Journal of Microwaves, Optoelectronics and Electromagnetic Applications, Vol. 18, No. 4, December 2019 482
DOI: http://dx.doi.org/10.1590/2179-10742019v18i41791

Design and Fabrication of a Novel Compact Low-loss Microstrip Diplexer for WCDMA and WiMAX Applications

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***Abstract*— In this paper, a novel miniaturized microstrip diplexer using two bandpass filters (BPFs) is designed and fabricated. The filters consist of stub loaded coupled lines. Additional stubs and T-shape feeding structures are added to miniaturize the size of the presented diplexer. With the adopted special structure, low insertion losses and compact size are obtained. The introduced diplexer operates at 2.12 GHz for WCDMA application and 3.94 GHz for WiMAX application. The obtained insertion losses are 0.25 dB at 2.12 GHz and 0.26 dB at 3.94 GHz. A design technique for analyzing the proposed resonator is introduced to tune the resonance frequencies and obtain a compact size. The size of the proposed diplexer is 23.4 × 16.9 mm^2 (0.038 λ_g^2). The measurement result of the fabricated diplexer validates the design technique and simulation results.**

***Index Terms*—** Compact, Coupled lines, Diplexer, Microstrip.

I. INTRODUCTION

Due to the rapid growth of portable electrical devices, designers try to find new methods to miniaturize the electronic components along with improving their performances [1], [2]. Microstrip devices have been widely used in designing of RF/wireless antennas, microwave circuits, and wireless communication systems [3]-[5]. A diplexer is a passive electrical device with filtered frequency response, which is used to receive and transmit signals by using an antenna in the modern microwave and wireless communication systems *i.e.*, radars, satellites and cellular phones. They require high compactness, low loss, high isolation, low cost, and easy fabrication. They are formed by two bandpass filters, which are connected for passing in two distinct frequency bands.

With the growing of wireless applications, various types of diplexers have been presented in recent years [6]-[18]. In [6], [7] novel structures have been introduced to obtain microstrip diplexers with low insertion losses for wireless applications. However, they are relatively large. Also, in [6] the return losses are high. Folded single stepped-impedance resonator [8], coupled stepped impedance

received 31 May 2019; for review 6 June 2019; accepted 12 Sept 2019
ISSN 2179-1074

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resonators [9], triangular resonators [10], complex meandrous loops [11], and spiral based resonators [12] have been utilized for designing microstrip diplexers. They have some problems such as high loss or large implementation area. For examples, the realized diplexers in [8]-[11] have the high insertion losses at two passbands, whereas, the proposed diplexers in [8]-[10] are large. In [12], using the spiral based resonators, a compact microstrip diplexer has been designed, but the complexity of small spiral structure causes difficulties in manufacturing as well as imprecision in measurement. Moreover, the obtained return losses at two passbands are not good. In [13], using open loops and resistors, three microstrip diplexers have been proposed with the aim of reducing the size. However, the large sizes of the lumped resistors and open-ended loop resonators have a negative impact on reducing the size. Also, similar to the other references, the problem of the large insertion loss exists. Based on employing the open loops and T-shape open stubs, a microstrip diplexer with low loss has been designed in [14]. Nevertheless, similar to most of mentioned references, it could not save the size. Meanwhile, a too large microstrip diplexer is presented in [15] for ultra-wide-band (UWB) and WLAN. In [16], a compact structure has been used for designing a microstrip diplexer. It operates at 2.35 GHz and 2.59 GHz for 4G wireless communication systems. It has two close center frequencies as a result of utilizing a symmetrical structure. In [17], a large size diplexer using microstrip coupled resonators has been proposed with a high design freedom degree.

The purpose of this paper is to introduce a method of reducing the size and losses at the desired frequencies of a microstrip diplexer. Hence, two bandpass filters are designed using coupled line resonators loaded by the various stubs. Then, a miniaturization method is presented to achieve two smaller filters. Finally, a microstrip diplexer is designed using the presented compact filters.

