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Full Length Research Paper

Modified design of bootlace lens for multiple beam forming

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As of now, utility of microwave bootlace lens is well established. For broadband and wide scanning network, it is required to optimize and use features of this lens for better communication and scanning device. This paper presents the design of a compact bootlace lenses for multiple beam forming. Equations to design the lens have been given. The designed lenses has been fabricated and tested. The measured results are in close agreement with the designed values.

Key words: Multiple beam forming, antenna design, bootlace lens, wide area scanning, rotman lens.

INTRODUCTION

Microwave bootlace lens forms an important class of multiple beam forming networks. Ruze (1950) suggested a lens for wide angle scanning. Rotman and Turner (1963) and Leonakis (1986) suggested modification in Ruze's lens to improve the scanning capabilities. Four approaches have been reported for the design of bootlace lens (2, 4, 5 and 6). Rotman and Turner (1963) described the design of bootlace lens for parallel plate configuration, however, the same design concept for the design of bootlace lens in microstrip configuration can be used by dividing the lens region by square root of the of the relative dielectric constant of the substrate of the microstrip. In the design approach proposed by Rotman and Turner, the off axis focal points F_1 and F_2 were located on angle α and –α respectively. Katagi et al. (1984) suggested an improved method to design bootlace lens, the suggested approach reduces the phase error for large array length. Gagnon (1989) modified the design approach proposed in (Rotman and Turner, 1963) by locating the off axis focal points at angles β and –β, where β is determined according to the Snell's law that is, $\sin\beta = \sqrt{\varepsilon_r} \sin \alpha$ where ε_r is the relative dielectric constant. In the approach proposed by Singhal et al. (2003), the off axis focal points were located at angles β and –β, where the value of β is calculated to equalize the height of feed and array contours. In the present work bootlace lenses have been designed by all the four reported design approaches and analysed by contour integral approach.

All the reported design approaches are based on the phase shift comparison. Lot of work has been reported on the shape and phase error of the bootlace lens (Singhal et al., 2003; Shrama et al., 1992; Peterson and Rausch, 1999; Hansen, 1992; Sbarra et al., 2007). The reported work describes the shape and phase error of the bootlace lens in term of on axis and off axis focal length along with the other design parameters.

In the present work, effects of radius and center of focal arc on the shape and phase error of the lens have been investigated. Bootlace lenses have been designed at UHF band with different number of input and output ports for an angular coverage of ± 35°.

LENS DESIGN

Figure 1 shows the cross section of a trifocal bootlace lens. One focal point F_0 is located on the central axis and two others F_1 and F_2 are symmetrically located on the either side of a circular focal arc of which (0,-K) is the center and R is the radius. Outer contour I_2 is a straight line and defines the position of the radiating elements. I_1 is the inner contour of the lens (also called the array contour). The inner and outer contours are connected by TEM mode transmission lines W (N). Two off axis focal points F_1 and F_2 are located on the focal arc at angles +β and –β. Angle β can be suitably selected to equalize the height of feed and array contour, it is required that the lens be designed in such a way that the out going beams make angles –α, 0 and +α with the x - axis when feeds is placed at F_1, F_0 and F_2 respectively. A ray originating from F_1 may reach the wave-front through a general point P(X, Y) on the inner contour I_1, transmission line W(N) and point Q(N) on the outer contour and then trace a straight line at an angle –α and terminate perpendicular

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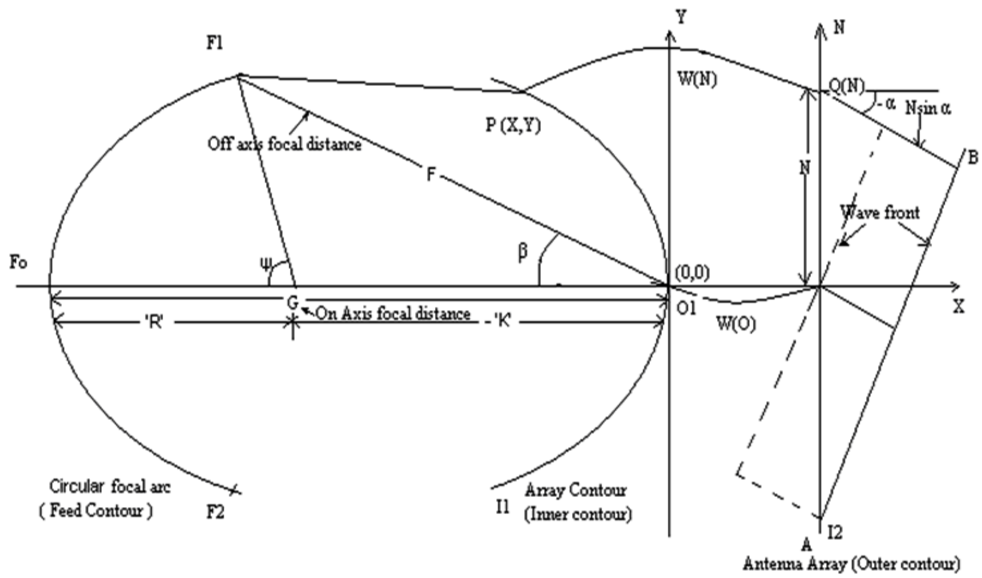

Figure 1. Cross-section of the bootlace lens geometry.

