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SHAPING OF DUAL REFLECTOR ANTENNAS FOR IMPROVEMENT OF SCAN PERFORMANCE

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Introduction

Modern communications satellites are equipped with high gain reflector antennas with contoured beams for various purposes. A contoured beam of complex cross section is generated by exciting several feed elements simultaneously, where each feed radiates a narrow and almost circular beam. The element beams which are directed towards the edge of the coverage region will suffer from various scan degradations.

For future systems there is a need for more frequency re-uses and improved beam coverage flexibility. Simultaneously there is a trend towards the use of higher frequencies, such as the 20/30 GHz bands. This will result in narrower element beams and the scan aberration is likely to be a limiting factor for the performance that can be realized.

The present paper describes a technique for shaping the reflector surfaces of a dual reflector antenna system. In this way a very significant reduction of the scan aberrations in a multibeam antenna may be achieved.

Background

The two reflectors in a dual reflector system provide an extra degree of freedom compared with a single reflector system, and this can be used to improve the scan performance. It is suggested by Dragone (1978) to eliminate the first order astigmatism by tilting the subreflector and feed axes according to the condition of Tanaka and Mizusawa (1975) and Mizugutch (1976). This condition also minimizes cross polarization and is important for the scan performance because astigmatism is the dominating aberration in a non-shaped offset Cassegrain or Gregorian system. Another possibility is the bifocal dual reflector system (Rappaport (1982)), where the reflector surfaces are shaped in order to give the system two exact focal points corresponding to two different far field directions. More than two exact focal points is not possible in a dual reflector system.

In this paper we present a method for improving the scan performance in a general scan region e.g. a plane or a conical region. The reflector surfaces are shaped in order to distribute the aberrations uniformly in the desired region, so that the large aberrations at the edge of the coverage are reduced, and the small aberrations at the center are increased.

Theory

The principles of the shaping procedure are now explained. The reflector surfaces are shaped by an iterative procedure, and an initial system must be chosen as a starting point. Also a number of

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far field directions must be chosen where the performance of the antenna should be improved. In each iteration the aberrations at the feed positions corresponding to the chosen far field directions are calculated, and the surfaces are adjusted in a systematical way in order to reduce the aberrations.

In the iteration procedure a numerical representation of the reflector surfaces is necessary. We have chosen to use cubic basis-splines, which was found to be very efficient and accurate. The main reflector surface $z = f(x,y)$ is expanded in the series

$$f(x,y) = \sum_{ij} c_{ij} B_i(x) B_j(y) \tag{1}$$

and similar for the subreflector

$$g(x,y) = \sum_{ij} d_{ij} B_i(x) B_j(y) \tag{2}$$

where $B_i(x)$ and $B_j(y)$ are basis-spline functions and c_{ij}, d_{ij} expansion coefficients.

The feed position for a scanned beam is determined by looking at the antenna as a receiving system. A number of rays are traced from incidence of the main reflector to the feed position, where the final rays form an approximative focal point. A point $\bar{r}_i$ is chosen on each of the final rays, and the mean value $\bar{\mu}$ of the points $\bar{r}_i$ is used as feed position. The variance V

$$V = \sum_{i=1}^{N} \frac{1}{N}(\bar{r}_i - \bar{\mu})^2 \tag{3}$$

gives an estimate of the magnitude of the aberrations. The points $\bar{r}_i$ on the final rays are chosen so that the sum (3) is minimized.

The optimization of the reflector surfaces is performed by a numerical Levenberg-Marquardt algorithm for minimization of a sum of squares of non-linear functions. Here the sum of squares to be minimized is given by (3) and the variables are the c_{ij}, d_{ij}-coefficients.

Examples

As starting point for the shaping we use the Cassegrain antenna shown in Figure 1, where the system is drawn in the plane of symmetry. The subreflector is a plane, and the main reflector is a paraboloid with focal length $f/D = 1.5$. A plane scan region of $\pm 7^\circ$ orthogonal to the plane of symmetry is now considered. This corresponds to the scan directions $\phi = 90^\circ$, $\theta = 0^\circ - 7^\circ$ and $\phi = 270^\circ$, $\theta = 0^\circ - 7^\circ$. First the system is shaped for the directions $\theta = 7^\circ$, $\phi = 90^\circ$ and $\theta = 7^\circ$, $\phi = 270^\circ$, which gives a bifocal system. In the next example the system is shaped for the five directions $\theta = 0^\circ$, 3.5°, 7° for $\phi = 90^\circ$ and $\theta = 3.5^\circ$, 7° for $\phi = 270^\circ$, in order to give a uniform distribution of the aberrations in the scan plane. The maximum directivity and the efficiency loss, which is due to a non-constant phase and amplitude in the aperture, are shown in Table 1 and Fig. 2, respectively. It is seen that the efficiency loss is much reduced for the bifocal system, but nearly eliminated for the system shaped for five directions. The efficiency loss is here reduced to a level of about 0.5 dB, which is due to the feed taper that gives a non-constant amplitude distribution. The low efficiency loss of the system shaped for five directions gives a directivity in the whole scan region $\theta = \pm 7^{\circ}$ at the same level as the non-shaped system in the center direction. Patterns are shown in Figure 3 and a 3D-plot of the subreflector in Figure 4. The shaping only deforms the surfaces with approx. 3 wavelengths.

