A Diplexer based on Hybrid Cavity and Microstrip Structure

Jiao Shu and Yerong Zhang

College of Electronic and Optical Engineering
Nanjing University of Posts and Telecommunications, Nanjing, 210003, China
sjsj6668@outlook.com, zhangyr@njupt.edu.cn

Abstract **─** This paper presents a high selective diplexer with hybrid filters, which is composed by dual-mode microstrip resonators with metallic coaxial shielding cases of RF module. By utilizing vertical space above microstrip circuits which greatly saves space, an additional pair of transmission pole and zero are hereby added in the passband and stopband, respectively. The proposed structure provides high quality-factors to enhance frequency selectivity. For demonstration, a diplexer prototype is designed and fabricated at the center frequencies (CF) of 2.40 and 3.45 GHz with a 3-dB passband bandwidth of 200 MHz. The measured insertion losses (IL) are 1.45 dB and 1.61 dB in the lower and upper passbands respectively. The output isolation between two channels is measured greater than 32 dB.

Index Terms **─** Cavity, diplexer, hybrid structure, microstrip.

I. INTRODUCTION

Diplexers are the key components in modern multi-services and multi-band communication systems, especially in the radio frequency (RF) front-ends. They are used to separate one input signal from two different frequencies into two individual signals at the output ports, or to combine two separate input signals into one. In order to decrease the number of antennas, the full-duplex wireless communication systems utilize diplexers for transmitting and receiving signals. In order to meet the demands of modern systems with stringent requirements, high-performance diplexers are necessary. Numerous literatures on designing diplexers have been reported in recent years. Compact composite right/left-handed (CRLH) microstrip resonators were used in diplexer [1]. Dual-mode resonators were employed to achieve a compact and wide-stopband diplexer [2]. High quality-factor (Q-factor) dielectric resonators were utilized to design diplexer in base station applications [3]. Substrate integrated waveguide (SIW) loaded with complementary split ring resonators (CSRRs) were applied to develop a compact diplexer [4]. SIW dual-mode filters with circular and elliptic cavities were implemented on a high performance diplexer [5].

In this paper, the diplexer with two triple-mode high-selectivity bandpass filters is designed. The proposed hybrid filter structure is realized by a metallic coaxial resonator formed by shielding cavity with a copper rod in space and a dual-mode planar microstrip resonator on the surface. In the case of maximizing the vertical space above the planar circuit, the third resonant mode has been generated without size enlargement. These hybrid structures not only introduce pairs of transmission zeros and poles which improved the out-of-band suppression but also greatly enhance the unloaded Q-factors. A high selective diplexer at frequencies of 2.4/3.45 GHz is designed and fabricated to demonstrate the proposed structure with good in-band performance. The measured results exhibit good agreements with the simulated ones by careful comparisons.

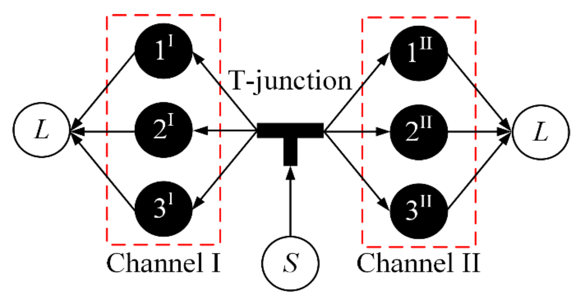


Fig. 1. Coupling and routing topology of the proposed diplexer.

II. DESIGN OF DIPLEXER AND FILTERS

The coupling and routing topology of the hybrid diplexer with triple-mode responses is illustrated in Fig. 1. Figure 2 shows the 3D configurations of the proposed hybrid diplexer which consists of two triple-mode filters. Meanwhile, the structures of the planar circuit parts are described in Fig. 3.

