Deep Space Network

103
34-m HEF Subnet Telecommunications Interface

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Review Acknowledgment

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Document Change Log

Rev	Issue Date	Prepared By	Affected Sections or pages	Change Summary
Initial	11/30/2000	Stephen Slobin Robert Sniffin	All	New Module
A	04/02/2007	Stephen Slobin Robert Sniffin	ALL	Documents installation of a 200 W S-band uplink at DSS-45 and DSS-65. Revised *TAMW* formulation for noise temperature to be consistent with Rev. B of module 105.
B	09/19/2008	Stephen Slobin Robert Sniffin	2. Table 1 & 2	Provides measured performance of S-band uplink at DSS 45 and DSS 65 and editorial changes.
C	08/01/2014	Stephen Slobin	Table 1 Table 3 Table 4 Table 5 Table A-3 Figure 1a Figure 1b Figure 7	Updated to include DSS-15 S-band transmitter. New DSS-15 Tamw for X-band dual-HEMT feed. New DSS-15/45/65 Tamw for low-gain mode. New wind-effect gain model. New Tamw and Top for DSS-15/45/65 X-band. New T1, T2, a for DSS-15/45/65 X-band. New for DSS-15. Re-numbered to include DSS-45/65 only. New noise temperatures for DSS-15 X-band.
D	08/03/2023	Stephen Slobin Christine Chang	Sections 1 and 2 Tables 1, 2, 3, 5 A-1, A-3 Old Figures 3, 4 7, 8 New Figures 3-7	DSS-15 and DSS-45 decommissioned. Parameters shown only for DSS-65. Gain and noise temperature for DSS-15 and DSS-45 shown as N/A. Removed Renumbered

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1 Introduction

1.1 Purpose

This module provides the performance parameters for the Deep Space Network (DSN) High-efficiency (HEF) 34-meter antennas that are necessary to perform the nominal design of a telecommunications link. It also summarizes the capabilities of these antennas for mission planning purposes and for comparison with other ground station antennas. As of the issue date of this module, only DSS-65 (Madrid) is operational. DSS-15 (Goldstone) and DSS-45 (Canberra) have been decommissioned, but the antennas still exist at their original locations. Some information about the decommissioned antennas has been retained in this module, for historical/archive purposes. As such, in the Tables where different Values are shown for the different antennas, the values for DSS-15 and DSS-45 are given as "N/A", but the Parameter and Remarks columns have been retained.

In the future, when/if DSS-15 and DSS-45 are reactivated, their configurations are very likely to be slightly different than shown in the block diagrams (Figures 1a and 1b). It is likely that all HEF antennas will end up having two X-band HEMTs, one for RCP and one for LCP, as shown in the block diagram for DSS-15.

1.2 Scope

The scope of this module is limited to providing those parameters that characterize the RF performance of the 34-meter HEF antennas. The parameters do not include effects of weather, such as reduction of system gain and increase in system noise temperature that are common to all antenna types. These are discussed in module 105, Atmospheric and Environmental Effects. This module also does not discuss mechanical restrictions on antenna performance that are covered in module 302, Antenna Positioning, or the effects of terrain masking that are covered in Module 301, Coverage and Geometry.

2 General Information

The DSN 34-m Antenna HEF Subnet contains three 34-meter diameter high-efficiency antennas. Only DSS-65 (Madrid) is still operational. Information about the equipment and configurations of the decommissioned antennas is retained in this section for historical purposes. These antennas employ an elevation over azimuth (AZ-EL) axis configuration, a single dual-frequency feedhorn, and a dual-shaped reflector design. Although this subnet is referred to as the High-Efficiency Subnet, the efficiency of the antennas is approximately the same as all other DSN antennas. The subnet was constructed when a subnet of lower-efficiency antennas (34m HA-DEC and 26m X-Y) was in existence, and the name has been retained. One antenna (DSS-15) is located at Goldstone, California; one (DSS-45) near Canberra, Australia; and one (DSS-65) near Madrid, Spain. The precise station locations are shown in Module 301, Coverage and Geometry.

Block diagrams of the 34-meter HEF microwave and transmitter equipment are shown in Figures 1a (DSS-15) and 1b (DSS-45 and DSS-65). Most of the microwave and transmitter equipment has been removed from DSS-15 and DSS-45. DSS-15 contained dual X-band HEMTs (one for RCP and one for LCP), while DSS-45 contained the older X-band maser and X-band HEMT configuration, with RCP and LCP, non-diplexed and diplexed, available for each low-noise amplifier (LNA). DSS-65 presently has a configuration identical to what existed at DSS-45. Additionally, DSS-65 offers a low-gain mode (−20 dB) for use at high received signal power levels for spacecraft near the Earth. DSS-65 has an orthomode junction for X-band that permits simultaneous RCP and LCP operation, although one polarization is in the non-diplexed mode and the other is in the higher-noise diplexed mode. DSS-15 was considered to be always-diplexed at X-band because it had a diplexing junction, and no lower-noise configuration was available. For X-band listen-only operation at DSS-65, or when transmitting and receiving on opposite polarizations, the low-noise path (orthomode upper arm) is used for reception. If the spacecraft receives and transmits simultaneously with the same polarization, the diplexed path must be used and the noise temperature will be higher. A waveguide labyrinth is used to couple S-band signals into and out of the feed. This would provide simultaneous RCP and LCP reception, although the presence of only one S-band low noise amplifier and receiver channel limits the use to selectable RCP or LCP. At DSS-65, the S-band polarization selection switch is used to implement a diplexed signal path in addition to the (non-simultaneous) non-diplexed, low-noise signal path. Either polarization can be low-noise or diplexed.

A 20 kW X-band transmitter is available at DSS-65. There is also a 250 W S-band transmitter intended for near-earth spacecraft support as an alternative to the beam waveguide (BWG) antennas DSS-24, -26, -34, -36, -54, and -56 described in module 104. The 250 W S-band transmitters at DSS-15 and DSS-45 have been removed and installed in the -6 BWG antennas, although they are still shown in the block diagrams for those antennas (Figures 1a and 1b). In addition to spacecraft tracking, the DSN 34-m antenna subnet is also used for very-long baseline interferometry and radio-source catalog maintenance.

2.1 Telecommunications Parameters

The significant parameters of the DSS-65 34-meter HEF antenna that influence telecommunications link design are listed in Tables 1, 2, and 3. Variations in these parameters that are inherent in the design of the antennas are discussed below. Other factors that degrade link performance are discussed in modules 105 (Atmospheric and Environmental Effects) and 106 (Solar Corona and Wind Effects). Values for DSS-15 and DSS-45 are shown as N/A, to indicate that those antennas have been decommissioned.

2.1.1 Antenna Gain Variation

The antenna gains in Tables 1, 2, and 3 do not include the effect of atmospheric attenuation and should be regarded as vacuum gain at the specified reference point.

2.1.1.1 *Frequency Effects*

Antenna gains are specified at the indicated frequency (f_0). For operation at higher frequencies in the same band, the gain (dBi) must be increased by 20 log (f/f_0). For operation at lower frequencies in the same band, the gain must be reduced by 20 log (f/f_0).

