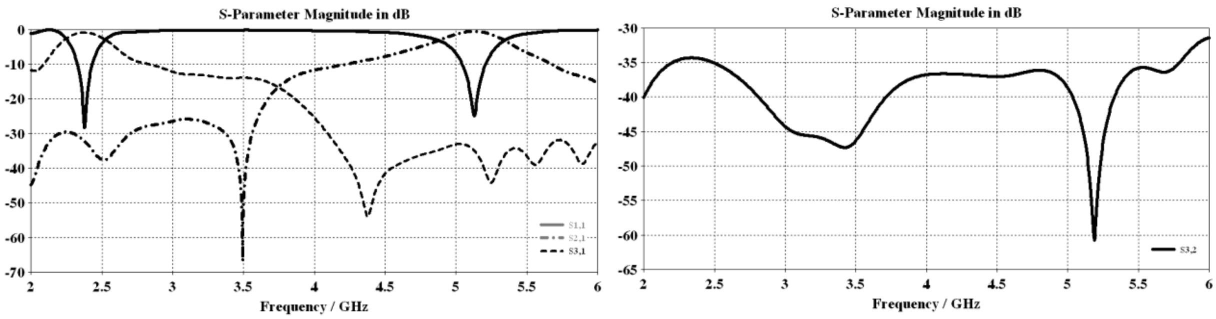


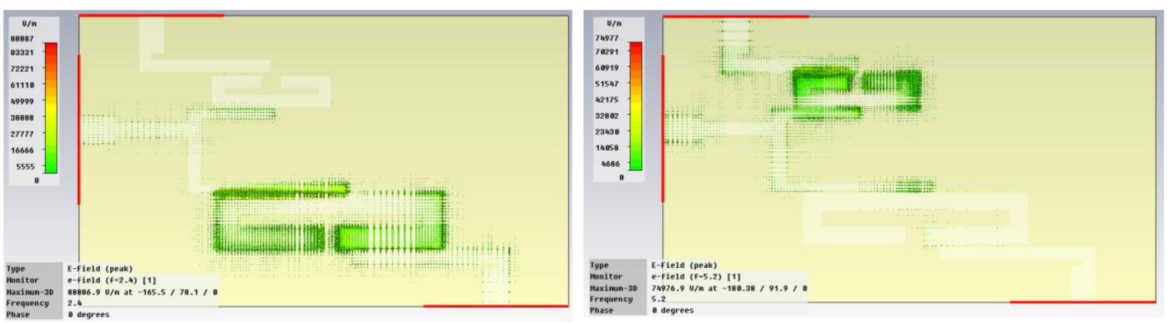

Fig. 8. The simulated results of the proposed diplexer using CST-MW.

Table I shows the simulated results with CST and ADS and measured results for comparison. As we can clearly see the table indicates a good agreement between the different results.

TABLE I. Simulation and measurement results of the diplexer.

| **Parameter** | **Simulation results (ADS)** | | **Simulation results (CST)** | | **Measured Results** | |
|---|---|---|---|---|---|---|
| | **TX** | **RX** | **TX** | **RX** | **TX** | **RX** |
| Frequency GHz | 2.41 | 5.21 | 2.376 | 5.13 | 2.45 | 5.14 |
| Bandwidth | 196 MHz | 232 MHz | 391 MHz | 451 MHz | 163 MHz | - |
| Insertion loss [dB] | 0.92 | 1.28 | 0.91 | 0.51 | 2 | 3.7 |
| Return loss [dB] | 28 | 30.8 | 28 | 24.7 | 17.8 | 19.5 |

From the simulated results listed in the table I, a deviation frequency of 34 MHz and 80 MHz is observed in the Tx and Rx bands respectively, between the results obtained with ADS and CST software. This large deviation can be attributed to the use of two different level of meshing density in both simulations. Also ADS is a 2 D electromagnetic software using an infinite ground, for CST is a 3 D simulator with a finite ground.

