Progress In Electromagnetics Research Letters, Vol. 73, 105–112, 2018

Design of Broadband Transition Structure from Microstrip to Slotline with Band Notched Characteristic

Fa-Kun Sun, Wu-Sheng Ji*, Xiao-Chun Ji, Pei-Pei Han, Ying-Yun Tong, and Zhi-Yue Zhang

Abstract—In this paper, a broadband transition structure from microstrip line to slotline with band-notched characteristic is proposed. To match the $50\,\Omega$ microstrip line, 4 Chebyshev impedance transformations are used in the transition structure, and its bandwidth is widened. There is a fan-shaped radial line at the microstrip terminal. A U-shaped slot is etched on the microstrip line with stepped impedance matching to achieve band-notch characteristic. By changing the length of the slot, the band notch is realized at different frequencies. Simulation and optimization of the transition structure are made by using the high frequency simulation software HFSS to achieve the band-notch function at 3.37–3.84 GHz and 10.67–11.14 GHz. In the rest of the band, return loss S_{11} is less than -15 dB, and voltage standing wave ratio (VSWR) is less than 1.5.

1. INTRODUCTION

With the rapid development of communication technology, wireless spectrum resources are becoming more and more intensive, which lead to the integration level of communication devices to gradually increase. This means that a variety of wireless communication modules work stably and efficiently at the same time. This also puts forward higher requirements to the microwave devices and front-end key components of communication devices. Therefore, the mutual interference between communication frequency bands needs to be considered. In order to eliminate interference, we could suppress the interference frequency band in the process of signal transmission, before transmitting to the antenna. Therefore, the complexity of the antenna design can be reduced. In microwave circuits, there are transitions between different transmission lines, which can suppress interference bands in the transition structure. In [1–6], band notch is achieved by etching slot on the microstrip line, which changes surface current distribution. It cannot transmit power since the current appears in standing wave condition at a particular frequency. Adding parasitic elements [7] is another method to suppressing the interference. Parasitic elements can induce the opposite current to the transmission line current. The last one is adding open stubs [8], which is essentially similar to capacitive loading.

With formulation and development of the fifth generation of mobile communication technology (5G) standard, 5G millimeter-wave circuit has attracted much attention of the academia and industry circles. China's Ministry of Industry and Information Technology has announced the test band of the millimeter wave of 5G technology, including 3.3–3.6 GHz, 4.8–5 GHz, 24.75–27.5 GHz and 37–42.5 GHz. When a circuit is applied to 4.8–5 GHz frequency band, the interference from the adjacent frequency band 3.3–3.6 GHz should be suppressed.

Based on [9], a transition structure of microstrip line to slotline with notch characteristics is proposed in this paper. Respectively, changing the bottom straight slotline of the transition structure and the fan-shaped short-circuit terminal of the slotline in [9] to interdigitated slotline and the petal type,

Received 16 November 2017, Accepted 30 January 2018, Scheduled 23 February 2018
* Corresponding author: Wu-Sheng Ji (jiwusheng@tute.edu.cn).
The authors are with the Tianjin University of Technology and Education, Tianjin 300222, China.

the performance of the transitional structure is improved without slot. To match the 50 Ω microstrip line, 4 Chebyshev impedance transformations are used in the transition structure. In order to achieve the suppression of the interference frequency band, a U-shaped slot is etched on the step impedance matching microstrip line to realize the notch effect. The U-shaped slot is etched on the microstrip line to form the DMS structure. Unlike DGS, the DMS structure can effectively avoid the electromagnetic wave leakage caused by the defect of the ground plate and is less prone to interference with other components in the microwave circuit. In this paper, this transition structure achieves the band-notch function at 3.37–3.84 GHz and 10.67–11.14 GHz so as to suppress the 3.3–3.6 GHz frequency band and keep the 4.8–5.0 GHz band uninterrupted. And in the remaining frequency band, the return loss S_{11} is better than −15 dB, VSWR less than 1.5, and the performance is excellent.

