Deep Space Network

301
Coverage and Geometry

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DSN No. **810-005, 301, Rev. K**
Issue Date: September 13, 2016
JPL D-19379 (CL#16-4191)

Jet Propulsion Laboratory
California Institute of Technology

Review Acknowledgment

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Document Change Log

-Rev	Issue Date	Prepared By	Affected Sections or Pages	Change Summary
Initial	11/30/2000	Robert Sniffin	All	New Module
A	4/15/2003	Robert Sniffin	2.1.1, 2.1.4, 2.2.3, 3.	Identified 11-m subnet as non-operational. Corrected equations 4, and 7. Added DSS 55. Documented improved coverage for MDSCC antennas. Expressed Geodetic coordinates in terms of WGS84 ellipsoid. Revised Proposed Capabilities.
B	2/5/2004	Robert Sniffin	2.1.2, 2.1.2.1, 2.11.2.2, 2.1.5, 2.2.3.6, 2.2.3.10, 2.2.4	Corrects locations of DSS 26, 54 and DSS 55. Revises locations of other stations. Adds Table 7 (location uncertainties). Provides final receive and transmit masks for DSS 55. Adds Figure 8 and renumbered subsequent figures.
C	8/20/2005	Robert Sniffin	Tables 2, 5,& 6.	Documents new location and masking of DSS 65.
D	9/19/2008	Robert Sniffin	2.1.1, 2.2.3.7 – 2.2.3.10, Tables 1, 2, 5 – 7, Figures 9 & 10	Deleted references to 11-m antenna subnet stations and DSS 16 that have been decommissioned. Revised Figures 9 and 10 and titles of Figures 11 and 12. Deleted Figure 15 and renumbered subsequent figures.
E	12/15/2009	Robert Sniffin	Tables 1, 2, 5 – 7, Figures 9, 10, 22, & 27	Deleted references, the affected Figures, and information in the Tables due to the 26-m stations decommissioning. Renumbered the Figures.
F	6/1/2010	Andrew Kwok	Page 18	Corrected DSS-27 cable wrap limits in Table 8. Eliminated the Rev. E designation for the document series.
G	10/1/2011	Robert Sniffin Christine Chang	2.2.2, 2.2.3, 2.2.4, Figures 5 and 11 – 23	Corrected transmit mask of DSS-65 and revised 34-m HEF transmit coverage chart. Revised all horizon masks to show wrap limits and locations of nearby antennas. Merged 2.2.2.1 into 2.2.2. Added explanation of difference between land mask and mask used for calculating spacecraft rise and set times. Updated discussion of Spacecraft Visibility plot program in 2.2.3.
H	10/17/2012	Robert Sniffin Christine Chang	2.2.3.6, Figures 7, 8,10, 20 and 21	Incorporated changes in transmit limits at DSS-54 and DSS-55.
I	06/12/2014	Stephen Slobin Christine Chang Robert Sniffin	Figure 16 Figure 17 Tables 2, 5, 6, 7 Table 8	Removed references to DSS 27 and DSS 65 (old). Added new transmit horizon mask for DSS-34. Added new figure for DSS-35. Added coordinates for DSS-35. Added wrap limits for DSS-35.
J	09/10/2014	Stephen Slobin Christine Chang Robert Sniffin	2.2.4 Figure 17	Clarified description of horizon mask plotted values. Updated receive horizon mask for DSS-35. Added L/P transmit horizon mask for DSS-35.

-Rev	Issue Date	Prepared By	Affected Sections or Pages	Change Summary
K	09/13//2016	Stephen Slobin Christine Chang	Tables 1, 8 Tables 2, 5, 6, 7 Tables 2, 5, 6, 7 Figure 16 Figure 17 Figure 18 Figures 18-23 Sec. 2.2.4	DSS-36 added. Updated position values for DSS-35. New position values for DSS-36. New transmit and receive horizon masks for DSS-34. New receive horizon mask for DSS-35. New DSS-36 horizon masks. Renumbered 19-24. Expanded description of DSS-34, -35, -36 horizon masks.

Contents

Illustrations

Tables

Table **Page**

1 Introduction

1.1 Purpose

This module describes the geometry and coverage visibility provided by the DSN for support of spacecraft telecommunications.

1.2 Scope

This module provides the Deep Space Network (DSN) station coordinates that are required for spacecraft navigation and to locate the stations with respect to other points on the Earth's surface. Coverage charts are provided to illustrate areas of coverage and non-coverage from selected combinations of stations for spacecraft at selected altitudes. Horizon masks are included so the effects of terrain masking can be anticipated.

2 General Information

2.1 Station Locations

The following paragraphs discuss the important concepts relating to establishing the location of the DSN antennas.

2.1.1 Antenna Reference Point

The coordinates provided by this module refer to a specific point on each antenna. For antennas where the axes intersect, the reference point is the intersection of the axes. For antennas for which the axes do not intersect, the reference point is the intersection of the primary (lower) axis with a plane perpendicular to the primary axis and containing the secondary (upper) axis. Table 1 lists the DSN antennas by type and provides the axis offset where appropriate. The effect of this offset is to cause the range observable to be a function of antenna position as discussed in module 203 of this handbook.

Although the antenna reference point is fixed, the path length between this point and a spacecraft normally increases as the antenna elevation is changed from the horizon to zenith. This results from the antenna subreflector being moved to provide maximum gain as gravity distorts the antenna geometry. The effect can be modeled as a decrease in antenna height and a latitude/longitude position change as a function of azimuth and elevation angle for orbit determination purposes. The effect is greatest on the 70-m antennas (approximately 6.7 cm) and is discussed in the appropriate Telecommunications Interface modules of this handbook. Subreflector movement can be disabled for activities such as very-long baseline interferometry (VLBI) where a constant path length is more important than maximum gain.

Table 1. DSN Antenna Types

Antenna Type	Station Identifiers	Primary and Secondary Axes	Axis Offset
70-m	14, 43, 63	Az/El	0
34-m High Efficiency (HEF)	15, 45, 65	Az/El	0
34-m Beam Waveguide (BWG)	24, 25, 26, 34, 35, 36, 54, 55	Az/El	0
Note: Az/El antenna azimuth plane is tangent to the Earth's surface, and antenna at 90-degrees elevation is pointing at zenith.			

2.1.2 IERS Terrestrial Reference Frame

To use station locations with sub-meter accuracy, it is necessary to clearly define a coordinate system that is global in scope. The International Earth Rotation and Reference Systems Service (IERS) has been correlating station locations from many different services and has established a coordinate frame known as the IERS Terrestrial Reference Frame (ITRF). The IERS also maintains a celestial coordinate system and coordinates delivery of Earth-orientation measurements that describe the motion of station locations in inertial space. The DSN has adopted the IERS terrestrial system to permit its users to have station locations consistent with widely available Earth-orientation information.

The IERS issues a new list of nominal station locations each year, and these locations are accurate at the few-cm level. At this level of accuracy, one must account for ongoing tectonic plate motion (continental drift), as well as other forms of crustal motion. For this reason ITRF position coordinates are considered valid for a specified epoch date, and one must apply appropriate velocities to estimate position coordinates for any other date. Relative to the ITRF, even points located on the stable part of the North American plate move continuously at a rate of about 2.5 cm/yr.

The coordinates in this module are based on the 1993 realization of the ITRF, namely ITRF93, documented in IERS Technical Note 18 (Reference 1). ITRF93 was different from earlier realizations of the ITRF in that it was defined to be consistent with the Earth Orientation Parameters (EOP) distributed through January 1, 1997. Earlier realizations of the ITRF were known to be inconsistent (at the 1-3 cm level) with the Earth orientation distributions.

After ITRF93 was published, the IERS decided to improve the accuracy of the EOP series and make it consistent with the ITRF effective January 1, 1997. This date was chosen because it enabled a defect in the definition of universal time to be removed at a time when its contribution was zero. In anticipation of this change, ITRF94 and ITRF95 were made consistent with the pre-ITRF93 definition of the terrestrial reference frame, and all prior EOP series were recomputed in accordance with the new system.

The DSN continues to deliver Earth-orientation calibrations to navigation teams that are consistent with the earlier definition and using the ITRF93 reference frame because it is impractical for planetary navigators to adopt an IERS standard that changes approximately every year. Users interested in precise comparison with other systems should keep in mind the small systematic differences.

Position values for the new BWG antenna in Australia, DSS-36, are given in Tables 2, 5, 6, and 7.

2.1.2.1 Cartesian Coordinates

Figure 1 illustrates the relationship between the Cartesian coordinates and geocentric coordinates discussed below. The Cartesian coordinates of the DSN station locations are fits to many years of tracking and Very-Long Baseline Interferometry data and are expressed in the ITRF93 reference system in Table 2.

2.1.2.2 Estimated DSN Site Velocities

The locations given in Table 2 are for the epoch 2003.0. To transform these locations to any other epoch, the site velocities should be used. Table 3 gives the site velocities for the DSN stations, in both Cartesian (x, y, z) and east-north-vertical (e, n, v) components.

2.1.3 Geodetic Coordinates

Locations on the Earth's surface are defined with respect to the geoid. That is, the surface around or within the Earth that is normal to the direction of gravity at all points and coincides with mean sea level (MSL) in the oceans. The geoid is not a regular surface because of variations in the Earth's gravitational force. To avoid having to make computations with respect to this non-mathematical surface, computations are made with respect to an ellipsoid, that is, the surface created by rotating an ellipse around one of its two axes. The ellipsoid is uniquely defined by specifying the equatorial radius and the flattening (that is, the amount that the ellipsoid deviates from a perfect sphere). The relationship between the polar and equatorial axes is given by the following expression:

$$\text{(polar axis)} = \text{(equatorial axis)} \times (1 - 1/\text{flattening}) \qquad (1)$$

In the past, the ellipsoid used was chosen to be a best fit to the geoid in the area of interest. However, the presence of the Global Positioning Satellite (GPS) system has resulted in a single ellipsoid, named the WGS 84 Ellipsoid, being adopted for most geodetic measurements. This ellipsoid, while providing a good fit to the entire Earth, results in larger differences between the geoid and the ellipsoid than could be obtained when ellipsoids were chosen to fit only a

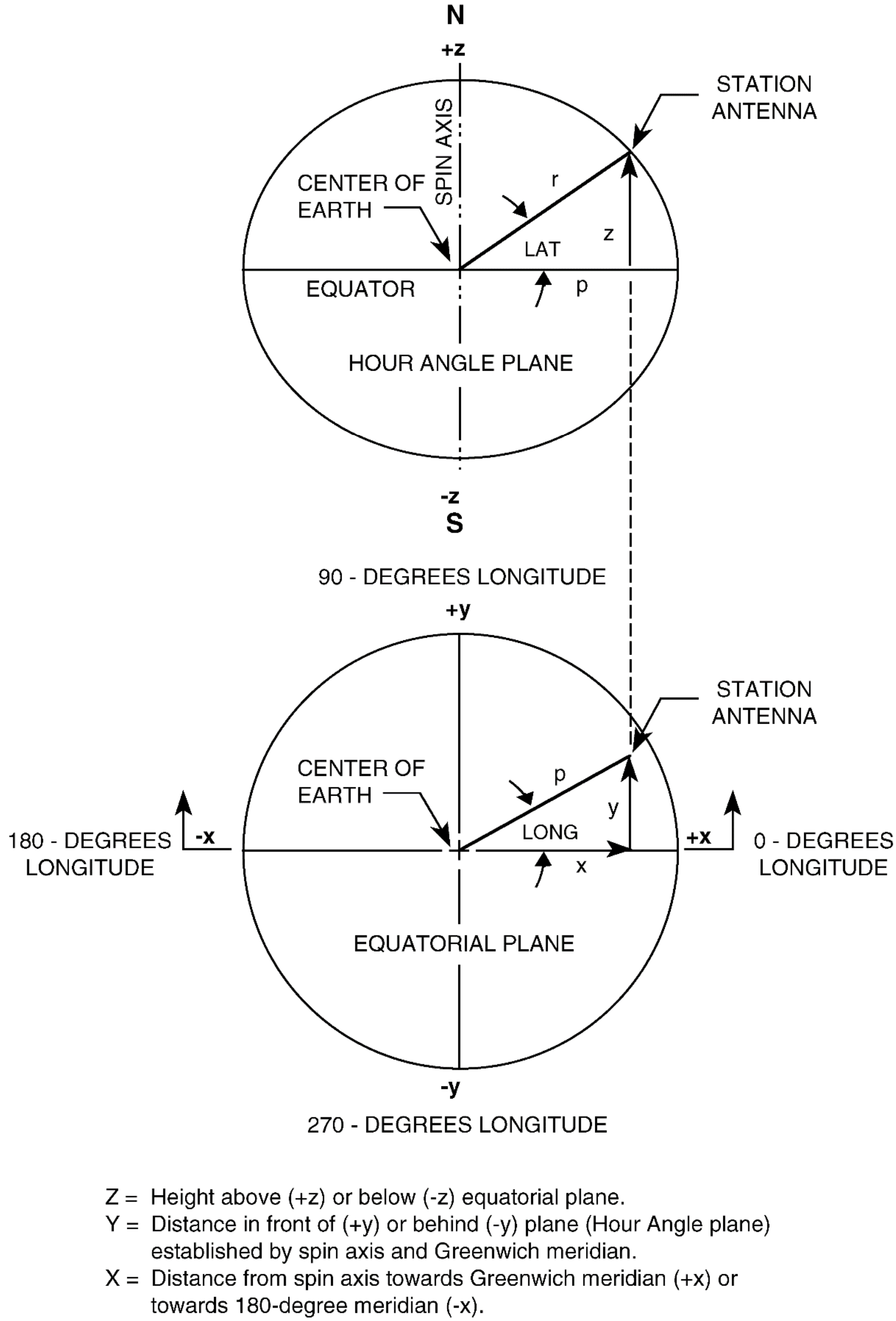

Figure 1. Cartesian and Geocentric Coordinate System Relationships

Table 2. Cartesian Coordinates for DSN Stations in ITRF93 Reference Frame, Epoch 2003.0

Antenna[1]		Cartesian Coordinates		
Name	Description	x(m)	y(m)	z(m)
DSS 13	34-m R & D	–2351112.659	–4655530.636	+3660912.728
DSS 14	70-m	–2353621.420	–4641341.472	+3677052.318
DSS 15	34-m HEF	–2353538.958	–4641649.429	+3676669.984
DSS 24	34-m BWG	–2354906.711	–4646840.095	+3669242.325
DSS 25	34-m BWG	–2355022.014	–4646953.204	+3669040.567
DSS 26	34-m BWG	–2354890.797	–4647166.328	+3668871.755
DSS 34[1]	34-m BWG	–4461147.093	+2682439.239	–3674393.133
DSS 35[1]	34-m BWG	−4461273.090	+2682568.925	−3674152.093
DSS 36[1]	34-m BWG	−4461168.415	+2682814.657	−3674083.901
DSS 43	70-m	–4460894.917	+2682361.507	–3674748.152
DSS 45	34-m HEF	–4460935.578	+2682765.661	–3674380.982
DSS 54	34-m BWG	+4849434.488	–360723.8999	+4114618.835
DSS 55	34-m BWG	+4849525.256	–360606.0932	+4114495.084
DSS 63	70-m	+4849092.518	–360180.3480	+4115109.251
DSS 65	34-m HEF	+4849339.634	–360427.6637	+4114750.733

1. Notes: Position absolute accuracy estimated to be +/−3 cm (0.030 m) (1-sigma) for each coordinate.

Table 3. Site Velocities for DSN Stations

Complex	x(m/yr)	y(m/yr)	z(m/yr)	e(m/yr)	n(m/yr)	v(m/yr)
Goldstone (Stations 1x & 2x)	–0.0180	0.0065	–0.0038	–0.0190	–0.0045	–0.0003
Canberra (Stations 3x & 4x)	–0.0335	–0.0041	0.0392	0.0208	0.0474	–0.0012
Madrid (Stations 5x & 6x)	–0.0100	0.0242	0.0156	0.0234	0.0195	0.0012

portion of the Earth. This difference, the *Geoidal Separation*, must be subtracted from the WGS 84 height measurements to give the height with respect to mean sea level.

