Design of Three-State Diplexer Using a Planar Triple-Mode Resonator

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***Abstract*—A highly integrated three-state diplexer (TSD) on a single planar elliptical structure is for the first time presented in this paper. Three resonant modes are investigated in a planar elliptical resonator, e.g., two TM_{11} degenerate modes and one TM_{21} mode. These three resonant modes are designed to form three filtering channels, which are further combined to generate three states of a diplexer, namely, TSD. The planar elliptical triple-mode resonator is fed by three microstrip lines to form a triple-mode TSD. In order to validate the concept, the designed planar TSD is fabricated and measured. The measured results are in good agreement with the simulated ones.**

***Index Terms*—Diplexer, duplexer, elliptical resonator, filter, three-state diplexer (TSD), triple-mode resonator.**

I. Introduction

THE diplexer is an important component for wireless communication systems due to its inherent nature of frequency division applied for frequency up-conversion and down-conversion links, where the multiple diplexers are generally used in multichannel selections of a complex system. As the research launches, the designs and synthesis of diplexers have been comprehensively investigated [1]–[17].

The traditional approach of designing a diplexer normally employs two filters to form the separated passbands at the cost of enlarged circuit layout and unneglectable economic cost. This inspires the research for the diplexer miniaturization and cost reduction [7]–[17], including the common resonator technologies [9], [10], compact resonator structures [11]–[13], and multimode technologies [14]–[17]. Noticeably, all the aforementioned works have put significant attentions on miniaturization of a single diplexer, which has incremental benefits for the typical up- and down-conversion systems. Even though the achieved miniaturization techniques have the distinguished features for a standard diplexer system, it is found that these approaches require multiple diplexers to be used for multiple-channel systems, raising an unavoidable issue of complicated system architecture, massive circuit layouts, and, consequently, nonnegligible challenges in terms of system cost control. Therefore, it turns out to be an interesting and effective way of achieving the multifunctional diplexer with compact size into a single circuit structure.

In this paper, a highly integrated multifunctional diplexer, namely, three-state diplexer (TSD), is presented and realized using a triple-mode elliptical-shaped resonator for good control of three resonant modes. Taking advantages of the multimode resonator technologies [18]–[21], the overall size of the circuit has been significantly miniaturized by employing the proposed triple-mode elliptical patch resonator. To the best of the authors' knowledge, this is the first time that the functions of multiple diplexers are realized using a single resonator structure. This TSD has potential application in frequency-hopping communication, as there are three frequency states for frequency-hopping system to choose.

The remainder of this paper elaborates with the following arrangement. In Section II, the concept of the integration of three diplexers is introduced and a triple-mode elliptical resonator is presented as a candidate for designing the TSD. Section III demonstrates the designed TSD based on the proposed triple-mode elliptical resonator with the derived empirical formulae for calculating the resonant frequencies. In Section IV, the simulation and measured results are presented. Finally, a conclusion is presented in Section V.

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II. Design Concept

A. Topology of TSD

Fig. 1(a) depicts the block diagram of the proposed TSD. The proposed TSD has three ports and three filtering elements.

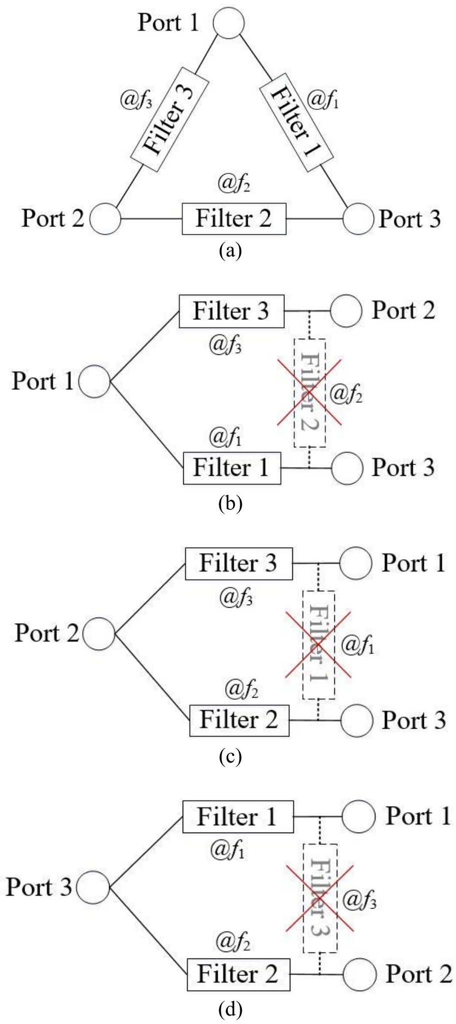

Fig. 1. Topologies of the proposed TSD (a) Block diagram. (b) State1, port1 is the common port. (c) State 2, port2 is the common port. (d) State3, port3 is the common port.