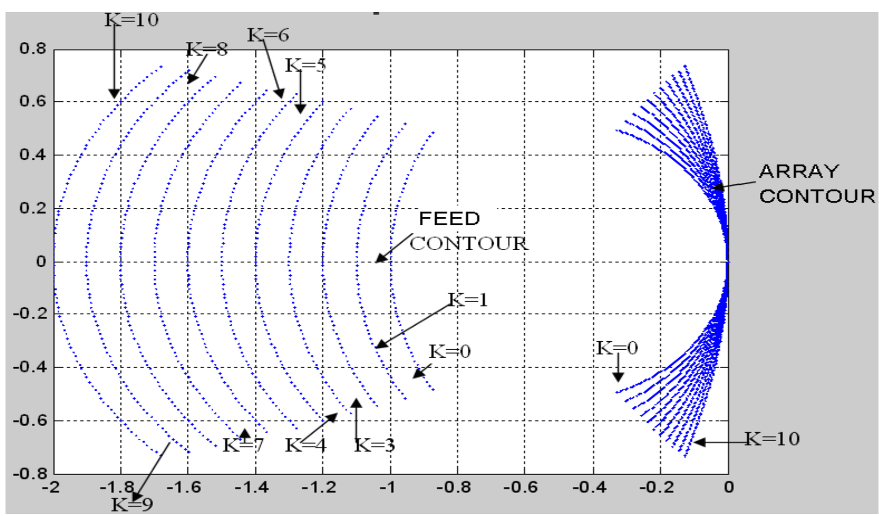

Figure 2. Effect of the center the feed contour on the shape of the lens.

to the wave-front. Also, the ray from F_1 may reach the wave-front from and F_1 to pint O_1 and then through transmission line W (0) to the wave-front. Similarly, rays from other feed points may reach their respective wave-front.

Inner contour and transmission lines are designed from the design equations which are derived using the fact that at the wave-front, all of these rays must be in phase independent of the path they travel. This requires that the total phase shift in traversing the path to reach the wave-front in each case be equal. Using this concept, the following design equations can be written

$$\sqrt{\varepsilon_r}\,(F_1P) + \sqrt{\varepsilon_{re}}\,W(N) + N\sin\alpha = \sqrt{\varepsilon_r}\,F + \sqrt{\varepsilon_{re}}\,W(O) \quad (1)$$

$$\sqrt{\varepsilon_r}\,(F_2P) + \sqrt{\varepsilon_{re}}\,W(N) - N\sin\alpha = \sqrt{\varepsilon_r}\,F + \sqrt{\varepsilon_{re}}\,W(O) \quad (2)$$

$$\sqrt{\varepsilon_r}\,(F_0P) + \sqrt{\varepsilon_{re}}\,W(N) = \sqrt{\varepsilon_r}\,G + \sqrt{\varepsilon_{re}}\,W(O) \quad (3)$$

Where

$$(F_1P)^2 = (X + F\cos\beta)^2 + (Y - F\sin\beta)^2 \quad (4)$$

$$(F_2P)^2 = (X + F\cos\beta)^2 + (Y + F\sin\beta)^2 \quad (5)$$

$$(F_0P)^2 = (X + G)^2 + (Y)^2 \quad (6)$$

N - Indicate the position of the radiating elements called the lens aperture;

ε_r - Substrate dielectric constant;

ε_{re} - Effective dielectric constant of the transmission line.

The other parameters involved in the design equations are shown in Figure 1.

Using the above design equations and the approach suggested in (Singhal et al., 2003), the bootlace lens can be designed.

Effects of the radius and the center of the feed contour on the shape of the lens

Figure 2 shows the shape of the feed and array contours for different position at the center (0, -K) of the feed contour, keeping

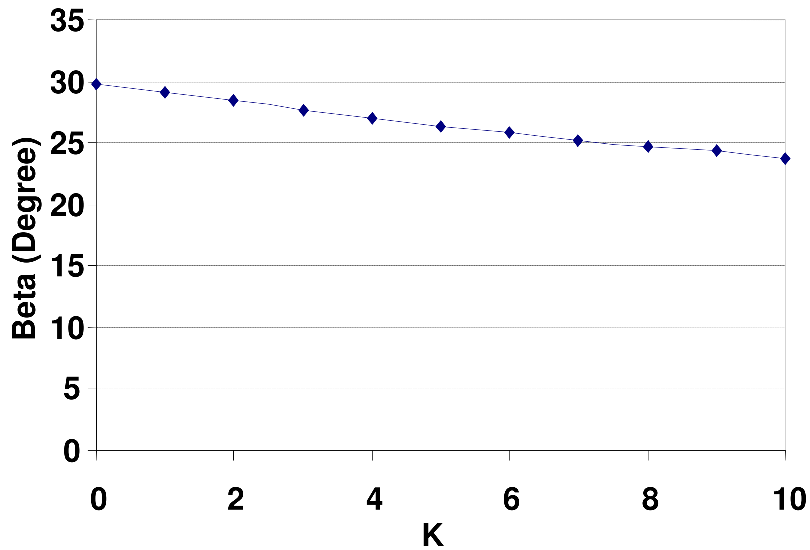

Figure 3. Variation of β with Center K.