Geoidal separations are typically determined from satellite altimetry and gravity measurements and maintained as a grid of points in longitude and latitude. Modern GPS equipment uses a sixteen point interpolation routine to estimate the surface curvature in the grid-square of interest and the geoidal separation at the specific point within the grid-square. Table 4 provides the average geoidal separation for the three DSN complexes. These numbers do not take into consideration such things as topography within the complex and grading that was done when the antennas were installed.

Table 4. Average Geoidal Separations for the DSN Complexes

Complex	Geoidal Separation (m)
Goldstone (Stations 1x & 2x)	–30.6
Canberra (Stations 3x & 4x)	19.3
Madrid (Stations 5x & 6x)	54.1

Once the Cartesian coordinates (x, y, z) are known, they can be transformed to geodetic coordinates in longitude, latitude, and height (λ, ϕ, h) with respect to the ellipsoid by the following non-iterative method (Reference 2):

$$\lambda = \tan^{-1}\frac{y}{x} \tag{2}$$

$$\phi = \tan^{-1}\left(\frac{z(1-\mathrm{f}) + e^2 \mathrm{a} \sin^3 \mu}{(1-\mathrm{f})\left(p - e^2 \mathrm{a} \cos^3 \mu\right)} \right) \tag{3}$$

$$h = p\cos\phi + z\sin\phi - a\left(1 - e^2 \sin^2 \phi\right)^{\frac{1}{2}} \tag{4}$$

where:

$$\mathrm{f} = \frac{1}{\text{flattening}} \tag{5}$$

$$e^2 = 2\mathrm{f} - \mathrm{f}^2 \tag{6}$$

$$p = \left(x^2 + y^2\right)^{\frac{1}{2}} \tag{7}$$

$$r = \left(p^2 + z^2\right)^{\frac{1}{2}} \tag{8}$$

$$\mu = \tan^{-1} \frac{z}{p}\left[(1-\mathrm{f}) + \frac{e^2 \mathrm{a}}{r} \right] \tag{9}$$

Table 5 provides geodetic coordinates derived by the preceding approach using the WGS84 ellipsoid that has a semi-major axis (a) of 6378137 m and a flattening of 298.2572236. In this table, for stations in the southern hemisphere (negative latitude) the tabular values for latitude (degrees, minutes, seconds) are ALL negative, although the minus sign is shown associated only with the degree value, as is conventionally done.

2.1.4 Geocentric Coordinates

Geocentric coordinates are used by navigation analysts when corrections to station locations are being investigated. They relate the station location to the Earth's center of mass in terms of the geocentric radius and the angles between the station and the equatorial and hour angle planes. Geocentric coordinates for the DSN stations are provided in Table 6.

2.1.5 Station Location Uncertainties

The primary reference antennas at each complex are the 34-m HEF antennas. Their location has been established by very-long baseline Interferometry (VLBI) measurements over a period of many years and their location uncertainty is that of the VLBI technique. The uncertainty of the other station locations depends on the method used to link their position to that of the HEFs. The estimated location uncertainties for all stations are provided in Table 7.

Table 5. Geodetic Coordinates for DSN Stations With Respect to the WGS 84 Ellipsoid

Antenna		latitude (ϕ)[3]			longitude (λ)			height(h)[1]
Name	Description	deg	min	sec	deg	min	sec	(m)
DSS 13	34-m R & D	35	14	49.79131	243	12	19.94761	1070.444
DSS 14	70-m	35	25	33.24312	243	6	37.66244	1001.390
DSS 15	34-m HEF	35	25	18.67179	243	6	46.09762	973.211
DSS 24	34-m BWG	35	20	23.61416	243	7	30.74007	951.499
DSS 25	34-m BWG	35	20	15.40306	243	7	28.69246	959.634
DSS 26	34-m BWG	35	20	8.48118	243	7	37.14062	968.686
DSS 34[2]	34-m BWG	–35	23	54.52383	148	58	55.07191	692.020
DSS 35[2]	34-m BWG	−35	23	44.86387	148	58	53.24088	694.897
DSS 36[2]	34-m BWG	−35	23	42.36634	148	58	42.75912	685.503
DSS 43	70-m	–35	24	8.72724	148	58	52.56231	688.867
DSS 45	34-m HEF	–35	23	54.44766	148	58	39.66828	674.347
DSS 54	34-m BWG	40	25	32.23805	355	44	45.25141	837.051
DSS 55	34-m BWG	40	25	27.46525	355	44	50.52012	819.061
DSS 63	70-m	40	25	52.35510	355	45	7.16924	864.816
DSS 65	34-m HEF	40	25	37.94289	355	44	57.48397	833.854

Notes:

1. Geoidal separation must be subtracted from WGS 84 height to get MSL height.
2. Latitude, longitude, and height absolute accuracy estimated to be +/-0.001 sec and +/-3 cm (0.030 m) (1-sigma)
3. For southern hemisphere antennas deg, min, sec should all be considered negative numbers.

Table 6. Geocentric Coordinates for DSN Stations

Antenna		Geocentric Coordinates			
Name	**Description**	**Spin Radius (m)**	**Latitude (deg)**	**Longitude (deg)**	**Geocentric Radius (m)**
DSS 13	34-m R & D	5215524.541	35.0660180	243.2055410	6372125.096
DSS 14	70-m	5203996.968	35.2443523	243.1104618	6371993.267
DSS 15	34-m HEF	5204234.338	35.2403129	243.1128049	6371966.511
DSS 24	34-m BWG	5209482.543	35.1585346	243.1252056	6371973.601
DSS 25	34-m BWG	5209635.569	35.1562591	243.1246368	6371982.537
DSS 26	34-m BWG	5209766.354	35.1543409	243.1269835	6371992.264
DSS 34[1]	34-m BWG	5205508.011	-35.2169824	148.9819644	6371693.538
DSS 35[1]	34-m BWG	5205682.820	-35.2143051	148.9814558	6371697.358
DSS 36[1]	34-m BWG	5205719.750	-35.2136127	148.9785442	6371688.208
DSS 43	70-m	5205251.840	-35.2209189	148.9812673	6371688.998
DSS 45	34-m HEF	5205494.965	-35.2169608	148.9776856	6371675.873
DSS 54	34-m BWG	4862832.157	40.2357726	355.7459032	6370025.490
DSS 55	34-m BWG	4862913.938	40.2344478	355.7473667	6370007.988
DSS 63	70-m	4862450.835	40.2413554	355.7519915	6370051.198
DSS 65	34-m HEF	4862715.598	40.2373555	355.7493011	6370021.709

Notes:

1. Latitude, longitude, and radius absolute accuracy estimated to be +/-0.0000003 deg and +/-3 cm (0.030 m) (1-sigma) for each coordinate.

Table 7. DSN Stations Location Uncertainties

Antenna		Location Uncertainties (m, 1-sigma))		
Name	**Description**	**Spin Radius**	**Longitude**	**z**
DSS 13	34-m R & D	0.025	0.036	0.031
DSS 14	70-m	0.024	0.035	0.030
DSS 15	34-m HEF	0.023	0.035	0.030
DSS 24	34-m BWG	0.029	0.036	0.033
DSS 25	34-m BWG	0.029	0.036	0.033
DSS 26	34-m BWG	0.030	0.038	0.034
DSS 34	34-m BWG	0.030	0.030	0.030
DSS 35	34-m BWG	0.030	0.030	0.030
DSS 36	34-m BWG	0.030	0.030	0.030
DSS 43	70-m	0.026	0.035	0.032
DSS 45	34-m HEF	0.024	0.035	0.031
DSS 54	34-m BWG	0.032	0.036	0.034
DSS 55	34-m BWG	0.050	0.037	0.048
DSS 63	70-m	0.027	0.035	0.031
DSS 65	34-m HEF	0.026	0.034	0.030

2.2 Coverage and Mutual Visibility

The coverage and mutual visibility provided for spacecraft tracking depends on the altitude of the spacecraft, the particular antenna being used, the blockage of the antenna beam by the land mask and structures in the immediate vicinity of the antennas, and whether simultaneous uplink coverage is required. Receive limits are governed by the mechanical capabilities of the antennas and the terrain mask. Transmitter limits, on the other hand, are based on radiation hazard considerations to on-site personnel and the general public and are set above the terrain mask and the antenna mechanical limits.

2.2.1 Use of Transmitters Below Designated Elevation Limits

Requests for coordination to relinquish the transmitter radiation restrictions will be considered for spacecraft emergency conditions or for critical mission support requirements (conditions where low elevation or high-power transmitter radiation is critical to mission objectives). In either event, the uplink radiation power should be selected as the minimum needed for reliable spacecraft support. In general, there is no transmission allowed below 10.2-10.5 degrees elevation by any antenna at any power level. Additionally, at DSS-43 the 400-kW transmitter may not be used below 17-degrees elevation angle at any power level, and special airspace coordination is required at powers above 100 kW. The JPL internal document 842-40-321 (Rev. D and later) should be consulted when it is necessary to determine the airspace restrictions and azimuth and elevation limits for the various stations.

2.2.1.1 Spacecraft Emergencies

The need for violation of transmitter radiation restrictions to support a spacecraft emergency will be determined by the DSN. The restrictions will be released after assuring that appropriate local authorities have been notified and precautions have been taken to ensure the safety of both on-site and off-site personnel.

2.2.1.2 Critical Mission Support

If critical mission activities require the transmitter radiation restrictions to be violated, the project is responsible for notifying the DSN through their normal point of contact three months before the activity is scheduled. The request must include enough information to enable the DSN to support it before the appropriate authorities. Requests made less than three months in advance will be supported on a best-efforts basis and will have a lower probability of receiving permission to transmit. Requests will be accepted or denied a minimum of two weeks before the planned activity.

2.2.2 Mechanical Limits on Surveillance Visibility

All DSN antennas have areas of non-coverage caused by mechanical limits of the antennas. The first area is the mechanical elevation limit, which is approximately six degrees for antennas using an azimuth-elevation mount. A second area of non-coverage is an area immediately above the antenna referred to as the *keyhole*.

The keyhole of the DSN azimuth-elevation antennas is directly overhead and results from the fact that high azimuth angular rates are needed to track spacecraft passing nearly overhead, at zenith. For the 70-m antennas, with a maximum azimuth tracking rate of 0.25 deg/sec, spacecraft can be tracked continuously to an elevation of about 89 degrees. For the 34-m antennas, with a maximum azimuth tracking rate of 0.4 deg/sec, spacecraft can be tracked continuously to a maximum elevation of about 89.5 degrees. Thus, the size of the keyhole depends on how fast the antenna can be slewed in azimuth. Specifications on antenna motion are contained in module 302, Antenna Positioning. The locations of the DSN antennas are such that overhead tracks are not required for spacecraft operating near the plane of the ecliptic.

The DSN azimuth-elevation antennas have an additional restriction on antenna motion caused by the routing path of cables and hoses between the fixed and rotating portions of the antenna. This azimuth cable wrap has no effect on surveillance visibility but does place a restriction on the time between tracks due to the requirement to unwind the cables. Table 8 provides the approximate cable wrap limits for the DSN azimuth-elevation antennas.

Table 8. Approximate Cable Wrap Limits for Azimuth-Elevation Antennas

Antenna		Azimuth Position (Degrees)		
Name(s)	**Description**	**Center of Wrap**	**Clockwise (CW) Limit**	**Counterclockwise (CCW) Limit**
DSS 14, 63	70-m	45	310	140
DSS 43	70-m	135	40	230
DSS 15, 65	34-m HEF	135	360	270
DSS 45	34-m HEF	45	270	180
DSS 24, 25, 26, 54, 55	34-m BWG	135	360	270
DSS 34, 35, 36	34-m BWG	45	270	180

2.2.3 Coverage Charts

The following figures provide examples of coverage for various combinations of stations, spacecraft altitudes, and type of support. The coverage limits in these figures were plotted by a program written as a collection of Microsoft Excel macros with shading and labels added for publication. The latest version of this program combines the capability to draw the coverage charts with the capability to plot the station horizon masks and is available for download from the 810-005 web site < http://deepspace.jpl.nasa.gov/dsndocs/810-005/>. The file includes a spreadsheet with the antenna coordinates and mask data used to create the figures.

2.2.3.1 70-m Receive Coverage of Planetary Spacecraft

Figure 2 illustrates the receive coverage of planetary spacecraft by the DSN 70-m antenna subnet. The small ovals at each antenna location on the figure represent the 70-m antenna keyholes above each station and are approximately to scale.

2.2.3.2 70-m Transmit Coverage of Planetary Spacecraft

Figure 3 illustrates the transmit coverage of planetary spacecraft by the DSN 70-m antenna subnet using a 10.4-degree transmit elevation limit at DSS 14 and a 10.2-degree transmit elevation limit at DSS 43 and DSS 63. The small ovals at the antenna locations on the figure represent the 70-m antenna keyholes. The reduced coverage to the west of DSS 63 is caused by the need to have a 20.2-degree elevation limit to protect the high ground to the northwest of the station.

2.2.3.3 34-m HEF Receive Coverage of Planetary Spacecraft

Figure 4 illustrates the receive coverage of planetary spacecraft by the DSN 34-m HEF antenna subnet. The keyhole above each 34-m HEF antenna is very small and is somewhat exaggerated for clarity on the maps. This chart is very similar to Figure 2 but is included to show that the location of DSS 65 shifts the apparent position of the high ground to the north and west of where it is observed from DSS 63.

2.2.3.4 34-m HEF Transmit Coverage of Planetary Spacecraft

Figure 5 illustrates the transmit coverage of planetary spacecraft by the DSN 34-m HEF antenna subnet. As is the case in Figure 4, the size of the circles used to indicate the keyholes on the map are larger than the actual size of the 34-m HEF antenna keyholes. The transmit elevation limit is 10.6-degrees at DSS 15 and 10.5-degrees at DSS 45. At DSS 65, the transmit limit is 10.3 degrees but it is increased to 14.0 degrees when the antenna is pointed in a northerly direction from 326.6 to 355.1 degrees azimuth and again from 24.1 to 50.9 degrees azimuth. This is done to clear the hills to the north, north-west and other antennas to the north, north-east of DSS 65’s new location.

2.2.3.5 34-m BWG Receive Coverage of Planetary Spacecraft

Figure 6 illustrates the receive coverage of planetary spacecraft by a subnet of DSN 34-m BWG antennas capable of supporting X and Ka bands. As is the case with the other 34-m antennas, the size of the keyhole circles on the map is larger than the actual size of the antenna keyholes. This chart is very similar to Figures 2 and 4 but is included to show that the location of DSS 55 shifts the apparent position of the high ground to where it does not significantly affect tracking coverage.

2.2.3.6 34-m BWG Transmit Coverage of Planetary Spacecraft

Figure 7 illustrates the transmit coverage of planetary spacecraft by the same subnet of 34-m BWG antennas (DSS 26, 34, and 55) shown in Figure 6. DSS 55 is sited southeast of DSS 54 at a slightly lower elevation. To allow an adequate clearance above DSS 54 for the DSS 55 transmitter pencil beam, an 18.36-degree lower elevation limit is placed on the DSS 55 transmitter between 304.9 and 360 degrees. Figure 8 is included primarily to show the effect of substituting DSS 54 for DSS 55. There is no significant coverage difference between any of the 3 Goldstone BWG stations. Coverage by DSS 54 between 344.4 and 8.5 degrees azimuth is limited to elevations above 13.3 degrees in order to protect the high ground north-west of the station.

