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Microstrip Diplexer Design Using Open/Shorted Coupled Lines

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Abstract—A novel microstrip diplexer with high selectivity and isolation performance is proposed through the combination of two compact bandpass filters composed of open/shorted lines and an open stub, which are designed for LTE application. Six transmission zeros in the upper stopband are used to suppress the harmonic of the microstrip diplexer. The transmission zeros near the passband can be adjusted conveniently by only changing the electrical length of the open/shorted stubs. A diplexer prototype with two passbands at 1.8 GHz and 2.1 GHz is fabricated. The isolation between the two channels is greater than 40 dB from 0.1 to 6.5 GHz.

1. INTRODUCTION

The diplexer is one of the important components in wireless communication systems to transmit and receive signals by a single antenna. In general, diplexers require high compactness, low cost, high isolation, high selectivity, and ease to realize. In recent years, several advanced techniques for designing the diplexer have been proposed [1–7]. The matching network and combining circuit ensure that both filters match the antenna and have good isolation between them. The T-junction may be the most popularly used combining circuit. The length and width of its two branches must be chosen carefully [1, 2], allowing each filter to match the antenna and introduce an open circuit at the middle band of the other. To reduce the size, the common resonator technology is proposed to remove the input junction in the diplexer designs [3]. In [4], a stepped-impedance coupled-line structure to suppress the second-harmonic spurious response in the passband of a microstrip hairpin diplexer is proposed. In [5], a compact and high-isolation diplexer is developed using hybrid resonators. There were some other methods such as the composite right/left-handed transmission lines [6] and double-sided parallel-strip line [7] to design microstrip diplexers.

In this paper, a high-isolation and high-rejection diplexer based on the open/shorted lines with independently controllable transmission zeros is proposed. By properly assigning the transmission zeros of each channel filter, both output isolation and out-of-band rejection can be improved. Note that the transmission zeros can be tuned arbitrarily without increasing complex coupled structures and degrading the passband performance. For demonstration, a microstrip diplexer with two-order Chebyshev bandpass response has been designed and implemented to verify the proposed concept.

2. PROPOSED DIPLEXER WITH HIGH ISOLATION

As illustrated in Figs. 1(a) and (b), the configuration of the presented microstrip diplexer combines two compact filters with the T-junction. The T-junction has two branches, each linked to one of the two filters. The length of the branch connected to Filter A is about quarter of the guide wavelength of Filter B. It functioned as an "open" stub to channel B and stopped the channel B signal passing

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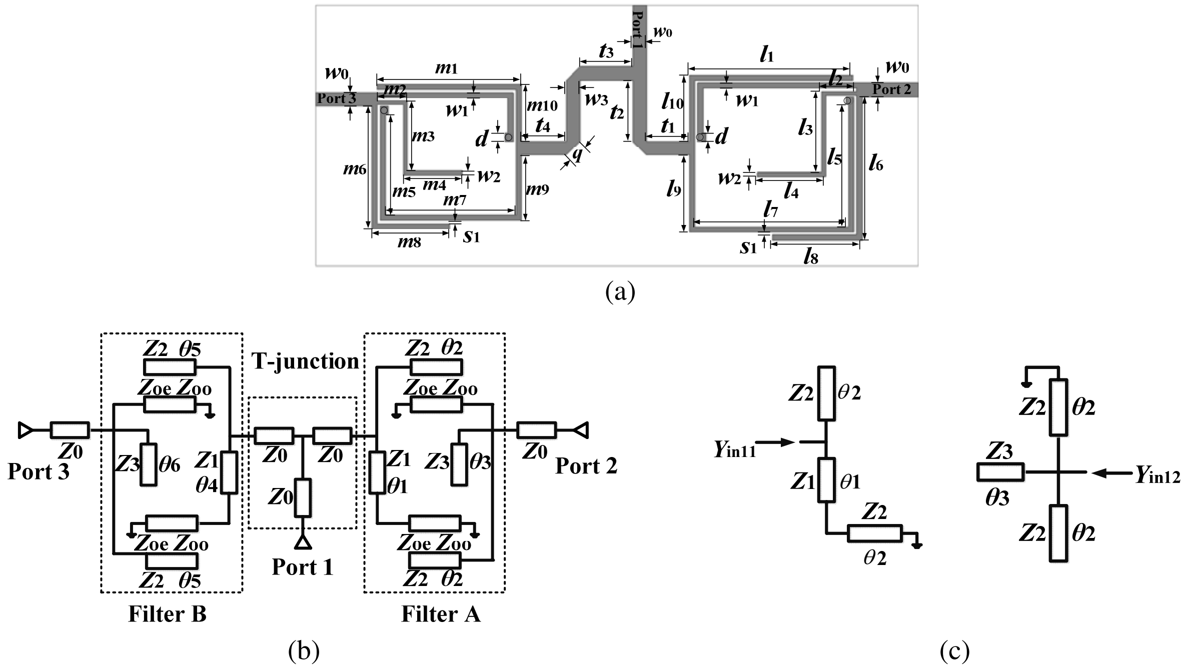


