Design of Compact Planar Diplexer Based on Novel Spiral-Based Resonators

Ke LU, Guang-Ming WANG, Hai-yang XU, Xiong YIN

Missile Institute of Air Force Engineering University, Sanyuan, Shaanxi, 713800, China

lookluna@126.com, wgming01@sina.com, xuhaiyang.8888@163.com, yinxiong325@163.com

Abstract. *A miniaturized planar diplexer utilizing the novel spiral-based resonators is proposed. The given cell which is initially proposed in this article is composed of two separated rectangular spirals which are asymmetrical to each other and thus, it is called as 'asymmetrical separated spirals resonator' (ASSR). ASSR has more superior transmission property than the previous prototype and extremely compact dimension is also achieved. It is demonstrated that ASSR can exhibit bandpass performance with high frequency selectivity and good transmission property within the relatively low frequency band. Based on the given characteristic, one planar diplexer composed of T-junction and two ASSRs is synthesized and the fabricated prototype with compact dimension is achieved, thanks to ASSRs explored. Simultaneously, the transversal dimension of each channel is extremely compact because ASSRs are completely embedded in the feed lines. Both the simulated and measured results indicate that satisfactory impedance matching and high isolation between two channels are achieved. Furthermore, the proposed diplexer is uniplanar and no defected ground structure is introduced.*

Keywords

Miniaturized planar diplexer, spiral-based resonator, high frequency selectivity

1. Introduction

The planar diplexers which are the key components in the RF terminals are widely utilized because of their light-weight, low cost and easy fabrication. Simultaneously, it is convenient for the planar diplexers to integrate with other printed components. Thus, various methods have been extensively studied to design the planar diplexers with superior performance. In [1], one planar diplexer based on the double-loop-coupled-resonator filter was proposed for the 3G communication systems. The given double-loop-coupled-resonator is composed of two uniplanar double spiral resonant cells which were proposed formally in the latter literature. The mixed coupling phenomenon within the given resonator is utilized to generate the transmission zeros with the aim of enhancing the channel isolation and band rejection. Whereas, the transversal dimension of the given resonator is much larger than the one of the feed line which will lead to the difficulty in optimizing the layout when the planar diplexer is applied to the integrated circuits. For the planar diplexer proposed in [2], the square ring stepped impedance resonator is utilized to get the bandpass filter with compact dimension and satisfactory bandpass performance. The given prototype also operates through the electromagnetic coupling and the problem of large transversal dimension is maintained. In [3], the bandpass filters of the planar diplexer are designed through cascading two sections. One is the composite right\left-handed section composed of complementary split rings resonator (CSRR) and series gap on the conducting strip while the other is the combination of CSRRs and shunt-connected inductive strips. The defected ground structures introduced in the given diplexer may lead to the back radiation problem. Simultaneously, two different sections will surely increase the design procedures and adjustment difficulty. On the other hand, the shunt-connected strips also cause the problem of large transversal dimension. Recently, one planar diplexer based on the combination of the substrate integrated waveguide (SIW) and CSRRs etched on the waveguide surface is proposed [4]. Rather good performance has been achieved, but the disadvantage of the large transversal dimension still exists, because the transversal dimension of SIW is still larger than the one of the feed line.

In this article, one novel spiral-based resonator is initially proposed and applied to the planar diplexer. The spiral-based resonator derives from the uniplanar double spiral resonant cell (UDSRC) and the transmission line based on UDSRCs in [5], [6]. In [7], one metamaterial cell was presented to solve the limitation to achieve the compact dimension for the previous UDSRC-based transmission line. The given cell is composed of two separated rectangular spirals which are symmetrical to each other and here it is called as 'symmetrical separated spirals resonator' (SSSR) for convenience. The cell proposed in this article is the improved vision of SSSR. It is composed of two separated rectangular spirals which are asymmetrical to each other while it is called as 'asymmetrical separated spirals resonator' (ASSR) for comparison. It is demonstrated that ASSR exhibits more superior transmission property than SSSR. Through parametric analysis, simple design rules about the geometrical parameters of ASSR are achieved. Then, one planar diplexer utilizing ASSRs is designed and fabricated. The fabricated prototype with the compact dimension of $0.17\lambda\times0.04\lambda$is achieved ($\lambda$ is free-space wavelength at the center frequency of the lower passband). The width of the transversal section of each channel is 0.02λ because ASSRs are completely embedded in the feed lines. The proposed diplexer is uniplanar, so that there is no back radiation problem which is common for the defected ground structures.

