64-m Antenna Automatic Subreflector Focusing Controller

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Defocussing of the radio frequency beam arises from gravity-induced structural deformations as the antenna rotates about the elevation axis. The new Subreflector Controller generates the axial (z) and lateral (y) offset corrections necessary to move the subreflector, thus minimizing the gain losses due to this defocussing. This article discusses the technique used to determine these offset errors and presents a description of the new Subreflector Controller.

I. Introduction

With the progressive needs to communicate with farther depths of space comes the increased need to improve the efficiency of the existing NASA - JPL Deep Space Network (DSN) ground antennas. The DSN, incorporating both mechanical and microwave engineering efforts, has initiated this task, with a main goal to increase the large antenna (64-m diameter) network performance by approximately 1.9 dB at X-band.

Some of the modifications being developed include the following:

(1) Fabrication of precise main and subreflector surfaces (0.5 dB)

(2) The use of optimally shaped single or dual reflectors (0.3 dB)

(3) The extension of the main reflector diameter to 70 m (0.8 dB) with several structural and optical pointing changes (0.1 dB)

(4) The subreflector focusing automation and upgrade (0.2 dB) described in this report

The present 64-m antenna subreflector consists of a 6.4-m (21-ft) diameter, asymmetrical, hyperboloidal surface with a moveable vertex plate, a 0.3-m (1-ft) high solid skirt attached at a fixed tilt angle about the perimeter of the hyperboloid, a hub, a backup space frame structure, and four independently adjusted motion mechanisms comprising electric motors and jack screws. The four subreflector motion (focusing) mechanisms are located to allow linear travel along the x- (cross elevation), y- (elevation), and z- (axial or microwave beam) axes in addition to rotational travel to select any of several feed horns for use. These focus adjustments permit the subreflector to optimize the radio frequency (RF) alignment and maximize gain for any one of the five feed positions on the tricone assembly. Defocussing of the RF beam arises from gravity-induced structural deformations as the antenna rotates about the elevation axis. The subreflector controller generates the corrective signals which move the subreflector to minimize the gain loss due to defocussing. The axial (z) and y-axes corrections are automated, while any X-axis corrections (minor) can be adjusted manually, if needed.

This report discusses the technique used to determine the focusing offsets or Δy and Δz corrections necessary to reduce gain losses due to gravity-induced structural deformations.

Also included is a description of the new subreflector controller designed to enforce these corrections. Operating instructions, theory of operation, and associated software for the SRC belong in an operation and maintenance manual (in preparation).

II. Focus Offsets

The surface panels of the 64-m antenna main reflector are initially set to represent ideal cassegrain conditions when the antenna is oriented at an elevation angle of 45 degrees (where most tracking occurs). As the antenna rotates about the elevation axis, gravity distortions are introduced due to changes in the direction of the gravity force vectors with respect to the antenna symmetric (z) axis (Ref. 1). Structure deformations contribute to a reduced RF performance since these displace the focus as demonstrated in Fig. 1 and increase antenna gain losses.

Displacements of the focus in axial (z) and lateral (y) directions have major effects on gain loss because they correspond to the focus of the best-fit paraboloid and the virtual secondary focus of the hyperboloid. These offsets can be compensated for using the new subreflector controller which automatically generates the correct signals to move the subreflector in both the axial and y directions.

A series of tests on the large antenna at DSS 14 were run to determine the optimum subreflector z-axis focus position vs the elevation angle. These tests consisted of a series of conical scanning (CONSCAN) boresight and subreflector focus measurements using an astronomical radio source. A polynomial least squares curve fit was applied with a correction function of the form

$$\Delta z = A + BX + CX^2 + DX^3 \qquad (1)$$

where Δz is the Z-axis focus offset and X is the elevation angle complement. The constants are found as follows: A = 14.2 mm (0.560 in.), B = -0.068 mm/deg (-0.00271 in./deg), C = -0.0069 mm/deg (-0.000275 in./deg), D = 0.000033 mm/deg (0.0000013 in./deg) and X is (90-E) where E is the elevation angle in degrees. This polynomial provided the required correction of the subreflector Z- position, plotted as shown in Fig. 2. A maximum correction of about 25 mm (1 in.) is needed therefore at $E = 0$ (horizon position).

