DESIGN AND FABRICATION OF A COMPACT MICROSTRIP TRIPLEXER FOR WIMAX AND WIRELESS APPLICATIONS

Abbas Rezaei[1*] – Salah I. Yahya[2,3] – Leila Noori[4] – Mohd Haizal Jamaluddin[5]

[1]Department of Electrical Engineering, Kermanshah University of Technology, Kermanshah, Iran
[2]Department of Communication and Computer Engineering, Cihan University-Erbil, Erbil, Kurdistan Region, Iraq
[3]Department of Software Engineering, Faculty of Engineering, Koya University, Koya KOY45, Kurdistan Region, Iraq
[4]Department of Electrical and Electronics Engineering, Shiraz University of Technology, Shiraz, Iran
[5]Wireless Communication Centre, School of Electrical Engineering, Universiti Teknologi Malaysia, Johor, Malaysia

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Abstract:

A novel structure to design a microstrip triplexer for wireless and WiMAX applications is presented. To obtain a compact microstrip layout, step impedance resonators and coupled lines are used. The introduced triplexer has a size of $0.35\lambda_g \times 0.26\lambda_g$*, where* λ_g *is calculated at 2.3 GHz. Also, the obtained insertion losses are 0.78 dB, 1.1 dB and 0.62 dB at 2.3 GHz, 3.2 GHz and 3.6 GHz, respectively. The LC model of the presented resonator is investigated to tune three resonance frequencies by calculating numerical values of inductors and capacitors. Finally, the designed triplexer is simulated and measured.*

1 Introduction

Recently, microstrip triplexers have been widely used in modern communication systems for separating signals that are close together, as well as selecting the desired frequency ranges in crowded frequency bands. Having low insertion losses and compact size are important factors for designing a high-performance microstrip triplexer. In [1], a triplexer composed of a dual-band bandpass filter and a lowpass filter is realized by using microstrip matching cells, stepped-impedance, parallel coupled lines, hairpin and open-loop resonator. It has a low insertion losses, weak frequency selectivity and large size. Most of the previous works could not reduce the insertion loss [2-11]. Also, some of the previous designs have large sizes [4-7]. In [3], a microstrip triplexer constructed by hairpins is presented. To design a triplexer in [4], step impedance structures are used as matching networks to integrate main resonators so that a high selectivity response is achieved. Coupled open-loop resonators and coupled lines are utilized to obtain a microstrip triplexer in [12]. It has good performances in terms of high selectivity and isolation. Another diplexer is constructed in [5] by using open-loop resonators for mobile communication systems at 1.8 GHz, WiMAX applications at 3.2 GHz and C-band applications at 4.4 GHz. In [6], a high isolation microstrip triplexer is obtained using parallel-coupled lines and U-shape structures. In [7], a microstrip triplexer with wide fractional bandwidths is presented using a star junction structure. In [8], asymmetric split-ring resonators are utilized to create a compact microstrip triplexer with three close channels (2.15, 2.95 and 3.80 GHz). In [10], a low pass-band pass triplexer is demonstrated in a T-shape, U-shape and hairpin resonators. In [9], the third order parallel-coupled band pass filters are integrated to introduce a wide stop band triplexer. In [11], a compact triplexer is designed by using coupled lines and radial structures. In [12, 13], two microstrip triplexers are achieved to improve the insertion loss. In [14], a fully integrated triplexer with a large implementation area is proposed for multi-band ultra-wideband applications.

A new microstrip triplexer is designed in [15] based on the properties of coupled lines, steps, and spiral cells to operate at 2.67 GHz for 4G LTE and at 3.1 GHz and 3.43 GHz for WiMAX. A microstrip triplexer

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[*] Corresponding author
E-mail address: a.rezaee@kut.ac.ir

with wide stop band is proposed in [16] using uniform impedance and common crossed resonators. In [17], a novel microstrip triplexer is proposed for wireless applications, which consists of spiral and patch cells. In [18], a novel microstrip triplexer is designed using split ring resonators for LTE application. In [19], two multiband microstrip multiplexers are proposed using distributed coupling method. They consist of asymmetric stepped-impedance resonators, a distributed coupling feeding line. In [20], a double-stub-loaded resonator is utilized to design a microstrip triplexer. In [21], uniform impedance and common crossed resonators are utilized to design a novel microstrip triplexer.

