Computational Methods and Theoretical Results for the Ka-band Array Feed Compensation System - Deformable Flat Plate Experiment at the NASA/JPL 70-meter Antenna

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Introduction: During the period from November 1998 through February 1999, a series of measurements was carried out on the 70-m antenna at DSS 14 to determine the performance characteristics of two systems designed to compensate for the effects of elevation-dependent gravity distortion of the main reflector on antenna gain. The array feed compensation system (AFCS) and the deformable flat plate (DFP) system were both mounted on the same feed cone and each was used independently as well as jointly to measure and improve the antenna aperture efficiency as a function of elevation angle. The experimental data is presented in [1] and [2].

This write-up contains a description of the computational method and theoretical results for the DFP and Array Feed systems.

The basic analysis tool is a Physical Optics reflector analysis code that was ported to a parallel computer for faster execution times. There are several steps involved in computing the RF performance of the various systems.

1. A model of the RF distortions of the main reflector is required. This model is based upon measured holography maps of the 70-meter antenna obtained at 3 elevation angles. The holography maps are then processed (using an appropriate gravity mechanical model of the dish) to provide surface distortion maps at all elevation angles. This technique is further described in [3].

2. From the surface distortion maps, ray optics is used to determine the theoretical shape of the DFP that will exactly phase compensate the distortions.

3. From the theoretical shape and a NASTRAN mechanical model of the plate, the actuator positions that generate a surface that provides the best RMS fit to the theoretical model are selected. Using the actuator positions and the NASTRAN model provides an accurate description of the actual mirror shape.

4. Starting from the mechanical drawings of the feed, a computed RF feed pattern is generated. This pattern is expanded into a set of spherical wave modes so that a complete near field analysis of the reflector system can be obtained.

5. For the array feed, the excitation coefficients that provide the maximum gain are computed using a phase conjugate technique.

The basic experimental geometry consisted of a dual shaped 70-meter antenna system; a refocusing ellipse, a DFP and an array feed system. To provide physical insight to the systems performance, focal plane field plots are presented at several elevations. Curves of predicted performance are shown for the DFP system, AFCS and combined DFP/AFCS system.

Geometry: The experiment geometry is shown in Figure 1. The main elements are the 70-meter main and subreflector, a refocusing ellipse, the DFP and the receive feed system. The focal point of the Dual Reflector 70-meter system is labeled F1 and the focal point where the feed is placed is labeled F2. Looking at the system in the transmit mode, the output of the feed system is refocused at F1, the input to the dual reflector system. The parameters of the ellipse are chosen to map the fields (with no magnification) from F2 to F1. Hence, the performance of the 70-meter system would be the same if the same feed were placed at either F1 or F2.

Focal Plane Analysis: To provide some insight on the performance of the various systems, the focal plane fields are displayed for several conditions. Figure 2 shows the focal plane fields for an undistorted system. It is easy to envision that a single feed horn with the proper spot size would be optimal for this system. Figure 3 shows that the focal plane fields are significantly spread out for the 85-degree elevation distortion case. Figure 4 shows the results at the F2 focal point for the case of the 16-actuator plate (actual plate shape that best fits the desired shape) and for a smoothed theoretical plate. Observe that the focal plane spread has been significantly reduced. Also observe that the theoretical plate provides nearly complete compensation.

Comparison of Computed vs. Measured Results: The computed vs. measured results for the array feed at F1 are shown in Figure 5. The graph represents gain improvement obtained by using the 7-element array feed over the power in the center element alone. The solid curve (and black data points) represents the measured data. Two cases are shown: one using a Zernike polynomial representation of the main dish and the other using the full holography maps. The principle difference between these two surface representations is that the full holography maps capture the higher order spatial characteristics of the distortion. Even though there is a significant gain difference between the Zernike polynomials and the full holography there is only a very modest improvement in the array feed performance. This indicates that the higher-order distortions in the full holography maps versus the Zernike polynomial description cannot be compensated by the array feed. The computed vs. measured results for the DFP compensation is shown in Figure 6. Both the computed and measured results represent the difference between the DFP in the flat (uncompensated) and flexed (compensated) mode. Since the derivation of the shape of the DFP used only the Zernike polynomial representation of the main-dish distortion, only small differences should be expected between calculated results with either surface representation. The computed vs. measured results for the combined DFP/AFCS are shown in Figure 7. There are several curves shown on the figure. The solid curve is the measured baseline efficiency. The calculated results for the combined DFP/AFCS are shown in circles. The measured performance of the combined DFP/AFCS system is shown but only data for lower elevation angles was obtained. Observe that the measured and calculated values agree to within a few percent.