2. CONFIGURATION AND THEORETICAL ANALYSIS OF MICROSTRIP-SLOTLINE TRANSITION STRUCTURE WITH NOTCH FUNCTION

2.1. Design of Microstrip-Slotline Transition Structure with Notch Function

As shown in Figure 1(a), a broadband back to back structure with band-notched characteristics is designed in this paper. Figure 1(b) represents the enlarged view of a microstrip etched U-shaped slot. The transition structure works in a range of 2–14 GHz. The dielectric material is FR4, with a relative dielectric constant ε_r of 4.4, dielectric loss tangent $\tan\delta$ of 0.02 and thickness of 0.6 mm. The microstrip radial stubs and microstrip multisection matching transformers are at the top layer of a substrate while the ground plane is at the bottom layer. The slotline, and the slot radial stubs are in the ground plane. The slot line is cross-finger groove, and the slot radial line is garland type. The U-shaped slot is etched on the microstrip line with stepped impedance matching to achieve band-notch characteristics, which can be used to suppress the interference of the irrelevant frequency band. To achieve broadband, a Chebyshev four-section transformer is used. The interdigital structure of slotline can be viewed as a capacitor as long as its size is much smaller than the wavelength λ. The capacitance is determined by the fringing field of interdigital gap formed by etching, and is proportional to the

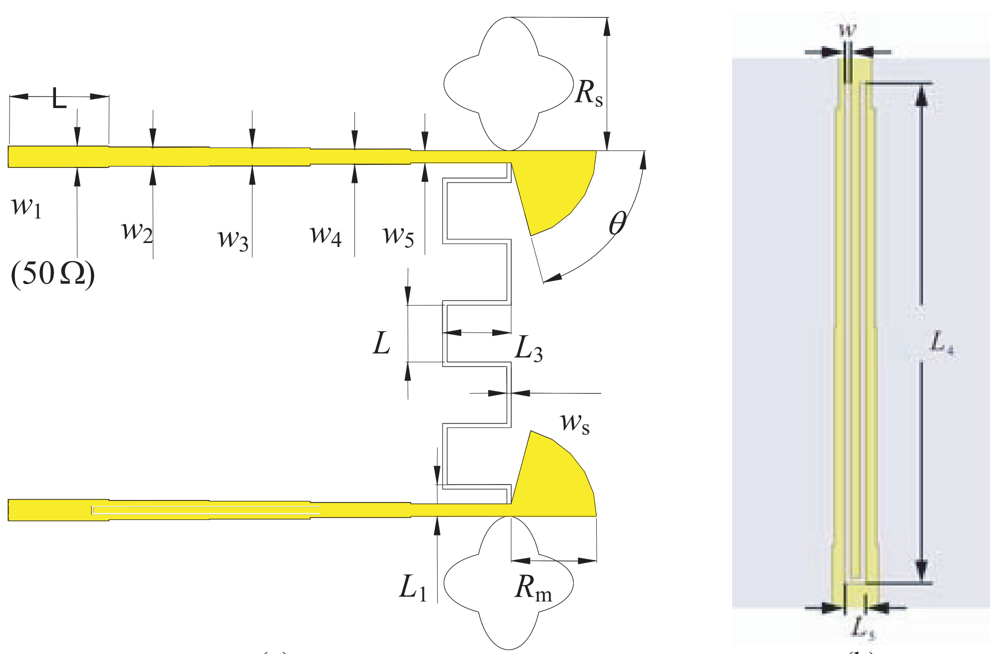


Figure 1. Schematic diagram of transition with band notched characteristic (The yellow graphics are microstrip lines and the blank graphics are slot lines. L_4 is the length of U-shaped slot in the microstrip line). (a) Design block diagram, (b) enlargement diagram of microstrip etched U-shaped slot.

length of the finger and the ratio between the finger width and gap width. Slotline termination can be considered as simple equivalent circuits such as a resistance and serial inductance [10]. The resistance represents radiation losses, and the inductance represents inductive phenomena at the line termination. The center frequency of the transition is designed at 7.5 GHz. The dimensions of the microstrip and slotline radial stubs are $R_m = \lambda_{gm}/4 = 4.77\,\text{mm}$ and $R_s = \lambda_{gs}/4 = 8\,\text{mm}$, where λ_{gm} and λ_{gs} are the guided wavelengths of the microstrip line and the slotline at the center frequency, respectively. The petal-shaped slot is on the ground line of the microstrip line. It is formed by two concentric elliptical surfaces that are perpendicular to each other with the same area. The major and minor radials of the ellipse are $a = 4\,\text{mm}$ and $b = 2\,\text{mm}$, respectively.

