Design of Compact BPF and Planar Diplexer for UMTS using Embedded-Scheme Resonator

Bin-Feng ZONG [1], *Guang-Ming WANG* [1], *Ya-Wei WANG* [1], *Fan WU* [2]

[1] Air and missile defense college, Air Force Engineering University, Shaanxi Province 710051, People's Republic of China
[2] Air Force Engineering University, Shaanxi Province 710051, People's Republic of China

zongbinfeng@sina.com, wgming01@sina.com

Abstract. *A compact planar diplexer utilizing embedded-scheme resonator (ESR) is designed for universal mobile telecommunications system (UMTS). The ESR is formed by embedding interdigital resonators into an open loop resonator. Based on the proposed ESR, a narrowband bandpass filter suitable for diplexer design is proposed, fabricated and measured. The measured results demonstrate that the filter exhibits good transmission properties within band and high frequency selectivity. The rectangular area occupied by the filter has overall dimensions only 0.086*λ_g *by 0.105*λ_g*, promises good potential in wireless communication systems that require compact size and high encapsulation quality. Then, a compact planar diplexer operating at the TX-band of 1920-1980 MHz and the RX-band of 2110-2170 MHz, which is composed of a meander T-junction and two filters initially separately designed, is synthesized, simulated and measured. Both the simulated and measured results indicate that satisfied impedance matching and good isolation between two paths have been achieved.*

Keywords

Embedded-scheme resonator, bandpass filter, planar diplexer.

1. Introduction

The planar diplexer, a three-port multifrequency device, is indispensable in radio frequency (RF) front-ends of modern wireless communication systems because of its light weight, low cost and ease of fabrication. As the planar diplexer is easy to integrate with other devices, various methods have been studied to design planar diplexers with excellent performance. In [1], a diplexer composed of two bandpass filters (BPFs) implemented by quasi-lumped elements was proposed for UMTS operating in the TX-band of 1920-1980 MHz and the RX-band of 2110-2170 MHz. The quasi-lumped structure is composed of coplanar waveguide (CPW) and microstrip structure. This structure provides a serial distribution inductance and capacitance shunt to the ground, which creates an attenuation pole for enhancing the channel isolation between the TX-port and the RX-port. However, the fabrication technology of this diplexer is so complex that it leads to difficulty in application to the integrated circuits. Another planar diplexer designed for UMTS, using square open loop with stepped impedance resonators, was introduced in [2], but the given prototype is based on the electromagnetic coupling and the transversal dimension of the diplexer is too large for a compact system. Additionally, a type of frequency selective diplexer using microwave photonic band gap (PBG) structures was proposed in [3], where the propagation of incident wave in the microwave region can be controlled by two different PBGs, but preparation of PBG materials costs so much that it is not suitable to mass production. In [4], a microstrip diplexer for 3G wireless communication system using fractal geometry was designed. However, its large size results in little advantages in compact system.

In recent years, left-handed material has become one of the most active research fields, and many components have been designed using composite right/left-handed transmission lines (CRLH-TL) [5], [6]. In [5], a diplexer based on two-stage CSRR-based structure was proposed. In this structure, a series gap is etched in the output CSRR stage and two shunt stubs are added in the input cell. However, the back radiation problem will be introduced in designed diplexer due to the existence of defected ground structures (DGS), and two different sections will complicate the design procedures and increase size.

In this paper, a planar compact narrowband BPF operating at 2 GHz is designed based on an ESR, which was initially proposed. The ESR is formed by embedding interdigital resonators into an open loop resonator. To achieve a desired external coupling for operating band, a folded T-shaped feed line is adopted. It is demonstrated that the filters have transmission zeros at both sides of the passband for good attenuation and sharp transition bands. Moreover, components based on the resonator are suitable for narrowband systems. Through parametric analysis, simple design rules for the geometrical parameters of the ESR are achieved, and two filters operating at the TX-band of 1920-1980 MHz and the RX-band of 2110-2170 MHz are obtained using these design rules. Then, a planar diplexer for UMTS was designed and fabricated using the proposed type of filters.

