MICROSTRIP LENS DESIGN FOR BFN WITH ADJUSTABLE PHASE CENTERS OF ANTENNA FEEDS

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1. Introduction

A BFN (Beam Forming Network) for a multibeam reflector antenna is generally a complicated circuit involving many hybrids, and the structure of its feeds (called cluster feeds or array feeds) is also complex because the radiating elements should be placed on a curved surface considering the focal locus of the reflector (Fig. 1).

To achieve simply a BFN, a BFN design [1] was proposed that uses a microstrip lens [2-4]. It can be manufactured on a printed-circuit board at low cost using a simple etching process.

In this paper, we go one step further, we propose a new lens design for a simple BFN that uses a microstrip lens to enable the application of a linear-array to the array feed. The proposed lens design enables the BFN to achieve various arrangements of the phase center positions of feed excitations without changing the arrangement of the array feed in order to satisfy the requirements of various focal-curves of reflectors. This paper first describes the principle of the proposed lens design. Next, we introduce the characteristics of the new BFN employing the proposed lens design, and demonstrate that the phase center position of each excitation can be adjusted by using this design method.

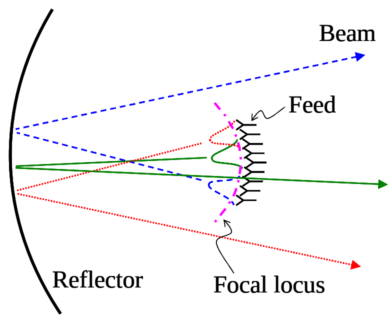

Fig. 1. Cluster feed of multibeam reflector antenna

2. Design Concept for Proposed Lens

The BFN configuration [1] using a microstrip lens is shown in Fig. 2. The proposed lens design is based on this BFN configuration. Usually, lens aberrations degrade the quality of the output signal distribution of the BFN. The odd-order aberrations of these lenses can be counterbalanced by making the design of these lenses the same. However, even-order aberrations of the lenses are redoubled. Figure 3 shows the

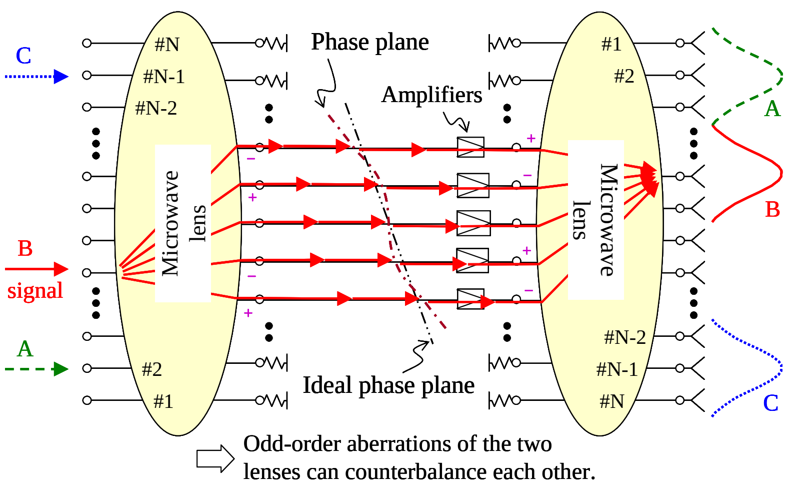

Fig. 2. BFN design employing a microstrip lens

ISBN: 4-88552-206-4 C3055©IEICE

relationship between the phase center position and the even-order phase distribution of the feed excitation. If the phase value of all elements is the same, the phase center location corresponds to the position of the array feed (Fig. 3(a)). On the other hand, if the shape of the phase plane is convex the phase center position shifts backward (Fig. 3(b)), and if the shape of the phase plane is concave the phase center position shifts forward (Fig. 3(c)). Therefore, if we can control the shape of the phase plane for each excitation, the phase center position of each excitation can be adjusted without changing the arrangement of the array feed.