The microstrip line, which employs multisection impedances matching transformers, is at the top layer of the substrate. To match Z_0 to $50\,\Omega$, a Chebyshev four-section transformer with its sections' impedances of $53\,\Omega$, $55\,\Omega$, $61\,\Omega$, and $68\,\Omega$ is used [9], and the line width varies from large to small. Using high frequency electromagnetic simulation software ANSYS HFSS15, the broadband microstrip to slotline transition structure with band-notched characteristic is simulated and optimized to achieve the final size as follows: $L = 5.42\,\text{mm}$, $w_1 = 1.15\,\text{mm}$, $w_2 = 1.04\,\text{mm}$, $w_3 = 0.98\,\text{mm}$, $w_4 = 0.81\,\text{mm}$, $w_5 = 0.66\,\text{mm}$, $R_m = 4.77\,\text{mm}$, $\theta = 75°$; $w_s = 0.24\,\text{mm}$, $L_1 = 3.7\,\text{mm}$, $L_2 = 3.6\,\text{mm}$, $L_3 = 1.6\,\text{mm}$; $L_5 = 0.5\,\text{mm}$, $w = 0.1\,\text{mm}$, $L_4 = 12.4\,\text{mm}$.

2.2. Theoretical Analysis

Slot etching in the microstrip line is what is called the defect microstrip structure (DMS). DMS changes the surface current distribution and transmission path. It also changes the distribution of the electromagnetic field on the microstrip line, and in doing so the current at a specific frequency exhibits standing wave state, unable to transfer energy, hence the function of band suppression is realized. The DMS has similar stopband characteristics to the defect structure (DGS), so equivalent circuit parameters of DMS can be extracted from the equivalent parallel LC resonant circuit theory of DGS. The U-shaped DMS equivalent circuit [11] is shown in Figure 2. L_{ps1} and C_{ps1} in parallel constitute the first stage LC resonant circuit, and L_{ps2} and C_{ps2} in parallel form the second stage LC resonant circuit. f_{01} and f_{02} are the notch center frequencies in the two notch bands, respectively; $\Delta f_{\text{bandnotch1}}$ and $\Delta f_{\text{bandnotch2}}$ are the first notch frequency bandwidth and second notch bandwidth, respectively. L_{ps1}, C_{ps1}, L_{ps2} and C_{ps2} can be calculated from the calculation formula in [11]. The calculation is as follows:

$$C_{ps1} = \frac{1}{Z_0} \times \frac{1}{4\pi\Delta f_{\textbf{band notch}1}} \quad L_{ps1} = \frac{1}{(2\pi f_{01})^2 C_{ps1}} \tag{1}$$

$$C_{ps2} = \frac{1}{Z_1} \times \frac{1}{4\pi\Delta f_{\textbf{band notch}2}} \quad L_{ps2} = \frac{1}{(2\pi f_{02})^2 C_{ps2}} \tag{2}$$

$$C_{ps1} = \frac{1}{50} \times \frac{1}{4\pi \times (3.84 - 3.37) \times 10^9} = \frac{1}{50} \times \frac{1}{4\pi \times 0.47 \times 10^9} \approx 3.39\,\text{pF} \tag{3}$$

$$L_{ps1} = \frac{1}{(2\pi f_{01})^2 C_{ps1}} = \frac{1}{(2\pi \times 3.6 \times 10^9)^2 \times 3.39 \times 10^{-12}} \approx 0.577\,\text{nH} \tag{4}$$

$$C_{ps2} = \frac{1}{61} \times \frac{1}{4\pi \times (11.14 - 10.67) \times 10^9} = \frac{1}{61} \times \frac{1}{4\pi \times 0.47 \times 10^9} \approx 2.777\,\text{pF} \tag{5}$$

