A Design of Rotman Lens for Phase Antenna Array

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Abstract— In this work, a wide banded planar multi-input/output port Rotman lens for phase array antennas is investigated by simulation. The Rotman lens consists of lens and delay lines. With essential parameters, the outline of the lens is calculated by Matlab, in this way we can design a Rotman lens with certain functions, also the model is constructed by simulation software with the data imported from Matlab. The lens consists of the lens and the delay line. A useful segmented design of the delay line is applied to improve the transmission efficiency. A principle for dumpy port design is raised to improve the output characteristics. By this way, the magnitude error of different frequency is limited within 3 dB and below 5 dB when the port is changed. The lens offers a phase shift from -70 degree to +70 degree with a changeable step.

I. INTRODUCTION

Beam former is widely used for phased array antennas, which can provide the wide scan angles. Thus, a well-designed phase shifter is needed. Optic the branch of science concerned with high-frequency electromagnetic waves, similarly with Microwave engineering. That indicates we can solve the problem by an optical means. Rotman lens is an optical component. Although some beam formers offer a wider scan angle or a larger bandwidth, only the Rotman lens offers a compromise in performance that includes a scan range from -60 degree to +60 degree. [1] In 1967, first microstrip Rotman lens and scan expansion was introduced. And in 1970, the first 2-dimensional Rotman lens stack was demonstrated. [2] Rotman lens consists of beam ports (input ports) ,array ports(output ports), dumpy ports, and the transmission line connected to them.(shown in Fig. 1) The signal is excited from one of the beam ports, and the lens acts as a phase shifter, thus making the phase of the array ports lined up(or down). When the input port is changed, The OPD (optical path difference) of the output ports changes and the tolerance of the output ports changes, too. Once Excited by the center beam port, the phases of the array ports are the same. In this work, we calculate the outline curves of the Rotman lens first, then construct the model for simulation, and verify the frequency banded enhancement characteristics. Furthermore, the phase and magnitude will be investigated.
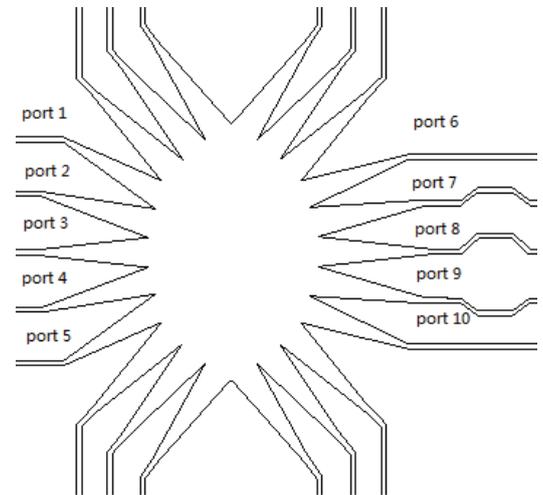

Fig. 1. An Overview of Rotman Lens

II. DESIGN

A. Design Equations

The equations of the outline curves are shown below.[3]

$$F_2 P \sqrt{\epsilon_r} + W \sqrt{\epsilon_e} - Y_3 \sin(\Psi_\alpha) = f_2 \sqrt{\epsilon_r} + W_0 \sqrt{\epsilon_e} \quad (1)$$

$$F_1 P \sqrt{\epsilon_r} + W \sqrt{\epsilon_e} = f_1 \sqrt{\epsilon_r} + W_0 \sqrt{\epsilon_e} \quad (2)$$

$$F_2 P \sqrt{\epsilon_r} + W \sqrt{\epsilon_e} + Y_3 \sin(\Psi_\alpha) = f_2 \sqrt{\epsilon_r} + W_0 \sqrt{\epsilon_e} \quad (3)$$

From the equations above ,we note that the dimension does not depend on frequency. Thus indicates the lens is ultra-wide-banded. The next step is to calculate parameters of the curves. α is the focal angle, θ_m is the maximum beam scan angle ,let $a_0 = \cos(\alpha)$,$b_0 = \sin(\alpha)$ and $c_0 = \sin(\theta_m)$.z is the y axis of the array ports, array outline curve is $\Gamma(x, y)$,in which
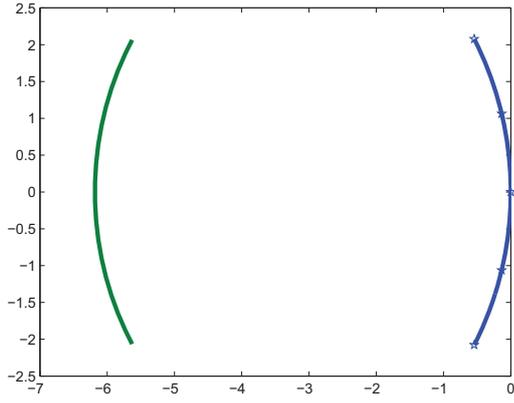
Fig. 2. The Outline Calculated by Matlab