2.2.3.7 34-m BWG Receive Coverage of Near Earth Spacecraft

Figure 9 illustrates the receive coverage of near-Earth spacecraft by the DSN 34-m BWG antennas at altitudes of 500 km, 5000 km, and geosynchronous (35789 km) using the near-Earth support stations, DSS 24, 34, and 54. As is the case with the other 34-m antennas, the size of the keyhole circles on the map is larger than the actual size of the antenna keyholes. It should be noted that by lunar distance, the coverage is essentially the same as the planetary coverage shown in Figure 6.

2.2.3.8 34-m BWG Transmit Coverage of Near Earth Spacecraft

Figure 10 illustrates the transmit coverage of near-Earth spacecraft by the DSN 34-m BWG antennas at altitudes of 500 km, 5000 km, and geosynchronous (35789 km) using the near-Earth support stations. As is the case with Figure 11, the keyholes are shown larger than actual size and coverage at lunar distance is essentially the same as the planetary coverage shown In Figure 7.

2.2.4 Horizon Masks and Antenna Limits

Figures 11 through 24 show the horizon mask and transmitter limits for all DSN stations. Figure 18 has been added to show the receive and transmit horizon masks for new Australian antenna DSS-36, based on radiometric measurements made in 2016. The transmitter limits are identified as the L/P (low power) transmitter mask or the H/P (high power) transmitter mask depending on the type of transmitter that is available. Only DSS-43 has both an L/P and H/P transmitter, but all stations use the same elevation limits for all their transmitters. In general, the absolute lower elevation limit for uplink transmission is 10.0 degrees, unless a higher limit is required to clear terrain or some other obstruction. The dotted line curves in the figures, which should be used for PLANNING purposes, include interlock position uncertainties of as much as 0.5 degrees so as to guarantee that there is no transmission at an elevation angle less than 10.0 degrees or closer than some safe distance (at least several meters) above an elevated horizon. At DSS-43 the 400-kW high-power transmitter may not be used below 17-degrees elevation angle at any power level, and special airspace coordination is required at powers above 100 kW. See also Section 2.1.1.

The masks and limits are the ones used to establish the coverage depicted in Figures 2 through 10. Each chart shows antenna coordinates in two coordinate systems. For all DSN antennas, the coordinate systems are azimuth-elevation and hour angle-declination.

Charts showing hour angle-declination coordinates can be used to provide an elevation profile (for estimating antenna gain and noise temperature) for spacecraft at planetary distances where the declination remains constant for an entire tracking pass. The hour angle curves on these charts have been spaced at increments of 15 degrees so that pass length may conveniently be estimated. These figures were plotted by a program written as a collection of Microsoft Excel macros. The program has recently been merged into the coverage program discussed in paragraph 2.2.3 so that a single database of station data can be used for both sets of plots.

The mask data for all antennas, except the three Canberra BWG antennas, represent measurements made from the lower edge of the antenna and in general were measured at 1-degree azimuth increments with added points where structures affect the mask between the 1-degree points. For actual spacecraft tracking that can rise or set at any azimuth, a set of smoothed polynomials has been created for each station that approximates the land mask both at and between the measured points. This can result in small errors when the polynomials are evaluated at the measured points. These errors are always less than 0.1 degree and in most cases are less than 0.02 degrees.

The receive horizon masks for DSS-34, DSS-35, and DSS-36, Figures 16 thru 18, were measured by radiometric techniques to determine the actual antenna elevation angle where the increase in system noise temperature due to the beam impinging upon the terrain, and the accompanying blockage of the beam, would create an antenna G/T degradation that would make reliable spacecraft tracking impossible. The noise temperature increase chosen to define the receive horizon was +50 K, which would result in an approximately 3 dB increase in system noise temperature, and a 1 dB decrease of gain, resulting in a total G/T degradation of about 4 dB. Because of configuration changes to DSS-35, only the DSS-34 and DSS-36 receive horizons are determined by this method. The DSS-35 receive horizon was modeled from the existing +2.5 K noise contour by lowering that profile by 2 degrees. Future radiometric measurements on DSS-35 will determine a more accurate receive horizon. The transmit horizon masks were determined by the azimuth profile where the system noise temperature increase was 2.5 K, where the lower edge of the beam was just touching the terrain. An additional 0.5 degrees elevation was added to account for interlock position uncertainties. The transmit profiles for DSS-34 and DSS-35 were squared-off so that the beam clearance was 0.5 degrees above the highest obstacle, dropping down to 10.5 degrees at azimuths where the 10.5 degree elevation was 0.5 degrees above the +2.5 K profile, or about 2-3 degrees above the receive mask. The transmit horizon mask for DSS-36, Figure 18, was also measured by radiometric means, but the transmit mask is now a continuous function of azimuth, and the transmitter lower limits will have these values, defined by a set of polynomials, each over small ranges of azimuth.

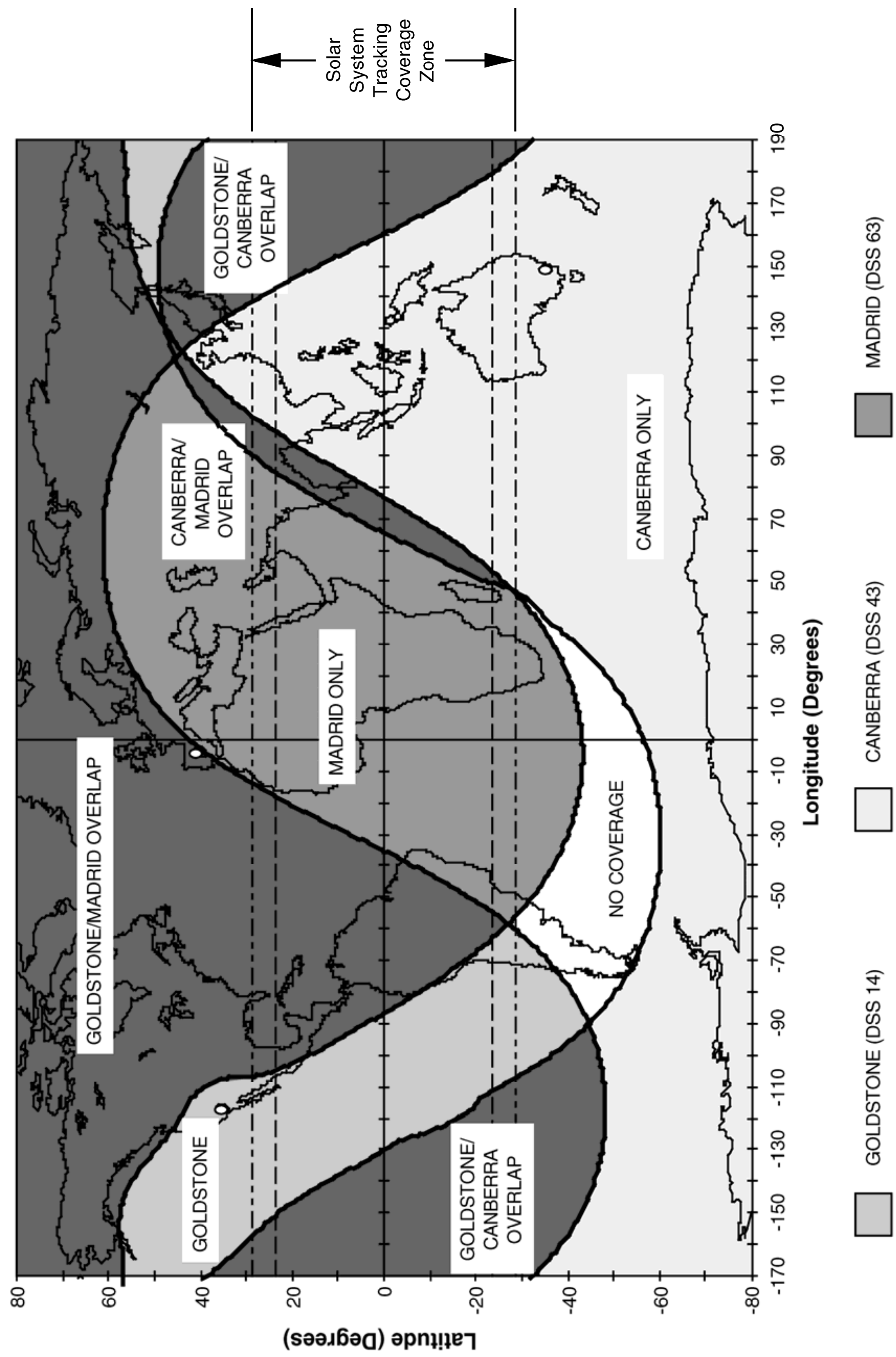
Solar System Tracking Coverage Zone
GOLDSTONE/MADRID OVERLAP
GOLDSTONE
GOLDSTONE/CANBERRA OVERLAP
CANBERRA/MADRID OVERLAP
MADRID ONLY
NO COVERAGE
CANBERRA ONLY
GOLDSTONE/CANBERRA OVERLAP
Latitude (Degrees)
80
60
40
20
0
-20
-40
-60
-80
Longitude (Degrees)
-170
-150
-130
-110
-90
-70
-50
-30
-10
10
30
50
70
90
110
130
150
170
190
GOLDSTONE (DSS 14)
CANBERRA (DSS 43)
MADRID (DSS 63)

Figure 2. DSN 70-m Subnet Receive Coverage, Planetary Spacecraft.

Figure 2. DSN 70-m Subnet Receive Coverage, Planetary Spacecraft

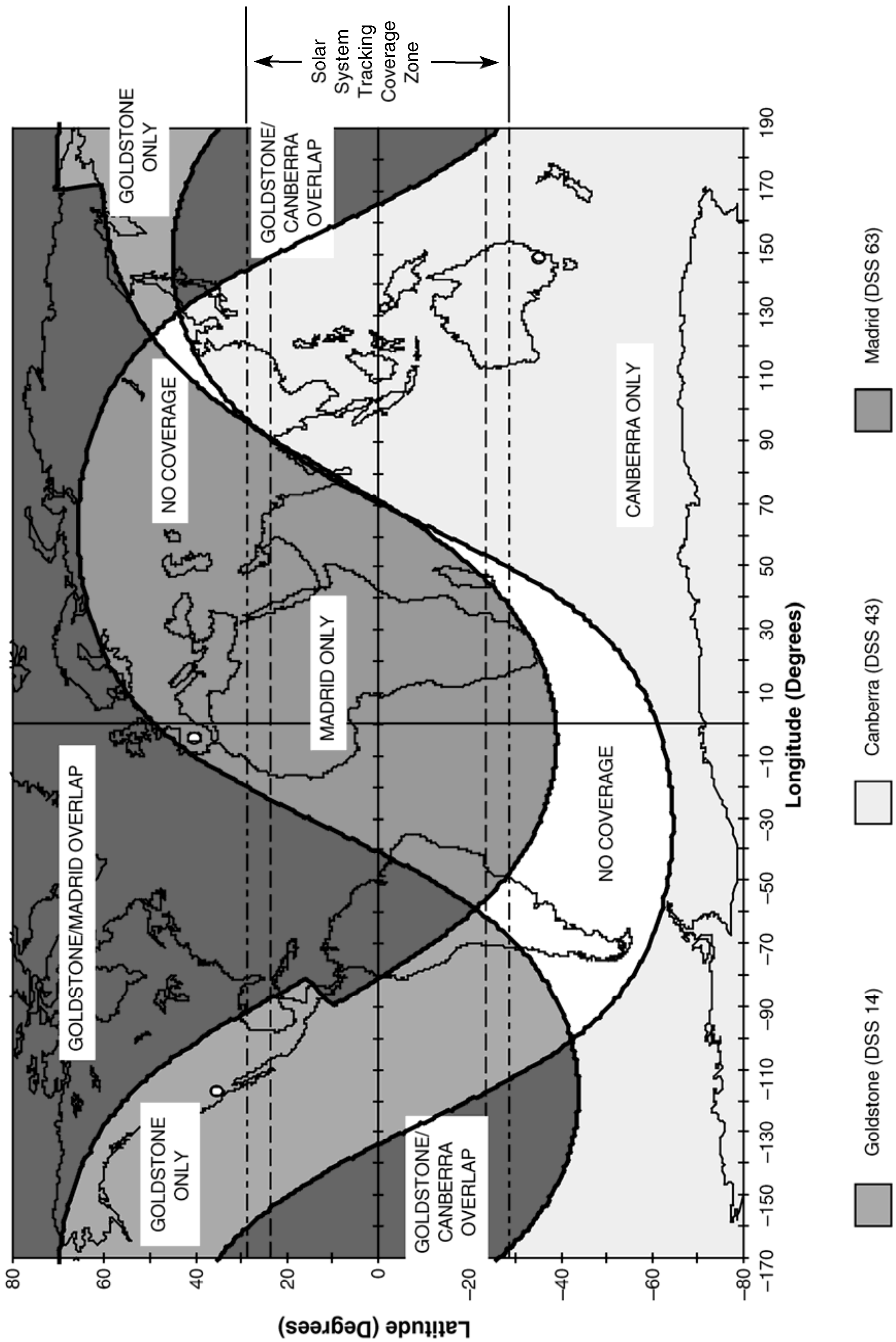

Figure 3. DSN 70-m Subnet Transmit Coverage, Planetary Spacecraft.

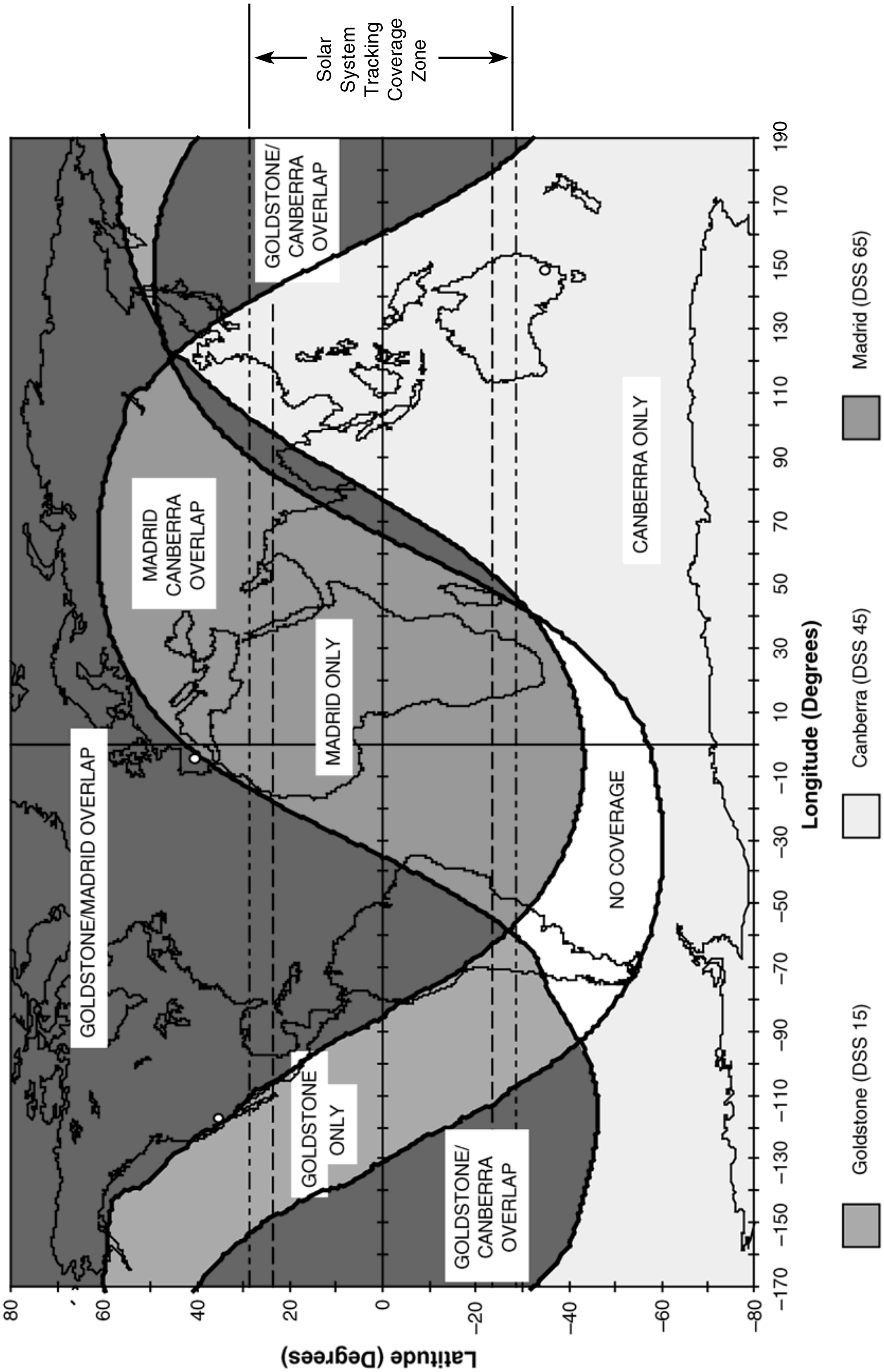

Figure 4. DSN 34-m HEF Subnet Receive Coverage, Planetary Spacecraft.

