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Electronic Compensation For Reflector Surface Distortion To Improve Radiation Pattern Characteristics Of Antennas

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ELECTRONIC COMPENSATION FOR REFLECTOR SURFACE DISTORTION TO IMPROVE RADIATION PATTERN CHARACTERISTICS OF ANTENNAS

Abstract

A simple procedure is described for determining the excitation coefficients of an array feed which compensates for the surface distortion of a reflector antenna to improve the radiation pattern in such a way as to approximate the performance of the undistorted antenna. A computer simulation for a practical feed array is presented as an example of compensation for the distortion of an actual antenna.

Introduction

Large reflector antennas are commonly used for high-gain and low-sidelobe applications. However, distortions in the reflector surface due to thermal gradients, gravity loads, manufacturing tolerances, etc., can significantly degrade the performance of the antenna. Large deployable reflectors for space applications may also be distorted due to errors in the deployment mechanism. Mechanical adjustment of the reflector surface can improve the performance, provided the proper adjustment mechanisms have been designed into the antenna. An array feed with adjustment capability of the amplitude and phase excitations of the array elements can provide an alternative (or supplement) to the mechanical means of improving the radiation performance of a distorted reflector antenna. Improving the performance of a distorted reflector antenna by adjustment of the array feed excitation is sometimes referred to as "electronic compensation". The purpose of this paper is to describe a simple method of determining the amplitude and phase excitations of an array feed to compensate for the surface distortion of a reflector antenna in order to approximate the performance of the "smooth" reflector.

Feed Array Excitation

The problem is to determine the amplitudes of N number of individual functions superimposed to approximate a desired function of x and y at discrete points in the x,y plane. In the present application, the function to be approximated is the complex field distribution in the aperture of a reflector antenna and the individual functions are the reflector aperture field distributions from individual radiators of an N-element array feed. Actually, the far-field of the reflector antenna in discrete angular directions could be taken as the desired function to be approximated and the far-field of the reflector due to each element of the array feed would then become the individual functions. The procedure is the same for both applications.

The desired aperture field in the x,y plane is represented by the complex function, $F(x,y)$, and the aperture field due to the n-th array feed element is represented by the function, $f_n(x,y)$, with complex amplitude, A_n. The superposition of all aperture fields due to the array feed elements is equated to the desired aperture field at discrete points (x_i,y_i) in the aperture plane as

$$\sum_{n=1}^{N} A_n f_n(x_i,y_i) \simeq F(x_i,y_i) \qquad i=1,2,3,\ldots,I \tag{1}$$

where I is the total number of discrete points in the aperture plane where the desired field is to be approximated. The complex amplitudes, A_n, are determined such that the desired aperture field is approximated in a least-squared sense by the N-element array feed. This is accomplished by defining the quantity, G, as

$$G = \sum_{i=1}^{I} \left[F(x_i,y_i) - \sum_{n=1}^{N} A_n f_n(x_i,y_i) \right]^2 \tag{2}$$

and minimizing G with respect to A_m, for $m=1,2,3,\ldots,N$

$$\frac{\partial G}{\partial A_m} = -2\sum_{i=1}^{I} \left[f_m(x_i,y_i) \left(F(x_i,y_i) - \sum_{n=1}^{N} A_n f_n(x_i,y_i) \right) \right] = 0 \tag{3}$$

which results in N equations with N unknowns.

By making the following definitions:

$$B_m = \sum_{i=1}^{I} f_m(x_i,y_i)\, F(x_i,y_i) \tag{4}$$

$$S_{mn} = \sum_{i=1}^{I} f_m(x_i,y_i)\, f_n(x_i,y_i) \tag{5}$$

the problem can be expressed in convenient matrix notation as

$$\begin{bmatrix} B_1 \\ B_2 \\ \vdots \\ B_N \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & \cdots & S_{1N} \\ S_{21} & S_{22} & \cdots & S_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ S_{N1} & S_{N2} & \cdots & S_{NN} \end{bmatrix} \begin{bmatrix} A_1 \\ A_2 \\ \vdots \\ A_N \end{bmatrix} \tag{6}$$

The complex values, A_n, for the excitation coefficients of the array feed elements are then determined from equation (6) by matrix inversion.

The feed array excitation determined by this method neither maximizes the peak gain of the reflector antenna nor minimizes the sidelobes of the antenna, but approximates the desired aperture field distribution and therefore the desired radiation pattern in all angular space within the limitations of the N-element array feed. If the excitation coefficients were determined by applying the procedure to the far-field of the reflector antenna, as mentioned earlier, then the approximation would apply to the radiation pattern in the specified discrete angular directions, (θ_i,ϕ_i), with no restrictions on the radiation pattern in other directions. However, specifying (θ_i,ϕ_i) closely spaced within some far-field angular region of interest might be useful in some applications. Applying the procedure to either the aperture field or the far-field may also be useful in determining the initial excitation coefficients in an iterative optimization scheme and thus reduce the number of iterations required.

Example

The 15-meter hoop/column mesh deployable antenna is used to illustrate through computer simulations that adjustment of array feed excitations can achieve an appreciable improvement in the radiation pattern characteristics by compensating for the surface distortion. The surface distortion used in the simulation is the deviation from a paraboloid as measured by a metric camera while the antenna was deployed in the Martin-Marietta Near-Field Facility in July 1985.

The array feed used in the simulation is a triangular-grid array of multi-mode conical horns, which was originally designed as a reconfigurable feed for a commerical satelite antenna. This array feed was selected for the simulation because it possessed the capability of computer controlled adjustment of amplitude and phase for 16 elements and was being made available for testing with the hoop/column antenna. The calculations were performed to determine whether sufficient performance improvement could be achieved in order to justify an experimental test in the near-field facility. The calculations were performed with 7, 19, and 37 elements in a hexagonal array with the possibility of expanding the original array to include the additional elements if necessary. Subsequently, due to deterioration, the beamforming network for the original array was found to be unusable and the experimental tests were cancelled. However, the results of the computer simulations do show significant improvement in performance. The calculations were performed at 6.4 GHz with 3.5 inch center-to-center spacing of the array elements using the measured radiation pattern of a single horn as the array element illumination of the distorted surface to calculate the geometric-optics aperture fields of the reflector.