2. Design of ASSR

2.1 Improvement of Spiral-Based Resonators

The spiral-based metamaterial cell, uniplanar double spiral resonant cell (UDSRC) was initially investigated in [5], [6]. This cell is produced by connecting two rectangular spirals in series with thin metallic strip. But single UDSRC cannot exhibit the expected bandpass property like the left-handed transmission line. As shown in Fig.1, 'prototype A', the UDSRC-based transmission line was proposed and its left-handed propagation property was demonstrated.

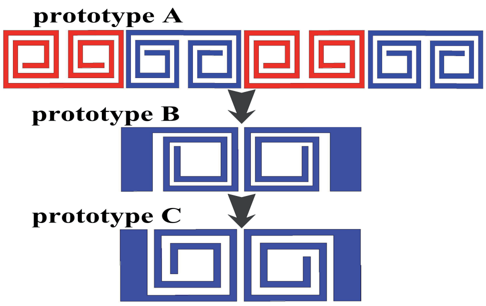

Fig. 1. Schematic representation of the improvement of spiral-based resonators.

For 'prototype A', to get the bandpass property, two or more UDSRCs are necessary and thus, further miniaturization is difficult to some extent. To solve this limitation, 'prototype B', SSSR is proposed in [7] and the bandpass property can be achieved with only two rectangular spirals. For this cell, the two rectangular spirals are separated and arranged symmetrically to each other. In this article, 'prototype C', ASSR is proposed. Different from SSSR, the two separated rectangular spirals of ASSR are asymmetrical to each other. It will be seen that this change can improve the transmission property greatly in the following analysis. Then, the geometry of ASSR is depicted in detail in Fig. 2.

It is interesting to investigate the influence of the geometry difference between SSSR and ASSR by comparing the transmission property through full-wave simulation. All the simulations in this work are implemented by HFSS. Two groups of geometrical parameters are chosen in the comparison whose results are shown in Fig. 3. In addition, it should be noted that W2 should be set as small as possible. Because both SSSR and ASSR primarily operate through electromagnetic coupling, the large W2 may degrade the transmission property greatly. Thus, W2 is kept constant to 0.1 mm throughout this work. Meanwhile, W1 is set equal to 4.6 mm, the width of 50 ohm microstrip line in this article. The substrate with relative dielectric constant of 2.2 and thickness of 1.5 mm is utilized in both simulation and fabrication.

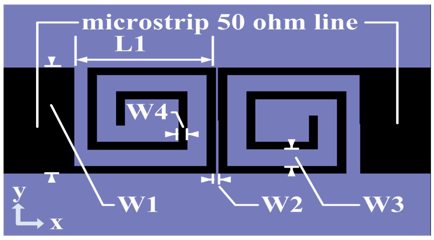

Fig. 2. Configuration of ASSR

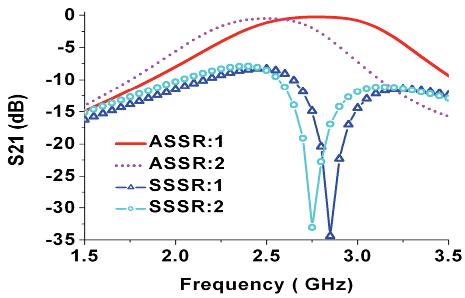

Fig. 3. Comparison of S21 of ASSR and SSSR. In this figure, '1' represents the combination of the geometrical parameters: L1 = 4.8 mm, W3 = 0.7 mm, W4 = 0.2 mm. '2' represents the combination: L1 = 5.4 mm, W3 = 0.7 mm, W4 = 0.2 mm.