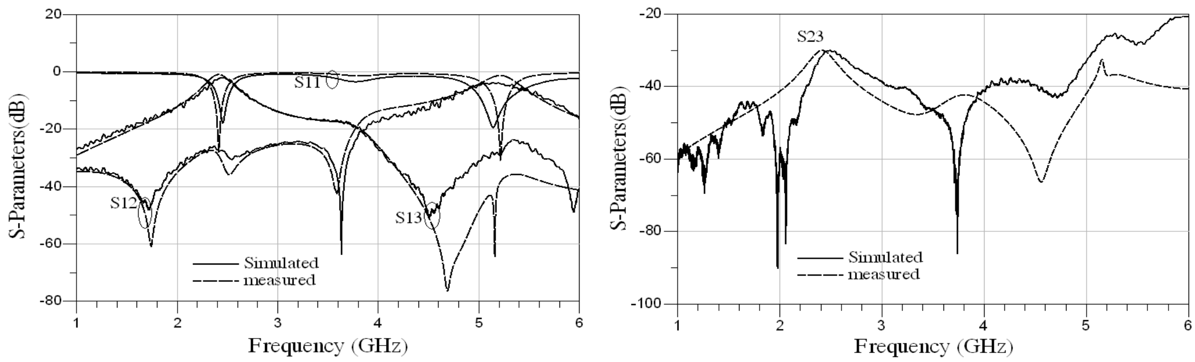


(a) (b)

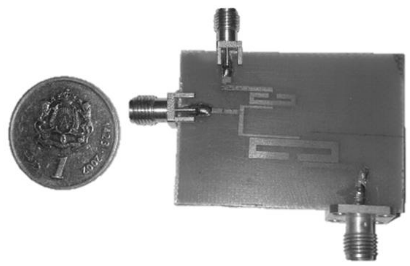
Fig. 9. Electrical-field distribution at (a) 2.4GHz and (b) 5.2 GHz.

The electrical-field distributions of the open loop diplexer at 2.4 GHz and 5.2 GHz are shown in fig. 9. Fig. 9.a plot electrical-field distribution at 2.4 GHz, the concentration of the current at the lower pass band filter is very high while that at the higher pass filter is much lower. Fig. 9.b present electrical-field distribution of the proposed diplexer at 5.2 GHz, as shown the current is concentrated at the higher pass band filter.

To verify the simulation results using ADS and CST microwave studio, Fig. 10.b displays a photograph of the fabricated diplexer; the proposed circuit is fabricated on the FR4 substrate with a thickness of 1.58 mm, a relative electric constant of 4.4, a loss tangent of 0.025 and a conductor thickness of 35 um. The circuit size is relatively small, with an area nearly equal to ($20\times52mm^2$).




(a)



(b)

Fig. 10. (a) Simulated and measured frequency response of the fabricated filter (b) The photograph of the manufactured diplexer.

The measured S-parameters of the manufactured diplexer are characterized in Agilent Technologies N5242A PNA-X Network Analyzer. Fig. 10.a shows the comparison between the measured and the simulated results. The measured response of the diplexer has $S_{11}$ of 17.8 dB for the download band and 19.5 dB for the upload channel. The measured insertion losses are less than 3.8 dB and 2 dB at the center frequencies for the Rx and the Tx channels respectively. From the fig. 10.a the measured isolation between the two channels of the proposed diplexer is better than 25 dB. However there is a deviation between the center frequencies of the simulated and measured results (about 60 MHz) which can be explained to the fabrication error or /and the change of the materiel properties.

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## IV. CONCLUSION

In this paper, a new microstrip diplexer using open loop resonators with compact size, low cost and high isolation with suppression of the unwanted spurious resonant frequencies is designed, simulated and fabricated for the WLANs applications. The diplexer is formed by two band pass filters based on an asymmetric fork-form feed line and two open loop resonators operated at 2.4 GHz and 5.2 GHz respectively. The electrical performances of the diplexer are excellent for such circuits using microstrip technology, an insertion loss lower than 3.8 dB and 2 dB in the higher and lower pass bands respectively and a high isolation between the two channels greater than 25 dB are obtained. The simulated result shows a good agreement with the measured frequency response. Additionally the proposed diplexer is expected to apply in modern multi-service communication systems.

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