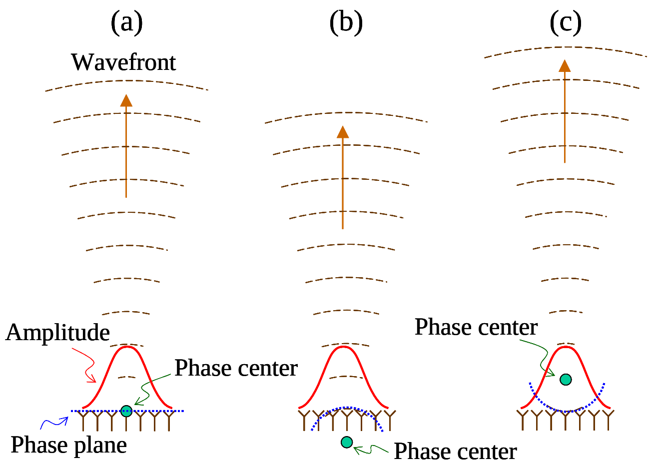

Fig. 3. Phase center position of antenna feeds

Figure 4 shows the design of the proposed lens, which can control the variation in the even-order aberration from input port to input port. The shape of the lens is determined as the area where two circles overlap. In Fig. 4, the lens contours are indicated by curves Σ_1 and Σ_2. The radius of these circles is R, and the distance between the centers is R–S. Here, S is the important design parameter of the proposed lens. Points P_i, P_i', and K have coordinates (x, Δy), (–x, Δy) and (x, R+S–Δy), respectively, and Δy is given by the equation $\Delta y = R - (R^2 - x^2)^{1/2}$

The even-order path-length error for the ray that passes through A is given by the following,

$$\Delta A_{even} = (L_i + L_i')/2 - L_0 = L_i - L_0 \quad \text{—— (1)}$$

Here L_0 and L_i represent the path length from A to P_0 and the path length from A to P_i, respectively. The even-order path-length error for the ray that passes through K is given by the following,

$$\Delta K_{even} = (L_{ki} + L_{ki}')/2 - L_{k0} \quad \text{—— (2)}$$

Here, L_{k0} and L_{ki} represent the path length from K to P_0 and the path length from K to P_i, respectively.

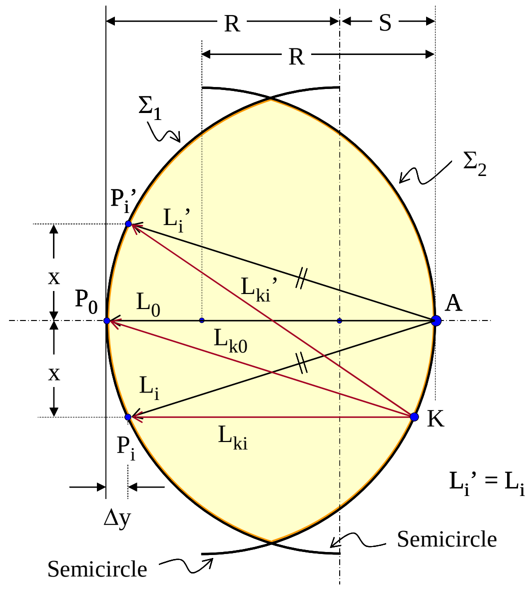

Fig. 4. Proposed microstrip lens design

Now, we evaluate the variation in the even-order aberration of the lens by using $\Delta K_{even} - \Delta A_{even}$. If we replace $(R^2 - x^2)^{1/2}$ with Y, $\Delta K_{even} - \Delta A_{even}$ is given by the following,

$$\Delta K_{even} - \Delta A_{even} = Y + R/2 + 3S/2 - 2\,(R^2 + 2YS + S^2)^{1/2} + [-YR + YS + (5R^2 - 2RS + S^2)/4]^{1/2} \quad \text{——(3)}$$

$$\approx -R\,(R - 2\,S)\,(Y - R)^2 / (R + S)^3 \quad \text{——(3')}$$

Equation (3') is a power series approximation of Eq. (3) for Y close to R, up to $(Y-R)^2$.
The above results show that the variation in the even-order aberration of the lens, which is designed for S = R/2, is slight. Furthermore, if the lens is designed for S > R/2, the variation is given as a positive value. If the lens is designed for S < R/2, the variation is given as a negative value.

