Microstrip diplexer based on common dual-band filter

Xuehui Guan\textsuperscript{1(a)}, Hui Su\textsuperscript{1}, Fangqi Yang\textsuperscript{2}, Pin Wen\textsuperscript{1}, and Zhewang Ma\textsuperscript{3}

\textsuperscript{1} School of Information Engineering, East China Jiaotong University, Nanchang 330013, P. R. China
\textsuperscript{2} Jiangxi Mobile Yichun Branch, Yichun 336000, P. R. China
\textsuperscript{3} Graduate School of Science and Engineering, Saitama University, Saitama 338–8570, Japan
\textsuperscript{a}) xuehuiguan@gmail.com

Abstract: A novel microstrip diplexer with novel coupling structure is proposed in this letter. The proposed diplexer is designed with several stepped-impedance resonators. A dual-mode dual-band filter unit is used in this design to replace the conventional matching network, what is more, the dual-mode dual-band filter unit is resonance with other circuit resonator. The diplexer size can be reduced efficiently in this way. The proposed diplexer is composed by two four-pole chebyshev filters with six stepped-impedance resonators. Based on the structure, a diplexer with the central frequency of 1.89 GHz and 2.35 GHz for 4G wireless communication application is fabricated and measured. Good agreements between measured results and simulated results verify the proposed structure well.

Keywords: microstrip diplexer, dual-band filter, common resonator

Classification: Microwave and millimeter-wave devices, circuits, and modules

References

1 Introduction

Diplexer is one of the essential components in the RF front end of most multi-service and multiband communication systems to reduce the number of antennas [1, 2, 3, 4, 5, 6]. Therefore, researchers show great interest in the high performance and low profile diplexers. The most intuitive approach is to combine two compact filters with a T-junction [7, 8, 9]. This kind of diplexers, however, is large in size from the junction. In [10, 11, 12], compact diplexers and multiplexer are proposed using Low Temperature Co-fired Ceramic (LTCC) technology. In [13, 14], the common resonator technology is proposed to replace the junction in the diplexer designs and reduces the diplexer circuit size. In our previous work [15], good impedance matching in both of the two passbands is achieved by introducing a stub-load dual-mode resonator without needing any additional matching network. Moreover, the total number of resonators in a diplexer with unchanged-in-band frequency response in two passbands can be certainly reduced.

In this article, a novel compact microstrip diplexer with novel coupling is proposed. The diplexer is composed by two four-pole bandpass filters. A dual-mode dual-band filter unit is applied as the common resonator. Each band filter is composed by a dual-mode dual-band filter unit and two SIRs. A coupling scheme for the filter is given and the coupling matrix is synthesized. Finally, a diplexer,
operating in the 1.89/2.35 GHz band for 4G wireless communication is designed and measured, and the isolation between two passband are below −40 dB. Good agreement can be obtained between measured and simulated results.

2 Theory and design

A. Construction of the diplexer

The conventional and proposed coupling structures of diplexer are shown in Fig. 1(a) and (b), respectively, where each node represents a resonator and the solid lines between nodes represent the direct coupling path. The design idea is to share the common resonator unit (CRU) for all two filter channels to save resonator space and a three-port matching network as compared with the conventional ones. The proposed diplexer structure different from our previous work [15] is that the frequency response of the common resonator unit is dual-mode dual-band. So the proposed diplexer coupling structure can save more number of the resonator. In our proposed structure, the common resonator unit composed by four resonator modes M₁, M₁′, M₂ and M₂′. So the external quality factor of the two bandpass filters can be controlled by the gap between the feedline and M₁, and the resonance between the CRU and other resonator controlled by the gap between the M₂ and M₃ or M₂ and M₅.

B. Dual-mode dual-band unit

As to a stepped-impedance resonator (SIR) shown in Fig. 2, its input impedance from one end can be deduced as:

$$Z_{in} = jZ_2 \tan \theta_1 \tan 2\theta_1 - R_Z + R_Z \tan \theta_2 (\tan \theta_2 + R_Z \tan 2\theta_1) \frac{R_Z}{R_Z (\tan \theta_2 + R_Z \tan 2\theta_1) - (\tan \theta_2 \tan 2\theta_1 - R_Z) \tan \theta_2}$$

(1)

where $Z_1$, $Z_2$, and $\theta_1$, $\theta_2$ are the characteristic impedance and electrical length of the resonator shown in Fig. 2, $R_Z = Z_2/Z_1$ is the impedance ratio.

By applying the resonating condition, it can be deduced that

$$\theta_0 = \theta_1 = \theta_2 = \arctan \sqrt{R_Z},$$

(2)

And the resonant frequencies of first spurious frequency to fundamental is
\[ \frac{f_1}{f_0} = \frac{\pi}{2 \arctan \sqrt{R_z}} \]  \tag{3}

Fig. 2. Diagram of a stepped-impedance resonator.