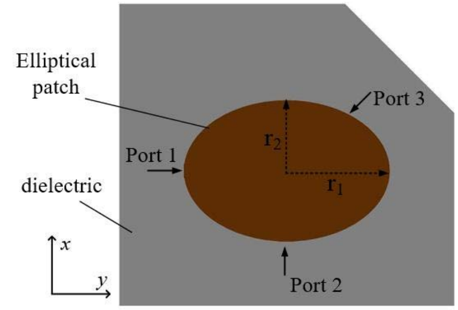

Fig. 2. Top view of planar elliptical triple-mode resonator.

The three filtering elements are individually placed between every two neighboring ports. In detail, Filter 1, Filter 2, and Filter 3 are placed between port 1 and port 3, port 2 and port 3, and port 1 and port 2, respectively. Furthermore, the Filter 1, Filter 2, and Filter 3 operate at different passband frequencies f_1, f_2, and f_3, respectively. The TSD is designed with three operation states in the same diplexer circuit, when the port 1, port 2, and port 3 are set as the common ports, respectively, corresponding to the block diagrams, as shown in Fig. 1(b)–(d). The operational principles of the three states can be summarized as follows:

State 1: When the port1 is set as the common port, the filtering channel 1 and filtering channel 3 are utilized to construct a first-state diplexer operating at f_1 and f_3, simultaneously, while the filtering channel 2 (f_2) is not functioning.

State 2: When the port 2 is set as the common port, the filtering channel 2 and filtering channel 3 are utilized to construct a second-state diplexer operating at f_2 and f_3, simultaneously, while the filtering channel 1 (f_1) is not functioning.

State 3: When the port 3 is set as the common port, the filtering channel 1 and filtering channel 2 are utilized to construct a third-state diplexer operating at f_1 and f_2, simultaneously, while the filtering channel 3 (f_3) is not functioning.

Therefore, this circuit topology with different port excitations can have three operational states as a multifunctional diplexer.

B. Elliptical Shape Triple-Mode Resonator

Fig. 2 presents the top view of the elliptical-shaped triple-mode resonator used to implement the function of TSD. The printed circuit board (PCB) with the dielectric constant of 2.55 and the thickness of 0.8 mm is used. The elliptical patch is engineered on the top layer of the PCB with the full metal layer at the backside of the PCB functioning as the ground. The long axis radius and short axis radius of the elliptical patch are named as r_1 and r_2, respectively. The electric field distributions of the three elliptical patch resonant modes are presented in Fig. 3. The degenerate mode TM_{11+} and TM_{11-} of this elliptical resonator are signed as mode 1 and mode 2, and the higher order mode TM_{21} is assigned as mode 3.

The port 1, port 2, and port 3 are put on the particular position as shown in Fig. 2, e.g., port 1 and port 2 are orthogonal to each other along the x- and y-axis, respectively, while port 3 is 45° oriented from x-/y-axis. The three ports excite this triple-mode resonator under weak coupling condition. In Fig. 3(a), it can be observed that the electric field

$$f_{\mathrm{mn}} = \frac{\chi_{\mathrm{mn}} C}{2\pi a_e \sqrt{\varepsilon_r}} \tag{1}$$

$$a_e = r_1 \left[1 + \frac{2h}{\pi r_1 \varepsilon_r}\left(\ln \frac{\pi r_1}{2h} + 1.7726\right)\right]^{\frac{1}{2}} \tag{2}$$

$$a_e = r_2 \left[1 + \frac{2h}{\pi r_2 \varepsilon_r}\left(\ln \frac{\pi r_2}{2h} + 1.7726\right)\right]^{\frac{1}{2}} \tag{3}$$

$$a_e = r_3 \left[1 + \frac{2h}{\pi r_3 \varepsilon_r}\left(\ln \frac{\pi r_3}{2h} + 1.7726\right)\right]^{\frac{1}{2}} \tag{4}$$

$$r_3 = \frac{3r_1}{4} + \frac{r_2}{4} \tag{5}$$

is strong at both port 1 and port 3, but it is very weak at port 2. This implies that the electromagnetic (EM) energy has a channel connecting port 1 and port 3, while port 2 is the isolation port. The EM energy can flow between neither port 1 and port 2, nor port 3 and port 2. In Fig. 3(b), the electric field

