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Novel compact microstrip diplexer for GSM applications

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Research Paper

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In this paper, a microstrip diplexer is designed based on a novel structure consisting of the meandrous and patch cells. It operates at 0.8 and 0.9 GHz for global system for mobile communications applications. The proposed diplexer is well miniaturized with an overall size of 0.01 λg^2. It has the narrowband channels making it appropriate for the modern long-range communication systems, which are widely accepted by the industry. The introduced diplexer has the other advantages of low insertion and return losses and the good isolation between channels better than −30 dB. Moreover, there is a good upper stopband rejection so that the first and second harmonics are suppressed with a maximum level of −30 dB. The designing method is based on finding the effective parameters to control the resonance frequency, miniaturization and harmonic attenuation simultaneously. To validate the designing method and simulation results, the proposed diplexer is fabricated and measured. There is a good agreement between the simulated and measured results.

Introduction

Planar compact diplexers with high performance are key devices in the modern wireless communication systems. They are used to separate signals from antennas. Using a novel structure is an advantage of a well-designed diplexer. Hence, various types of microstrip structures have been utilized to design several diplexers [1–13]. In [1], spiral structures have been integrated using coupled lines while the ports have been connected to cone shape cells. The proposed structure in [2] is consisting of four coupled rectangular open loop resonators loaded by several number of lumped resistors and capacitors. Two open loop resonators consisting of triangular cells have been integrated by a T-shaped cell in [3]. The microstrip diplexer in [4] has been designed based on two stub loaded U-shaped resonators that are connected using three coupled lines. The proposed structure in [5] is consisting of two engraved semi-circular cells connected to coupled lines. In [6], two E-shaped structures have been loaded to a horizontal transmission line. The common port of this diplexer has been located between the transmission line in the opposite side of the E-shaped cells. In [7], a U-shaped junction connects two rectangular dual spiral resonators. In [8], an open square structure loaded by step impedance cells has been utilized. Moreover, low impedance coupled lines have been embedded in this structure. The open loop resonators loaded by T-shaped stubs have been used in [9]. The introduced resonator in [10] is a pair of coupled lines connected to the step impedance cells. The resonators in [10] have been integrated by a simple transmission line. In [11], three step impedance cells have been coupled and then connected to the coupled line feed structures. In [12], two meandrous closed loops have been connected to interdigital feed lines. They have been connected together by a simple transmission line similar to the designed diplexer in [10]. A microstrip line loaded by interdigital capacitors has been used as a resonator in [13], in which two similar resonators have been utilized to obtain two passbands. The common disadvantage of these reported diplexers is their large dimensions. A high-performance diplexer demanded by modern wireless communication systems has the features of low insertion and return losses (RLs), high isolation, and well-attenuated harmonics. Accordingly, the proposed structure in [1] improved the losses, but it has low isolation between its channels. The designed diplexers in [2] and [3] can suppress the first up to fourth harmonics with a maximum harmonic level of −20 dB. However, they have undesired RLs. Moreover, the designed diplexer in [2] has large insertion losses (ILs) and low isolation between its channels. The designed diplexer in [3] has two narrow channels making it appropriate for the modern long-range communication systems, which are widely accepted by the industry [4, 5]. The reported diplexer in [6] has a good isolation, but it can attenuate only the first harmonic, while it has large insertion and RLs. The problem of large losses is remained in [7] and [8]. Meanwhile, they have low isolations between their channels. In [7], third harmonics are attenuated with a maximum level of −20 dB. The designed diplexer in [9] has a wide fractional bandwidth (FBW) and good isolation. The proposed diplexer in [10] operating at 2.36 and 4 GHz has low ILs but large RLs. The introduced diplexer in [11] works at 1.8/2.4 GHz for global system for mobile communications (GSM)/WLAN applications. It has low

ILs and wide FBWs. The reported diplexers in [8–13] could not attenuate the harmonics. Meanwhile, in [10–13] low isolations between the channels have been obtained.

