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AN OFFSET TOROIDAL TRI-REFLECTOR SYSTEM FOR MULTI-BEAM ANTENNA APPLICATIONS

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I. INTRODUCTION

As radio communications systems grow up to be congested, the advantages of an multi-beam antenna over a number of single-beam antennas become more and more attractive from both economic and operational points of view. The authors developed an offset spherical reflector antenna for a Ku-band earth station, which could produce simultaneously four beams without moving the spherical main reflector [1]. In such a multi-beam reflector antenna with a large FOV (field-of-view), a spherical/toroidal surface is commonly utilized and the shaped sub-reflectors are introduced to compensate the spherical aberration [2]. A phase correcting reflector is necessary for each beam and its size is limited so as not to interfere with adjacent ones. Therefore, when a beam separation angle is required to be small in terms of beam widths, it becomes difficult to achieve high radiation performances, such as low sidelobe characteristics, because of the limited size of correctors which would preferably be greater than a few tens of wavelengths in order to compensate the aberration.

In this paper, we propose a new type of troidal reflector system having no phase corrector for an individual beam but a triple of shared toroidal reflectors to minimize the aberration, which is applicable to multi-beam antennas with a large FOV and a small beam separation angle. The measured data of an experimental antenna demonstrate its high electrical performances.

II. TOROIDAL TRI-REFLECTOR SYSTEM WITH MINIMUM ABERRATION

Figure 1 illustrates the geometry of a new type of tri-reflector system proposed. The cross-section curve of main, sub-, and auxiliary reflector is a parabola, ellipse, and hyperbola, respectively. The key feature of this reflector system is that all of the three reflectors are toroidal and their principal axes exactly coincide; each reflector is a part of quadratic surface of revolution with the same rotational axis A-A'. Thus the system offers fully symmetry which can be used for wide-angle beam scanning. The parameters of those cross-section curves as well as the distance Z_0 between the main reflector and the principal axis are so optimized to minimize the aberration (path length error ΔZ). The r.m.s. value of path length error is plotted against the distance Z_0 in Fig. 2. It should be noted that without a phase corrector the path length error can be effectively cancelled by optimizing Z_0 in the tri-reflector system proposed. Figure 3 shows the aperture mapping and distribution of the residual error obtained by tracing rays emerging from the focus F_0 as a function of polar grid coordinates (θ, ϕ). (In Fig. 3, the scale is imbalanced to exaggerate the path length error.) Not a circular aperture mapping but a elliptic one ($D_x : D_y = 1.675 : 1$) is obtained. In the example shown in Fig. 2, the minimum residual error in r.m.s. corresponds to be less than $\lambda/32$ (λ : wavelength) for effective D/λ value of about 100 (, where $D^2 = D_x * D_y$).

III. EXPERIMENTAL ANTENNA AND ITS CHARACTERISTICS

An experimental antenna, shown in Fig. 4, was designed and fabricated with a feed array. The cross section of the reflector system meets with the zero cross-polarization condition [3]. Five equally spaced feeds are so arranged with their axes parallel to the principal axis of the toroids, that the apertures of feeds lie on a focal plane. Thus the favorable condition for easy connection with feed networks and less mutual coupling between horns is achieved. Dual-mode conical horns of 3.1 λ (λ : wavelengths) in inner diameter are used as primary feeds. The minimum beam separation angle, which is one of the key figures for multi-beam antennas, is determined by the intervals between the adjacent horns, and is about 2.5 degrees for the experimental antenna, which could be still more improved by using dielectric loaded horns. The angle γ subtended by the reflector system at the principal axis is 70 degrees, which is determined to cover the scanning angle of approximately ± 10 degrees in FOV. The equivalent D/λ value of the experimental antenna is about 50.

First, the radiation characteristics of the antenna was evaluated for the central, non-scanning beam. The near-axis radiation patterns measured in the azimuthal plane are plotted in Fig. 5 with the predicted patterns calculated under PO (physical optics) approximation. Sufficient agreements were achieved between the measurements and the calculations, showing the low sidelobe characteristics much better than the reference diagram of 29 - 25 log(θ) dBi. The measured peak gain was 42.2 dBi, whereas the calculated one was 42.26 dBi. The half-power beam width was about 1.1 degrees in the azimuthal plane and about 1.9 degrees in the orthogonal plane. Because of the large offset configuration and the elliptic aperture, the residual cross-polar radiation level was relatively high and about -20 dB at the peak. The wide-angle radiation pattern, shown in Fig. 6, was satisfactory.