2. Filter Design Based on ESR

2.1 Filter Configuration and Design Concept

Fig. 1 shows the configuration of the proposed filter based on the ESR. As we can see, the ESR is formed by embedding interdigital resonators into an open loop resonator, and the interdigital resonators are both shorted to the ground through metallic via holes on the fingers which are far away from the split. The open loop can produce a resonance frequency because it can be treated as a parallel *LC* resonant tank composed of inductance L_o and capacitance C_o shunt to the host transmission line. The interdigital structure can perform slow wave property [7], so the resonant frequency of open loop resonator can be decreased. The ground shorted finger also provides a parallel *LC* resonant tank composed of inductance L_c and capacitance C_c and another resonant frequency can be produced. As these poles are located at close frequencies, a filter with two transmission poles can be obtained. The ground-shorted embedded interdigital resonator can be equal to a serial distribution inductance L_g and capacitance C_g shunt to the ground, and a transmission zero appears.

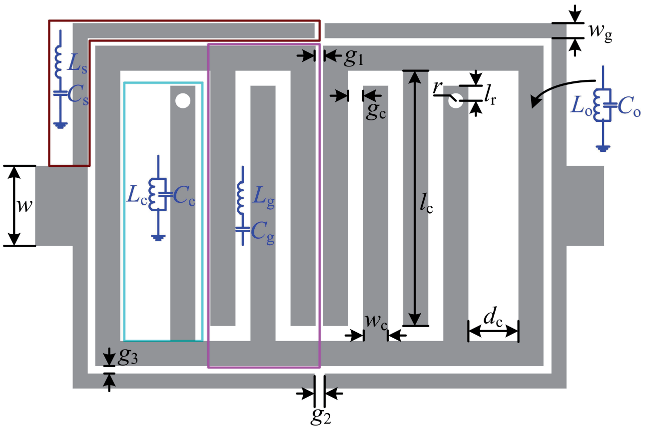


Fig. 1. Configiration of the proposed filter.

To achieve a desired external coupling for operating band, a folded T-shaped feed line is adopted in this paper. And this T-shaped feed line can also provide a serial *LC* tank composed of inductance L_s and capacitance C_s, which can offer a transmission zero for good selectivity and suppression. By tuning the parameters g_1, g_2, g_3 and w_g, good external coupling can be achieved and transmission zero appears at necessary frequency.

