# A Method for Minimizing the Phase Errors of Rotman Lenses

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### Abstract

**A method is introduced for determining the feed curves of Rotman lenses such that the phase errors are minimized. The method ensures that there are at least three zero phase error points on the radiating array for each off focal beam position. The results of a path length error study show that there is a very significant drop in the level of the maximum phase errors (in the order of about 4:1) compared with the commonly used circular and elliptical feed curves.**

## 1. Introduction

In many communication applications it is desirable to have high effective power (ie high gain) as well as wide angular coverage. Multibeam antennas with a feed network are employed for this purpose. Rotman lens fed array antennas are multibeam array antennas used in many antenna applications to obtain simultaneous multiple beams over wide angles [1]-[3]. The design of the Rotman lens is based on path length equality, which make the system inherently wideband. As these lens fed arrays are simple to design and easy to construct, they have widely been used in various fields of communications.

A Rotman lens is a two dimensional constrained lens with three focal points. There are antenna elements on the two curves of the lens (Fig. 1). The antenna elements on the inner curve of the lens are connected to the antenna elements on the outer curve (i.e. the radiating array) by transmission lines. The radiating array is usually a linear array but it may be nonlinear as well. The coordinates of the inner lens curve and the lengths of the transmission lines are the design variables of the lens. For each position on the radiating array the values of these variables are obtained by equating the path lengths from the three chosen focal points to appropriate phase fronts [1]. A curve containing these three focal points is called the feed curve. Antenna elements are also placed on this curve. Each antenna element on the feed curve produces a beam in a certain direction in space. Although the phase fronts obtained by placing feed antennas at the focal points have no phase error, the phase fronts for the feed antennas at points between these focal points (on the feed curve) will have some phase errors. These phase errors may be significant for large size Rotman lenses with large number of multiple beams. Any phase errors cause deterioration in the gain and sidelobe level of the beams.

In [1] Rotman and Turner have a circular arc passing through the focal points. Hansen [3] and Singhal et al [4] propose that an elliptical curve is used as a feed curve. Katagi et al [5] propose an integral method to obtain the feed curve which seems to have similar results to the elliptical feed curve [3].

In this paper we propose a simple but very effective method to reduce the phase errors for off focal feed points. The method for obtaining the new feed curve and a comparison of the phase error performances of Rotman lenses using this new feed curve, a circular feed curve and an elliptical feed curve are given below.

## 2. Design Method

The geometry of the Rotman lens is shown in Fig 1. The focal points are at $F_1$ ( $f_0 - f_1\cos\alpha_1, f_1\sin\alpha_1$ ), O ( $0,0$ ) and $F_2$ ( $f_0 - f_1\cos\alpha_1, -f_1\sin\alpha_1$ ) where $f_1$ is the off axis focal length ( $F_1O_1$ and $F_2O_2$ ), $f_0$ is the on axis focal length ( $OO_1$ ) and $\alpha_1$ is the angle subtended by the off axis focal points at $F_1$ and $F_2$ .The coordinates of the points on the inner lens curve as well as the lengths of the transmission lines are obtained by solving the three equations given below as in [1].