The proposed diplexer is comprising of two individuation channels connected with 50Ohm common input/output ports through a T-junction. Figure 1 shows the routing topology of triple mode resonator. The black node in each channel represents a resonant mode. For each proposed hybrid filter, the even and odd modes

Submitted On: December 27, 2018
Accepted On: May 12, 2019

(mode 1 and 3) are generated by planar microstrip structures, while the shielding cavity forms the high-Q resonant mode (mode 2) with a copper rod. Symbol S and symbol L are utilized to represent the input and output port. The band-pass filters of each channel are designed by using the hybrid cavity-microstrip structure with different specifications.

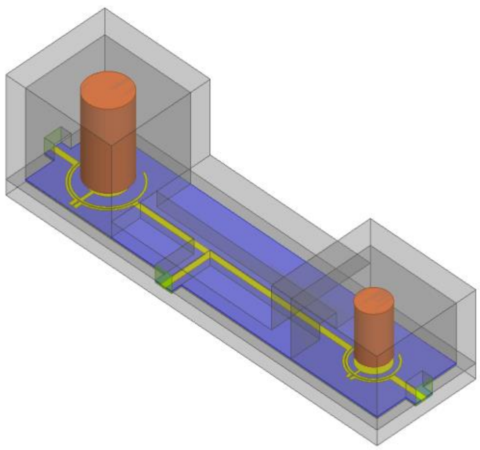
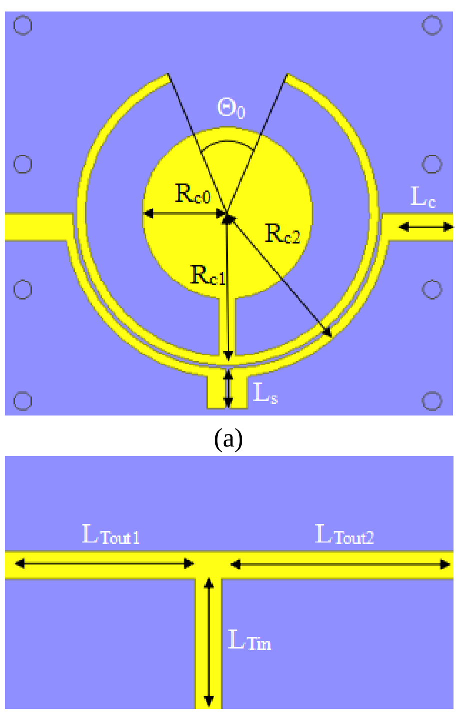


Fig. 2. 3D Configuration of the proposed diplexer.

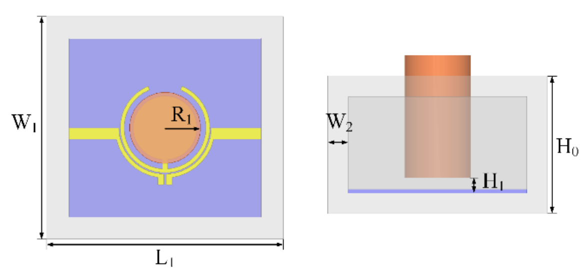


(b)

Fig. 3. Configurations of the diplexer components: (a) microstrip resonator and (b) T-junction.

After the two individual channels are designed, the T-junction is carefully designed and optimized for connecting the two sub-channels with I/O ports, and one stub could be considered as an open circuit to another.