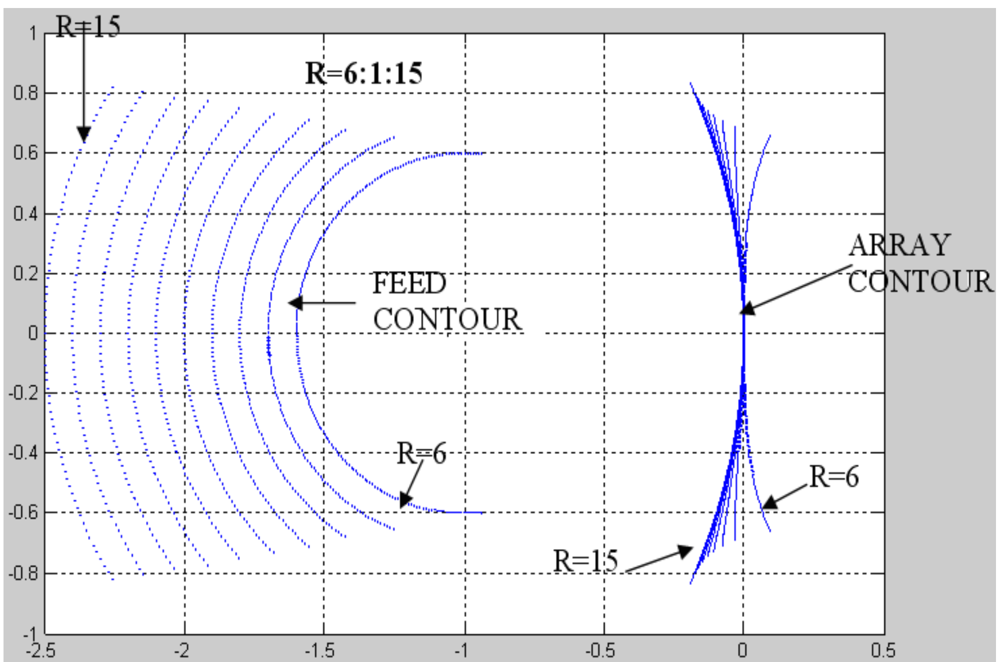

Figure 4. Effect of the radius of the feed contour on the shape of the lens.

the other parameters constant As the feed contour moves away from array contour (value of K increases) array contour opens.

Angle β is determined in such a way that the height of feed and array contours remain equal. Figure 3 shows the variation of β with different values of K, as K increases β decreases.

Figure 4 shows the variation of the shape of the feed and array contours with the radius R of the feed contours. As radius decreases, curvature of feed contour increases and array contour opens. There is limit of the radius when the shape of the array contour changes from concave to convex.

As shown in Figure 5 at R = 6.65, the array contour is almost a straight line, with further decrease in R, the array contour will become convex. Figure 6 shows the variation of angle β with the radius, as the radius increases, β decreases.

Effects of the radius and the center of the feed contour on the phase error of the lens

Figure 7(a) - (d) shows the variation of phase along the lens aperture for different values of K (center for the focal arc) with R (radius of the focal arc) as the parameters. It can be observed that for certain values of R and K the phase error is minimum. Therefore, it is required to select the value of R and K carefully; the

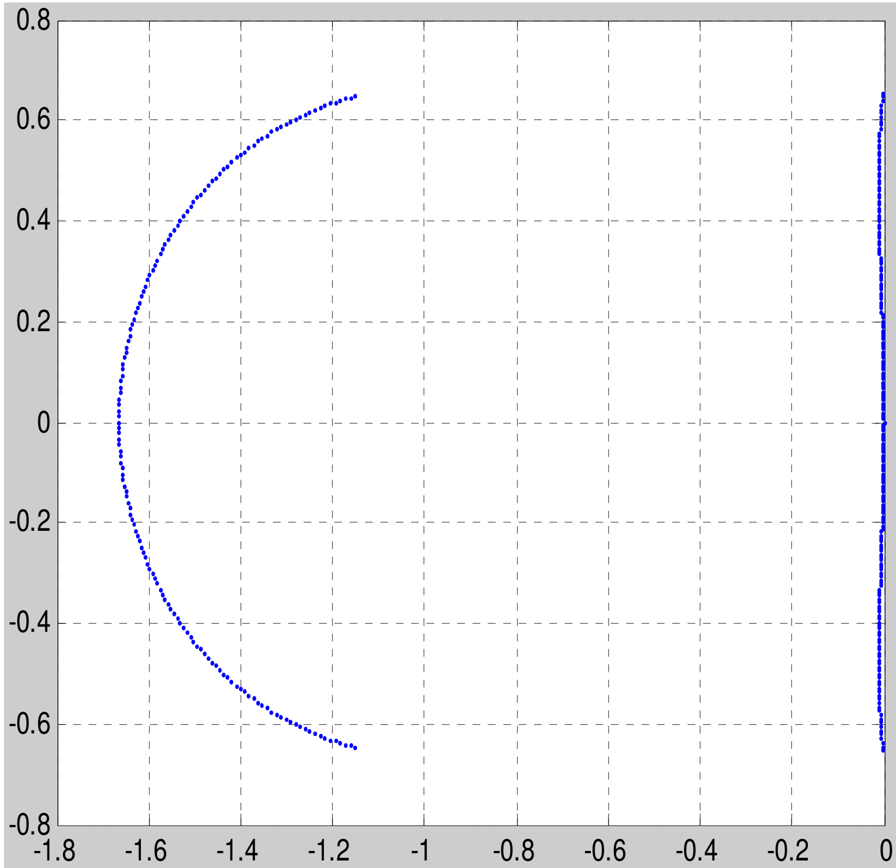

Figure 5. Feed and array contour at R = 6.65.

