Analysis and Design of Ku Band Coaxial-waveguide Transition

Chao Wang[1], Gaofeng Guo[1], Junhu Wang[2], and En Li[1]

[1]University of Electronic Science and Technology of China, Chengdu 611731, China
[2]Aerospace Research Institute of Materials and Processing Technology, Beijing 100076, China

Abstract— Coaxial-waveguide transition plays an important role in microwave system. Based on the influence of waveguide ladder exerted on transmission performance of electromagnetic wave in guided wave system, this paper demonstrates the situations of this structure applied in Ku band coaxial-waveguide converter designation. The reflected wave and insertion loss have been reduced by using a multi-steps structure with the coaxial probe excitation. The effectiveness of impedance matching is well-improved, and the transmission performance of coaxial-waveguide converter is highly-advanced. Simulation results proved the effectiveness of waveguide ladder in designing coaxial-waveguide converters. The VSWR of coaxial-waveguide transition designed in this paper is less than 1.04 in the 12.4–18 GHz octave bandwidth, and the high modulus produced is very small.

1. INTRODUCTION

Coaxial-waveguide transitions play an important role in microwave system which are very necessary and critical passive microwave components in Radar equipment, precision guidance and microwave testing circuit. Design of transitions from coaxial to waveguide applicable to commercial and military microwave system is of valuable importance. In the dielectric material permittivity test system, the performance of components is critical to the accuracy of the test result. Main aim for the designers is to achieve low levels of return loss during transformation of TEM mode in coaxial to TE-mode in waveguide in operating frequency band. The VSWR of coaxial-waveguide transition designed in this paper is less than 1.04 (return loss less than 34 dB) in the 12.4–18 GHz octave bandwidth, and the high modulus produced is very small. This paper introduces a standard 50 ohm coaxial cable which outer radius is 1 mm, inner radius is 0.435 mm and the dielectric constant is 2.08.

2. THE BASIC THEORY AND ANALYSIS

In this paper, the design of mode converter is based on the utilization of a rectangular cavity and a cylinder probe with conical part, a 4-step Chebyshev-response impedance transformer was designed using the combination construction with single ridge waveguide and reduced size rectangular waveguide. Design formulas resulting in an equal ripple or Chebyshev-type response were given by Cohn, Collin [1], and Riblet, and were experimentally verified.

Figure 1 shows the proposed structure of the transition. The transition consists of stepped impedance transformer and mode converter. It is well known that, the characteristic impedance of rectangular waveguide is a function of frequency rather thana constant value. Therefore a multi-step matching transformer is essentially for such extreme high impedance ratio together with wide fractional bandwidth. The first step for this approach was selection of the waveguide cross section,

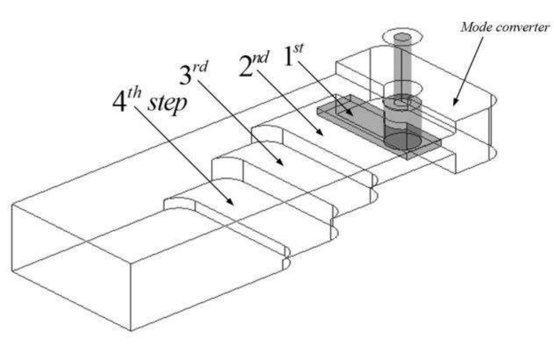

Figure 1: Structure of the proposed transitio.

with its resulting characteristic impedance and guided wavelength. The combination construction with single-ridge waveguide (the fist-step) and reduced size waveguide (the second-, third- and forth-step) was employed to frame a 4-section Chebyshev response quarter-wave transformer [2]. Single-ridge waveguide portion has been used due to its compatibility with both conventional circular coaxial and rectangular waveguide. The characteristic impedance of each step has been calculated [3]. Calculation by HFSS, we can know wave impedance is $Z = 298\,\text{Ohm}$ which correspond the center frequency is $f_0 = 15.2\,\text{GHz}$. The length l of each section in terms of the guide wavelengths in that section is defined by:

$$\begin{aligned}\Gamma(\theta) &= 2e^{-jN\theta}\left[\Gamma_0\cos N\theta + \Gamma_1\cos(N-2)\theta + \ldots + \Gamma_n\cos(N-2n)\theta + \ldots\right] \\ &= Ae^{-jN\theta}\mathrm{T}_N(\sec\theta_m\cos\theta)\end{aligned} \tag{1}$$

As we know, $N = 4$. So we can obtain

$$\Gamma(\theta) = 2e^{-j4\theta}\left[\Gamma_0\cos 4\theta + \Gamma_1\cos 2\theta + \frac{1}{2}\Gamma_2\right] = Ae^{-j4\theta}\mathrm{T}_4(\sec\theta_m\cos\theta) \tag{2}$$

As $A = \Gamma_m = 0.05$ and

$$\sec\theta_m = \cosh\left[\frac{1}{N}ar\cosh\left(\frac{\ln Z_L/Z_0}{2\Gamma_m}\right)\right] = \cosh\left[\frac{1}{4}ar\cosh\left(\frac{\ln 298/50}{2\times 0.05}\right)\right] = 1.4251 \tag{3}$$