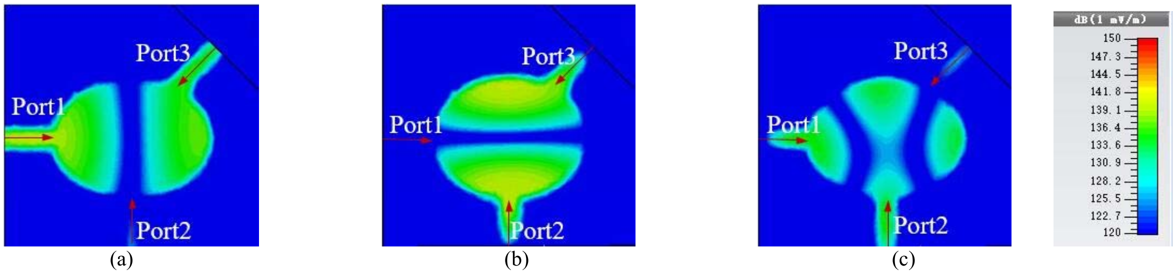

Fig. 3. Resonant modes of the proposed elliptical triple-mode resonator. (a) TM_{11+}. (b) TM_{11-}. (c) TM_{21}.

TABLE I
COUPLING STRENGTH BETWEEN PORTS AND RESONANT MODES

	TM_{11+}	TM_{11-}	TM_{21}
Port 1	strong	weak	strong
Port 2	weak	strong	strong
Port 3	strong	strong	weak

TABLE II
PASSBANDS AT EACH TRANSMISSION PATH

	Port 1	Port 2	Port 3
Port 1		$Passband_3$	$Passband_1$
Port 2	$Passband_3$		$Passband_2$
Port 3	$Passband_1$	$Passband_2$	

is strong at both port 2 and port 3, but it is very weak at port 1. This implies that the EM energy has a channel connecting port 2 and port 3, while port 1 is the isolation port. The EM energy can flow between neither port 1 and port 3, nor port 1 and port 2. Similarly, in Fig. 3(c), the electric field is strong at both port 1 and port 2, while port 3 is the isolation port, the EM energy cannot flow between port 1 and port 3, or port 2 and port 3. Consequently, the coupling strength corresponding to the ports and resonant modes can be summarized in Table I.

Therefore, it can be concluded that there are passband between port 1 and port 3 for mode TM_{11+}, passband between port 2 and port 3 for mode TM_{11-}, and passband between port 1 and port 2 for TM_{21}, which can be named as $Passband_1$, $Passband_2$, and $Passband_3$, respectively. These three passbands locate at the lower, middle, and higher frequency bands, respectively. The relationship among these three passbands and three ports can be concluded in Table II.

To study the resonant modes of this elliptical patch resonator, the resonant frequencies of the three resonant modes are first elaborated by the empirical formulas modified from the circular patch resonator [22]. The resonant frequency of the circular patch resonator can be calculated by (1), and the a_e in (2)–(4) is the effective radius of the elliptical patch resonator of mode 1, mode 2, and mode 3, respectively. It is worth noting that the (2)–(4) are modified from effective radius formulae of circular patch resonator in [22]. Equations (2) and (3) are modified from the fundamental mode equation of circular patch resonator to calculate the first two resonant frequencies of elliptical patch resonator of TM_{11+} and TM_{11-} when $m = n = 1$. Equation (4) is modified from the second-harmonic mode of circular patch resonator to calculate the third resonant frequency of elliptical patch resonator of TM_{21}