Figure 5 shows an example of the proposed lens. Input/output signals are transmitted through the tapered microstrip line to improve the input/output impedance matching. Phase shifters shown in the figure are used to compensate for the path-length errors from the center of one side to any port on the other side. Figures 6(a), 6(b), and 6(c) show the even-order phase distortions of the lenses, which are designed for S = 0.25R, 0.5R, and 0.75R, respectively. The width of the adjacent ports is a half wavelength, and the number of ports on either side is 18. Parameter R for S = 0.25R, 0.5R, and 0.75R are 3.79 λ, 3.41 λ, and 3.11 λ, respectively. These figures demonstrate that the variation in the even-order aberration of the proposed lens is adjusted by changing the value of the design parameter, S.

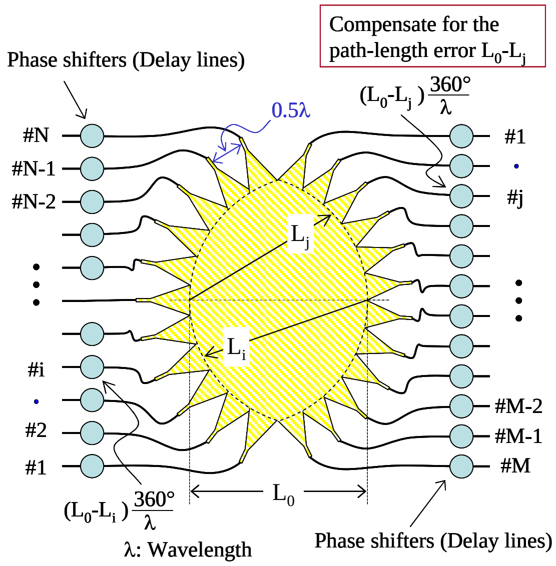

Fig. 5. Example of proposed microstrip lens

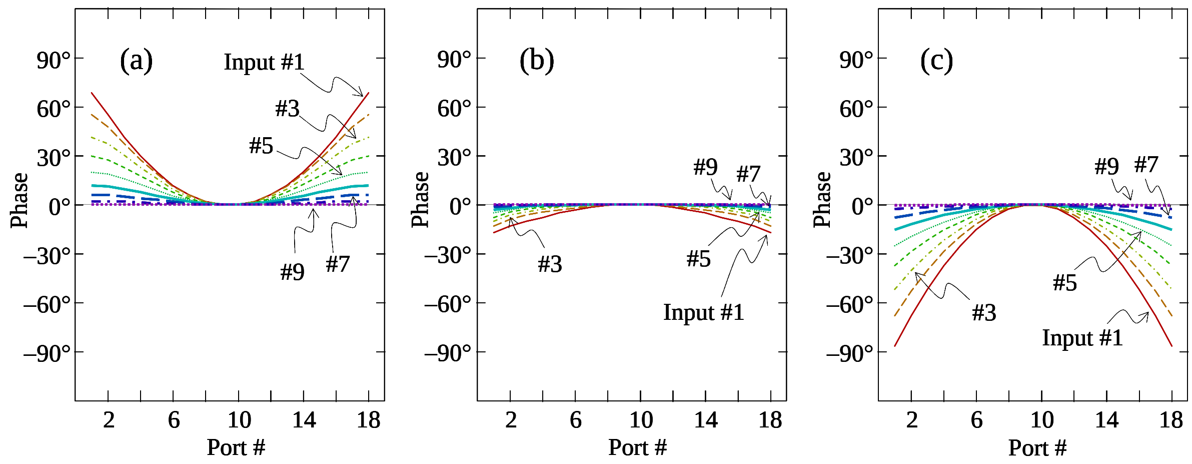

Fig. 6. Even-order phase distortions of lens output signals,
(a) S = 0.25R ; (b) S = 0.5R ; (c) S = 0.75R16

3. Characteristics of Proposed BFN

Figure 7 shows the configuration of the BFN using the proposed lens. The phase shifters located on the beam-port side and the antenna-element side are used to compensate for the path-length error given by L_0–L_j. These are the same as those shown in Fig. 5. The

