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DESIGN OF SYMMETRIC BOOTLACE LENS WITH GAIN ANALYSIS AT UHF BAND

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Abstract—Bootlace lens is the most appropriate choice for multiple beam forming. A compact symmetric bootlace lens has been developed. Here, a theoretical modal is developed which predicts the primary amplitude distribution across the array port of the lens. Amplitude distribution depends upon the gain performance of array contour of the lens. This theoretical modal develops a symmetric bootlace lens without complex analysis.

1. INTRODUCTION

Electronic scanning antennas have numerous applications including communication and collision avoidance system. A Bootlace lens [1–5] is attractive choice for wide angle coverage, because of its simple design and compact size. The multiple detector or sources mounted on the focal arc of the lens provide a convenient way for either the detection of spatially separated multiple targets or the generation of multiple beams.

2. LENS DESIGN

The cross section of the geometry of the proposed lens is shown in Figure 1. Lens consists of a circle $S1$ on which three focal points are located. It is assumed that point $F0$ is located at the axis of the lens. Points $F1$ and $F2$ are located symmetrically either side of the lens at an angle $\pm\alpha$. Radiating elements are located on an arbitrary surface $S2$ and connected to pickup circle $S1$ through TEM mode transmission lines $W(0)$, $W(1)$, $W(2)$, ... , $W(N)$.

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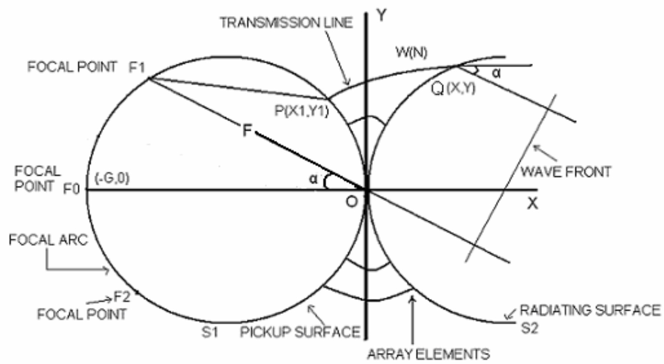

Figure 1. Proposed lens geometry.

Lens outer surface $S2$ is designed such that outgoing beam makes an angle $-\alpha$, 0 and α with the axis when feed points are placed at $F1$, $F0$ and $F2$ respectively. A ray originating from $F1$ may reach the wave front from $F1$ to a general point $P(X1, Y1)$ on the circle, from $P(X1, Y1)$ through transmission line $W(N)$ to point $Q(X, Y)$ on the outer surface then tracing a straight line at an angle α with the X-axis and terminates perpendicular to the wave front. Similarly a ray may reach the wave front from $F1$ to point O and then wave front through transmission line $W(0)$.

At the wave front all the rays must be in phase independent of the path they travel. This require that total phase shift in traversing the path to reach the wave-front in each of these cases must be equal. Using the requirement of consist phase-shift following design equation are written [6, 7]

$$\varepsilon_r^{1/2}(F1P)+\varepsilon_{re}^{1/2}W(N)-X\cos\alpha+Y\sin\alpha=\varepsilon_r^{1/2}F+\varepsilon_{re}^{1/2}W(0) \quad (1)$$

$$\varepsilon_r^{1/2}(F2P)+\varepsilon_{re}^{1/2}W(N)-X\cos\alpha-Y\sin\alpha=\varepsilon_r^{1/2}F+\varepsilon_{re}^{1/2}W(0) \quad (2)$$

$$\varepsilon_r^{1/2}(F0P)+\varepsilon_{re}^{1/2}W(N)-X=\varepsilon_r^{1/2}F+\varepsilon_{re}^{1/2}W(0) \quad (3)$$

where:

$$\begin{aligned}(F1P)^2 &= F^2+X1^2+Y1^2+2FX1\cos\alpha-2FY1\sin\alpha\\ (F2P)^2 &= F^2+X1^2+Y1^2+2FX1\cos\alpha+2FY1\sin\alpha\\ (F0P)^2 &= X1^2+Y1^2+2GX1+G^2\end{aligned}$$

ε_r — dielectric constant of the lens substrate
ε_{re} — effective dielectric constant of the transmission lines

Algebraic manipulation of above equations yield

$$Y = \varepsilon_r^{1/2}(P2 - P1)/(2\sin\alpha) \tag{4}$$
$$X = \varepsilon_r^{1/2}(P1 + P2 - 2P0 - 2F + 2G)/[2(\cos\alpha - 1)] \tag{5}$$
$$W = \varepsilon_r^{1/2}(P0 - G) - X \tag{6}$$

where:

$$\begin{aligned} W &= \varepsilon_{re}^{1/2}(W(0) - W(N)) \\ P1 &= F1P \\ P2 &= F2P \\ \text{and} \quad P0 &= F0P \end{aligned}$$

For fixed value of design parameters α and G (diameter of the circle $S1$) lens surface $S2$ may be designed using the above equations.

