New Design of Directional Coupler Based on Ridge-waveguide

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Keywords: Ridge Waveguide, Directional Coupler, Coupling, Chebyshev Function.

Abstract: Ridge waveguide devices are used extensively in microwave system because with the same section size, ridge waveguides have relatively wider single-mode bandwidth than rectangular waveguides. A new method for designing a directional coupler whose main and vice-waveguide are both ridge waveguide is presented, mean while, Chebyshev function is used as distribution function. The designing of the coupler is simulated by HFSS.

1 INTRODUCTION

A number of scholars have been systematically studied the design of directional couplers, especially, the main and vice-waveguides of the directional coupler are rectangular waveguide. But main and vice-waveguides are ridge waveguide is relatively rare. The boundary conditions of ridge waveguide are more complex, it is quite difficult to analytic solution to the field of the ridge waveguide, which limits the study and applications of the ridge waveguide. Ridge waveguide is divided into the ridge area and the slot area by W. J. Getsinger, and the transverse electric field is matched to deduce the analytical expression to descript the ridge waveguide, which laid the foundation to study ridge waveguide[Getsinger, 1962].

The Chebyshev function has been proposed as a distribution function by scholars in the study of microwave devices, which can improve the device performance. Therefore, the pore size distribution of the holes is on the Chebyshev function, a directional coupler device of the center frequency of 3GHz, the coupling of -40dB is designed using the small hole coupling theory. HFSS simulations show that such a design in a wide frequency range, the coupling is relatively flat.

2 MAIN BODY

2.1Calculation of $A_v^{\pm}$ [Miller, 1954]

The main and vice-waveguides of the multi-hole directional coupler are in the fundamental mode of the waveguide. Coupling holes are relatively symmetrical distribution to the centerline, not only the locations of each pair of symmetrical holes symmetry, but also the shape and size of them are symmetry. The main waveguide excites the fundamental positive and anti-wave through those coupling holes in the vice waveguide, respectively, whose relative intensity are $a_0^{\pm}$, $a_1^{\pm} \dots a_n^{\pm}$, where the superscript $\pm$ are the positive and reverse wave, respectively, the subscript are the coupling hole number, the total number of coupling holes is $N = 2n + 1$.

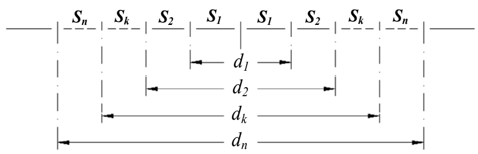

Figure 1: Multihole directional coupler.

The voltage of the positive and reverse wave which are excited by the modes of the main waveguide m in the vice waveguide[Wang Wenxiang, 2003].

$$A_v^{\pm} = a_0^{\pm} + \left| \begin{matrix} 2a_1^{\pm}\cos\theta_1^{\pm} + 2a_2^{\pm}\cos\theta_2^{\pm} + \cdots \\ + 2a_k^{\pm}\cos\theta_k^{\pm} + \cdots + 2a_n^{\pm}\cos\theta_n^{\pm} \end{matrix} \right| = a_0^{\pm} + 2\left|\sum_{k=1}^{n} a_k^{\pm}\cos\theta_k^{\pm}\right| \quad (1)$$

Where
$$\left.\begin{matrix} \theta_k^{\pm} = (\beta_m \mp \beta_v) d_k / 2 \\ d_k = 2\sum_{k=1}^{n} S_k \end{matrix}\right\} \quad (2)$$

2.2Determination of S

In multihole coupling the space between the coupling holes S_k are equal and the space is S, which is the pitch coupling, so

$$d_k = 2kS \quad (3)$$

$$\theta_k^{\pm} = 2k\varphi^{\pm} \quad (4)$$

where $\varphi^{\pm} = (\beta_m \mp \beta_v)S/2$ (5)

When $\theta_k^{+} = i_k\pi$, $(i_k = 0,1,2,\cdots)$, when, all the positive waves are overlaying, while when $\theta_k^{-} = (i_k + 1/2)\pi$, $(i_k = 0,1,2,\cdots)$, all the reverse wave are to offset each other(a_0 is excepted). Therefore, according to the above conclusions, selecting the appropriate value i_k, the hole spacing S can be got.