$$F_1P + w + Y\sin\theta_1 = f_1 + w_0 \tag{1}$$

$$F_2P + w - Y\sin\theta_1 = f_1 + w_0 \tag{2}$$

$$OP + w = f_0 + w_0 \tag{3}$$

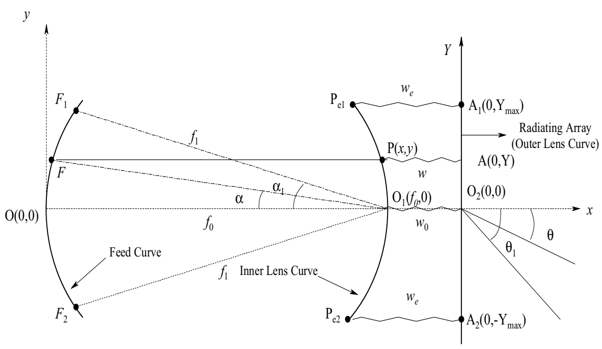


**Fig. 1.** Rotman Lens Geometry

where P is a general point on the inner lens curve with coordinates ($x, y$), Y is ordinate of the corresponding point A on the radiating array, $w$ is the length of the transmission line between P and A, $w_0$ is the length of the transmission line between the center point of the inner lens curve ($O_1$)and the center point of the radiating array point ($O_2$)and $\theta_1$ is the angle of the beam for the off axis focal points. The relationship between $\alpha_1$ and $\theta_1$ is given by sin $\alpha_1$ = k sin $\theta_1$ , k is a constant which is a design parameter of the lens. The radiating array is 2 $Y_{\max}$ long and it is between the points $A_1$ (0, $Y_{\max}$ ) and $A_2$ (0, $-Y_{\max}$ ).

Path length difference to the phase front determines the phase errors. Path length error studies show that the path length errors for off focal point feed positions are large for the end elements (or for elements near the end) of the radiating array when circular or elliptical feed curves are used. If the path length errors for these elements are reduced, the overall phase performance will be improved. The method we propose is based on having zero phase error at three points on the radiating array. After obtaining the inner lens curve for the three chosen focal point positions, the coordinates of the feed curve ( $x_f$ , $y_f$ ) can be obtained such that the path lengths from each point F on the feed curve through the two end elements of the radiating array ( $A_1$ and $A_2$ ) to the corresponding phase front are equal to the path lengths from F through the centre elements at $O_1$ and $O_2$ to the same phase front. This way it is ensured that there are at least three points on the radiating array where the path length errors are zero.
Using the nomenclature of Fig. 1 we can write two equalities:

$$FP_{e1} + w_e + Y_{\max} \sin\theta = FO_1 + w_0 \tag{4}$$

$$FP_{e2} + w_e - Y_{\max} \sin\theta = FO_1 + w_0 \tag{5}$$

where $P_{e1}$ and $P_{e2}$ are the end points of the inner lens curve and $w_e$ is the transmission line length for the two end points.

These equations are solved for $x_f$ and $y_f$ for each $\alpha$ angle to obtain the feed curve, where $\alpha$ is the angle subtended by the point F. Rather than the end points of the radiating array, we can, alternatively, choose two points close to the end points for path length equality. The equations (4) and (5) are changed accordingly. The distance from the end points of the radiating array can be used as a design parameter. This small shift in the position of the points will reduce the maximum path length error further.

## 3. Path Length Errors

The path length errors determine the phase errors of the multiple beams of the Rotman lens fed array. For each position along the radiating array, $A(0,Y)$, the path length error for off focal point feed position F can be obtained by the difference in path length from F through P and A to the phase front, and from F to the phase front through $O_1$ and $O_2$, as given below:

$$\Delta l = FP + w + Y\sin\theta - FO_1 - w_0 \tag{6}$$

Fig. 2 shows the path length errors for a typical Rotman lens with a circular feed curve. The circle passes through the points $F_1$ , O and $F_2$ . The parameters of this lens are $f_0 = 1$, $f_1 = 0.9$, $\theta_1 = 50^0$, $Y_{\max} = 0.625$ and $k = 0.9$ . As $f_0 = 1$ the path length error $\Delta l$ is normalized to $f_0$ . In Fig. 2 the path length errors are given for off focal beam positions ( $\theta$ ) at $5^0$ , $15^0$ , $25^0$ , $35^0$ , $45^0$ . The relationship between $\alpha$ and $\theta$ is given by sin $\alpha$ = k sin $\theta$ . We can observe that as $\theta = 25^0$ beam is furthest away from the focal beams it has the largest errors.

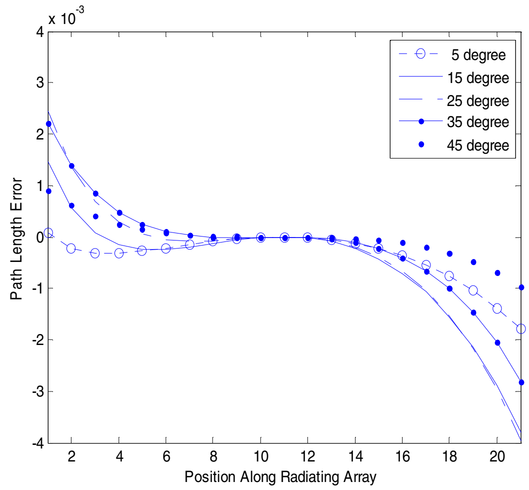


**Fig. 2.** Path length error $(\Delta l / f_0)$ for different off focal beam directions-circular feed curve

Fig. 3 shows the path length errors for the same Rotman lens with an elliptical feed curve. As there is no unique ellipse passing through the three focal points, we chose the ellipse which had the smallest maximum path length error, which had an eccentricity of 0.4.

