Design of microstrip planar triplexer for multi-mode/multi-band wireless systems

Chen Zhu, Jianyi Zhou, Yanwei Wang

Abstract: A novel microstrip planar triplexer for multi-mode/multi-band wireless systems has been proposed in this paper. The proposed triplexer is composed of a dual-band bandpass filter (BPF), a low pass filter using microstrip stepped-impedance hairpin resonators and simple associated matching circuits. And the dual-band BPF is realized by using parallel coupled microstrip lines and open-loop stepped-impedance resonators (SIRs) loaded with two shunt open stubs. Compared with the conventional triplexer configuration, it only needs to design two filters. The designed triplexer has three channels, from 0.8 to 1 GHz for GSM/CDMA, from 2.4 to 2.5 GHz and from 4.9 to 5.8 GHz, for WLAN separately. It has low insertion loss, good return loss, high isolation, low ripple in each passband. Measurement results of the fabricated triplexer are shown to match well with the electromagnetic simulation, which validate the proposed structure.

Key words: Triplexer, multi-mode/multi-band, dual-band, stepped-impedance resonators (SIRs)

Ⅰ. Introduction

In recent years, the wireless communication systems, such as the cellular mobile communication systems (CDMA, GSM, WCDMA, TD-SCDMA), the wireless local area networks (WLAN), the short range communication systems (Bluetooth, UWB), provide convenient communication services in modern society. In an airplane, when the onboard wireless communication services are provided, many different systems may be used simultaneously. Compact equipments that support multi-mode/multi-band wireless systems are very attractive and will be widely used in the future. Among them, a multiplexer is an important component of the transceiver for modern wireless or mobile communication systems. It combines with the multi-mode/multi-band wireless systems and the ultra wide band antenna. Therefore the performance of the triplexer has a direct impact on the whole system.

The dual-band bandpass filter is one of the most important components in the RF front-end. There is no need to design two bandpass filters as the dual-band BPF can select two passband frequencies. Many works [1]-[8] have been done to get good performance before. Then two simple matching circuits are added to separate the two passbands. This structure can be called the diplexer and also several configurations [9]-[12] have been proposed before. In order to get a triplexer, another suitable lowpass filter [13]-[19] is designed to combine the diplexer through matching circuit.

Basically, a triplexer is composed of bandpass filters and associated matching circuits, and thus proper designs of high-performance filters and matching circuits are very essential in the development of a triplexer. Recently, planar diplexers and triplexers were demonstrated by properly locating the attenuation poles near the passband of the diplexer and triplexer [20], [21]. In [22], the low-temperature co-fired ceramic (LTCC) diplexer and triplexer were implemented using a parallel-coupled line filter connected with a capacitor. And the stepped-impedance resonators (SIRs) [23] play important roles for the matching circuits or the SIRs [24], [25] have been directly used in the filter to reduce the size of the triplexers. However, all of them always require three separate bandpass filters and the design procedure for the triplexer structures is more complicated than that for diplexer structures. In this paper, only two filters and several matching circuits are designed and a simple procedure is presented on how to design a triplexer structure. This paper is organized as follows: In Section II, a novel dual-band BPF that covers 2.4-2.5GHz and 4.9-5.8GHz bands is presented. Structure of the diplexer with a dual-band BPF and two simple matching circuits is then provided in Section III. Finally, the design and fabrication of the triplexer are given in the Section IV. Our conclusion is given in Section V.

Ⅱ. Design of the dual-band BPF

It is easy to design a filter that covers 2.4-2.5 GHz band whereas it is difficult to design a filter that covers 4.9-5.8 GHz band. So in order to make the circuit simple and compact, a novel dual-band bandpass filter is designed to cover these two bands. In the past, adopting a cascade connection of a broadband band-pass filter and a bandstop filter [1], reduced-length parallel coupled lines [2], and the main transmission-line with shunt stubs and shunt serial resonators [3] are the normal ways to achieve dual-band BPFs. However, these approaches raised the circuit complexity and increased the circuit size. There is a high isolation between the two passbands, such as using hairpin resonators [4] or a ring resonator [5], while the performance of insertion loss is poor. When they use stepped-impedance resonators (SIRs) [6][7] and joint sharing of input and output ports of the two resonators [8] to obtain good performance, the bandwidth of each filter at the second passband is not wide. So there is a demand to design a compact size, high isolation loss, low insertion loss and wide band dual-band bandpass filter.