The grounded planar dual-mode open-loop microstrip resonators in each channel have been demonstrated in the previous literature [6], and are utilized to design microstrip resonators with low Q-factor. The limited and relatively low unloaded quality factor is a part of the significant problems restricting the performance of filters. It is a known fact that coaxial resonators have greater quality factors than microstrip resonators. To obtain higher Q-factor and the selectivity of filter with the full use of the vertical space above the planar circuit, we introduced a copper rod into the shielding cavity for generating triple-mode resonance. As shown in Fig. 3 (a), the planar microstrip part consists of input and output coupling lines with dual-mode circular open-loop resonators. The characteristic impedance of the input/output lines are selected as 50Ω, and the length of source-load coupling line is L_s. The dual-mode filter is comprised of a half-wavelength resonator with a circular open stub placed in its center. The radius of the inner circular stub is R_{c0}, the radius of the open-loop resonator is R_{c1}, and the radius of the feeder is R_{c2}. From Fig. 3 (b), the T-junction with three stubs which connect the input port with two separate channels, the length of the stubs is L_{Tin}, L_{Tout1} and L_{Tout2} respectively. The layout of the proposed hybrid bandpass filter is shown in Fig. 4, while the radius of the centered copper rod is R_1, and the distance from the bottom of the rod to the planar microstrip circuit is H_1. The length, width, height, and thickness of the shielding cavity are L_1, W_1, H_0, and W_2, respectively. By welding the copper rod inside the shielding cavity to produce additional transmission zero and transmission pole, thereby enhancing out-of-band suppression and effectively improves the anti-jamming ability.



(a) (b)

Fig. 4. Layout of the proposed hybrid bandpass filter: (a) top view and (b) orthographic view.

Design of the proposed hybrid diplexer follows the following steps:

Step1: Based on the odd and even mode theory analysis, the initial dimensions of the dual-mode microstrip bandpass filters which operate at 2.4 GHz and 3.5 GHz are determined, respectively. For each microstrip filter, two transmission zeros in the higher frequency stopband of the filter are determined by the half-wavelength resonator with a circular stub. By changing the radius of the inner circular stub and increasing the length of source-load coupling feeders, the two transmission zeros in the higher frequency stopband can be adequately controlled. The first transmission zero moves to a higher frequency as the radius increases. The second transmission zero moves to a lower frequency as the coupling length decreases.

Step2: To improve the ability of out-of-band suppression and to improve the anti-jamming performance, we adopt the hybrid structure of a shielding cavity with a copper rod to generate the third resonant mode. By controlling the distance between the copper rod to the planar circuit, the frequency responses of the transmission zero in the lower stopband and the pole in the passband can be tuned to obtain the best triple-mode frequency response.

Step3: Optimizing the T-junction to connect both the triple-order bandpass filters to form the desired diplexer. For each stub of the two output ports, one stub could be considered as an open circuit to another.

To address the above scenario, we take the hybrid filter of Channel II with a central operating frequency of 3.45 GHz as the prototype model. Its coupling topology is shown in Fig. 1. Modes 1 and 3 are the even and odd modes of the planar dual-band microstrip resonator, while Mode 2 is formed by the coaxial shielding cavity. The coupling schemes can be analyzed from its coupling matrix [7]:

$$M=\begin{bmatrix} 0 & 0.4696 & 0.4575 & 0.7696 & -0.0145 \\ 0.4696 & -1.435 & 0 & 0 & 0.4696 \\ 0.4575 & 0 & 1.4029 & 0 & 0.4575 \\ 0.7696 & 0 & 0 & -0.0544 & -0.7696 \\ -0.0145 & 0.4696 & 0.4575 & -0.7696 & 0 \end{bmatrix}.$$

Since the proposed triple mode hybrid resonator exhibits symmetry, the coupling matrix is agreed with $M_{S1}=M_{1L}$, $M_{S2}=M_{2L}$, and $M_{S3}=-M_{3L}$. An additional transmission zero is implemented by the source-load coupling on the planar resonators. Although the cross-couplings are not precisely equal to zero, the number of cross-couplings is minimal that considered negligible when compared with the main couplings, which makes it easier to represent the coupling matrix. The generalized coupling matrix of the proposed hybrid filter of 3.45GHz is designed by synthesis method.

The geometric dimensions of the exampled 3.45GHz Channel with coaxial shielding cavity is derived as R_1=4.3mm, W_1=30mm, L_1=32mm, W_2=3mm, and H_0=20mm. Meanwhile, parameters of planar microstrip resonator are R_{c0}=4.3mm, R_{c1}=6.05mm, R_{c2}=6.75mm with Θ_0=22.4 deg. Figure 5 presents the frequency responses of the shielding cavity with or without the copper rod.