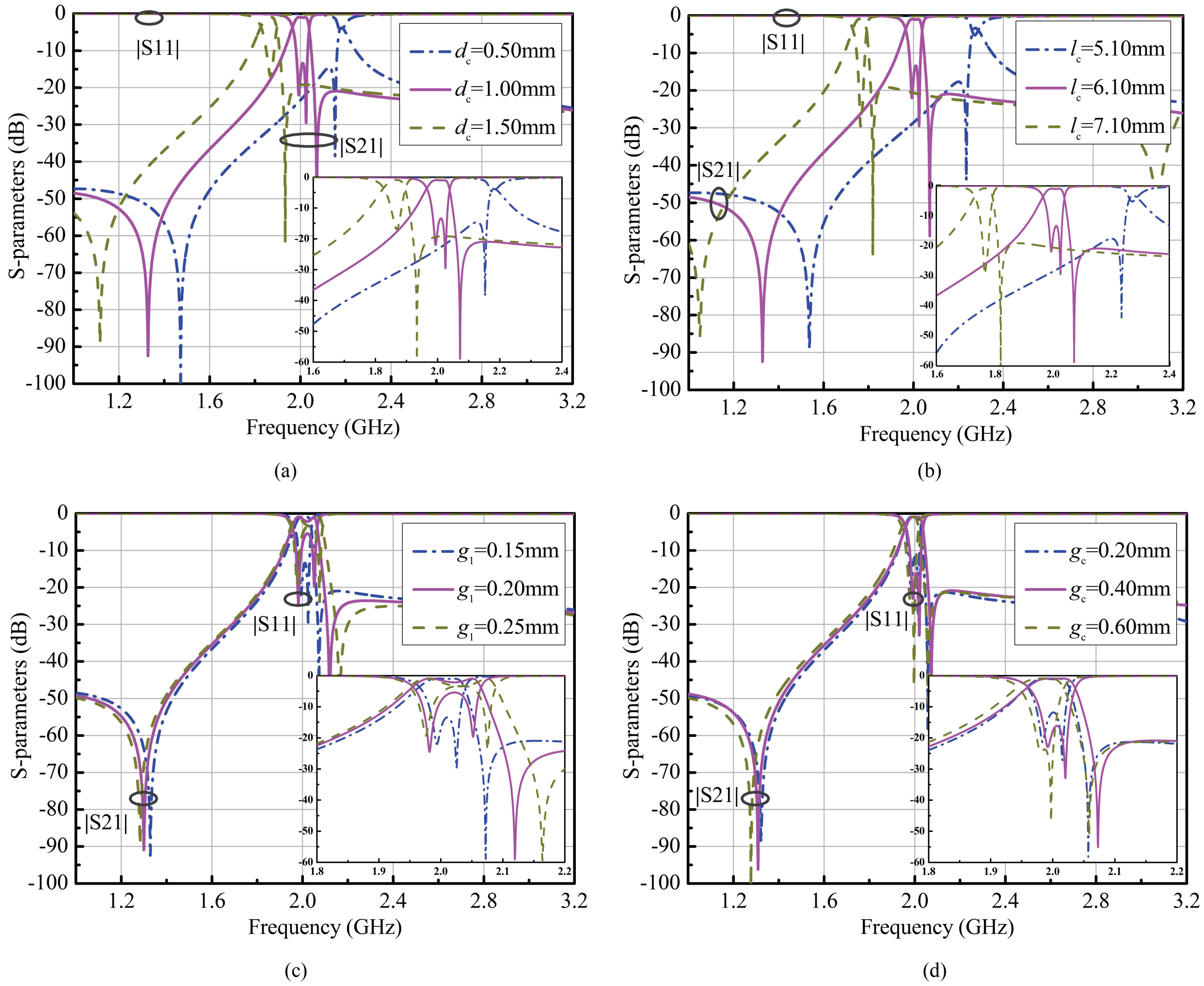


Fig. 2. Simulated S-parameters for the ESR with key parameters varying (a) d_c, (b) l_c, (c) g_1, (d) g_c.

From the above analysis, we can infer that the proposed filter has two transmission poles in band and two transmission zeros. At design procedure, the transmission zeros can be put at both sides of the band by adjusting dimensions of the proposed filter for good selectivity.

2.2 Parametric Analysis

In order to design a filter effectively, the geometrical parameters study is necessary. The effects of varying the key parameters of the ESR are present in Fig. 2. To reduce the number of variables, the following parameters of the resonator are kept constant in this section: $w_c = 0.5$ mm, $r = 0.15$ mm, $l_r = 0.35$ mm, as well as the width of 50 ohm microstrip line w, which is 1.6 mm. The F4B-2 substrate with a relative dielectric constant of 2.65 and thickness of 0.6 mm is utilized in both simulation and fabrication.

In Fig. 2(a) and (b), it is interesting to learn that the increase of d_c and l_c will move the passband of the filter downward. For d_c, a slight variation of ±0.5 mm can result in shifting of the centre frequency by ±0.2 GHz; and for l_c, it can also lead to about ±0.2 GHz shifting with ±1 mm change. Thus, d_c and l_c can be adjusted to set the passband within the required frequency band. It can also be learned that the transmission zero close to the passband is shifted from one side to another as d_c and l_c are decreasing. So, a narrow transition band can be controlled at both sides of the passband. Unfortunately, the insertion loss is deteriorated when the value of d_c and l_c are too low or too high. In Fig. 2(c), it can be observed that when g_1 becomes bigger, the upper transmission pole is influenced more greatly than the lower one, and the frequency of upper pole is increased. When g_c is varied as shown in Fig. 2(d), the transmission characteristics are affected slightly, which can play an assistant role in filter design.

2.3 Fabrication and Measurement of the Proposed Filter

To validate the characteristics of the proposed filter based on the ESR, a filter operating at 2 GHz has been fabricated and measured. The structure parameters are $l_c = 6.1$ mm, $g_c = 0.3$ mm, $d_c = 1$ mm, $w_g = 0.3$ mm, $g_1 = 0.15$ mm, $g_2 = 0.2$ mm, $g_3 = 0.15$ mm. Fig. 3 depicts the photograph of the fabricated filter. An Anritsu ME7808A vector network analyzer is used for measurement. Fig. 4 shows both full-wave simulated and measured results of the filter. It can be observed that the fabricated filter has centre frequency of 2.05 GHz, which deviates slightly from the simulated results. The transmission zeros at both sides of the passband are also shifted. The lower one is decreased from 1.33 GHz to 1.25 GHz, and the upper one is increased from 2.07 GHz to 2.2 GHz, which slightly influences on selectivity. The transmission zero at 2.2 GHz is very close to the passband for high sharp transition bands. Besides, |S21| is lower than -20 dB from 1.2 GHz to 1.93 GHz and from 2.15 GHz to 3.6 GHz, which shows good out-of-band suppression of this filter. As a whole, good agreement between the measured and simulated results is obtained.