2.1.1.2 *Elevation Angle Effects*

Structural deformation causes a reduction in gain whenever the antenna is operated at an elevation angle other than the angle where the reflector panels were aligned. The effective gain of the antenna is also reduced by atmospheric attenuation, which is a function of elevation. Figures 2 and 3 show the estimated DSS-65 gain versus elevation angle for the hypothetical vacuum condition (structural deformation only) and with 0%, 50%, and 90% weather conditions, designated as CD (cumulative distribution) = 0.00, 0.50, and 0.90. A CD of 0.00 (0%) means the minimum weather effect (exceeded 100% of the time). A CD of 0.90 (90%) means that effect which is exceeded only 10% of the time. Qualitatively, a CD of 0.00 corresponds to the driest condition of the atmosphere; a CD of 0.50 corresponds to humid or very light clouds; and 0.90 corresponds to very cloudy, but with no rain. A CD of 0.25 corresponds to average clear weather and often is used when comparing gains of different antennas. Comprehensive S-band and X-band weather effects models (for weather conditions up to 99% cumulative distribution) are provided in module 105 for detailed design control table use. Equations and parameters for the curves in Figures 2 through 5 are provided in Appendix A.

Figure 2 depicts the S-band (2295 MHz) net gain for DSS-65 as a function of elevation angle and weather condition, including the vacuum condition. Net gain means vacuum-condition gain as reduced by atmosphere attenuation. Figure 3 presents the X-band (8420 MHz) net gain for DSS-65. All gains are referred to the feedhorn aperture, and the equations and parameters of these curves are given in Appendix A. The models use a flat-Earth, horizontally stratified atmosphere approximation.

It should be noted in Appendix A, Table A-1, that the gain parameters do not vary for different configurations (e.g., LNA-1 non-diplexed vs. LNA-1 diplexed), as they do in Table A-3 for the noise temperature parameters. This is due to the fact that the gain is referenced to the feedhorn aperture, and configurations "downstream" (e.g., orthomode and diplexer paths) do not affect the value of gain at the aperture. When G and T are referenced to the LNA input, both the G and T parameters vary with antenna configuration. When referenced to the feedhorn aperture, only T varies with configuration. The observed differences in antenna G/T are attributed only to different values of noise temperature, because G and T are both referenced to the feedhorn aperture.

2.1.1.3 *Wind Loading*

The gain reduction at X-band due to wind loading is listed in Table 4. The tabular data are for structural deformation only and presume that the antenna is maintained on-point by conical scan (CONSCAN, discussed in module 302) or an equivalent process. In addition to structural deformation, wind introduces a pointing error that is related to the antenna elevation angle, the angle between the antenna and the wind, and the wind speed. The effects of pointing error are discussed below. Cumulative probability distributions of wind velocity at Goldstone are given in module 105.

2.1.2 System Noise Temperature Variation

The operating system temperature (T_{op}) varies as a function of elevation angle due to changes in the path length through the atmosphere and ground noise received by the sidelobe pattern of the antenna. Figures 4 and 5 show the combined effects of these factors at S- and X-bands for DSS-65 in a hypothetical vacuum (no atmosphere) and no cosmic noise condition (T_{sky} = 0, see Appendix A.2), for non-diplexed antenna configurations, and with the three weather conditions described above. The equations and parameters for these curves are provided in Appendix A of this module. The models use a flat-Earth, horizontally stratified atmosphere approximation.

The system operating noise temperature, T_{op}, consists of two parts, an *antenna-microwave component,* T_{AMW}, for the contribution of the antenna and microwave hardware only, and a *sky component*, T_{sky}, that consists of the atmosphere noise plus the cosmic microwave background noise attenuated by the atmosphere loss. T_{AMW} is shown in Figures 4 and 5 as "ANT-UWV". The system operating noise temperature is given by

$$T_{op}(\theta) = T_{AMW} + T_{sky} = \left[T_1 + T_2 e^{-a\theta}\right] + \left[T_{atm}(\theta) + T'_{CMB}(\theta)\right]$$

where

$T_{sky} = T_{atm}(\theta) + T'_{CMB}(\theta)$

T_1, T_2 and a are coefficients and exponent given in Appendix A, Table A-3

T_{atm} is the atmosphere contribution term, calculated from Module 105

T'_{CMB} is the attenuated cosmic contribution, calculated from Module 105

More details of this calculation are given in Appendix A of this module.

Figure 4 shows the S-band (2295 MHz) system noise temperature curves for DSS-65, LNA-1 (HEMT), non-diplexed, referenced to the feedhorn aperture. The DSS-65 X-band (8420 MHz) system temperature referenced to the feedhorn aperture is shown in Figure 5, for LNA-1, RCP HEMT, non-diplexed. The diplexed configuration higher noise temperatures can be calculated using the parameters given in Appendix A.

The T_{AMW} noise temperature values in Table 3 are stated with reference to the feedhorn aperture and arise from antenna and microwave hardware contribution only. No atmosphere or cosmic background contribution is included. Table 5 presents values for DSS-65 in all configurations at zenith, with average-clear CD = 0.25 weather. The values of T_{AMW}, T_{sky}, and T_{op} in Table 5 are calculated by methods presented in Module 105 using year-average attenuation values in Tables 10–15 of that module.

When two low-noise amplifiers (LNAs) are available for use, as at X-band, the amplifier in the lowest noise configuration is designated as LNA-1. Under some conditions, LNA-2 may be used, and the higher noise temperature values apply.

2.1.3 Pointing Accuracy

Figures 6 and 7 show the effects of pointing error on effective transmit and receive gain of the antenna. These curves are Gaussian beam-shape approximations based on measured and predicted antenna beamwidths. Data have been normalized to eliminate elevation and wind-loading effects. The equations used to derive the curves are provided in Appendix A.

Table 1. S-Band Transmit Characteristics, DSS-65

Parameter	Value	Remarks
ANTENNA		
Gain at 2070 MHz (near-earth)	55.40 ±0.2 dBi	At elevation angle of peak gain, referenced to feedhorn aperture for matched polarization; no atmosphere included
Transmitter Waveguide Loss	0.6 ±0.1 dB	250 W transmitter output terminal (waterload switch) to feedhorn aperture
Half-Power Beamwidth	0.258 ±0.004 deg	Angular width (2-sided) between half-power points at specified frequency
Polarization	RCP or LCP	Remotely selected.
Ellipticity	1.0 dB (max)	Peak-to-peak axial ratio defined as the ratio of peak-to-trough received voltages with a rotating linearly polarized source and the feed configured as a circularly (elliptically) polarized receiving antenna
Pointing Loss		
Angular	See module 302	See also Figure 6
CONSCAN	0.03 dB	At S-band, using X-band CONSCAN reference set for 0.1 dB loss
	0.1 dB	At S-band, using S-band CONSCAN reference set for 0.1 dB loss
EXCITER AND TRANSMITTER		
RF Power Output	47.0–54.0, ±0.25 dBm	Referenced to 250-W transmitter output terminal (waterload switch). Settability is limited to 0.25 dB by measurement equipment precision
Power output varies across the bandwidth and may be as much as 0.5 dB below the set value if the frequency is adjusted to a value other than where the power was set. In general, amplitude drift and variation with frequency will be less at higher output power, but specified performance is guaranteed over the operating range of 50 to 250 Watts.		
EIRP (maximum)	108.8, ±0.35 dBm	

Table 1. S-Band Transmit Characteristics, DSS-65 (Continued)