We can obtain

$$\begin{aligned}&2\left[\Gamma_0\cos 4\theta + \Gamma_1\cos 2\theta + \frac{1}{2}\Gamma_2\right] = A\left[\sec^4\theta_m(\cos 4\theta + 4\cos 2\theta + 3) - 4\sec^2\theta_m(\cos 2\theta + 1) + 1\right] \\ &= A\sec^4\theta_m\cdot\cos 4\theta + \left(4A\sec^4\theta_m - 4A\sec^2\theta_m\right)\cdot\cos 2\theta + \left(3A\sec^4\theta_m - 4A\sec^2\theta_m + A\right)\end{aligned} \tag{4}$$

The corresponding coefficient equation can be obtained

$$\begin{aligned}2\Gamma_0 &= A\sec^4\theta_m \Rightarrow \Gamma_0 = \Gamma_4 = 0.1031 \\ 2\Gamma_1 &= 4A\sec^4\theta_m - 4A\sec^2\theta_m \Rightarrow \Gamma_1 = \Gamma_3 = 0.2094 \\ \Gamma_2 &= 3A\sec^4\theta_m - 4A\sec^2\theta_m + A \Rightarrow \Gamma_2 = 0.2625\end{aligned} \tag{5}$$

So when $n = 0$, we can obtain

$$\begin{aligned}&\ln Z_1 = \ln Z_0 + 2\Gamma_0 = \ln 50 + 2\times 0.1031 = 4.1182 \Rightarrow Z_1 = 61.4485HFSS \Rightarrow l_1 = 1.63\,\text{mm} \\ &n = 1,\ \ln Z_2 = \ln Z_1 + 2\Gamma_1 = 4.537 \Rightarrow Z_2 = 93.4101 \Rightarrow l_2 = 2.48\,\text{mm} \\ &n = 2,\ \ln Z_3 = \ln Z_2 + 2\Gamma_2 = 5.062 \Rightarrow Z_3 = 157.906 \Rightarrow l_3 = 4.19\,\text{mm} \\ &n = 3,\ \ln Z_4 = \ln Z_3 + 2\Gamma_3 = 5.4808 \Rightarrow Z_4 = 240.038 \Rightarrow l_4 = 6.38\,\text{mm}\end{aligned} \tag{6}$$

where Γ is the reflection coefficient, and we can roughly calculate the length of each section with formulas (1) to (6).

It has been observed that by reconstruction the coaxial waveguide junction portion, a considerable decrease in VSWR can be achieved. A majority of the field in this section is concentrated in the TEM mode between the cylinder probe and the up wall of the ridged waveguide, and then radiated into the multistep impedance transformer, with just a few energy being propagated into the short-circuited waveguide cavity (shown in Fig. 2). This probably occurs because the equivalent reactance result from the rectangular waveguide cavity stub may be sufficiently high to be neglected in an approximate treatment [4]. The hybrid section does, in fact, support multi-modes of propagation, whereas most of the energy has been transformed into TE10 mode while pass through the mode converter. The advantage of this rectangular waveguide-coaxial portion is the ability to redistribute the electromagnetic field as it propagates from a coaxial waveguide through the single-ridge waveguide.

3. OPTIMIZATION AND RESULTS

The proposed structure has been applied to realize a broadband coaxial-waveguide transition with return loss less than $-34\,\text{dB}$ in the frequency band between 12.4 to 18 GHz. The transition has

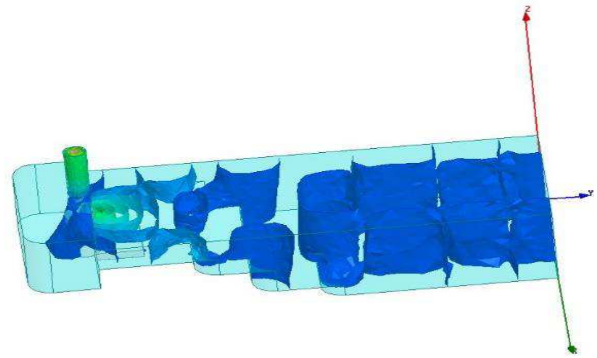

Figure 2: Field overlays of the transition.

been designed using the high frequency structure simulator Agilent HFSS based on finite-element field solver and simulation results are reported in Figure 3 and Figure 4. The design was optimized for use with a waveguide dielectric material test system for the operating frequency band from 12.4 GHz to 18 GHz. None but dominate mode wave can propagate in the rectangular waveguide in this frequency range. The length of the impedance transformer section has been calculated with formulas (1) to (6) and the shorted circular waveguide cavity is made equal to a quarter of the free-space wavelength at the mid-band frequency. Through simulation and optimization, we can get high of l_1 = 1st = 4 mm, l_2 = 2nd = 4.1 mm, l_3 = 3rd = 4.7 mm, l_4 = 4th = 5.7 mm. Those parameters are calculated on the base of wide-band impedance match theory, which is appropriate for the homogeneous case.