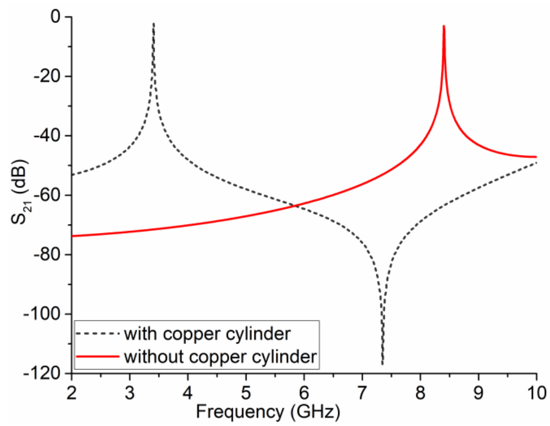


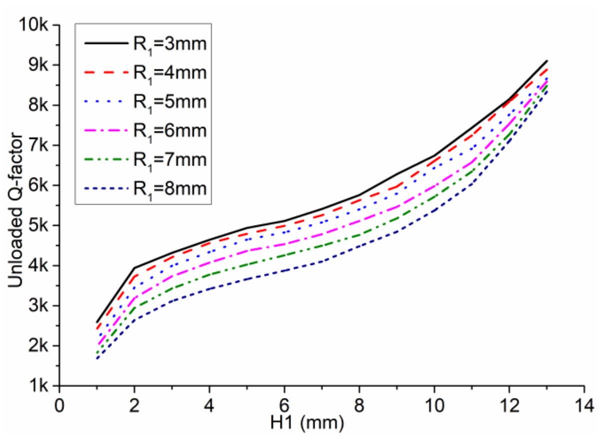
Fig. 5. Frequency responses of shielding cavity with or without copper cylinder.

Without the copper rod, the cavity resonates at the fundamental frequency of the TE_{101} mode (which operates at 8.36 GHz), by introducing the copper rod into the shielding cavity, the resonant frequency shifts to the lower band. Figure 6 exhibits the variation of resonant frequencies and unloaded Q factors with H_1 and R_1, when H_1 equals to 2.2 mm, and the resonant frequency is 3.41 GHz.

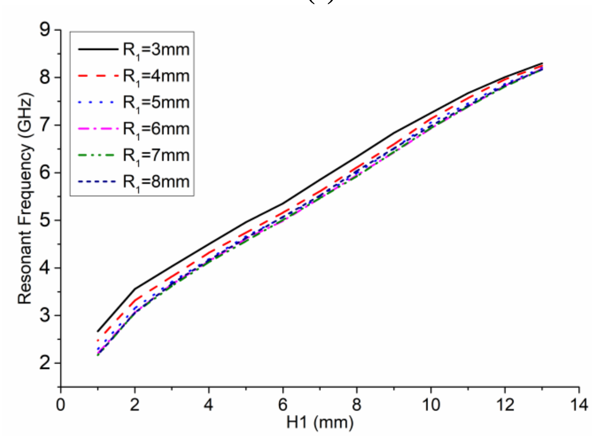
With the increase of H_1, the resonant frequency of the shielding cavity moves upward, and the Q_factor increases. With the additions of R_1, the resonant frequency moves to reduce, and the Q-factor decrease. However, with larger values of R_1, the influences on the resonant frequency and Q_factor decrease. For different resonance center frequencies, it is necessary to select the optimal values of H_1 and R_1 to obtain the best Q value by simulation. As a result, the proposed hybrid structure exhibits a higher unloaded Q-factor than the conventional microstrip resonators.

To verify the design concepts above, we designed and fabricated two hybrid cavity-microstrip bandpass filters on substrates, with the dielectric constant of 2.2 and a thickness of 0.508mm, operating at 2.40 GHz and 3.45 GHz respectively. The simulated and measured results are illustrated in Fig. 7 and Fig. 8, the simulated and measured results of the designed filters are shown with appropriate agreements.

