Improved Design of Ku Band High Power Rectangular Waveguide Directional Coupler

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Abstract— This paper demonstrates an effective designing method of the high power rectangular waveguide directional coupler. The coupler designed using this method has wide band, high directivity, flat coupling, low voltage standing ratio and manufacturing accuracy. According to the required technology parameter, and the engineering design method based on the modified Bethe aperture coupling theory, the relevant parameters of equally spaced waveguide directional coupler are preliminarily designed. On the basis of this, using simulation software HFSS to do the simulation and optimization of the space between three outside coupling holes of the head end and the tail end, the performance of isolation is improved. A directional coupler at Ku waveband is designed in this paper, the error between the simulation value of coupling and the required value $-10\,\mathrm{dB}$ is less than $0.6\,\mathrm{dB}$, and after optimization, the isolation is less than $-47\,\mathrm{dB}$ in the whole operating frequency band.

1. INTRODUCTION

Directional couplers play an important role in almost every microwave application for measuring the power levels of signals in microwave systems, it was widely used in measurement, communication, radar and other electronic equipment. The traditional design method is based on the Bethe aperture coupling theory. In order to adapt the different needs of the development of electronic equipment, the directional coupler from the single hole coupling to porous coupling, from the waveguide narrow side coupled to the broadside coupled, to satisfy the different requirements of narrowband, broadband, strong coupling and weak coupling [1]. As a result of the directional coupler has stable performance, it is index were not affected by ambient temperature, so there is a method for the high power microwave measurement as shown in Figure 1. According to the coupling degree and direction of directional coupler to convert and calculate the power of signal source.

The physical properties of the transmission lines and their coupling method dictates the coupling properties of the coupler [2], so different kinds of couplers have their advantages and disadvantages. Microstrip and stripline directional couplers have attractive broad-band characteristics, but they are affected by their significant losses and low power-handling capabilities when high power handling is required; coaxial directional couplers are the traditional high-power solution when bandwidth are not critical [3]; waveguide Bethe hole couplers are usually used in high-power applications,unfortunately they have a relatively bandwidth, at least in terms of its directivity. But if the couplers are designed with as eries of coupling holes, the extra degrees of freedom can be used to increase this bandwidth. The principle of operation and design of such a multihole waveguide coupler is very similar to that of the multisection matching transform. After the basic aperture coupling theory which is proposed by Bethe and Cohn [4], scholars from many countries do further research on it in order to meet the various needs.

In this paper, an effective designing method of the directional coupler with wide frequency band and high directivity is proposed, and using this method, a directional coupler is designed with the aid of simulation software HFSS (High Frequency structure Simulator). So first, we design an equally spaced waveguide directional coupler according to there quired parameter and the modified Bethe aperture coupling theory; then we optimize the space between the coupling holes and reduce the size of some coupling holes of the head end and the tail end to get a valuable coupler with flatter coupling coefficient and higher directivity. A directional coupler at Ku waveband ($12.4 \sim 18\,\mathrm{GHz}$) is designed in this paper, the error between the simulation value and the required value is less than $0.6\,\mathrm{dB}$ and the directivity is more than $37\,\mathrm{dB}$. Meanwhile, it reduces the requirement of the manufacturing accuracy as far as possible in consideration of the influence of manufacturing errors.

2. THE PERFORMANCE INDEX OF THE DIRECTIONAL COUPLER

As shown in Figure 1. The directional coupler is a network with four ports. They are the input port, through port, coupling port and isolation port. Describes the performance index of the directional coupler are coupling, isolation, direction, bandwidth.

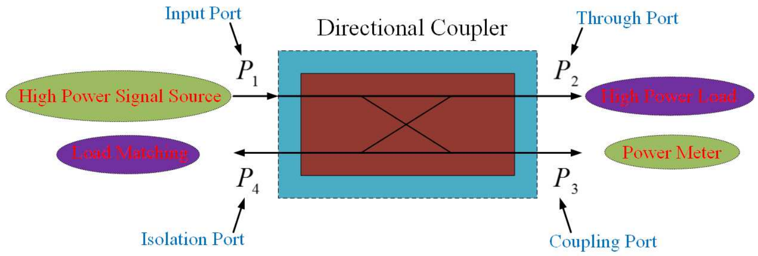

Figure 1: Structure of high power microwave through directional coupler.