Second, the beam scanning characteristics was evaluated. Figure 7 shows the superimposed, near-axis radiation patterns of scanned beams with scanning angle of 0, -5, -10, -15, and -20 degrees. The experimental antenna covered the predetermined FOV of ± 10 degrees with gain loss less than -0.5 dB and no degradation of sidelobe characteristics. This means that the sectorial part with subtended angle of only 50 (= 70 - 2*10) degrees contributes to produce an excellent pencil-beam and the extended area is just for beam-scanning. The gain loss and the pattern degradation for much scanned beams greater than ± 10 degrees are mainly due to spill-over effect and increase of reflector edge illumination level. The larger the subtended angle γ, the wider the FOV to be served. If two sets of the experimental antennas were connected to form a continuous reflector system, for example, it would give a large FOV of 90 (= 70*2 - 50) degrees.

IV. CONCLUSIONS

This paper proposes a new configuration of an offset tri-reflector system of toroids for multi-beam applications. It was found and verified that the combination of the optimized cross-section curves of triple toroidal reflectors could effectively cancel the spherical aberration. By showing the satisfactory radiation characteristics, the experimental antenna demonstrated its applicability to multi-beam antennas with both a large FOV and a small beam separation angle.

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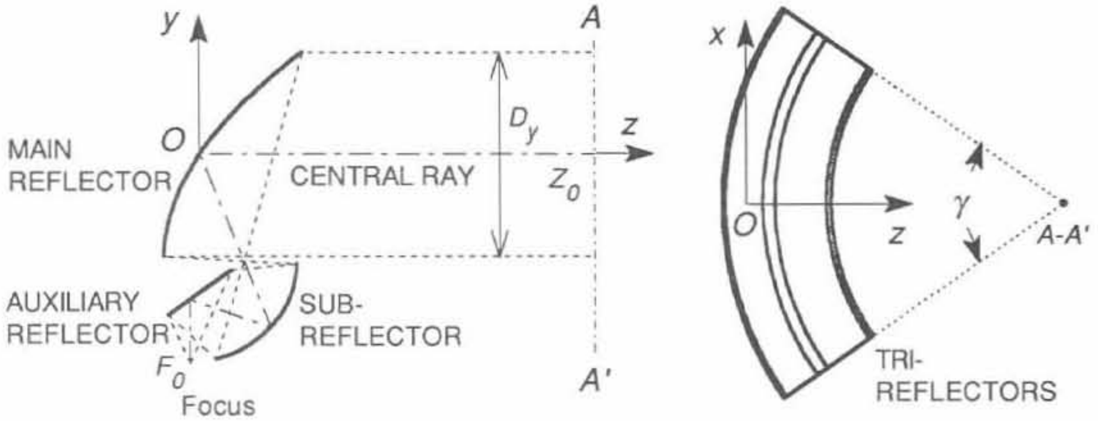


(a) Cross-sectional view. (b) Top view.

Figure 1. Geometry of an offset toroidal tri-reflector system.

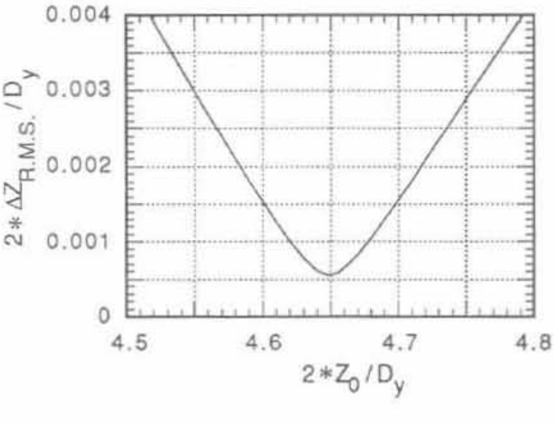


Figure 2. Path length error vs. Z_0.