Figure 1. Structure and circuits of proposed microstrip diplexer. (a) Top view of the diplexer, (b) equivalent circuit of the diplexer, (c) the input admittance Y_{in} of the filter A.

through Filter A. For the same reason, the length of the branch connected to Filter B is about quarter of the guide wavelength of Filter A. The performance of the diplexer was carefully optimized by tuning the two branches.

The input admittance Y_{in11}/Y_{in12} and the external quality factor Q_{e11}/Q_{e12} of the Filter A in Fig. 1(c) can be calculated as

$$Y_{in11} = -j\cot(\theta_1+\theta_2)/Z_1 + j\tan\theta_2/Z_1 \tag{1}$$

$$Y_{in12} = -j\cot\theta_2/Z_1 + j\tan\theta_2/Z_1 + j\tan\theta_3/Z_3 \tag{2}$$

$$Q_{e11} = 0.5R_{L11}\left[(\theta_1+\theta_2)\csc^2(\theta_1+\theta_2)/Z_1 + \theta_2\sec^2\theta_2/Z_1\right] \tag{3}$$

$$Q_{e12} = 0.5R_{L12}\left[(\theta_2\csc^2\theta_2/Z_1 + \theta_2\sec^2\theta_2/Z_1 + \theta_3\sec^2\theta_3/Z_3\right] \tag{4}$$

Then, the geometric parameters of the filter are adjusted to satisfy the desired resonant frequency and external quality factor according to (1) = (2) = 0 and (3) = (4), respectively.

The simulated response of Filter A is shown in Fig. 2. The filter originally has three transmission zeros (f_{01}, f_{03}, f_{s1}) of the open/shorted stubs (θ_1, θ_2, θ_3) in upper stopband, and two zeros f_{01} and f_{03} can be created near each passband to sharpen the skirt. The transmission zeros ($2f_{01}$, $3f_{01}$) created by the bandstop transmission characteristic of the open/shorted coupled lines and the transmission zeros ($2f_{s1}$) of the shorted stubs can be also used to improve the upper stopband of the narrow-band bandpass filter. In addition, the signals transmitted from the two paths of the filter have the same magnitude but out-of-phase and are thus cancelled out, resulting in the generation of f_{tsc} [8]. The transmission zeros at the lower or upper side of the passband can be adjusted conveniently without degrading the passband performance by only changing the electrical length of the open/shorted stubs. To validate the concept, the lumped element values of the second-order Chebyshev prototype filter are selected to be: $g_0 = 1$, $g_1 = 0.8431$, $g_2 = 0.6220$, $g_3 = 1.3554$. Based on (5), the required coupling coefficient and external quality factor can be calculated that $Q_{e1} = 16.9$, $k = 0.06$.

$$Q_e = \frac{g_0 g_1}{\text{FBW}}, \quad k = \frac{\text{FBW}}{\sqrt{g_1 g_2}} \tag{5}$$

Figure 3 shows the extracted k against the gap (s_1) of the open/shorted coupled lines. The final parameters for the circuit of Fig. 1(b) are: $Z_0 = 50\,\Omega$, $Z_1 = 100\,\Omega$, $Z_2 = 100\,\Omega$, $Z_3 = 120\,\Omega$, $Z_{oe} = 127\,\Omega$,

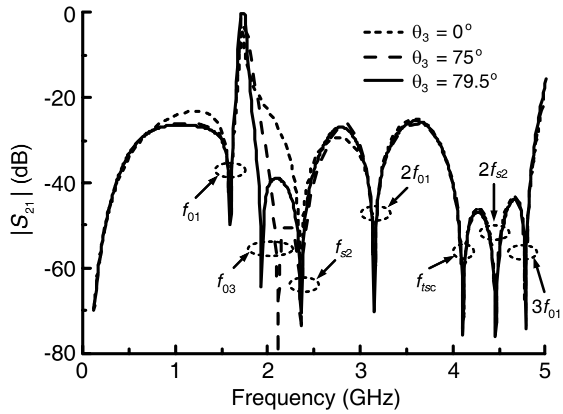


Figure 2. Simulated frequency responses versus θ_3 of the filter A, $\theta_1 = 66°$, $\theta_2 = 102°$.