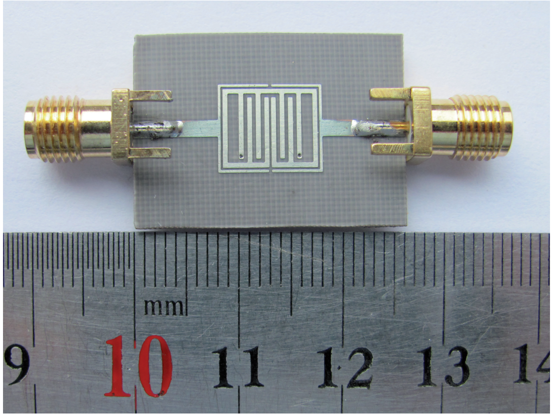


Fig. 3. Photograph of the fabricated filter.

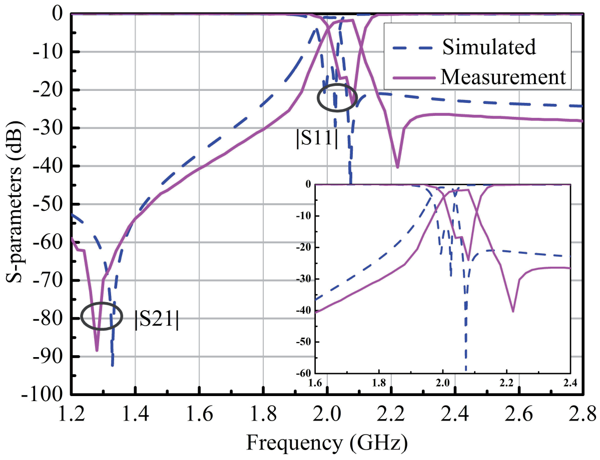


Fig. 4. Simulated and measured S-parameter of the proposed narrowband filter.

	Insertion loss	2-D dimension
This work	1.72dB	0.105λg by 0.086λg
Ref.8	2.5dB	0.167λg by 0.087λg
Ref.9	2.04dB	0.225λg by 0. 140λg
Ref.10	2dB	>0.219λg by 0. 219λg

Tab. 1. Comparison with the narrowband BPFs in references.

The rectangle area occupied by the filter has overall dimensions of $0.086\lambda_g$ by $0.105\lambda_g$, where λ_g is the guide wavelength at 2.05 GHz. To our best knowledge, the proposed filter is the smallest of this kind reported in the literature until now. Tab. 1 provides dimension and insertion loss comparison between the proposed filter and other designs in the previous literature [8-10]. According to the results, the insertion loss of proposed filter is less than for those filters in the literature. Simultaneously, the overall dimension of the filter in this paper is smaller than for the referenced filters, making it very useful for wireless communication systems that require high encapsulation quality.

3. Planar Diplexer for UMTS

Under the guidance of the above design rules, the filters operating at the TX-band and the RX-band for UMTS based on the ESR can be designed. Tab. 2 gives specific parameters for these two filters.

Channels	l_c	g_c	d_c	w_c	r
TX-band	6.8	0.3	0.6	0.5	0.15
RX-band	5.4	0.3	1.2	0.5	0.15
Channels	l_r	g_1	g_2	g_3	w_g
TX-band	0.35	0.16	0.2	0.12	0.2
RX-band	0.3	0.18	0.2	0.15	0.3

Tab. 2. The geometrical parameters of the TX- and RX-band filters (unit: mm).