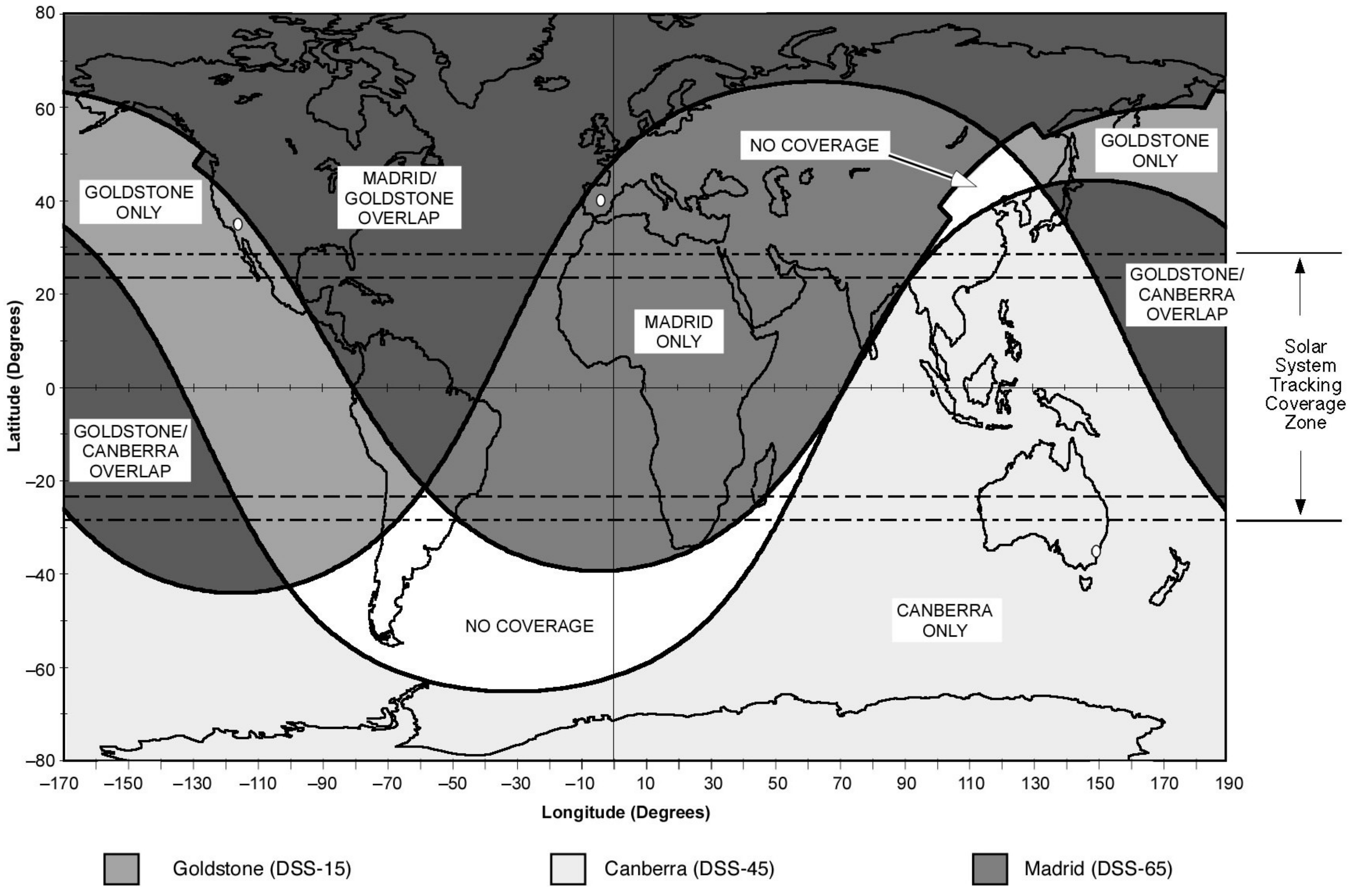

Figure 5. DSN 34-m HEF Subnet Transmit Coverage, Planetary Spacecraft

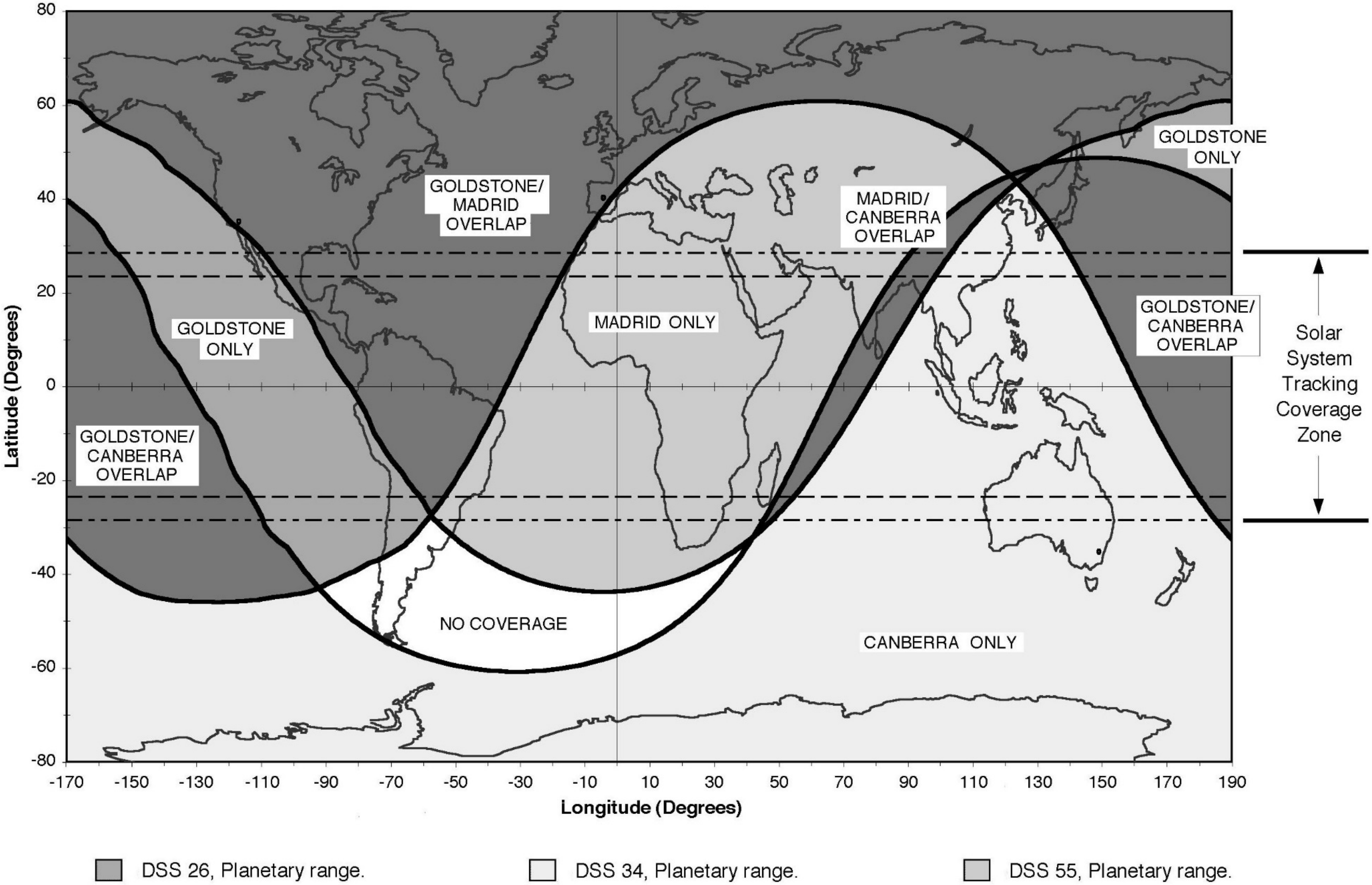

Figure 6. DSN 34-m BWG Antennas Receive Coverage, Planetary Spacecraft, Using DSS 26, 34, and 55

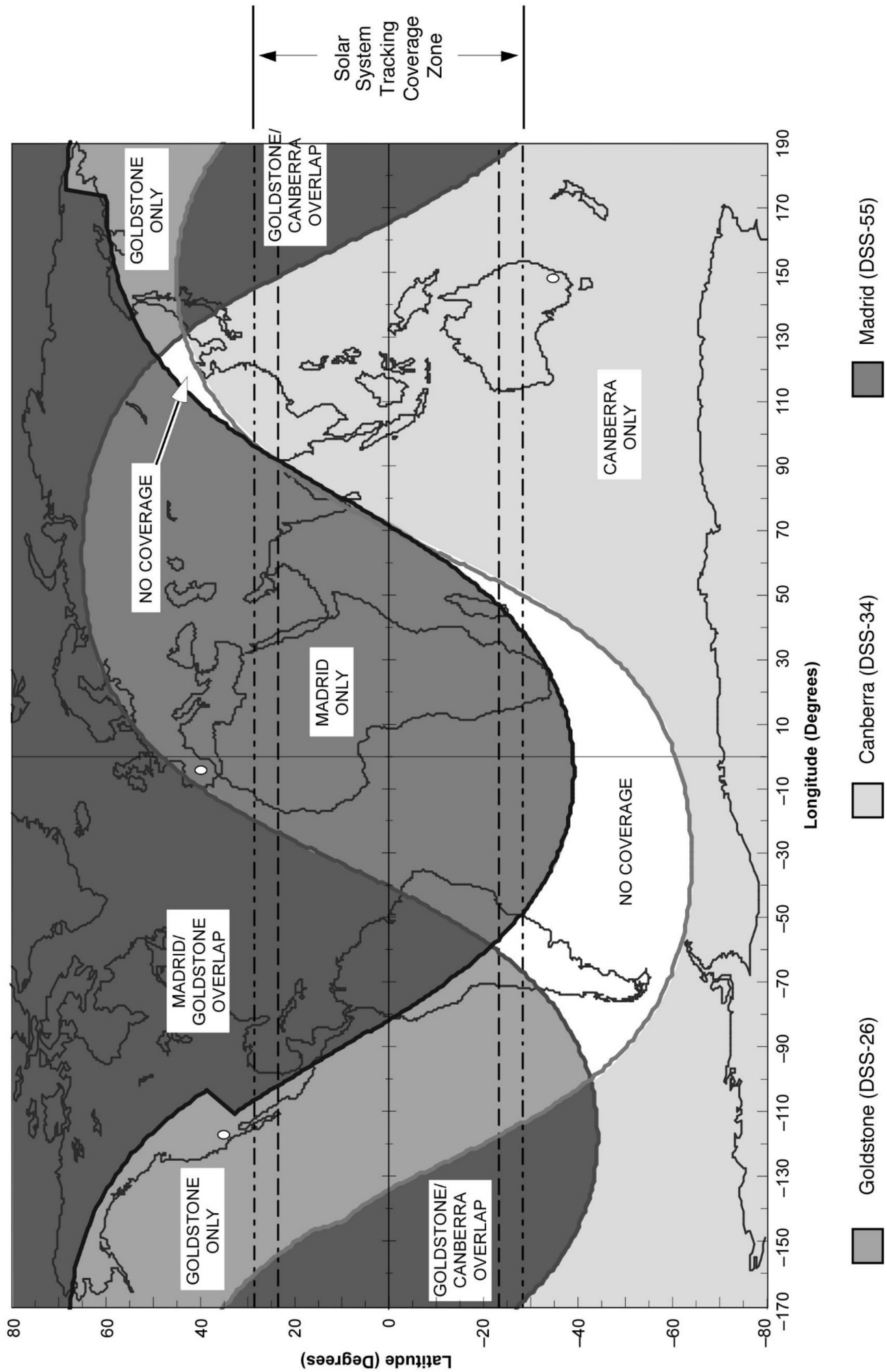

Figure 7. DSN 34-m BWG Antennas Transmit Coverage, Planetary Spacecraft, Using DSS 26, 34, and 55.

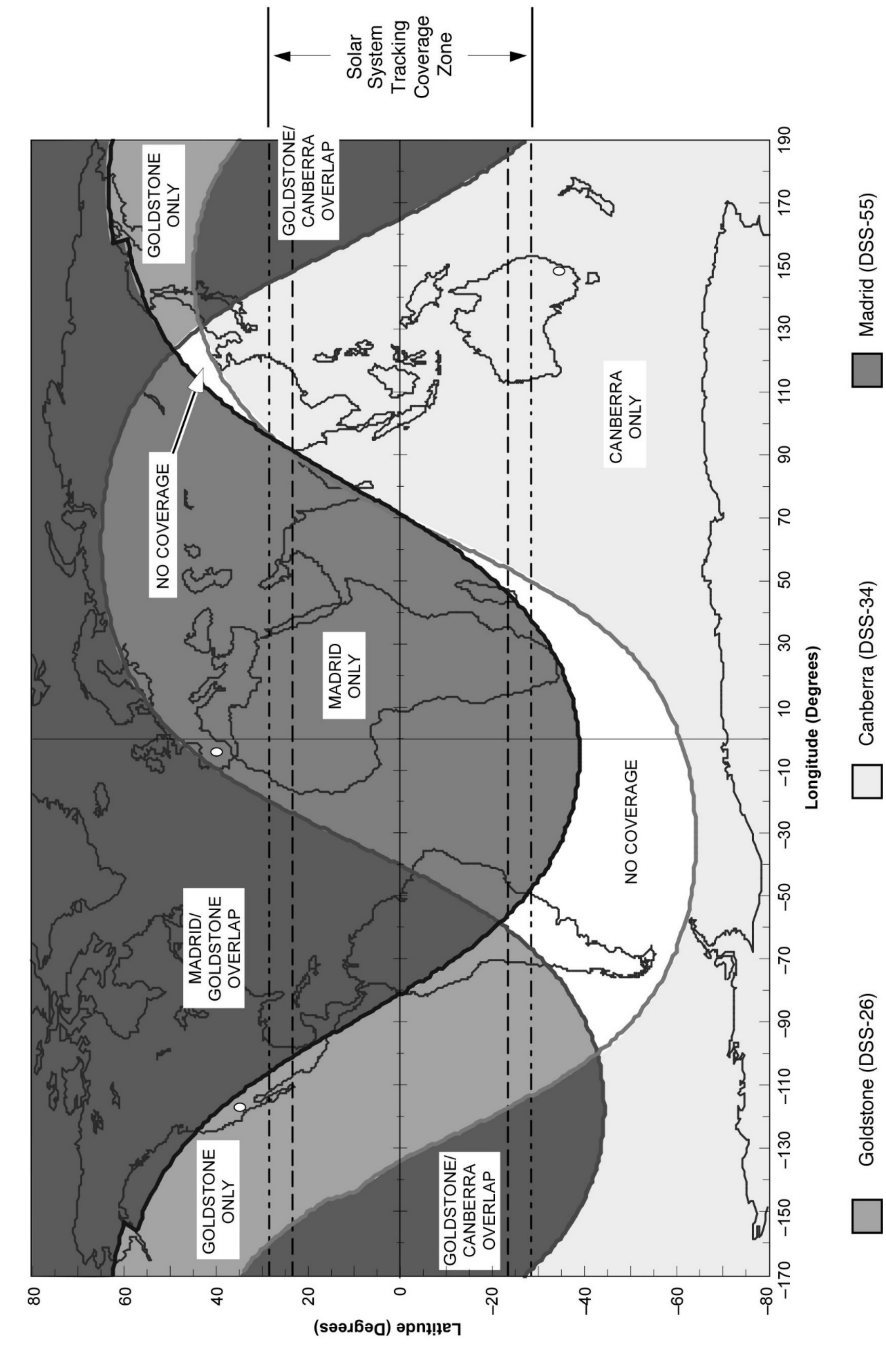

Figure 8. DSN 34-m BWG Antennas Transmit Coverage, Planetary Spacecraft, Using DSS 24, 34, and 54.