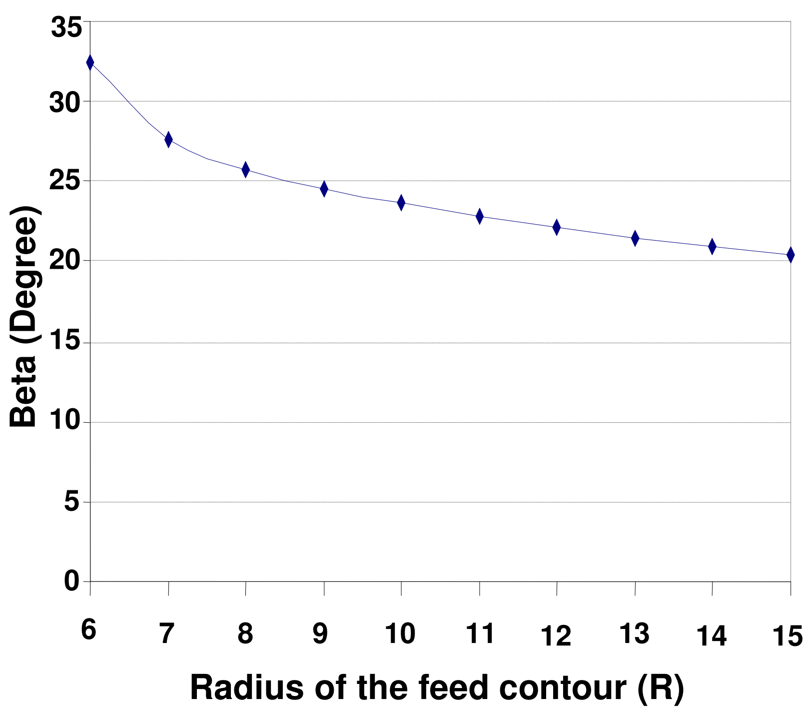

Figure 6. Variation of β with the radius of the feed contour.

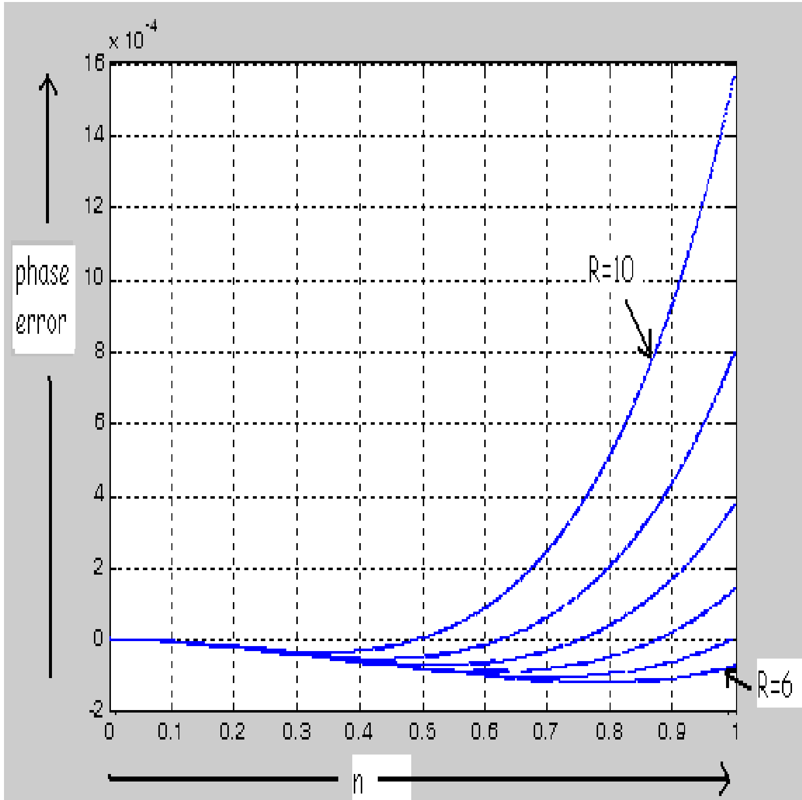

Figure7(a). Variation of phase error along the lens aperture for K = 2.

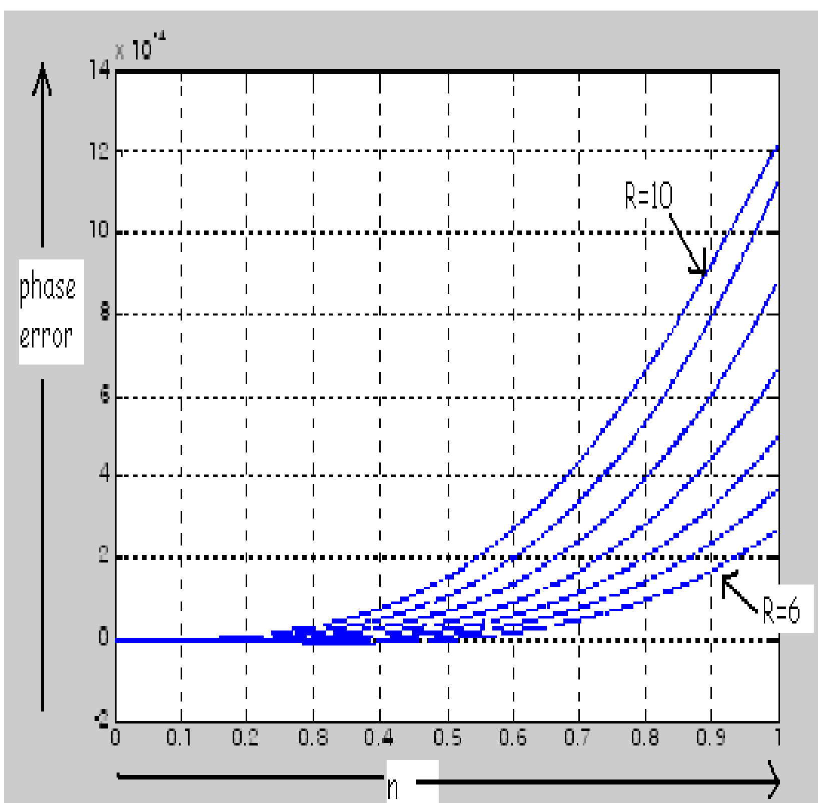

Figure7(b). Variation of phase error along the lens aperture for K = 4.