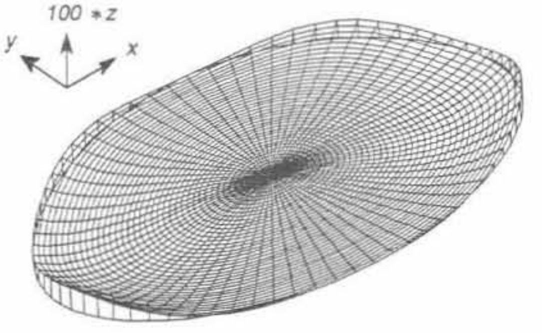


Figure 3. Aperture mapping.
(Path length error is exaggerated.)

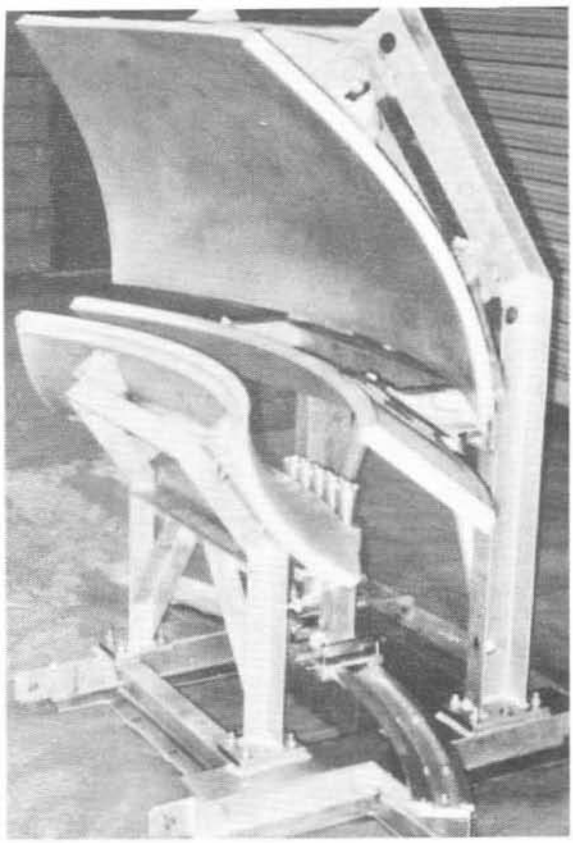
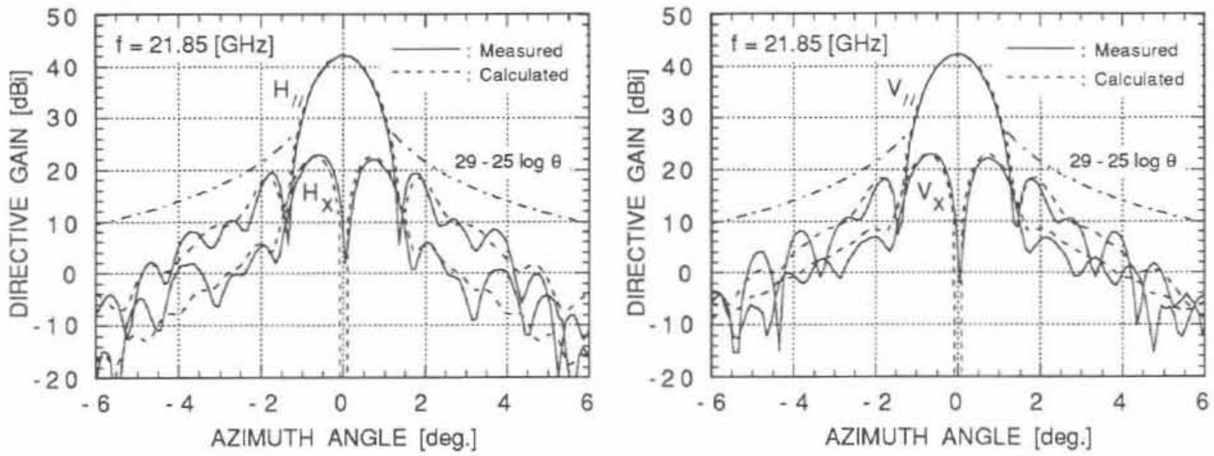


Figure. 4 Experimental antenna.