In this work, a high-performance microstrip diplexer for GSM is designed. The advantages of our diplexer are its novel structure, very compact size, low losses and good isolation. It has relatively narrow channels, which make it appropriate for long-range RF communication systems. Meanwhile, the first and second harmonics are attenuated with a maximum level of −30 dB. The designing process is organized as follows: First, an LC model of a novel basic structure is proposed. Then, to have a symmetric structure, the even and odd modes analysis is performed to find the effective parameters on the resonance frequency and miniaturization. After that, a microstrip filter is proposed based on the analyzed basic structure. Finally, using the proposed filter, a diplexer is presented by integrating two similar filters with different dimensions to operate at two separated frequencies.

Designing method

Fig. 1(a) shows the proposed basic structure consisting of a meandrous cell, which connects two ports. In order to control the resonance frequency and save the size, two patch cells are loaded on the meandrous cell. To have a passband, a passive LC circuit is needed. Hence, the transition between ports can be predicted using a LC model of the proposed basic resonator. A capacitor can be provided by a patch cell while an inductor can be created by the other thinner parts or coupled lines. The reason for choosing a patch capacitor is to save the size. The spiral cell provides an inductor while it needs a little space. An approximated LC model of the proposed basic structure is presented in Fig. 1(b), where the effects of steps and bents are removed because the effects of steps and bents are significant at the frequencies higher than 10 GHz.

In the LC circuit, the meandrous cell is replaced by the inductor L_m, the small stubs with the physical length l_s are modeled by the inductor L_s, and the patch square capacitors are shown by C_p. From the LC equivalent circuit, we can write the input impedance at the angular resonance frequency ω as follows:

$$Z_{in} = \frac{[1-\omega^2 L_s C_p] \times [1-\omega^2 (L_s + L_m) C_p]}{j\omega C_p [2-\omega^2 C_p (2L_s + L_m)]}. \tag{1}$$

Since the proposed basic structure is symmetric, we can do the even and odd modes analysis. The odd and even modes resonance frequencies can be obtained for the input impedance $Z_{in} = 0$ and $Z_{in}^{-1} = 0$, respectively [14, 15]. Accordingly, the even and odd modes angular resonance frequencies (ω_e and ω_o) are calculated as follow:

$$\text{Even mode}: 2-\omega_e^2 C_p (2L_s + L_m) = 0 \Rightarrow \omega_e = \sqrt{\frac{2}{C_p(2L_s+L_m)}}$$

$$\text{Odd mode}: \begin{cases} 1-\omega_o^2 L_s C_p = 0 \Rightarrow \omega_{o1} = \sqrt{\dfrac{1}{L_s C_p}} \\ 1-\omega_o^2 (L_s+L_m) C_p = 0 \Rightarrow \omega_{o2} = \sqrt{\dfrac{1}{(L_s+L_m)C_p}}. \end{cases} \tag{2}$$

Due to the small stub features, we can assume that $L_s \ll L_m$. Therefore, $\omega_e = \sqrt{2}\omega_{O2}$ while $\omega_{o1} > \omega_{o2}$ and ω_e. Hence, ω_{o1} is a harmonic created by the physical length l_s [15]. Moving this harmonic to higher frequencies is desirable so that smaller L_s results in shifting of this harmonic to the right. According to this, the length l_s is decreased as far as possible. If we can tune ω_{o2} and ω_e for 0.8 GHz GSM applications, then it can be said that with a good approximation $\omega_e \approx \omega_{o2}$. For $\omega_e = \omega_{o2} = 2\pi \times 0.8 \times 10^9$, $C_p \times L_m \approx 1400$. Therefore, the resonance frequency can be obtained by increasing the length of meandrous cell and incorporating it in a small space. According to above discussion, we can miniaturize the overall size, tune the resonance frequency and suppress the harmonics simultaneously. Since the proposed basic structure is a single-mode resonator, it can be upgraded to a bandpass filter by additional optimization. The layout configuration of the designed bandpass filter is depicted in Fig. 2, where all dimensions are in mm. It has a symmetric structure consisting of the meandrous cells connected to the patch structures. Figure 3(a) illustrates the frequency response of the proposed filter. It is depending on the dimensions of physical lengths L_1, L_2, and L_3.