The purpose of this paper is designing a novel compact microstrip triplexer with a simple structure to operate at the frequencies of 2.3 GHz, 3.2 GHz and 3.6 GHz for WiMAX and wireless applications. For this purpose, a microstrip resonator is proposed and its *LC* equivalent model is portrayed. Then, a designing method is introduced to improve the frequency response. After that, to survey three excitation modes three sets of the numerical values of capacitors and inductors are obtained so that three pass bands can be created by changing the values of the capacitors and inductors. Finally, using the proposed resonators a novel microstrip triplexer is presented and optimized.

2 Design of diplexer

Coupled lines loaded by microstrip cells and stubs are integrated to work as a resonator, as shown in Figure 1a. This basic structure will be used to design a compact triplexer. An *LC* model for the coupled lines is selected based on the proposed model in [22, 23]. The equivalent *LC* circuit of the introduced resonator is shown in Figure 1b. In the *LC* equivalent circuit, L_C demonstrates the coupling between coupled lines. Furthermore, the equivalent model of half line includes L_e and C_e. The *LC* model of stub1 is replaced by the inductor and capacitor L_1 and C_1. Accordingly, stub1 can be a step impedance cell while C_1 and L_1 are related to the wider and thinner parts respectively. Similarly, we assume stub 2 is another step impedance cell which its *LC* model includes the capacitor and inductor C_2 and L_2.

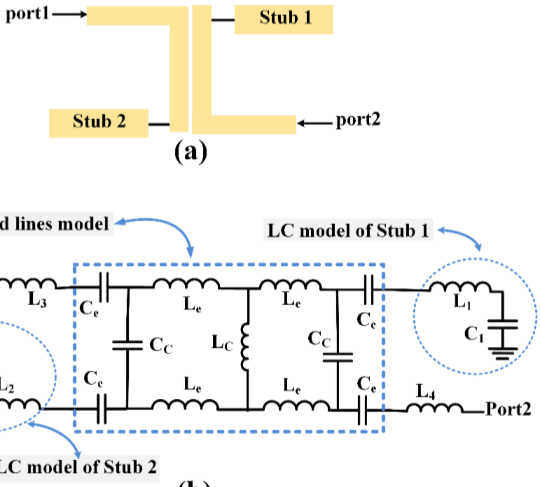

Figure 1. Presented resonator (a) layout (b) LC equivalent circuit.

Since the effect of the bents and steps in widths is considerable at the frequencies greater than 10 GHz, in the case of our design their effects are unimportant. Therefore, our proposed *LC* circuit is an approximated model. The transmission lines connected to port1 and port2 have inductance features as depicted by inductors L_3 and L_4 respectively [24]. We simulated the *LC* equivalent circuit of the proposed resonators for different values of the inductors and capacitors. As shown in Table 1, three sets of the numerical values of the capacitors and inductors are obtained to resonance at the requested frequencies of 3.6 GHz, 3.2 GHz and 2.3 GHz. The results of the introduced resonator are depicted in Figure 2.

From the numerical data, the impedance of each section Z_c can be calculated. By selecting a dielectric constant of 2.2 and having the calculated impedances of each section, we can calculate the ratio w/h for each microstrip cell using the following equation [24]:

Table 1. Numerical values for the equivalent LC model of the introduced resonator.

	L_e (nH)	L_c (nH)	L_1 (nH)	L_2 (nH)	L_3 (nH)	L_4 (nH)	C_C (pF)	C_e (pF)	C_1 (pF)	C_2 (pF)
Resonance at 3.61 GHz	0.5	6	2.5	0.56	0.5	1.6	4	2	0.5	3
Resonance at 3.2 GHz	0.5	6	2.5	10	0.5	1.6	22	2	2	3
Resonance at 2.3 GHz	1	0.2	3.3	10	3.75	1.8	10	1	0.5	3