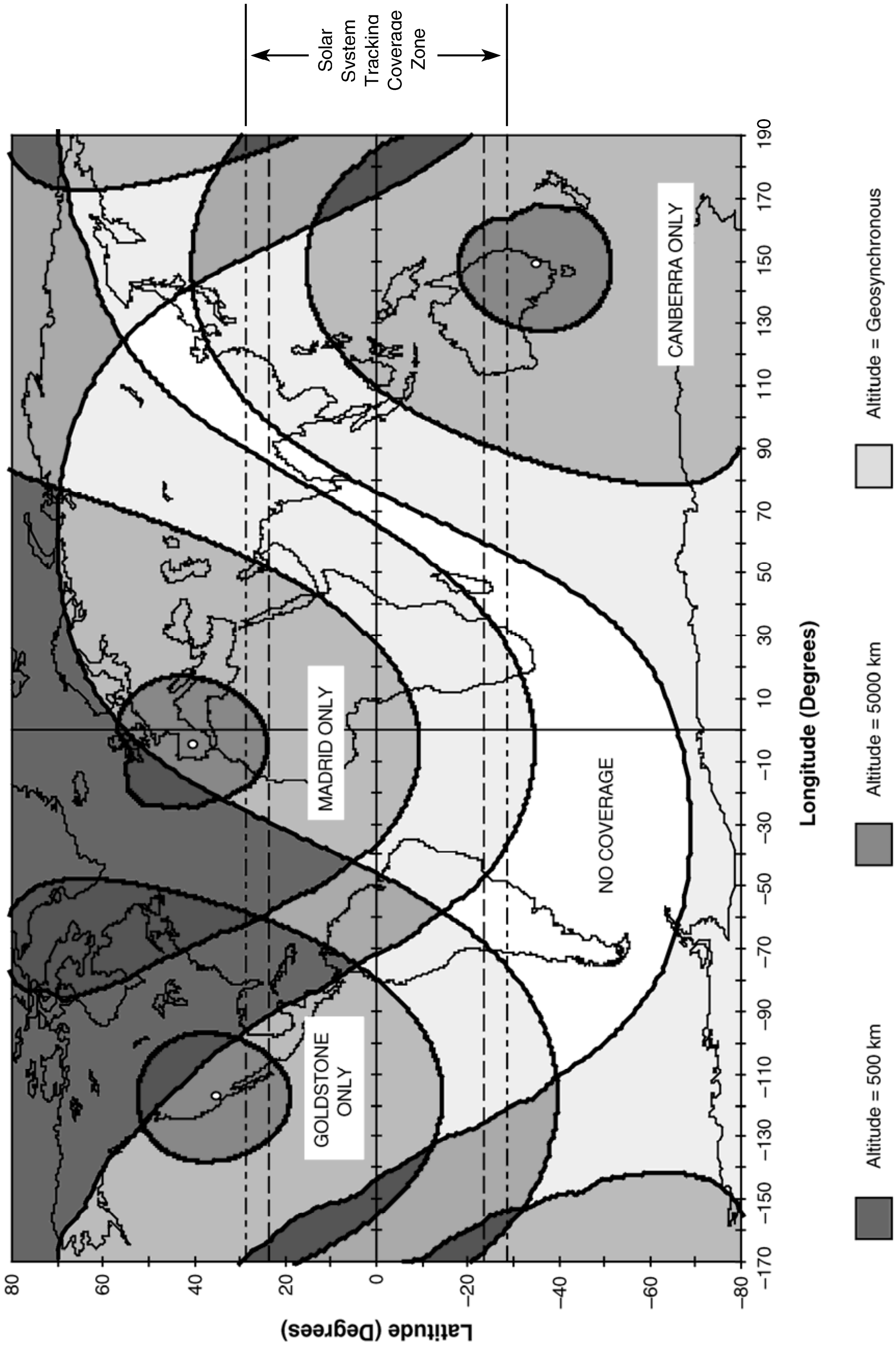

Figure 9. DSN 34-m BWG Antennas Receive Coverage, Near-Earth Spacecraft

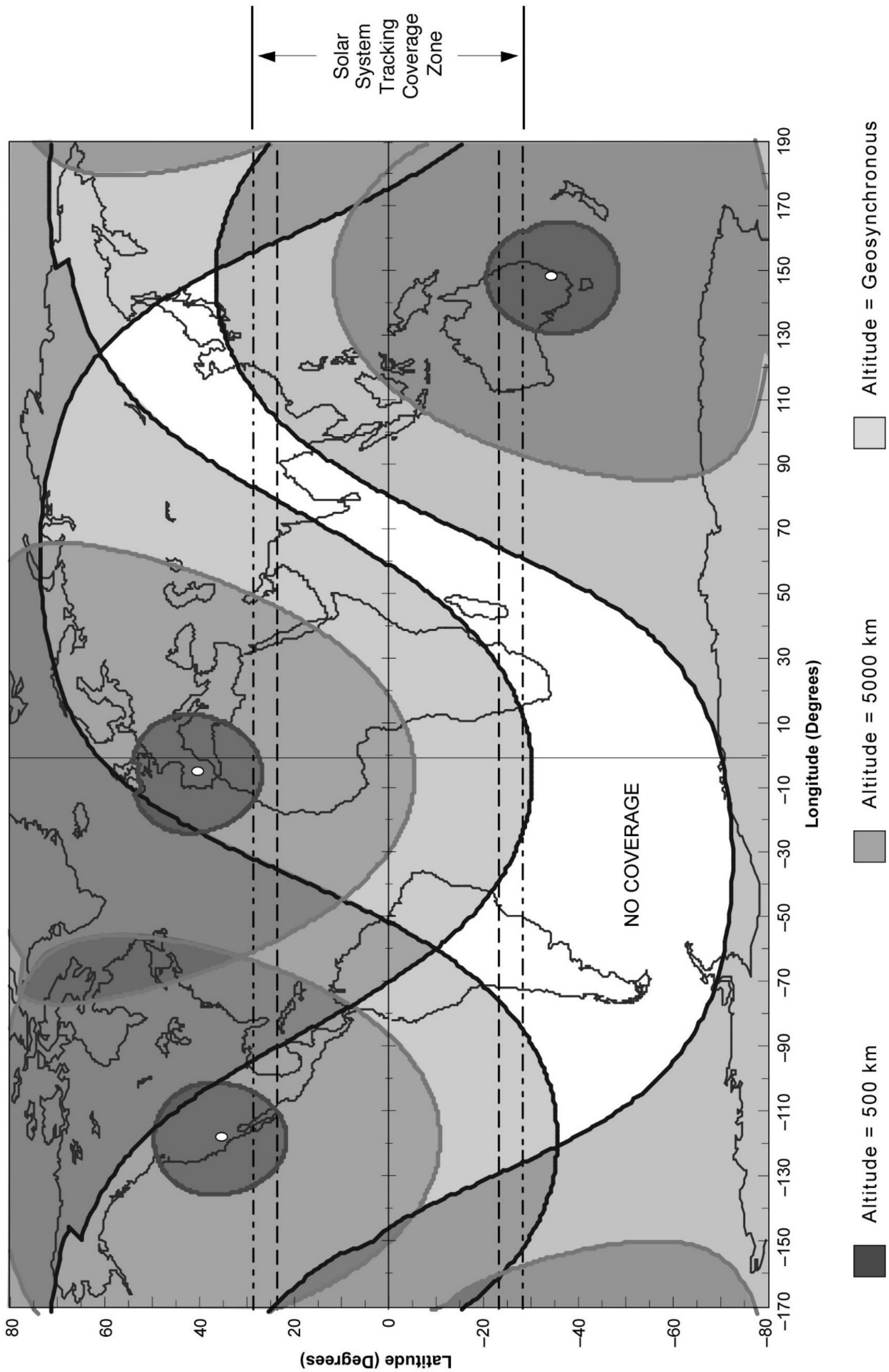

Figure 10 DSN 34-m BWG Antennas Transmit Coverage, Near-Earth Spacecraft

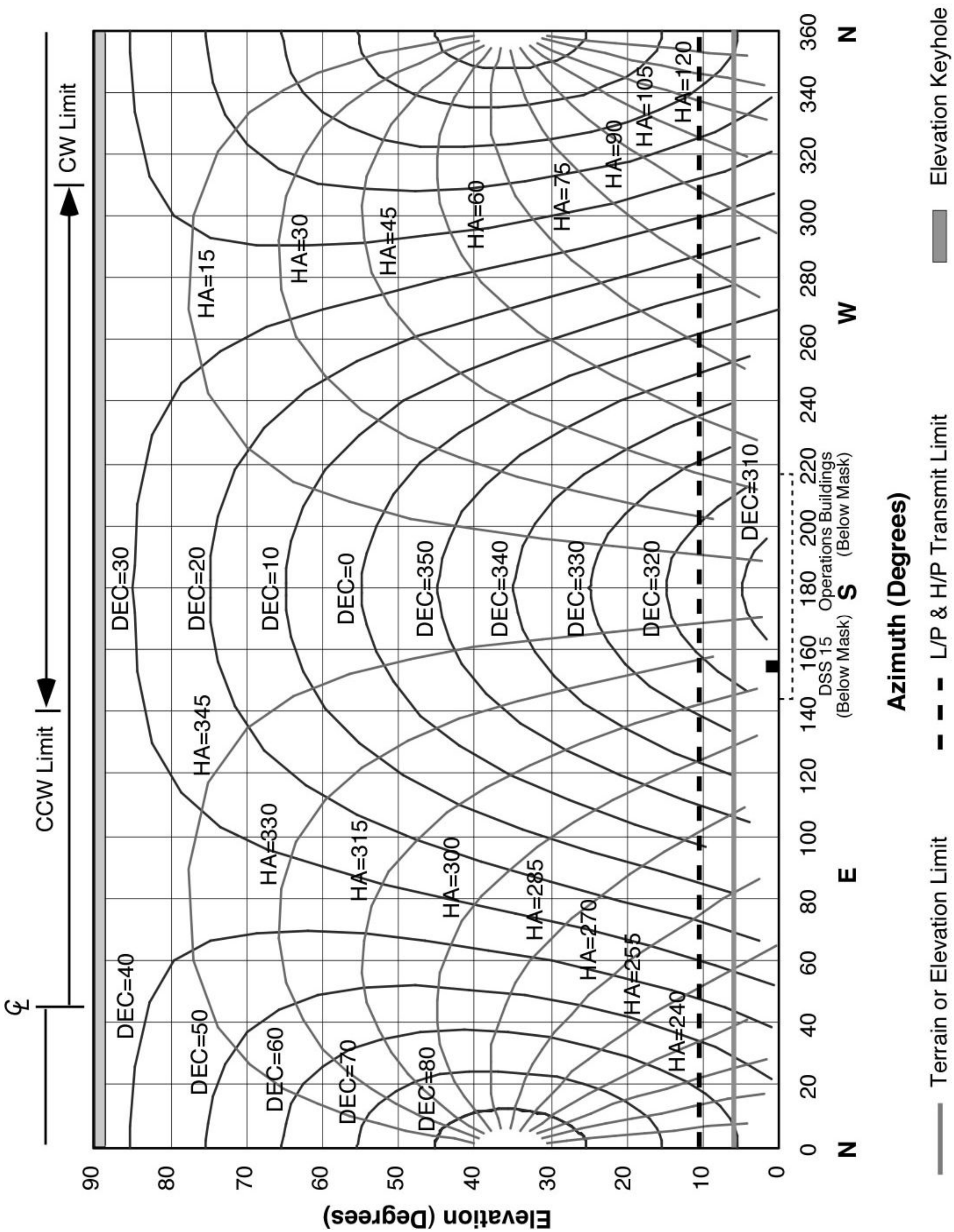

Figure 11. DSS 14 Hour-Angle and Declination Profiles and Horizon Mask

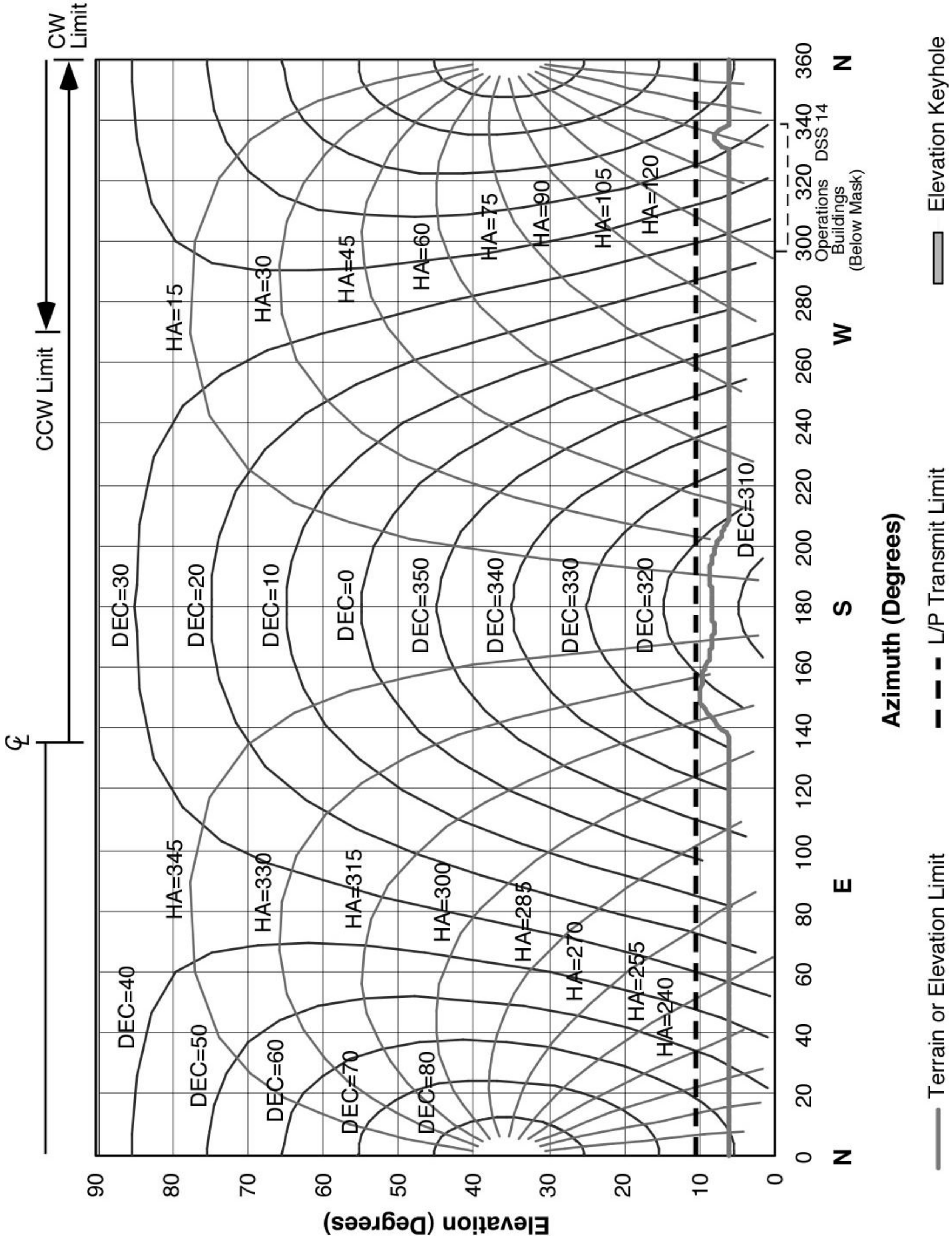

Figure 12. DSS 15 Hour-Angle and Declination Profiles and Horizon Mask

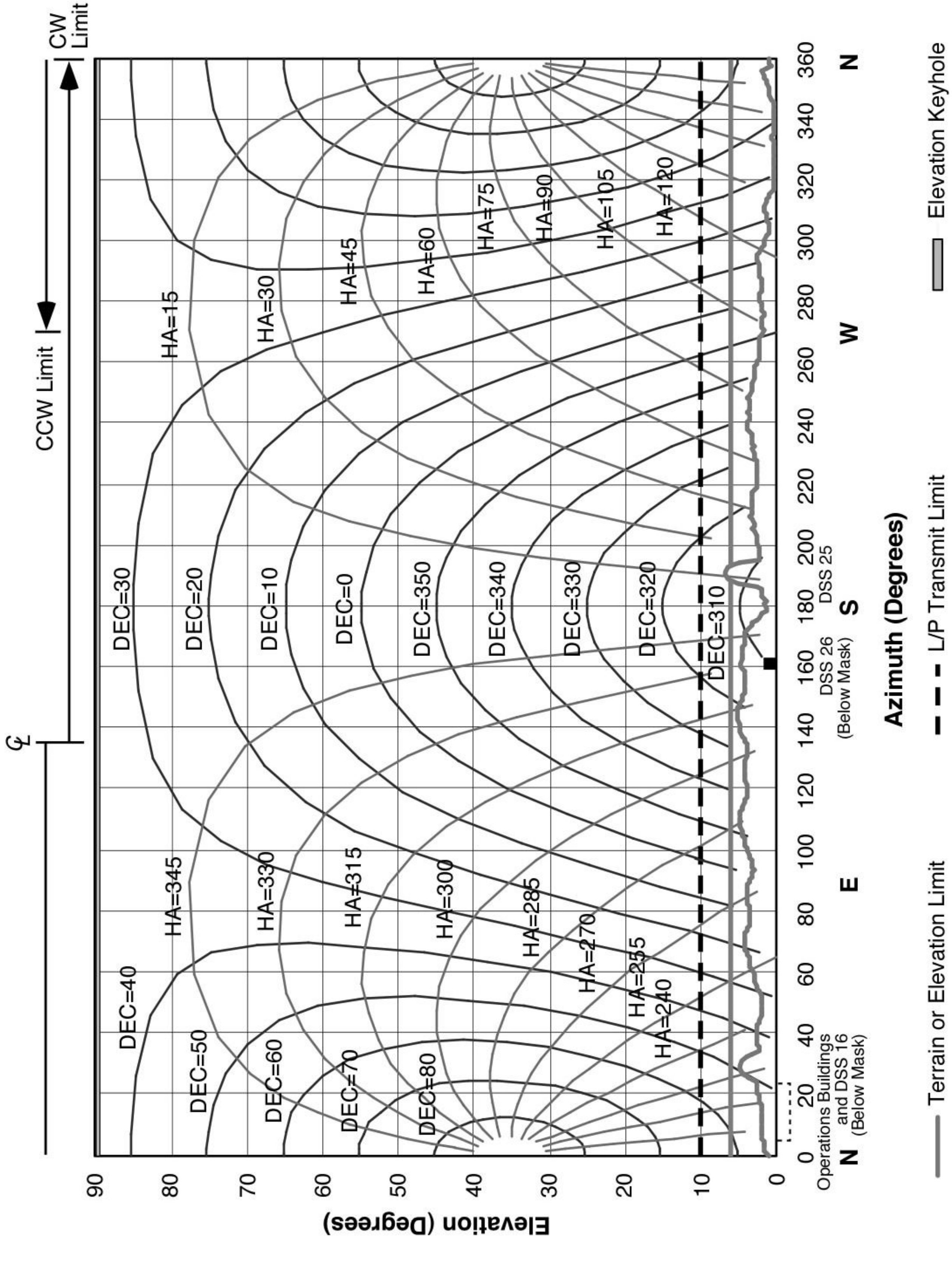

