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RESEARCH PAPER

Design of a microstrip dual-frequency diplexer using microstrip cells analysis and coupled lines components

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In this paper, a microstrip diplexer composed of two similar resonators is designed. The proposed resonator is consisting of four microstrip cells, which are connected to a coupled lines structure. In order to select a suitable geometric structure, first, all cells are assumed as undefined structures where there is a lack of basic information about their geometry and dimensions. Then, an equivalent LC circuit of the coupled lines is introduced and analyzed to estimate the general structure of the resonator respect to a requested resonance frequency. The proposed diplexer is designed to operate at 2.36 and 4 GHz for wireless applications. The insertion losses (S_{21} and S_{31}) are decreased significantly at the resonance frequencies, so that they are 0.2 and 0.4 dB at 2.36 and 4 GHz, respectively. The designed diplexer is fabricated and measured and the measurement results are in a good agreement with the simulations.

Keywords: Diplexer, Coupled lines, Microstrip, Resonator

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I. INTRODUCTION

Most of diplexers are composed of two bandpass filters, which separate two desired frequency bands for using in the modern wireless communication systems. With the growing of wireless applications, many different structures have been introduced for the planer diplexers. Although low passband insertion loss is an important advantage, some of the earlier works have proposed diplexers with high insertion loss [1–4]. In order to achieve high-performance diplexers, the interdigital capacitors [3], interdigital hairpin resonators [4], spiral-based resonators [5], and the closed loops with interdigital structures [6] have been used. Since the use of a complex interdigital and spiral resonators leads to hard fabrication as well as low accuracy of measurement data, a simpler diplexer has been realized in [7]. In [8], a microstrip diplexer has been implemented using a step-impedance resonator, which provides a degree of freedom to improve the rejection band. In [9], a high isolation diplexer has been introduced using a dual-mode resonator. By using this structure, the insertion losses at both passbands have been decreased clearly. In [10], a diplexer has been presented using slot-line resonators to generate the filtering response. In [11], a microstrip diplexer has been designed, which has low insertion losses at lower and higher passbands, but takes up a lot of space. Furthermore, the frequency response of this diplexer confirms the poor frequency selectivity so that S_{31} is not well attenuated below its passband. In [12], three demonstrative diplexers have been presented. To reduce the overall size of them, resistors, open stubs, and shorted stubs have been imbedded inside the open-ended loop resonators. However, the insertion losses at lower and upper passbands are large as well as most of the earlier works. In [13], a microstrip diplexer based on a symmetric structure has been introduced to operate at two quite close channels (2.35/2.59 GHz). In [14], H-type resonators have been utilized to miniaturize a microstrip diplexer, which operates at the UMTS upload and download bands. In this paper, first, two bandpass filters are realized using four microstrip cells and a coupled lines structure. Then, an equivalent *LC* circuit of the coupled lines is studied to determine the geometrical structure of the cells. After determining the cells a microstrip diplexer is designed to operate at 2.36 and 4 GHz for the wireless applications. The passband about 2.36 GHz (UHF band) can be used in the wireless local area networks, microwave links, radars, satellites, and navigation aid systems. Furthermore, a passband, which covers near the frequency range of 4 GHz is a subset of SHF band that can be used in radars, microwave links, terrestrial mobile communications, and satellite communications. Another achievement of this paper is the improved insertion losses at both passbands by employing a simpler structure than the interdigital and spiral resonators.

II. DIPLEXER DESIGN

As shown in Fig. 1(a), the coupled lines, which are connected to the extra microstrip cells are applied to create a resonance