The y-axis focus offset (Δy) was determined analytically using the NASTRAN structural analysis computer program. The results included the offset of the best-fit paraboloid focus from the virtual focus of the hyperboloid (relative to setting elevation angle of 45 degrees). After curve-fitting, a y-axis correction equation is obtained as

$$\Delta y = 3.41 \left[\sqrt{2} \cos E - 1\right] \qquad (2)$$

where Δy is the y-axis focus offset in inches. Equation (2) is plotted as shown in Fig. 2. At extreme elevation angles (90°) the y-axis offset can reach approximately 100 mm (4 in.).

After determining the Δy and Δz offsets, the Radiation Pattern Computer program (Ref. 2) was used to determine the expected gain losses that would result without subreflector corrections. As an example, Fig. 3 shows a plot of the gain loss given as its equivalent surface distortion (in mm) vs focus offsets for 8.45 GHz.

The new subreflector Controller software incorporates Eqs. (1) and (2) and is described in detail below.

III. Controller Description

The subreflector axial (z) and y positioning are controlled by a closed loop as shown by the block diagram in Fig. 4. The loop is closed using the subreflector axial (or y) synchro position encoder as the feedback element.

The Subreflector Controller (SRC) and Interface are sketched in Fig. 5. The SRC receives the antenna elevation position data from the Antenna Servo Controller (ASC) at a rate of one sample per second. The ASC transmits this data to the SRC through the 534 Serial Communications Board. The maximum elevation the antenna is able to change is 0.25 deg/s. The antenna elevation angle is used as an index into a look-up table stored in the memory of the SRC where the subreflector offset values are located (as defined by Eqs. [1] and [2]). The actual subreflector position is read from the X, Y, and Z position synchros on the subreflector and entered into the SRC through synchro-to-digital converter (12-bit). If the actual position of the subreflector is not within 1.27 mm (0.050 in.) of the desired position, then a rate command will be generated through the 12-bit digital/analog converter (D/A), which will engage the motor drives of the subreflector at a fixed rate. Once the motor drives start, they will continue to move the subreflector until it has reached its desired position. At that time all commands to the subreflector motor drives will stop. The final position will be displayed on the SRC.

IV. Positional Accuracy

The new SRC must be capable of meeting the existing positional accuracy requirements summarized in Table 1. Positional accuracy of the 64-m antenna subreflector is based on these capabilities and the calculated value of offset, due to gravity deformations. The calculated offset values reside in a look-up table which is part of the SRC software. Axial (z) offsets are calculated at 0.088-degree elevation angle intervals and lateral (y) offsets at 0.022-degree elevation angle intervals with an error tolerance of 0.25 mm (0.010 in.). The actual accuracy for z-axis and y-axis positioning was chosen to be ±1.25 mm (±0.050 in.), thus providing a limiting 0.5 dB gain loss. The "deadband" tolerance is wide compared to the positioning accuracy, and once the subreflector stops, it would take several seconds for the elevation angle change to require another subreflector position adjustment.

V. Summary

The Subreflector Controller (SRC) provides a method for correcting error offsets of the RF beam due to gravity-induced structural deformations. The SRC unit has been designed and tested at DSS 14, demonstrating the potential for increased large antenna performance.

References

1. Katow, M. S., "34-meter Antenna-Subreflector Translations to Maximize RF Gain," *TDA Progress Report 42-62*, Jet Propulsion Laboratory, Pasadena, California, January and February 1981, pp. 112-120.
2. Guiar, C. N., and Hughes, R. D., "NASA Tech. Brief on JPL Antenna Radiation Pattern Computer Program (ANRAD)," 1983.

Table 1. Performance capabilities of the subreflector and antenna drive electronics

Parameter	Y Axis	Z Axis
Maximum Axis Travel, mm (in.)	152.4 (6)	203.2 (8)
Maximum Rate of Travel, mm/s (in./s)	0.20 (0.008)	1.27 (0.050)
Maximum Error for 0.05 dB Gain Loss, mm (in.)	2.54 (0.100)	1.27 (0.050)
Maximum Movement/Degree Elevation, mm (in.)	20.3 (0.80)	5.60 (0.22)
Maximum Required Tracking Rate, mm/s (in./s)	0.50 (0.020)	0.15 (0.006)
Maximum Position Resolution, mm (in.)	0.062 (0.00244)	0.062 (0.00244)