Then, a diplexer for UMTS based on the filters of the TX-band and the RX-band is designed. Fig. 6 depicts layout of the proposed diplexer. In this paper, a conventional T-junction divider is combined with the proposed filters operating at the TX-band and the RX-band. To eliminate crosstalk, good impedance matching is required. In detail, the input impedance needs to satisfy the following conditions for the centre frequencies of the TX-band and the RX-band [11]:

$$Z_{inA} = \begin{cases} \infty & \text{at RX-band} \\ 50\Omega & \text{at TX-band} \end{cases} \tag{1}$$

$$Z_{inB} = \begin{cases} 50\Omega & \text{at TX-band} \\ \infty & \text{at RX-band} \end{cases} \tag{2}$$

where Z_{inA} and Z_{inB} are the input impedances of the diplexer at the T-junction looking into the upper and the lower paths respectively. Here, the dashed lines are the reference planes. In general, by connecting the arms using a common microstrip line, which has the same characteristic impedance $Z_0 = 50\ \Omega$, can easily satisfy the condition. At the junction, it can ensure an open circuit while the other one is passageway. To reduce the required area of the diplexer, meander microstrip line is introduced. The lengths from the tapping position of the connecting microstrip to the TX- and RX-circuit are 43.4 and 42.9 mm, respectively.

Next, the proposed diplexer for UMTS has been fabricated and measured. The photograph of the fabricated diplexer is shown in Fig. 7. Fig. 8 presents the simulation and measurement results of the diplexer. It can be seen that the performance of the two filers designed independently agrees well with the proposed diplexer, which justifies applicability of this procedure. In Fig. 8(b), good agreement between the simulation and measurement results is observed. The measured center frequencies of the two channels are 1.96 GHz and 2.13 GHz, respectively, which shift slightly from the simulated results. The measured |S21| is better than -2 dB at the TX-band while |S11| is lower than -13 dB. |S31| is better than -1.7 dB and |S11| is lower than -20 dB at the RX-band, whereas the simulated minimum insertion losses are 1.1 dB at the TX-band and 1 dB at the RX-band, respectively. The difference between the measurement and simulation may be ascribed to the fabrication error and anisotropy of the substrate. Because the filter has transmission zeros at both sides of the passband for sharp transition bands, Ports 2 and 3 have good isolation (better than 24.8 dB) within the whole frequency band. Both measured suppressions at 1.96 GHz for TX-band filter and at 2.13 GHz of RX-band filter are better than 22 dB. The diplexer is uniplanar and it has compact dimension of $0.23\lambda_g \times 0.23\lambda_g$, where λ_g is the guide wavelength at the center frequency of the lower passband.

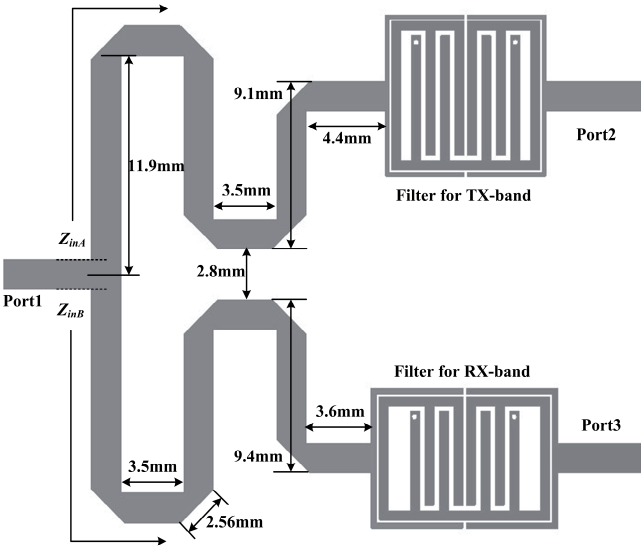


Fig. 6. Layout of the proposed diplexer for UMTS.

Tab. 3 compares isolations, suppressions and structure order of diplexers between the proposed one and those in reference [4], [5] and [11]. It can be found that the diplexer in this paper has advantages in size and insertion loss, which makes it satisfy the needs of UMTS.