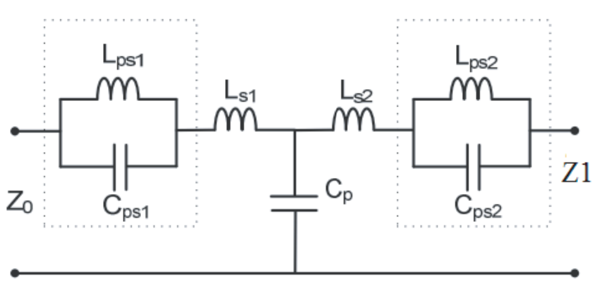


Figure 2. U-shaped DMS equivalent circuit.

$$L_{ps2} = \frac{1}{(2\pi f_{02})^2 C_{ps2}} = \frac{1}{(2\pi \times 10.84 \times 10^9)^2 \times 2.777 \times 10^{-12}} \approx 0.0787\,\text{nH} \tag{6}$$

3. SIMULATION AND ANALYSIS

Figure 3 shows simulated S_{11} and voltage standing wave ratio (VSWR) of the proposed structure with/without the U-shaped slot etching in the microstrip line. As can be seen from Figure 3, when the microstrip line is without the etched U-shaped slot, the S_{11} in 2–14 GHz are less than −15 dB, and VSWR is less than 1.5. When the microstrip line is etched with the U-shaped slot, the S_{11} and VSWR increase rapidly in 3.37–3.84 GHz and 10.67–11.14 GHz. Therefore, the inhibition effect of the two frequency bands is realized. The rest of the frequency range of the S_{11} is less than −15 dB and VSWR less than 1.5. The central frequency of the band notched is $f_{01} = 3.6$ GHz and $f_{02} = 10.84$ GHz, respectively.

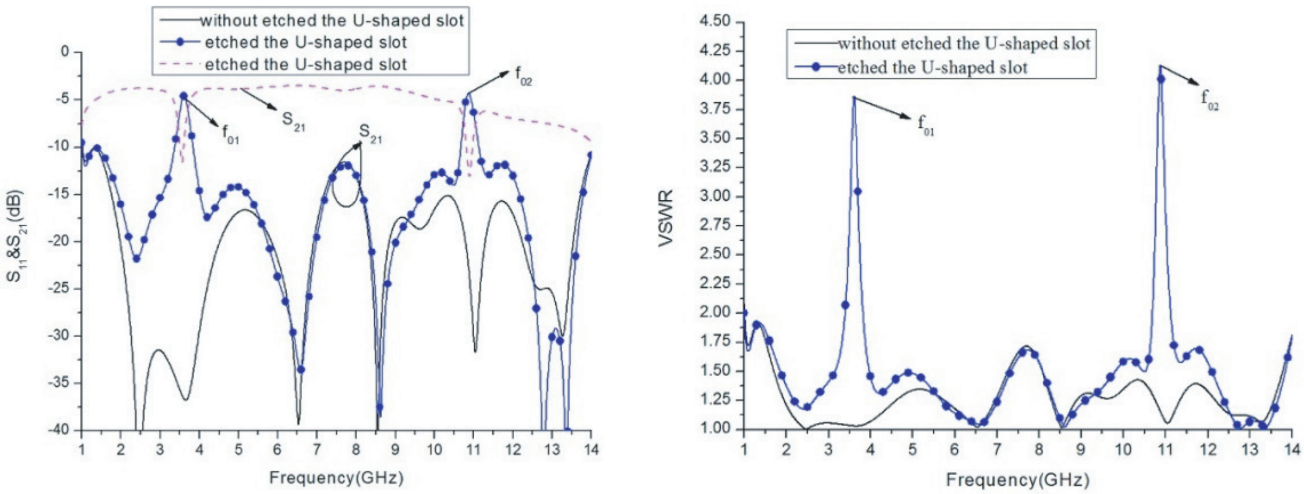


Figure 3. The diagram of simulation of S_{11} and the voltage standing wave ratio (VSWR) with U-shaped slot and without etching U-shaped slot in the microstrip line. (a) S_{11} parameter, (b) voltage standing wave ratio (VSWR).