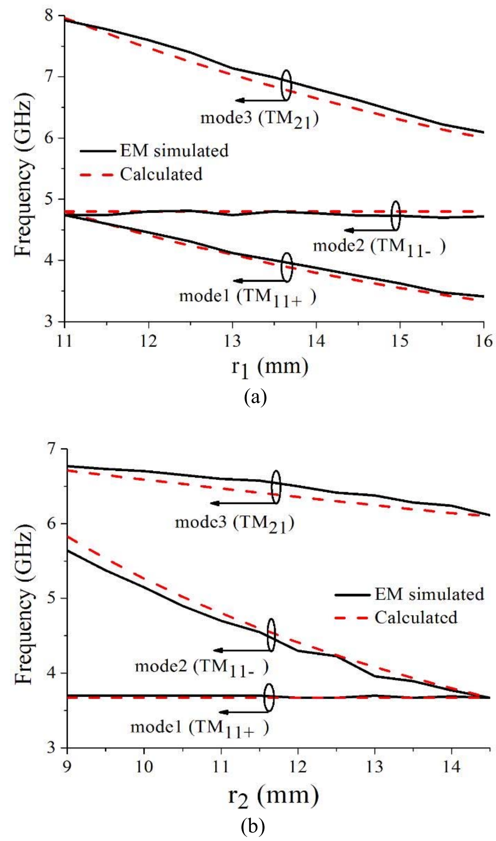

Fig. 4. Three resonant frequencies of the elliptical triple-mode resonator. (a) Against the varied r_1, when $r_2 = 11$ mm. (b) Against the varying r_2, when $r_1 = 14.5$ mm.

when $m = 2$ and $n = 1$. χ_{mn} is the roots of Bessel function. The C is the velocity of light, h is the thickness of the substrate, and the relative permittivity ε_r is 2.55. According to the roots of Bessel function, the χ_{11} is 1.841 and the χ_{21} is 3.054. The r_1 and r_2 are the long axis radius and short axis radius of the elliptical resonator, respectively. To validate the formula of (1)–(5) for calculating the resonant frequency of mode 1, mode 2, and mode 3 effectively, all these resonant frequencies are numerically extracted by the EM simulations and calculated by (1)–(5), which are reflected on Fig. 4 for comparison. The simulated resonant frequencies of the three resonant modes are found in good agreement with the calculated results. Therefore, the empirical formulas (1)–(5) are validated for calculating the three resonant frequencies of the elliptical resonator.

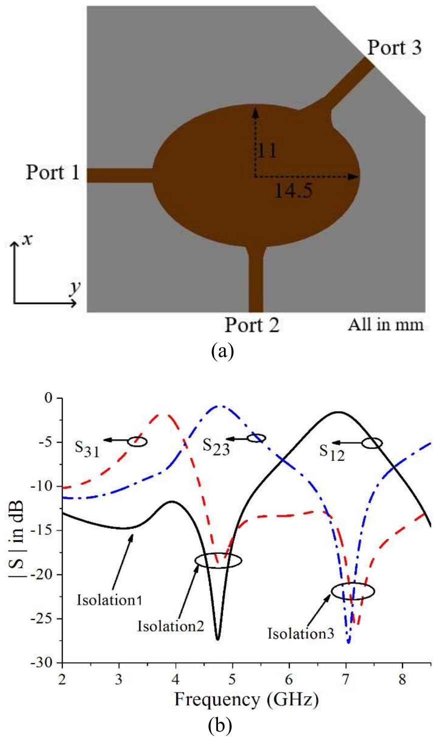

Fig. 5. TSD. (a) Circuit layout. (b) Simulated S-parameters.

TABLE III
EXTERNAL QUALITY FACTOR (QE) OF THREE PASSBANDS

	Filter1 (TM_{11+})	Filter2 (TM_{11-})	Filter3 (TM_{21})
FBW	17.9%	17.5%	11.2%
Synthesis	11.2	11.5	17.5
Extracted	10.9	11.3	17.3

III. IMPLEMENTATION OF TSD

In this section, there are two parts to elaborate the proposed TSD design based on the elliptical patch resonator. A simple elliptical patch filtering circuit is presented in part A to validate the discussion in Section II. In Section III-B, a slot-cut is engineered on the elliptical resonator to increase the degree of freedom for controlling the third resonant frequency.

A. Validation

To validate the discussion in Section II, an elliptical resonator fed by three microstrip lines is proposed. Its configuration and simulated scattering parameters are shown in Fig. 5. The triple-mode elliptical patch is designed on the top layer of the PCB. The long axis radius (r_1) and short axis radius (r_2) are equal to 16 and 11 mm, respectively. Three passbands between the three ports are achieved as shown in Fig. 5(b), which coincides with the discussion at Section II. The three frequencies of these passbands can be calculated by using (1)–(5). The external quality factor is extracted in each passband which is given in Table III. The synthesis values of three external quality factors are well matched with the extracted one, showing good agreement between them. Meanwhile, the isolation between three ports is shown in Fig. 5(b). In detail, the Isolation_2 and Isolation_3 have the transmission zeros located around the resonant frequencies of the mode TM_{11-}, and TM_{21}. The Isolation_1 appears at around the resonant frequency of the mode TM_{11+}. Though it is not an obvious transmission zero, there is a deep suppression showing an improvement of the isolation between the port1 and port 2 near the frequency of Isolation_1. Therefore, the discussion about the passbands in Section II is evidently validated.