Figure 13. DSS 24 Hour-Angle and Declination Profiles and Horizon Mask

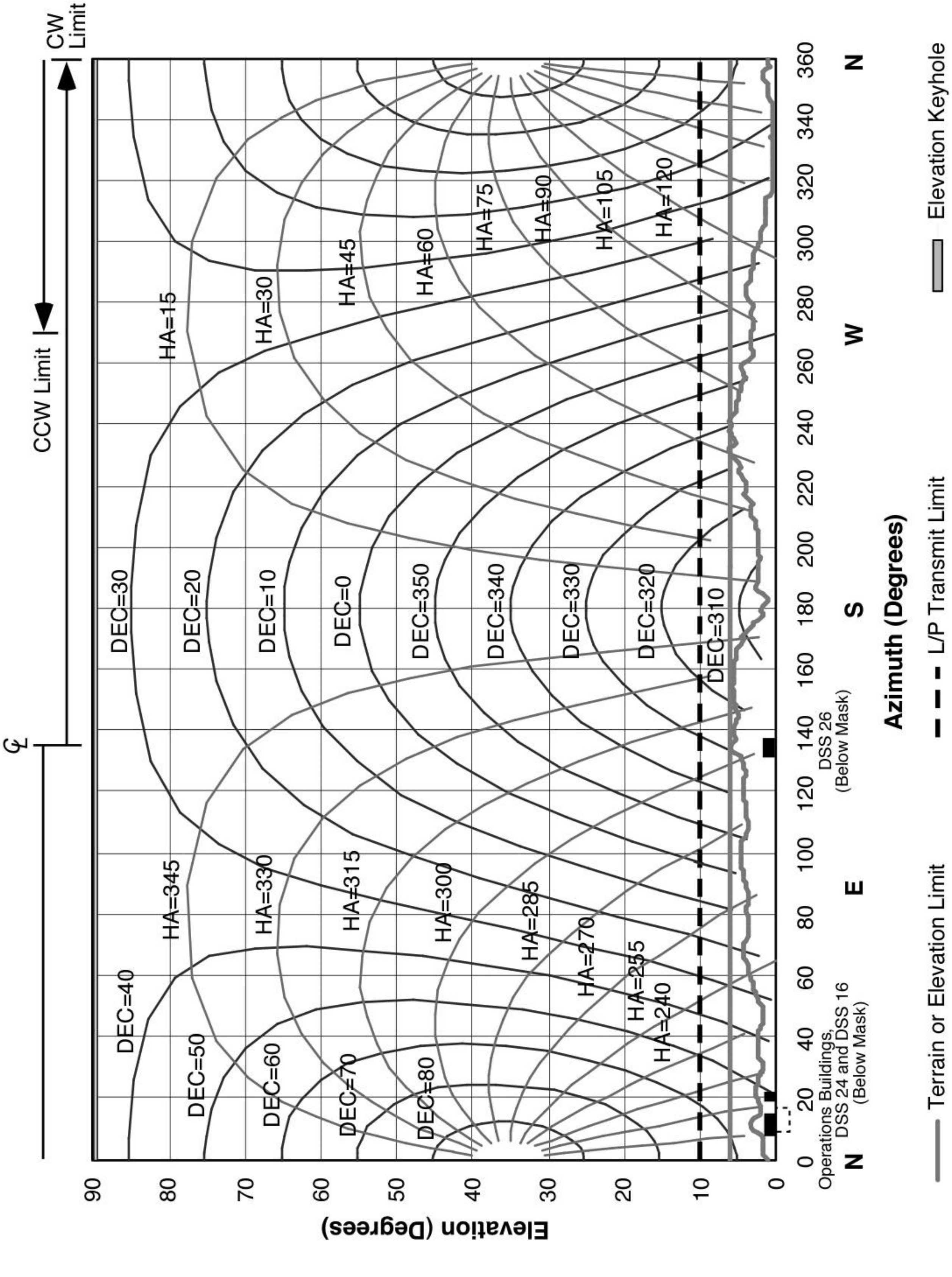

Figure 14. DSS 25 Hour-Angle and Declination Profiles and Horizon Mask

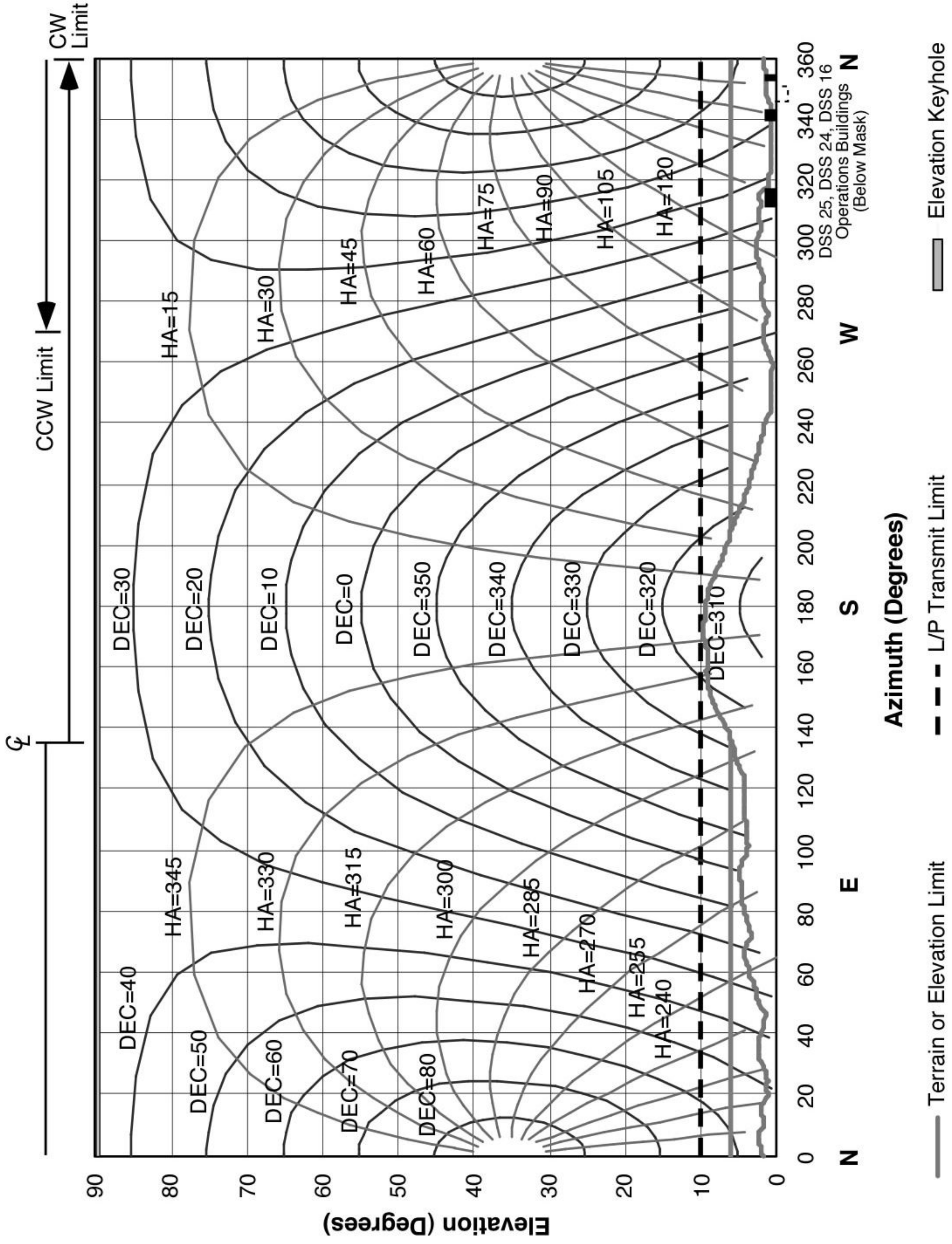

Figure 15. DSS 26 Hour-Angle and Declination Profiles and Horizon Mask

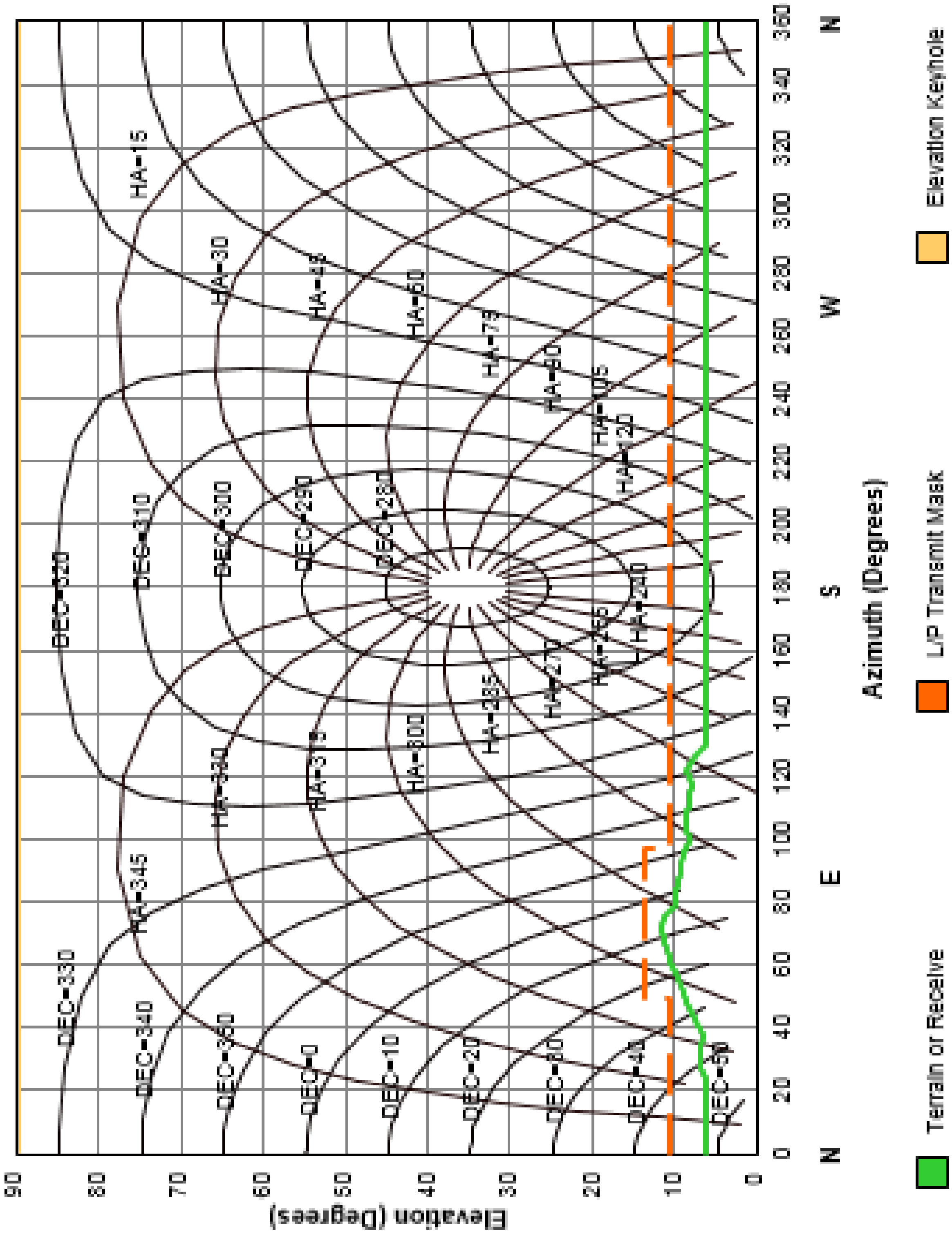

Figure 16. DSS 34 Hour-Angle and Declination Profiles and Horizon Mask

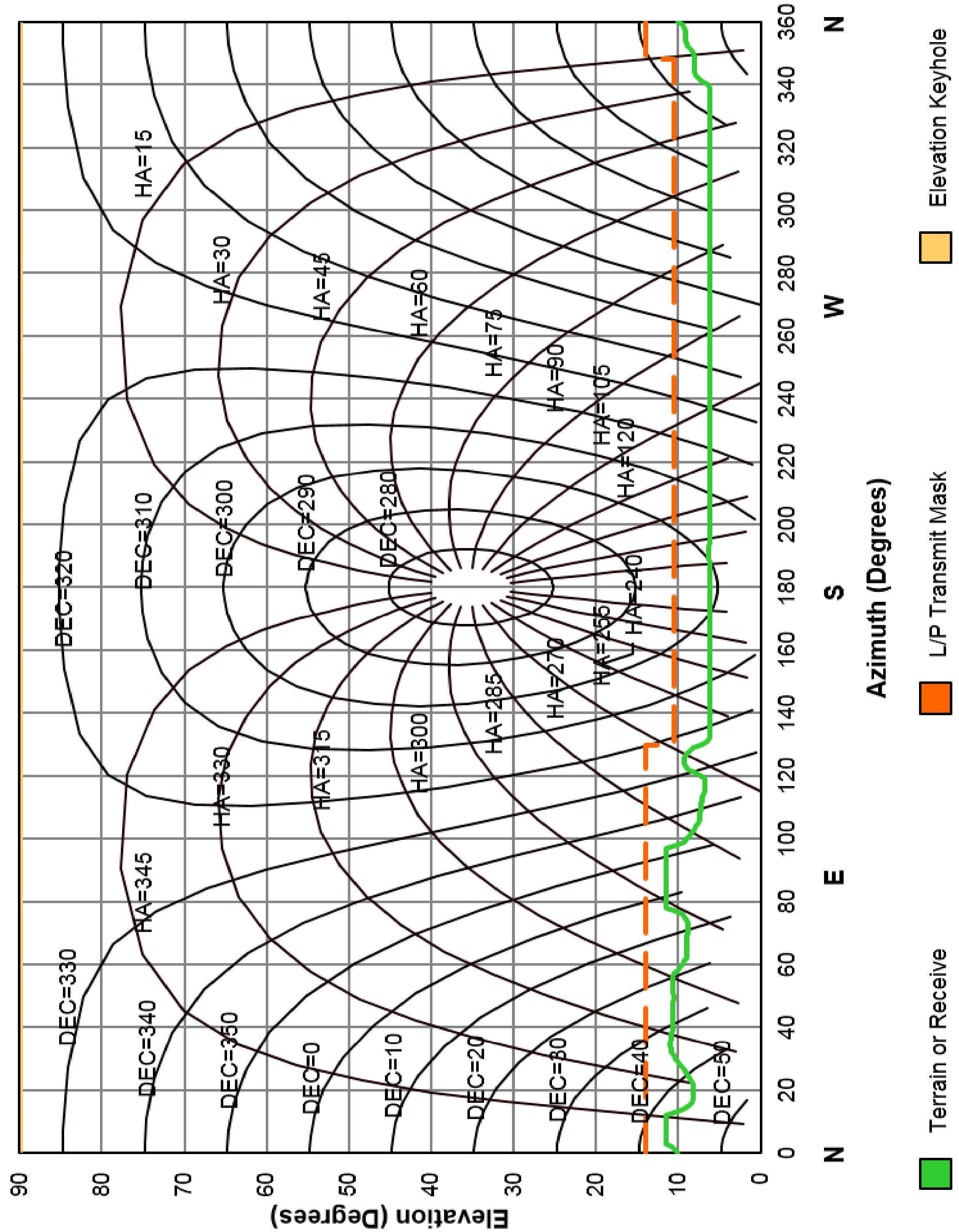

Figure 17. DSS 35 Hour-Angle and Declination Profiles and Horizon Mask

