The Analysis of Element and Array of Parabolic Reflector Antenna with Hexagonal Aperture

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***Abstract*—In this paper, the Hexagonal Aperture Parabolic Reflector (HAPR) array is presented to achieve high gains. Because of their hexagonal aperture, the HAPR antennas are easy to be integrated into a compact reflector array with a large total aperture. Investigations of efficiency and radiation properties of HAPR antennas are conducted, and compared with traditional Circular Aperture Parabolic Reflector (CAPR) ones. Simulated results demonstrate that the proposed antenna has comparable performances with CAPR one. The HAPR array's gain increases linearly from 39.86dB to 48.38dB, with a stable efficiency above 75%, as the number of elements varies from 1 to 7. HAPR array's advantages of high gain, stable efficiency, low cost and robust configuration would make it more practical in applications of long distance communication, radio-astronomy and so on.**

***Keywords*—compact reflector array; hexagonal aperture; high gain**

I. INTRODUCTION

Reflector antennas have high gain because of their large physical area, so they are widely adopted in long distance communication, high-resolution radars, radio-astronomy, such as satellite ground stations, deep space communications, and Earth Observation missions[1]. Theoretically, the gain of the antenna could increase unlimitedly as it is proportional to the size of the antenna's aperture area. However in practice, it is impossible to build arbitrarily large reflector antennas due to gravity induced distortions [2] or thermally induced distortions [3]. So there is a practical limit to the maximum gain in a single-reflector antenna.

In this paper, we present the Hexagonal Aperture Parabolic Reflector (HAPR) array. It was a compacted array composed of truncated traditional Circular Aperture Parabolic Reflectors (CAPR) with their inscribed hexagons. Because of their hexagonal rims, these elements are easy to be arranged in hexagonal cells to form a low profile array. In this way, the design complication and fabrication costing are dramatically reduced, and less distortions are introduced in this compact and robust array structure.

II. HAPR ELEMENT AND ARRAY CONFIGURATION

A. HARP Antenna Element

Hexagonal aperture parabolic reflector is derived form a traditional circular aperture parabolic reflector which is truncated by its inscribed hollow hexagon, as Fig.1 shows. The HAPR antenna element is composed by a feed horn and a HAPR dish. The surface curvature of its dish is as same as the traditional one, so it can transform a spherical wave radiated by the feed into a plane wave too.

B. HAPR Array

Because of the hexagonal rims, the HAPR antennas are easy to be integrated into a reflector array with not only a large aperture, but also a compact and solid structure which needs less installation space on the ground. Fig. 2 shows the configurations of planar array composed of 2 to 7 elements.

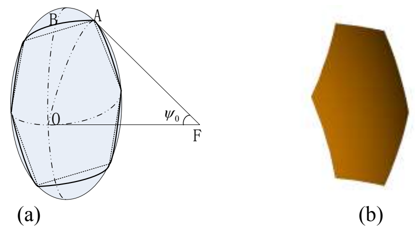


Fig. 1. A hexagonal parabolic reflector (a) Geometric configuration (b) 3D view

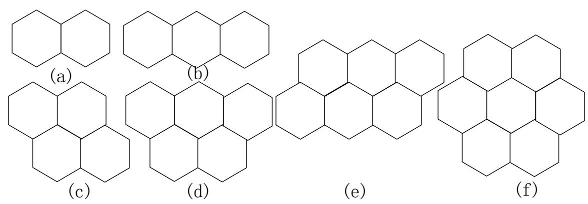


Fig. 2. The array configurations (a) 2 elements array (b) 3 elements array (c) 4 elements array (d) 5 elements array (e) 6 elements array (f) 7 elements array

III. HAPR ELEMENT AND ARRAY CONFIGURATION

A. Efficiency of CAPR Antenna

Gain is a key parameter of an antenna, which can be calculated as

$$G = 4\pi \xi_{ap} \xi_l S / \lambda^2 \tag{1}$$

where λ is the wavelength, S is the physical aperture area and ξ_{ap} is the antenna aperture efficiency which is the product of several subefficiencies including taper efficiency ξ_t, spillover efficiency ξ_s, phase efficiency ξ_p, polarization efficiency ξ_x, surface error efficiency ξ_r. Other loss such as blockage, mismatch, ohmic losses and so on is indicated by ξ_l.