Parameter	Value	Remarks
EXCITER AND TRANSMITTER (Continued)		
Frequency Range Covered	2025 to 2110 MHz	Near-earth
Instantaneous 1-dB Bandwidth	>85 MHz	
Coherent with Earth Orbiter S-Band D/L Allocation	2028.8–2108.7 MHz	240/221 turnaround ratio
Tunability		At transmitter output frequency
Phase Continuous Tuning Range	2.0 MHz	
Maximum Tuning Rate	±12.1 kHz/s	
Frequency Error	0.012 Hz	Average over 100 ms with respect to frequency specified by predicts
Ramp Rate Error	0.001 Hz/s	Average over 4.5 s with respect to rate calculated from frequency predicts
Stability		At transmitter output frequency
Output Power Stability	–0.5, +1.0 dB	From initial calibration value over an 8-h period at a fixed frequency
Group Delay Stability	≤3.0 ns, RMS	Ranging modulation signal path over an 8-h period (see module 203)
Frequency Stability		Allan deviation
1 s	9.0×10^{-13}	
10 s	9.0×10^{-14}	
1000–3600 s	3.0×10^{-15}	
Spurious Output		Below carrier
1–10 Hz	–60 dB	
10 Hz–1.5 MHz	–70 dB	
1.5 MHz–8 MHz	–80 dB	
2nd Harmonic	–80 dB	
3rd, 4th & 5th Harmonics	–90 dB	

Table 2. X-Band Transmit Characteristics, DSS-65

Parameter	Value	Remarks
ANTENNA		
Gain at 7145 MHz (deep-space)	67.05 ±0.2 dBi	At elevation angle of peak gain, referenced to feedhorn aperture for matched polarization; no atmosphere included
Transmitter Waveguide Loss	0.25 ±0.05 dB	20-kW transmitter output terminal (waterload switch) to feedhorn aperture
Half-Power Beamwidth	0.0777 ±0.004 deg	Angular width (2-sided) between half-power points at specified frequency
Polarization	RCP or LCP	One polarization at a time, remotely selected
Ellipticity	1.0 dB (max)	Peak-to-peak axial ratio defined as the ratio of peak-to-trough received voltages with a rotating linearly polarized source and the feed configured as a circularly (elliptically) polarized receiving antenna
Pointing Loss		
Angular	See module 302	See also Figure 7
CONSCAN	0.1 dB	X-band CONSCAN reference set for 0.1 dB loss
EXCITER AND TRANSMITTER		
RF Power Output	73.0, +0.0, –1.0 dBm	Referenced to 20-kW transmitter output terminal (waterload switch). Settability is limited to 0.25 dB by measurement equipment precision
Power output varies across the bandwidth and may be as much as 1 dB below nominal rating. Performance will also vary from tube to tube. Normal procedure is to run the tubes saturated, but unsaturated operation is also possible. The point at which saturation is achieved depends on drive power and beam voltage. The 20-kW tubes are normally saturated for power levels greater than 63 dBm (2 kW). Minimum power out of the 20-kW tubes is about 53 dBm (200 W). Efficiency of the tubes drops off rapidly below nominal rated output.		
EIRP	139.8, +0.2, –1.0 dBm	

Table 2. X-Band Transmit Characteristics, DSS-65 (Continued)

Parameter	Value	Remarks
EXCITER AND TRANSMITTER (Continued)		
Frequency Range Covered	7145 to 7190 MHz	Deep-space
Instantaneous 1-dB Bandwidth (MHz)	45 MHz	
Coherent with Deep Space S-Band D/L Allocation	7151.9–7177.3 MHz	240/749 turnaround ratio
Coherent with Deep Space S-Band D/L Allocation	7151.9–7188.9 MHz	880/749 turnaround ratio
Tunability		At transmitter output frequency
Phase Continuous Tuning Range	2.0 MHz	
Maximum Tuning Rate	±12.1 kHz/s	
Frequency Error	0.012 Hz	Average over 100 ms with respect to frequency specified by predicts
Ramp Rate Error	0.001 Hz/s	Average over 4.5 s with respect to rate calculated from frequency predicts
Output Power Stability		From initial calibration value over an 8-h period at a fixed frequency
Saturated Drive	± 0.3 dB, peak	
Unsaturated Drive	± 0.5 dB, peak	
Output Power Variation		Across any 2 MHz segment
Saturated Drive	≤ 0.3 dB, p-p	
Unsaturated Drive	≤ 0.5 dB, p-p	
Group Delay Stability	≤ 1.5 ns, RMS	Ranging modulation signal path over 8 h period (see module 203)
Frequency Stability		Allan deviation
1 s	1.0×10^{-12}	
10 s	1.0×10^{-13}	
1000–3600 s	3.0×10^{-13}	

Table 2. X-Band Transmit Characteristics, DSS-65 (Continued)

Parameter	Value	Remarks
Spurious Output		Below carrier
1–10 Hz	–50 dB	
10 Hz–1.5 MHz	–60 dB	
1.5 MHz–8 MHz	–45 dB	
2nd Harmonic	–75 dB	
3rd, 4th & 5th Harmonics	–60 dB	

Table 3. S- and X-Band Receive Characteristics, DSS-65

Parameter	Value	Remarks
ANTENNA		
Gain (deep-space)		At elevation angle of peak gain for matched polarization, no atmosphere included. Favorable (+) and adverse (–) tolerances have a triangular PDF. See Figures 2 and 3 for elevation dependency.
S-Band (2295 MHz)	56.07 ±0.25 dBi	Referenced to feedhorn aperture
X-Band (8420 MHz)	68.41 ±0.2 dBi	Referenced to feedhorn aperture
Half-Power Beamwidth (deg.)		Angular width (2-sided) between half-power points at specified frequency
S-Band	0.242 ±0.020 deg	
X-Band	0.0660 ±0.004 deg	
Polarization		Remotely selected
S-Band	RCP or LCP	
X-Band	RCP or LCP	Same or opposite from transmit polarization
Ellipticity (dB)	0.7 dB	Peak-to-peak voltage axial ratio, RCP and LCP. See definition in Table 1.
S-Band	≤1.0 dB	
X-Band	≤0.8 dB	

Table 3. S- and X-Band Receive Characteristics, DSS-65 (Continued)

Parameter	Value	Remarks
ANTENNA (Continued)		
Pointing Loss		
Angular	See module 302	See also Figures 6 and 7
CONSCAN		
S-Band	0.03 dB, 3-sigma	Loss at S-band when using X-band CONSCAN reference set for 0.1 dB loss at X-band
	0.1 dB, 3-sigma	Recommended value when using S-band CONSCAN reference
X-Band	0.1 dB, 3-sigma	Recommended value when using X-band CONSCAN reference
RECEIVER		
Frequency Ranges Covered (MHz))		
S-Band	2200–2300 MHz	Deep-space
X-Band		Deep-space
Telemetry	8400–8500 MHz	
VLBI	8200–8600 MHz	Wide-band HEMT LNA
Recommended Maximum Signal Power	-90.0 dBm -70.0 dBm	At LNA input terminal (high-gain mode) AT LNA input terminal (low-gain mode)
Antenna-Microwave Noise Temperature (T_{AMW})		Near zenith, no atmosphere (vacuum) or cosmic noise included. See Table 5 for 25% CD average clear sky noise contribution. Favorable (–) and adverse (+) tolerances have triangular PDF. See Figures 4 and 5 for elevation dependency.
S-Band (2200–2300 MHz)		With respect to feedhorn aperture
DSS-65	34.00 ±2 K	LNA-1, HEMT, non-diplexed path
DSS-65	41.76 ±2 K	LNA-1, HEMT, diplexed path