2.1. Design Specification

This section describes an example of the design of bootlace lenses to feed an array of monopole antennas. It is required to the design the lens for the following requirements.

Angular coverage = ± 22.5

Number of antenna elements = 5

Number of input beams = 3

Central frequency = 629.5 MHz

For the above requirement the value of $G = 20\,\text{cm}$ and $\alpha = 22.5$ degree have been chosen. Using the design equations as described in the preceding section coordinates of array elements position has been calculated. The designed lens along with the port numbers is shown in Figure 2.

2.2. The Theoretical Modal of Lens

Figure 3 shows two two-dimensional antennas, which represent a beam port and an array port in the lens. We take the beam port as the transmitting antenna, where the two dimensional antenna gain $G(\theta)$ by the relation [8]

$$\text{Sd} = \text{Ptrans}/2\pi rh \tag{7}$$

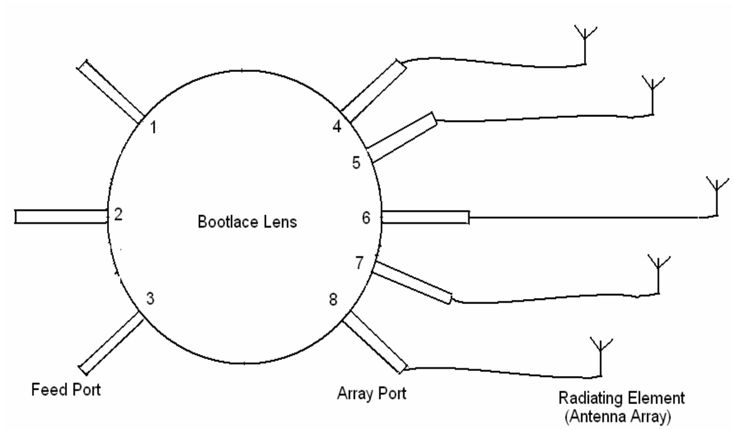

Figure 2. Lens along with the port numbers.

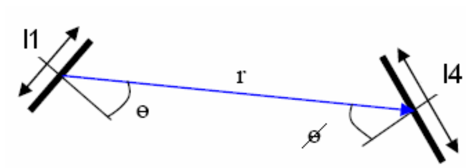

Figure 3. Port to port coupling.

where Sd = power flux density, Ptrans = power transmitted, r = distance away from the antenna, and h is the parallel plate separation. Maximum gain of a uniformly illuminated aperture of width L is

$$G\max = 2\pi L/\lambda \quad \text{in general } L \text{ is effective width} = Le \tag{8}$$

The two dimensional equivalent of the friis transmission formula

$$\begin{aligned} \text{Prec} &= \text{Sd}(\theta) \cdot A(\Phi) \\ &= (\text{Ptrans} \cdot G(\theta)/2\pi r h) \cdot Le(\Phi) \cdot h \end{aligned} \tag{9}$$

whence

$$\text{Prec}/\text{Ptrans} = (\lambda/4\pi^2 r) \cdot Gt(\theta) \cdot Gr(\Phi) \tag{10}$$

We still require the function $G(\theta)$, for this we use two dimensional field theory with an assumed cosine aperture field distribution. The directive gain is then found using Equation (7). If we ignore mismatch losses this can be taken to be $G(\theta)$.

$$G(\theta) = (2\pi l/\lambda) \cdot 8/\pi^2 \cdot \cos^2\theta \left((\cos(\pi l \sin\theta/\lambda)) \,/\, \left(1 - (2l\sin\theta/\lambda)^2\right)\right)^2 \tag{11}$$

If the port has width $l1$ and array port $l4$, we require $G(l1, \theta)$ and $G(l4, \Phi)$ for (10), where (θ) and (Φ) determined from the lens geometry.