II. DESIGNING METHOD

As shown in Fig. 1, two coupled lines are used as a resonator to design a microstrip diplexer. Four open stubs and two tapped line feed structures with the characteristic impedances Z and Z′ are added to improve the characteristics of the passband. In Fig. 2, the coupled lines resonator is represented by an equivalent RLC circuit. For a loss-less coupled line resonator $R = 0$, so the resonance frequency is $f_o = (2\pi\sqrt{LC})^{-1}$.

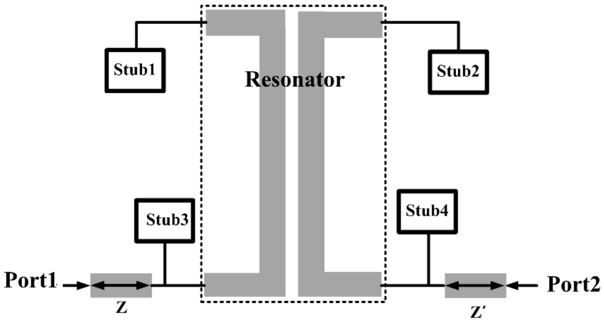


Fig. 1. Basic structure of the resonator for the diplexer design.

Brazilian Microwave and Optoelectronics Society-SBMO received 31 May 2019; for review 6 June 2019; accepted 12 Sept 2019
Brazilian Society of Electromagnetism-SBMag ISSN 2179-1074

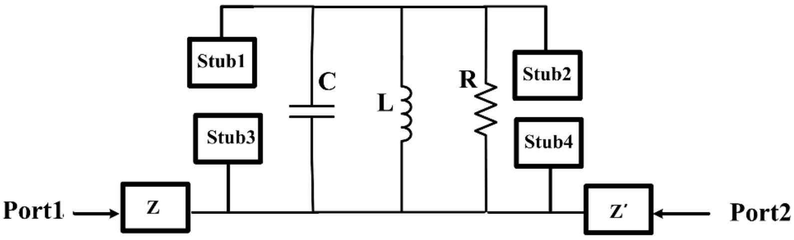


Fig. 2. Equivalent *RLC* circuit of the introduced filter.

For a low-loss network (assuming a zero resistance value), the input impedance is an imaginary value. If the resonator acts as a short circuit at the resonance frequency, the input impedance (viewed from port 2) is given by:

$$Z_{in} = \frac{z}{1 + z(y_{in1} + y_{in2} + y_{in3} + y_{in4})} + z' \tag{1}$$

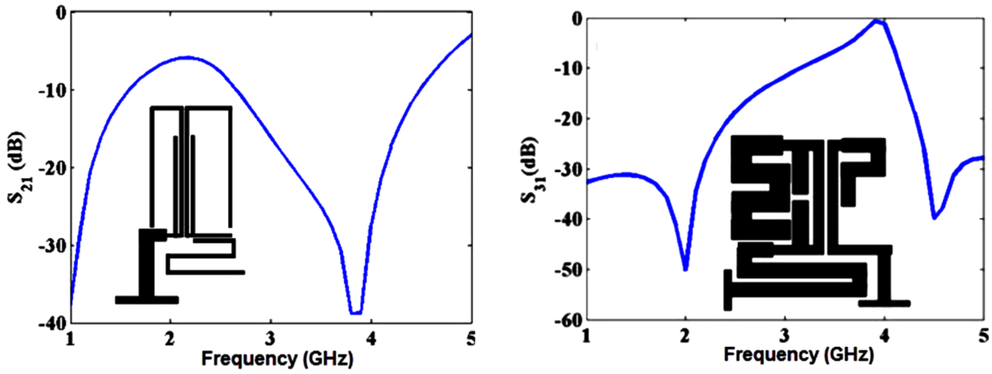
where y_{in1}, y_{in2}, y_{in3} and y_{in4} are the input admittances of the open-circuited stub1, stub2, stub3, and stub4, respectively. The input admittance of open-circuited transmission line can be written as; $y_{in} = jy_c \tan(\beta . l)$, where β, y_{c}, and l are the propagation constant, characteristic admittance, and physical length, respectively. Therefore, Z_{in} can be evaluated as follows:

