Deep Space Network

301
Coverage and Geometry

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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	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	6/12/2014	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	9/10/2014	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	9/13//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.
L	07/3/2018	Stephen Slobin Christine Chang	Table 1 Tables 2, 5, 6, 7 Table 8 Figure 15 Figure 16 Download Spreadsheet	Future antennas DSS-53 and DSS-56 added. Added coordinates for DSS-53 and DSS-56. New cable wrap limits for all antennas. Added high power transmit mask for DSS-26. New transmit horizon mask for DSS-34. Updated with new DSS-34 transmit horizon mask.
M	09/04/2020	Stephen Slobin Christine Chang	810-005 Downloads 810-005 Downloads Figures 11-24 Sec. 2.2.3 Sec. 2.2.4 Sec. 2.2.1 & 2.2.4 Tables 2, 5, 6, 7	New Download Spreadsheet for Spacecraft Coverage and Visibility. New Download Spreadsheet for Antenna Horizon Masks. New for DSN antenna horizon masks. Update to coverage charts. Update to horizon masks. Updated references to DSS-43 100 kW S-band and 80 kW X-band transmitters. Updated with latest DSS-56 location.
N	04/15/2022	Stephen Slobin Christine Chang	Sec. 2.2.4 Tables 2, 5, 6, 7 Table 8	Description of new DSS-53 location on masks and blockages. Updated with latest DSS-53 location. Notes added regarding station location accuracy. Updated DSS-53 cable wrap limits.

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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 and antenna blockage 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 (AZ/EL antennas), the reference point is the intersection of the axes. For antennas for which the axes do not intersect (HA/DEC antennas), 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. This antenna type has an axis offset, which must be accounted for in the range observable as a function of antenna positioning. There are currently no operational HA/DEC antennas in the DSN. Table 1 lists the DSN antennas by type.

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
70-m	14, 43, 63	AZ/EL
34-m High Efficiency (HEF)	15, 45, 65	AZ/EL
34-m Beam Waveguide (BWG)	24, 25, 26, 34, 35, 36, 53, 54, 55, 56	AZ/EL

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 and uncertainties for the all DSN antennas are given in Tables 2, 5, 6, and 7. Position values for decommissioned antennas are given for historical reference only.

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.