Table 3. S- and X-Band Receive Characteristics, DSS-65 (Continued)

Parameter	Value	Remarks
RECEIVER (continued)		
X-Band Dual-HEMT LNAs		With respect to feedhorn aperture
High-Gain Mode		normal configuration
DSS-15, LNA-1, HEMT, RCP	N/A	diplexed, 8200-8600 MHz
DSS-15, LNA-2, HEMT, LCP	N/A	diplexed, 8200-8600 MHz
DSS-15, LNA-1, HEMT, RCP	N/A	diplexed, w/ radar filter, 8200-8500 MHz
DSS-15, LNA-2, HEMT, LCP	N/A	diplexed, w/ radar filter, 8200-8500 MHz
Low-Gain Mode		high spacecraft received power
DSS-15, LNA-1, HEMT, RCP	N/A	diplexed, 8200-8600 MHz
DSS-15, LNA-2, HEMT, LCP	N/A	diplexed, 8200-8600 MHz
DSS-15, LNA-1, HEMT, RCP	N/A	diplexed, w/ radar filter, 8200-8500 MHz
DSS-15, LNA-2, HEMT, LCP	N/A	diplexed, w/ radar filter, 8200-8500 MHz
X-Band Maser/HEMT LNAs, High-Gain Mode, RCP/LCP		
DSS-45	N/A	LNA-1, maser, non-diplexed path, 8400-8500 MHz
DSS-65	15.43 ±2 K	
DSS-45	N/A	LNA-1, maser, diplexed path, 8400-8500 MHz
DSS-65	24.83 ±2 K	
DSS-45	N/A	LNA-2, HEMT, non-diplexed path, 8200-8600 MHz (wide-band)
DSS-65	32.16 ±2 K	
DSS-45	N/A	LNA-2, HEMT, diplexed path, 8400-8500 MHz (narrowed due to diplexer)
DSS-65	41.56 ±2 K	

Table 3. S- and X-Band Receive Characteristics, DSS-65 (Continued)

Parameter	Value	Remarks
X-Band Maser/HEMT LNAs, Low-Gain Mode, RCP/LCP		
DSS-45	N/A	LNA-1, maser, non-diplexed path, 8400-8500 MHz
DSS-65	20.52 ±2 K	
DSS-45	N/A	LNA-1, maser, diplexed path, 8400-8500 MHz
DSS-65	29.92 ±2 K	
DSS-45	N/A	LNA-2, HEMT, non-diplexed path, 8200-8600 MHz (wide-band)
DSS-65	43.16 ±2 K	
DSS-45	N/A	LNA-2, HEMT, diplexed path, 8400-8500 MHz (narrowed due to diplexer)
DSS-65	52.56 ±2 K	
Carrier Tracking Loop Noise B/W	0.25 – 200 Hz	Effective one-sided, noise-equivalent carrier loop bandwidth (B_L)

Table 4. Gain Reduction Due to Wind Loading, 34-m HEF Antennas

Wind Speed		X-Band Gain Reduction (dB)*
(km/hr)	(mph)	
10	6	0.0
30	19	0.01
50	31	0.06
70	43	0.21

* Assumes antenna is maintained on-point using CONSCAN or equivalent closed-loop pointing technique.

S-band gain reduction is less than 0.02 dB for wind speeds up to 70 km/hr.

Worst case, with most adverse wind orientation.

Table 5. T_{AMW}, T_{sky}, and T_{op} for CD=25% Average Clear Weather at Zenith, Referenced to Feedhorn Aperture

Configuration and Stations	Noise Temperatures, K		
	T_{AMW}	T_{sky}	T_{op}
S-band DSS-65:			
S-band, DSS-65, LNA-1, HEMT, non-diplexed	34.00	4.80	38.80
S-band, DSS-65, LNA-1, HEMT, diplexed	41.76	4.80	46.56
DSS-15 X-band High-Gain Mode (normal configuration):			
X-band, DSS-15, LNA-1, HEMT, RCP, diplexed	N/A	5.04	N/A
X-band, DSS-15, LNA-2, HEMT, LCP, diplexed	N/A	5.04	N/A
X-band, DSS-15, LNA-1, HEMT, RCP, diplexed, w/ narrow-band radar filter	N/A	5.04	N/A
X-band, DSS-15, LNA-2, HEMT, LCP, diplexed, w/ narrow-band radar filter	N/A	5.04	N/A
DSS-15 X-band Low-Gain Mode (high s/c received power):			
X-band, DSS-15, LNA-1, HEMT, RCP, diplexed	N/A	5.04	N/A
X-band, DSS-15, LNA-2, HEMT, LCP, diplexed	N/A	5.04	N/A
X-band, DSS-15, LNA-1, HEMT, RCP, diplexed, w/ narrow-band radar filter	N/A	5.04	N/A
X-band, DSS-15, LNA-2, HEMT, LCP, diplexed, w/ narrow-band radar filter	N/A	5.04	N/A
DSS-45 Maser/HEMT High-Gain Mode, RCP/LCP:			
X-band, DSS-45, LNA-1, maser, non-diplexed	N/A	5.39	N/A
X-band, DSS-45, LNA-1, maser, diplexed	N/A	5.39	N/A
X-band, DSS-45, LNA-2, HEMT, non-diplexed	N/A	5.39	N/A
X-band, DSS-45, LNA-2, HEMT, diplexed	N/A	5.39	N/A
DSS-45 Maser/HEMT Low-Gain Mode, RCP/LCP:			
X-band, DSS-45, LNA-1, maser, non-diplexed	N/A	5.39	N/A
X-band, DSS-45, LNA-1, maser, diplexed	N/A	5.39	N/A
X-band, DSS-45, LNA-2, HEMT, non-diplexed	N/A	5.39	N/A
X-band, DSS-45, LNA-2, HEMT, diplexed	N/A	5.39	N/A

Table 5. T_{AMW}, T_{sky}, and T_{op} for CD=25% Average Clear Weather at Zenith, Referenced to Feedhorn Aperture (Continued)

Configuration and Stations	Noise Temperatures, K		
	T_{AMW}	T_{sky}	T_{op}
DSS-65 Maser/HEMT High-Gain Mode RCP/LCP:			
X-band, DSS-65, LNA-1, maser, non-diplexed	15.43	5.27	20.70
X-band, DSS-65, LNA-1, maser, diplexed	24.83	5.27	29.10
X-band, DSS-65, LNA-2, HEMT, non-diplexed	32.16	5.27	37.43
X-band, DSS-65, LNA-2, HEMT, diplexed	41.56	5.27	46.83
DSS-65 Maser/HEMT Low-Gain Mode, RCP/LCP:			
X-band, DSS-65, LNA-1, maser, non-diplexed	20.52	5.27	25.79
X-band, DSS-65, LNA-1, maser, diplexed	29.92	5.27	35.19
X-band, DSS-65, LNA-2, HEMT, non-diplexed	43.16	5.27	48.43
X-band, DSS-65, LNA-2, HEMT, diplexed	52.56	5.27	57.83