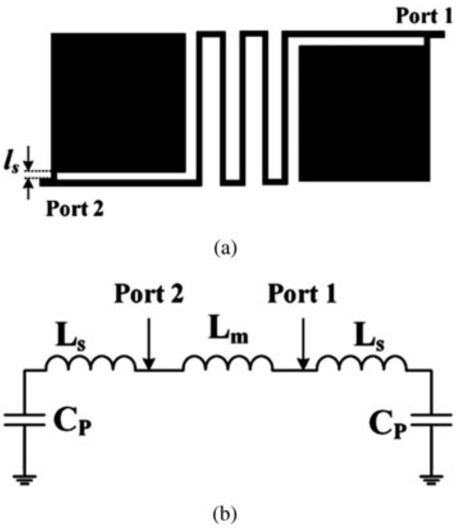


Fig. 1. Proposed basic structure (a) layout, (b) LC model.

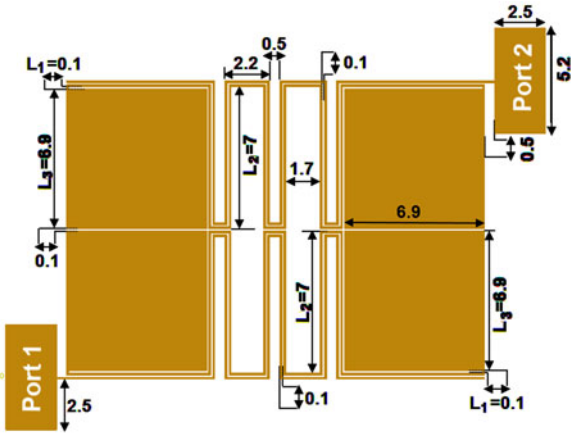
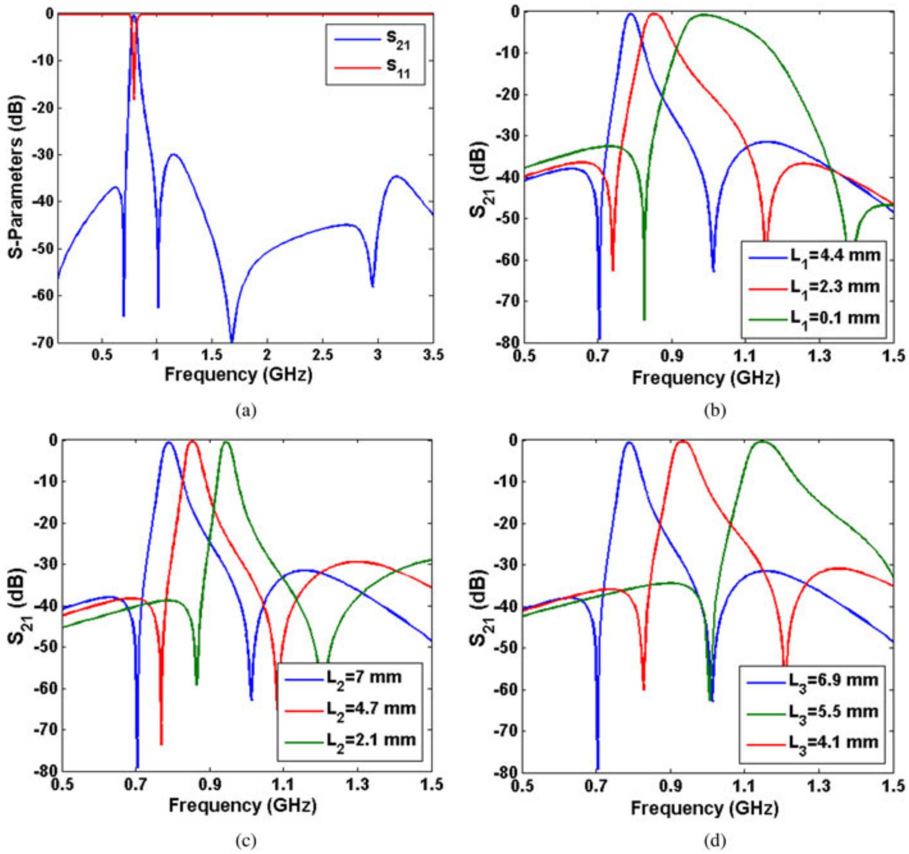


Fig. 2. Layout configuration of the proposed filter with its corresponding dimensions in mm.