$$Z_{in} = \frac{z}{1 + jzy_c[\tan(\beta l_1) + \tan(\beta l_2) + \tan(\beta l_3) + \tan(\beta l_4)]} + z' \tag{2}$$

where l_1, l_2, l_3 and l_4 are the physical lengths of the open-circuited stub1, stub2, stub3, and stub4, respectively. In (2), the characteristic admittance of the open stubs is assumed as equal parameters. This assumption is true when the widths of stubs are equal (in a same substrate). Based on [19], when the operating frequency and effective dielectric constant are presented by f_{o} and ε_{re}, respectively, then propagation constant can be written as $\beta = \frac{f_o \pi \sqrt{\varepsilon_{re}}}{150}$. Also, a short-circuited bipolar network is in the resonant state. It means that the input impedance is zero. Therefore, from (2):

$$\frac{z + z'}{y_c zz'} j = [\tan(f_o(\frac{\pi\sqrt{\varepsilon_{re}}}{150})l_1) + \tan(f_o(\frac{\pi\sqrt{\varepsilon_{re}}}{150})l_2) + \tan(f_o(\frac{\pi\sqrt{\varepsilon_{re}}}{150})l_3) + \tan(f_o(\frac{\pi\sqrt{\varepsilon_{re}}}{150})l_4)] \tag{3}$$

By putting the desired resonance frequency and having a determined dielectric constant in the above equation, the other parameters can be set so that two sides of the equation to be equivalent. This means that the lengths of the stubs as well as the impedances of the two tapped lines (z and z′) must be adjusted so that the minimum size and desired frequency response are obtained simultaneously. It is essential to note that f_{o} is determined by adjusting the inductor *L* and the capacitor *C* as shown in Fig. 3. Therefore, the coupled lines effect is clear so that the widths and lengths of coupled lines must be adjusted to obtain the desired resonance frequency. Based on (3), it is clear that a high design freedom degree is achieved. According to the above discussion, two miniaturized microstrip bandpass filters (BPFs) are obtained at 2.12 GHz and 3.94 GHz to be used in the diplexer design, see Fig. 3(a) and Fig. 3(b), respectively.



(a) (b)

Fig. 3. Layout and simulation results of the proposed (a) 2.12 GHz BPF. (b) 3.94 GHz BPF.

To achieve the proposed diplexer structure, two designed BPFs are integrated. Fig. 4 shows the proposed diplexer layout. Connecting two proposed filters at the same port (port1) results in achieving two channels. The dimensions of the filters in Fig. 3 are exactly equal to the proposed diplexer dimensions shown in Fig. 4. To select the dimensions of the introduced diplexer as depicted in Fig.3, the optimization technique is performed. Fig. 5 shows the proposed diplexer where the most effective cells are marked as the lengths l_1, l_2, l_3, l_4 , and the gaps S_1 and S_2.

The distributions of current density at 3.94 GHz and 2.12 GHz are illustrated in Fig. 6. As shown in Fig. 6, the coupled lines, especially those with the length l_2, create the first channel. Also, the maximum distribution of current density is in the right resonator for the second resonance frequency.

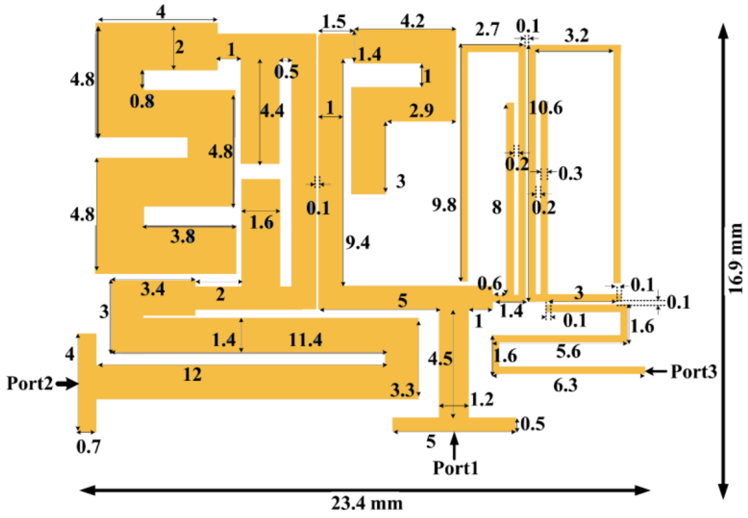


Fig. 4. Dimensions (in millimeter) of the introduced diplexer.