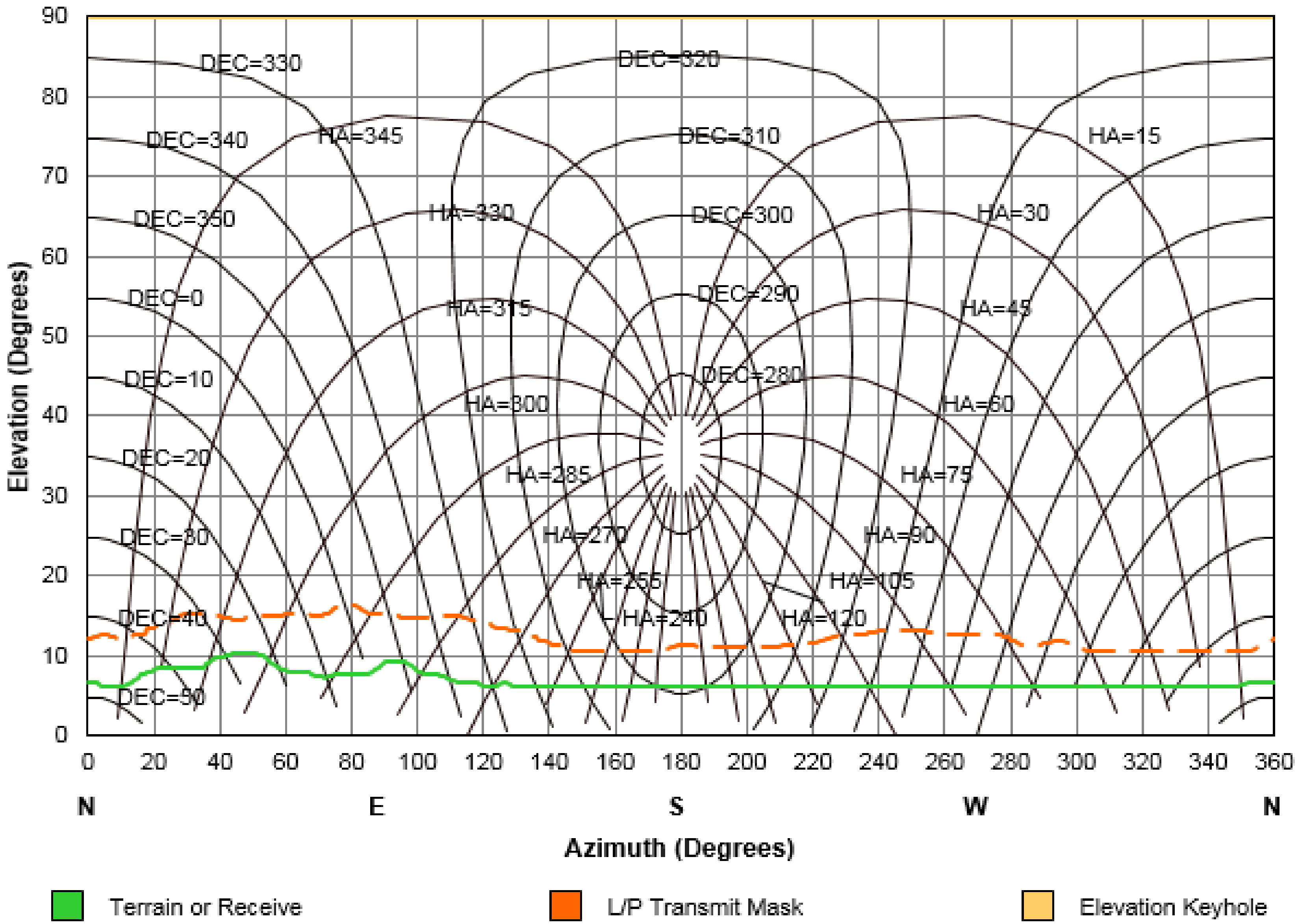

Figure 18. DSS 36 Hour-Angle and Declination Profiles and Horizon Mask

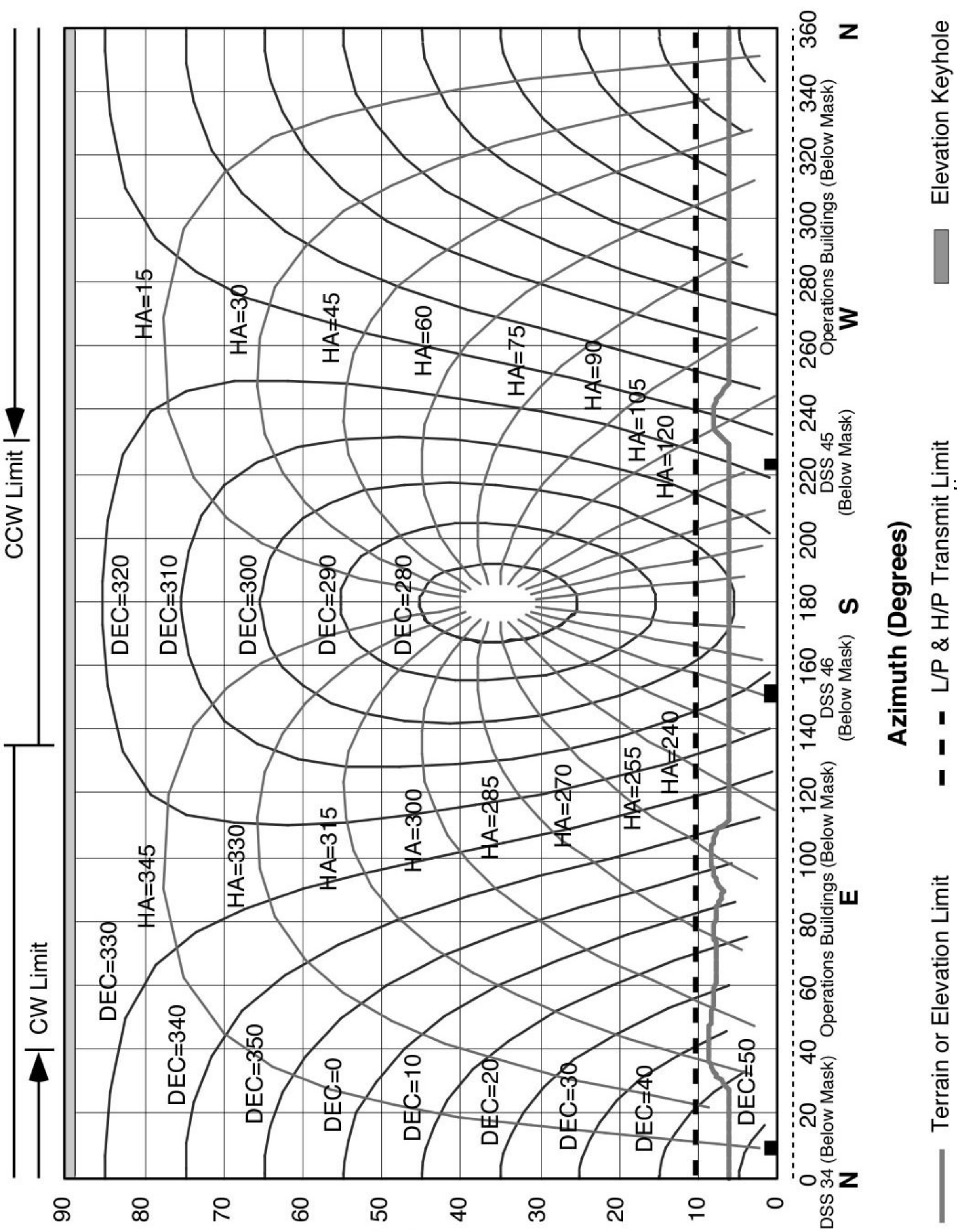

Figure 19. DSS 43 Hour-Angle and Declination Profiles and Horizon Mask

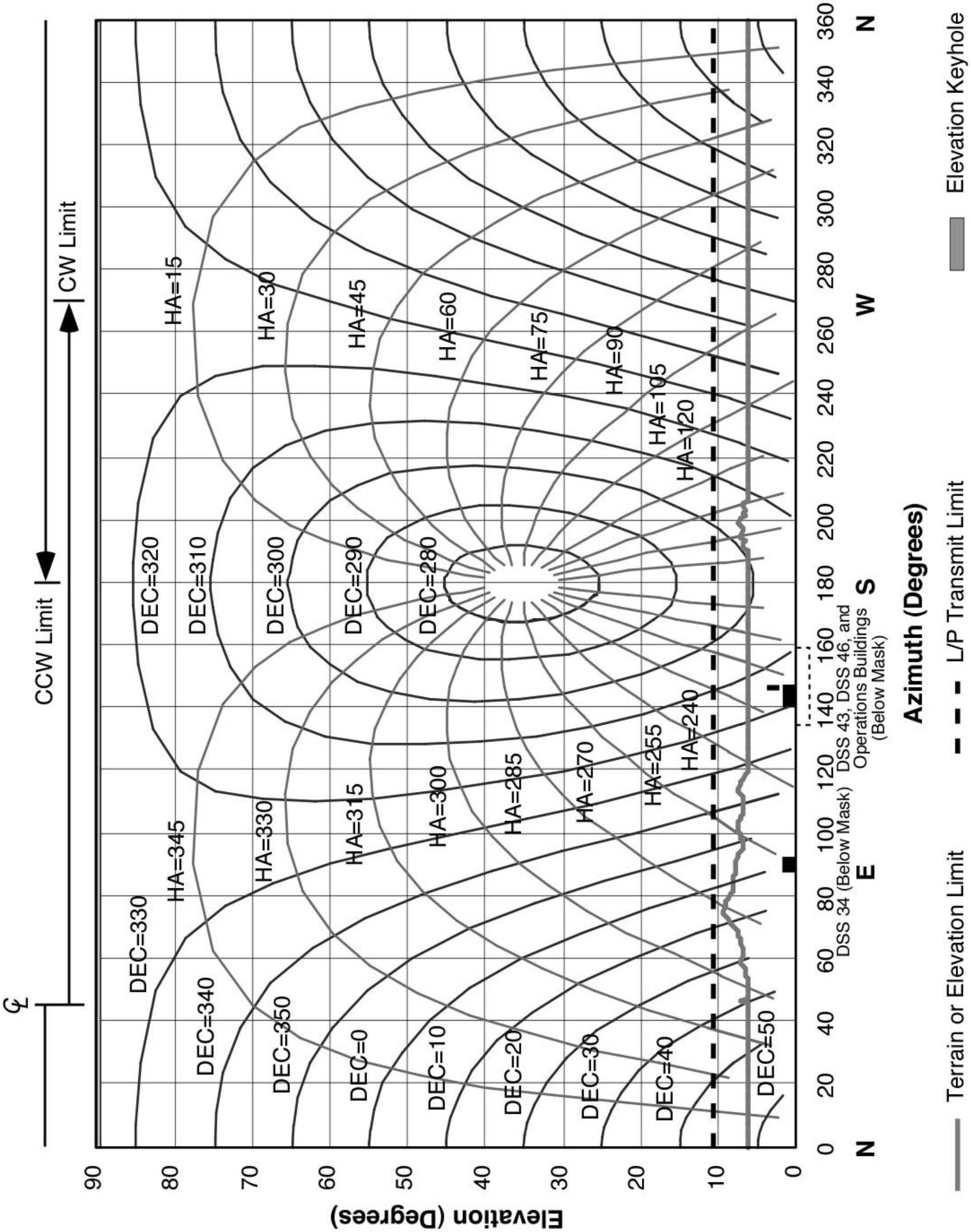

Figure 20. DSS 45 Hour-Angle and Declination Profiles and Horizon Mask

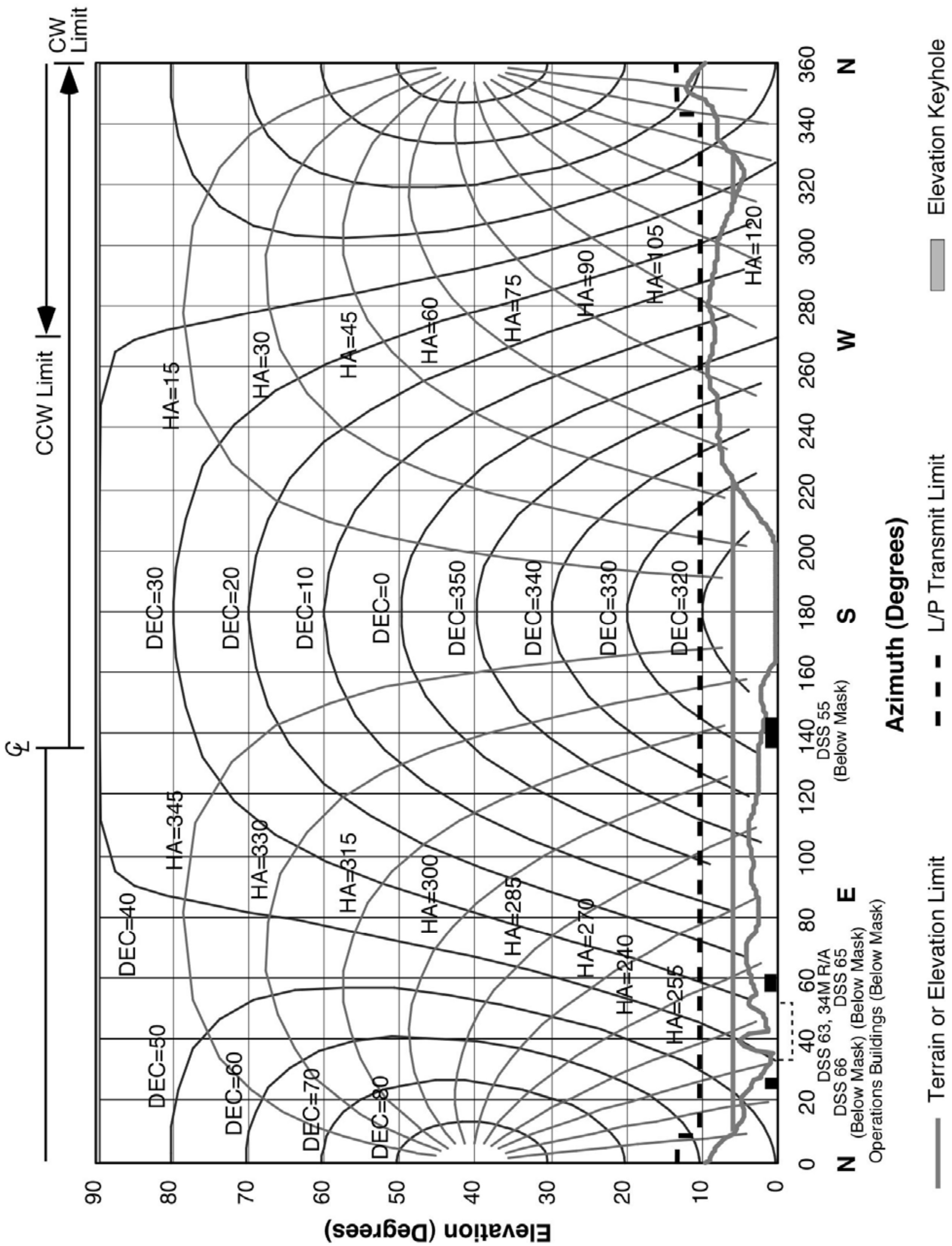

Figure 21. DSS 54 Hour-Angle and Declination Profiles and Horizon Mask