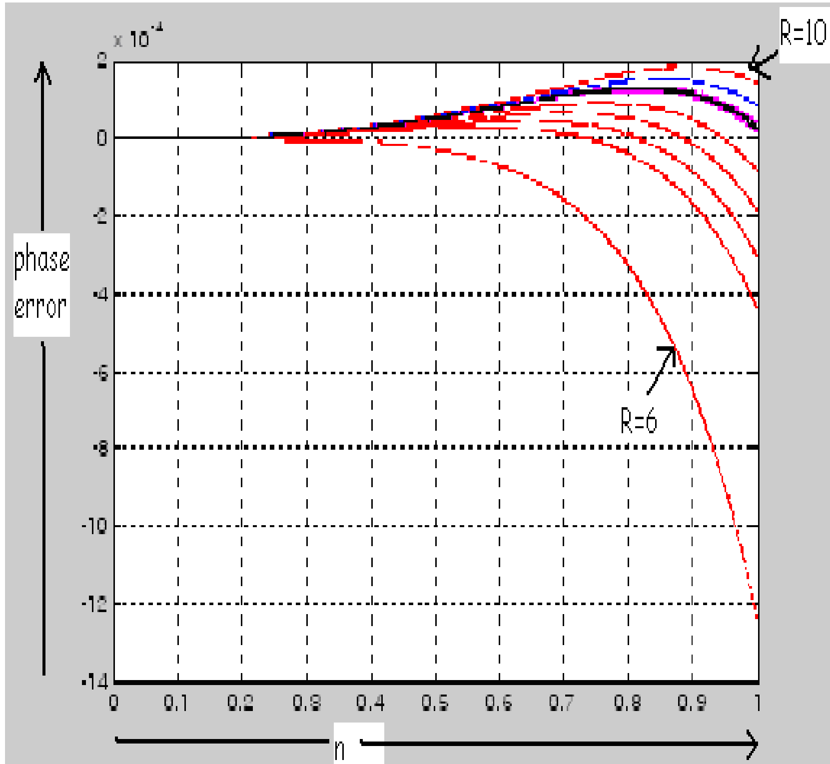

Figure7(c). Variation of phase error along the lens aperture for K = 6.

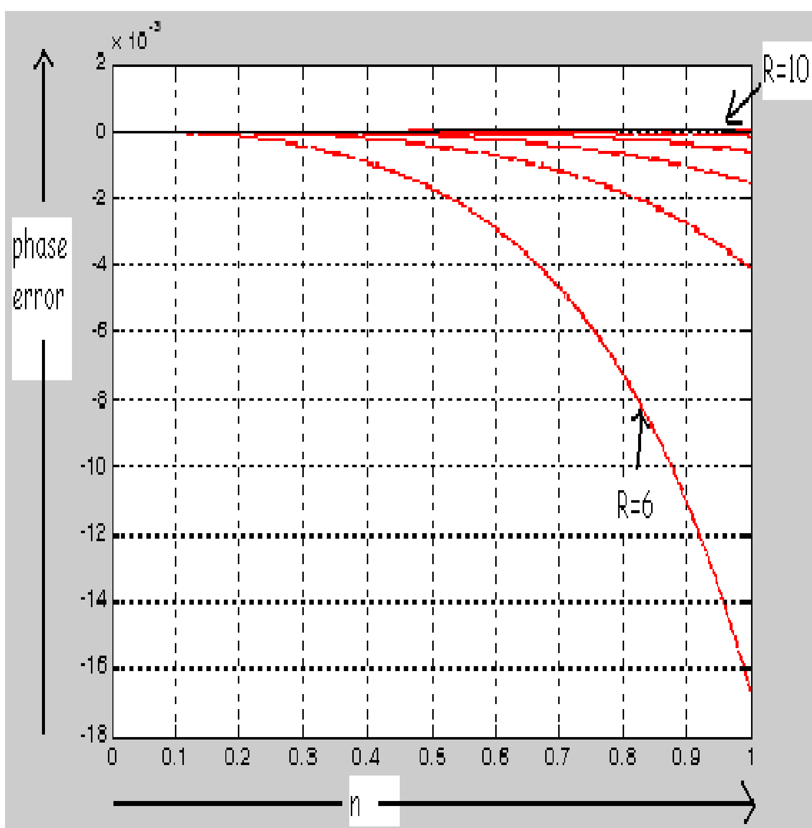

Figure 7(d). Variation of phase error along the lens aperture for K = 10.