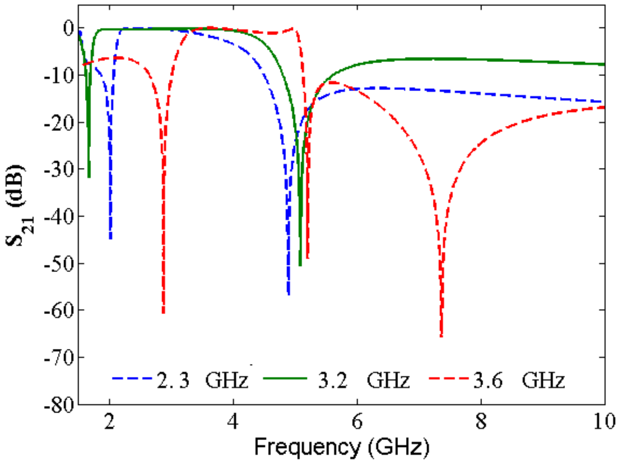

Figure 2. Simulation results of the proposed resonator for three sets of values in Table 1.

$$\begin{aligned}
&\text{for } w/h \le 1:\\
&\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left\{(1 + 12\frac{h}{w})^{-0.5} + 0.04(1 - \frac{w}{h})^2\right\}\\
&Zc = \frac{\eta}{2\pi\sqrt{\varepsilon_{re}}}\ln(\frac{8h}{w} + 0.25\frac{w}{h})\\
&\text{for } w/h \ge 1:\\
&\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}(1 + 12\frac{h}{w})^{-0.5}\\
&Zc = \frac{\eta}{\sqrt{\varepsilon_{re}}}\left\{\frac{w}{h} + 1.393 + 0.677\ln(\frac{w}{h} + 1.444)\right\}^{-1}
\end{aligned} \tag{1}$$

After achieving w/h for each cell, the overall dimensions of microstrip cell will be obtained. According to this method, the shape and dimensions of the proposed resonator can be achieved. Using the proposed resonator a microstrip triplexer is realized as shown in Figure 3. There are four pairs of the coupled lines which one of them is added to integrate the resonators rather than as a resonator. T-shape taped line feed structures are utilized to improve the matching. The coupled lines at port3 are placed horizontally to reduce the size.

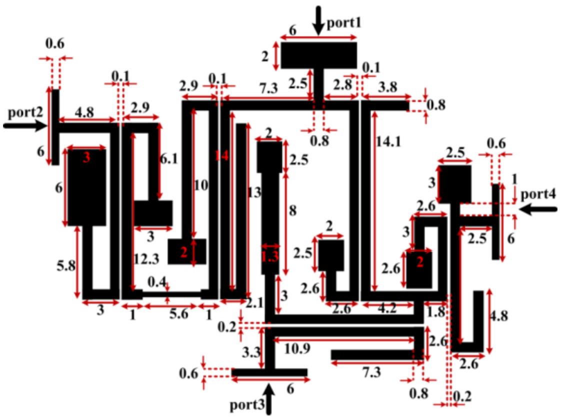

Figure 3. The proposed triplexer layout (dimensions are in millimeter).

3 Results and discussion

We used ADS (Advanced Design System) software for designing and simulation of the proposed microstrip triplexer. To fabricate the designed triplexer an RT/duroid5880 substrate with tanδ=0.0009, *h*=31 mil and ε_r=2.22 is used. We used the N5230A network analyzer to measure the frequency responses. In Figure 4a, the measured and simulated S-parameters, i.e., S_{21}, S_{31}, S_{41} and S_{11} are shown. From Figure 4 it is clear that the band widths are 120 MHz (centered at 2.3 GHz), 180 MHz (centered at 3.2 GHz) and 60 MHz (centered at 3.6 GHz).