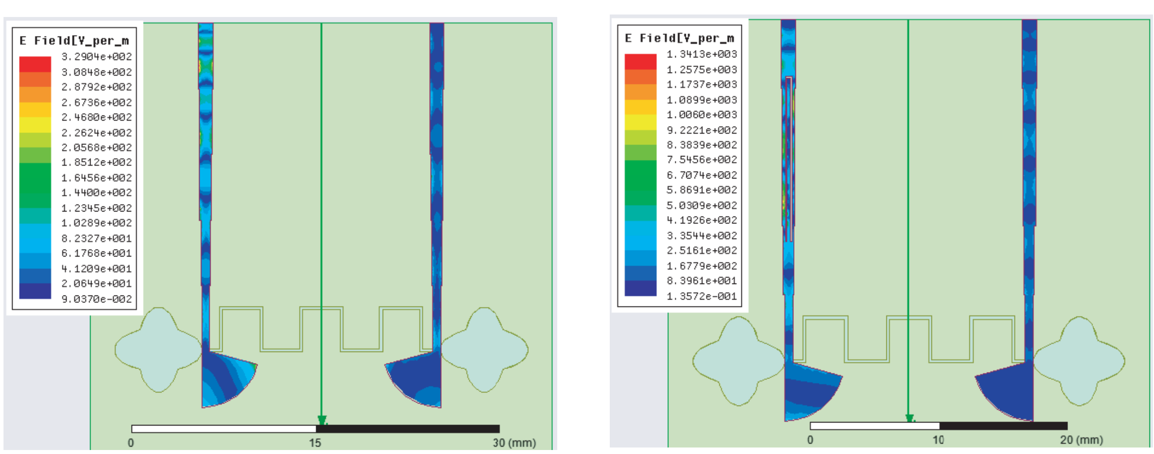
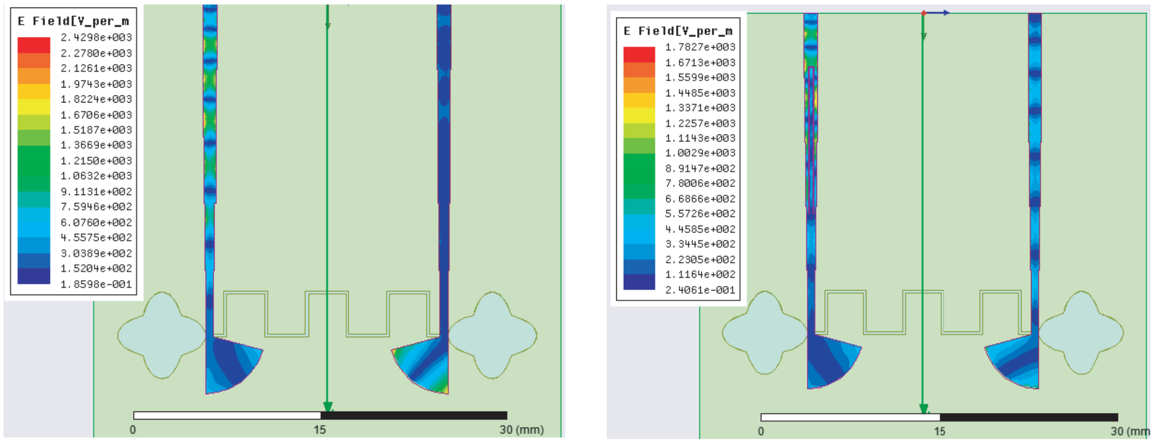
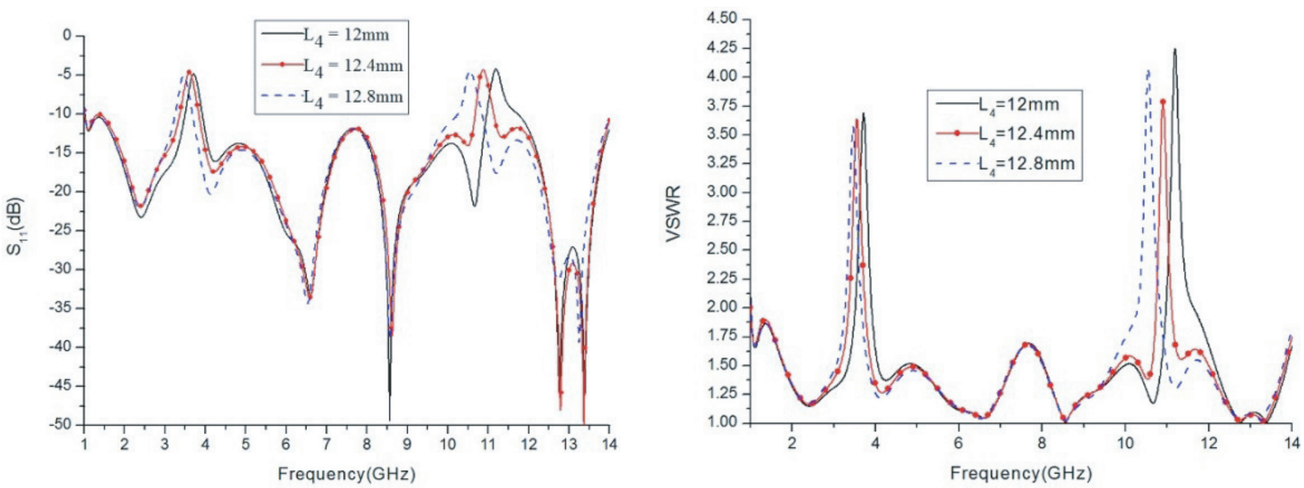