The "desired" aperture field was obtained by illuminating the "smooth" reflector with a 7-element cluster array with uniform phase for all element excitations and -14dB amplitude excitation for the outer 6-element ring. This 7-element cluster excitation was selected because it produces a secondary radiation pattern with -28dB maximum sidelobes for one quadrant of the hoop/column antenna. The initial 7-element feed cluster configuration is shown in figure 1 with the array excitations indicated. The aperture distribution for the "smooth" reflector is shown in figure 2, and the radiation pattern is shown in figure 3. The aperture distribution (amplitude and phase) in figure 2 is the "desired" function to be approximated by the array feed when compensating for the distortion of the reflector surface.

The measured surface distortion is plotted in figure 4 with the height of the distortion exaggerated so as to be visible on the plot. The rms of the distortion is 0.061 inches, with extreme values of -0.598 inch and +0.210 inch. It should be noted that the surface distortion used in this paper is obtained from measurements of targets located at the surface "tie-points" only. The actual mesh surface between the tie-points exhibits a "pillowing" effect relative to the paraboloidal surface and, due to the periodic nature of these "pillows", distinct wide-angle sidelobes will be produced in the secondary radiation pattern. However, the main beam and close-in sidelobe degradation are dictated by the distortion shown in figure 4; therefore, this distortion is used for the compensation calculations.

Geometric optics is used to calculate the apertures fields of the reflector and, for small surface distortions, the primary effect on the aperture fields will be a change in the phase distribution in a direct relationship to the surface distortion, due to the change in ray path length. The aperture fields for the distorted reflector are shown in figure 5 and the corresponding secondary radiation pattern is shown in figure 6. Evaluating the excitation coefficients for the 7-element array to compensate for the surface distortion yields an insignificant improvement in the radiation pattern and indicates that more array elements are required.

Surface compensation calculations were performed with a 19-element hexagonal cluster of horns as shown in figure 7 with the excitation coefficients indicated. The aperture field from the distorted reflector with this 19-element feed is plotted in figure 8 and the secondary radiation pattern is shown in figure 9. An appreciable improvement in the main beam and close-in sidelobes was obtained by using this 19-element array feed.

A larger hexagonal array of 37-elements was also used to further improve the radiation pattern. The excitation coefficients of this 37-element array are shown in figure 10 and the aperture field distribution is plotted in figure 11. The secondary radiation pattern in figure 12 approachs the "smooth" reflector pattern performance.

Conclusion

It has been shown that the radiation pattern performance of a distorted reflector antenna can be improved significantly by using an array feed. Using a least-squared procedure to determine the array feed element excitations which will approximate the smooth reflector aperture field can produce a secondary radiation pattern which approaches the performance of the undistorted antenna without mechanical adjustment of the distorted surface. This compensation procedure may also serve to "fine-tune" the performance of a reflector antenna which has mechanical adjustment capability.

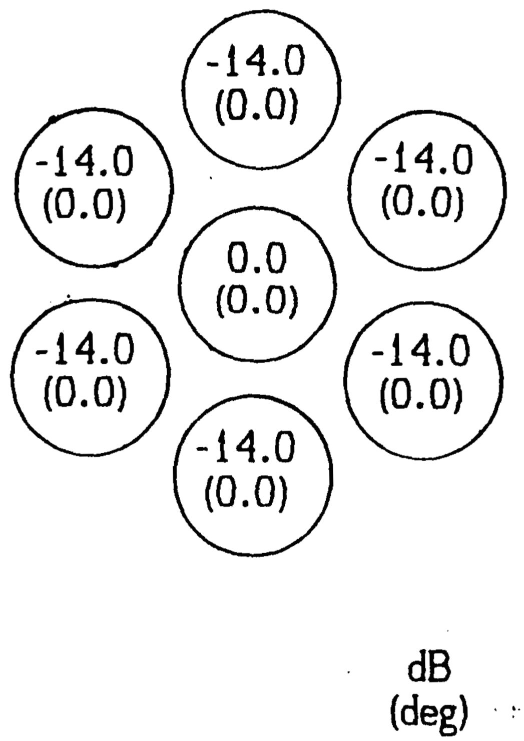

Figure 1. 7-element array geometry and excitation coefficients.

