70-meter Deep Space Network Antenna Upgrade Performance

D. A. Bathker, A. G. Cha, D. J. Rochblatt, B. L. Seidel, and S. D. Slobin
Jet Propulsion Laboratory, California Institute of Technology
Pasadena, California 91109

The three major antennas of the NASA/JPL/Deep Space Network have been substantially modified for improved microwave performance. The original 64m quadric-profiled Cassegrains were extended to 70m, with shaped dual-reflector profiles for uniform illumination, as well as improved manufacturing and setting accuracies for the reflecting surfaces. Field work began in August 1986 and was completed by August 1988. The Project goals, based on predesign estimates, were +1.4 dB gain increase at S-band (2285 MHz) and +1.9 dB gain increase at X-band (8420 MHz), with no degradation in critically low receive system noise levels.

As shown in Table 1, detailed design expectations are 75.8% aperture efficiency at S-band and 71.1% at X-band. Estimated minimum-likely aperture efficiencies were derived by considering uncertainties in various design factors. The estimated minimum likely efficiencies are 0.749 and 0.688 for the two frequency bands, respectively. Maximum efficiencies possible are 0.765 for each frequency band, for the hypothetical case of perfect beam pointing, perfect surface tolerance, and in the case of the X-band, with future elimination of a minor feedhorn anomaly. The 0.765 maximum possible efficiency is considered a useful index with which to judge the design, consisting of the very-low-noise X-band optimization, and the centerline symmetric main reflector with offset (tricone) feeding. Offset Cassegrain feeding necessitates an asymmetrical (not a figure of revolution) shaped subreflector for axial system pointing. Additionally, the X-band is required to pass through a dichroic-pass filter, while simultaneous S-band is achieved via a system of four reflectors. The overall optics design is conservatively optimized for X-band, for a conceivable future total system operating noise level of 15 kelvin at 30° elevation.

In contrast to the detail design expectation of 0.749 to 0.758 aperture efficiency at S-band, the measurements show that 0.756 ($\pm$0.008) was achieved. Compared with previous 64m performance, 1.91 dB improvement was obtained at S-band.

In contrast to the design expectation of 0.688 to 0.711 aperture efficiency at X-band, the three antenna measurements show 0.687 ($\pm$0.015). The simple average of the three measurements coincidentally agrees closely with the estimated minimum likely value. Compared with previous 64m performance, an average of 2.13 dB improvement at X-band was obtained. Figure 1 shows the measured X-band 70m gain performance for the three antennas, together with the nominal design expectation.

The absolute accuracy of these aperture efficiency measurements is dominated by uncertainties surrounding the absolute flux density from natural radio source calibrators. The primary calibrator values used by JPL/DSN in evaluation of aperture efficiency are listed below:

Frequency, MHz	3C274 Flux, Jansky	Source Resolution Correction Factor (70m Antenna)	70m Beamwidth, degrees	Flux Accuracy, +/-3σ, dB	Measurement Accuracy, +/-3σ, dB
2295	138.5	1.205	0.108	0.22	0.28
8420	45.20	1.18	0.030	0.40	0.44

In addition to the large improvement in aperture efficiency, somewhat lower total system operating noise levels were obtained. Approximately 1.5 and 0.7 kelvin improvements at S- and X-bands, respectively, were obtained. The best measurements at S-band show 18.3 kelvin total at zenith and about 21 kelvin total at 30° elevation. At X-band, all three antennas are quite uniform at 20.9 kelvin ($\pm$0.3 kelvin) at zenith and about 25.5 kelvin at 30° elevation. Figure 2 shows system noise levels with elevation angle. The two upper curves are total operating system noise levels (with atmosphere), while the lower curves have the nominally clear-dry atmosphere numerically removed. The lower curves are indicative of acceptably small antenna spillover and scattering noise components.