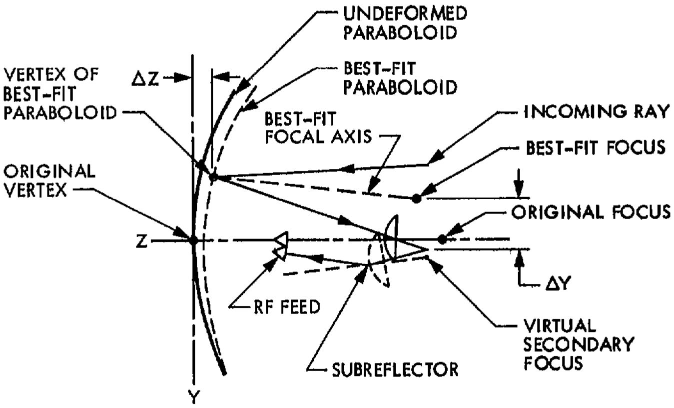

Fig. 1. RF center ray tracing and hyperboloid offsets with gravity distortions

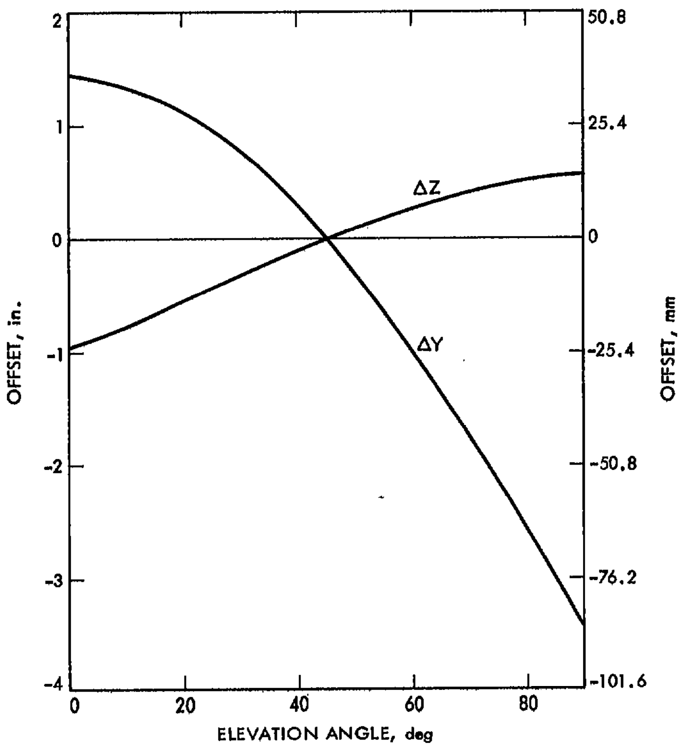

Fig. 2. Focus offset vs elevation angle

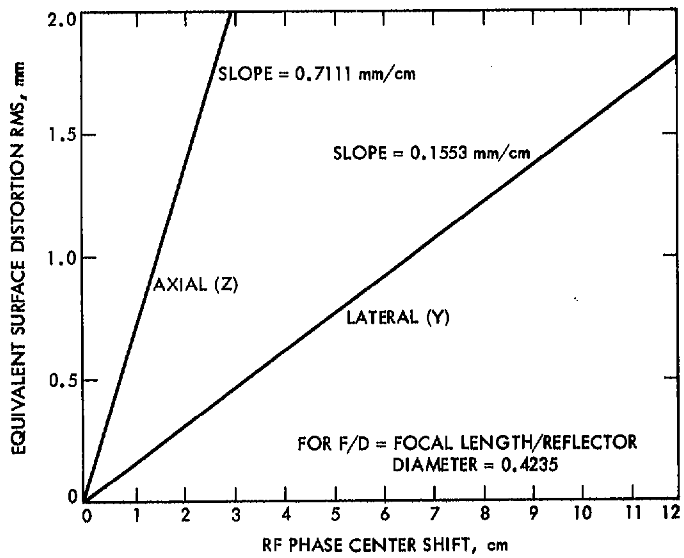

Fig. 3. Gain loss (Ruze equivalent surface distortion RMS) vs focus offsets for 64-m antenna at X-band