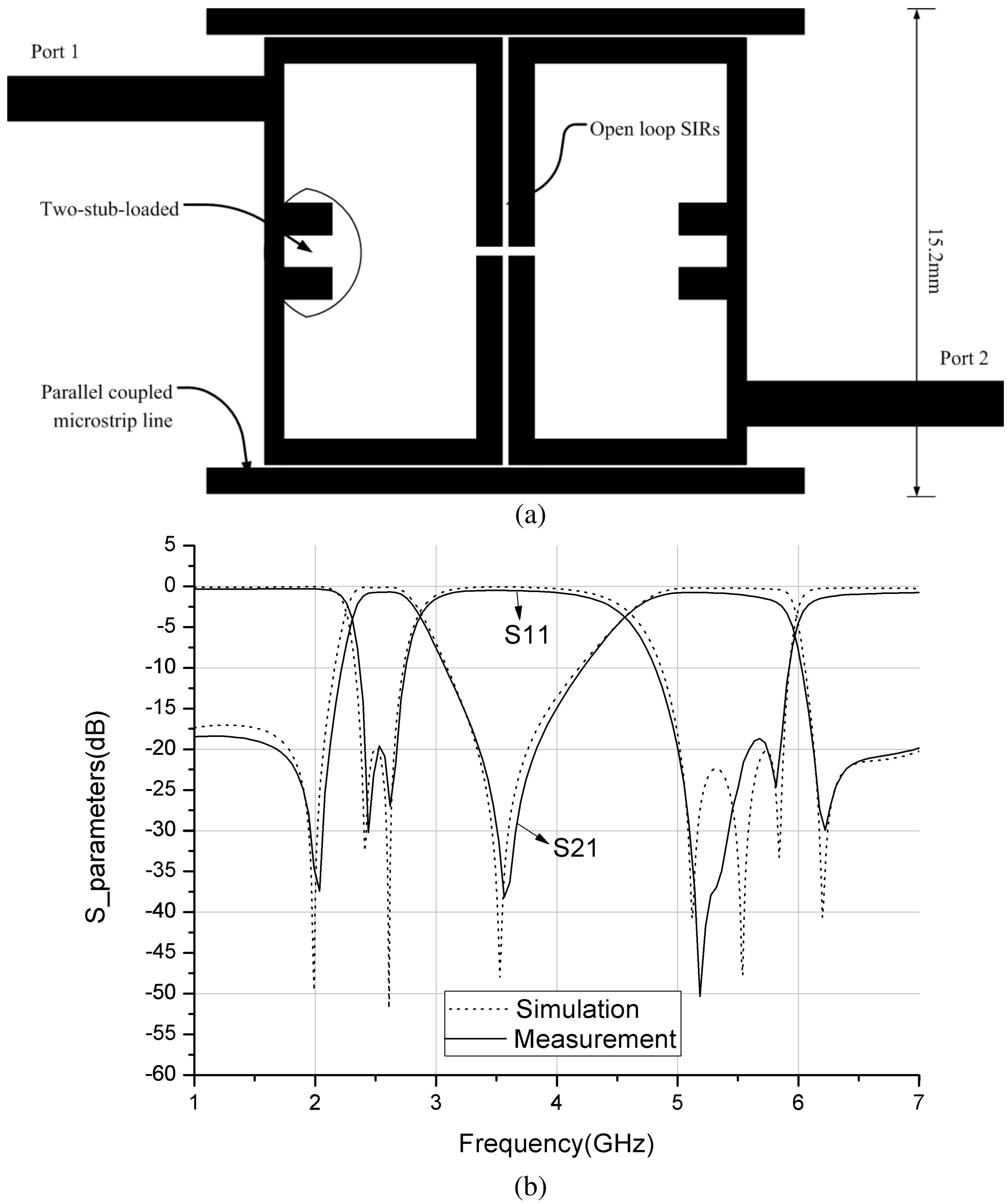

Fig. 1. The proposed dual-band bandpass filter (a) Schematic, (b) Comparison of S-parameter between simulated and measured

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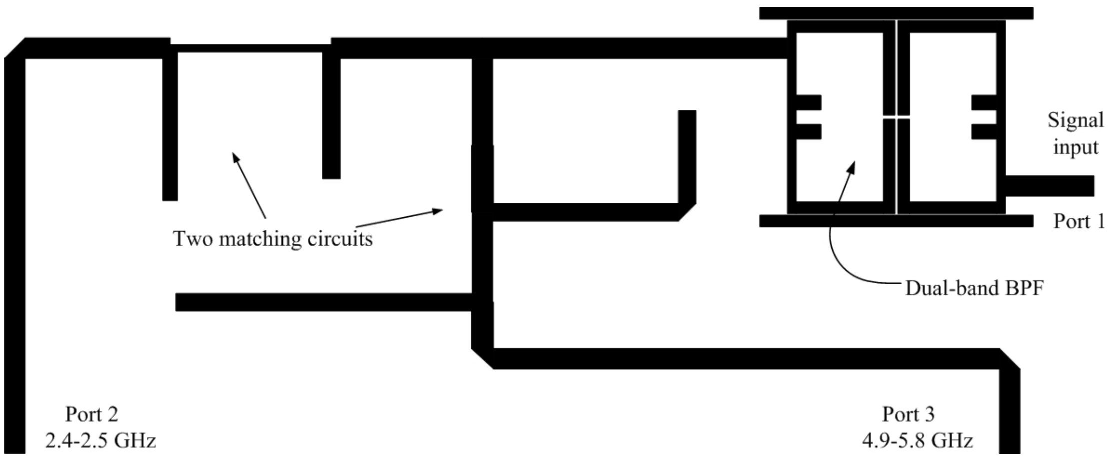
In this paper, on the basis of the previous considerations, it is presented that a new configuration of a dual-band filter using two-stub-loaded open-loop SIRs and parallel coupled microstrip lines. The schematic of the proposed dual-band filter is shown in Fig.