(a) (b) (c) (d)

Fig. 3. (a) Frequency response of the proposed filter, (b) S_{21} as a function of L_1, (c) S_{21} as a function of L_2, (d) S_{21} as a function of L_3.

Therefore, the frequency responses as a function of L_1, L_2, and L_3 are shown in Fig. 3(b)–(d), respectively. Figure 3(b) demonstrates the increasing of L_1 which makes the channel wider. According to Fig. 3(b)–(d), increasing the mentioned lengths shifts the resonance frequency to the left. The frequency response of the proposed filter is optimized by tuning these physical lengths consisting of the lengths of patch, meandrous, and small cells.

After designing of the proposed filter, two similar filters are integrated to have two channels. In order to avoid frequency interference, these filters are a little different in dimensions. By decreasing the difference in dimensions between the two filters, the created passbands will be closer to each other. This increases the losses and decreases the isolation between channels. Therefore, the additional optimizations are done to have a high performance and close channels. By integrating two bandpass filters, a microstrip diplexer is achieved as shown in Fig. 4 with its corresponding dimensions in mm. The dimensions of the bandpass filter connected to port 2 and common port 1 is same with Fig. 2. The proposed diplexer consists of meandrous cells connected to the engraved patch structures. The filters are integrated using a small simple transmission line connected to the common port. This structure can save the size and improve the isolation between channels simultaneously.

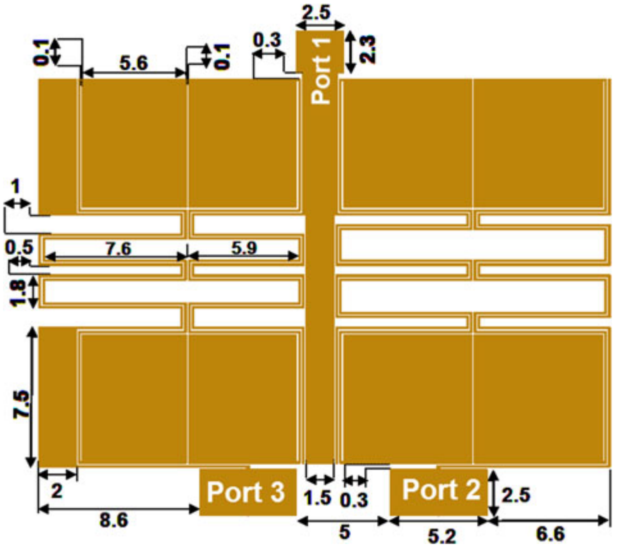


Fig. 4. Layout configuration of the proposed diplexer.

Results and discussion

The proposed diplexer is simulated by Advanced Design System (ADS) full-wave EM simulator. It is fabricated on a Rogers_RT_Duroid5880 substrate with $\varepsilon_r = 2.22$, $h = 31$ mil, and a loss tangent of 0.0009. An Agilent network analyzer N5230A carried out the measurements. Figure 5(a) depicts the simulated and measured S_{21} and S_{31}. It shows that the introduced diplexer works at 0.8 and 0.9 GHz, which makes it appropriate for GSM applications. The first channel is from 0.786 to 0.811 GHz and the second channel is from 0.889 to 0.918 GHz with the FBWs of 3.12 and 3.2% for the first (FO_1) and second (FO_2) channels, respectively. The narrow channels make it suitable for the long-range communication applications. The designed diplexer has the low ILs of 0.28 and 0.29 dB at the first and second channels, respectively. Due to the copper and junction losses, the measured