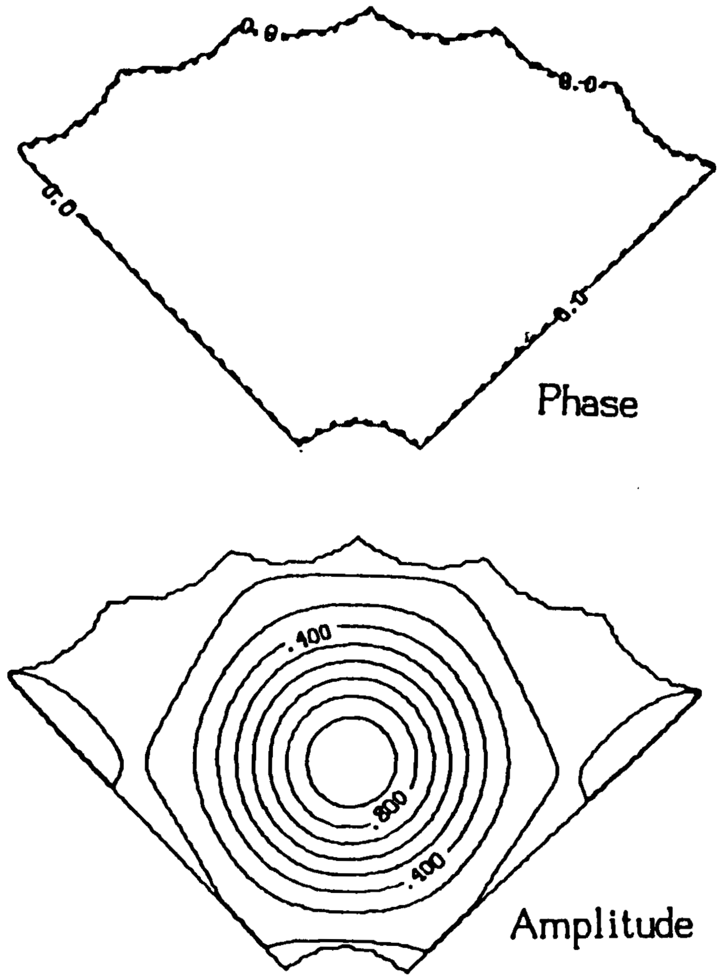

Figure 2. Smooth reflector aperture distribution with 7-element cluster array feed.

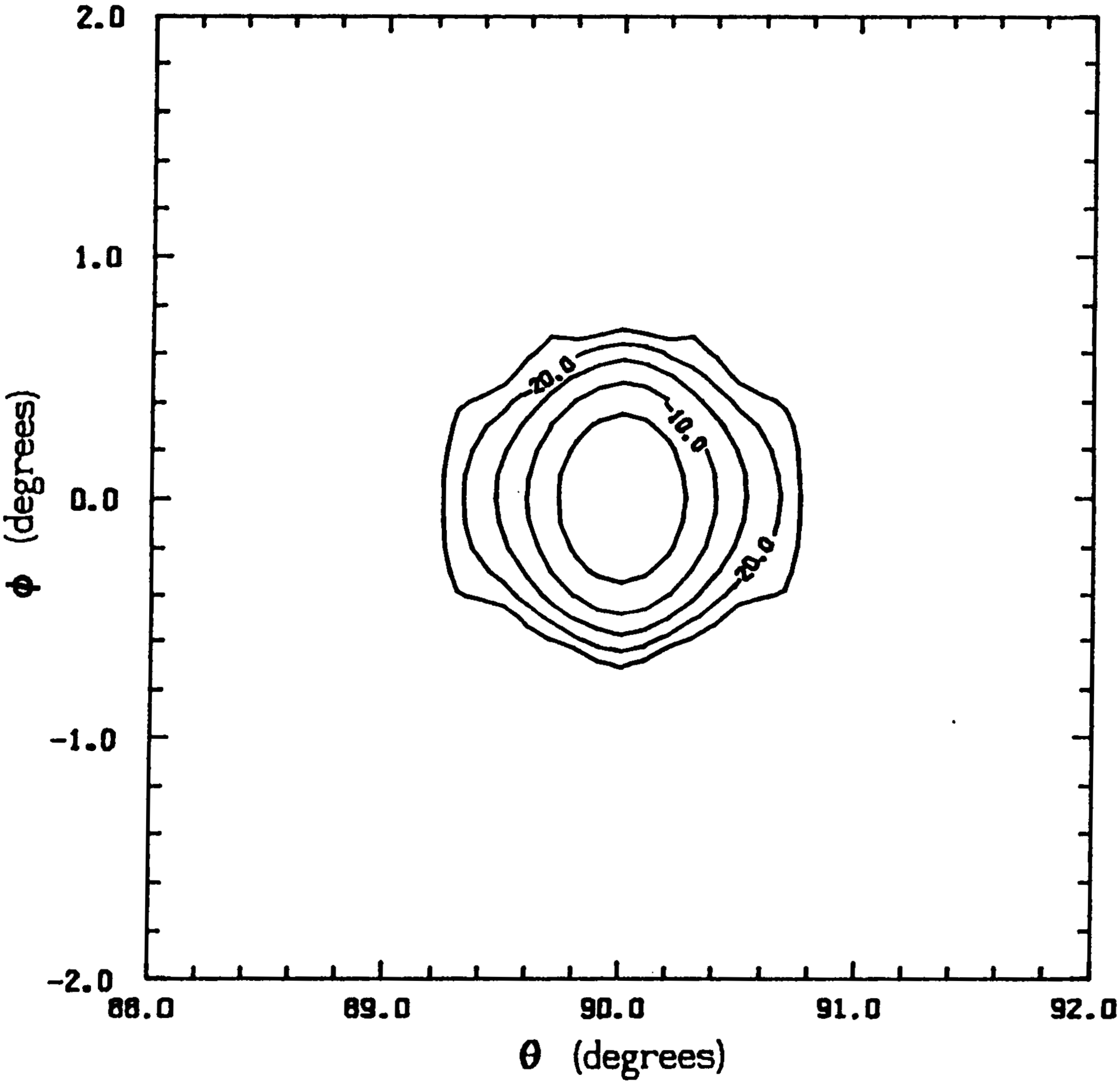

Figure 3. Radiation pattern contours for smooth reflector with 7-element cluster array feed.