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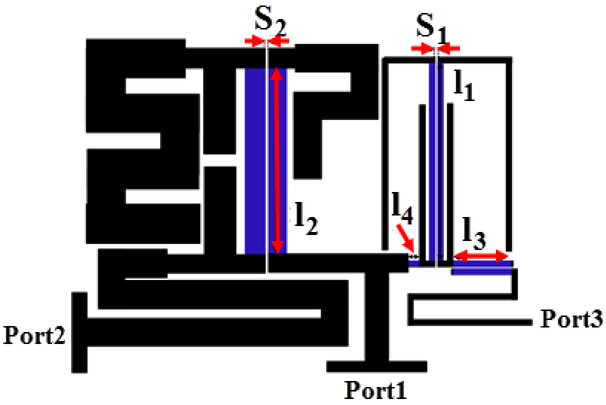
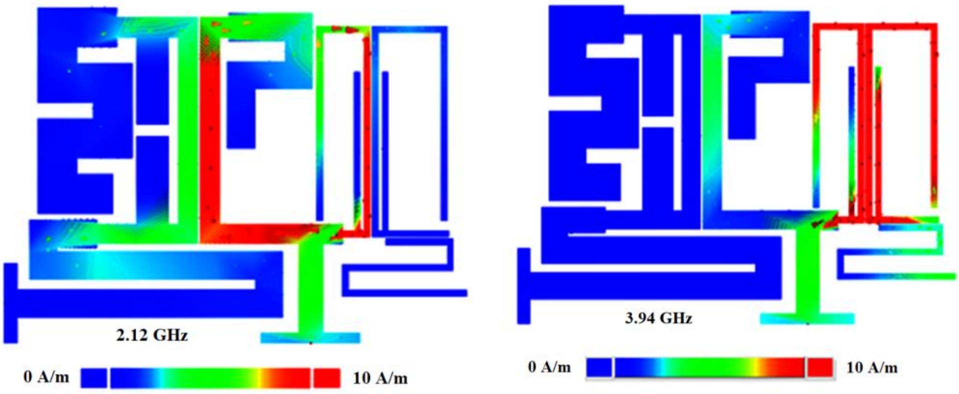


Fig. 5. Layout of the introduced diplexer.