1(a). The proposed dual-band filter consists of two coupled open loop SIRs, two open stubs and two parallel coupled microstrip lines. The fundamental resonance frequency is related to the total length of the resonator which can be fixed to retain the central passband frequency. The second passband frequency can be adjusted by changing the relative position and size of the stubs and the lengths of the two coupling microstrip lines. The main function of the two parallel coupled microstrip lines is to make the bandwidth of second passband wider by increasing the ratio of the coupling coefficient between the two open-loop SIRs. Because the second passband frequency is not the twice of the first passband frequency, adopting SIR structure and two-stub-loaded has more variables and becomes more flexible compared with conventional uniform-impedance-resonator (UIR) and one stub-loaded respectively.

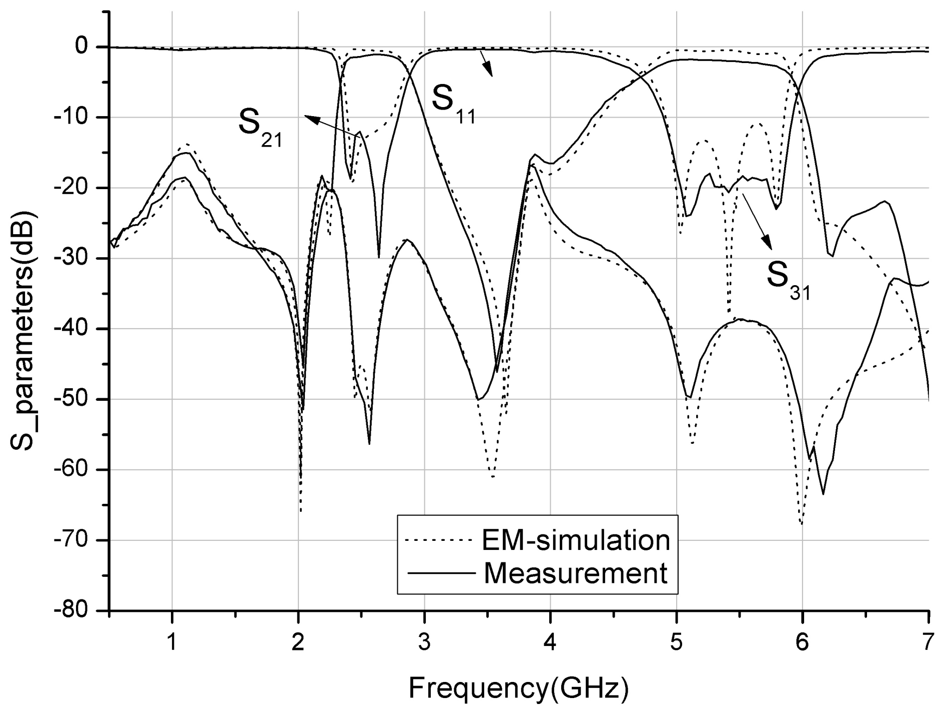
In this study, all the circuits are fabricated on the F4B substrate with a relative dielectric constant of 2.65, loss tangent = 0.002 and a thickness of 0.5 mm. Simulation is performed by HFSS. Measurement is performed from 1 GHz to 7 GHz with an E5230A vector network analyzer. Fig. 1(b) shows the measured S-parameters and the full-wave simulation results from HFSS 11. It is concluded that the measurement result is basically the same as the simulation result under no modification in the layout. It meets the demands that cover 2.4-2.5 GHz and 4.9-5.8 GHz bands. The experimental results are in good agreement with the simulation results.

Ⅲ. Design of the diplexer

First step for the diplexer is to design two useable filters, secondly to combine the designed filters with the matching network. From [5] to [7], although the stepped-impedance resonators (SIRs) or hairpin structure is used, the size of the diplexers is still not satisfied. In this paper, we implement the dual-band BPF mentioned above and two matching circuits to design the diplexer, which will make the design of triplexer easier.