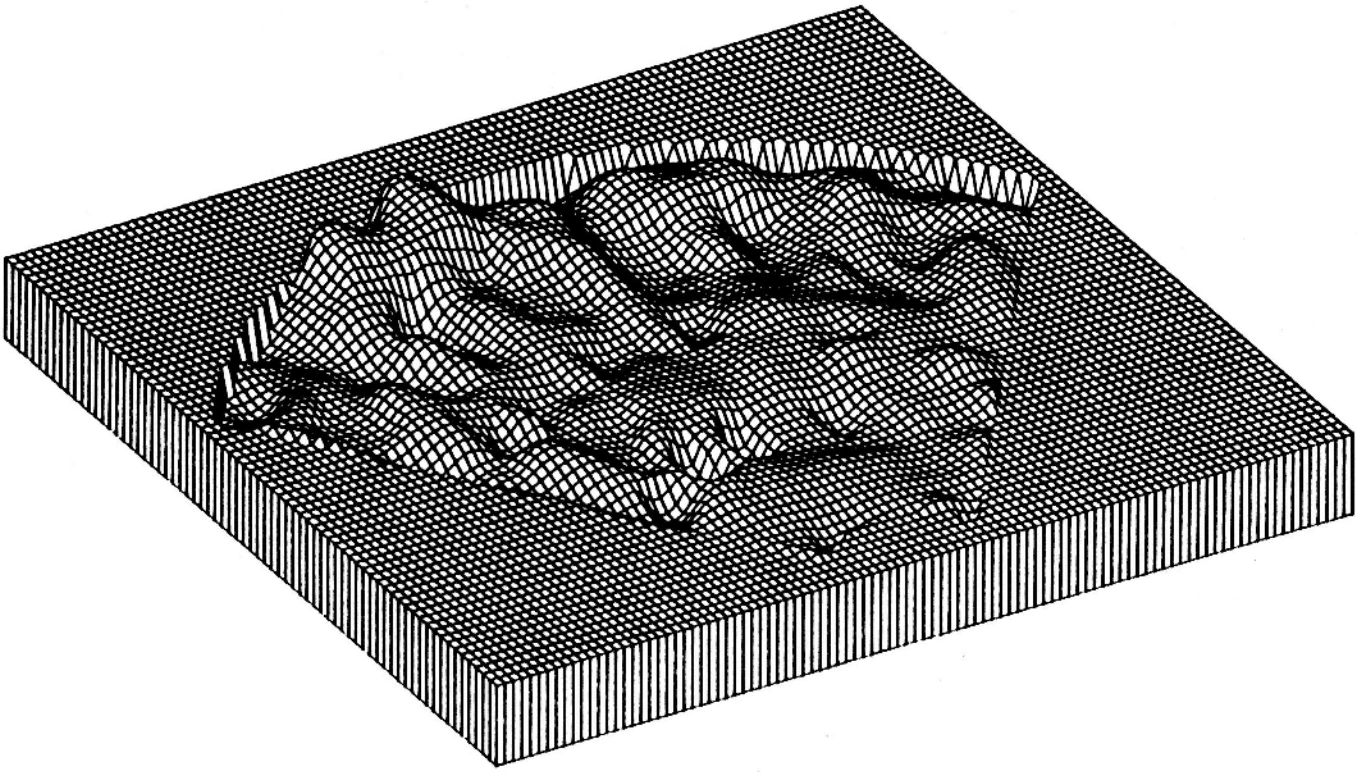

Figure 4. Measured deviation from paraboloidal surface for one quadrant of hoop/column reflector antenna.

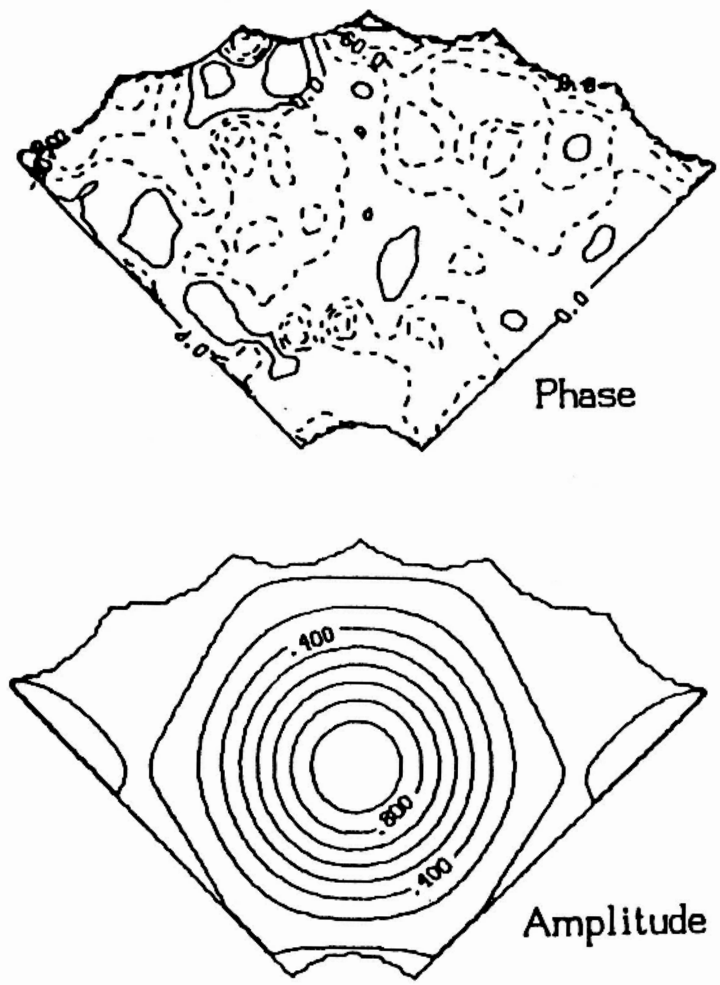

Figure 5. Distorted reflector aperture distribution with 7-element cluster array feed.