2.3Calculation of the Single-hole Coupling Coefficient

In order to improve the performance of the directional coupler, the coupling strength of the coupling region is set to change according to some certain laws. To this end, the hole spacing is fixed unchanged, leaving the pore size changes according to certain rules, that is the different aperture holes are arranged so that the coupling strength of the coupling region to meet a certain distribution. We use the Chebyshev distribution law to arrange the pore size of the hole [Levy, 1959, Jiang P Y, 2004].

For the equal spacing ranging and the unequal intensity distribution, there are the following equations.

$$a_0^{\pm} = \delta_0 a^{\pm}, a_1^{\pm} = \delta_1 a^{\pm}, \cdots, a_n^{\pm} = \delta_n a^{\pm} \quad (6)$$

While (1) changes into

$$A_v^{\pm} = a^{\pm}\left|\delta_0 + 2\sum_{k=1}^{n}\delta_k\cos(2k\varphi^{\pm})\right| \quad (7)$$

First Chebyshev function is defined as

$$T_n(x) = \cos(n\arccos x) \; (|x| \le 1) \quad (8)$$

When $x = \cos\varphi^{-}$, so $\varphi^{-} = \arccos x$ $|x| \le 1$,and

$$A_v^{-} = a^{-}\left|\delta_0 T_0(x) + 2\sum_{k=1}^{n}\delta_k T_{2k}(x)\right| \quad (9)$$

The reverse incentives A_v^{-} are limited not exceed a certain maximum value within a certain range, so the result is

$$A_v^{-} = K\left|T_{2n}(tx)\right| \quad (10)$$

According to experience, t is set as 1.5, then equal the functions (9) and (10), making the corresponding coefficient equal, then $\delta_0, \delta_1, \cdots \delta_n$ can be obtained when the number holes is N

$$a^{+} = 10^{C/20} / \left(\left|\delta_0 + 2\sum_{k=1}^{n}\delta_k\cos(2k\varphi^{\pm})\right|\right) \quad (11)$$

where C is the coupling coefficient of the directional coupler (dB). From the coefficient $\delta_0, \delta_1, \cdots \delta_n$, the coupling coefficient of the single hole can be calculated.

2.4Calculation of the Single-hole Radius

According to the field expressions of the ridge waveguide[Getsinger, 1962] and small hole coupling theory[Bethe, 1944, Collin, 1966], the relative amplitude of the waves of the vice-waveguide:

$$a_k^{\pm} = a_{1,k} \mp a_{2,k} \tag{12}$$

where

$$a_{1,k} = -\frac{j\omega}{p_s}\varepsilon_0 \frac{2}{3} r_k^{3} K_e R_e \left\{ \begin{array}{l} \left[\begin{array}{l} \dfrac{d\cos k_c s/2}{b\sin k_c l}\sin k_c x_1 + \\ \displaystyle\sum_{n=1}^{\infty}\frac{2}{n\pi}\frac{\cos k_c s/2}{\sinh\gamma_n l}\sin\frac{n\pi d}{b}\sinh\gamma_n x_1\cos\frac{n\pi y_1}{b} \end{array} \right]\times \\ \left[\begin{array}{l} \dfrac{d\cos k_c s/2}{b\sin k_c l}\sin k_c x_2 \\ +\displaystyle\sum_{n=1}^{\infty}\frac{2}{n\pi}\frac{\cos k_c s/2}{\sinh\gamma_n l}\sin\frac{n\pi d}{b}\sinh\gamma_n x_2\cos\frac{n\pi y_2}{b} \end{array} \right] \end{array} \right\} \tag{13}$$