A very important element of this Project was application of the microwave holographic technique.[1] Holographic imaging was achieved by use of 12-GHz band geostationary satellite beacon signals providing approximately 75-dB SNR on beam peak, with over 40 dB SNR in the reference channel. Imaging was used for adjustment of the nearly 1300 individual reflector panels on each antenna. Additionally, holographic imaging provided data on quantifying the aperture illumination uniformity, the blockage and diffraction phenomena, the rotating subreflector alignment quality, gravity loading, and excellent estimates of the achieved surface tolerance following adjustment. At high lateral resolution (0.42m), the surface tolerance achievable, presuming infinite ability to adjust, is found to be 0.3mm rms. This is essentially the panel manufacturing precision, together with a holography data system noise component. It is believed that the achievable surface tolerance is about 0.4mm rms for these antennas. Due to time constraints, the goal was to meet only the Project specification, which was 0.65mm rms at 0.42m resolution. Effectively, surface adjustments were not refined for the last available 0.1 dB at X-band, although data is in hand which may enable this to be achieved in the future.

The finite lateral resolution of 0.42m provides averaging of the true rms surface tolerance over each visibility cell. The 0.65mm indications obtained on all three 70m antennas translates to an estimated effective rms of 0.70mm. (All rms values quoted herein are in surface-normal measure, not axial nor pathlength rms measure.)

[1]Microwave holographic imaging was provided by Eikontech, Ltd., Sheffield, U.K.

In summary, the three DSN 64-meter antennas have been substantially modified to high-efficiency 70m antennas. The measured S-band aperture efficiency is over 75 percent and the X-band average is nearly 70 percent. At X-band, approximately 0.2 dB (about 3 additional efficiency percents) can be obtained in post-Project refinement activity. The 75/70 percent measurements are in very close agreement with detailed engineering expectations. High-resolution microwave holography was successfully applied, primarily to meet vital Project schedule constraints. The holography assisted in assuring a quick and adequate surface alignment, and provided very important microwave performance checks and quantifications.

ACKNOWLEDGMENT

The research described in this publication was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

Table 1. Design-Expected S-/X-Band 70m Efficiency Performances

Item	S-Band	X-Band	Note
Rear Spillover	0.994	0.997	
Forward Spillover	0.959	0.964	
Illumination Ampl.	0.959	0.982	Standard Feedhorn
Illumination Phase	0.994	0.989	
Cross Polarization	1.00	~1.00	
$M \neq 1$ Modes	0.980	0.996	
Central Blockage	0.983	0.988	
Quadripod Blockage	0.9008	0.9008	5.1% Effective
Dichroic Reflectivity	0.9993	--	Below Plane Reflector
Surface Reflectivities	0.998 (4)	0.998 (2)	
Surface Tolerances	0.9946 (4)	0.9527 (2)	
Pointing Squint	0.996	1.000	X-Band Beam Peaked
Waveguide Dissipation	0.9795	0.984	
Waveguide VSWR	0.9908	0.9908	
Dichroic VSWR	--	0.990	
Compromise Feedhorn	--	0.975	Stovepipe Extension
TOTAL	0.758 (+63.28 dBi at 2285 MHz)	0.711 (+74.34 dBi at 8420 MHz)	

