Compact microstrip balanced-to-balanced diplexer using stub-loaded dual-mode resonators

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Abstract: A new microstrip balanced-to-balanced diplexer based on stub-loaded dual-mode resonators is presented in this letter. The proposed balanced diplexer primarily consists of two balanced bandpass filter channels, and both channels can be independently designed, thus bringing great flexibility in the diplexer design. Besides, due to the direct connection of two dual-mode balanced filters, no additional matching networks are demanded at the common input port, leading to a significant size reduction. A bandpass coupled line structure is introducing as output feeding line which generates transmission zero on lower side of passband. For demonstration, a prototype balanced diplexer operating at 2.20 and 2.63 GHz is implemented and measured with 3-dB fractional bandwidths of 7.3\% and 6.8\%. Both simulated and experimental results are provided in satisfactory agreement.

Keywords: stub-loaded dual-mode resonator, bandpass coupled line, balanced-to-balanced diplexer

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

References


1 Introduction

The diplexer is a three-port network that splits incoming signals from a common input port into two channels with different operating frequencies. It is a significant RF component for communication systems. As we know, the diplexer can be realized in various techniques such as cavity, waveguide, microstrip and substrate-integrated waveguide (SIW) [1, 2, 3, 4]. Among them, the microstrip diplexer is the preferred one due to its low cost and compact layout. Most microstrip diplexers in published literatures are constructed in single-ended structures [5, 6]. Although balanced circuits [7, 8] like balanced filter and power divider are widely used in modern systems owing to their higher immunity and good common-mode (CM) rejection performance, but balanced microstrip diplexer is discussed only in limited literatures in recent years. Zhou et al. propose a balanced diplexer with uniform impedance resonators and short-ended microstrip parallel-coupling feedlines [9]. Although it can operate without extra junction matching network, but the performance in upper passband is not as good as that in lower passband. By applying 16 close loops, a via-free and compact diplexer is proposed in [10]. However, both the return losses and insertion losses were poor. In addition, with dual-open/short-stub loaded resonators, Jiang et al. design a quad-channel balanced diplexer [11], but it is only suit for narrow-band application. Therefore, it is significant to further improve the performance of the balanced diplexers.

In this letter, a new microstrip balanced-to-balanced diplexer has been proposed. The proposed balanced diplexer is made up of two balanced bandpass filter paths. Each balanced bandpass filter path can be designed independently based on two identical stub-loaded dual-mode resonators. It should be mentioned that no extra matching networks are required at the common balanced input port in our proposal. Transmission zeros (TZs) are generated by the output feeding line which
has bandpass coupled line structure. For demonstration, a prototype balanced-to-balanced diplexer operating at 2.20 and 2.63 GHz is designed, fabricated and measured with 3-dB fractional bandwidths of 7.3% and 6.8%. The performance of practical diplexer agrees with simulation well.

2 Design of balanced-to-balanced diplexer

Fig. 1 depicts the configuration of proposed balanced diplexer. Basically, the diplexer is composed of two balanced filter channels with a common input feed line, and each balanced filter channel is implemented based on a pair of stub-loaded dual-mode resonators which derived from E-shape resonators. As shown in Fig. 1, the employed each pair of resonators (A and A’ or B and B’) is rotationally symmetrical with regard to the centre of the common input feed line and has to operate simultaneously at the same frequency. In addition, the bandpass coupled line structure in [12] is adopted as the output feeding line to generate TZs at low frequency region.

![Fig. 1. The configuration of proposed balanced diplexer](image)

Fig. 2 depicts schematic view of the involved stub-loaded dual-mode resonator with its bisections. The resonator can be expounded with even-/odd-mode theory, then two fundamental resonant frequencies can be obtained as

\[
\begin{align*}
    f_{\text{even}} &= \frac{c}{2(L_1 + L_2)\sqrt{\varepsilon_e}}, \\
    f_{\text{odd}} &= \frac{c}{4L_1\sqrt{\varepsilon_e}}
\end{align*}
\]

where \( c \) is the speed of light in free space, \( \varepsilon_e \) is the effective dielectric constant of microstrip line. Note that \( Y_2 = 2Y_1 \) is assumed for simplification. Obviously, the stub length \( L_2 \) can be adjusted to achieve proper even-mode resonant frequencies while the odd-mode ones maintains. In this context, we can utilize the property to achieve a proper bandwidth of the balanced diplexer.