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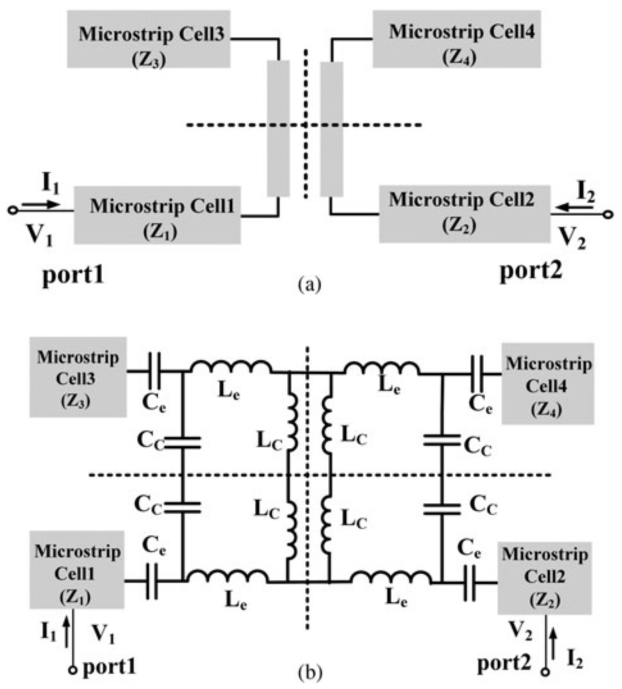


Fig. 1. (a) Proposed resonator, (b) replacing the equivalent *LC* model of the coupled lines in the proposed resonator.

frequency. In Fig. 1(a), the parameters (V_1, I_1) and (V_2, I_2) are the voltages and currents of port1 and port2, respectively and Z_1, Z_2, Z_3, and Z_4 are the characteristic impedances of the microstrip cells. According to Williams and Kim [15], an optional equivalent *LC* circuit of the symmetric coupled lines can be replaced as shown in Fig. 1(b). The inductors L_C are used to model the coupling between the lines. The equivalent circuit of the each half of the distributed line includes an inductor L_e and a capacitor C_e. Due to the symmetric structure of the coupled lines, the magnetic/electric walls are established between the coupled lines [16] that make L_C an open/short circuit. By considering the predetermined resonance frequency, the challenge is to characterize the geometrical structure of the microstrip cells, while the inductors L_C are open/short circuited because of the magnetic/electric walls. Under three conditions a simplified equivalent model of the proposed resonator (see Fig. 2(a)) can be obtained as follows:

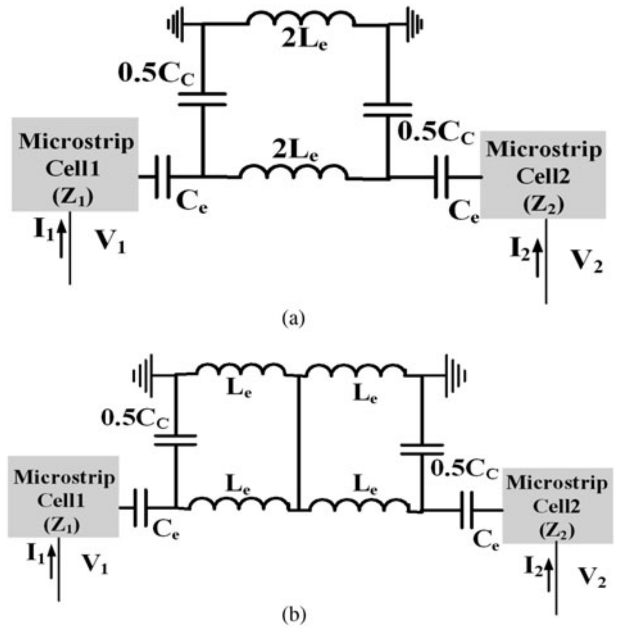


Fig. 2. (a) Simplified circuit of the proposed resonator under three circumstances: magnetic wall, elimination of the effect of the capacitor C_e connected to the microstrip Cell3 and microstrip Cell4 by Z_3 and Z_4. (b) Simplified circuit of Fig. 1(b) under three circumstances: electric wall, elimination of the effect of the capacitor C_e connected to the microstrip Cell3, and microstrip Cell4 by Z_3 and Z_4.

1. Magnetic wall between the coupled lines;
2. Microstrip Cell4 becomes a step with an *LC* model, which is composed of capacitors and inductors. Also the effect of C_e, which is connected to the microstrip Cell4 is ignored;
3. The *LC* equivalent circuit of the microstrip Cell3 becomes an inductor equal to $L = (C_e\omega_o^2)^{-1}$ (where $\omega_o = 2\pi F_o$ and F_o is the resonance frequency). We assume that this inductor removes the effect of the capacitor C_e, which is connected to microstrip Cell3.