It can be seen that there flection coefficient of the original model is below −22 dB (shown in Fig. 4). However, the model based on computed data for the homogeneous case might provide initial design parameters of the transition [5]. Those parameters are valuable reference for subsequent modification to a more nearly optimum performance. And several attempts have been made to modify the lengths of stepped impedance transformer sections to compensate for the shunt capacitances introduced by the step discontinuities. The design was optimized through several iterations and the results are presented in Fig. 4. Better than −34 dB return loss was obtained in the whole operating frequency band from 12.4 GHz to 18 GHz. Fig. 3 shows the input VSWR versus change with the working frequency, and we can see that the VSWR is less than 1.04 reflection coefficients less than −34 dB in Fig. 4. The real coaxial-waveguide transition used for testing is shown in Fig. 5 and the test results compared with the simulation results are almost the same.

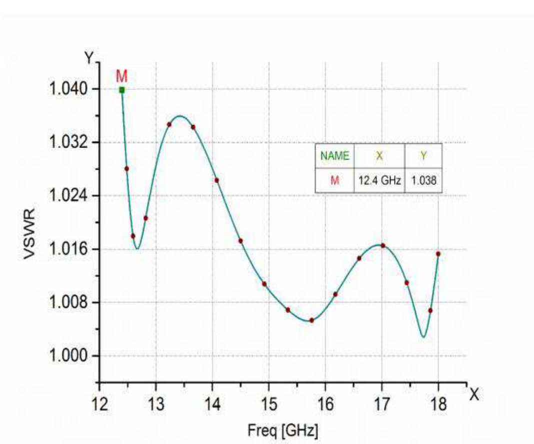

Figure 3: The cure of input VSWR for coaxial-waveguide transition.

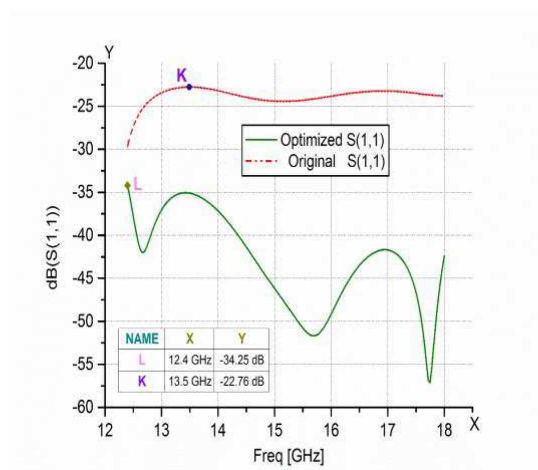

Figure 4: Comparison of the original and optimized reflection coefficient for the coax-to-rectangular waveguide transition.

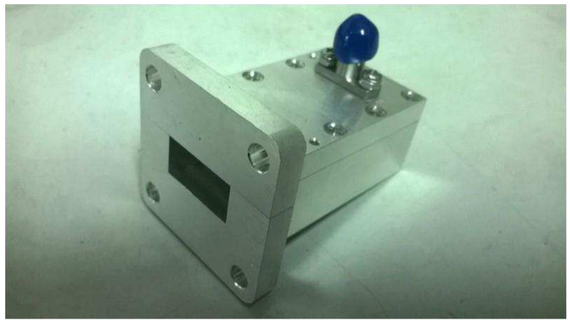

Figure 5: The real coaxial-waveguide transition.

4. CONCLUSION

In this paper, we study on some the wave transformation from the coaxial line to rectangular waveguide. Coaxial-waveguide transition has been widely used in various microwave systems. So a novel transition from coaxial line to rectangular waveguide is proposed in this paper. Feasible way to optimize performance of the transition is analyzed and verified. Very good broadband performance of this transformer is described through rigorous simulation result. The prototype of this transition achieves return loss less than −34 dB, possible applications include high accuracy microwave material test and broadband horn antenna feeds. And we will research coaxial-waveguide transition which can be applied in widerband.

REFERENCES

1. Collin, R. E., *Field Theory of Guided Wave*, 323–332, McGraw-Hill, New York, 1961.
2. Wang, Y., "An X-band coaxial-to-rectangular waveguide transition," *Microwave Technology and Computational Electromagnetics*, 129–131, 2011.
3. Collin, R. E., "Theory and design of wide-band multisession quarter-wave transformers," *Proc. IRE Trans. on Microwave Theory and Techniques*, Vol. 3, 16–21, Apr. 1955.
4. Bialkowski, M. E., "Analysis of a coaxial-to-waveguide adaptor including a discended probe and a tuning post," *IEEE MTT*, Vol. 43, 344–349, Feb. 1995.
5. Cohn, S. B., "Optimum design of stepped transmission-line transformer," *IRE Trans. on Microwave Theory and Techniques*, Vol. 3, 16–21, Apr. 1995.