(a)



(b)

Fig. 2. (a) Layout of the proposed microstrip diplexer, (b) Simulation and measurement of the diplexer with dual-band BPF

In this study, the compact microstrip diplexer based on the configuration in [8], which uses only a single dual-band bandpass filter and two matching circuits at the output ports, is proposed with its layout shown in Fig. 2(a). Through adjusting the dimension of the dual-band bandpass filter structure, the proposed diplexer can be implemented. The proposed diplexer is more compact than the conventional diplexer with two filter circuits. In order to obtain better performance, the parameters should be properly designed such as that the input impedances should satisfy the conditions at the output planar of the dual-band bandpass filter.

$$Z_{in1}(f_a) = 50\Omega \quad Z_{in1}(f_b) = \infty \qquad (1)$$

$$Z_{in2}(f_b) = 50\Omega \quad Z_{in2}(f_a) = \infty \qquad (2)$$

The two matching circuits are realized by the double-shunt-stub tuning which is called π type circuit so as to meet the impedance conditions (1) and (2). This diplexer is a three ports device. Port 1 and 2 is used to filter signal at 2.4-2.5GHz, while port 1 and port 3 can select the signal from the frequency of 4.9GHz to 5.8GHz.

Simulation is also performed with HFSS. Measurement is performed from 0.5 GHz to 7 GHz with an Agilent PNA-X N5242 vector network analyzer. The electromagnetic simulation and measured S-parameter results of the implemented diplexer are shown in Fig. 2(b). Through using two simple matching circuits, the low and high passbands have been well separated. The measured return losses at lower and higher bands are less than -12.5 and -10.3 dB, respectively. The measured insertion losses at lower and higher bands are approximately less than 1.7 and 2.8 dB, respectively. Obviously the measured results are in good agreement with simulated ones.