After obtained the two filters with desired frequency responses, the T-junction is correctly designed for channel connection with the input/output ports. The specifications for both resonators and T-junction which constituted the exampled 2.4/3.45GHz diplexer are listed in Table 1, the width of the microstrip lines for both input and output lines are 1.54mm (the width of 50Ω microstrip line). The distance between the feeders to the resonators is 0.2mm, and the width of both feeders and the connection line between the circular stub and resonators are equal to 0.5mm. This designed diplexer occupies an overall size of $0.9\lambda_0 \times 0.24\lambda_0 \times 0.216\lambda_0$, where λ_0 is the wavelength in free space at the center frequency of the lower channel.



(a)



(b)

Fig. 6. Resonant frequency (a) and unloaded Q-factors (b) with the variations on H_1 and R_1.

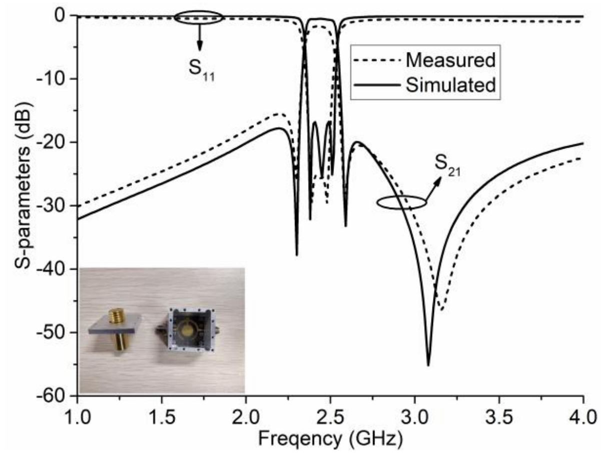


Fig. 7. Simulated and measured results of the proposed triple mode filter in Channel I.

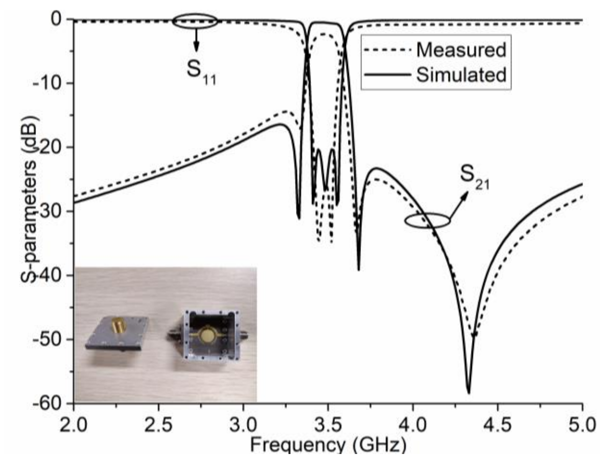


Fig. 8. Simulated and measured results of the proposed triple mode filter in Channel II.

Table 1: Specifications for the components of the diplexer

	R_{c0} (mm)	R_{c1}	R_{c2}	L_c	L_s	Θ_0 (deg)
Channel 1	4.8	8.5	9.2	4.3	2.2	23.2
Channel 2	4.3	6.05	6.75	6.75	1.4	22.4
	L_{Tin}(mm)		L_{Tout1}		L_{Tout2}	
T-junction	13.46		15		32	
	R_1	H_0	H_1	W_1	W_2	L_1
Cavity 1	6	27	2.1	30	3	32
Cavity 2	4.3	20	2.2	30	3	32

III. MEASUREMENT OF THE DIPLEXER

Based on the above analysis, the proposed hybrid cavity-microstrip structure is experimentally designed. The configuration for the 2.4/3.45GHz diplexer is shown in Fig. 2. The diplexer comprised of two individual triple-mode hybrid resonators connecting with a T-junction. Shielding cavities for each channel are fabricated by aluminum with an embedded copper cylinder. The planar microstrip circuits are fabricated on Taconic TLY-5 substrate with a relative dielectric constant of 2.2 and a thickness of 0.508mm. A photograph of the hybrid diplexer is shown in Fig. 9. And the simulated and measured results are presented in Fig. 10.