(a) Horizontal polarization. (b) Vertical polarization.

Figure 5. Near-axis radiation patterns.

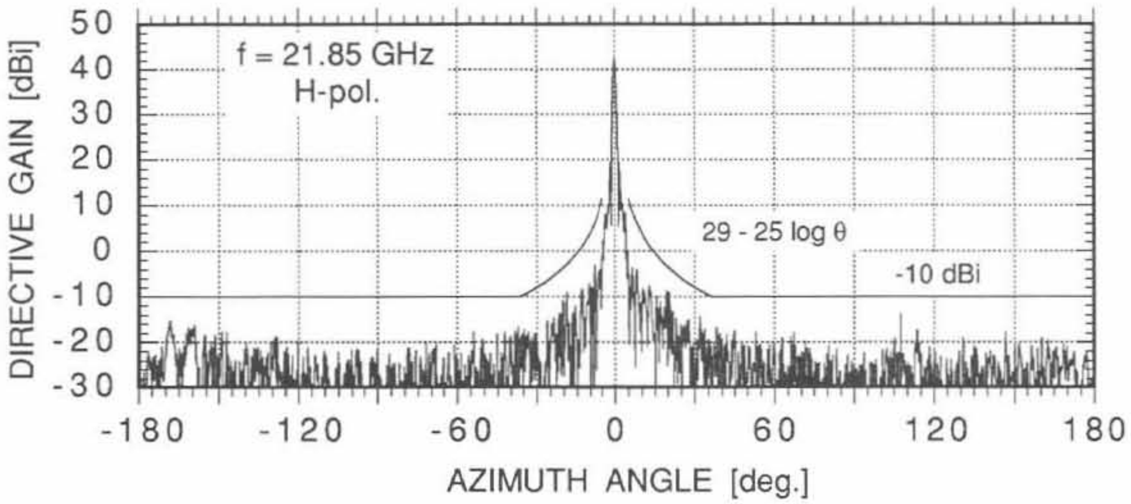


Figure 6. Measured wide-angle radiation pattern.

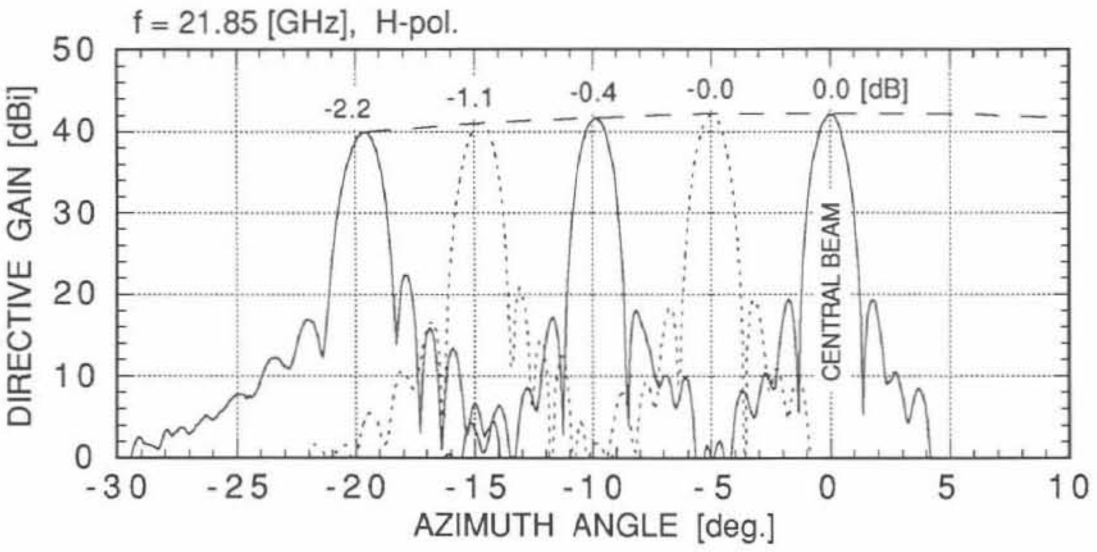


Figure 7. Measured beam-scanning characteristics.