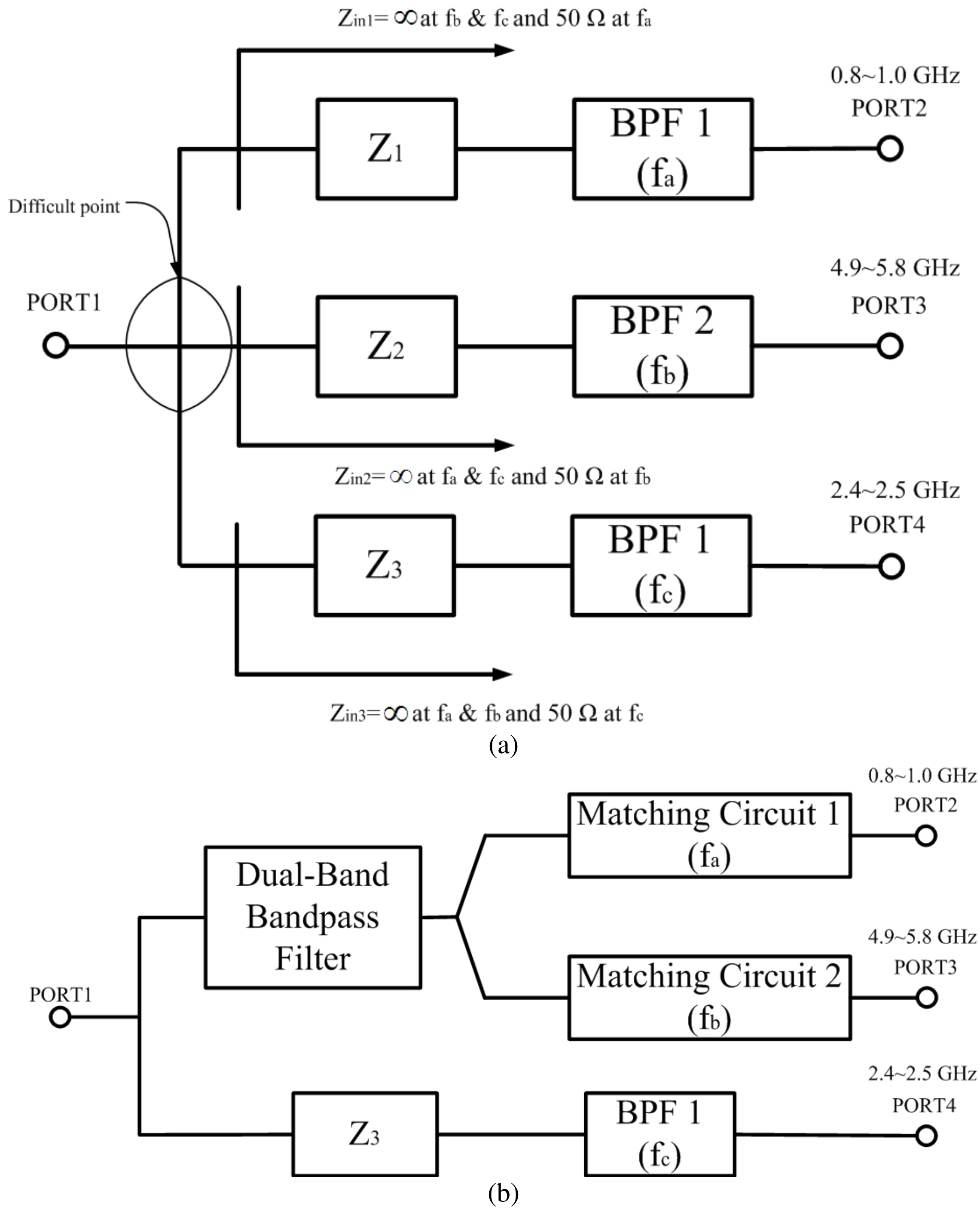


Fig. 3. Architecture of the triplexer structures (a) conventional, (b) proposed

Ⅳ. Design of the triplexer

From Fig. 3 it can be seen distinctly that the comparison of the architecture between the conventional triplexer and the proposed triplexer. Conventionally, it needs to design three suitable bandpass filters and assosiated matching circuits. And the design of branch lines is the key step for the diplexer and triplexer designs which tends to become more complicated and influences the characteristics of the triplexer. Normally in designing the T-junction and branch lines for a diplexer or triplexer, one of the ports should be matched at its center frequency and the other port(s) should be in open loop mode. Specifically, only one open condition is needed for the diplexer design, while two open conditions are required for the triplexer design. It should also satisfy the conditions:

$$Z_{in1}(f_a) = 50\Omega \; Z_{in1}(f_b) = Z_{in1}(f_c) = \infty \quad (3)$$

$$Z_{in2}(f_b) = 50\Omega \; Z_{in2}(f_a) = Z_{in2}(f_c) = \infty \quad (4)$$

$$Z_{in3}(f_c) = 50\Omega \; Z_{in3}(f_a) = Z_{in3}(f_b) = \infty \quad (5)$$

Consequently, the design procedure for the triplexer structures is more complicated than that for the diplexer structures. While in this paper, a relatively simplified design procedure is proposed. Fig. 3(b) shows the architecture of the proposed triplexer structure. First step is to design a diplexer using a dual-band BPF and simplified matching circuits. Then regarding the whole diplexer as a filter, it is combined with another LPF. The simple conditions of (1) and (2) should be satisfied twice. So a new triplexer has been done without two open conditions needed.

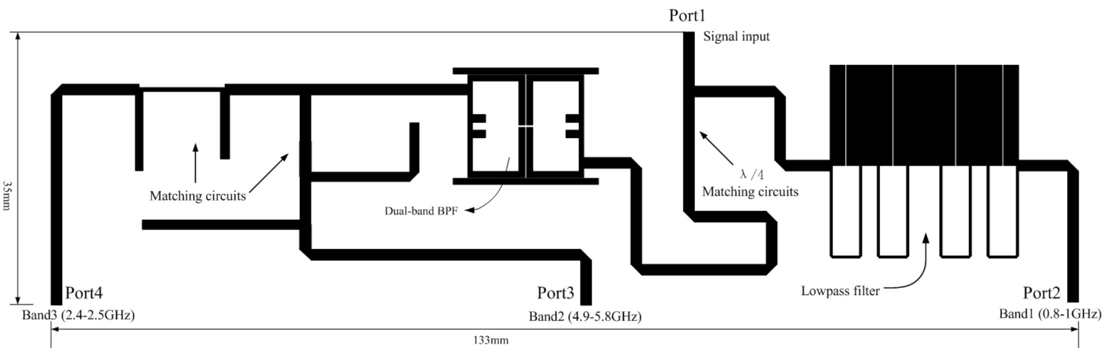


Fig. 4. Layout of the proposed microstrip triplexer

After the diplexer has been done, we are supposed to design another bandpass filter. For engineering applications, the antenna which is connected to the triplexer is designed to work from 800MHz to 6GHz. So it just needs to design a lowpass filter in the low frequency band. There have been many efforts to develop various kinds of compact lowpass filters so far. Using the slow-wave resonator [13] and using a microstrip stepped impedance hairpin resonator [14] are the ways to make the LPF compact. But the filters don't have sharp cutoff frequency response and wide stopband. To obtain a sharp skirt characteristics and a wide stopband, slit-loaded tapered compact microstrip resonator cell [15] and spiral compact microstrip resonant cells [16] were used, but the structures of them are comparatively complicated. Sometimes semi-lumped low-pass filter [17] [18] has been used due to the capability of harmonics and spurious suppression. Although the size of the semi-lumped filter is small and the structure is simple, using lumped elements increases the fabrication difficulties. Finally, cascading microstrip stepped-impedance hairpin resonators [19] is adopted for it has sharp cutoff frequency response, simple modeling and wide stopband up to 6GHz. The structure of the lowpass filter can be seen from the LPF part of Fig.4. Through optimizing the dimensions of the LPF, this filter has a 3-dB passband from dc to 1.03 GHz. The return loss is better than 11 dB from dc to 1

GHz. The insertion loss is lower than 0.5 dB. The rejection is greater than 50 dB from 1.45 to 6.22 GHz. It is very suitable for the proposed triplexer design.

