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

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Abstract—In this paper, a broadband transition structure from microstrip line to slotline with band-notched characteristic is proposed. To match the 50 Ω 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,
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 $\varepsilon_r$ 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 $\lambda$. The capacitance is determined by the fringing field of interdigital gap formed by etching, and is proportional to the

![Figure 1](image)

**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 $R_m = \lambda_{gm}/4 = 4.77$ mm and $R_s = \lambda_{gs}/4 = 8$ mm, where $\lambda_{gm}$ and $\lambda_{gs}$ 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 layer of the substrate. To match $Z_L$ to $Z_0$, the final size as follows: $L = 5.42$ mm, $w_1 = 1.15$ mm, $w_2 = 1.04$ mm, $w_3 = 0.98$ mm, $w_4 = 0.81$ mm, $w_5 = 0.66$ mm, $R_m = 4.77$ mm, $\theta = 75^\circ$; $w_s = 0.24$ mm, $L_1 = 3.7$ mm, $L_2 = 3.6$ mm, $L_3 = 1.6$ mm; $L_5 = 0.5$ mm, $w = 0.1$ mm, $L_4 = 12.4$ 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:

\[
C_{ps1} = \frac{1}{Z_0} \times \frac{1}{4\pi \Delta f_{\text{band notch 1}}} \quad L_{ps1} = \frac{1}{(2\pi f_{01})^2 C_{ps1}}
\]

\[
C_{ps2} = \frac{1}{Z_1} \times \frac{1}{4\pi \Delta f_{\text{band notch 2}}} \quad L_{ps2} = \frac{1}{(2\pi f_{02})^2 C_{ps2}}
\]

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

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

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

![Figure 2. U-shaped DMS equivalent circuit.](image)
\[ L_{ps2} = \frac{1}{(2\pi f_0^2 C_{ps2})^2} = \frac{1}{(2\pi \times 10.84 \times 10^9)^2 \times 2.777 \times 10^{-12}} \approx 0.0787 \text{ nH} \] (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 \(-15 \text{ dB})\), 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 \(-15 \text{ dB})\) and VSWR less than 1.5. The central frequency of the band notched is \( f_{01} = 3.6 \text{ GHz} \) and \( f_{02} = 10.84 \text{ GHz} \), 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.
Figure 5. Electric field diagram at 10.87 GHz. (a) Without etched U-shaped slot, (b) etched U-shaped slot.

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
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).

The 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 seen 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.

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

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