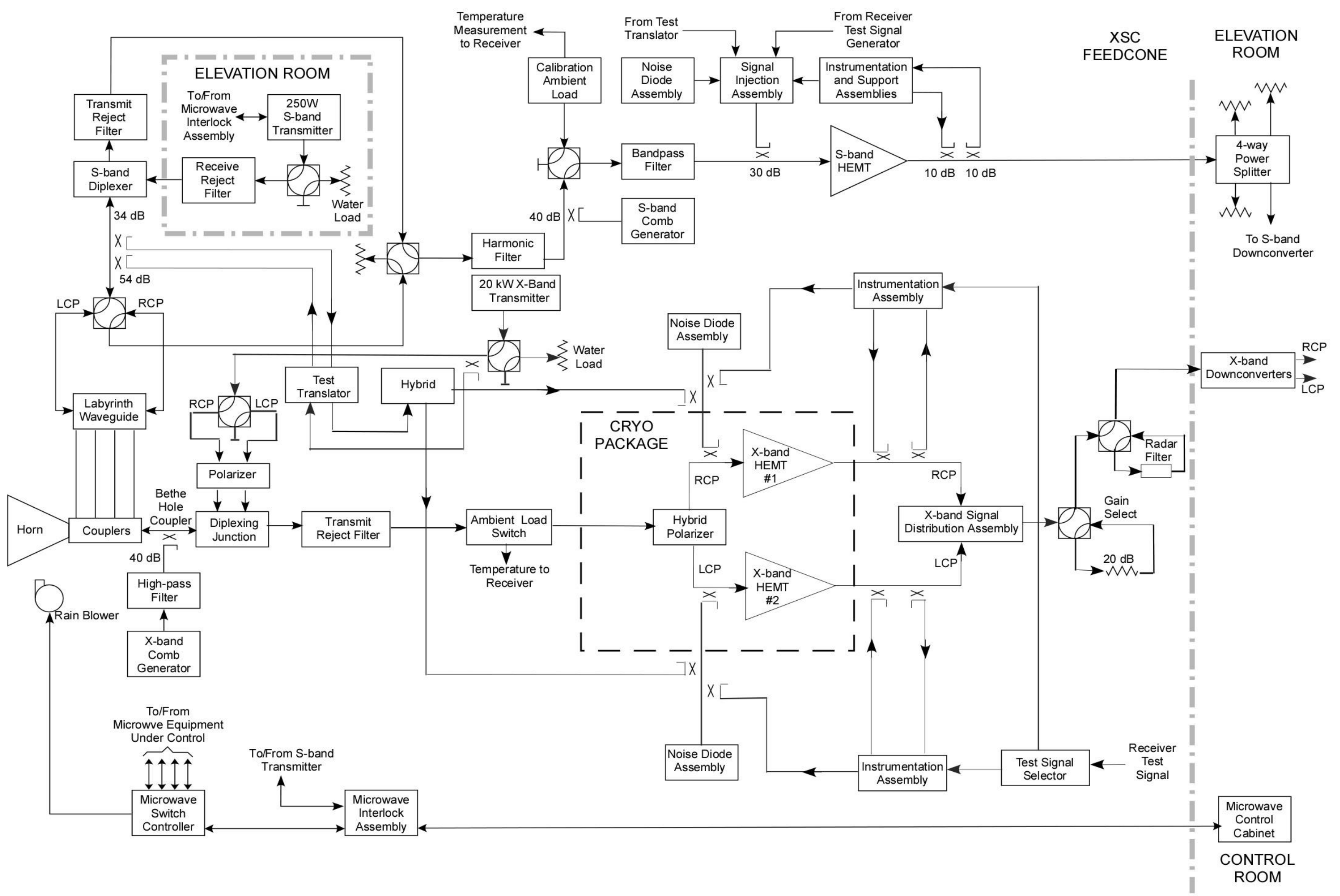

Figure 1a. Functional Block Diagram of the DSS-15 HEF Antenna (Decommissioned)

Fig

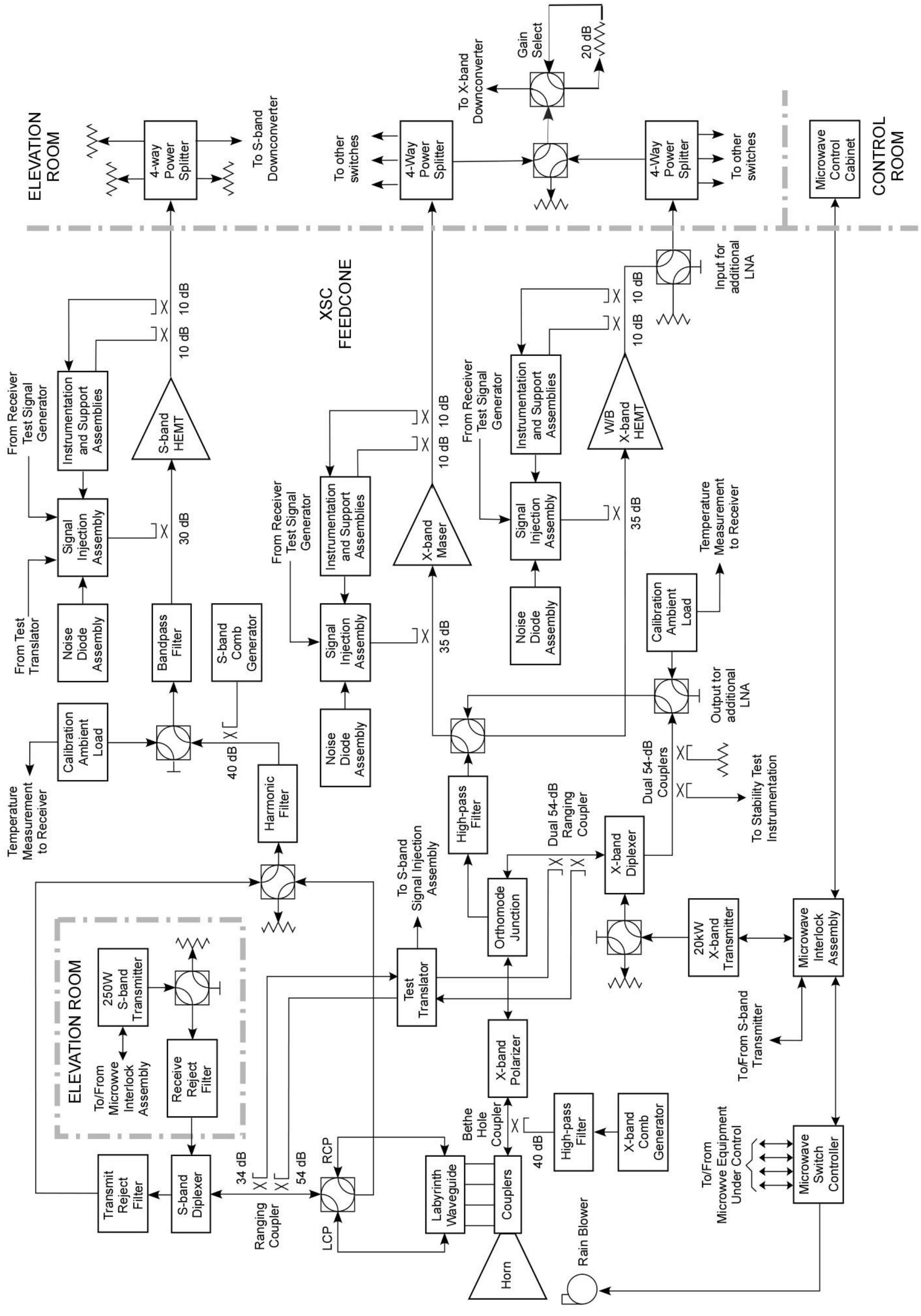

Figure 1b. Functional Block Diagram of the DSS-45 (Decommissioned) and DSS-65 HEF Antennas