B. Realization of TSD

It is clearly shown in Fig. 4 that the long axis radius (r_1) can control the resonant frequency of TM_{11+} mode and TM_{21} mode. Meanwhile, the short axis radius (r_2) can control the resonant frequency of TM_{11-} mode and slightly affect the TM_{21} mode. There are three frequencies with only two control variables (r_1 and r_2). In order to increase the degree of the freedom to control the third resonant frequency, one more variable is expected. Therefore, a slot-cut is introduced on the elliptical patch, as shown in Fig. 6(a). In this way, there are three independent parameters to control three resonant frequencies. The length of slot-cut (a) can control the resonant frequency of mode TM_{21} effectively, while slightly affecting the mode TM_{11+}. Under weak coupling condition, the varying resonant frequencies of the three resonant modes against the parameter r_1, r_2, and a are extracted and shown in Fig. 6(b)–(d), respectively. It is worth noting that there are many ways to open this slot to control the third resonant mode. In this paper, a vertical slot is chosen. This slot is slightly shifted from the center part of the resonator in order to have better inband impedance matching. Herein, the procedure to design the three resonant frequencies of the triple-mode resonator can be concluded in the following with a specification of three passband frequencies f_1, f_2, and f_3.

1) Apply (1)–(5) to calculate dimensions of r_1 and r_2 according to the given resonant frequencies of f_1 and f_2.
2) Implement a vertical slot and change the length of the slot a to obtain a desired frequency of f_3.
3) Optimize the passband frequencies in accordance to the mode charts in Fig. 4 by iterative fine tunings to obtain the desired three passband frequencies.
4) Optimize the performance by adding the tapped structure to the feeding lines and offsetting the slot-cut for impedance matching.

IV. RESULTS AND DISCUSSION

As discussed previously, three evenly distributed passbands are designed and optimized using this proposed method. The circuit layout with marked dimensions is shown in Fig. 7(a). The photograph of the fabricated circuit is shown in Fig. 7(b). The measured and simulated S-parameters are as shown in Fig. 7(c) and (d). The passband between port 1 and port 3 is designed at the 2.8 GHz, namely, Channel_1, while the passband between port 2 and port 3 is designed at the 4 GHz, namely, Channel_2. Finally, the passband between port 1 and port 2 is designed at 5.5 GHz, namely, Channel_3. The measured results are in a good agreement with simulated ones. The measured insertion loss is less than 1.5 dB. Meanwhile, the isolation between different filtering channels is better