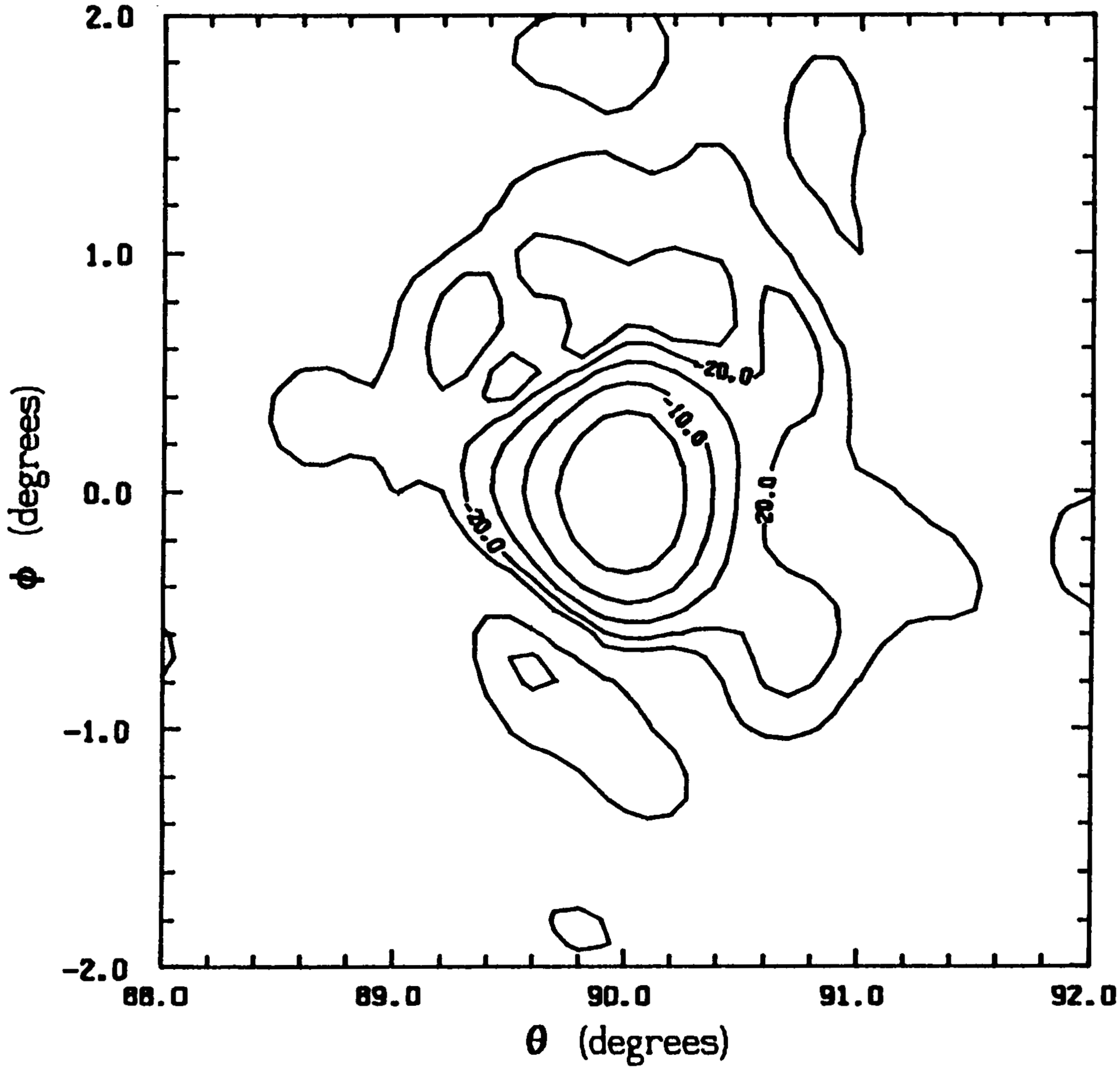

Figure 6. Radiation pattern contours for distorted reflector with 7-element cluster array feed.

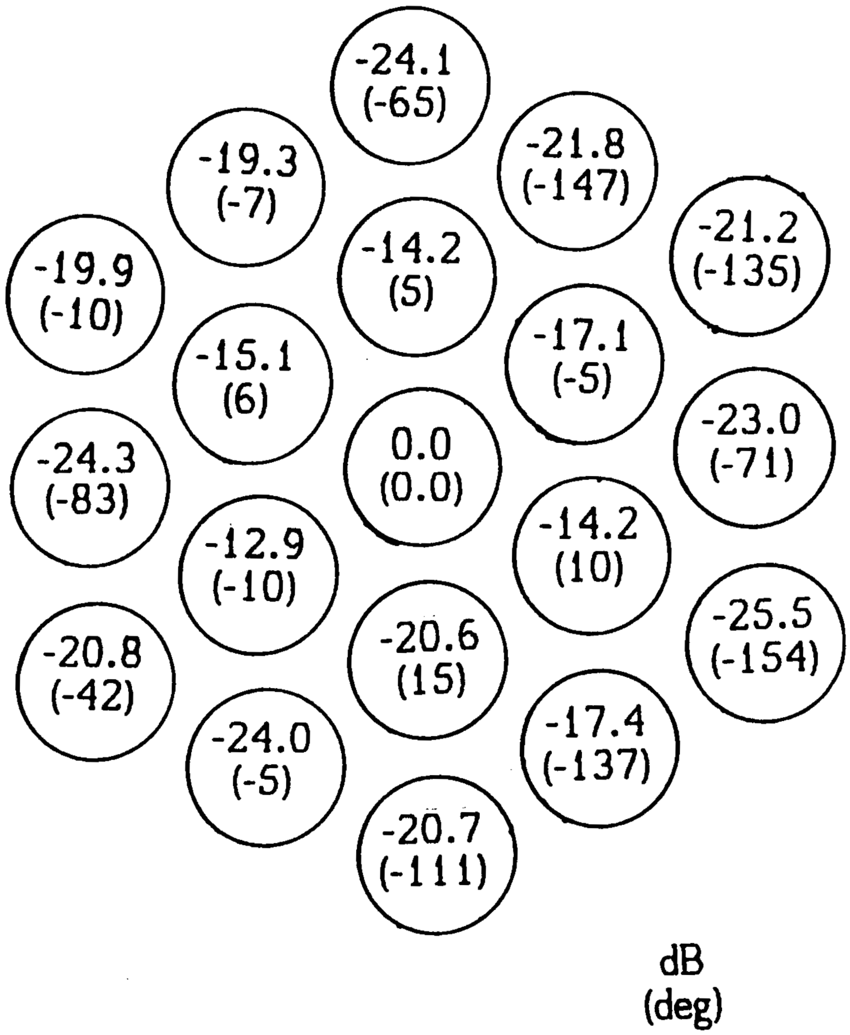

Figure 7. 19-element array geometry and excitation coefficients for surface distortion compensation.