The transmission matrix of the proposed resonator at the resonance frequency F_o, is calculated as follows:

$$T = \begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & Z_1 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} A_{LC} & B_{LC} \\ C_{LC} & D_{LC} \end{bmatrix} \begin{bmatrix} 1 & Z_2 \\ 0 & 1 \end{bmatrix}, \quad (1)$$

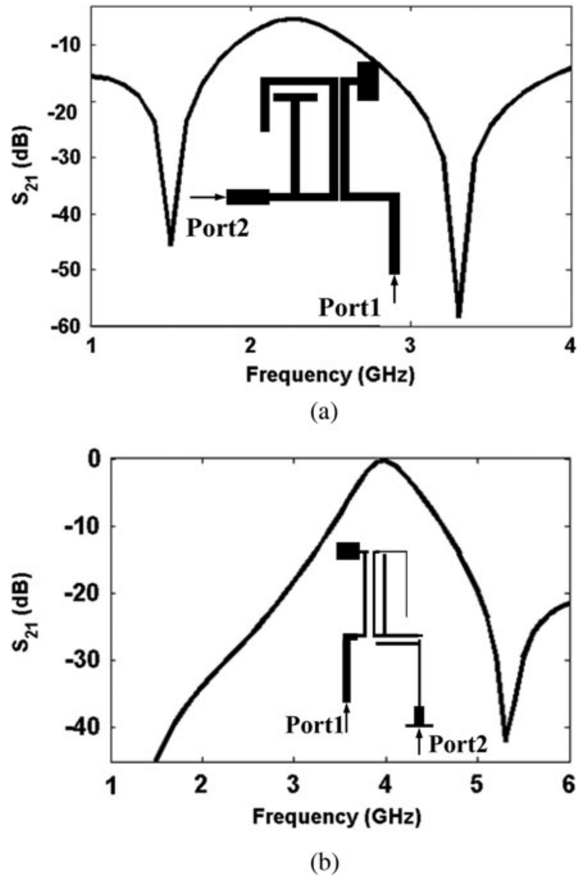


Fig. 3. Layouts and simulated frequency responses of the proposed: (a) 2.36 GHz filter, (b) 4 GHz filter.

where

$$\begin{bmatrix} A_{LC} & B_{LC} \\ C_{LC} & D_{LC} \end{bmatrix} = \begin{bmatrix} 1 & \frac{1}{j\omega_o C_e} \\ 0 & 1 \end{bmatrix} \times \begin{bmatrix} 1 & 0 \\ \frac{j\omega_o C_c}{2} & 1 \end{bmatrix} \times \begin{bmatrix} 1 & j2\omega_o L_e \\ 0 & 1 \end{bmatrix} \times \begin{bmatrix} 1 & 0 \\ \frac{j\omega_o C_c}{2} & 1 \end{bmatrix} \times \begin{bmatrix} 1 & \frac{1}{j\omega_o C_e} \\ 0 & 1 \end{bmatrix}.$$

In Equation (1), $\omega_o = 2\pi F_o$. From ABCD matrix the input admittance Y_{in} viewed from port1 is:

$$Y_{in} = \frac{I_1}{V_1}\Big|_{V_2=0} = \frac{D_1}{B_1} = \frac{Z_2 C_{LC} + D_{LC}}{B_1}. \qquad (2)$$

In order to excite the resonator, the numerator in Equation (2) should be zero. Therefore, the resonance condition is obtained as follows:

$$Z_2 = -\frac{D_{LC}}{C_{LC}} = \frac{\frac{C_c}{2C_e} + (1 - \omega_o^2 C_c L_e)}{-1 + j(0.5\omega_o^3 C_c^2 L_e - \omega_o C_c)}. \qquad (3)$$

According to Equation (3), the geometrical structure and dimensions of the microstrip Cell2 are dependent on the coupled lines structure and a requested resonance frequency.