$$a_{2,k} = \frac{j\omega}{p_s}\mu_0\left(-\frac{4}{3}r_k^{3}\right)R_m K_m \left\{ \begin{array}{l} \left\{ \begin{array}{l} \dfrac{k_z^{2}}{\eta^2 k^2}\left[\begin{array}{l} \dfrac{d\cos k_c s/2}{b\sin k_c l}\sin k_c x \\ +\displaystyle\sum_{n=1}^{\infty}\frac{2}{n\pi}\frac{\cos k_c s/2}{\sinh\gamma_n l}\sin\frac{n\pi d}{b}\sinh\gamma_n x_1\cos\frac{n\pi y_1}{b} \end{array} \right]\times \\ \left[\begin{array}{l} \dfrac{d\cos k_c s/2}{b\sin k_c l}\sin k_c x \\ +\displaystyle\sum_{n=1}^{\infty}\frac{2}{n\pi}\frac{\cos k_c s/2}{\sinh\gamma_n l}\sin\frac{n\pi d}{b}\sinh\gamma_n x_2\cos\frac{n\pi y_2}{b} \end{array} \right] \end{array} \right\} \\ -\left\{ \begin{array}{l} \dfrac{k_c^{2}}{\eta^2 k^2}\cos^2 k_c s/2\times \\ \left[\dfrac{d\cos k_c x_1}{b\sin k_c l} - \displaystyle\sum_{n=1}^{\infty}\frac{2}{n\pi}\frac{k_c\sin n\pi d/b}{\gamma_n\sinh\gamma_n l}\cosh\gamma_n x_1\cos\frac{n\pi y_1}{b} \right]\times \\ \left[\dfrac{d\cos k_c x_2}{b\sin k_c l} - \displaystyle\sum_{n=1}^{\infty}\frac{2}{n\pi}\frac{k_c\sin n\pi d/b}{\gamma_n\sinh\gamma_n l}\cosh\gamma_n x_1\cos\frac{n\pi y_2}{b} \right] \end{array} \right\} \end{array} \right\} \tag{14}$$

where p_s is the normalized power coefficient. K_e, R_e, K_m, R_m are the factor and the thickness of the macro-hole factor[Sporleder, 1979]. x_1, y_1 are the locations of the holes in the main waveguide, x_2, y_2 are the position of the vice-waveguide. From (12) and the single-hole coupling coefficient from above calculation, the aperture of the hole can be obtained.

3DESIGN EXAMPLES

3.1Design of an Example

The example directional coupler is set at the center frequency of 3GHz, the coupling is -40dB, so the standard single-ridge waveguide is chosen, the single-mode operating frequency range of the waveguide is 2.0 ~ 4.8GHz. The design directional coupler structure is as follows (Unit: inch)

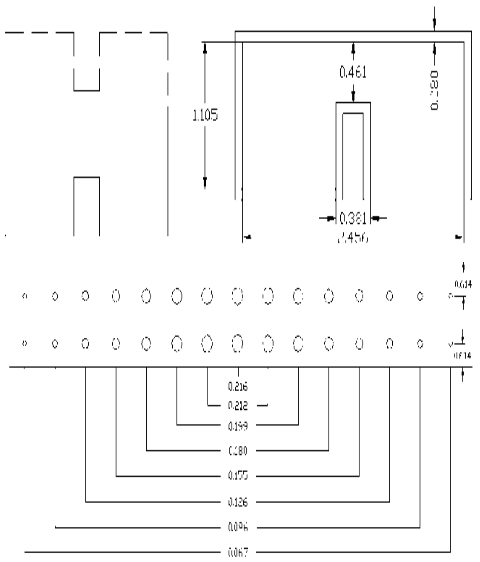

Figure 2:The structure and dimension of the directional coupler.

3.2Simulation Results

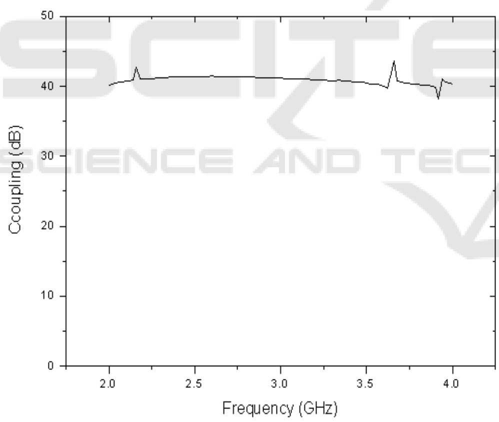

Figure 3:Coupling of the directional coupler versus the frequency.

It can be seen from the above simulation results figure that the coupling curve is relatively flat in broad frequency range, so our design method is feasible.

4CONCLUSIONS

It can be seen that when the coupling hole is two rows, each row is set as 15 holes, the radius of the center hole is 0.216 " in our example design. If the coupling is stronger, the aperture and the number of holes are need to increase. When the aperture is increased, then the aperture is too large, the small hole coupling theory is no longer reasonable. If the number of holes is increased, not only the fabrication becomes more difficult, but also the coupler length will increase. Therefore, the design method of the directional coupler whose main and vice-waveguides are ridge waveguide based on the small hole coupling theory is feasible only for the case of weak coupling.

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