According to the compared results, S21 of SSSR in both cases is higher than 10 dB in the given frequency range and thus, the transmission property of SSSR is not satisfactory. In [7], perfect bandpass performance was achieved through fabricating SSSR on the substrate with three layers, where the top and bottom layers were both the substrates with dielectric constant of 2.2 and the thickness of 2.4 mm and the middle one are the air layer with the height of 9 mm. The effective dielectric constant of the given three-layers substrate is approximately estimated to be much lower than 2.2 which is the minimum relative dielectric constant of single-layer substrate achievable for our experimental condition. Thus, it can be concluded that SSSR is not suitable for the application utilizing the single-layer substrate. Whereas, ASSR exhibits the passband with superior transmission property. It means that ASSR is more applicable than the other two prototypes.

2.2 Characteristic of ASSR

In order to design the ASSR-based components effectively, it is essential to investigate the design rules with respect to the geometrical parameters. Firstly, the influence of L1 is studied and Fig. 4 presents the simulated S parameters of ASSRs with different L1.

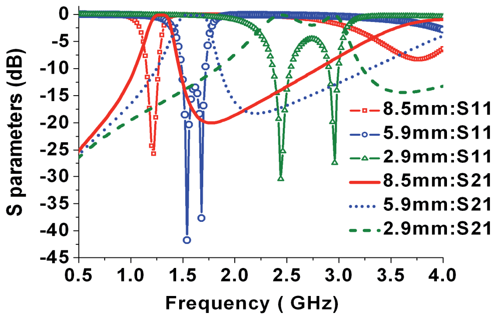

Fig. 4. Simulated S-parameters for ASSRs with different L1. In this case, W3 = 0.1 mm and W4 = 0.3 mm.

It is seen that the passband of ASSR moves downward with the increase of L1 and thus, L1 can be adjusted directively to achieve the passband within the required frequency band. Furthermore, from the results of S11, it is obvious that ASSR exhibits the bandpass property with two transmission poles. When L1 becomes smaller, these two poles separate more greatly and the frequency selectivity of the passband is deteriorated. In the extreme case, such as L1 is smaller than 2.9 mm, the single passband may degrade to the dual-passband as shown in Fig. 4. For planar diplexer, ASSR operating in the relatively low frequency band is beneficial, because of its high frequency selectivity and the poles which are sufficiently close to each other. The poles close to each other will alleviate the difficulty to get impedance matching in the synthesis procedure. Thanks to its intrinsic convoluted geometry, the dimension of ASSR is very compact, even operating in the relative low frequency band. Miniaturization enhancement of the components utilizing ASSR can be obtained due to the compact topology of this cell. With the aim of explaining this special property clearly, the dimensions of different ASSRs are compared in Tab. 1.

2L1+W2 (mm)	(2L1+W2)/ λ (%)	W1 (mm)	W1/ λ (%)	f0 (GHz)	λ (mm)
17.1	6.9	4.6	1.9	1.22	246
11.9	6.1	4.6	2.4	1.54	195
5.9	5.4	4.6	4.2	2.74	109

f0 is the center frequency of the passband and λ is the free-space wavelength at the corresponding f0

Tab. 1. Comparison of the dimensions of ASSRs with different L1.

Then, the parametric analysis of W3 and W4 are implemented and the results are depicted in Fig. 5 and Fig. 6, respectively.

As shown in Fig. 5, with the increase of W3, the passband shifts upwards and the bandwidth is broadened. In all cases, the transmission property within the passband is superior. It means that the passband and the bandwidth can be adjusted with respect to W3 for keeping the profile of ASSR (2L1+W2 and W1) constant. Thus, W3 provides another possibility to control the electromagnetic performance of ASSR. Furthermore, the minimized fabrication tolerance which can be achieved in our limited conditions is 0.1 mm while the width of ASSR, W1, is kept constant to 4.6 mm in order to get compact transversal dimension. Limited by these conditions, the values of W3 which can be utilized are within the limited range.