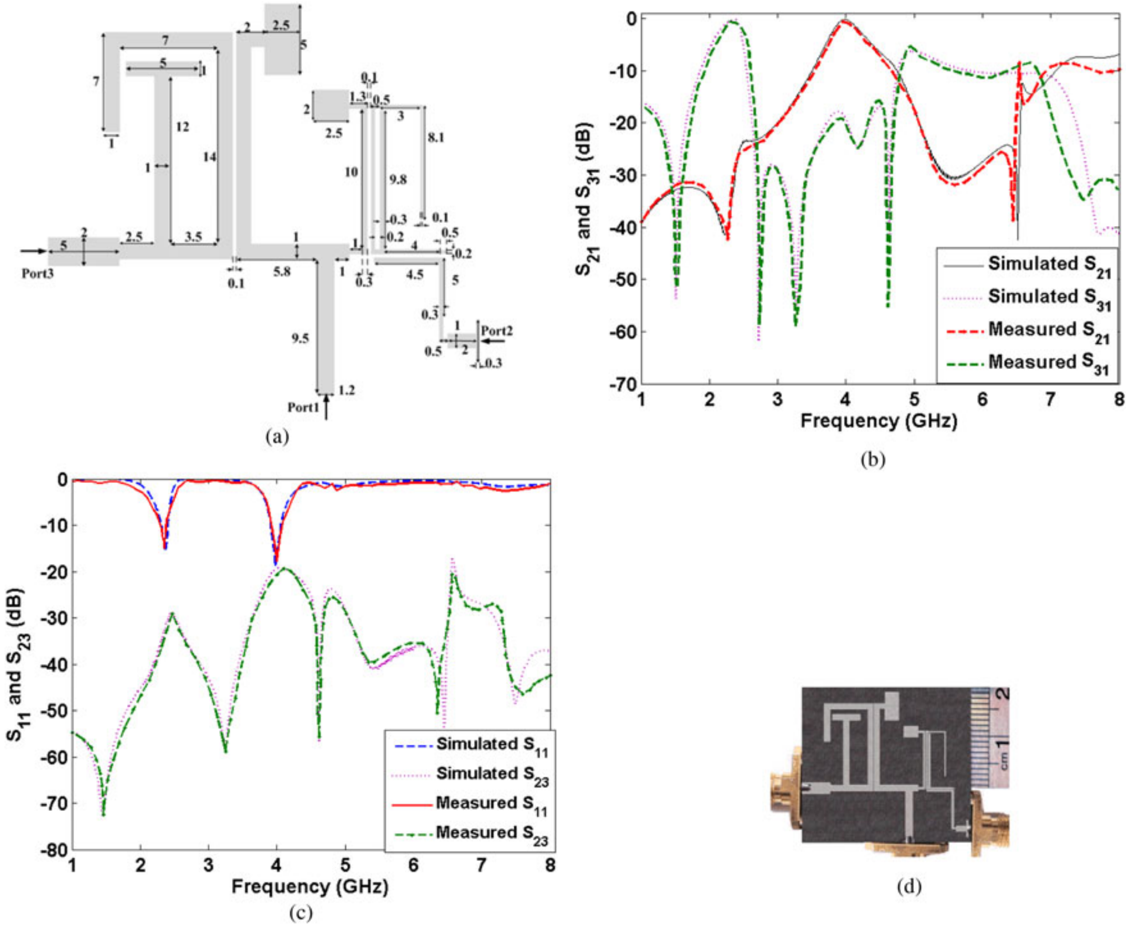
By replacing the electric wall, the proposed resonator is changed as shown in Fig. 2(b). Hence, the input impedance of the equivalent circuit seen from port1 (Z_{in}) can be written as follows:

$$Z_{in} = Z_1 + \frac{1}{j\omega_o C_e} + \frac{2L_e}{j\omega_o L_e C_c + 1/j\omega_o}. \qquad (4)$$

Due to the electric wall, the resonance condition is obtained for $Z_{in} = 0$. Under this condition Z_1 should be calculated by the following equation:

$$Z_1 = \left(\frac{1}{\omega_o C_e} - \frac{2L_e\omega_o}{1 - \omega_o^2 L_e C_c}\right) j. \qquad (5)$$