Figure 4. Electric field diagram at 3.6 GHz. (a) Without etched U-shaped slot, (b) etched U-shaped slot.



(a) (b)

Figure 5. Electric field diagram at 10.87 GHz. (a) Without etched U-shaped slot, (b) etched U-shaped slot.

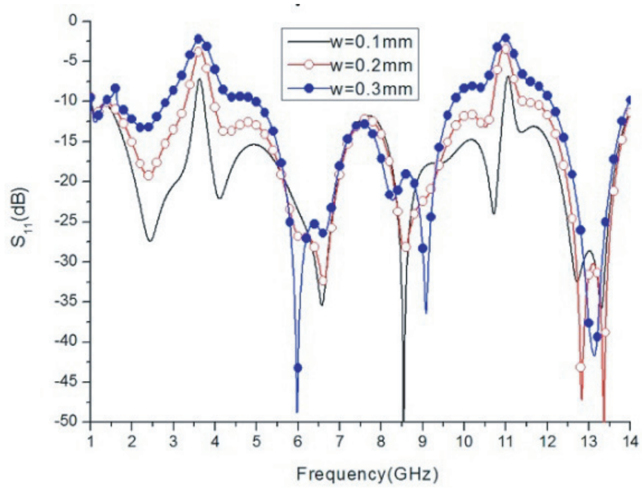


(a) (b)

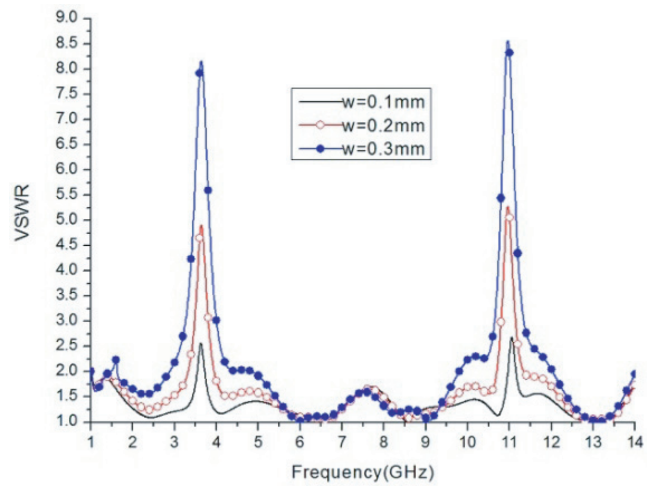
Figure 6. U-slot width w is constant, slot length L_4 changes with the notch frequency band. (a) S_{11} parameter, (b) voltage standing wave ratio (VSWR).