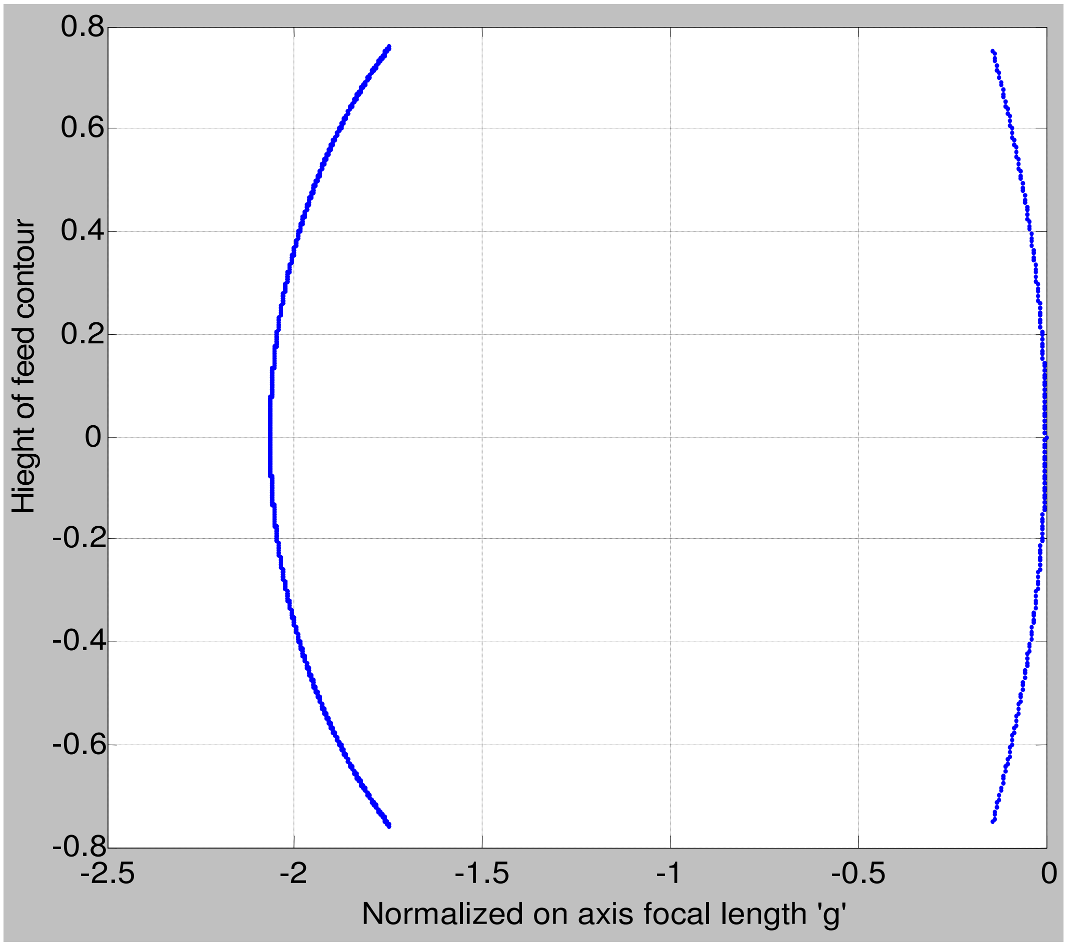

Figure 8. Designed feed and array contours for Bootlace Lens 1.

shape of the lens also depends upon R and K.

Design examples

Two bootlace lenses have been designed for operation at 0.8 GHz.
Lens 1: The first lens was designed for the following requirements.
Angular coverage = ± 35°.
Number of antenna elements = 10.
Number of input beams = 09.
Central Frequency = 0.8 GHz.
Spacing between antenna elements = 3.0 cm.

The complete structure was fabricated in microstrip version on substrate of thickness 1.6 mm and dielectric constant 4.7 and loss tangent is 0.02. Figure 8 shows the designed feed and array contours. Designed parameters have been suitable optimized to equalize the height of feed and array contours. Figure 9 shows the variation of the phase error along the lens aperture for the designed lens. Figure 10 shows the top view of the geometry of the designed bootlace in microstrip configuration. It consists of 39 ports. Port No. 1 to 9 are in input ports. Port No. 20 to 29 are the output ports. Port No. 10 to 19 and 30 to 39 are the dummy ports. Function of dummy ports is to cover the gap between feed contour and array contour. These dummy ports are terminated in 50 ohms dummy load. The input ports are connected to source and the output ports are connected to radiating elements. Lens 2: The second lens was designed for the following requirements:

Angular coverage = ± 35 °.
Number of antenna elements = 07.
Number of input beams = 07.
Central Frequency = 0.8 GHz.
Spacing between antenna elements = 4.0 cm. Second lens was fabricated on the same material as lens 1. Figure 11 shows the designed feed and array contours. Figure 12 shows the variation of the phase error along the lens aperture for the designed lens.

Figure 13 shows the top view of the geometry of the designed bootlace lens in microstrip configuration. It consists of total 22 ports; seven input ports, seven output ports and eight dummy ports.

RESULTS AND DISCUSSION

Table 1 shows the direction of the outgoing beam for input at different feed ports for bootlace lens 1. The bootlace lens was designed for an angular coverage of ±35° and it is covering an angular area from +36 to -33° and the outgoing beams are also uniformly spaced. The outcome of the designed lens is matching with the design

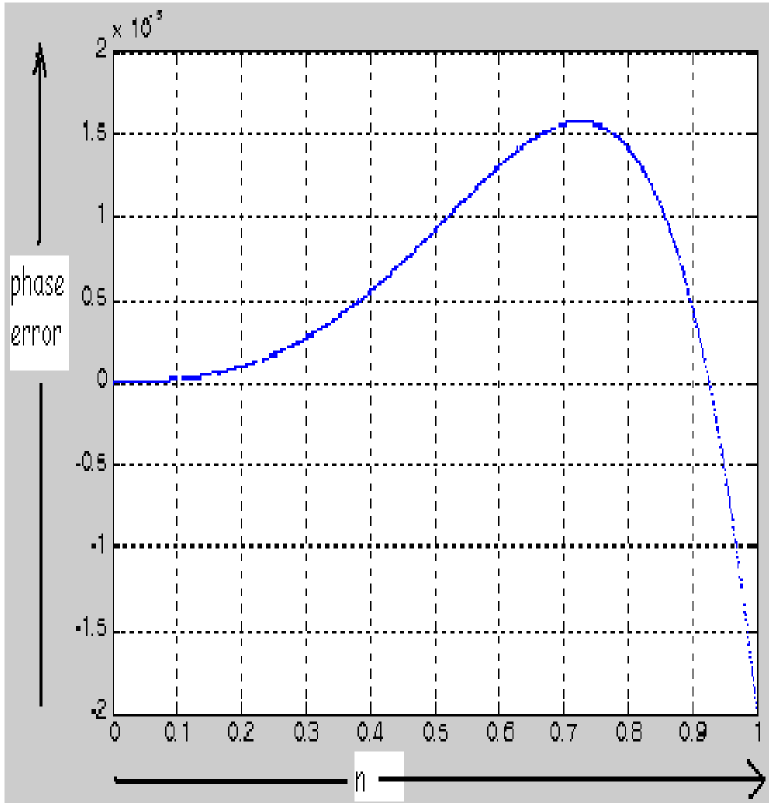

Figure 9. Normalized phase error for lens 1.