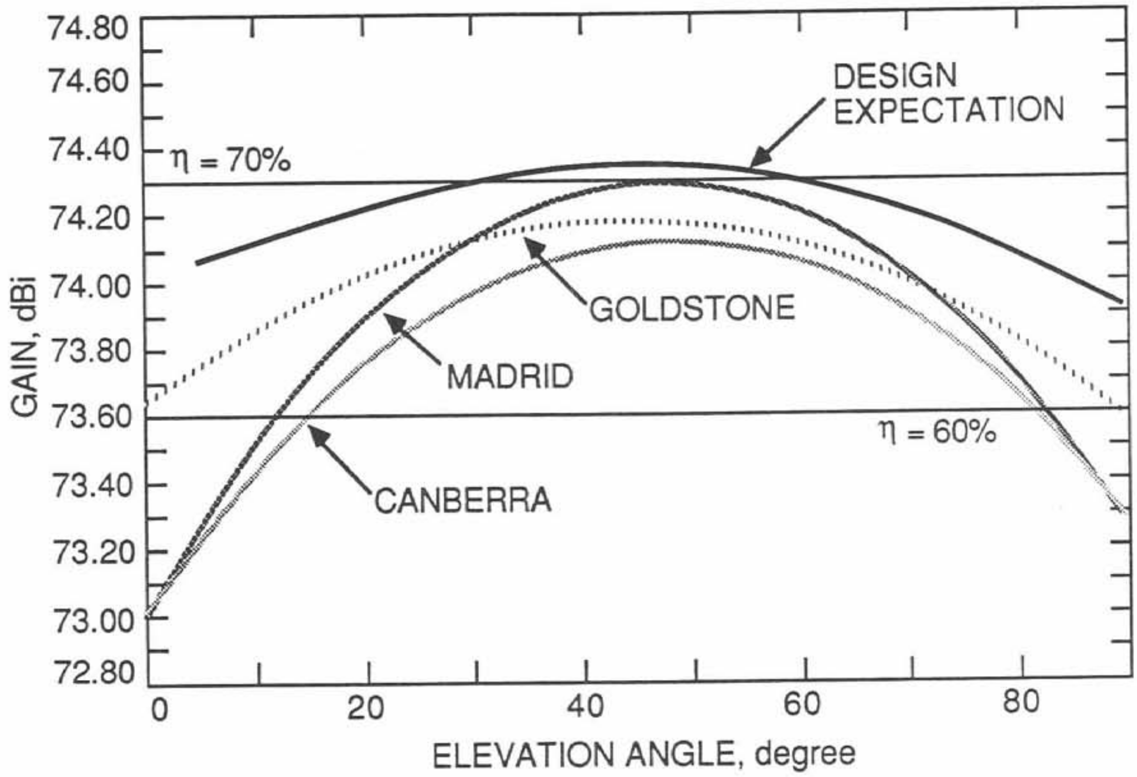

Figure 1. X-band measured gain performance for DSN 70m antennas.

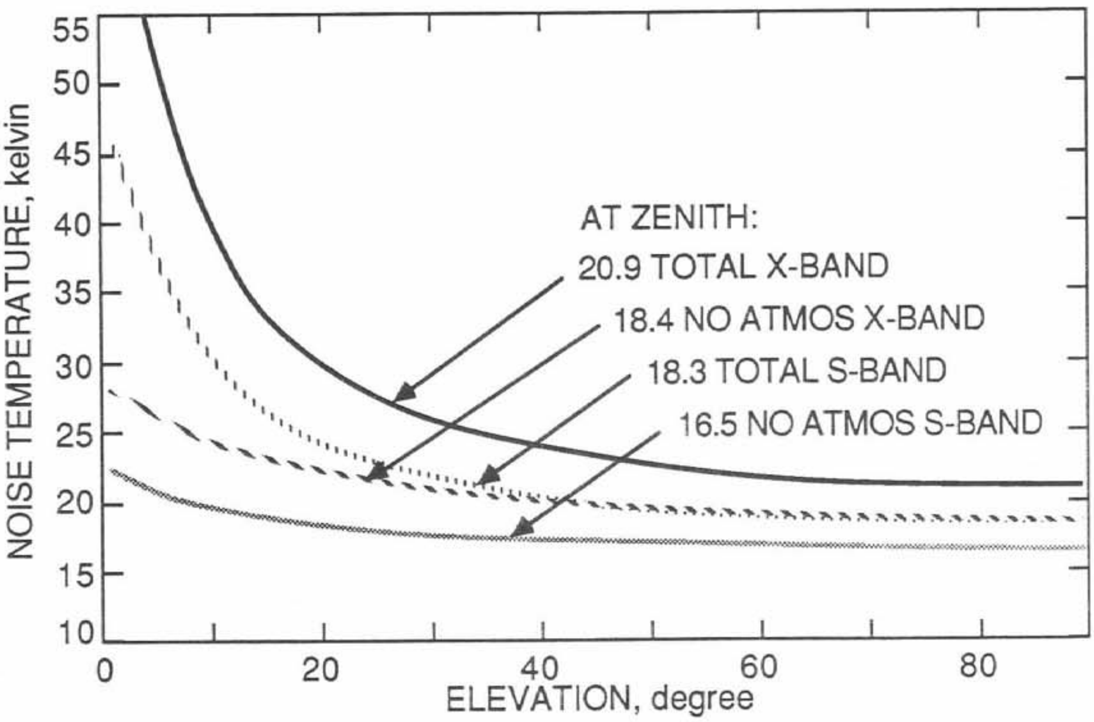

Figure 2. 70m antenna system noise levels.