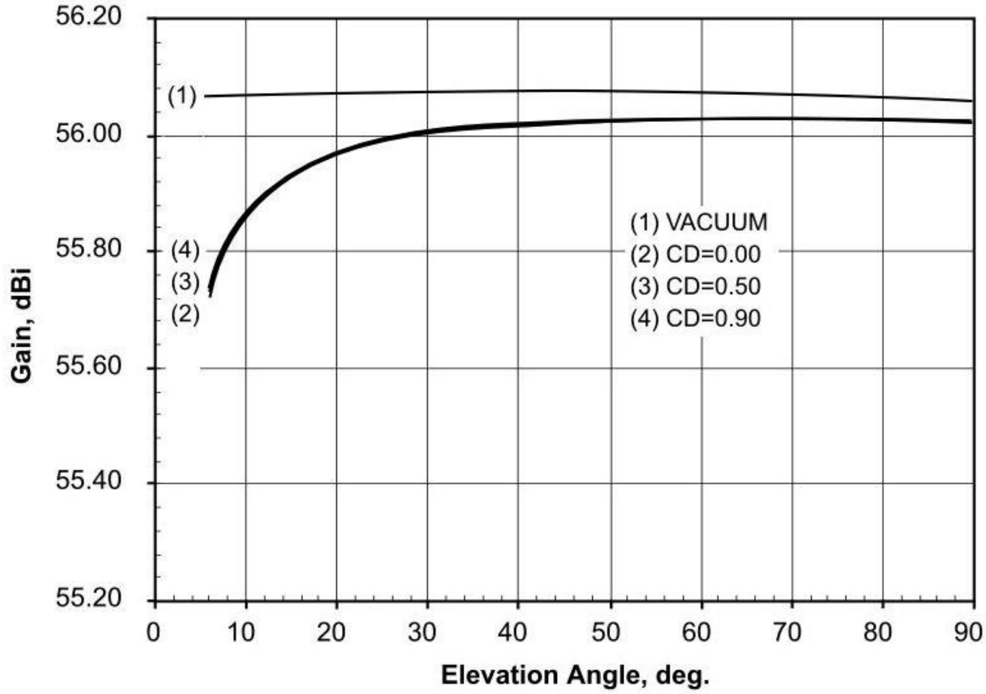

Figure 2. S-Band Receive Gain, DSS-65 Antenna, at Feedhorn Aperture

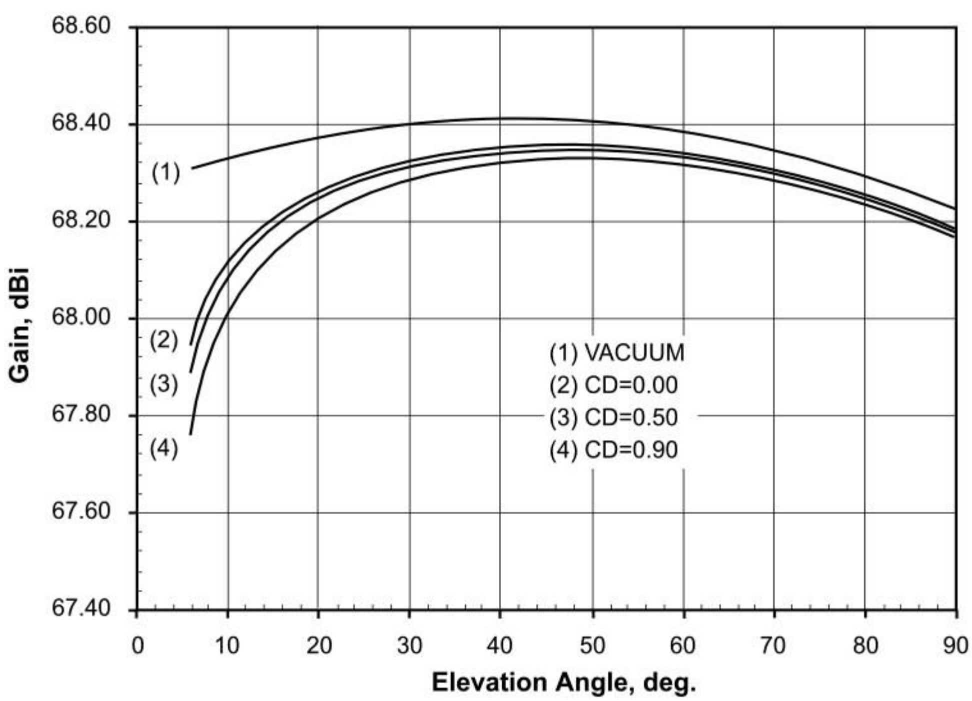

Figure 3. X-Band Receive Gain, DSS-65 Antenna, at Feedhorn Aperture

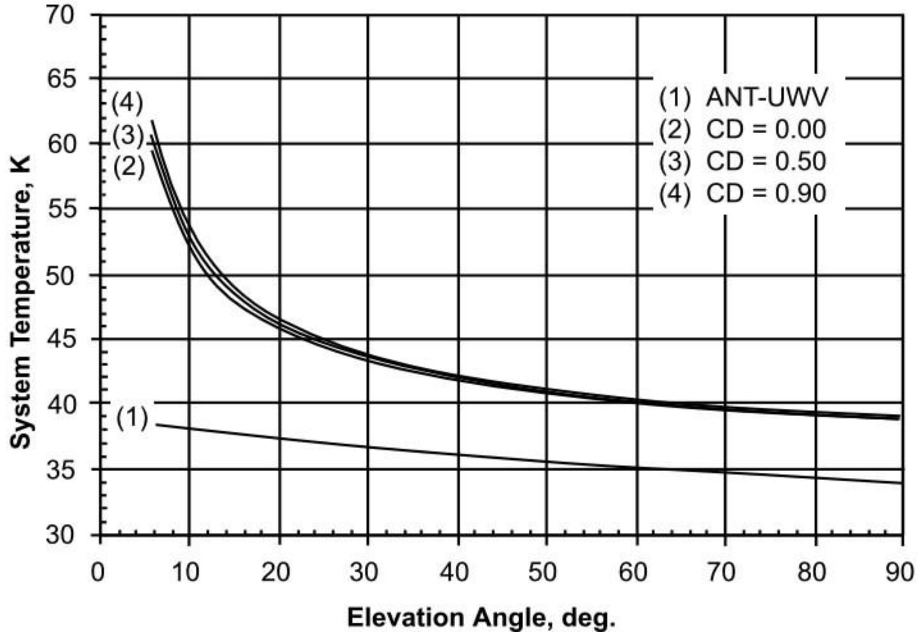

Figure 4. S-band System Noise Temperature, DSS-65, LNA-1, Non-Diplexed, at Feedhorn Aperture