The equivalent circuits of the proposed balanced diplexer under differential-mode (DM)/CM are illustrated in Fig. 3. Under DM excitation, the central line can be viewed as an electric wall, so a virtual-short-to-ground is present along the
symmetric line. The corresponding equivalent circuit can be obtained as shown in Fig. 3(a). As we can observe, the bandpass-type coupled-line is formed at both input/output ports under DM excitation, thus two dual-mode bandpass filtering responses can be performed between the input and two output ports.

Fig. 2. The schematic of involved stub-loaded dual-mode resonator (a) Integral layout (b) Odd-mode bisection (c) Even-mode bisection

Fig. 3. Equivalent circuit of proposed diplexer (a) differential-mode (b) common-mode

Fig. 4 gives the related coupling scheme of the proposed diplexer under DM excitation. Port $1^+ / 1^-$ is the input balanced port, then Port $2^+ / 2^-$ and Port $3^+ / 3^-$ are output balanced ports. Nodes (1, 2 and 1', 2') represent the resonant modes of stub-loaded resonators in two filter channels. It should be noted that the bandwidth of these dual working passbands can be adjusted individually by fine tuning the lengths ($L_1$, $L_2$ and $S$) and the gaps ($G_1$/$G_3$, $G_2$/$G_4$).

Fig. 4. Coupling of proposed balanced diplexer under differential-mode excitation
Alternatively, an open-circuited-to-ground boundary condition is present along the symmetric line under CM operation. Under this circumstance, the signals at the input port can’t be transmitted to two output ports due to the bandstop-type coupled-line as illustrated in Fig. 3(b).

3 Implementation and measurement

In order to validate our concept, a prototype of proposed balanced diplexer is designed and fabricated on a 0.508 mm thick Rogers RO4003C substrate with permittivity of 3.55, loss tangent of 0.0027. Final dimensions labeled in Fig. 1 are summarized as follows (Units: mm): 

\[
\begin{align*}
L_1 &= 3, & L_2 &= 5.9, & L_3 &= 17, & L_4 &= 13.5, & L_5 &= 12.9, & L_6 &= 8.05, & L_7 &= 5.65, & L_8 &= 6.5, & L_9 &= 0.95, & L_{10} &= 8.8, & L_{11} &= 17.2, & L_{12} &= 13.2, & W &= 0.4, & W_1 &= 1, & W_2 &= 1.4, & W_3 &= 0.5, & W_4 &= 0.7, & S &= 3.8, & G_1 &= 0.2, & G_2 &= 0.2, & G_3 &= 0.2, & G_4 &= 0.2.
\end{align*}
\]

The photograph of fabricated diplexer is shown in Fig. 5. The dimension of practical diplexer is about 0.61 \( \lambda_g \times 0.34 \lambda_g \), where \( \lambda_g \) is the guided wavelength at 2.20 GHz.

![Fig. 5. The photograph of the practical balanced-to-balanced diplexer](image)

The simulation is conducted by the commercial software, ANSYS HFSS, and the measurement is executed on the Agilent N5244A vector network analyzer. The performances of simulation and measurement are in good agreement and they are both illustrated in Fig. 6.

For the DM operation, as shown in Fig. 6(a), the measured DM fractional bandwidth are of 7.3% and 6.8%, respectively, with two central frequencies of 2.20 and 2.63 GHz. The measured minimum in-band insertion losses are about 1.06 and 1.09 dB, while both return losses are better than 17 dB. The TZs at 1.35 GHz and 1.75 GHz are generated by the bandpass coupled line of output ports, which help a lot to improve the frequency selectivity. What is more, the TZs at the high side of each passband are generated due to the quarter-wavelength resonance of the stub loaded in the dual-mode resonator. For CM response, the suppressions in both channels are better than 23 dB, which shown in Fig. 6(b). Fig. 6(c) depicts the isolation between two filter channels under DM/CM operation, which are both better than 38 dB.
4 Conclusion

In this letter, a new balanced-to-balanced microstrip diplexer is proposed and designed. The proposed balanced diplexer primarily consists of two balanced bandpass filter paths, and each balanced filter path can be designed independently based on two identical stub-loaded dual-mode resonators. The measured results show good DM performance of the proposed balanced diplexer, with high CM suppression and good isolation. Owing to these properties, it is our belief that the proposed balanced diplexer can obtain widespread application in many balanced circuit systems.