Finally the system is shaped for the 9 directions $\theta = 0^{\circ}$, $\phi = 0^{\circ}$ and $\theta = 3.5^{\circ}$, $\phi = 0^{\circ}$, $\pm 45^{\circ}$, $\pm 90^{\circ}$, $\pm 135^{\circ}$, 180° to obtain a conical scan region of 3.5 degrees. From Table 1 it is found that the shaped system has a scan-loss of approx. 2 dB compared to approx. 6.5 dB for the non-shaped system.

Conclusion

The shaping procedure described in this paper is able to improve the scan performance of a dual reflector antenna significantly compared with both non-shaped and bifocal antennas. When the required scan region is a plane, the shaping becomes particularly important, but also for scan in a conical region the shaping gives an improvement. For a large conical scan region of e.g. 10° or more a top-fed or front-fed Cassegrain system which satisfies the condition of Mizugutch seems to be favourable. Shaping of these antenna types only gives minor improvements.

References

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scan direction \ antenna type		1	2	3	4
θ	ϕ				
0°,	0°	58.51	55.33	58.31	57.37
1.75°,	90°	57.01	55.51	58.29	
3.50°,	90°	52.82	56.19	58.24	57.58
5.25°,	90°	49.48	57.57	58.21	
7.00°,	90°	46.53	58.38	58.15	
3.50°,	0°	52.05			56.50
3.50°,	180°	53.65			56.40

Table 1 Maximum directivity. 1: non-shaped system, 2: bifocal system, 3: shaping for scan in a plane, 4: shaping for conical scan.

$2\frac{1}{2}^{\circ}$
SCAN
ANGLE

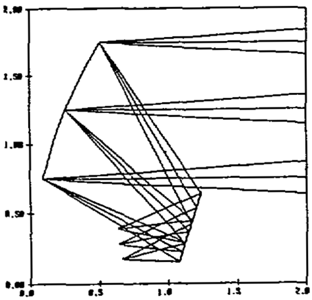

Figure 1
Cassegrain system. Aperture diameter $D/\lambda = 300$ (λ = wavelength), focal length $f/D = 1.5$. 10 dB edge taper

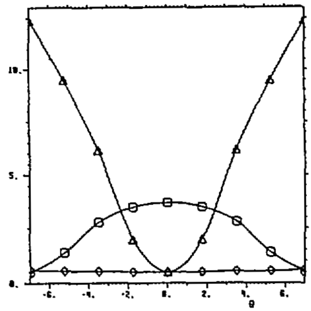

Figure 2
Efficiency loss vs. scan angle θ, $\phi = 90^{\circ}$.
△ non-shaped
□ bifocal system
◇ shaping for scan in a plane

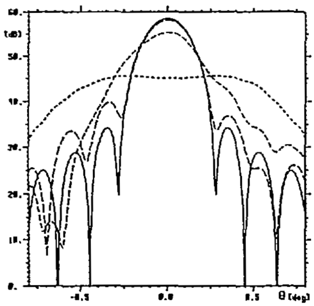

Figure 3
Patterns for
——— non-shaped system, $\theta = 0^{\circ}$, $\phi = 0^{\circ}$
········ non-shaped system, $\theta = 7^{\circ}$, $\phi = 90^{\circ}$
------ bifocal system, $\theta = 0^{\circ}$, $\phi = 0^{\circ}$
— — — shaping for scan in a plane, $\theta = 7^{\circ}$, $\phi = 90^{\circ}$

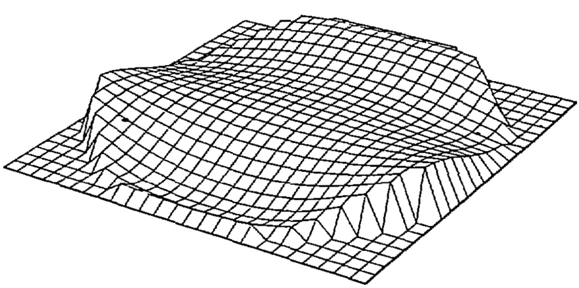

Figure 4 3D-plot of subreflector. The deviation of the subreflector from a plane is scaled by 15.