Equation (5) shows that Z_1 is the sum of an inductor L (in H) and a capacitor C (in F), which are given by $L = (C_e\omega_o^2)^{-1}$ and $C = (1 - \omega_o^2 L_e C_c)/2L_e\omega_o^2$. Therefore, the microstrip cell1 can be replaced by a step-impedance cell. Based on the above analysis, two similar microstrip bandpass filters are designed to operate at 2.3 and 4 GHz. The layouts and frequency responses of the 2.3 and 4 GHz filters are shown in Figs 3(a) and 3(b), respectively. By integrating the proposed filters at port1, a microstrip diplexer is realized. The layout of the proposed diplexer is shown in Fig. 4(a). The filters dimensions are exactly equal to the dimensions of the proposed diplexer. The



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

Fig. 4. (a) Configuration of the proposed diplexer (all dimensions are in mm), (b) transmissions curves (S_{21} and S_{31}), (c) return loss at port1 (S_{11}) and isolation (S_{23}), and (d) fabricated diplexer.

Table 1. Insertion losses, return losses, diplexer size, and resonance frequencies of the proposed diplexer in comparison with the previous works.

References	S_{21} (dB)	S_{31} (dB)	S_{11} at lower passband (dB)	S_{11} at upper passband (dB)	Approximated size (mm^2)	F_{o1} (GHz)	F_{o2} (GHz)
Proposed diplexer	0.2	0.4	−15	−11.8	27 × 29.9	2.36	4
[1]	2.2	2.1	−29	−29	47 × 24	1.8	2.45
[2]	2.3	2.2	−10	−10	55 × 80	5.8	6.2
[3]	3	3	−15	−15	–	8.1	9.9
[4]	1.5	1	−21	−13	55 × 42	0.945	1.81
[5]	0.7	0.4	−10	−10	19.64 × 6.7	1.2	1.75
[7]	1.2	1.4	−25	−14	16 × 16	2.16	2.91
[8]	2.0	2.1	–	–	29.26 × 27.9	1.8	2.45
[9]	2.8	3	–	–	31.12 × 27.67	8	9
[11]	0.4	0.4	−20	−20	73 × 63	0.925	1.79
[12]	1.5	1.2	−16.5	−16.5	54 × 24	1.55	2.17
[13]	–	–	−29	−38	23.5 × 13.5	2.35	2.59
[14]	1	1	−12	−20	52.9 × 21	1.9	2.2

measured and simulated frequency responses of the proposed diplexer are presented in Figs 4(b) and 4(c). A photograph of the fabricated diplexer is shown in Fig. 4(d).

III. RESULTS

First, the designed diplexer is simulated by ADS software using Momentum Simulator, and then it is implemented on a RT Duroid 5880 substrate. The thickness of the dielectric substrate is 31 mil with $\varepsilon_r = 2.22$ and the loss tangent 0.0009. The dimensions of the proposed structure are shown in Fig. 4(a) where all dimensions are in mm. The frequency response of the proposed diplexer confirms that the insertion losses (S_{21}, S_{31}) at 2.36/4 GHz are 0.2/0.4 dB, while the achieved return losses at the lower/higher resonance frequencies are −15/−16.8 dB. The isolation (S_{32}) at critical frequencies is measured, so that −49 dB at 2.36 GHz and −19.8 dB at 4 GHz are obtained. The measured S_{33} at 2.36 GHz is −14.33 dB and the measured S_{22} at 4 GHz is −10.04 dB. The overall size of the proposed diplexer is 27 × 29.9 mm^2. In Table 1, the insertion losses, return losses, implementation area, and resonance frequencies of the proposed diplexer are compared with the previous works. In Table 1, S_{21} and S_{31} are the insertion losses at the lower and upper passbands, respectively. According to Table 1, in comparison with the previous works, the best insertion losses and reasonable return losses are obtained at the both passbands.