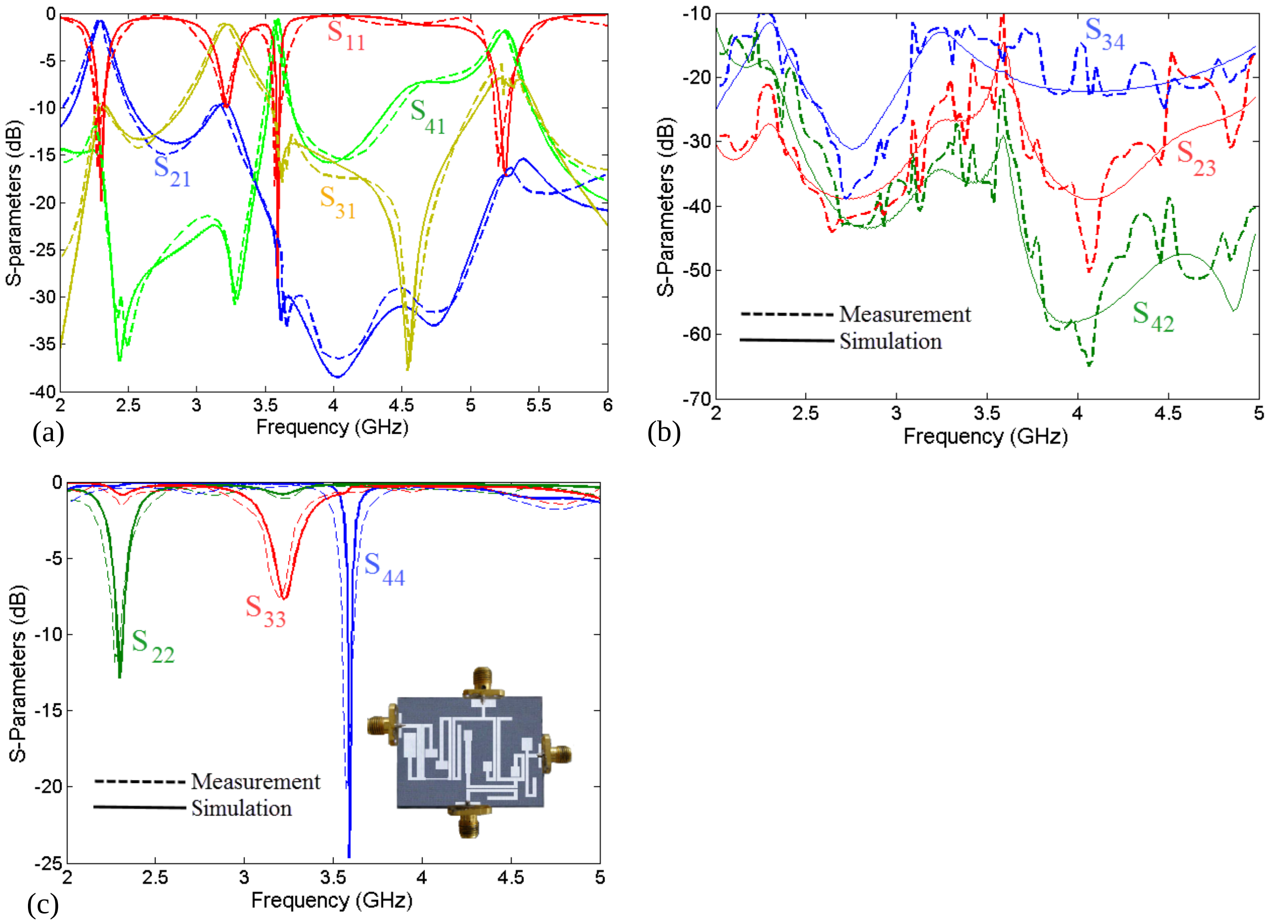

Figure 4. Measured and simulated (a) S_{21}, S_{31}, S_{41} and S_{11} (b)isolation between three ports (c) S_{22}, S_{33} and S_{44} and a photograph of the fabricated triplexer.

Also, the diplexer has low insertion losses (0.78 dB, 1.19 dB and 0.62 dB) at the center resonance frequencies. Also, the return losses of the input port at 2.3 GHz, 3.2 GHz and 3.6 GHz are 19.8 dB, 10 dB and 28 dB respectively. Figure 4b shows S_{23}, S_{34} and S_{42}. The important isolation values at the resonance frequencies are listed in Table 2. The photograph of the fabricated diplexer and return losses from ports 1, 2 and 3 (S_{22}, S_{33} and S_{44}) are presented in Figure 4c, where S_{22} is -12.88 dB at 2.3 GHz, S_{33} is -7.67 dB at 3.2 GHz and S_{44} is -24.67 dB at 3.6 GHz. The size of the introduced triplexer is 35.1mm×26.1mm or $0.35\lambda_g \times 0.26\lambda_g$, where λ_g is calculated at 2.3 GHz.

Table 2. Isolation at the resonance frequencies.

