A Novel Design of Ku Band Coaxial-waveguide Directional Coupler Used for the Measurement of the Short-circuited Line Method

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Abstract— An effective method was proposed to design a high power coaxial-waveguide directional coupler applied to the short-circuited line method. In this paper, the coupler designed using the proposing method has wide band, high directivity, flat coupling coefficient, lower SWR, and low requirement for machining accuracy. According to the required technology parameter, preliminary designed the aperture waveguide directional coupler and the adapter. In order to achieve the more excellent indices, we simulate and optimize the distance between the two hole and the two ends hole size of the coupler, the step size of the adapter. The VSWR of coaxial-waveguide transition designed in this paper is less than 1.06 in the 12.4–18 GHz octave bandwidth, and the high modulus produced is very small. Therefore, coaxial-waveguide directional coupler of the directivity and the coupling coefficient are improved.

1. INTRODUCTION

In the field of microwave measurement we need the coaxial-waveguide transitions which are playing an important role in microwave system and critical passive microwave components in Radar equipment, precision guidance and microwave testing circuit. Moreover, we need the Directional couplers in the measurement to sample the signal. In order to convenient our measurement we integrate the two components- the coaxial-waveguide transitions and the waveguide Directional couplers into one part. It has an excellent simulation result which VSWR is less than 1.05, the error between the simulation value of coupling and the required value $-14\,\text{dB}$ is less than $0.8\,\text{dB}$. It also has well performance in engineering application for Ku band measurement instrument of Terminal short-circuit.

2. THE BASIC THEORY AND ANALYSIS

We integrate the part in our design and the theory in each will be analysis in the following illustration.

In this paper, the design of coaxial-waveguide transitions 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 designed structure of the coaxial-waveguide transitions. It has two critical parts that are stepped impedance transformer and mode converter. We know that the characteristic impedance of rectangular waveguide is more a function of frequency than a constant value in the traditional theory. Hence we need a multi-step matching transformer to satisfy such extreme high impedance ratio and the wide fractional bandwidth. There are 4 steps in the aforementioned structure. The first step is for the selection of the waveguide cross section on the basis of its 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]. The part of Single-ridge waveguide has been used to satisfy the compatibility between the conventional circular coaxial and the rectangular waveguide. The characteristic impedance of each step has been computed [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:

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

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

$$\Gamma(\theta) = 2e^{-j4\theta}\left[\Gamma_0\cos 4\theta + \Gamma_1\cos 2\theta + \frac{1}{2}\Gamma_2\right] = Ae^{-j4\theta}T_4(\sec\theta_m\cos\theta) \tag{2}$$

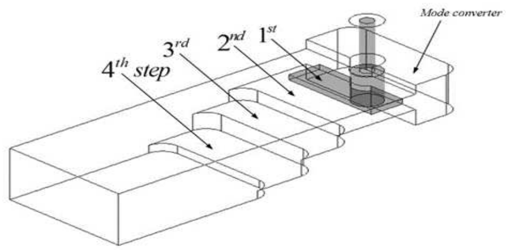


Figure 1: The structure of the coaxial-waveguide transitions.

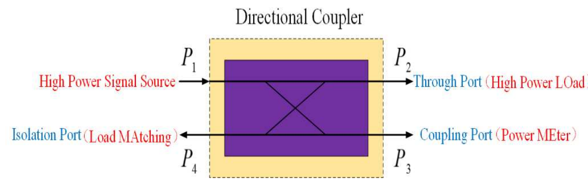


Figure 2: Structure of high power waveguide directional coupler.

As $A = \Gamma_m = 0.05$ and

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

We can obtain

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

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

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

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

In this paper, we also referred to the waveguide directional couplers. As is shown in the Figure 2, the coupler is a network with 4 ports which are the input port, through port, coupling port and isolation port.

There are four main index-coupling, isolation, direction and bandwidth-to weigh the performance of the coupler. Here are the calculating method of the four parameter

(1) Coupling

$$C = 10\cdot\lg\frac{P_3}{P_1} = 20\cdot\lg|S_{31}|\ (\mathrm{dB}) \tag{7}$$

(2) Isolation

$$I = 10\cdot\lg\frac{P_4}{P_1} = 20\cdot\lg|S_{41}|\ (\mathrm{dB}) \tag{8}$$

(3) Direction

$$D = 10\cdot\lg\frac{P_4}{P_3} = 20\cdot\lg|S_{43}|\ (\mathrm{dB}) \tag{9}$$

(4) Bandwidth

Bandwidth refers to the frequency range design index of directional coupler are meet the requirements.

3. OPTIMIZATION AND RESULTS

In Figure 3, we provided the model designed and simulated by the HFSS. In our model, port 1 is the input port which the signal fed, and port 3 is the coupling port which used to connect our waveguide device.