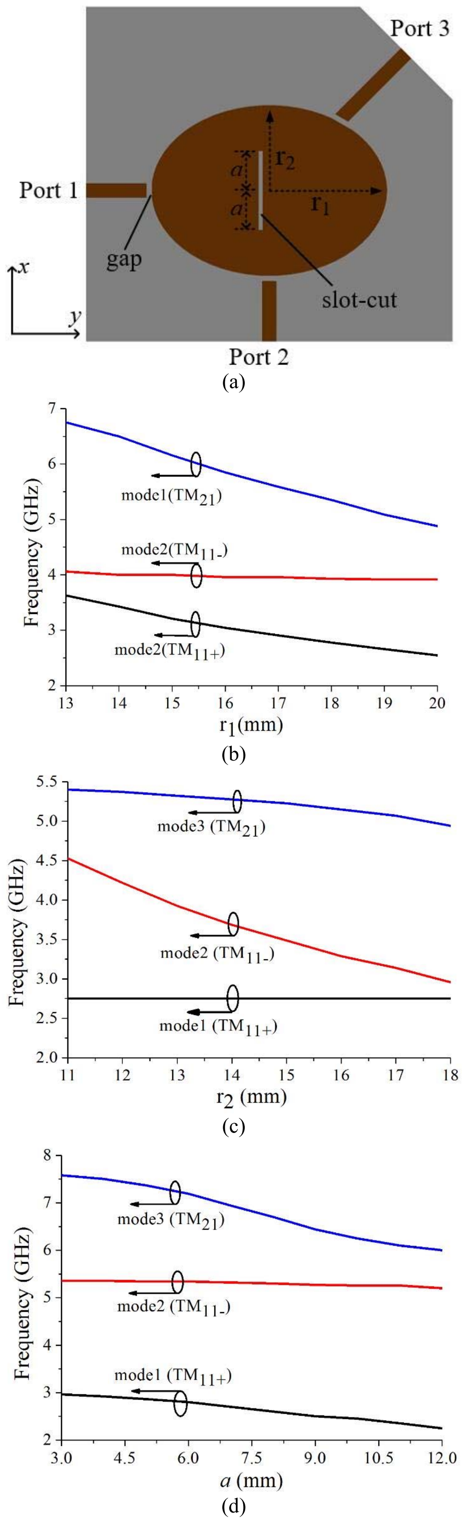

Fig. 6. Calculated resonant frequencies of the proposed triple-mode elliptical resonator with slot under weak coupling. (a) Configuration of elliptical resonant with slot cut. (b) Against varied r_1 when $r_2 = 13$ mm, $a = 6$ mm. (c) Against varied r_2 when $r_1 = 18$ mm, $a = 6$ mm. (d) Against varied a when $r_1 = 18$ mm, $r_2 = 13$ mm.

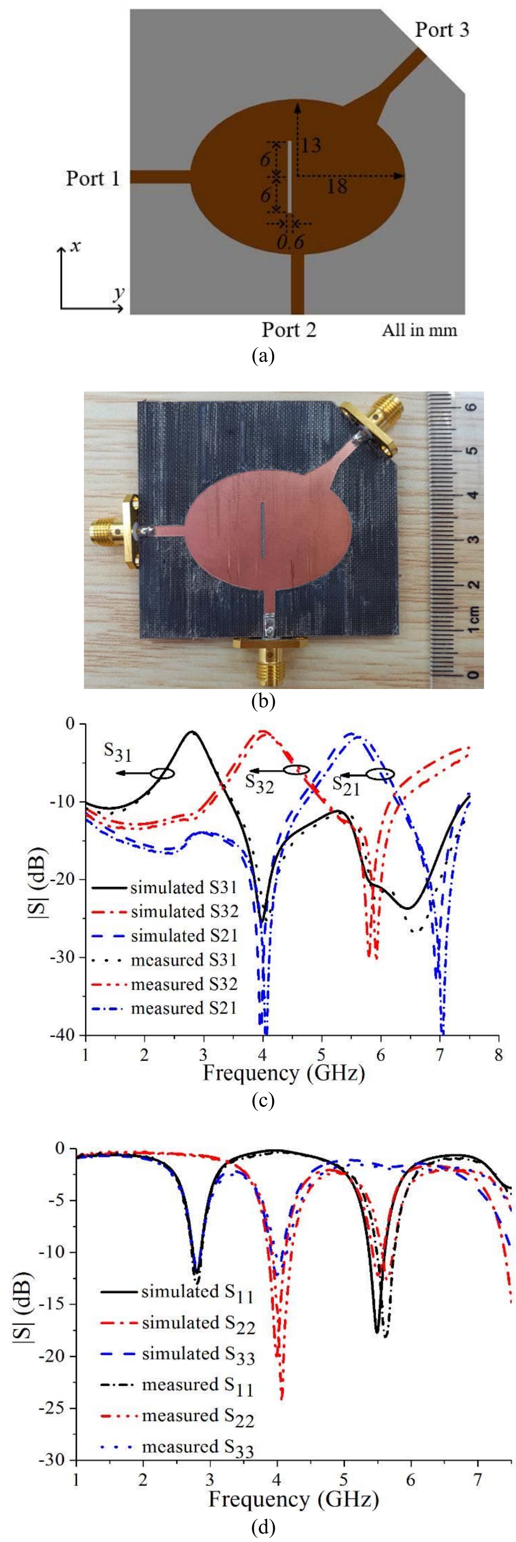

Fig. 7. TSD with slot. (a) Circuit layout with marked dimensions. (b) Photography. (c) Insertion loss. (d) Return loss.

than 12 dB. The three states operational functions can be summarized as follows.

State 1: When the port 1 is the common port of the diplexer, the Channel_1 and Channel_3 can be used as two filtering channels, as shown in Fig. 8(a).

State 2: When the port 2 is the common port of the diplexer, the two filtering channels are the Channel_2 and Channel_3, as shown in Fig. 8(b).

State 3: When port 3 is the common port of the diplexer, the two filtering channels are Channel_1 and Channel_2, as shown in Fig. 8(c).