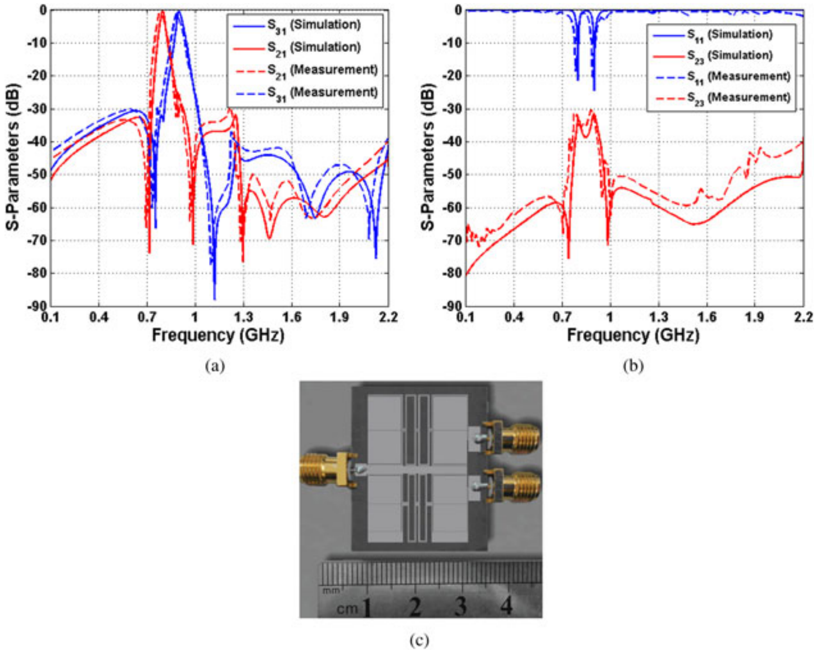


Fig. 5. (a) Simulated and measured S_{21} and S_{31}, (b) isolation and common port return loss, (c) a photograph of the fabricated diplexer.

Table 1. Comparison between the proposed diplexer and previous works

Refs	IL_1, IL_2 (dB)	F_{O1}, F_{O2} (GHz)	Upper stopband rejection	Isolation (dB)
	RL_1, RL_2 (dB)	Size (λg^2)	Maximum harmonic level	FBW_1, FBW_2
This work	0.28, 0.29	0.8, 0.9	2.75 F_{O1}	>30
	21.2, 24.3	0.010	−30 dB	3.2%, 3.2%
[1]	0.18, 0.39	2.4, 2.79	2.08 F_{O1}	>20.55
	27.1, 27.6	0.075	−14 dB	–
[2]	1.4, 2.3	1.05, 1.76	4 F_{O1}	–
	15, 20	0.089	−20 dB	6.1%, 4%
[3]	0.5, 0.4	2.3, 2.5	4.3 F_{O1}	>34
	15, 11	0.088	−20 dB	3.6%, 3.4%
[6]	1.2, 1.5	1.95, 2.14	1.28 F_{O1}	>35
	–	0.136	−30 dB	4.1%, 3.74%
[7]	1.35, 1.31	3.65, 5.2	3.8 F_{O1}	>25
	15, 15	0.05	−20 dB	8.2%, 7.69%
[8]	0.6, 0.9	2.6, 6	No	>13.8
	11.3, 12.4	0.076	No	4.2%, 5.1%
[9]	1, 0.9	2.3, 2.72	No	>30
	20, 20	0.127	No	6.1%, 5.8%
[10]	0.2, 0.4	2.36, 4	No	>20
	15, 11.8	0.089	No	–
[11]	0.09, 0.5	1.8, 2.4	No	>20
	21.5, 22.4	0.193	No	8.7%, 6%
[12]	2.1, 2.1	1.75, 1.85	No	>20
	20, 20	0.07	No	–
[13]	0.4, 0.42	1.8, 2.45	No	–
	20, 20	0.095	No	–

ILs are almost 0.4 dB more than the simulated results. As shown in Fig. 5(a) the first and second harmonics are suppressed with a maximum level of −30 dB. Figure 5(b) shows the simulated and measured common port RL and the isolation between the channels. The RLs at the lower and upper channels are better than 21.2 and 24.3 dB, respectively, while the isolation between channels is better than −30 dB. The proposed structure is well miniaturized with an overall size of $25\ \mathrm{mm} \times 30.1\ \mathrm{mm} = 0.097\ \lambda g \times 0.11\ \lambda g$, where λg is the guided wavelength on the substrate at the first resonance frequency. A photograph of the fabricated diplexer is depicted in Fig. 5(c). The size and performance of proposed diplexer are compared with the previous works. The comparison results are listed in Table 1. According to the comparison table, the proposed diplexer has the minimum size. Meanwhile, it has relatively low losses and high isolation.