Figure 4 and Figure 5 show a simulated electric field with a U-shaped slot and without U-shaped slot on the transition structure of microstrip line at the frequencies of 3.6 GHz and 10.87 GHz, respectively. It can be seen from Figures 4(a) and 5(a) that when the microstrip line is without the U-shaped slot, the electric field of the microstrip line is changed from strong to weak periodically. From Figure 4(b) and 5(b) it can be seen that when the microstrip line is with etched U-shaped slot, the electric field in the U-shaped slot is broken, and the inside of the U-shaped slot microstrip line electric field intensity is smaller, and the external electric field is stronger than the electric field in other parts.

The microstrip line slot length L_4 and width w are discussed and analyzed. Figure 6 is the simulation S_{11} parameter and VSWR when the width of the slot w ($w = 0.1$ mm) is constant, and the U-shaped slot length L_4 varies. As shown in Figure 6, when width w of the slot is constant and slot length L_4 increases, the notch frequency band moves to the negative direction of the X-axis, and the notch frequency is decreased. When the slot length L_4 is reduced, the notch frequency band moves in the positive direction of X-axis, while the notch frequency increases; Figure 7 is the simulation S_{11} parameter and VSWR when the slot length L_4 ($L_4 = 12.4$ mm) is constant and the U-shaped slot width w varies. It can be seen from Figure 7 that when the slot length L_4 ($L_4 = 12.4$ mm) is constant and the



(a)



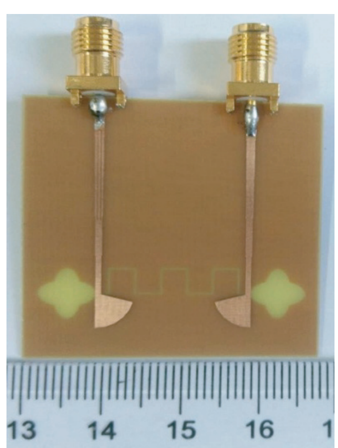
(b)

Figure 7. U-slot length L_4 is constant, slot width w changes with the notch frequency band. (a) S_{11} parameter, (b) voltage standing wave ratio (VSWR).

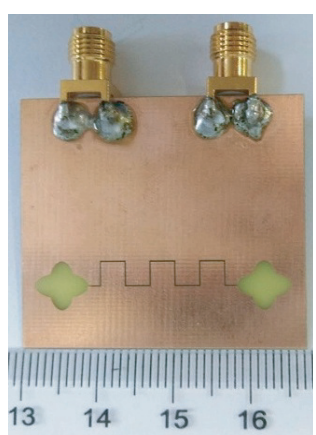
slot width w increases, the width of the notch band will not change obviously, while the VSWR and S_{11} at the center of the notch frequency increase. In general, when the slot width w is constant, the notch position of the transitional structure can be changed by changing the slot length. When the slot length L_4 is constant, the notch structure of the transitional structure depth can be changed by changing the slot width.

4. FABRICATION AND RESULTS

A prototype of the transition was fabricated according to the aforementioned design result, as shown in Figure 8. Figure 9 shows the simulated and measured results. The measured results are obtained by using network analyzer AV3629. It can be see from Figure 9 that there is some difference between the simulation and measurement results both in center frequency. The simulation wave is slightly offset compared to measured one, but the trend is basically the same. These errors can be caused by large circuit dielectric loss, manufacturing error of circuit, test condition, etc.



(a)



(b)

Figure 8. Photograph of the transition with band notched characteristic: (a) front side photograph, (b) rear side photograph.