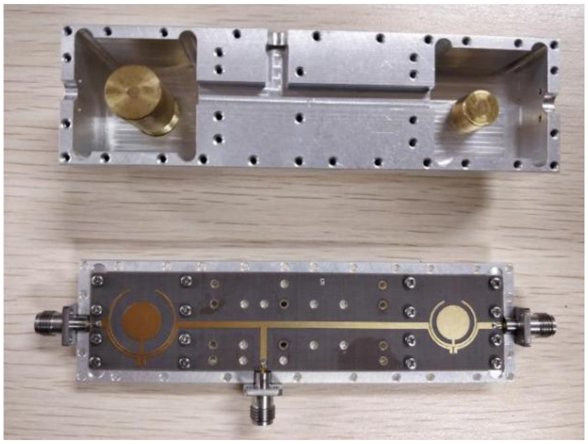


Fig. 9. Photograph of the proposed diplexer.

The measured frequencies of the two channels are centered at 2.40 GHz and 3.45 GHz with the corresponding 3-dB bandwidth of 8.3% and 5.8%. And the insertion losses of the two channels are 1.45 dB and 1.61 dB individually, which might comprise additional losses from surface mounted adapter (SMA) connectors. Measurement return losses are always better than 16 dB and 20 dB in the lower passband and higher passband. Three transmission zeros are generated to enhance the selectivity of each channel. The isolation between the two channels is better than 32 dB from 1 to 5 GHz. We hypothesized that the slight discrepancies between the measured and simulated results perhaps because of the connections with the test fixture and the unexpectedly tolerances from fabrication. Table 2 summarized comparisons between diplexers from reported in Section I and the proposed diplexer, since the heights of the airbox were not given in [1], [3] and [4], the values of height (the third parameter) in Table 2 are estimated from simulation conditions does not include the thickness of shielding cavities(five times as the thickness of the substrate).

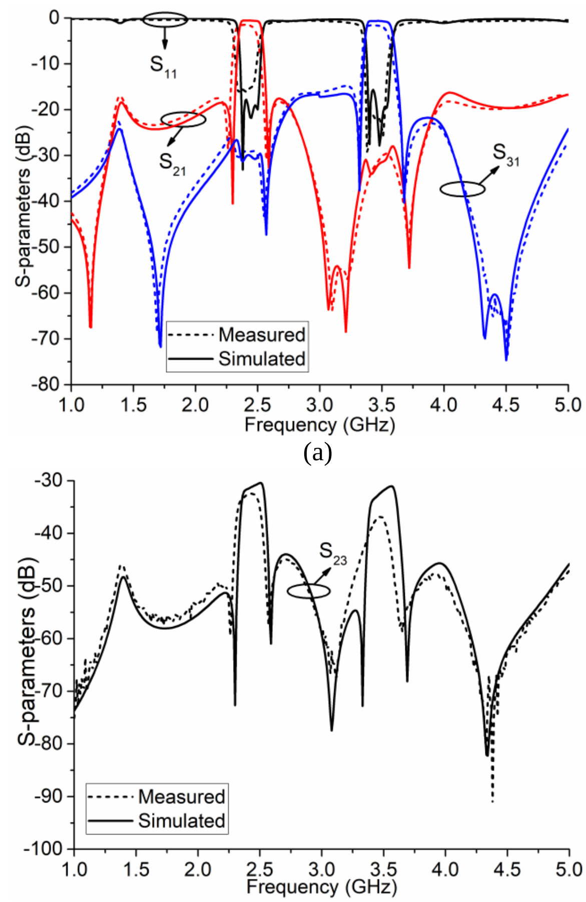


Fig. 10. Comparisons of simulated and measured results for: (a) S11, S21 and S31 and (b) S23 of the proposed diplexer.