References

[1] P. Richter, M. Franco and David Rochblatt, "Data Analysis and Results of the Ka-band Array Feed Compensation System / Deformable Flat Plate Experiment at DSS-14", TMO Progress Report 42-139 July to December 1999, Jet Propulsion Laboratory, Pasadena California, November 15, 1999

[2] V. Vilnrotter and D. Fort, "Demonstration and Evaluation of the Ka-band Array Feed Compensation System on the 70-meter Antenna at DSS-14", TMO Progress Report 42-139 July to December 1999, Jet Propulsion Laboratory, Pasadena California, November 15, 1999

[3] D. J. Rochblatt, D. J. Hoppe, W. A. Imbriale, M. Franco, P. H. Richter, P. M. Withington, H. J. Jackson, "A Methodology For The Open Loop Calibration Of A Deformable Flat Plate On a 70-Meter Antenna", AP2000 Millennium Conference on Antennas and Propagation, Davos, Switzerland, April 2000.

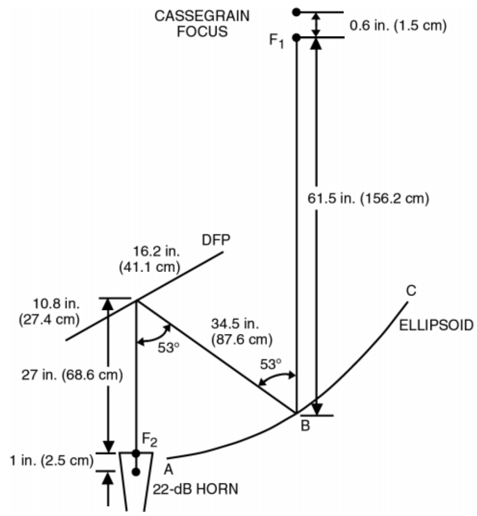

Fig. 1. Geometry.

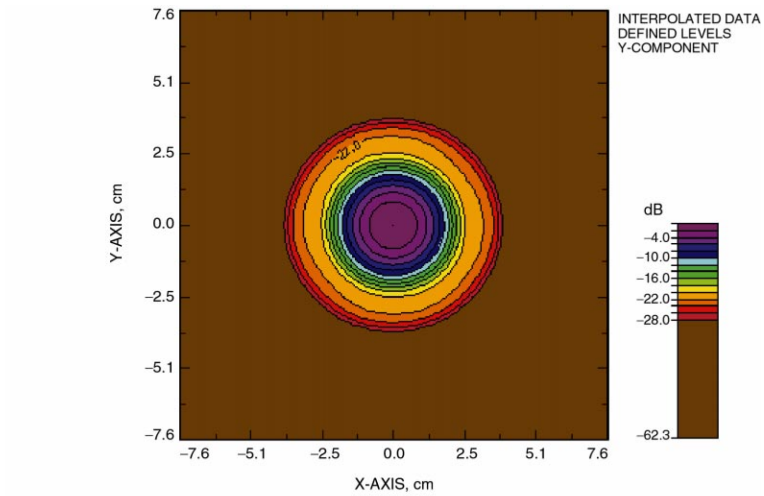

Fig. 2. Focal plane distribution of the undistorted dual reflector system.

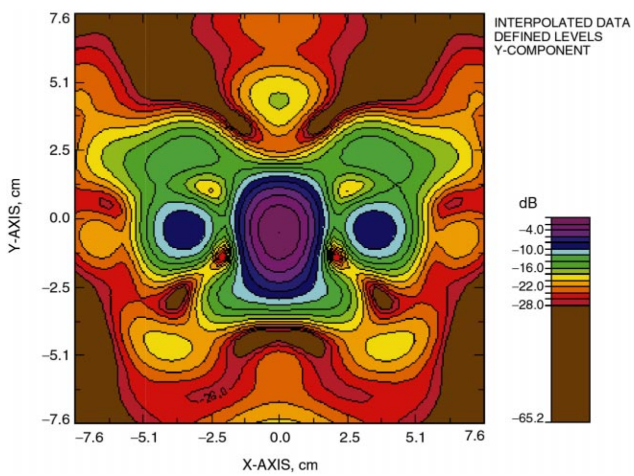

Fig. 3. Focal plane distribution of the dual reflector system, 85 degree elevation.