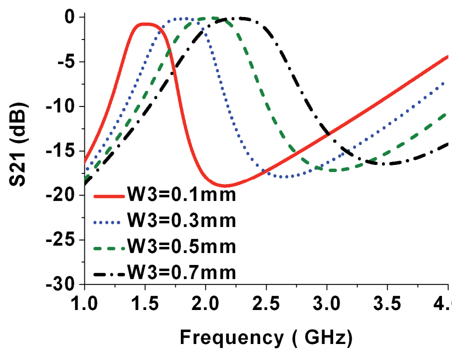

Fig. 5. Simulated S21 for ASSRs with different W3. In this case, L1 = 5.5 mm and W4 = 0.2 mm.

As observed in Fig. 6, the increase of W4 will also make the passband shift upward and the bandwidth broaden. But, the transmission property within the passband degrades with the increase of W4. This disadvantage makes W4 not suitable to be an adjustment parameter. According to the above analysis, W4 is set to 0.2 mm or 0.3 mm. Subsequently, the bandpass property fulfilling required specifications can be easily achieved following the above-mentioned design rules. It is a good start point to design the diplexer.

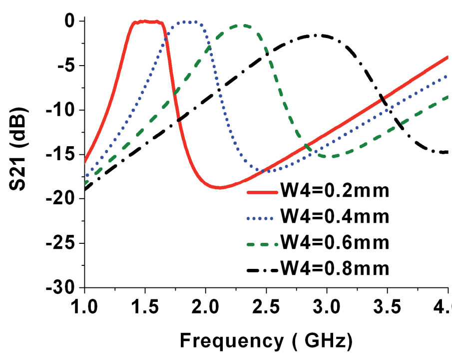

Fig. 6. Simulated S21 for ASSRs with different W4. In this case, L1 = 5.5 mm and W3 = 0.1 mm.

3. Design and Fabrication of ASSR-Based Diplexer

Based on the above discussion, ASSRs can be utilized to design the bandpass filter with miniaturized dimension and high frequency selectivity for the planar diplexer. The diplexer designed in this article involves T-junctions and two channel filters realized by ASSRs while its configuration is depicted in Fig. 7. At the first step, these two filters (filter1 and filter2 shown in Fig. 7) are designed independently to achieve the passbands with the center frequencies at 1.2 GHz and 1.75 GHz, respectively. Under the guide of the above design rules, the given specification can be achieved effectively while the simulated transmission efficient of these two filters is shown in Fig. 8(a). Next, these two filters and the T-junction are combined together to synthesize one planar diplexer. Even the two bandpass filters satisfy the given specification, the optimization process is still necessary to get the impedance matching and high isolation between the two channels without distortion of the bandpass performance [8-10]. The optimization process is implemented through adjusting S1 and S2 depicted in Fig. 7 and S-parameters of the diplexer after optimization are shown in Fig.8 (b). Then, the geometrical parameters of the optimized prototype are summarized as following: S1 = 4.7 mm and S2 = 3.5 mm. For filter 1, L1 = 6.5 mm, W3 = 0.2 mm and W4 = 0.3 mm. For filter 2, L1 = 8.9 mm, W3 = 0.1 mm, W4 = 0.2 mm.

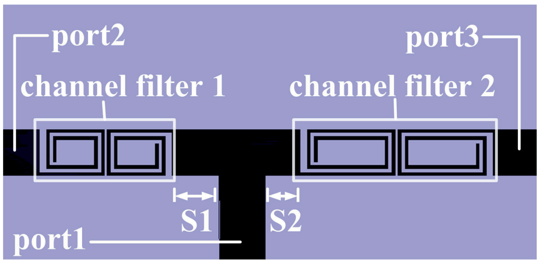

Fig. 7. Configuration of the proposed diplexer.

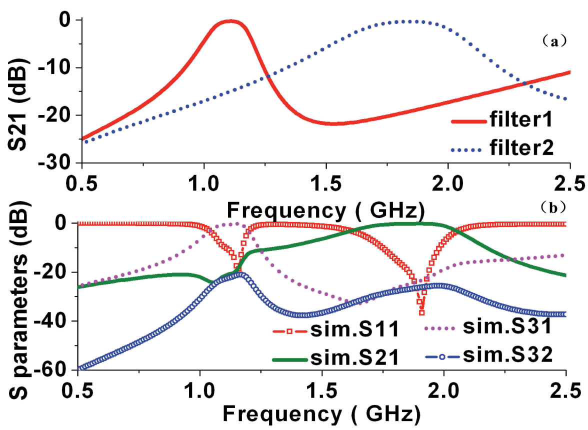

Fig. 8. (a) Simulated S21 for independently designed filter1 and filter2. (b) Simulated S-parameters for the proposed diplexer.

