# Microstrip Diplexer Design Using Common T-Shaped Resonator

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***Abstract*—This study presents a novel microstrip diplexer with a joint T-shaped resonator. The T-shaped resonator has an extremely small frequency ratio using microstrip with practical line width. Additionally, the T-shaped resonator can be used as a frequency selective signal splitter, making it feasible to design a diplexer for a system with two extremely close bands. The diplexer using a joint T-shaped resonator does not require combining circuits and matching networks. A diplexer used in the UMTS-WCDMA system is designed and measured. The proposed diplexer has high isolation and wide stopband in addition to satisfying the passband requirement. A satisfactory agreement between the simulated results and the measured results validate the proposed configuration.**

***Index Terms*—Coupled filter, diplexer, T-shaped resonator.**

## I. Introduction

DIPLEXERS are important devices in modern communication system. A typical full duplex wireless communication system uses diplexers to transmit and receive signals by a single antenna. A diplexer is also used to separate a common input signal into two individual output streams with distinct bands in dual-band systems. The frequency division duplex (FDD) scheme is widely used in high-tier mobile phone systems such as GSM, CDMAone, and UMTS-WCDMA. Basically, an FDD diplexer consists of two filters, associated matching networks, and a combining circuit.

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. T-junctions with open stubs [3] or a step impedance transformer [4] have been developed to improve the performance. To enhance the isolation, adding open stubs at the TX port and the RX port has been presented [3], [5].

Because the diplexer consists of two filters, the simplest means of reducing the diplexer size is miniaturizing both filters [1]–[4]. Another approach uses an improved diplexer structure,

Manuscript received March 20, 2011; revised August 01, 2011; accepted September 02, 2011. Date of publication October 06, 2011; date of current version November 09, 2011.

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Digital Object Identifier 10.1109/LMWC.2011.2168949

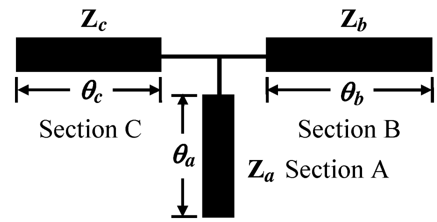


Fig. 1. T-shaped resonator.

instead of simply combining two independent filters. The feasibility of either integrating a dual-band filter with an additional matching network [6], or with a frequency splitter [7] has been examined. The diplexer combining the two filters by using a common stepped impedance resonator (SIR) [8] or composite right/left handed (CRLH) resonator [9] does not require a T-junction, subsequently reducing the diplexer size. However, for most FDD systems, the TX and the RX bands are extremely close to each other, implying that the impedance ratio of the SIR is impractical. On the other hand, the CRLH resonator has not been reported to have two very close resonance frequencies under the restriction of line width.

This work presents a novel FDD diplexer employing a T-shaped resonator as the common resonator and frequency selective splitter. The T-shaped resonator is composed of a three-section transmission line. Each section has an adjustable characteristic impedance and length. The frequency ratio can be almost 1.0. Therefore, the proposed diplexer has the same merits as those with a common resonator [8], [9], and is suitable for a system having two extremely close bands. The frequency selecting behavior of the T-shaped resonator makes the diplexer with high isolation. A diplexer equips in the UMTS-WCDMA system is designed and measured. The simulated results and the measured results validate the proposed structure.

## II. T-Shaped Resonator

Fig. 1 illustrates the structure of the T-shaped resonator, where $Z_a$, $Z_b$, and $Z_c$ denote the characteristic impedances of each section. Although the T-shaped resonator is similar to the stub-loaded resonators [10], the impedances and lengths of all sections can be unequal. In [10], the short stub is connected to a half-wavelength UIR, implying that $Z_b = Z_c$. This resonator uses the short stub to adjust the second resonance frequency of the UIR. In this work, the characteristic impedance and length of each section can all differ from each other, implying that $Z_a \neq Z_b \neq Z_c$ and $\theta_a \neq \theta_b \neq \theta_c$.