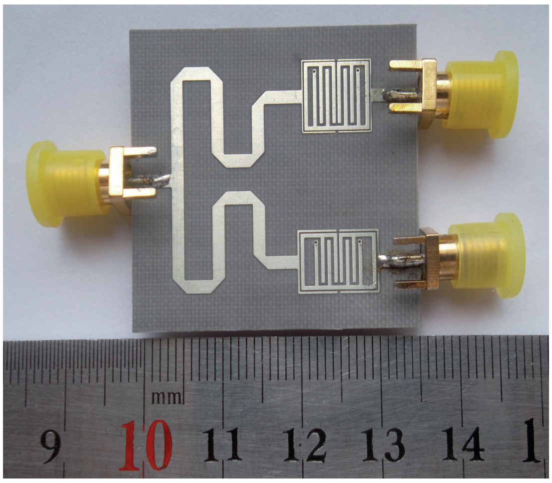
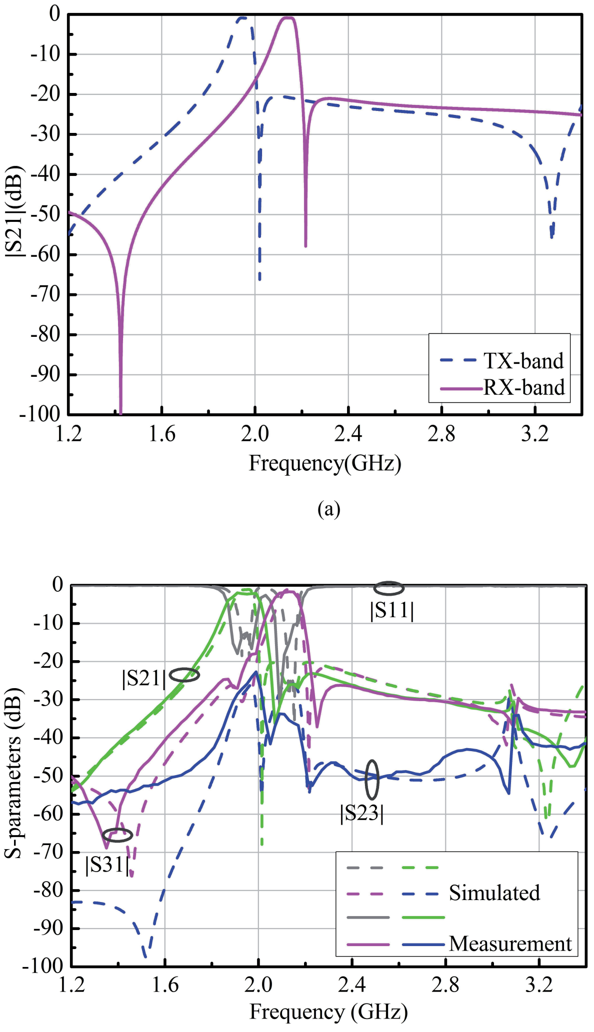


Fig. 7. Photograph of the planar diplexer for UMTS.

	|S23| (Isolations)		|S21| or |S31| (Suppressions)		|S21| or |S31| (Insertion loss)		Structure order	Dimension
	Channel1	Channel2	Channel1	Channel2	Channel1	Channel2		
This work	24.8dB@ 1.96GHz	33dB@ 2.13GHz	22dB@ 1.96GHz	33dB@ 2.13GHz	2dB@ 1.96GHz	1.7dB@ 2.13GHz	2	$0.23\lambda_g$ by $0.23\lambda_g$
Ref.4	>30dB@ 1.93GHz	>30dB@ 2.12GHz	>30dB@ 1.93GHz	>40dB@ 2.12GHz	>2dB@ 1.93GHz	>2dB@ 2.12GHz	6	Not given
Ref.5	>30dB@ 2.4GHz	>35dB@ 3GHz	>30dB@ 2.4GHz	>30dB@ 3GHz	2dB@ 2.4GHz	2dB@ 3GHz	2	$0.34\lambda_g$ by $0.62\lambda_g$
Ref.11	60dB@ 1.8GHz	60dB@ 2.45GHz	60dB@ 1.8GHz	60dB@ 2.45GHz	2.51dB@ 1.8GHz	2.17dB@ 2.45GHz	4	$0.18\lambda_g$ by $0.27\lambda_g$

Tab. 3. Comparison with some diplexers in references.



(a)

(b)

Fig. 8. (a) Simulated |S21| for independently designed the TX- and RX-band filters. (b) Simulated and measured S-parameters of the proposed diplexer for UMTS.

4. Conclusion

In this paper, a compact planar diplexer for UMTS using an ESR is proposed. Firstly, an extremely compact filter is investigated. It exhibits transmission properties superior to previous publications. Through parametric analysis, the influence of geometrical parameters is investigated thoroughly and two filters operating at the TX-band of 1920-1980 MHz and the RX-band of 2110-2170 MHz are designed. Based on the above results, a planar diplexer for UMTS composed of a folded T-junction and two different BPFs is designed and fabricated. The performance of the fabricated diplexer is satisfactory, not only its transmission property, but also the isolation. All of these merits make this diplexer a potential candidate for narrowband UMTS.