Conclusion

In this paper, a compact microstrip diplexer is designed based on proposing a novel microstrip basic structure. The proposed diplexer consists of engraved meandrous cells and patch structures. In order to tune the resonance frequencies at 0.8 and 0.9 GHz, the meandrous cells are embedded in the least possible area. Meanwhile, the dimensions of patches and meandrous cells are selected so that the overall size of our diplexer is only $0.01\ \lambda g^2$ which is the minimum in comparison to the pervious works. The introduced diplexer not only has the low insertion and RLs at both the channels, but also we can see a relatively high isolation between its channels. Moreover, the first and second harmonics are suppressed with a maximum level of −30 dB.

References

1. **Rezaei A, Noori L and Mohamadi H** (2017) Design of a novel compact microstrip diplexer with low insertion loss. *Microwave and Optical Technology Letters* **59**(7), 1672–1676.
2. **Feng W, Zhang Y and Che W** (2017) Tunable dual-band filter and diplexer based on folded open loop ring resonators. *IEEE Transactions on Circuits and Systems* **64**(9), 1047–1051.
3. **Salehi MR, Keyvan S, Abiri E and Noori L** (2016) Compact microstrip diplexer using new design of triangular open loop resonator for 4 G wireless communication systems. *AEU – International Journal of Electronics and Communications* **70**(7), 961–969.
4. **Noori L and Rezaei A** (2017) Design of a compact narrowband quad-channel diplexer for multi-channel long-range RF communication systems. In Analog Integrated Circuits and Signal Processing, First Online: 20 October 2017, 1–8.
5. **Noori L and Rezaei A** (2017) Design of microstrip wide stopband quad-band bandpass filters for multi-service communication systems. *AEU-International Journal of Electronics and Communications* **81**, 136–142.
6. **Guan X, Yang F, Liu H and Zhu L** (2014) Compact and high-isolation diplexer using dual-mode stub-loaded resonators. *IEEE Microwave Wireless Component Letters* **24**(6), 385–387.
7. **Bukuru D and Song K** (2015) Compact wide-stopband planar diplexer based on rectangular dual spiral resonator. *Microwave and Optical Technology Letters* **57**(1), 174–178.
8. **Noori L and Rezaei A** (2017) Design of a microstrip diplexer with a novel structure for WiMAX and wireless applications. *AEU-International Journal of Electronics and Communications* **77**, 18–22.
9. **Huang F, Wang J, Zhu L and Wu W** (2016) Compact microstrip balun diplexer using stub-loaded dual-mode resonators. *IET Electronic Letters* **52**, 1994–1996.
10. **Noori L and Rezaei A** (2017) Design of a microstrip dual-frequency diplexer using microstrip cells analysis and coupled lines components. International Journal of Microwave and Wireless Technologies, Cambridge University Press and the European Microwave Association, Published online: 15 February 2017, 1–5.
11. **Chinig A, Zbitou J, Errkik A, Tajmouati A, Abdellaoui L-E, Latrach M and Tribak A** (2015) Microstrip diplexer using stepped impedance resonators. *Wireless Personal Communications* **84**(4), 2537–2548.
12. **Peng H-S and Chiang Y-C** (2015) Microstrip diplexer constructed with new types of dual-mode ring filters. *IEEE Microwave Wireless Component Letters* **25**(1), 7–9.
13. **Bui D-H-N, Vuong TP, Allard B, Verdier J and Benech P** (2017) Compact low-loss microstrip diplexer for RF energy harvesting. *Electronics Letters* **53**(8), 552–554.
14. **Hayati M, Noori L and Adinehvand A** (2012) Compact dual-band bandpass filter using open loop resonator for multimode WLANs. *IET, Electronic Letters* **48**(10), 573–574.
15. **Rezaei A and Noori L** (2017) Tunable microstrip dual-band bandpass filter for WLAN applications. *Turkish Journal of Electrical Engineering & Computer Science* **25**, 1388–1393.

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