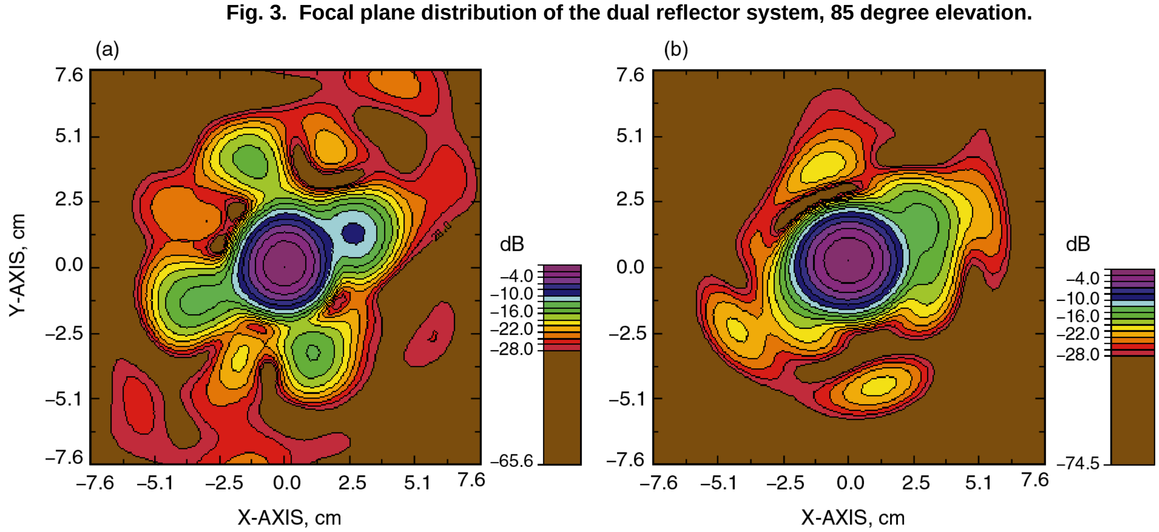

Fig. 4. Focal plane distribution at F_2, elevation = 45 deg (interpolated data, defined levels, y-component): (a) actual plate and (b) smoothed perfect plate.

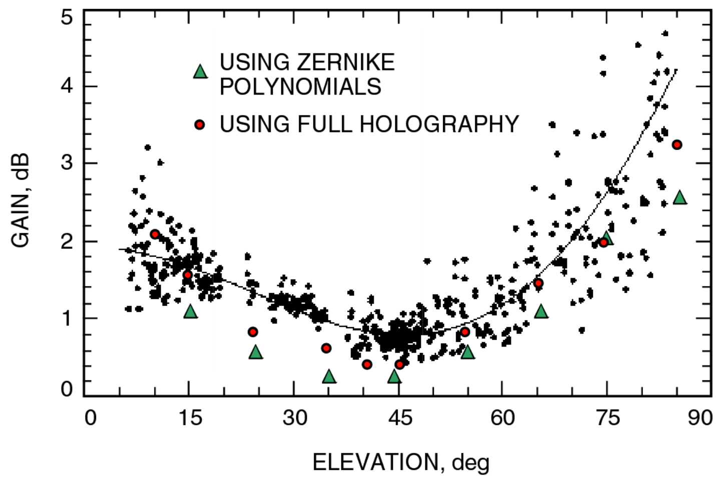

Fig. 5. Predicted and measured AFCS compensation.

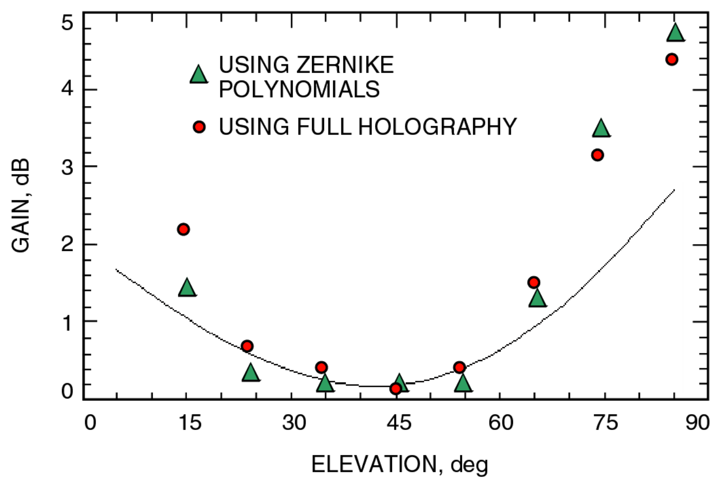

Fig. 6. Predicted and measured DFP compensation (actual plate).

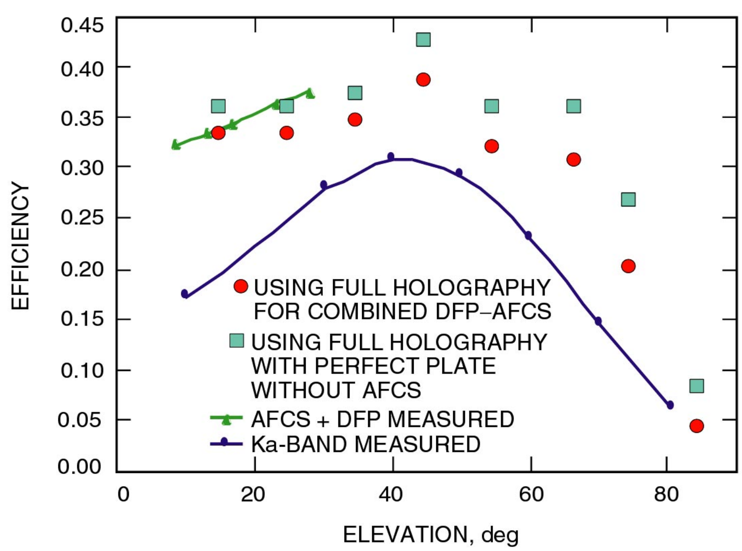

Fig. 7. Predicted and measured compensation with the combined DFP-AFCS (70-m antenna efficiency at Ka-band).