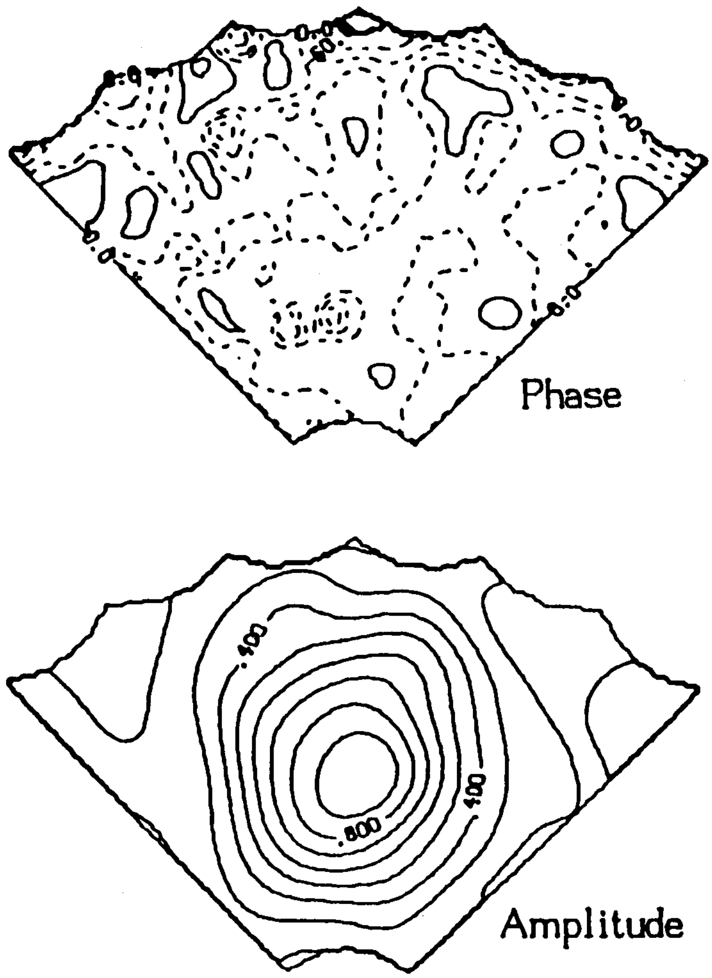

Figure 8. Distorted reflector aperture distribution after surface distortion compensation with 19-element array feed.