Of all the above mentioned efficiencies or loss factors, the taper efficiency ξ_t and spillover efficiency ξ_s are the primary ones that significantly affect the gain. The other subefficiencies have limited and similar impacts on the gain of CAPR and HAPR antenna. Therefore the analytic focus in this paper is placed on ξ_t and ξ_s, which are defined in equation (2) and (3) [4]:

$$\xi_t = \frac{\left|\int_A |E_a| dA\right|^2}{A\int_A |E_a|^2 dA} \tag{2}$$

$$\xi_s = \frac{P_a}{P_{feed}} \tag{3}$$

Where E_a is the aperture E-field, and A is the physical aperture area of the reflector, P_a is the total power through the aperture, P_{feed} is the total power of the feed antenna.

For a given feed, the traditional CAPR antenna is designed to make the illumination pattern taper to -10dB at the reflector rims for maximum gain. Usually in this situation, the ξ_t and ξ_s achieve a trade-off and their multiple achieves its peak, so the aperture efficiency is optimized.

B. *Efficiency of HAPR Antenna*

In order to analyze the efficiency variance between the HAPR antenna and CAPR antenna, an example of feed pattern that approximates practical patterns is introduced [4].

$$U_{feed}(\psi,\chi) = \begin{cases} U_0 \cos^4\psi, if\, 0 \le \psi \le \dfrac{\pi}{2} \\ 0, \qquad\qquad else \end{cases} \tag{4}$$

Based on Equ. (2)-(4), MATLAB is adopted to compute the function of ξ_t, ξ_s, and their product $\xi_t \cdot \xi_s$ of both the HARP and CARP antennas versus half illumination angle ψ_0. As the plot shown in Fig. 3, the taper efficiency and spillover efficiency are complementary. For a given feed with pattern of equation (4), as the half illumination angle ψ_0 increases, the taper efficiency ξ_t decreases in both CAPR and HAPR cases (the subscript $_{-C}$ means for CAPR antenna and $_{-H}$ for HAPR antenna). While the spillover decreases with the increase of ψ_0, the spillover efficiency ξ_s increase in both cases.

The product $\xi_{t-C} \cdot \xi_{s-C}$ of the CAPR antenna reaches the maximum value of 82% at ψ_0=53°, while the one of HAPR antenna is 78% at ψ_0 = 55°. Compared with the circular aperture dish, the hexagonal aperture dish has to take a larger ψ_0 to achieve its optimum. However, the larger ψ_0 is, the more inhomogeneous E-field would be introduced into aperture area, which make the $\xi_{t-H} \cdot \xi_{s-H}$ drop 4 percentage from CAPR's efficiency.

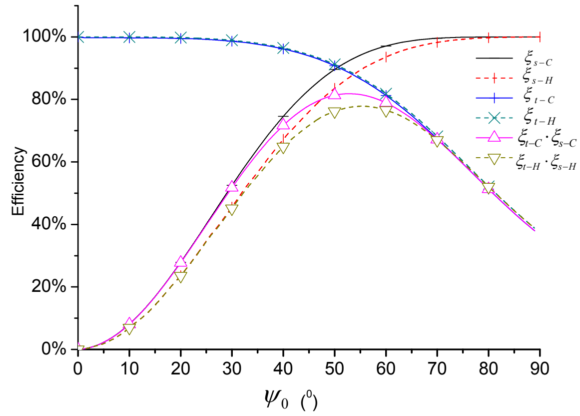


Fig. 3. Tradeoff between taper efficiency and spillover efficiency of CAPR antenna and HAPR antenna

Although the HAPR element's efficiency declines slightly compared with the CAPR element's. The merit of easy to be assembled makes HAPR antenna of great potential in array applications.

IV. SIMULATION RESULTS

To validate and analyze the performances of the proposed HAPR element and array, two types of antennas are considered as references. One is the ideal aperture antenna with 100% aperture efficiency, which owns uniform field distribution on the aperture. Another is the traditional CAPR antenna. The element is fed by a conical horn with 12.5GHz operating frequency, and its reflector is designed base on the -10dB criterion to get optimum aperture efficiency. Its radius R=0.43m, focal length F=0.6m. For a better comparability, the proposed HAPR antenna element is designed to possess the same aperture size rather than its own optimal one. The dish is fed by the same horn, which locates at the dish's focal. The commercial software FEKO is used to perform the simulations [5].