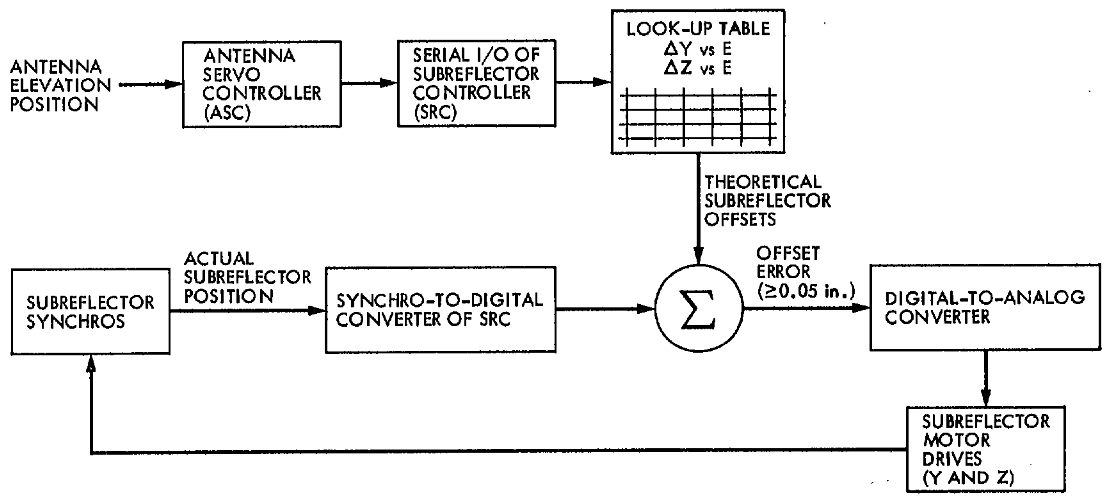

Fig. 4. Subreflector position servo block diagram

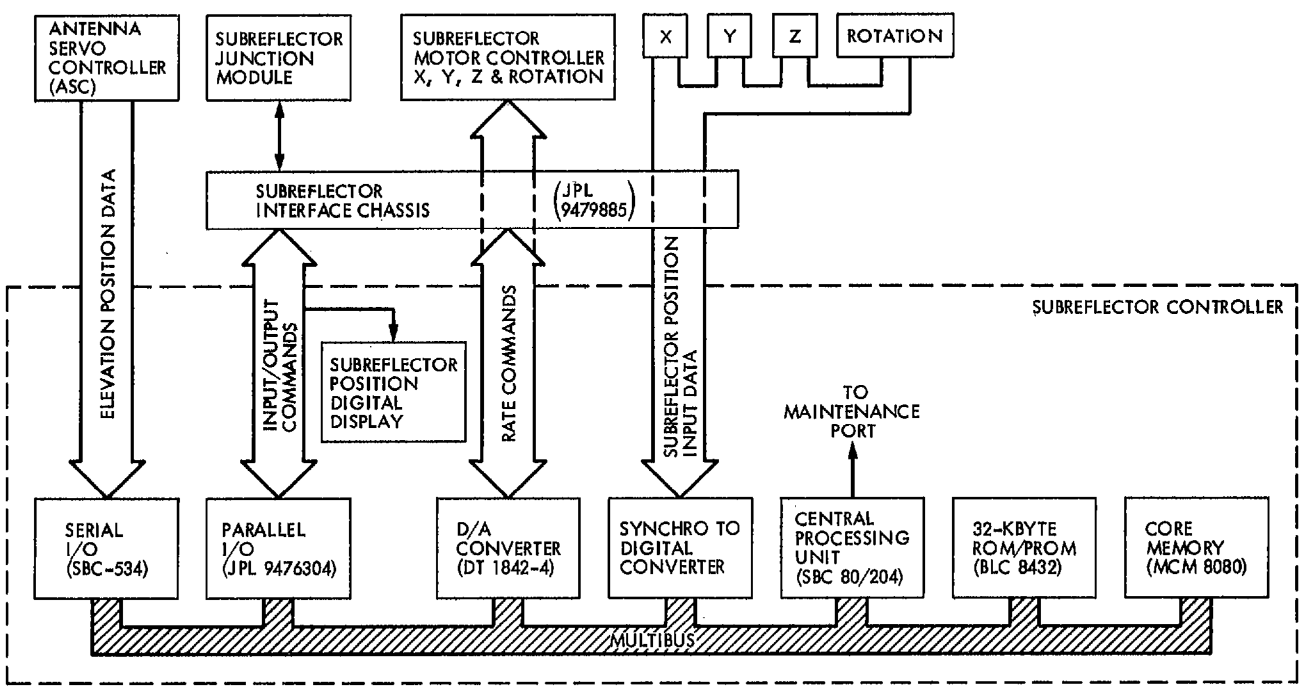

Fig. 5. Subreflector controller (SRC) and interface block diagram