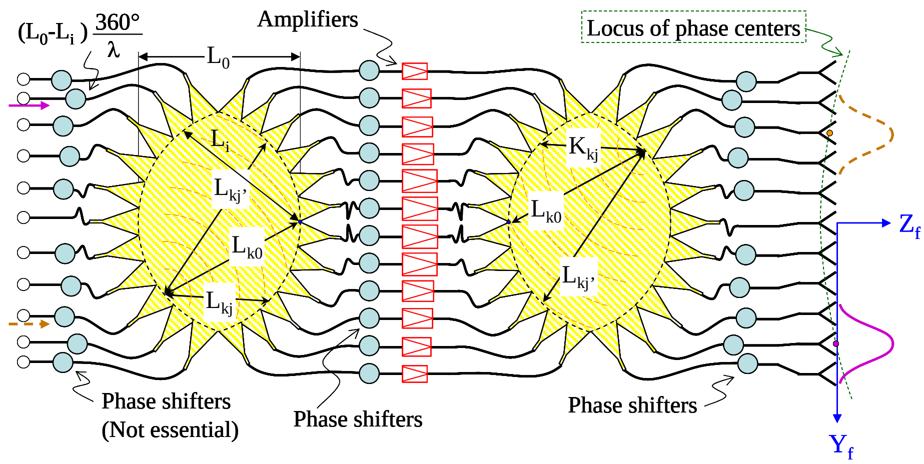

Fig. 7. BFN using proposed lens

phase shifters located between the two lenses are also used to compensate for the path-length errors shown in Fig. 5. In this case, the value of the compensation is given by $2(L_0–L_j)$. However, if the general performance of the amplitude distribution must be improved, we adopt a certain port K as the reference-position for the compensation. In this case, the value of the compensation is given by $(L_{K0}–L_{Kj}) + (L_{K0}–L_{Kj}')$.

Figure 8 shows the phase-center positions of the feed-array excitations using the BFN, which are designed for S = 0, 0.25R, 0.5R, 0.75R, and R. Each position of the phase center is calculated using the far-field radiation pattern. The width of the adjacent ports is 0.5 λ, and the number of ports on either side is 18. The reference port for the phase shifters located between the two lenses is #3 (and #16), and the element spacing is assumed to be 0.5 λ. The positions of the phase centers can be changed by more than 3 λ according to the value of the design parameter, S. These results show that various arrangements of the phase centers can be established by using the proposed lens design even when using a linear-array feed.

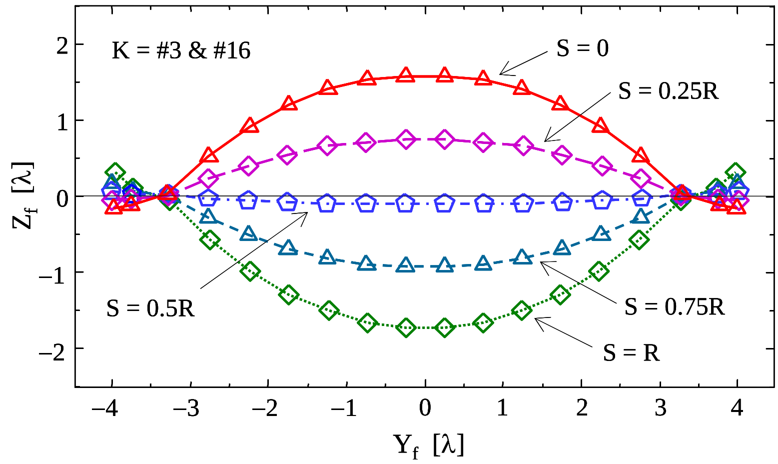

Fig. 8. Positions of phase centers

4. Conclusion

We proposed a new lens design for a simple BFN that uses a microstrip lens to enable application of a linear-array to the array feed. This lens design enables the BFN to adjust the phase-center positions of the feed excitations without changing the arrangement of the array feed by controlling the variation in the even-order aberration. The proposed design should simplify the feed structure and improve the antenna characteristics because the arrangement of the phase center positions can be adjusted according to the focal plane of the reflector even when using a linear-array feed.

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