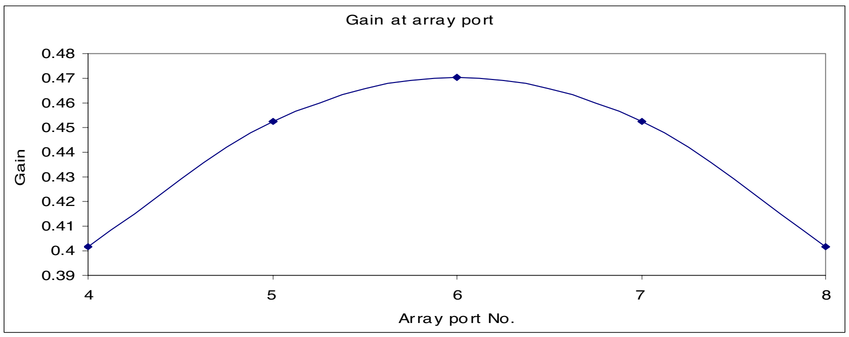

Figure 4. Gain at array ports when feeding at center feed port.

Table 1. Gain at input port $Gt(\theta)$.

Port No.	**Port width**	**Beam port transmit Angle (θ)**	**Gain at input port $Gt(\theta)$**
1	$l1 = 0.01$ m	$(+)22.5$ degree	0.4018
2	$l2 = 0.01$ m	0 degree	0.4705
3	$l3 = 0.01$ m	$(-)22.5$ degree	0.4018

3. RESULTS AND DISCUSSION

The calculated results are shows in Table 1, Table 2, and Table 3. In Table 1 show the gain performance at feeding port, similarly Table 2 show gains at array or radiating element port where we give feeding at centre port. Table 3 shows the receiving and transmitted power ratio. Figures 4 and 5 represent the graphical representation of gain performance of array contour and power ratio.

Table 2. Gain at array port $Gr(\Phi)$.

Port No.	Port width	Array port transmit Angle (Φ)	Gain at array port $Gr(\Phi)$
4	$l4 = 0.01\,\text{m}$	(+)22.5 degree	0.401777
5	$l5 = 0.01\,\text{m}$	(+)11.25 degree	0.452672
6	$l6 = 0.01\,\text{m}$	0 degree	0.470537
7	$l7 = 0.01\,\text{m}$	(−)11.25 degree	0.452672
8	$l8 = 0.01\,\text{m}$	(−)22.5 degree	0.401777

Table 3. Receiving and transmitted power ratio (prt).

Port No.	Port Width	At Array Port Output Angle (Φ)	Input At Center Feed prt (port2)	Input At Upper Feed prt (port1)	Input At Lower Feed prt (port3)
4	$l4 = 0.01\text{m}$	(+)22.5 degree	0.02223	0.018982	0.056945
5	$l5 = 0.01\text{m}$	(+)11.25	0.037569	0.032079	0.053466
6	$l6 = 0.01\text{m}$	0 degree	0.052069	0.044461	0.044461
7	$l7 = 0.01\text{m}$	(-)11.25	0.037569	0.053466	0.032079
8	$l8 = 0.01\text{m}$	(-)22.5 degree	0.02223	0.056945	0.018982

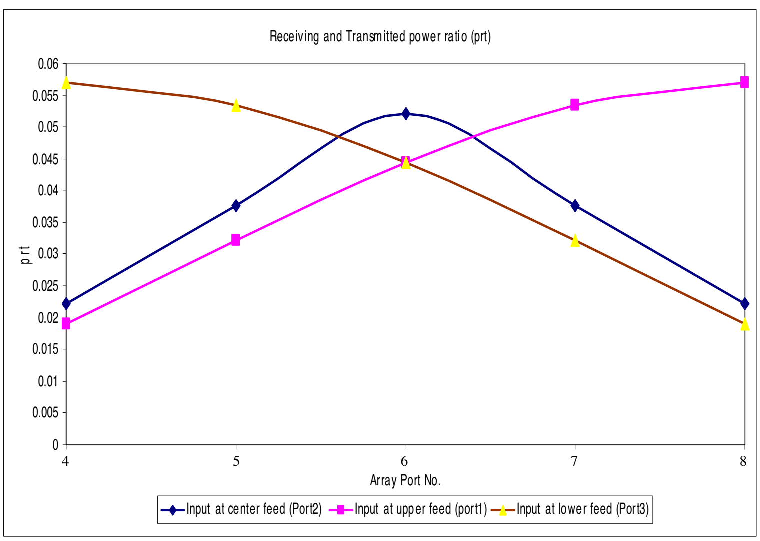

Figure 5. Receiving and transmitted power ratio (prt).

4. CONCLUDING REMARKS

A theoretical modal has been developed which allow the prediction of gain of beam or feed port and array port of the lens. In multiple beam forming bootlace lens to overcome the amplitude phase error, proper gain analysis is most important. For analysis point of view here I am taking symmetric bootlace lens, in other type of geometry this concept is also applicable.

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