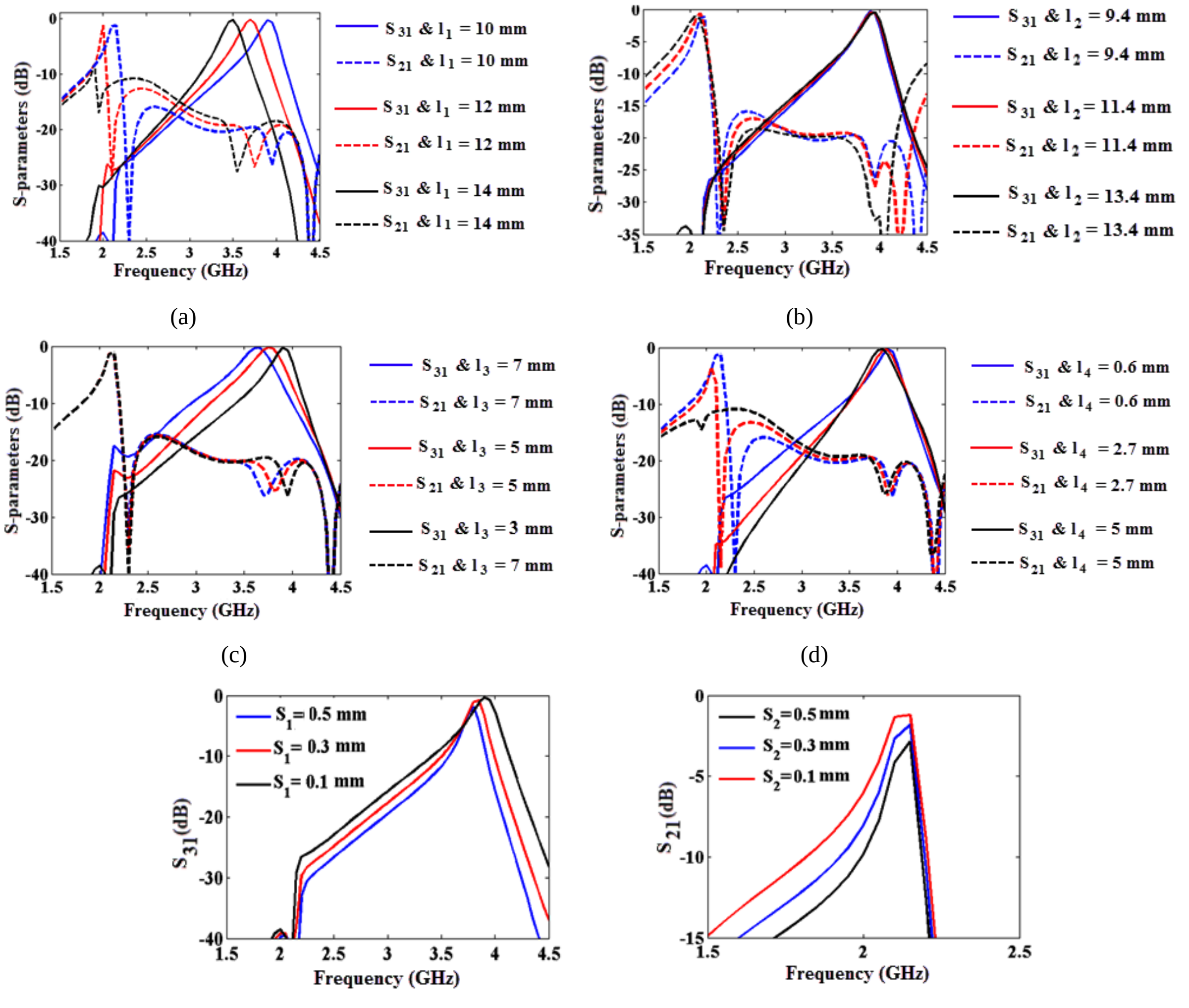


(a) (b)

Fig. 6. Simulation results of the current density distributionm at (a) 2.12 GHz, and (b) 3.94 GHz.

To prove the dual mode feature of the presented diplexer, we obtained its frequency responses as function of the physical widths and lengths l_1, l_2, l_3, l_4, S_1 and S_2. The results are presented in Fig. 7. These simulation results are obtained according to the dimensions presented in Fig. 4. Fig. 7 shows the shift of the second passband as a function of l_1, where by increasing this physical length the second resonance frequency shifts to the left. The first channel is affected by l_2 significantly. Changing of the physical length l_3 shifts the second channel, as well as l_1. Another important factor in creating the first resonance frequency is the microstrip cell with physical length l_4, where its effect is presented in Fig. 7. This cell is a part of the small integrator, which connects the bandpass filters. From Fig. 7(e) and Fig. 7(f) it can be seen that decreasing the space between coupled lines improves the insertion loss.

received 31 May 2019; for review 6 June 2019; accepted 12 Sept 2019



(a) (b)

(c) (d)

(e) (f)

Fig. 7. Simulated S_{31} and S_{21} as function of: (a) l_1, (b) l_2, (c) l_3, (d) l_4, (e) S_1, and (f) S_2.

Having an open circuit between the input and output ports creates a transmission zero. In the *LC* model of the proposed filter, the thinner parts have inductance features, whereas, the wider cells have capacitance features. When we connect these cells, at the special frequencies, they can create open circuits. These frequencies are TZs frequencies.

III. RESULTS AND DISCUSSION

EM simulator of ADS software is used to design and simulate the presented diplexer. We used RT/Duroid 5880 substrate to implement the designed diplexer. The thickness of the substrate, loss tangent and dielectric constant are 31 mils, 0.0009 and 2.2, respectively. An HP8757A Network Analyzer carried out the measurements. Fig. 8 shows the comparison of simulated and measured S_{21}, S_{31}, S_{11}, and S_{32} with a photograph of the proposed microstrip diplexer, where two passbands resonance frequencies at 2.12 GHz and 3.94 GHz are obtained.