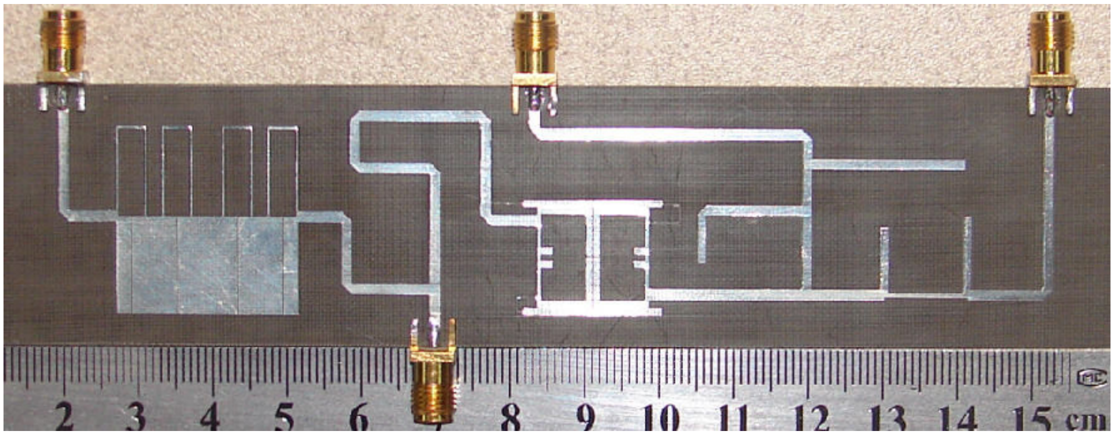


Fig. 5. Photograph of the fabricated microstrop triplexer

The diplexer as mentioned in Section III and the proposed lowpass filter connected with the T-junction and quarter-wavelength branch lines could form the triplexer shown in Fig. 3 (b). The whole layout of the designed triplexer is shown in Fig. 4. T-junction is used for not only connecting the diplexer and the LPF but also power splitting. Meanwhile, in order to make the two filters do not interfere with each other, it is needed that cascading a length of $\lambda_a/4$ (λ_a is the center frequency guided wave length of the first band), characteristic impedance of 50Ω microstrip transmission line transform before the diplexer. At the antenna port, it can be seen as short circuit for the first band. Through the $\lambda_a/4$ conversion of the transmission line, it is in open loop mode. So the diplexer and the LPF will not interfere with each other. It is the same as the other part. As the effect of T-junction, the actual length of series microstrip is less than a quarter-wavelength, which can be determined using the HFSS software optimization. After simulation, it is founded that there is a new transmission zero generated by the lowpass filter and the diplexer at the frequency of 525 MHz. Fortunately it does not affect the performance of 0.8-1GHz. Photograph of the fabricated microstrip triplexer is shown in Fig. 5. The size of the fabricated triplexer is 35 × 133 mm^2. Because the multi-mode/multi-band RF systems have been identified the horizontal size, the positions of each port of the proposed triplexer are fixed. What we can do is to make the vertical size small enough. It can be seen that there is only 35mm of the vertical size.