(1) Coupling

$$C = 10 \cdot \lg \frac{P_3}{P_1} = 20 \cdot \lg |S_{31}| \ \text{(dB)} \tag{1}$$

(2) Isolation

$$\mathrm{I} = 10 \cdot \lg \frac{P_4}{P_1} = 20 \cdot \lg |S_{41}| \ \text{(dB)} \tag{2}$$

(3) Direction

$$D = 10 \cdot \lg \frac{P_4}{P_3} = 20 \cdot \lg |S_{43}| \ \text{(dB)} \tag{3}$$

(4) Bandwidth

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

3. DESIGN AND OPTIMIZATION OF DIRECTIONAL COUPLER

3.1. The Design Requirements

The design of a bandwidth of $12.4 \sim 18$ GHz, the coupling degree of C is -10 dB, directional D is greater than 37 dB.

3.2. Theoretical Basis

Aperture coupling theory was first proposed by Bethe, then large aperture coupling Cohn and McDonald on the finite thickness of the improved [5]. Bethe directional coupler is signal through a single hole in two waveguide broadside on the public from a waveguide coupled to another waveguide. The directional characteristics of directional coupler is through the use of two separate wave or wave component in the coupling port is added, and the isolation port phase cancellation and produce.

3.3. Design Procedure

Chebyshev response, Binomial response and equivalent aperture response are generally used in waveguide coupling. A Chebyshev coupler has a broader-band performance than the corresponding coupler designed with the binomial response, while the Chebyshev coupler requires higher manufacturing accuracy. As we all known, errors of the coupling apertures are inevitable in the manufacturing process, the higher manufacturing accuracy, the greater errors it brings, then it will lead to unsatisfactory results. To minimize manufacturing accuracy, we choose equivalent aperture response and optimize the aperture spacing and the radius of some apertures, which not only reduces errors but also improves coupling coefficient and directivity.

(1) Aperture array distribution

Figure 2 shows the structure of the coupling wall between the two waveguides proposed in this paper. It consists of two rows that have a distance of s between the center of circles and the edge of the waveguide, and ten columns that have different spacing. The coupling hole heart distance waveguide edge distance is S, aperture spacing are d, d_1 and d_2, aperture radius are r, r_1 and r_2.

(2) Aperture spacing

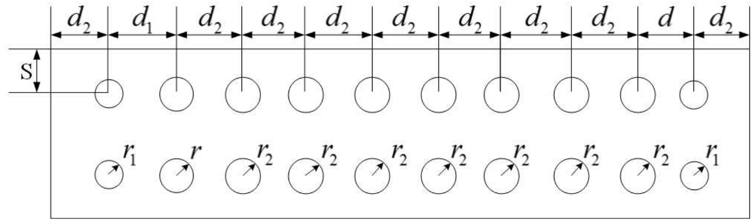

Figure 2: Aperture array distribution of Ku band directional coupler.

According to the principle of phase superposition, thespacing between the apertures should be kept constant andequal to a quarter wavelength of the center frequency of theband.

$$d = \frac{1}{4}\lambda_{g_0} = \frac{1}{4}\frac{2\lambda_{g_1}\lambda_{g_2}}{\lambda_{g_1} + \lambda_{g_2}} \tag{4}$$

where λ_{g_0} is the guide wavelength, λ_{g_1} is the minimum guide wavelength and λ_{g_2} is the maximum guide wavelength. d has a significant influence on coupling coefficient and directivity, thus we can adjust it to achieve flatter C and better D. According to the result of optimization, we choose $d = 5.8\,\text{mm}$, $d_1 = 6.35\,\text{mm}$ and $d_2 = 6.3\,\text{mm}$.

(3) Aperture radius

K_f and K_b are constants for the forward and backward coupling coefficients. The coupling and directivity can be calculated as

$$C = -20\lg|K_f| - 20\lg\sum_{n=0}^{N} r_n^3 \tag{5}$$

$$D = -C - 20\lg|K_b| - 20\lg\left|\frac{\sum\limits_{n=0}^{N} r_n^3 e^{-2j\beta nd}}{\sum\limits_{n=0}^{N} F_n}\right| \tag{6}$$

We can easily obtain r_n and N. The bigger aperture is, the more coupling it will be. We finally choose $N = 7\,\text{mm}$, $r = 2.55\,\text{mm}$, $r_1 = 2.15\,\text{mm}$ and $r_2 = 2.7\,\text{mm}$ inconsideration of manufacturing accuracy.