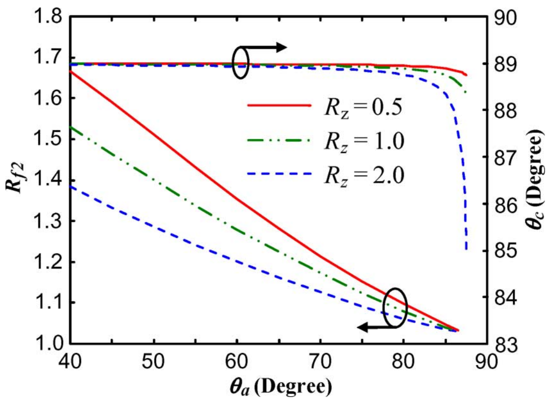


Fig. 2. Frequency ratio of the second resonance frequency $f_2$ to the fundamental resonance frequency $f_1$ and electrical length of section C for different impedance ratio. The electrical length $\theta_b = 91^\circ$.

The input admittance of the resonator seen from the open end of section A is

$$Y_{in} = -jY_a \cdot \frac{Y_a \tan R_{fn}\theta_a + Y_b \tan R_{fn}\theta_b + Y_c \tan R_{fn}\theta_c}{\tan R_{fn}\theta_a (Y_b \tan R_{fn}\theta_b + Y_c \tan R_{fn}\theta_c) - Y_a} \tag{1}$$

and the resonance condition is derived as

$$\frac{\tan R_{fn}\theta_a}{Z_a} + \frac{\tan R_{fn}\theta_b}{Z_b} + \frac{\tan R_{fn}\theta_c}{Z_c} = 0 \tag{2}$$

where $R_{fn}$ is the frequency ratio of the $n$-th resonance frequency $f_n$ to the fundamental resonance frequency $f_1$. The electrical lengths $\theta_a$, $\theta_b$, and $\theta_c$ are defined at $f_1$.

Fig. 2 shows the frequency ratio $R_{f2}$ and the electrical length $\theta_c$, which varied with $\theta_a$ for different impedance ratio, $R_Z \equiv Z_b/Z_a$. Here $Z_b$ is assumed to be equal to $Z_c$. Notably, the frequency ratio can be smaller than 1.1. This finding suggests the T-shaped resonator can be used to construct a dual-band circuit operating at two extremely close frequencies, making it appropriate for most FDD systems, which generally have two close bands. For instance, the GSM diplexer demands 902.5 MHz for transmitting and 947.5 MHz for receiving, in which the required frequency ratio is 1.05. In contrast with the conventional SIRs, the SIR requires an impedance ratio of 179.01, which requires an extremely wide middle transmission line or an extremely narrow outer transmission line.

Fig. 3 shows the current distributions of the T-shaped resonator at the first two resonance frequencies for $\theta_c < \theta_a < \theta_b$. Most of the current flows through section A to B at the lower resonance frequency; in addition, most of the current flows through section A to C at a higher resonance frequency. This finding suggests the coupling through section B is strong and through section C is weak at a lower resonance frequency, while the coupling through section C is strong and through section B is weak at a higher resonance frequency. Thus, the T-shaped resonator can be used as a signal splitter that separates signals of two different frequencies.