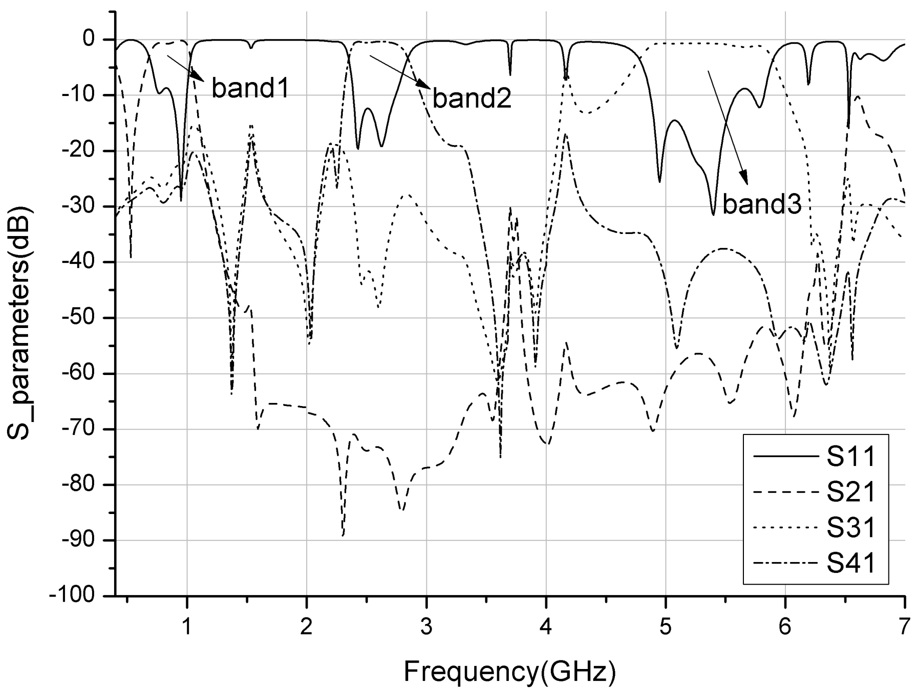
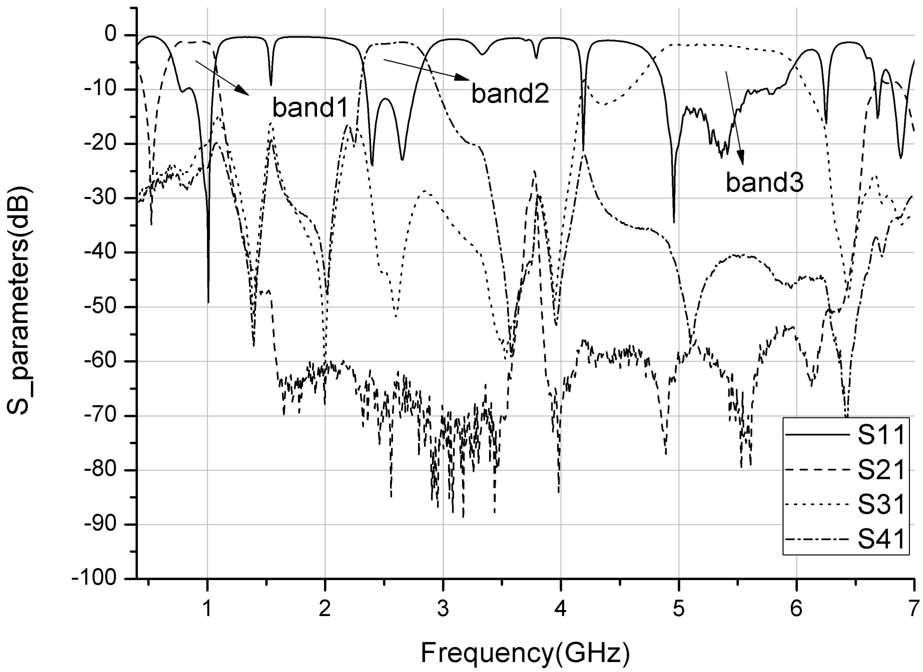
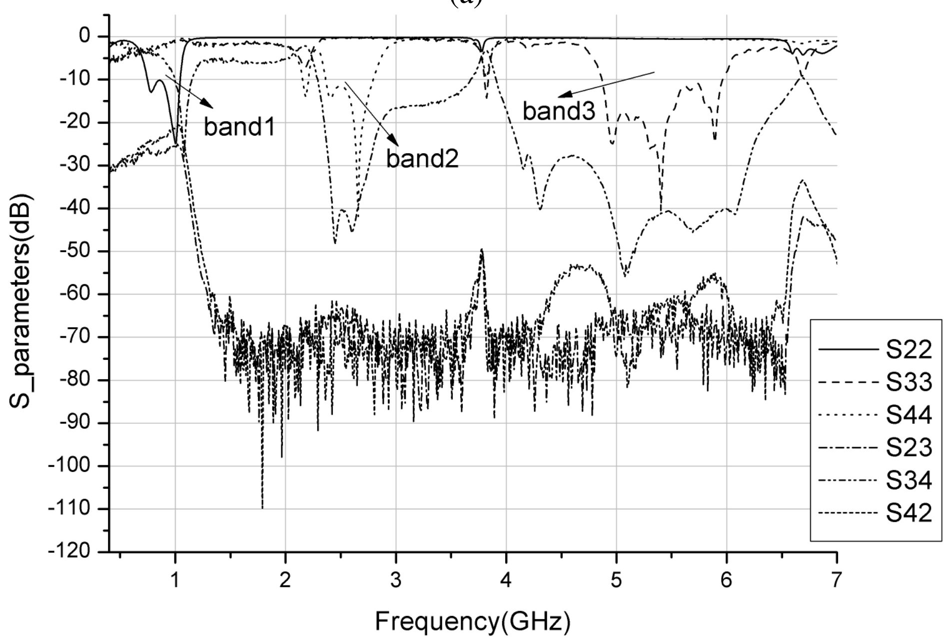