IV. CONCLUSION

In this paper, the coupled lines, which are connected to the microstrip cells, are presented as a resonator. Using the equivalent *LC* circuit of the coupled lines, the proposed resonator is analyzed to estimate the structures of the microstrip cells and coupled lines under consideration of the predetermined resonance frequency. Based on the proposed resonator structure, two microstrip bandpass filters are realized. By integrating the proposed filters at a common port a high-performance microstrip diplexer is achieved to operate at 2.36 and 4 GHz. The designed diplexer has the improved insertion losses and high isolations at the both resonance frequencies, so that the obtained isolation (S_{32}) is −49 dB at 2.36 GHz and −19.7 dB at 4 GHz.

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REFERENCES

[1] Chinig, A. et al.: A new microstrip diplexer using coupled stepped impedance resonators. Int. J. Electr. Comput. Energetic Electr. Commun. Eng., **9** (2015), 41–44.

[2] Khalaj-Amirhosseini, M.; Moghavvemi, M.; Ameri, H.; Attaran, A.: Microstrip Diplexers with double-stub bandpass filters. Int. J. Commun. Antenna Propag., **1** (2011), 64–67.

[3] Nath, M.: Design and characterization of microstrip diplexer. Int. J. Eng. Trends Technol., **3** (2012), 183–186.

[4] Hsu, C.-H.; Tung, H.-H.; Hsu, C.-K.; Lin, J.-S.; Yang, H.-W.: Microstrip Diplexer Using High Permittivity Substrate, in Progress in Electromagnetics Research Symp. Proc., China, September 12, 2011, 497–500.

[5] LU, K.; WANG, G.-M.; XU, H.-Y.; YIN, X.: Design of compact planar diplexer based on novel spiral-based resonators. Radioengineering, **21** (2012), 528–532.

[6] L-Morales, H.; Sun, J.S.; C-Chavez, A.; Itoh, T.; Cervantes, J. L: Novel microstrip diplexer for ultra-wide-band (UWB) and wireless LAN (WLAN) bands. J. Electromagn. Waves Appl., **27** (2013), 1338–1350.

[7] Li, J.; Huang, Y.; Zhao, X.; Wen, G.: Compact microstrip bandpass diplexer based on twist revised split ring resonators. Int. J. Antennas Propag., **21** (2015), 528–532.

[8] Liu, H.; Xu, W.; Zhang, Z.; Guan, X.: Compact diplexer using slot line stepped impedance resonator. IEEE Microw. Wireless Compon. Lett., **23** (2013), 75–77.

[9] Cheng, F.; Lin, X.; Song, K.; Jiang, Y.; Fan, Y.: Compact diplexer with high isolation using the dual-mode substrate integrated waveguide resonator. IEEE Microw. Wireless Compon. Lett., **23** (2013), 459–461.

[10] Kuan, H.; Yang, R.Y.; Weng, M.H.; Chen, W.L.: A novel parallel-coupled line diplexer excited using slot-line resonators for ultra-wideband communications. Microw. Opt. Technol. Lett., **51** (2009), 1552–1555.

[11] Brinda, R.; Anisha Parveen, P.: Design of RF diplexer for mobile communication. Int. J. Comput. Appl., **85** (2014), 16–20.

[12] Shi, J.; Chen, J.-X.; Bao, Z.-H.: Diplexers based on microstrip line resonators with loaded elements. Progr. Electromagn. Res., **115** (2011), 423–439.

[13] Yang, F.; Guan, X.; Zhu, L.; Liu, H.: Compact Microstrip Diplexer for 4 G Wireless Communication, in Progress in Electromagnetics Research Symp. Proc., vol. 25 (2014), 599–602.

[14] Cabral, H.A.; Bezerra, S.T.G.; Melo, M.T.: A diplexer for UMTS applications, in IEEE MTT-S Int. Microwave and Optoelectronics Conf., Belém, Brazil, 3–6 November, 2009, 215–217.

[15] Williams, L.; Kim, S.: Enhance the design of LTCC RF modules. Microwaves & RF, **42** (2003), 90–96.

[16] Hong, J.S.; Lancaster, M.J.: Microstrip Filters for RF/Microwave Applications, Wiley, New York, 2001.

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