As shown in Fig. 8, the performance of the two filers independently designed agrees well with the results of the proposed diplexer which demonstrates that the proposed design procedures are effective and usable. To provide space for the SMA connectors, 50ohm microstrip lines with the length of 5 mm are cascaded at all three ports. The proposed diplexer is then fabricated and measured by an Anritsu ME7808A vector network analyzer while the measured results are listed in Fig. 9. The photograph of the fabricated prototype is shown in Fig. 10.

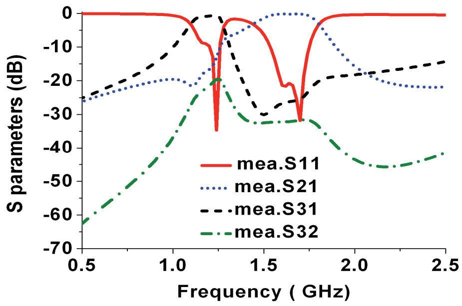

Fig. 9. Measured S-parameters for the fabricated prototype.

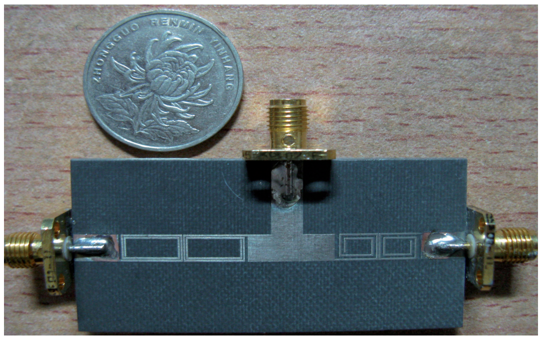

Fig.10. Photograph of the fabricated prototype.

According to the measured results, for Channel 2, S31 is better than 0.78 dB at 1.2 GHz while S11 is higher than 10 dB from 1.19 GHz to 1.25 GHz. Meanwhile, for Channel 1, S21 is better than 0.47 dB at 1.75 GHz and S11 is higher than 10 dB from 1.54 GHz to 1.76 GHz. In addition, the measured isolation between ports 2 and 3 is better than 20 dB within the whole frequency band. On the whole, the measured results agree well with the simulated ones and the minor discrepancy is due to the fabrication inaccuracy. What is more, remarkable miniaturization of the proposed planar diplexer has been achieved, thanks to ASSRs utilized. Then, Tab. 2 provides a dimension comparison between the proposed diplexer and other designs with similar topology in the previous literatures.

	2-D dimension	MTSW
This work	0.17 λ ×0.04 λ	0.02 λ
Ref. 1	0.11 λ ×0.16 λ	0.06 λ
Ref. 2	0.55 λ ×0.15 λ	0.14 λ
Ref. 4	0.27 λ ×0.22 λ	0.18 λ
Ref.11	0.31 λ ×0.27 λ	0.19 λ

'MTSW' denotes the width of the channel with the maximum transverse section. λ is free-space wavelength at the center frequency of the lower passband.

Tab. 2. Comparison of the dimension between the proposed diplexer and the references.

According to the compared results, it is seen that the dimension of the proposed planar diplexer is the most compact in all the designs listed in Tab. 2. Furthermore, for the proposed diplexer, the extremely compact transversal dimension of each channel has been achieved, because ASSRs are completely embedded in the microstrip line.

4. Conclusions

In this article, one compact planar diplexer based on one novel spiral-based resonator, asymmetrical separated spirals resonator (ASSR) is proposed. ASSR with extremely compact dimension exhibits more superior passband transmission property than the previous prototype. Through parametric analysis, the influence of geometrical parameters is investigated thoroughly and the given results provide an effective guideline to design ASSR. Based on the above results, one planar diplexer composed of T-junction and two different ASSRs is design and synthesized. The performance of the fabricated prototype is satisfactory and the compact transversal dimension of each channel is also achieved. What is more, the proposed diplexer is uniplanar so that no back radiating problem which common for the defected ground structures is introduced. In general, the proposed diplexer is suitable for the multiband and multiservice applications required compact dimension.