Fig. 6. Simulated responses of the proposed triplexer



(a)



(b)

Fig. 7. Measured results of the triplexer (a) insertion loss and return loss, (b) isolation

The measurement is performed from 0.4 GHz to 7 GHz with an Agilent PNA-X N5242 vector network analyzer. The measured and simulated results of the implemented triplexer are shown in Figs. 6 and 7. Through measurement the coupled matrix is obtained as follows:

$$S_{ij\_GC}=\begin{bmatrix}0 & S_{12} & & \\ & 0 & S_{23} & S_{24} \\ & & 0 & \\ & & & 0\end{bmatrix}\Rightarrow S_{ij0.9GHz}=\begin{bmatrix}-13.12 & -0.37 & & \\ & -13.03 & -24.16 & -27.75 \\ & & -1.67 & \\ & & & -1.63\end{bmatrix} \quad (6)$$

$$S_{ij\_WLAN5.0}=\begin{bmatrix}0 & & S_{13} & \\ & 0 & S_{23} & \\ & & 0 & S_{34} \\ & & & 0\end{bmatrix}\Rightarrow S_{ij5.35GHz}=\begin{bmatrix}-31.54 & & -0.69 & \\ & -0.14 & -24.16 & \\ & & -30.63 & -37.79 \\ & & & -0.22\end{bmatrix} \quad (7)$$

$$S_{ij\_WLAN2.4}=\begin{bmatrix}0 & & & S_{14} \\ & 0 & & S_{24} \\ & & 0 & S_{34} \\ & & & 0\end{bmatrix}\Rightarrow S_{ij2.45GHz}=\begin{bmatrix}-16.16 & & & -0.41 \\ & -0.04 & & -71.12 \\ & & -0.08 & -44.54 \\ & & & -16.61\end{bmatrix} \quad (8)$$

At the port 1, the coupled matrix is designed to be lower than -15dB at the specified frequencies. And at the different channel ports, the return loss should be controlled below -20dB. Due to the process error, at the center frequency of three separated bandwidth, the measured coupled matrix of the ports can be seen in Fig.4. S_{ij}(i=j) is lower than -13dB and S_{1j} is greater than -0.7dB.It can be concluded by Analyzed from the data that the different ports achieve good isolation and the insert loss between the antenna and each port is very low. Based on two characters mentioned above, three different communication systems can work simultaneously through designed triplexer. More work can be done to improve the two simple matching circuits such as using stepped-impedance resonators. The measured return losses and isolation at the high frequency are higher than the simulated results since the loss tangent of used commercial substrate usually increases as frequency increases. It can be concluded from the data that the highest insertion loss is only 2.9dB in the whole demand bands. The basic parameters can be seen clearly from the Table 1 below. The experimental results are in good agreement with the simulation results. The existence of insertion loss is mainly due to both conductor and dielectric loss of circuit. The slight difference between the simulated and measured results might be due to the fabricated mistake and unperfected ground. It can be improved by more careful fabrication and measurement technology. After the proposed triplexer has been done, the combination of the triplexer, multi-mode/multi-band RF frontend and the UWB antenna is valuable to develop the broadband wireless communication system.

Tab.1 Measured and simulated parameters of the proposed triplexer at 0.9&5.35&2.45GHz

Proposed triplexer	Bandwidth (%)		Insertion loss (dB)		Return loss (dB)	
	Sim.	Mea.	Sim.	Mea.	Sim.	Mea.
Band 1	22.2	28.4	0.37	1.24	13.1	11.8
Band 2	17.6	17.6	0.68	1.90	25.9	21.3
Band 3	13.6	16.0	0.40	1.65	16.2	13.8

V. Conclusion

A fully integrated planar microstrip triplexer which has good multiband responses at 0.8-1, 2.4-2.5, and 4.9-5.8 GHz for multi-mode/multi-band wireless systems has been presented in this paper. First, design a new dual-band bandpass filter which is consisting of two parallel coupled microstrip lines and open-loop stepped-impedance resonators (SIRs) loaded with two shunt open stubs. Then this filter can be used to develop the diplexer and triplexer. In order to make the design procedure simple, only a dual-band bandpass filter and a lowpass filter are used, designed and combined. The fabricated triplexer has the advantage of high integration, good transmission and isolation performances. Agreement between measurement and EM-simulation has evidenced the feasibility of our study. As a result, the proposed triplexer works well in the multi-mode/multi-band wireless systems and is particularly suitable for multiband and multiservice applications in the future.

Ⅵ. Acknowledgment

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