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References

[1] XU, W.-Q., HO, M.-H., HSU, C-I.-G. Quasi-lumped design of UMTS diplexer using combined CPW and microstrip. *IEEE Microwave and Optical Technology Letters,* 2009, vol. 51, no. 1, p. 150 - 152.

[2] HUANG, C.-Y., WENG, M.-H. High band isolation and wide stopband diplexer using dual-mode stepped-impendance resonators. *Progress In Electromagnetics Research*, 2010, vol. 100, p. 299 to 308.

[3] OH, S.-S., KEE, C.-S., KIM, J.-E., PARK, H.-Y. Duplexer using microwave photonic band gap structure. *Applied Physics Letters*, 2000, vol. 76, no. 16, p. 2301 - 2303.

[4] LIANG, J.-G., CHEN, W.-L., WANG, G.-M. Harmonics suppression microstrip diplexer for 3G wireless communication system using fractal-shaped geometry. *IEEE Microwave and Optical Technology Letters,* 2007, vol. 49, no. 12, p. 150 - 152.

[5] BONACHE, J., GIL, I., GARCIA-GARCIA, J., MARTIN, F. Complementary split ring resonators for microstrip diplexer design. *Electronics Letters*, July 2005, vol. 41, no. 14, p. 810-811.

[6] JIMENEZ-MARTIN, J.-L., GONZALEZ-POSADAS, V., ARQUES, F.-J., GARCIA-MUNOZ, L.-E., SEGOVIA-VARGAS, D. Dual band high efficiency power amplifier based on CRLH lines. *Radioengineering*, 2009, vol. 18, no. 4, p. 567 - 578.

[7] WANG, C.-W., MA, T.-G., CHANG, C.-F. A new planar artifical transmission line and its applications to a miniaturized butler matrix. *IEEE Transaction Microwave Theory and Techniques,* 2007, vol. 55, no. 12, p. 2792 - 2801.

[8] HSU, H.-W., LAI, C.-H., MA, T.-G. A miniaturized dual-mode ring bandpass filter. *IEEE Microwave and Wireless Components Letters,* 2010, vol. 20, no. 10, p. 542 - 544.

[9] GÖRÜR, A., KARUPZ, C. Miniature dual-mode microstrip filters. *IEEE Microwave and Wireless Components Letters,* 2007, vol. 17, no. 1, p. 37 - 39.

[10] ZHU, L., TAN, B.-C., QUEK, S.-J. Miniaturized dual-mode bandpass filter using inductively loaded cross-slotted patch resonator. *IEEE Microwave and Wireless Components Letters,* 2005, vol. 15, no. 1, p. 22 - 24.

[11] YANG, T., CHI, P.-L., ITOH, T. High isolation and compact diplexer using the hybrid resonators. *IEEE Microwave and Wireless Components Letters,* 2010, vol. 20, no. 10, p. 551 - 553.

About Authors ...

Bin-Feng ZONG was born in Jiangsu province of People’s Republic of China. He received his B.S. and M.S. degrees from the Air Force Engineering University, Xi’an, China, in 2010 and 2012, respectively. His research interests include microstrip resonators, composite right/left-handed (CRLH) transmission lines and metamaterial-based antennas.

Guang-Ming WANG was born in Anhui province of People’s Republic of China. He received his B.S. and M.S. degrees from the Missile Institute of Air Force Engineering University, Xi’an, China, in 1982 and 1990, respectively, and his Ph.D. degree from the Electronic Science and Technology University, Chengdu, China, in 1994. Then, he joined the Air Force Engineering University as a professor in 2000 and is now the head of the Microwave Laboratory center in it. His current interest includes microwave circuits, antenna and propagation, and also the new structures include EBG, PBG, metamaterials and fractals, etc.

Ya-Wei WANG was born in Anhui province of People’s Republic of China. He received his B.S. and M.S. degrees from the Air Force Engineering University, Xi’an, China, in 2008 and 2011, respectively. His research interests are mainly spiral antennas, metamaterial-based antennas, etc.

Fan WU was born in Shaanxi province of People’s Republic of China. She received her B.S. and M.S. degrees in 1997 and 2007, respectively. She joined the Air Force Engineering University as an instructor in 1997. Her current interests are English for special science and technology and education management, etc.