## III. Design of a Diplexer Composed of Two Second-Order Filters

Fig. 4 illustrates the coupling path of the diplexer combining two second-order bandpass filters. Fig. 4(a) shows a

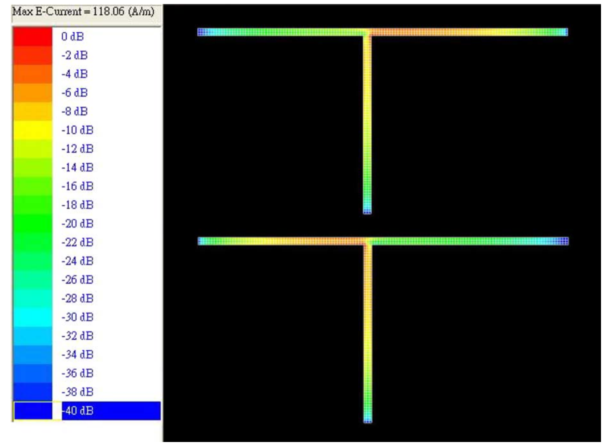


Fig. 3. Current distributions of T-shaped resonators at the first two resonance frequencies for $\theta_c < \theta_a < \theta_b$. The upper one is the current distribution at the fundamental resonance frequency, and the lower one is the current distribution at the second resonance frequency.

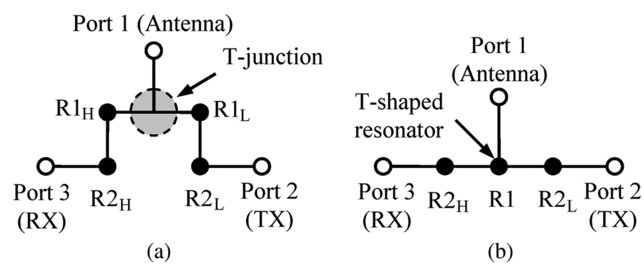


Fig. 4. Coupling path of the diplexer connecting two second-order bandpass filters by using (a) T-junction, and (b) T-shaped resonator, R1.

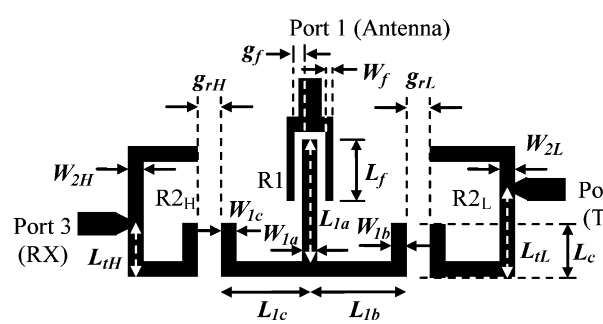


Fig. 5. Layout of the diplexer using the T-shaped resonator, R1, to combine two second-order bandpass filters. Port 1 uses coupled feeding, ports 2 and 3 use tapped feeding.

typical diplexer using a T-junction to connect two filters, while Fig. 4(b) shows the proposed diplexer using the joint T-shaped resonator. Because the coupling scheme is the same as that in [8] and [9], the proposed diplexer has the same merits. In addition, using the T-shaped resonator, instead of SIR [8] or CRLH resonator [9], as the joint resonator, the diplexer with two close bands can be fabricated using a practical line width. The frequency selective behavior also improves the isolation. Fig. 5 shows the corresponding layout.

The design procedure follows the traditional single band filter theory [11], except for the external quality factor at port 1. In this study, port 1 uses a coupled feeding structure such that an additional matching network is not required. The two required physical parameters controlling $Q_e$ are coupling length, $L_f$, and cou-