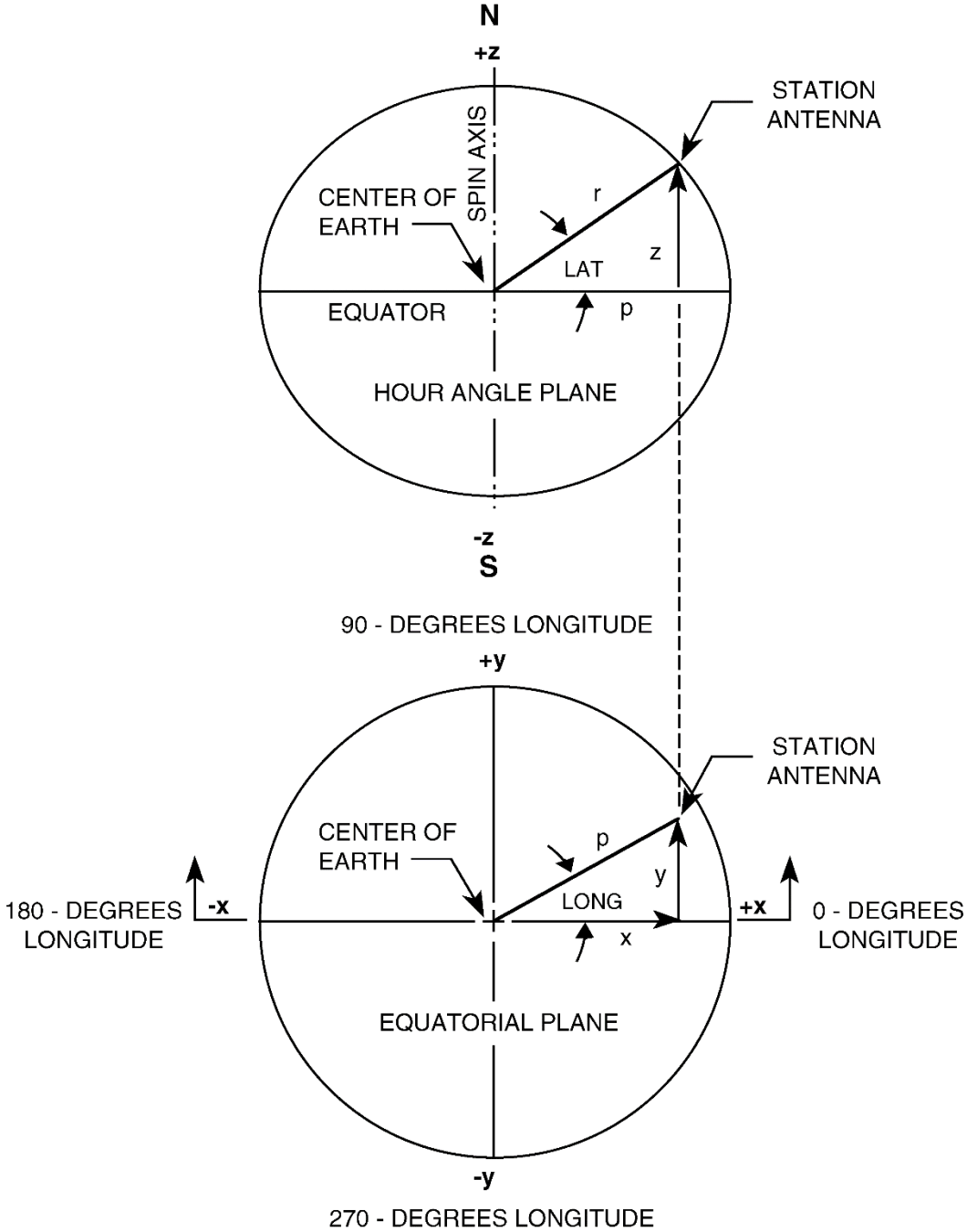
2.1.3 Geodetic Coordinates

Locations on the Earth’s surface are defined with respect to the geoid, 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, 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 System (GPS) 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



Z = Height above (+z) or below (-z) equatorial plane.
Y = Distance in front of (+y) or behind (-y) plane (Hour Angle plane) established by spin axis and Greenwich meridian.
X = Distance from spin axis towards Greenwich meridian (+x) or towards 180-degree meridian (-x).

Figure 1. Cartesian and Geocentric Coordinate System Relationships

Table 2. Cartesian Coordinates for DSN Stations in ITRF93 Reference Frame, Epoch 2003.0[3]

Antenna		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[2]	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[2]	34-m HEF	–4460935.578	+2682765.661	–3674380.982
DSS 53[1]	34-m BWG	+4849338.209	−360657.812	+4114746.173
DSS 54	34-m BWG	+4849434.488	–360723.8999	+4114618.835
DSS 55	34-m BWG	+4849525.256	–360606.0932	+4114495.084
DSS 56[1]	34-m BWG	+4849421.679	−360549.659	+4114646.987
DSS 63	70-m	+4849092.518	–360180.3480	+4115109.251
DSS 65	34-m HEF	+4849339.634	–360427.6637	+4114750.733

NOTES:

1. Position absolute accuracy estimated to be +/−3 cm (0.030 m) (1-sigma) for each coordinate.
2. Decommissioned. For historical reference only.
3. See NOTE, Table 7.

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 in the past have been 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. With the decommissioning of DSS-15 and DSS-45, and the future decommissioning of DSS-65, the location references are being migrated to BWG antennas at the same complexes. The uncertainty of station locations depends on the method used to link their position to that of the reference antennas. 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[5]

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[4]	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[4]	34-m HEF	–35	23	54.44766	148	58	39.66828	674.347
DSS 53[2]	34-m BWG	40	25	37.50154	355	44	47.74405	842.806
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 56[2]	34-m BWG	40	25	33.47285	355	44	52.58149	835.746
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 treated as negative numbers.
4. Decommissioned. For historical reference only.
5. See NOTE, Table 7.

Table 6. Geocentric Coordinates for DSN Stations[3]

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[2]	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[2]	34-m HEF	5205494.965	-35.2169608	148.9776856	6371675.873
DSS 53[1]	34-m BWG	4862731.241	40.2372333	355.7465956	6370030.706
DSS 54	4-m BWG	4862832.157	40.2357726	355.7459032	6370025.490
DSS 55	34-m BWG	4862913.938	40.2344478	355.7473667	6370007.988
DSS 56[1]	34-m BWG	4862806.461	40.2361152	355.7479393	6370024.058
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.
2. Decommissioned. For historical reference only.
3. See NOTE, Table 7.