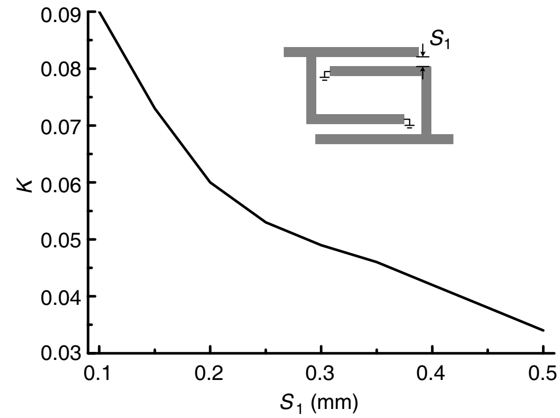


Figure 3. Variation of k against the coupling gap (s_1) of the open/shorted coupled lines.

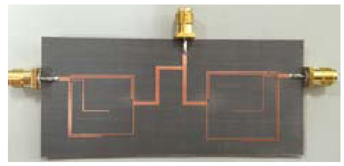
$Z_{oo} = 85\,\Omega$, $\theta_1 = 66°$@1.8 GHz, $\theta_2 = 102°$@1.8 GHz, $\theta_3 = 79.5°$@1.8 GHz, $\theta_4 = 66°$@2.1 GHz, $\theta_5 = 102°$@2.1 GHz, $\theta_6 = 79.5°$@2.1 GHz. The simulated results of the microstrip diplexer are shown Figs. 4(b) and (c), the 3-dB bandwidths for the two passbands are 5.0% (1.75–1.84 GHz), 5.2% (2.04–2.15 GHz) with return loss greater than 16 dB. The isolation is better than 40 dB from 0.1 to 6.28 GHz.

3. MEASURED RESULTS AND DISCUSSION

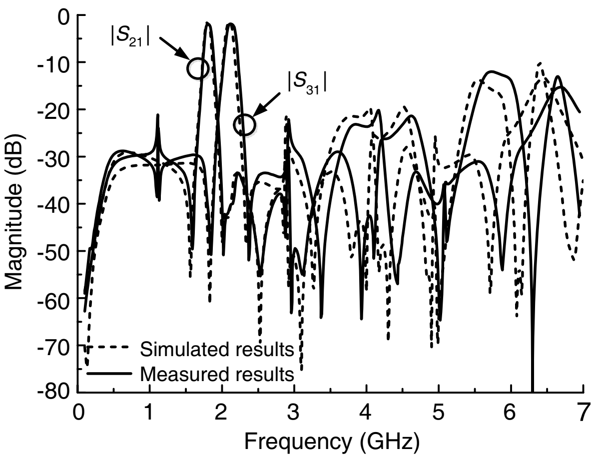
A prototype of the proposed microstrip diplexer is fabricated on the dielectric substrate with $\varepsilon_r = 2.65$, $h = 0.5$ mm, and $\tan\delta = 0.003$. A photograph, measured and simulated results of the microstrip diplexer are shown in Figs. 4(a)–(c). Obviously, the agreement between simulated and measured responses is very good. The measured in-band return losses at lower and higher passbands are better than 15 dB. The measured in-band insertion losses at lower and higher passbands are about 2.0 dB and 1.8 dB, respectively. The insertion losses are mainly attributed to the conductor loss of copper. The 3-dB bandwidths of the two passbands are 5.5% (1.76–1.86 GHz) and 6.2% (2.06–2.19 GHz), over 20-dB upper stopband can be realized from 1.93 to 5.48 GHz for channel A and 2.28 to 6.44 GHz for channel B. Six transmission zeros in upper stopband has been designed to obtain much better output isolation and out-of-band rejection. As a result, an excellent isolation exceeding 40 dB between the channels from 0.1 to 6.5 GHz is achieved. The transmission zeros near each passband edge are located at 1.59, 2.02 GHz and 1.84, 2.37 GHz, respectively, resulting in a sharp skirt. The size without the 50 Ω feed lines is $0.6\lambda \times 0.22\lambda$, in which λ is the guided wavelength at 1.8 GHz. The frequency discrepancies and less bandwidth of the passband for the measured results are mainly caused by the fabrication inaccuracy and measurement errors. Table 1 gives some measured results of different diplexers, the proposed diplexer has advantage of wideband isolation of the two passbands.