(4) Aperture thickness h

The coupling coefficient increases in the straight line within crease of aperture thickness. If h increases, the attenuation will also increase when the coupling wave passes through the coupling hole, thus the coupling coefficient will increase. Therefore, we can change h to adjust the coupling coefficient of the directional coupler according to the requirements. However, what we should pay attention to in the engineering design is that the increase of h will also increase the directional coupler's dimensions in the space. Coupling value for different aperture thickness h versus frequency is shown in Figure 3, and finally we choose $h = 0.5\,\text{mm}$ for the consideration of flatter coupling value.

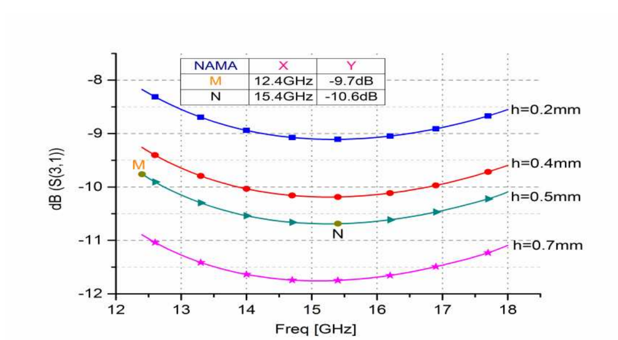

Figure 3: Coupling value for different aperture thickness h.

(5) The aperture offset from the sidewall of the guide

The distance between the center of circles and the sidewall of the guide is denoted as s, which has a huge influence on coupling coefficient especially for the low-frequency section. With the increase of s, the coupling coefficient decreases largely in the low frequency section and small in the high frequency section. Taking many factors into consideration, we choose $s = 3.1\,\mathrm{mm}$ ultimately.

4. SIMULATION RESULTS

The proposed structure has been applied to realize abroad band coupler with coupling coefficient about -10 dB anddirectivity bigger than 37 dB in the frequency band between12.4 to 18 GHz. The directional coupler is simulated with the aid of Ansoft HFSS and simulation results are reported in Figure 4 and Figure 5. It can be seen that directivity varies from -37.2 to 57.9 dB over the band and the isolation is less than -47 dB in the whole operating frequency band. The directional coupler uses waveguide structure, so the voltage standing wave ratio (VSWR) is generally ideal. Figure 5 gives input VSWR versus the working frequency, and we can see that the VSWR is less than 1.009.

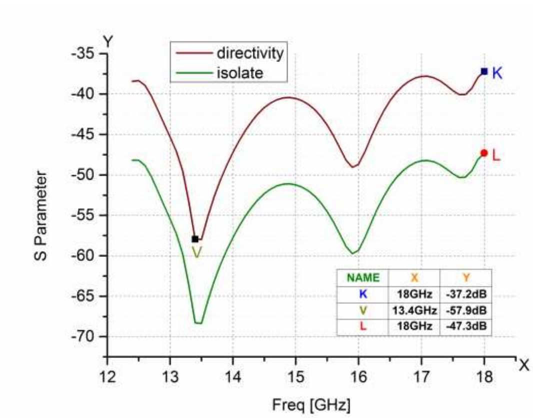

Figure 4: The cure of the S_{14} and directivity.

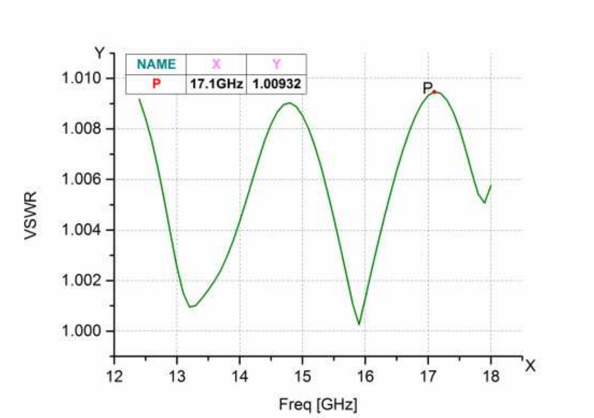

Figure 5: The cure of input VSWR.

5. CONCLUSION

A novel method has been proposed and analyzed for designing directional couplers in this paper. This method represents a significant improvement for high-power measurement systems since they have flat coupling coefficient, good directivity, low VSWR, high power handling capacity etc., and can be fabricated at low cost with smaller manufacturing errors. A Ku band rectangular waveguide directional coupler has been designed and simulated using the HFSS software. Because of little manufacturing accuracy, this method will have many applications in microwave wireless communication measurement systems.

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