Acknowledgements

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References

[1] GORON, E., COUPEZ, J. P., PERSON, CH., TOUTAIN, Y., LATTARD, H., PERROT, F. Accessing to UMTS filtering specifications using new microstrip miniaturized loop filters. In *Proc. 2003 IEEE International Microwave Symposium*, 2003, p. 1599-1602

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

[3] BONACHE, J., GILL, I., GARCÍA-GARCÍA, J., MARTÍN, F. Complementary split ring resonators for microstrip diplexer design. *Electronics Letters*, 2005, vol. 41, no. 14.

[4] DONG, Y. D., ITOH, T. Substrate integrated waveguide loaded by complementary split-ring resonators for miniaturized diplexer design. *IEEE Microwave and Wireless Component Letters*, 2011, vol. 21, no. 1, p. 10-12.

[5] YUNCHUAN, G., GOUSSETIS, G., FERESIDIS, A. P., VARDAXOGLOU, J. C. Efficient modeling of novel uniplanar left-handed metamaterials. *IEEE Transactions on Microwave Theory and Techniques*, 2005, vol. 53, no. 4, p. 1462 – 1468.

[6] KOKKINOS, T., FERESIDIS, A. P., VARDAXOGLOU, J. C. Analysis and application of metamaterial spiral-based transmission lines. In I*nternational Workshop on Antenna Technology: Small and Smart Antennas Metamaterials and Applications, IWAT 2007*. Cambridge (UK), 2007, p. 233-236

[7] KOKKINOS, T, FERESIDIS, A. P. Low-profile folded monopoles with embedded planar metamaterial phase-shifting lines. *IEEE Transactions on Antennas and Propagation*, 2009, vol. 57, no. 10, p. 2997-3008.

[8] ISIK, O., ESSELLE, K. P., GE, Y. Compact microstrip and CPW duplexers using complementary and conventional logarithmic spiral resonators. In *Proc. IEEE Int. Symp. on Antennas Propag. (AP-S)*. Honolulu, 2007, p. 4977-4980.

[9] SANG, S. O., KEE, C. S., KIM, J. E., HAE, Y. P. etc. Duplexer using microwave photonic band gap structure. *Applied Physics Letters*, 2000, vol. 76, no. 16, p. 2301-2303.

[10] CHI, P. L., ITOH, T. Novel diplexer synthesis using the composite right/left-handed phase-advance/delay lines. *IEEE MTTs Digest*, 2009, p. 117-120.

[11] KUAN, H., YANG, R. Y., WENG, M. H., CHEN, W. L. A novel parallel-coupled line diplexer excited using slot-line resonators for ultra-wideband communications. *Microwave and Optical Technology Letters*, 2009, vol. 51, no. 6, p. 1551-1555.

About Authors…

Ke LU was born in Shanxi province of China. He received the B.S. degree in Electrical Engineering and M.S. degree in the Communication and Information Systems in 2006 and 2009, respectively, from the Air Force Engineering University, where he is currently working toward the Ph.D. degree. His research interests include the designs and applications of metamaterials.

Guang-Ming WANG was born in Anhui province of China. He received his BS and MS degrees from the Missile Institute of Air Force Engineering University, Xi'an, China, in 1982 and 1990, respectively, and his PhD 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. His current interest includes microwave circuits, antenna and propagation.

Hai-yang XU was born in Sichuan province of China. He received the B.S. degree in Electrical Engineering and M.S. degree in the Microwave project in 2006 and 2009, respectively, from the Air Force Engineering University, where he is currently working toward the Ph.D. degree. His research interest is on the design of UWB antenna.

Xiong YIN was born in Hunan province of China. He received the B.S. degree in Electrical Engineering and M.S. degree in the Microwave project in 2007 and 2010, respectively, from the Air Force Engineering University, where he is currently working toward the Ph.D. degree. His research interest is on the electromagnetic band-gap structure.