Fig. 3. The Model for Simulation

$$x = \frac{1}{g - a_0}[(1 - g)w - \frac{1}{2}\eta^2] \tag{4}$$

$$y = (1 - w)\frac{\eta}{b_0} \tag{5}$$

$$\eta = \frac{c_0 z}{a_0} \tag{6}$$

Parameter a, b and c are defined below.[4]

$$a = \frac{(g - 1)^2}{(g - a)^2} + \frac{\eta^2}{(b_0)^2} - \frac{g\eta^2}{g - a} \tag{7}$$

$$b = \frac{2g(1 - a)}{g - a_0} - \frac{(1 - g)\eta^2}{(g - a_0)^2} - \frac{2\eta^2}{b_0^2} \tag{8}$$

$$c = \frac{\eta^4}{4(g - a_0)} + \frac{\eta^2}{b_0^2} - \frac{g\eta^2}{g - a_0} \tag{9}$$

The curve of the array ports is $\Gamma_2(R, \theta)$. Here we choose $\alpha = 50$ degree ,$\theta_m = 45$ degree ,$g = 1.07$,with 5 beam ports and 5 array ports. By these parameters, the curves can be calculated by Matlab, the result is shown in Fig. 2.

To realize desired phase shift, an additional delay line with the length of w is needed, The parameter w is determined by the equation below.

$$aw^2 + bw + c = 0 \tag{10}$$

Ignore the w which is below zero ,we get

$$w = \frac{-b + \sqrt{b^2 - 4ac}}{2a} \tag{11}$$

The transmission line consists of a delay line and two impedance matching lines. The first part matches the impedance between the lens and the delay line. And the second part matches the delay line's impedance with 50 Ohm.
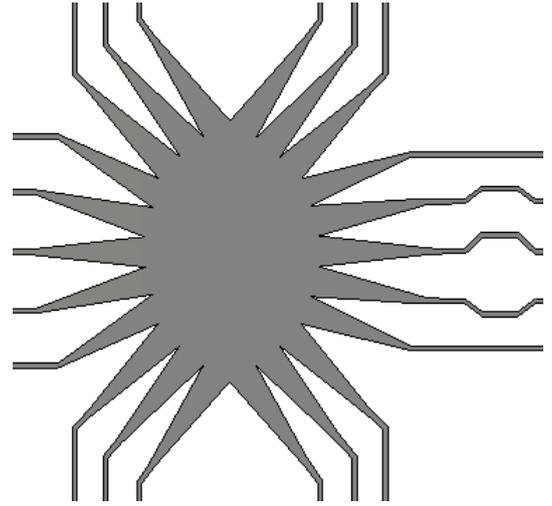
Furthermore, the impedance matching line between the lens and a delay line can increase the received power of the output ports, thus avoid a serious reflection. As a triangle delay line will cause more reflected wave, this delay line is designed like a trapezium, which reduces reflection and offers a particular delay of phase. The impedance matching lines can also be realized by a $\lambda_g/4$-length transmission line for miniaturization, because the dimension depends on frequency and the design will be narrow banded. Dumpy ports should cover the outline to ensure the absorption of the higher-order model. With this precondition, to use fewer dumpy ports will increase the utilization of the ports.

B. Simulation

With the curves above, we can construct the model with the microstrip line. The dimension of the lens applies the parameter above. Rogers 4003 is used, whose permittivity is 3.55, and the thickness is 0. 8mm. Import the curves into simulation software and the final model is shown in Fig. 3. The S parameters of the output ports are shown in Fig. 4 to Fig. 9.

C. Analysis

Note that when the input port is port 1, the received energy of the output ports are almost the same, with a fluctuation below 3 dB. This feature indicates the lens can be applied on phase array antenna. The bandwidth is extremely wide as the figures show, from 7 GHz to 12 GHz. When working at higher frequency, the OPD is influenced by the higher model of the microstrip line. The phase characteristic shows a perfect fit with the conclusion above. When the input port is changed, the fluctuation between different output ports is less than 5 dB, and the tolerance changes by about 35 degrees, i.e. 70