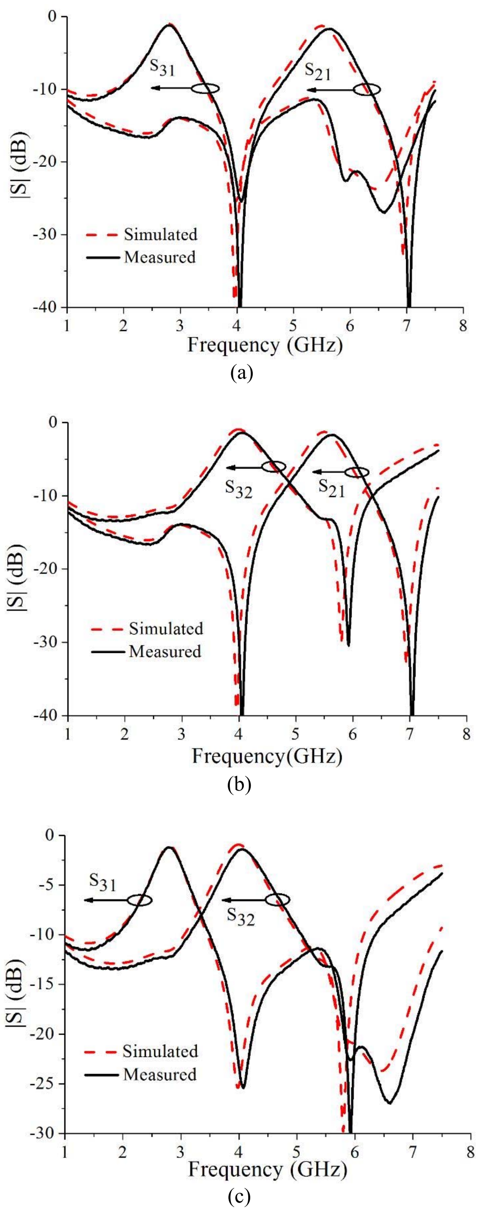

Fig. 8. TSD. (a) Port1 as the common port. (b) Port2 as the common port. (c) Port3 as the common port.

Therefore, the proposed approach of designing a TSD is validated to be feasible for the implementation of multifunctional diplexer.

V. Conclusion

In this paper, a new concept that integrates three filtering channels to achieve three states of diplexers on a single resonator circuit is for the first time proposed, namely, TSD. A planar TSD structure based on a planar triple-mode elliptical-shaped resonator was designed and fabricated to validate this concept. The simulation and measured results are well matched to each other, thereby evidently validating the feasibility of the proposed design approached.

References

[1] A. A. Kirilenko, S. L. Senkevich, V. I. Tkachenko, and B. G. Tysik, "Waveguide diplexer and multiplexer design," *IEEE Trans. Microw. Theory Techn.*, vol. 42, no. 7, pp. 1393–1396, Jul. 1994.

[2] A. R. Brown and G. M. Rebeiz, "A high-performance integrated K-band diplexer," *IEEE Trans. Microw. Theory Techn.*, vol. 47, no. 8, pp. 1477–1481, Aug. 1999.

[3] L. J. Ricardi, "A diplexer using hybrid junctions," *IEEE Trans. Microw. Theory Techn.*, vol. MTT-14, no. 8, pp. 364–371, Aug. 1966.

[4] K. L. Wu and W. Meng, "A direct synthesis approach for microwave filters with a complex load and its application to direct diplexer design," *IEEE Trans. Microw. Theory Techn.*, vol. 55, no. 5, pp. 364–371, May 2007.

[5] H. J. Tang, W. Hong, J.-X. Chen, G. Q. Luo, and K. Wu, "Development of millimeter-wave planar diplexers based on complementary characters of dual-mode substrate integrated waveguide filters with circular and elliptic cavities," *IEEE Trans. Microw. Theory Techn.*, vol. 55, no. 4, pp. 776–782, Apr. 2007.

[6] F.-C. Chen *et al.*, "Design of wide-stopband bandpass filter and diplexer using uniform impedance resonators," *IEEE Trans. Microw. Theory Techn.*, vol. 64, no. 12, pp. 4192–4203, Dec. 2016.

[7] A. Morini, T. Rozzi, M. Farina, and G. Venanzoni, "A new look at the practical design of compact diplexers," *IEEE Trans. Microw. Theory Techn.*, vol. 54, no. 9, pp. 3515–3520, Sep. 2006.