The gain of the ideal aperture antenna element is 41.07dB, which could be derived from formula (1), when 100% efficiency was substituted into it. However, it is not achievable in practice. Because of some unavoidable factors, such as tapered E-field distributions, feed horn's shielding effect and so on, the antenna's efficiency drops. Simulation results in Fig. 4 show that the gains of traditional and proposed HAPR antenna elements are 39.88dB and 39.86dB respectively, about 1dB drop from the ideal one. The sidelobe level of traditional CAPR antenna is below -32.03dB. While the ones in the E plane and H plane of the proposed HAPR antenna are below -28.37dB and -31.10dB respectively.

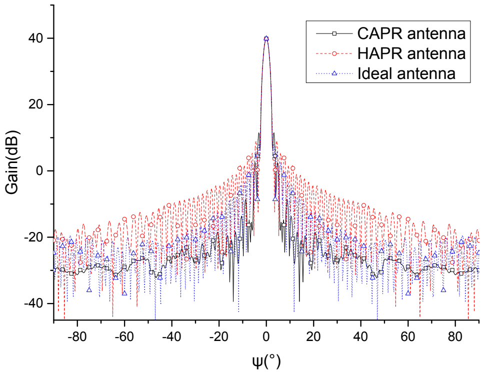


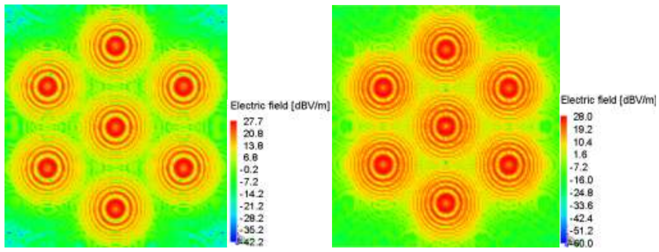
Fig. 4. The patterns of the traditional CAPR antenna and the HAPR antenna with the same aperture size in H plane.

Planar arrays (Fig. 2) are discussed in this paper too. The ideal aperture antennas and traditional CAPR antennas are aligned in the same topology with same total aperture areas, to be considered as references. Table 1 shows the gains of three types of array. The gain estimation of ideal aperture antenna increases linearly from 41.07dB to 49.52dB with the increase of aperture area. Similar trends are occurring in the CAPR and HAPR array's simulation results, but with about 1dB drop. The efficiencies of the HAPR array (a)-(f) just drop less than 0.4% compared with the CAPR series. When the elements number reaches seven, the gain of the HAPR array is 48.31dB, growing by 8.45dB to approximately 7 times of the HAPR element's gain. The nearly linear growth of HAPR arrays' gains benefits from the remarkably stable antenna efficiency which is kept within the range of 75.73%-75.78%.

TABLE 1 GAINS OF THREE TYPES OF ARRAY

Elements	*1*	*2*	*3*	*4*	*5*	*6*	*7*
G_{ideal}(dB)	41.07	44.08	45.84	47.09	48.06	48.85	49.52
G_{CAPR}(dB)	39.88	42.89	44.66	45.90	46.87	47.66	48.33
G_{HAPR}(dB)	39.86	42.87	44.64	45.88	46.85	47.64	48.31

For most of the compact arrays, there exist significant mutual coupling effects between the elements, which may dramatically decrease the array efficiency as the elements increase. While in the proposed array, the mutual coupling between elements is inconspicuous. Fig. 5 shows that both the traditional and proposed 7-dish arrays have the similar aperture distributions as their corresponding elements'. The interferences between the elements are inconspicuous because of the tapered E-fields distribution on each electrically large element's aperture, which guarantees a nearly linear gain increase with the increase of elements. So massive use of elements is feasible in such array configuration, thus achieving linear growth of Gain.



(a) (b)

Fig.5. The aperture distribution of 7 elements array (a) traditional CAPR array (b) proposed HAPR array

V. CONCLUSIONS

A HARP antenna is presented and discussed in this paper, which can be utilized to increase the array gain linearly. Some investigations on the efficiency and radiation characteristics of the proposed HAPR are conducted and compared with the traditional CAPR array. Simulated results demonstrate that the performance of the proposed HAPR antenna element has degraded slightly compared with traditional one, it still has an efficiency of above 75%. The inter-element coupling effects are inconspicuous, so the proposed HAPR array can keep a nearly linear increasing gain and a remarkable stable efficiency, as the number of elements increased. In theory, the proposed HARP array's gain and output power would increase without an upper limit, as long as there are enough dishes and fed horns. The advantages of low cost, robust configuration, compact structure and high gain make HAPR array possess a bright future in super large aperture antenna designs.

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