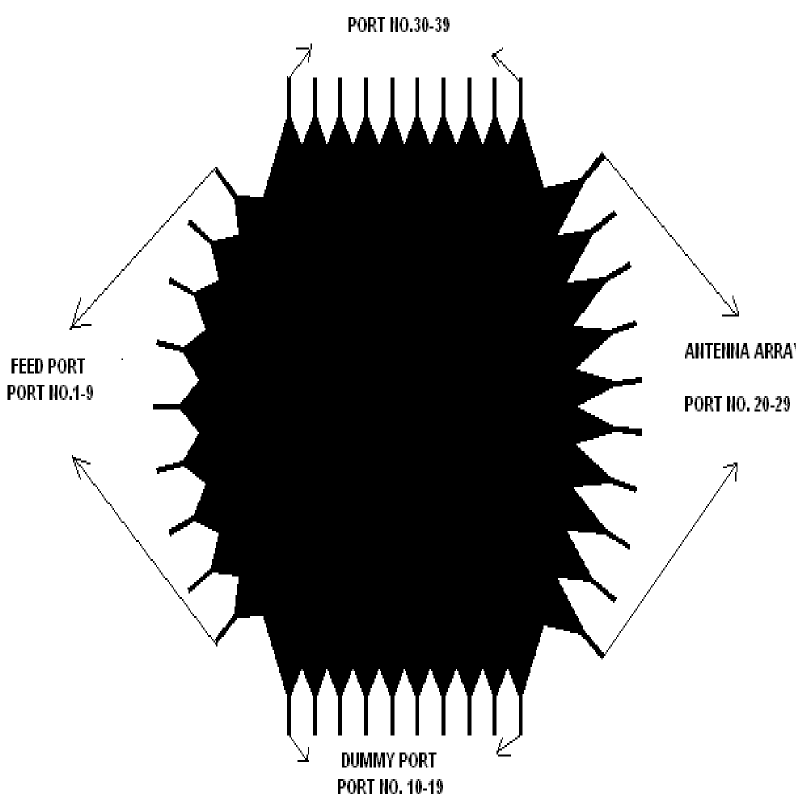

Figure 10. To view the designed bootlace lens 1 in microstrip configuration.

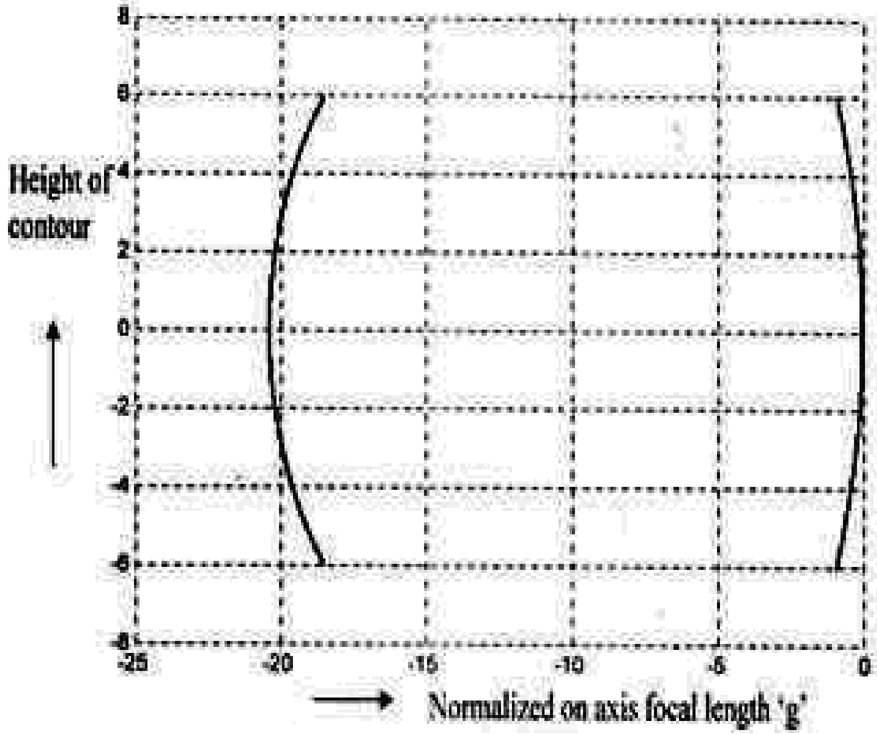

Figure 11. Designed feed and array contour for bootlace Lens 2.