	2.3 GHz	**3.2 GHz**	**3.6 GHz**
S_{23} (dB)	-17.85	-34.57	-29.66
S_{34} (dB)	-11.47	-13.18	-19.24
S_{24} (dB)	-27.29	-27.24	-14.87

Table 3 illustrates the comparison with the previous works. Considering the information in the comparison table, relatively low insertion losses and compact circuit size are the strong points of the proposed triplexer, while the return losses and fractional band widths are acceptable. According to the obtained data, the maximum values of S_{34}, S_{32} and S_{24} from 2 GHz up to 5 GHz are -11.47 dB, -11.6 dB and -14.6 dB respectively. In comparison with references [15, 16] and [20, 21], our diplexer has smaller size. Also, it is better than reported diplexers in [16, 20-21] in term of insertion losses.

4 Conclusion

We presented a compact microstrip triplexer. The introduced triplexer is constructed by coupled lines and step impedance resonators for operating at 3.2 GHz, 3.6 GHz and 2.3 GHz for WiMAX and wireless applications. We presented an *LC* equivalent model of the introduced resonator and used it to tune the resonance frequencies. The proposed triplexer was compared with the previously reported designs. The obtained results showed that the introduced triplexer of a simple structure has a very compact size of 0.095 λ_g^2 (916 mm^2). Moreover, reasonable return losses and insertion losses are obtained at all pass bands.

Table 3. Comparison with the previous reported triplexers.

Reference	**f_{r1}, f_{r2}, f_{r3} (GHz)***	**Δ_1, Δ_2, Δ_3** (%)**	**IL$_1$, IL$_2$, IL$_3$*** (dB)**	**RL$_1$, RL$_2$, RL$_3$**** (dB)**	**Size (mm^2)**	**Size (λ_g^2)**
[1]	0.9, 2.45, 5.35	22, 4, 16	0.37, 0.68, 0.4	11.8, 21.3, 13.8	4655	0.111
[2]	3.2, 3.7, 4.4	6.6, 7.3, 8.2	2.7, 2.5, 1.8	20, 20, 20	414	0.136
[3]	1, 1.25, 1.5	4.6, 6.3, 3	2.7, 1.8, 3.2	16, 16, 16	2513	0.064
[4]	1.4, 1.7,1.9	4.9, 4.5, 4.8	3.4, 3.5, 3.6	---	4871	0.358
[5]	1.8, 3.1, 4.4	7.4, 7.4, 6.2	1.97, 1.99, 2.3	24, 22, 25	1122	0.177
[6]	1.5, 1.7, 1.9	3.3, 2.9, 2.6	4.9, 5.8, 5.95	---	5304	0.132
[7]	3.3, 3.89,4.56	16.2, 13, 16	2.2, 2.3, 2.3	14, 14, 14	784	0.275
[8]	2.15, 3.95, 3.8	---	2.9, 2.2, 1.7	20, 20, 20	320	0.016
[9]	2.05, 2.45, 3.5	4.8, 4, 5.7	1.5, 1.8, 1.5	13, 13, 13	4000	0.346
[10]	1, 2.4, 5.8	---	0.8, 2.1, 2.5	14.5, 12, 12.9	2940	---
[11]	1.2, 1.8, 2.4	14, 14, 13	1.3, 1.3, 1.2	11.6, 14, 10	---	0.055
[12]	2.4, 3.5, 5.8	6, 4.5, 3.6	0.9, 1.1, 1.3	---	870	0.119
[13]	0.9, 2.4, 5.5	---	0.7, 1.7, 1.5	---	---	---
[14]	3.4, 3.9, 4.4	---	From 1.6 to 2.2	---	3180	---
[15]	2.67, 3.1, 3.43	---	0.72, 0.63, 0.71	24.5, 24, 24.7	---	0.137
[16]	2.4, 3.5, 5.2	---	2.42, 1.62, 1.95	less than 15	---	0.164
[20]	1.88, 2.1, 2.6	0.86, 1.4, 0.96	1.3, 2.3, 3.2	22, 25, 21	---	> 0.1
[21]	2.4, 3.5, 5.2	---	2.42, 1.62, 1.95	>15	1350	0.16
This work	2.3, 3.2, 3.6	5.2, 5.5, 1.6	0.78, 1.1, 0.62	19.8, 10, 28	916	0.095

* f_{r1}, f_{r2} and f_{r3} are the resonance frequencies (first, second and third, respectively).

** Δ_i ($i = 1, 2, 3$) are the fractional bandwidths of the channel *i*.

*** IL$_i$ ($i = 1, 2, 3$) are the insertion losses of the channel *i*.

**** RL_i (i = 1, 2, 3) are the return losses of the channel *i*.

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