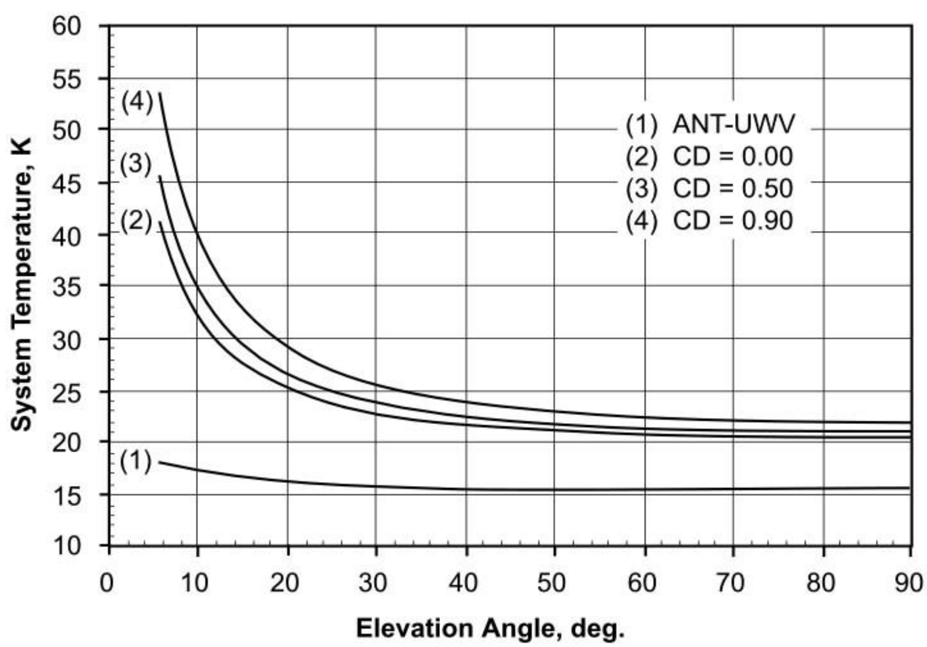

Figure 5. X-Band System Noise Temperature, DSS-65, LNA-1, Non-Diplexed, at Feedhorn Aperture

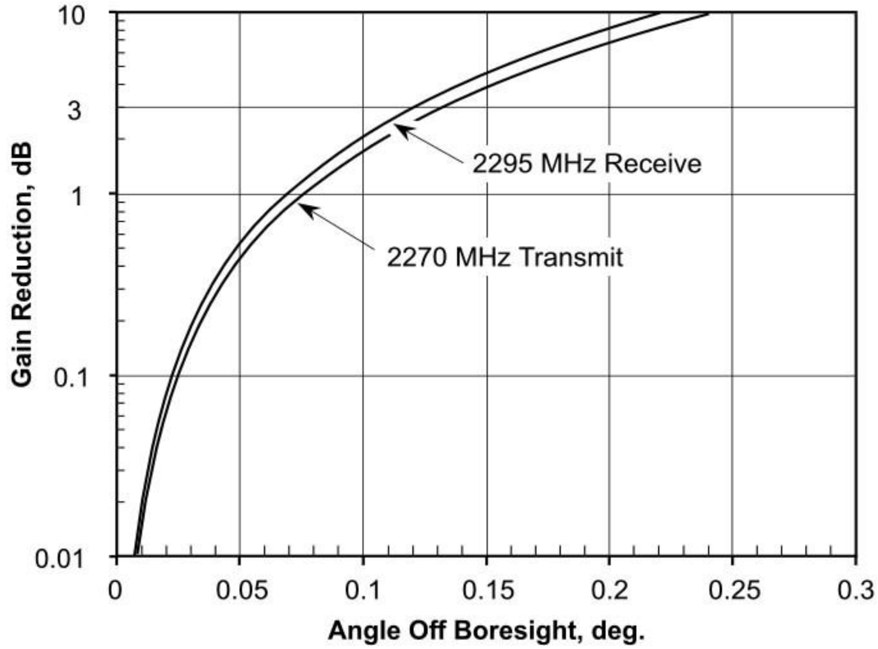

Figure 6. S-Band Gain Reduction Versus Angle Off Boresight

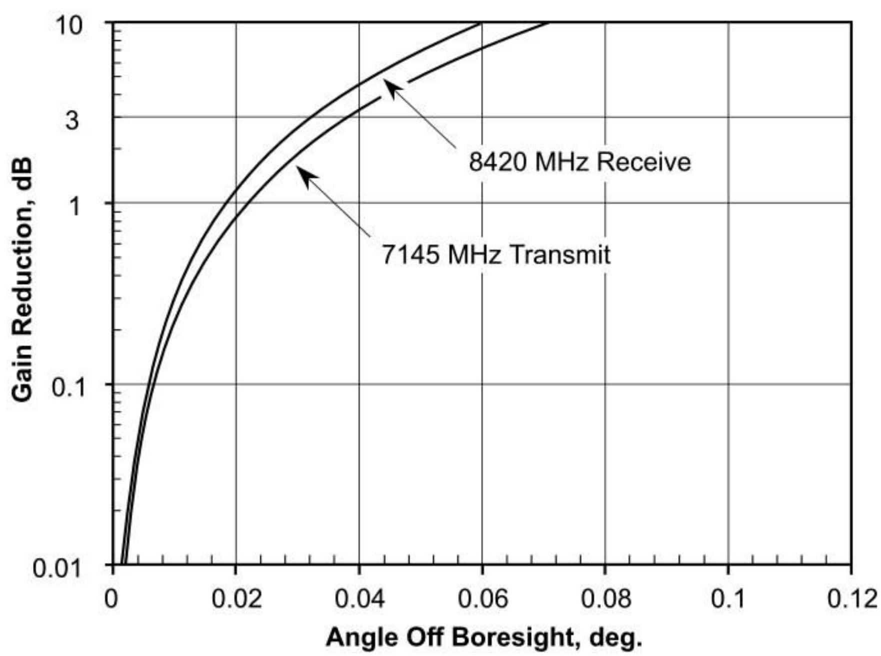

Figure 7. X-Band Gain Reduction Versus Angle Off Boresight

Appendix A
Equations for Modeling

A.1 Equations for Gain Versus Elevation Angle

The following equation can be used to generate S- and X-band transmit and receive gain versus elevation curves for DSS-65. The gains are referenced to the feedhorn aperture, so different configurations (e.g., LNA-1 non-diplexed and LNA-2 diplexed) will have the same gain values. Examples of these curves are shown in Figures 2 and 3 for S- and X-bands. See paragraph 2.1.1.1 for frequency effect modeling and Module 105 for atmospheric attenuation at weather conditions corresponding to cumulative distributions from 0% to 99%. The year-average atmosphere attenuations for CD = 0.00, 0.50, and 0.90 are also given in Table A-2.

$$G(\theta) = G_0 - G_1(\theta - \gamma)^2 - \frac{A_{ZEN}}{\sin\theta}, \text{ dBi} \quad \text{(A1)}$$

where

θ = antenna elevation angle (deg.) $6 \le \theta \le 90$

G_0, G_1, γ = parameters from Table A-1

A_{ZEN} = zenith atmospheric attenuation from Table A-2 or from Tables 10 through 15 in Module 105, dB.

A.2 Equations for System Noise Temperature Versus Elevation Angle

The following equations can be used to generate S- and X-band receive system noise temperature versus elevation curves for DSS-65. Examples of these curves are shown in Figures 4 and 5. See Module 105 for atmospheric attenuation at weather conditions corresponding to cumulative distributions from 0% to 99%. Atmosphere attenuations for CD = 0.00, 0.50, and 0.90 are also given in Table A-2.