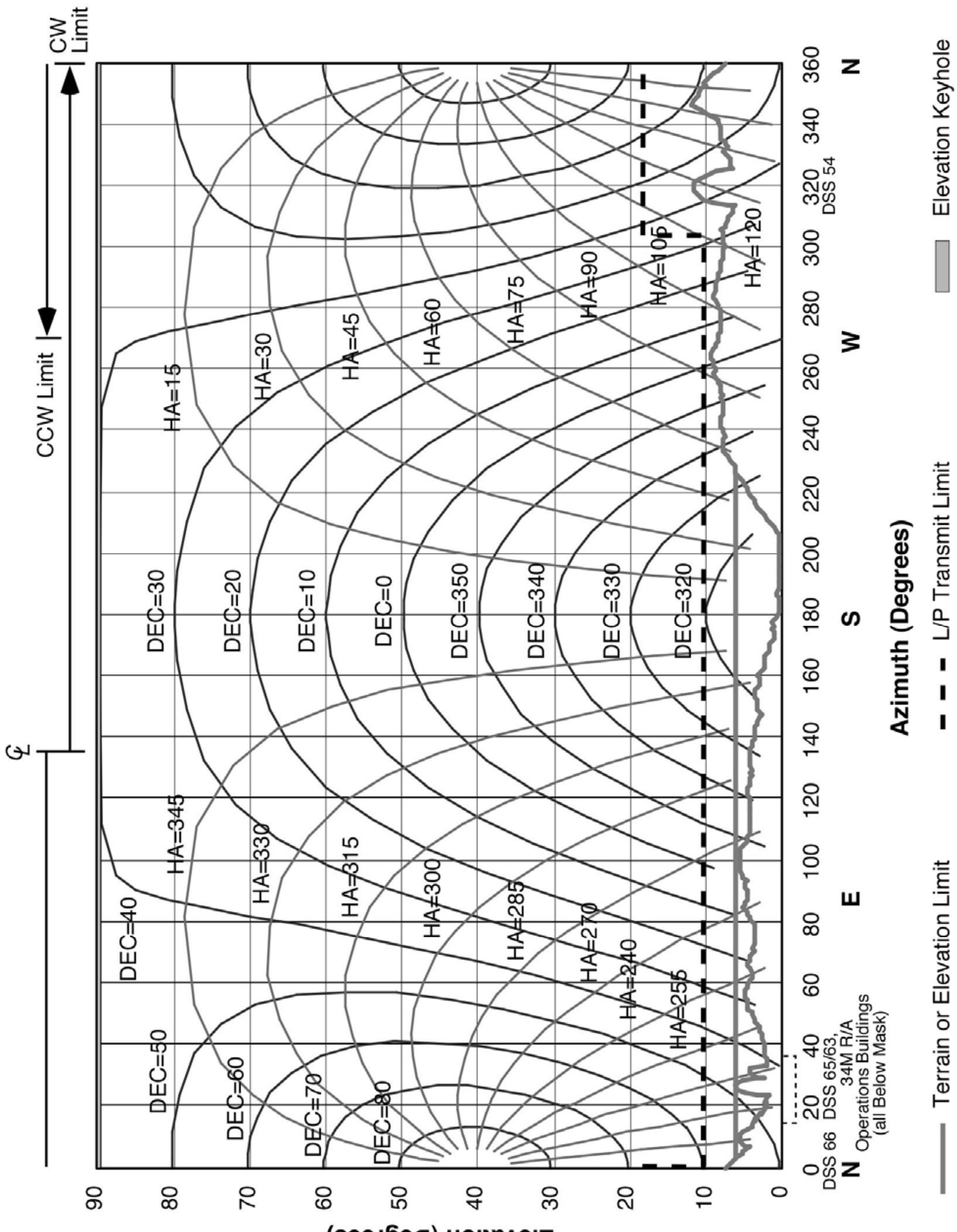

Figure 22. DSS 55 Hour-Angle and Declination Profiles and Horizon Mask

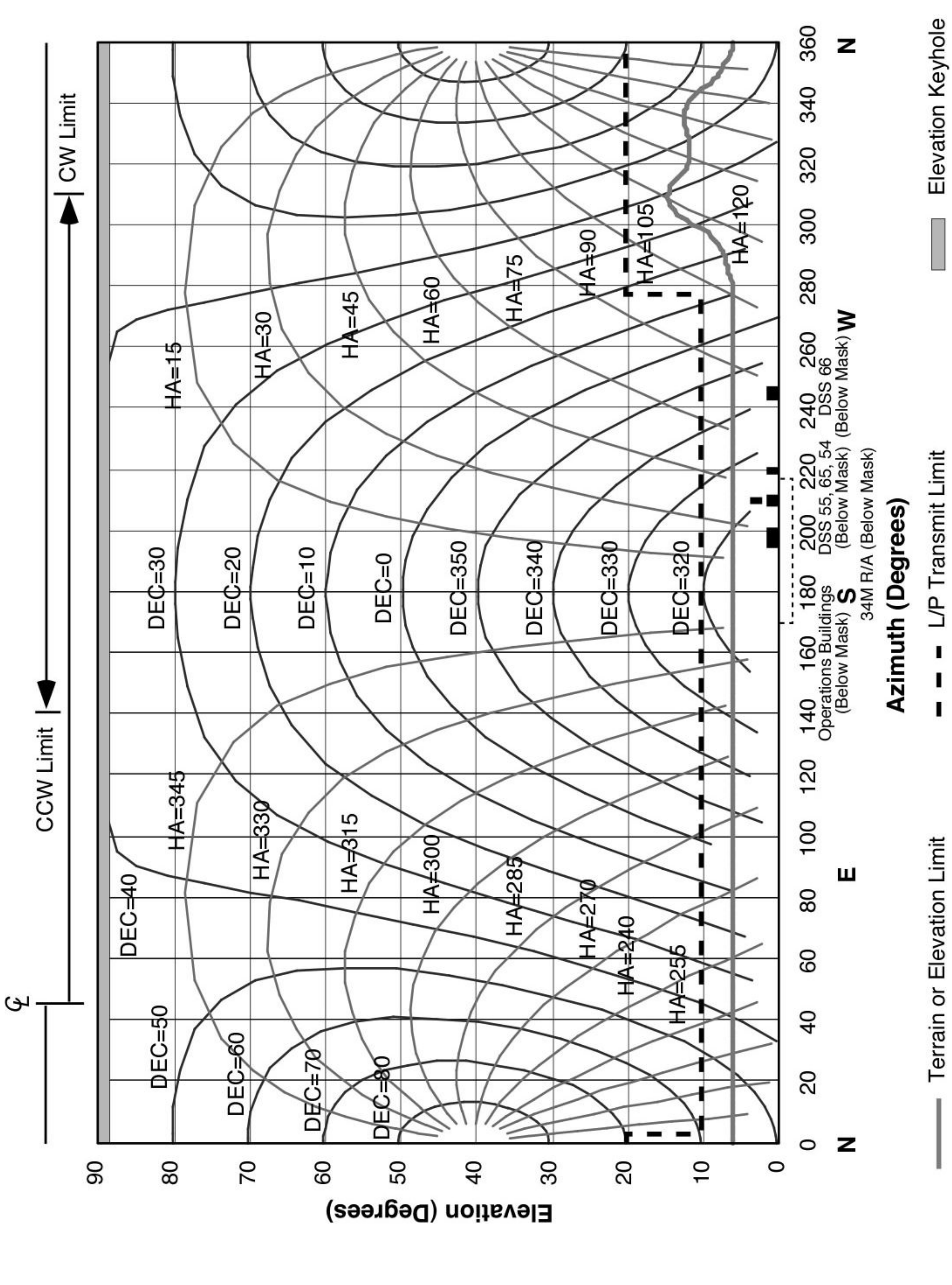

Figure 23. DSS 63 Hour-Angle and Declination Profiles and Horizon Mask

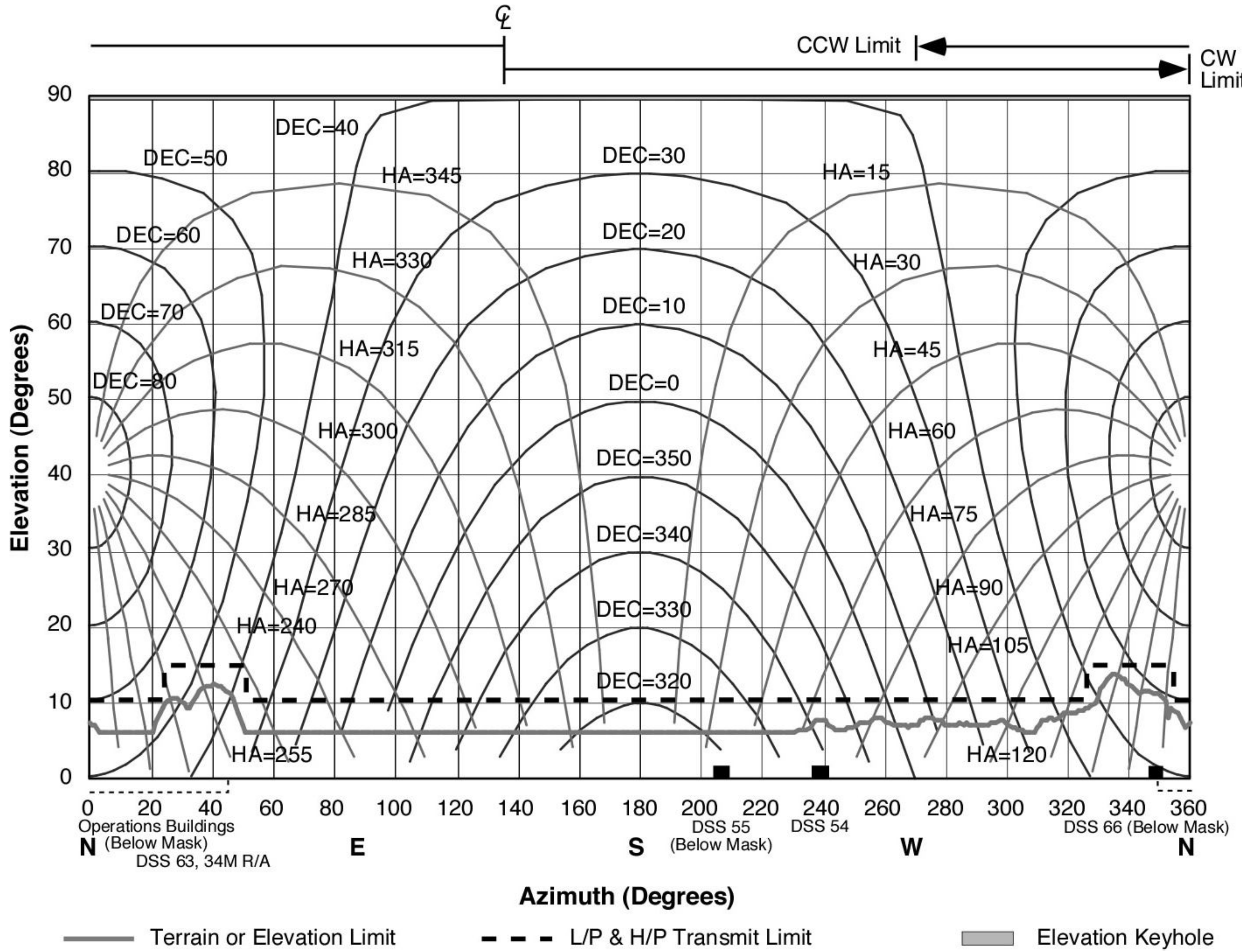

Figure 24. DSS 65 Hour-Angle and Declination Profiles and Horizon Mask

Appendix A
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2 B. R. Bowring, "The accuracy of geodetic latitude and height equations," *Survey Review*, 28, pp. 202-206, 1985.