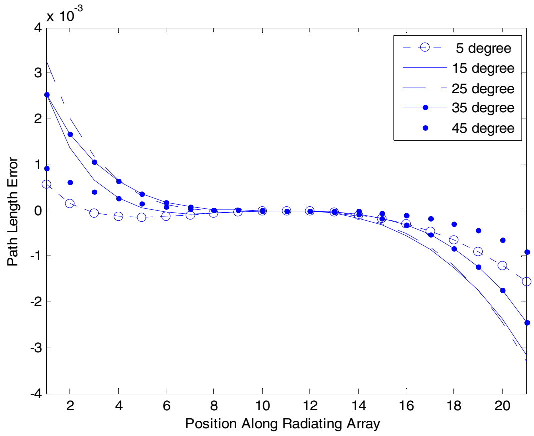


**Fig. 3.** Path length error $(\Delta l / f_0)$ for different off focal beam directions-elliptical feed curve

Fig. 4 and Fig. 5 show the path length errors for the same Rotman lens with a feed curve obtained by using the equations 4 and 5. Fig. 4 gives the errors when the two end points ( $Y = \pm Y_{\max}$ ) of the radiating array have zero error and Fig.5 gives the errors when the two points at $Y = \pm 0.9Y_{\max}$ have zero error. It can be observed from Figs. 2, 3, 4 and 5 that the path length errors are considerably smaller when the new feed curve is used. There is a reduction in the maximum path length errors for the above example in the order of about 4:1. The results in Fig. 5 also indicate that the distance of the zero error position from the end point of the radiating array can be used as a design parameter to minimize the path length errors.

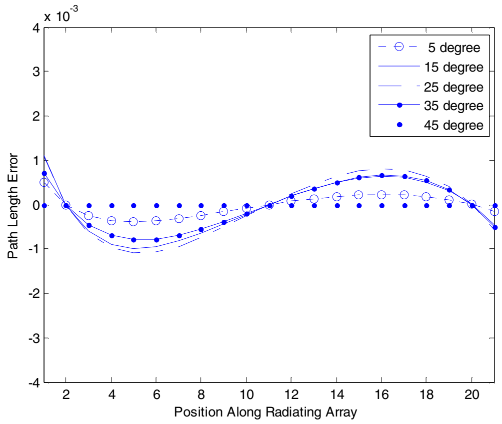


**Fig. 4.** Path length error $(\Delta l / f_0)$ for different off focal beam directions- new feed curve (zeros at end points)

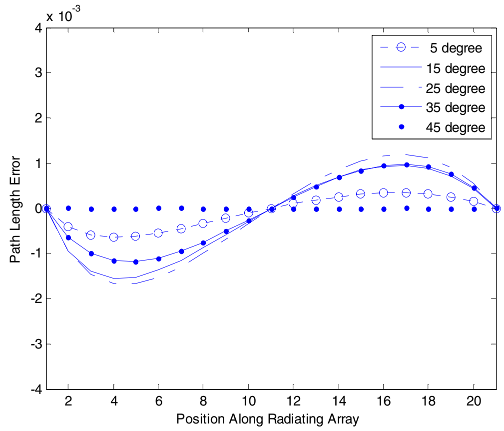


**Fig. 5.** Path length error $(\Delta l / f_0)$ for different off focal beam directions- new feed curve (zeros at $Y = \pm 0.9 Y_{\max}$ )

## 4. Conclusions

A new and effective method is introduced for determining the feed curve of a Rotman lens. The method is based on having three zero error positions on the radiating array for each feed curve point. The design equations for the new feed curve are presented. A study has been carried out to compare the path length error performance of the new feed curve with the performances of the circular and elliptical curves. The results show that the path length errors are considerably lower when the new curve is used.

## 7. References

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