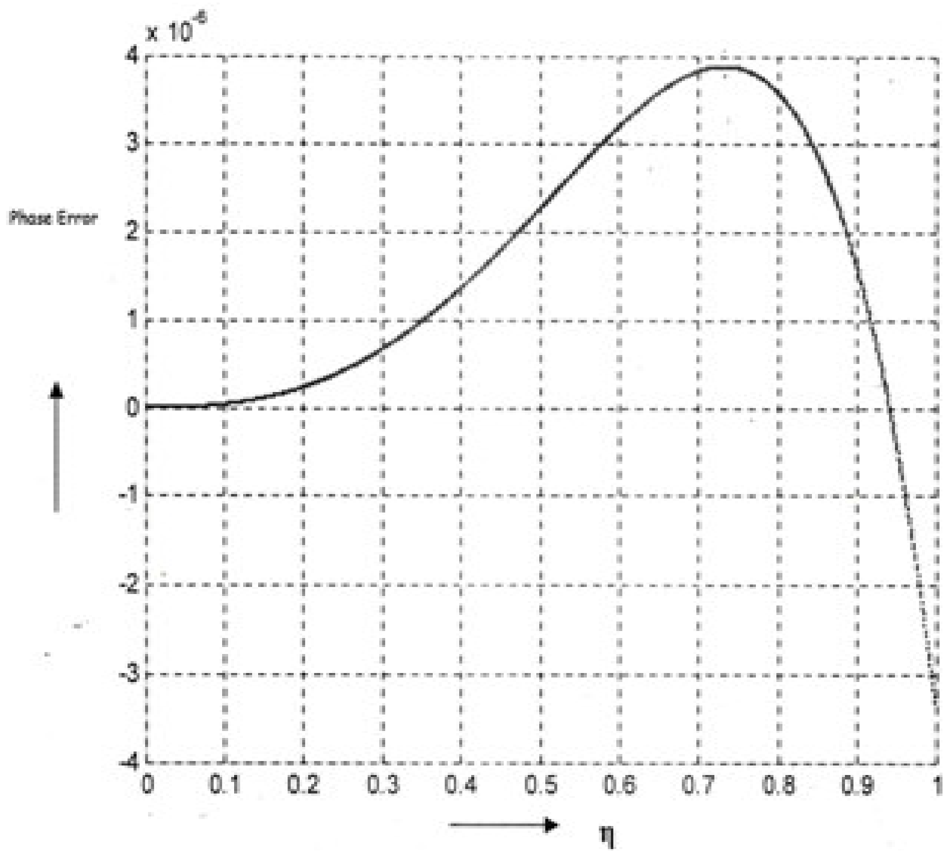

Figure 12. Normalized phase error for bootlace lens 2.

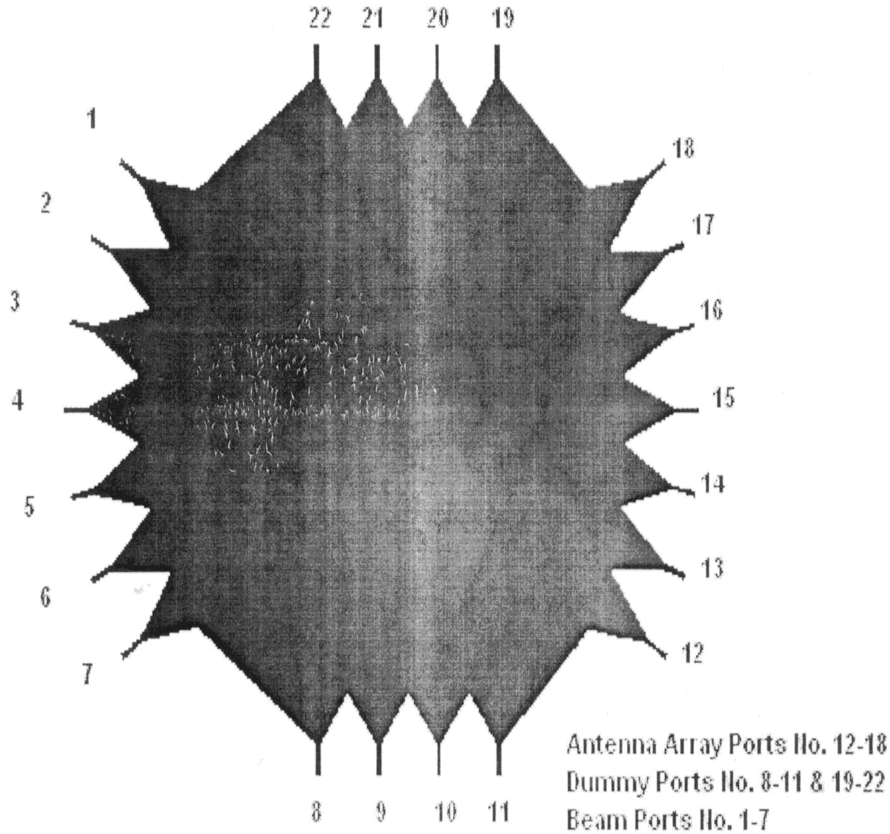

Figure 13. To view of the designed bootlace lens 2 in microstrip configuration.

Table 1. Direction of outgoing beam for input at different feed ports for lens 1.

Input port no.	Outgoing beam angle in degrees
1	36
2	27
3	17
4	10
5	0
6	-9
7	-18
8	-28
9	-33

values. Table 2 shows the direction of outgoing beam for input at different feed ports for lens 2. This is covering and angular are from + 38 to -36°.

Concluding remarks

Effects of the center position and radius of the feed contour on the shape and phase error of the bootlace lens have been investigated; these investigations are useful in selecting the design parameters. Two bootlace lenses have been designed for different requirements. The measured results are in close agreements with the design values.

ACKNOWLEDGEMENTS

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Table 2. Direction of outgoing beam for input at different feed ports for lens 2.

Input port no.	Outgoing beam angle in degrees
1	38
2	25
3	11
4	0
5	-11
6	-25
7	-36

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