System operating noise temperature:

$$T_{op}(\theta) = T_{AMW} + T_{sky} = \left[T_1 + T_2 e^{-a\theta}\right] + \left[T_{atm}(\theta) + T'_{CMB}(\theta)\right] \quad \text{(A2)}$$

Sky noise contribution:

$$T_{sky} = T_{atm}(\theta) + T'_{CMB}(\theta) \quad \text{(A3)}$$

Atmospheric attenuation:

$$A(\theta) = \frac{A_{zen}}{\sin(\theta)}, \text{ dB} \qquad \text{(A4)}$$

Atmospheric loss factor:

$$L(\theta) = 10^{\frac{A(\theta)}{10}}, \text{ dimensionless, } >1.0 \qquad \text{(A5)}$$

Atmospheric physical temperature:

$$T_p = 255 + 25 \times CD, \text{ K} \qquad \text{(A6)}$$

Atmospheric noise contribution:

$$T_{atm}(\theta) = T_p\left[1 - \frac{1}{L(\theta)}\right], \text{ K} \qquad \text{(A7)}$$

Effective cosmic background noise:

$$T'_{CMB}(\theta) = \frac{T_{CMB}}{L(\theta)}, \text{ K} \qquad \text{(A8)}$$

where

θ	=	antenna elevation angle (deg.), $6 \le \theta \le 90$
T_1, T_2, a	=	antenna-microwave noise temperature parameters from Table A-3
A_{ZEN}	=	zenith atmospheric attenuation, dB, from Table A-2 or from Tables 10 through 15 (S-, X-bands) in Module 105 as a function of frequency, station, and cumulative distribution (*CD*)
CD	=	cumulative distribution, $0 \le CD \le 0.99$, used to select A_{ZEN} from Table A-2 or from Tables 10 through 15 in Module 105
T_{CMB}	=	2.725 K, cosmic microwave background noise temperature

A.3 Equation for Gain Reduction Versus Pointing Error

The following equation can be used to generate gain-reduction versus pointing error curves examples of which are depicted in Figures 6 and 7.

$$\Delta G(\theta) = 10\log\left(e^{\frac{2.773\theta^2}{HPBW^2}} \right) \quad , \quad \text{dB} \tag{3}$$

where

θ = pointing error (deg.)

$HPBW$ = half-power beamwidth in degrees (from Tables 1, 2, or 3)

Table A-1. Vacuum Component of Gain Parameters

Configuration and Stations	Parameters†			
	G_0* (Transmit)	G_0* (Receive)	G_1	γ
S-band, DSS-65 (Figure 2)	55.40	56.07	0.000006	42.0
X-band, DSS-65 (Figure 3)	67.05	68.41	0.00008	42.0

NOTES:

† G_0 values are nominal at the frequency specified in Tables 1, 2, and 3. Other parameters apply to all frequencies within the same band.

* Favorable tolerance = +0.5 dB, adverse tolerance = –0.5 dB, with a triangular PDF.

Table A-2. S- and X-Band Year-Average Zenith Atmosphere Attenuation Above Vacuum (A_{ZEN})

Weather Condition †	A_{ZEN}, dB*					
	S-band			X-band		
	DSS-15 Goldstone	DSS-45 Canberra	DSS-65 Madrid	DSS-15 Goldstone	DSS-45 Canberra	DSS-65 Madrid
Vacuum	0.000	0.000	0.000	0.000	0.000	0.000
CD = 0.00	0.033	0.036	0.035	0.037	0.039	0.038
CD = 0.50	0.034	0.036	0.035	0.041	0.047	0.044
CD = 0.90	0.034	0.037	0.036	0.045	0.058	0.057

NOTES:

* From Tables 10 through 15 in module 105

† CD = cumulative distribution.

Table A-3. Antenna-Microwave Noise Temperature Parameters, Referenced to Feedhorn Aperture

Configuration and Stations	**Parameters**		
	T_1*	T_2	a
S-band, DSS-65:			
S-band, DSS-65, LNA-1, HEMT, non-diplexed	31.80	7.10	0.013
S-band, DSS-65, LNA-1, HEMT, diplexed	39.40	7.60	0.013
DSS-15, X-band, High-Gain Mode (normal configuration):			
X-band, DSS-15, LNA-1, HEMT, RCP, diplexed	N/A	N/A	N/A
X-band, DSS-15, LNA-2, HEMT, LCP, diplexed	N/A	N/A	N/A
X-band, DSS-15, LNA-1, HEMT, RCP, diplexed, w/ narrow-band radar filter	N/A	N/A	N/A
X-band, DSS-15, LNA-2, HEMT, LCP, diplexed, w/ narrow-band radar filter	N/A	N/A	N/A
DSS-15, X-band, Low-Gain Mode (high s/c received power):			
X-band, DSS-15, LNA-1, HEMT, RCP, diplexed	N/A	N/A	N/A
X-band, DSS-15, LNA-2, HEMT, LCP, diplexed	N/A	N/A	N/A
X-band, DSS-15, LNA-1, HEMT, RCP, diplexed, w/ narrow-band radar filter	N/A	N/A	N/A
X-band, DSS-15, LNA-2, HEMT, LCP, diplexed, w/ narrow-band radar filter	N/A	N/A	N/A
DSS-45, Maser/HEMT, High-Gain Mode, RCP/LCP:			
X-band, DSS-45, LNA-1, maser, non-diplexed	N/A	N/A	N/A
X-band, DSS-45, LNA-1, maser, diplexed	N/A	N/A	N/A
X-band, DSS-45, LNA-2, HEMT, non-diplexed	N/A	N/A	N/A
X-band, DSS-45, LNA-2, HEMT, diplexed	N/A	N/A	N/A
DSS-45, Maser/HEMT, Low-Gain Mode, RCP/LCP:			
X-band, DSS-45, LNA-1, maser, non-diplexed	N/A	N/A	N/A
X-band, DSS-45, LNA-1, maser, diplexed	N/A	N/A	N/A
X-band, DSS-45, LNA-2, HEMT, non-diplexed	N/A	N/A	N/A
X-band, DSS-45, LNA-2, HEMT, diplexed	N/A	N/A	N/A

Table A-3. Antenna-Microwave Noise Temperature Parameters, Referenced to Feedhorn Aperture (Continued)

Configuration and Stations	**Parameters**		
	T*₁	***T*₂**	***a***
DSS-65, Maser/HEMT, High-Gain Mode, RCP/LCP:			
X-band, DSS-65, LNA-1, maser, non-diplexed	15.43	5.00	0.10
X-band, DSS-65, LNA-1, maser, diplexed	24.83	6.10	0.10
X-band, DSS-65, LNA-2, HEMT, non-diplexed	32.16	5.50	0.10
X-band, DSS-65, LNA-2, HEMT, diplexed	41.56	6.60	0.10
DSS-65, Maser/HEMT, Low-Gain Mode, RCP/LCP:			
X-band, DSS-65, LNA-1, maser, non-diplexed	20.52	5.00	0.10
X-band, DSS-65, LNA-1, maser, diplexed	29.92	6.10	0.10
X-band, DSS-65, LNA-2, HEMT, non-diplexed	43.16	5.50	0.10
X-band, DSS-65, LNA-2, HEMT, diplexed	52.56	6.60	0.10

NOTES:

* Favorable tolerance = –2 K, adverse tolerance = +2 K, with a triangular PDF.