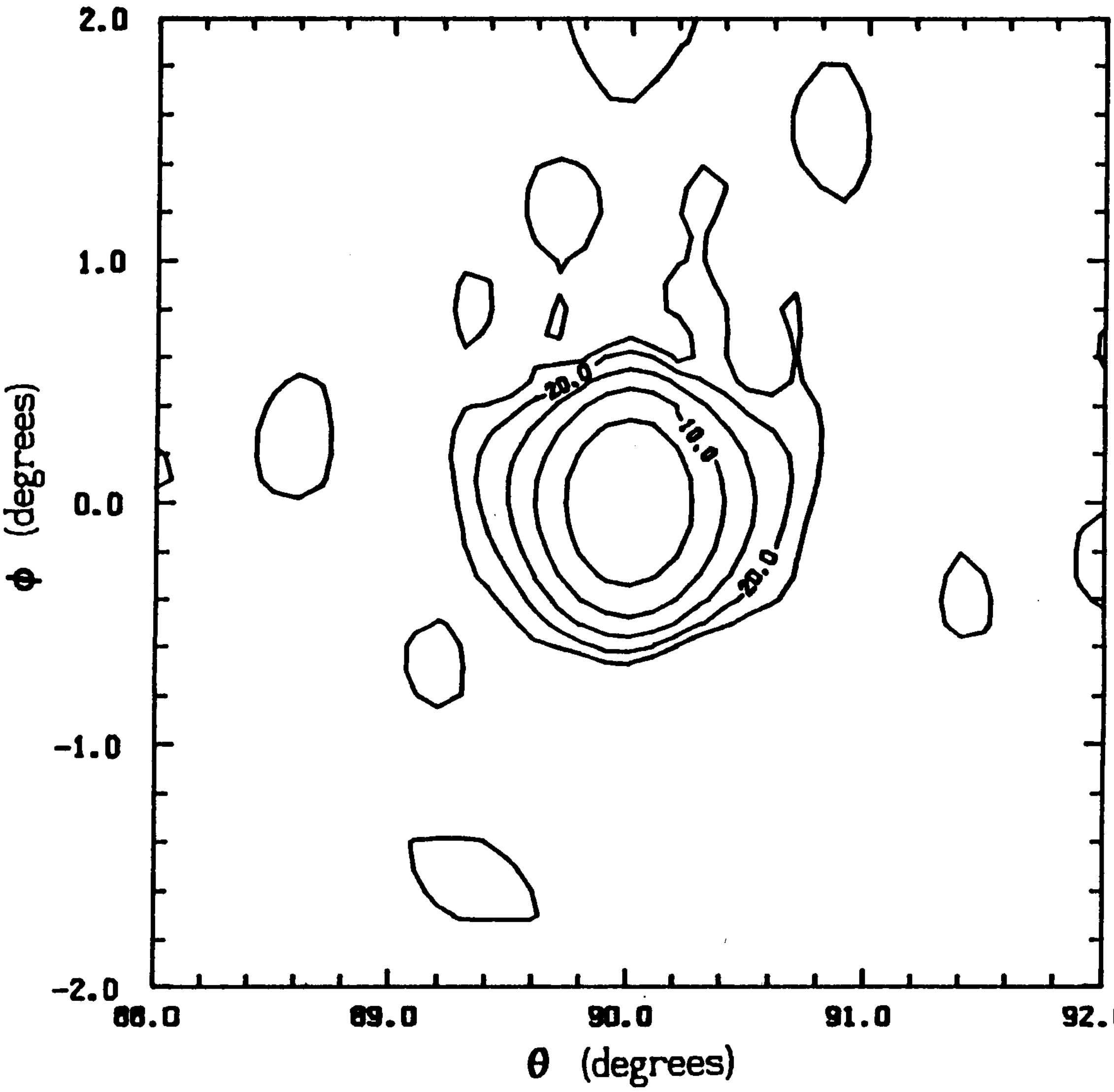

Figure 9. Radiation pattern contours for distorted reflector after surface distortion compensation with 19-element array feed.

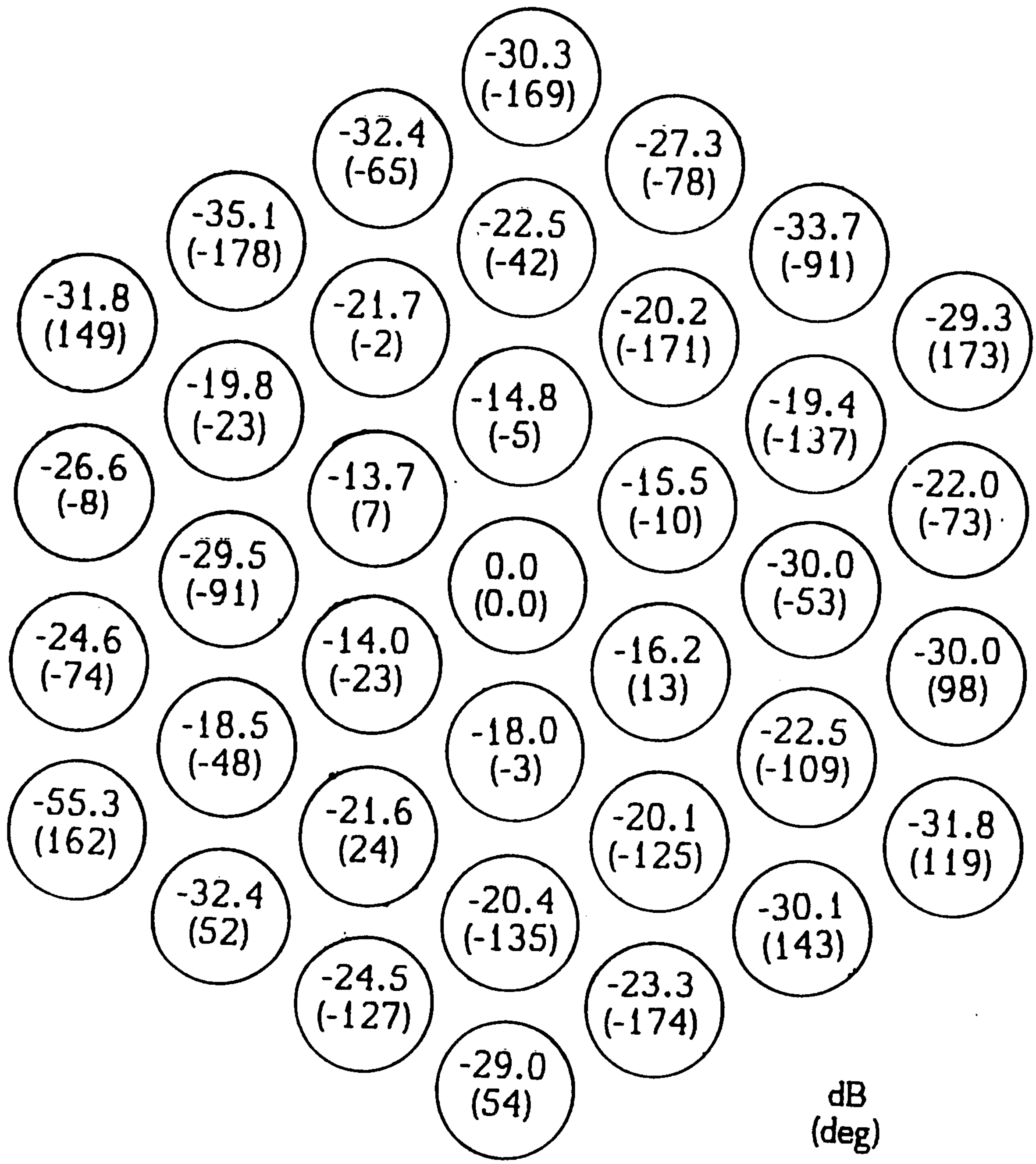

Figure 10. 37-element array geometry and excitation coefficients for surface distortion compensation.