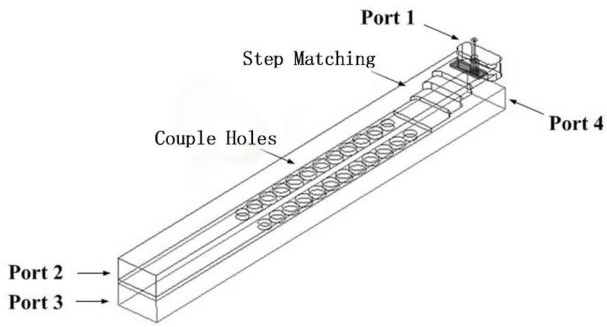
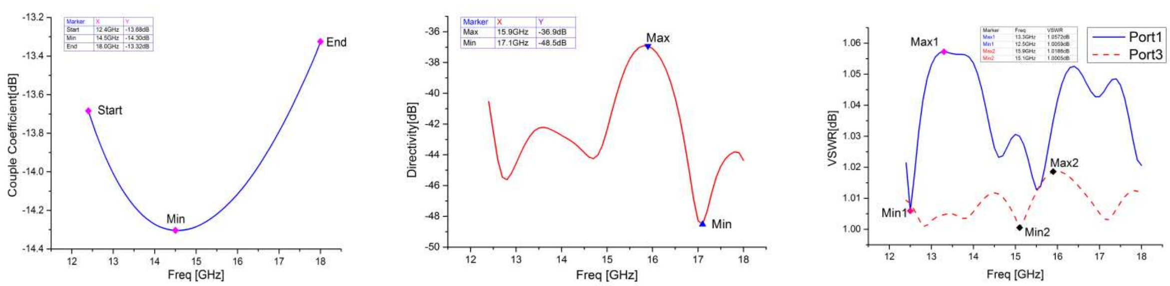


Figure 3: The model of the coaxial-waveguide we designed.

In Figures 4(a)–(c), we given the result of our simulation. In the Figure 4(a), the fluctuate of its couple coefficient is less than 1 dB (the couple coefficient we design is −13 dB). As is shown in Figure 4(b), the worst isolation of the coupler is −35 dB. In Figure 4(c),it is shown that the VSWR of the coupler is less than 1.1 which is better than 1.3 we needed in practice.



(a) (b) (c)

Figure 4: (a) The couple coefficient. (b) The directivity of the coupler. (c) The VSWR of the coupler.

As the result can satisfy our requirements, we processed the real product which is shown in Figure 5.

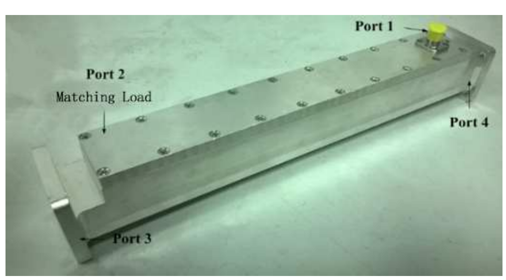
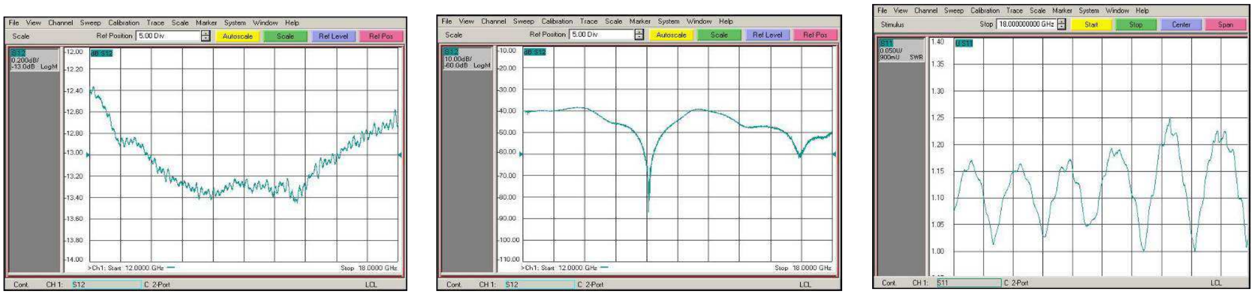


Figure 5: The real product of the coupler.

We measure our real product using Agilent E8363A and the result of the measurement of the coupler is shown in Figures 6(a)–(c). From the measurement, the range of the couple coefficient shown in Figure 6(a) is −12.4 dB $\sim$ −13.4 dB which means that the fluctuate of the couple coefficient is less than 1 dB, the isolation coefficient shown in Figure 6(b) is less than −40 dB, the VSWR shown in Figure 6(c) is less than 1.20.



(a) (b) (c)

Figure 6: (a) The couple coefficient. (b) The isolation coefficient. (c) The VSWR of the coupler.

4. CONCLUSION

It is easy to discover that there are some difference when compare the result of simulation with the result of measurement. For instance, the curves have some difference when compare Figure 4(b) with Figure 6(b). In Figure 4(c), the VSWR is less than 1.05, while the VSWR in Figure 6(c) is less than 1.2. Here we put forward several reasons that may contribute to the difference. The first reason is machine error such as the inner wall smoothness of the waveguide, which could affect the performance of the device. At the same time, if the impedance transformer can not machine accurately, there must be some influence on the VSWR. The second reason is the connection between the adapter and the coupler. The performance may be worse if the adapter and the coupler cannot mate tightly when we using the VNA to measure the coupler.

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