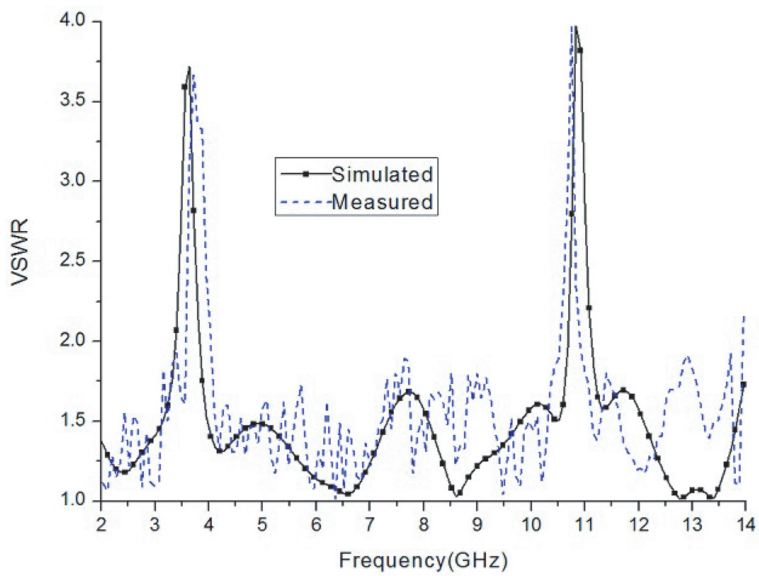


Figure 9. Simulated and measured results.

5. CONCLUSIONS

This paper presents and designs a new type of transition structure with band-notch characteristics, which realizes the transition of low transmission loss in the medium of low dielectric constant. The DMS structure is formed by etching a U-shaped slot on the microstrip line, thus the suppression of 3.37–3.84 GHz and 10.67–11.14 GHz bands is realized, without affecting the transmission performance in other bands. By changing the slot length, the notch frequency band can be offset, in such a way that the design is flexible. The DMS structure can effectively avoid electromagnetic wave leakage caused by the defect of the ground plane compared to DGS structure, and it will not interfere with other components in the microwave circuit. The notch structure can be applied in 5G mobile communication circuit.

ACKNOWLEDGMENT

This work was supported by Prepare Research Program of Tianjin University of Technology and Education in 2014, China, under Grant KJY14-05and Tianjin Research Program of Application Foundation and Advanced Technology, China, under Grant 14JCQNJC0110.

REFERENCES

1. Tu, S., Y.-C. Jiao, and Y. Song, "A Vivaldi antenna with notched frequency characteristics," *Chinese Journal of Radio Science*, Vol. 25, No. 2, 382–388, 2010 (in Chinese).
2. Wang, S.-J., H.-Z. Lin, Y.-X. Lai, et al., "Band-notched UWB bandpass filters with microstrip-to-slotline cross-junction transitions," *Chinese Journal of Electron Devices*, Vol. 39, No. 6, 522–525, 2016 (in Chinese).
3. Wu, J.-F. and J.-S. Li, "Compact ultra-wideband antenna with 3.5/5.5 GHz dual band-notched characteristic," *IEEE International Symposium on Microwave*, 446–450, 2013.
4. Sharma, A. and M. M. Sharma, "An UWB antenna design with dual band notched characteristic using U-shaped slots," *International Conference on Signal Processing and Communication (ICSC)*, 470–473, 2016.

5. Mewara, H. S., M. M. Sharma, R. Kumawat, et al., "Bandwidth enhancement of compact rectangular monopole UWB antenna using M-shaped strip with triple band notch characteristic," *International Conference on Computer, Communications and Electronics (Comptelix)*, 265–270, 2017.
6. Liao, J.-J., W.-B. Zeng, X.-D. Wu, et al., "Design of planar antenna with a band-notched characteristic for UWB application," *IEEE International Conference on Communication Problem-Solving (ICCP)*, 47–50, 2015.
7. Jung, J., H. Lee, and Y. Lim, "Compact band-notched ultra-wideband antenna with parasitic elements," *Electronics Letters*, Vol. 44, No. 19, 1104–1106, 2008.
8. Pan, C.-Y., J.-H. Duan, W.-L. Tu, et al., "Planar band-notched ultra-wideband monopole antenna using single open-circuited stub," *Microwave Conference*, 1962–1964, 2009.
9. Wang, N.-B., Y.-C. Jiao, L. Zhang, et al., "A Simple low-loss broadband 1–14 GHz microstrip-to-slotline transition," *Microwave Opt. Technol. Letters*, Vol. 51, No. 9, 2236–2239, 2010.
10. Zhang, Y.-C., B.-Z. Wang, and J. Hong, "Lumped-element microstrip-to-slotline transition," *Electronics Letters*, Vol. 40, No. 22, 1419–1420, 2004.
11. Chaudhary, G., P. Kim, Y. Jeong, J. Lim, et al., "Analysis and circuit modeling method for defected microstrip structure in planar transmission lines," *Microwave Conference*, 999–1002, 2012.