Table 1. Comparisons of measured results for some diplexers.

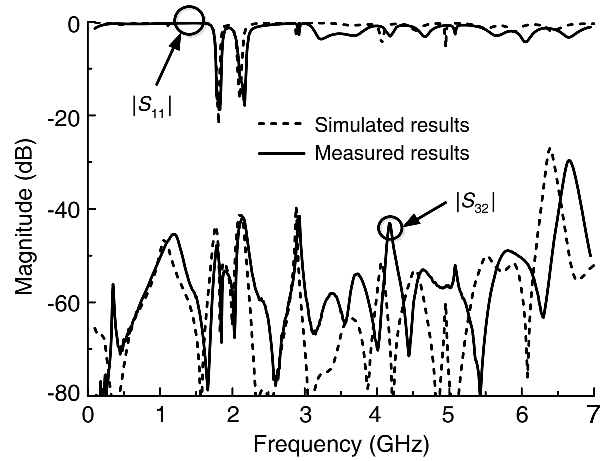
Diplexer Structures	1st/2nd Passbands (GHz)	Frequency ratio	Fractional bandwidth (%)	Passband insertion loss (dB)	Isolation (dB)
Ref. [1]	1.8/2.4	1.33	10/10	1.1/1.18	> 40 (1.0–6.62 GHz)
Ref. [2]	1.84/2.42	1.32	6.0/5.8	-	> 30 (0.1–6.0 GHz)
Ref. [3]-II	1.5/1.76	1.17	3.8/3.3	2.8/3.2	> 30 (1.0–2.2 GHz)
Ref. [4]	0.9/1.8	2.0	-	0.4/0.5	> 20 (0.1–3.0 GHz)
Ref. [5]	1.82/2.5	1.37	5.0/5.0	2.51/2.17	> 55 (0.5–4.0 GHz)
This work	1.8/2.1	1.16	5.5/6.2	2/1.8	> 40 (0.1–6.5 GHz)



(a)



(b)



(c)

Figure 4. Photograph, measured, simulated results of the microstrip diplexer, (a) photograph of the microstrip diplexer, (b) $|S_{21}|$ & $|S_{31}|$, (c) $|S_{11}|$ & $|S_{32}|$. ($l_1 = 23.95\,\text{mm}$, $l_2 = 5.16\,\text{mm}$, $l_3 = 11.66\,\text{mm}$, $l_4 = 10\,\text{mm}$, $l_5 = 19.56\,\text{mm}$, $l_6 = 21.16\,\text{mm}$, $l_7 = 23.1\,\text{mm}$, $l_8 = 12.74\,\text{mm}$, $l_9 = 11.36\,\text{mm}$, $l_{10} = 9.8\,\text{mm}$, $m_1 = 20.7\,\text{mm}$, $m_2 = 4.4\,\text{mm}$, $m_3 = 10\,\text{mm}$, $m_4 = 8.6\,\text{mm}$, $m_5 = 16.5\,\text{mm}$, $m_6 = 18.1\,\text{mm}$, $m_7 = 19.7\,\text{mm}$, $m_8 = 11\,\text{mm}$, $m_9 = 9.7\,\text{mm}$, $m_{10} = 8.4\,\text{mm}$, $t_1 = 6.7\,\text{mm}$, $t_2 = 10.32\,\text{mm}$, $t_3 = 7.7\,\text{mm}$, $t_4 = 7.0\,\text{mm}$, $w_0 = 1.34\,\text{mm}$, $w_1 = 0.4\,\text{mm}$, $w_2 = 0.3\,\text{mm}$, $w_3 = 1.34\,\text{mm}$, $d = 0.6\,\text{mm}$, $s_1 = 0.2\,\text{mm}$, $q = 1.89\,\text{mm}$, $69.68\,\text{mm} \times 24.96\,\text{mm}$, $\varepsilon_r = 2.65$, $h = 0.5\,\text{mm}$, $\tan\delta = 0.003$).

4. CONCLUSION

In this paper, a novel high selectivity and isolation microstrip diplexer for LTE application is designed by combining two compact bandpass filters with T-junction matching network. These filters not only are compact in size, but also can make one of the transmission zeros very close to the desired passband corners. A prototype with two passbands located at 1.8 and 2.1 GHz was fabricated and verified by simulation and measurement. The proposed diplexer has good isolation and a wide stopband to satisfy the passband specifications. Good agreement between the simulated and measured results validates the performance of the proposed microstrip diplexer, which make the proposed structure a good candidate for communication applications.

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