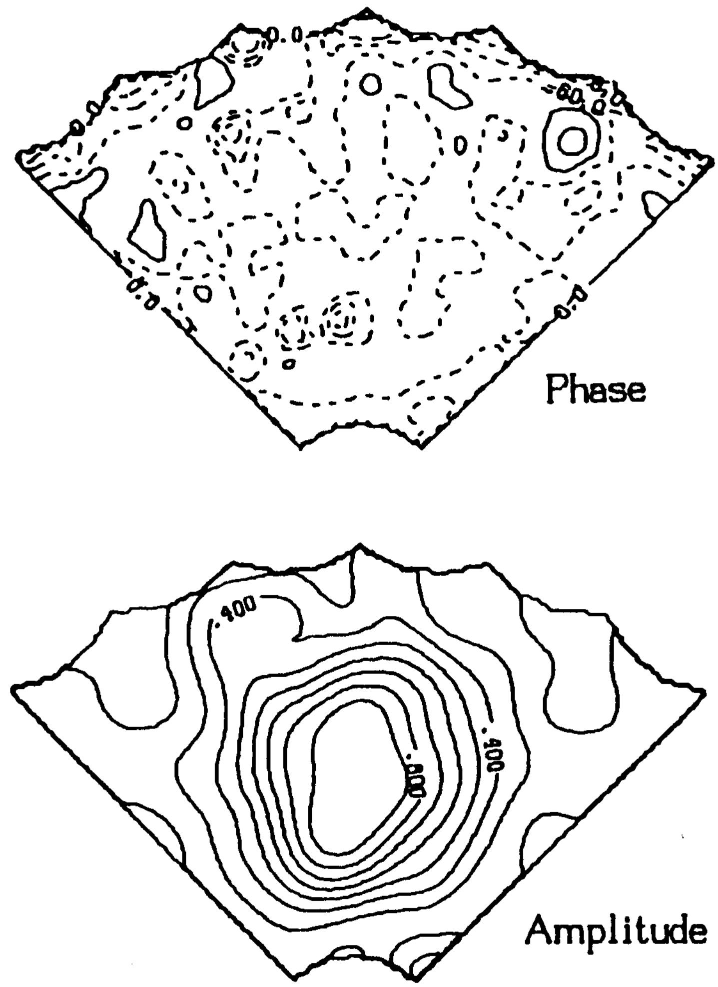

Figure 11. Distorted reflector aperture distribution after surface distortion compensation with 37-element array feed.

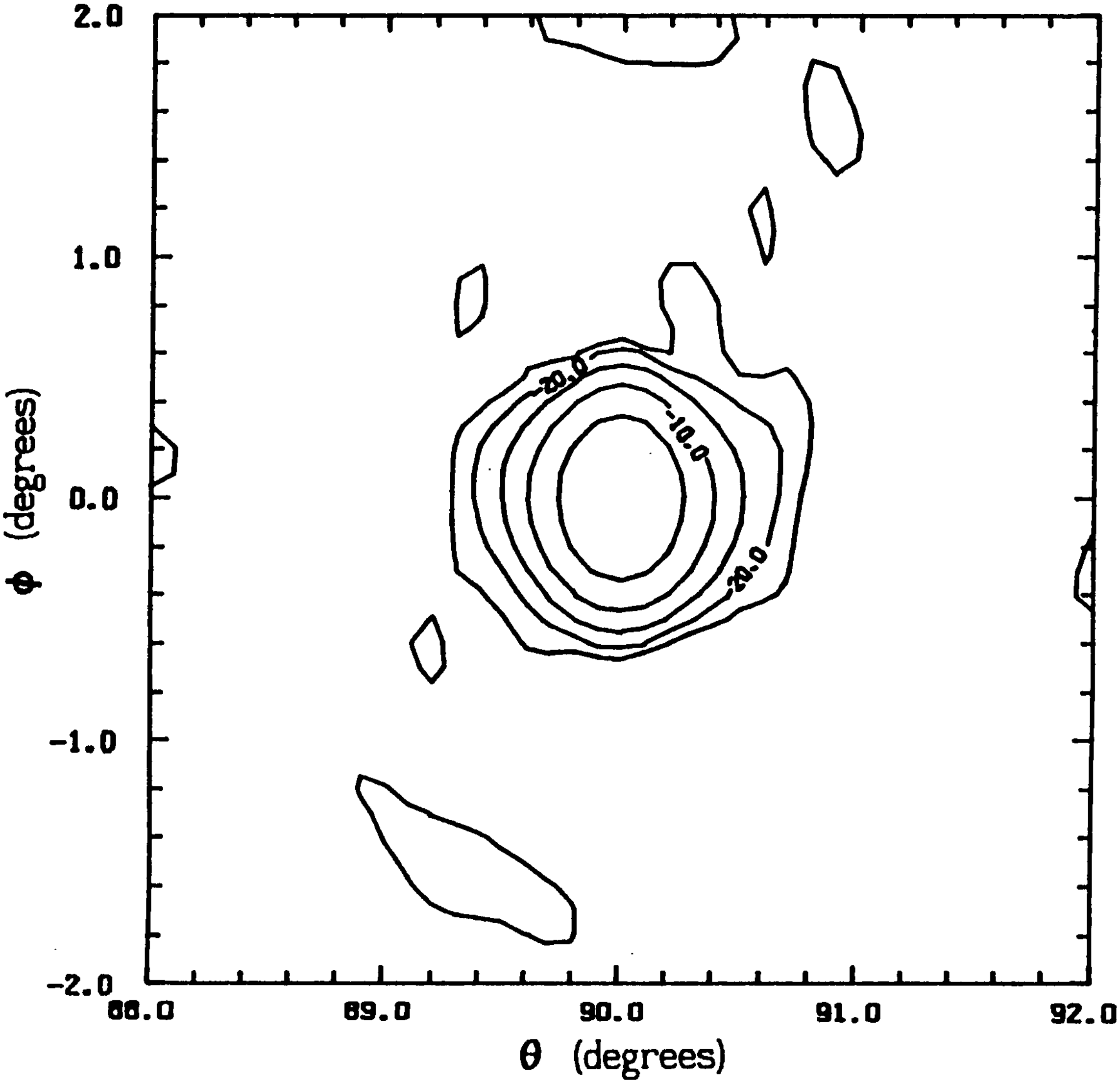

Figure 12. Radiation pattern contours for distorted reflector after surface distortion compensation with 37-element array feed.

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