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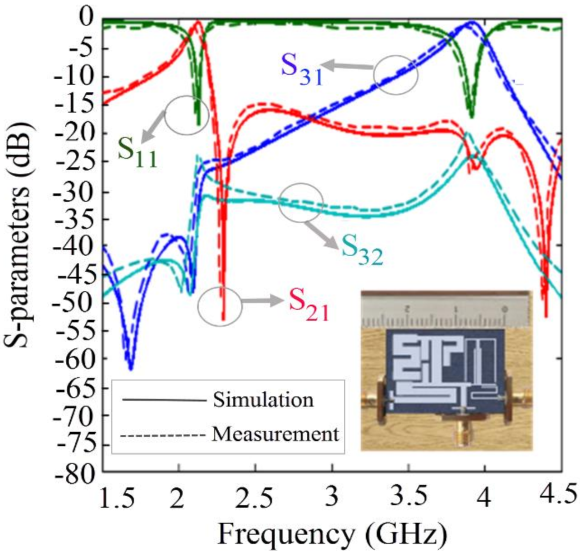


Fig. 8. S-parameters of the fabricated microstrip diplexer.

According to the frequency response presented in Fig. 8, the insertion loss at 2.12 GHz (S_{21}) is 0.25 dB and at 3.94 GHz (S_{31}) is 0.26 dB. The common port return losses are better than 18.4 dB for the first band and 17.4 dB for the second band. Moreover, the isolation between port3 and port2 (S_{32}) from 1 GHz up to 5 GHz is better than 35.2 dB and 24 dB at the resonance frequencies. The return loss at the resonance frequency of port3 (S_{22}) is 16.4 dB and the return loss at the resonance frequency of port2 (S_{33}) is 16.2 dB. Using the miniaturization techniques, the overall diplexer size is 0.23 λ_g × 0.16 λ_g (23.4 × 16.9 mm^2). The insertion losses at the two passbands (S_{21} and S_{31}), return losses of port1 at two passbands (S_{11}), approximated size, and resonance frequencies are compared with the other diplexers in Table I, where S-parameters are in dB, size is in mm^2, and resonance frequencies are in GHz. As shown in Table I, the proposed diplexer is compact and having good return losses, where the best insertion losses are achieved. The presented design in [10] has a compact size but it has not good return losses.

The presented diplexer is designed for WiMAX and WCDMA. Table I shows it is a well-designed structure. For example, it has a compact size and the lowest insertion losses at both channels. Only the introduced diplexer in [12] is smaller than our diplexer. However, it has large insertion loss and small return loss at both channels. Large common port return losses and large implementation areas are achieved in [7], [9] and [14]-[17]. The proposed diplexers in [9] and [14]-[17] have large insertion losses higher than 1.5 dB. Based on the above discussion, it is clear that the proposed diplexer is well miniaturized while it has low losses.

TABLE I. COMPARISON OF THE PROPOSED DIPLEXER WITH THE OTHER DIPLEXERS.

References	**S_{21} / S_{31} (dB)**	**S_{11} (dB)**	**Size (mm^2/ λ_g^2)**	**Passbands (GHz)**
Proposed diplexer	0.25/0.26	18.45/17.47	0.038	2.12/3.94
[6]	0.6/0.9	11.3/12.4	0.076	2.6/6
[7]	0.18/0.39	27.1/27.6	0.075	2.4/2.79
[8]	1.49/2.2	18.59/23.88	---	1.95/2.14
[9]	2.2/2.1	29/29	0.111	1.8/2.45
[10]	2.8/3	---	0.689	8/9
[11]	0.65/0.62	20/20	0.059	1.95/2.14
[12]	0.78/0.4	10/10	0.0068	1.2/1.75
[13]	1.5/1.2	16.5/16.5	0.149	1.55/2.17
[14]	1.5/1.3	21/21	0.085	2.3/2.55
[16]	----	29/38	0.082	2.35/2.59
[17]	2.2/2.1	27/26.3	0.064	1.82/2.41
[18]	1.2/1.5	---	0.136	1.95/2.14