Table 2: Comparisons with other reported literatures

Reference	CF (GHz)	Structure	Order	IL (dB)	Isolation (dB)	Size
[1]	1.80/2.38	Microstrip	3	1.38/1.44	>25	$0.12\lambda_g\times0.23\lambda_g\times0.022\lambda_g$
[2]	1.95/2.14	Microstrip	2	1.64/1.59	>30	$0.17\lambda_g\times0.35\lambda_g\times0.027\lambda_g$
[3]	2.55/2.66	Dielectric	3	0.63/1.10	>18	$1.02\lambda_0\times0.51\lambda_0\times0.52\lambda_0$
[4]	4.66/5.80	SIW	2	1.60/2.30	>32	$0.27\lambda_0\times0.217\lambda_0\times0.008\lambda_0$
This work	2.40/3.45	Hybrid	3	1.45/1.61	>32	$0.9\lambda_0\times0.24\lambda_0\times0.216\lambda_0$ ($1.18\lambda_g\times0.316\lambda_g\times0.284\lambda_g$)

IV. CONCLUSION

A hybrid cavity-microstrip diplexer with multiple-controllable TZs is proposed and demonstrated in this paper. Two triple-mode bandpass filters with high Q-factor and high selectivity are obtained by utilizing the proposed hybrid structure. In addition to the planar microstrip dual-mode resonator, the third resonant mode is produced by the couplings between the planar circuits and shielding cavity with a copper rod, significantly improves the frequency selectivity and the isolation between channels. The correctness of the design is verified by the prototype test; the measurement agrees well with simulated results. With the merits of low insertion loss, high selectivity and high isolation, which provides a good choice of modern multi-service and multi-band communication applications.

REFERENCES

[1] T. Yang, P. Chi, and T. Itoh, "Compact quarter-wave resonator and its applications to miniaturized diplexer and triplexer," *IEEE Transactions on Microwave Theory and Techniques*, vol. 59, no. 2, pp. 260-269, Feb. 2011.

[2] Q. Duan, K. Song, F. Chen, and Y. Fan, "Compact wide-stopband diplexer using dual mode resonators," *Electronics Letters*, vol. 51, no. 14, pp. 1085-1087, July 9, 2015.

[3] S. Wong, Z. Zhang, S. Feng, F. Chen, L. Zhu, and Q. Chu, "Triple-mode dielectric resonator diplexer for base-station applications," *IEEE Transactions on Microwave Theory and Techniques*, vol. 63, no. 12, pp. 3947-3953, Dec. 2015.

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

[5] H. J. Tang, W. Hong, J. 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 Transactions on Microwave Theory and Techniques*, vol. 55, no. 4, pp. 776-782, Apr. 2007.

[6] X. Zhang, Z. Yu, and J. Xu, "Design of microstrip dual-mode filters based on source-load coupling," *IEEE Microwave and Wireless Components Letters*, vol. 18, no. 10, pp. 677-679, Oct. 2008.

[7] J. R. Cameron, "General coupling matrix synthesis methods for Chebyshev filtering functions," *IEEE Transactions on Microwave Theory and Techniques*, vol. 47, no. 4, pp. 433-442, 1999.

Jiao Shu was born in Jiangsu, China. He received his B.S. degree from Nanjing University of Posts and Telecommunications in 2012. He received Master degree from Loyola Marymount University in 2013 in U.S. Since September 2014, he is a Ph.D. student at Nanjing University of Posts and Telecommunications. His interests involve RF/microwave devices, such as antennas and filters.

Yerong Zhang was born in Anhui, China. He received his Ph.D from University of Electronic Science and Technology of China in 1996. He is a Professor with NUPT. In recent years, his main research fields are mobile communication network planning and optimization, wireless communication and electromagnetic compatibility, electromagnetic scattering and imaging, and numerical calculation of electromagnetic theory.