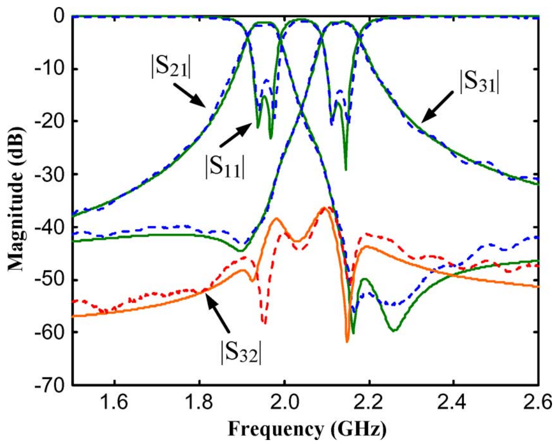


Fig. 6. Frequency responses of the simulated results (solid lines) and the measured results (dashed lines). Associated dimensions (unit mm): $W_{1a} = 1.0$, $W_{1b} = 2.0$, $W_{1c} = 2.0$, $L_{1a} = 24.1$, $L_{1b} = 17.15$, $L_{1c} = 12.8$, $W_{2L} = 2.0$, $W_{2H} = 2.0$, $W_f = 0.8$, $g_f = 1.0$, $L_f = 14.3$, $L_c = 11.2$, $g_{rL} = 1.7$, $g_{rH} = 1.75$, $L_{tL} = 8.7$, $L_{tH} = 4.0$.

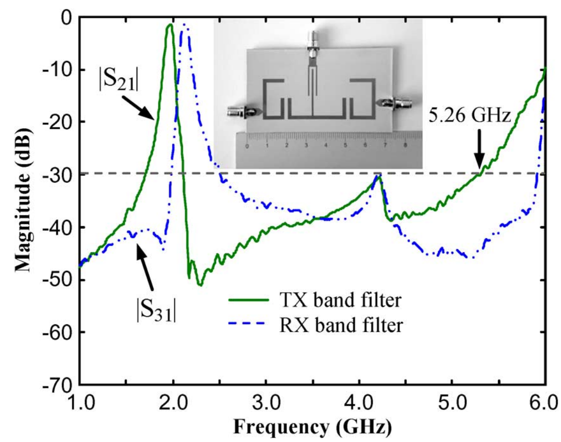


Fig. 7. Wideband frequency responses of the measured results. Photograph of the fabricated diplexer is inserted.

pling gap, $g_f$, which are determined by the procedure described in [12]. The third resonance frequency of the T-shaped resonator is 4.18 GHz, which is close to the second resonance frequencies of resonators $R_{2L}$ and $R_{2H}$. Therefore, the coupling length $L_c$ is chosen to be 90° to suppress the coupling near 4.18 GHz, leading to a wide stopband.

This section describes the design and evaluation of an FDD diplexer for UMTS-WCDMA system. The central frequencies of the TX filter and the RX filter are 1950 and 2140 MHz, respectively. The bandwidths are 60 MHz. Both TX filter and RX filter are a second-order Chebyshev bandpass filter with a 0.5 dB passband ripple. The diplexer is fabricated on a 60 mil-thick Rogers RO3003 substrate with a dielectric constant of 3.0 and a loss tangent of 0.0012.

Fig. 6 shows the numerical results simulated by Zeland IE3D 14.0, while the experimental results are measured by Agilent 8720ES network analyzer. For the TX band, the simulated and the measured insertion losses are 1.22 and 1.46 dB, respectively. In the RX band, the simulated and the measured insertion losses are 1.12 dB and 1.44 dB, respectively. The simulated and the measured isolations at the TX band are around 39 and 44 dB, and those at the RX band are 37 dB and 36 dB, respectively. Fig. 7 shows a photograph of the fabricated diplexer and the measured wide band response of this diplexer. The out-of-band rejections of both filters are more than 30 dB and reach up to 5.26 GHz.

## IV. Conclusion

This work presents a novel FDD diplexer that integrates a joint T-shaped resonator and two sets of open-loop resonators. The resonance condition of the T-shaped resonator is analyzed. The first two resonance frequencies of the T-shaped resonator can be extremely close to each other, making it feasible for most FDD systems. The current distribution reveals that the T-shaped acts similar to a frequency-selective signal splitter. Therefore, the proposed diplexer does not require a traditional combining circuit and an additional matching network. Additionally, the proposed diplexer uses fewer resonators. This structure is verified by simulations and measurements of a diplexer used in the UMTS-WCDMA system. The proposed diplexer has good isolation and a wide stopband in addition to satisfying the passband specifications. Good agreement between the simulated results and measured results validates the performance of the proposed microstrip diplexer.

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