Fig. 3. Frequencies ratio against the impedance ratio.

Fig. 3 gives the frequencies ratio against the impedance ratio. When \( R_z \) increase from 0.1 to 10, frequencies ratio decrease from 5 to 1.5. As to a diplexer works at 1.8 and 2.4 GHz, its ratio is 1.33. Two designed resonator can be used to realize the dual-band bandpass filter.

Fig. 4. Simulated frequency response of the dual-mode dual-band filter unit.

Fig. 4 shows the frequency response of the CRU. As shown in the Fig. 4, the CRU with the frequency response of dual-band characteristics is composed by a pair of half-wavelength SIRs. Two passbands are designed at 1.89 GHz and 2.35 GHz. The fundamental resonant mode and first spurious mode of SIR is used to form lower-passband and upper-passband of the diplexer, respectively. What’s more, the CRU also acts as the impedance matching network in a diplexer. So the number of the resonators is reduced, and the size of the diplexer is also decreased.
The other resonators are designed as a folded stepped-impedance resonator due to compactness consideration.

Fig. 5 shows the configuration of the proposed microstrip diplexer. As can be seen from Fig. 5, the proposed diplexer is formed by connecting four-order Chebyshev bandpass filters with a common resonator unit. Each bandpass filter is composed by a CRU and two bending stepped impedance resonators.

![Fig. 5. Configuration of proposed microstrip diplexer.](image)

The electric field distributions of the proposed diplexer at the lower and upper passbands are shown in Fig. 6. When the diplexer operates at lower passband (1.89 GHz), the high current density is located at the lower passband channel (1.89 GHz) whereas the upper passband channel (2.35 GHz) is considered as open circuit. Contrarily, when the diplexer operates at upper passband (2.35 GHz), the high current density are located at the higher passband channel (2.35 GHz) whereas the lower passband channel (1.89 GHz) is considered as open circuit. These performances verify the CRU has played an important role in impedance matching.

![Fig. 6. Current distributions for the lower passband @1.89 GHz and upper passband @2.35 GHz.](image)

3 Experimental results and discussion

For demonstration purpose, a microstrip diplexer operates at 1.89 GHz and 2.35 GHz, was designed on a substrate with dielectric constant of 3.5 and thickness of 0.8 mm. The dimensions of the diplexer are: \(l_1 = 24.3\) mm, \(l_2 = 9\) mm, \(l_3 = 27.85\) mm, \(l_4 = 6.7\) mm, \(l_5 = 20.85\) mm, \(l_6 = 5.9\) mm, \(w_1 = w_4 = w_6 = 0.4\) mm, \(w_2 = 8.25\) mm, \(w_3 = w_5 = 2.15\) mm, \(g_1 = 0.35\) mm, \(g_2 = 1.95\) mm, \(g_3 = 1.45\) mm, \(g_4 = 4.25\) mm, \(g_5 = 0.9\) mm, \(g_6 = 1.35\) mm, \(g_7 = 0.2\) mm, \(g_8 = 2.25\) mm, \(g_9 = 2.1\) mm, \(g_{10} = 1.8\) mm, \(g_{11} = 2.05\) mm, and \(g_{12} = 0.3\) mm. Fig. 7
shows the simulated and measured frequency responses. The measured 3-dB bandwidths of two channels are 3.2% and 1.8% with center frequencies of 1.89 and 2.35 GHz, respectively. The measured isolation is below 40 dB. The measured minimum insertion loss in two channels are found as 1.83 and 1.81 dB. The photograph of the fabricated filter is shown in Fig. 8. Its overall size is about $0.47\lambda_g \times 0.33\lambda_g$.

**Fig. 7.** Comparison between EM simulated (dashed line) and measured (solid line) results of the proposed diplexer. (a) $S_{11}$, $S_{21}$ and $S_{31}$, (b) $S_{23}$.

**Fig. 8.** Photograph of the fabricated diplexer

### 4 Conclusion

In this article, a novel microstrip diplexer with novel coupling structure is proposed and developed by using stepped impedance resonators. A dual-mode dual-band filter unit is used as a common resonator and replace the conventional matching network. The diplexer size can be reduced efficiently in this way. Finally, the diplexer for 4G wireless communication application is fabricated and measured. Measured results agree well with the simulated results, verifying the proposed structure and design methodology.

### Acknowledgments

This work is supported by National Science Foundation Committee of China (No. 61161005, No. 61461020), Jiangxi Provincial Cultivation Program for Academic and Technical Leaders of Major Subjects (20162BCB22018), and Natural Science Foundation of Jiangxi Province (20152ACB21007, 20165BCB19010), all in China.