[8] R. Bairavasubramanian, S. Pinel, J. Laskar, and J. Papapolymerou, "Compact 60-GHz bandpass filters and duplexers on liquid crystal polymer technology," *IEEE Microw. Wireless Compon. Lett.*, vol. 16, no. 5, pp. 237–239, May 2006.

[9] M.-L. Chuang and M.-T. Wu, "Microstrip diplexer design using common T-shaped resonator," *IEEE Microw. Wireless Compon. Lett.*, vol. 21, no. 11, pp. 583–585, Nov. 2011.

[10] C.-F. Chen, T. Huang, C.-P. Chou, and R. Wu, "Microstrip diplexers design with common resonator sections for compact size, but high isolation," *IEEE Trans. Microw. Theory Techn.*, vol. 54, no. 5, pp. 1945–1952, May 2006.

[11] T. Yang, P.-L. Chi, and T. Itoh, "Compact quarter-wave resonator and its applications to miniaturized diplexer and triplexer," *IEEE Trans. Microw. Theory Techn.*, vol. 59, no. 2, pp. 260–269, Feb. 2011.

[12] H. Liu, W. Xu, Z. Zhang, and X. Guan, "Compact diplexer using slotline stepped impedance resonator," *IEEE Microw. Wireless Compon. Lett.*, vol. 23, no. 2, pp. 75–77, Feb. 2013.

[13] Y. Dong and T. Itoh, "Substrate integrated waveguide loaded by complementary split-ring resonators for miniaturized diplexer design," *IEEE Microw. Wireless. Compon. Lett.*, vol. 21, no. 1, pp. 10–12, Jan. 2011.

[14] S.-W. Wong, Z.-C. Zhang, S.-F. Feng, F.-C. Chen, L. Zhu, and Q.-X. Chu, "Triple-mode dielectric resonator diplexer for base-station applications," *IEEE Trans. Microw. Theory Techn.*, vol. 63, no. 12, pp. 3947–3953, Dec. 2015.

[15] L. Zhu, R. R. Mansour, and M. Yu, "Compact waveguide dual-band filters and diplexers," *IEEE Trans. Microw. Theory Techn.*, vol. 65, no. 5, pp. 1525–1533, May 2017.

[16] F. Cheng, X. Lin, K. Song, Y. Jiang, and Y. Fan, "Compact diplexer with high isolation using the dual-mode substrate integrated waveguide resonator," *IEEE Microw. Wireless Compon. Lett.*, vol. 23, no. 9, pp. 459–461, Sep. 2013.

[17] H. S. Peng and Y. C. Chiang, "Microstrip diplexer constructed with new types of dual-mode ring filters," *IEEE Microw. Wireless Compon. Lett.*, vol. 25, no. 1, pp. 7–9, Jan. 2015.

[18] L. Zhu, S. Sun, and W. Menzel, "Ultra-wideband (UWB) bandpass filters using multiple-mode resonator," *IEEE Microw. Wireless Compon. Lett.*, vol. 15, no. 11, pp. 796–798, Nov. 2005.

[19] S. W. Wong and L. Zhu, "EBG-embedded multiple-mode resonator for UWB bandpass filter with improved upper-stopband performance," *IEEE Microw. Wireless Compon. Lett.*, vol. 17, no. 6, pp. 421–423, Jun. 2007.

[20] S. W. Wong and L. Zhu, "Quadruple-mode UWB bandpass filter with improved out-of-band rejection," *IEEE Microw. Wireless Compon. Lett.*, vol. 19, no. 3, pp. 152–154, Mar. 2009.

[21] R. Zhang and L. Zhu, "Synthesis design of a wideband bandpass filter with inductively coupled short-circuited multi-mode resonator," *IEEE Microw. Wireless Compon. Lett.*, vol. 22, no. 10, pp. 509–511, Oct. 2012.

[22] R. Garg, P. Bhartia, I. Bahl, and A. Ittipiboon, *Microstrip Antenna Design Handbook*. Boston, MA, USA: Artech House, 2000, pp. 317–398.

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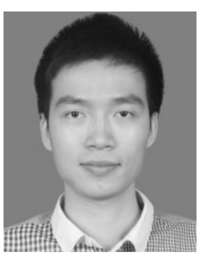

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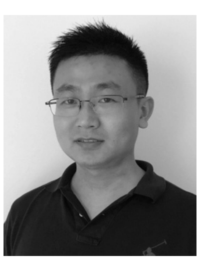

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