The external Q factor of the first and second channels Q_1 and Q_2 are calculated in accordance with the formulas in [7] as follows:

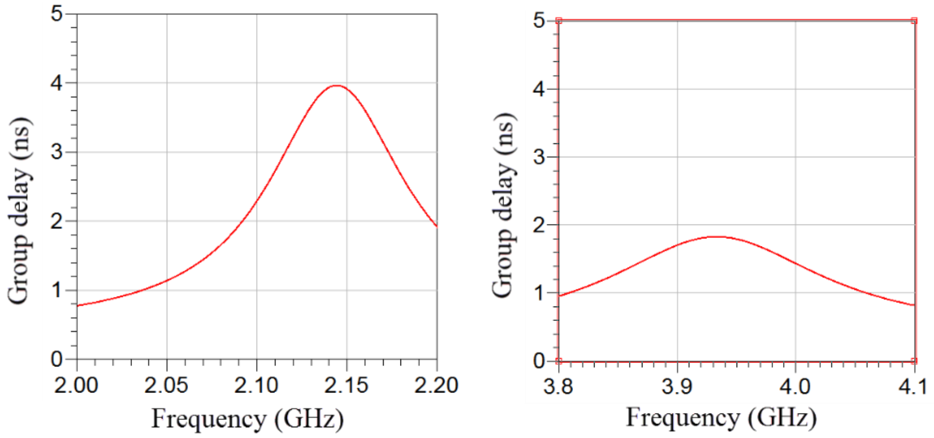
$$Q_1 = \frac{2F_{o1}}{(\Delta F_1)_{3dB}} \times 10^{\frac{\text{first channle insertion loss}}{20}} \cong 36$$

$$Q_2 = \frac{2F_{o2}}{(\Delta F_2)_{3dB}} \times 10^{\frac{\text{second channle insertion loss}}{20}} \cong 31 \qquad (4)$$

Where F_{o1} and F_{o2} are the first and second resonance frequencies (in GHz), respectively. Both insertion losses are in dB. $(\Delta F_1)_{3dB}$ and $(\Delta F_2)_{3dB}$ are the first and second -3 dB bandwidths. The first channel is from 2 GHz up to 2.2 GHz and the second channel is from 3.8 GHz up to 4.1 GHz. From the simulation results, the bandwidths of the first and second channels are 120 MHz and 260 MHz, respectively.

The group delay of diplexers usually is more than the group delay in filters, because the design of filters is easier than design of diplexers. Accordingly, many of published diplexers did not pay attention to this issue. A non-flat group delay results in the pulse distortion and non-flat passband. As it is shown in Fig. 9(a) and Fig. 9(b), the maximum group delay of our diplexer is less than 4 ns, which is good for a diplexer. On the other hand, the diplexers and multiplexers are less designed than the bandpass filters due to more complexity in their designing process. Therefore, the obtained group delay is good for a diplexer.

DOI: http://dx.doi.org/10.1590/2179-10742019v18i41791



(a) (b)

Fig. 9. Group delay of the (a) first passband and (b) second passband.

IV. CONCLUSION

A connection of coupled lines, stubs and tapped lines was utilized as the main structure to design a compact diplexer. Using the equivalent model of the proposed basic resonator, the input impedance as a function of the resonance frequency was obtained. Moreover, a miniaturization method at the desired frequency was presented. Using the proposed basic resonator, two compact microstrip BPFs were designed. Then, a microstrip diplexer with a total size of $0.23\ \lambda_g \times 0.16\ \lambda_g$ (23.4×16.9 mm^2) was proposed by employing the designed filters. The proposed diplexer has low insertion losses and good isolations at both resonance frequencies while the obtained isolation (S_{32}) is better than 24 dB from 1 GHz up to 4.5 GHz.

V. ACKNOWLEDGEMENTS

Authors would like to acknowledge the financial support of Kermanshah University of Technology for this research under grant number S/P/T/1177.

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