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 53	34-m BWG	0.03	0.03	0.03
DSS 54	34-m BWG	0.032	0.036	0.034
DSS 55	34-m BWG	0.050	0.037	0.048
DSS-56	34-m BWG	0.03	0.03	0.03
DSS 63	70-m	0.027	0.035	0.031
DSS 65	34-m HEF	0.026	0.034	0.030

NOTE:
The numbers in this table represent the uncertainties in location at the time of VLBI measurements. In the years since the measurements, a number of occurrences have conspired to increase the uncertainties to as much as 0.1 meter, 1-sigma. This is due to events such as the 2019 Ridgecrest earthquake, which affected Goldstone at the level of several centimeters, as well as uncertainty in tectonic plate velocities integrating up over the years.

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. DSS-43 (Canberra) will have new S-band (100 kW) and X-band (80 kW) transmitters operational as of February 2021. These transmitters cannot be used below 17.4 degrees elevation angle at any power level above 20 kW. JPL internal document 842-40-321 (Rev. C 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 0.8 deg/sec, spacecraft can be tracked continuously to a maximum elevation of about 89.7 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 AZ/EL 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 AZ/EL antennas. Users with appropriate access should also refer to the following link for the latest updates to the cable wrap limits:

https://spsweb.fltops.jpl.nasa.gov
(Select “SPS Support Files” tab and then select “view Station Parameters” tab.)

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

Antenna		Azimuth Position (Degrees)		
Name(s)	Description	Counterclockwise (CCW) Limit	Neutral	Clockwise (CW) Limit
DSS 14	70-m	140.0	45	309.9
DSS 43	70-m	230.2	135	39.8
DSS 63	70-m	142.0	45	309.5
DSS 15 (see Note)	34-m HEF	271.3	135	358.9
DSS 45 (see Note)	34-m HEF	181.1	45	268.9
DSS 65	34-m HEF	271.3	135	358.9
DSS 24	34-m BWG	270.2	135	359.7
DSS 25	34-m BWG	270.2	135	359.7
DSS 26	34-m BWG	270.2	135	359.7
DSS 34	34-m BWG	180.0	45	269.7
DSS 35	34-m BWG	159.3	45	271.4
DSS 36	34-m BWG	159.3	45	268.0
DSS 53	34-m BWG	275.0	135.1	359.9
DSS 54	34-m BWG	269.9	140	359.7
DSS 55	34-m BWG	263.4	135	359.6
DSS 56	34-m BWG	270.0	135.05	359.0

NOTE: DSS-45 decommissioned as of 10/2016. DSS-15 decommissioned as of 5/2018.

2.2.3 Coverage Charts

Figures 2-10 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 coverage areas shown are the locations on earth over which a spacecraft must be so that it is visible by all the stations at an antenna complex, subject to the altitude and receive/transmit elevation limits given for that particular case. The latest version of this program combines the capability to draw the coverage charts and is available for download from the 810-005 web sites:

https://deepspace.jpl.nasa.gov/dsndocs/810-005/downloads/ .

The coverage charts are available from "Download Spacecraft Coverage and Visibility Spreadsheet for 301". The file includes a spreadsheet with the antenna coordinates used to create the figures. For antennas grouped closely at each complex (e.g. the BWG antennas at Goldstone), the visibility differences among the antennas are insignificant. This

download spreadsheet should not be used for generating the horizon masks. Horizon mask plots are available from the 301N download spreadsheet (see Section 2.2.4). The spacecraft coverage spreadsheet uses generic elevation limits for the receive and transmit elevations. These are 6.0 degrees for receive, 10.0 degrees for low-power transmit, and 13.5 degrees for high-power transmit. There is no azimuth variation of these elevation limits, and the coverages thus shown will be the maximum available for spacecraft at the given altitude values, including geosynchronous and deep-space spacecraft, subject to the minimum elevation limits given in the specific antenna horizon masks (Section 2.2.4). The following coverage cases were drawn in Figures 2-10 for specific elevation limits somewhat different from the generic elevation limits given in the coverage and visibility download spreadsheet.

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 (seen over the western United States) 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 south-east 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 northwest 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 at 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 other figures, 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

Horizon mask data and plots are available from the 810-005 download website at

https://deepspace.jpl.nasa.gov/dsndocs/810-005/downloads/.

The horizon mask charts are available from “Download Horizon Mask Spreadsheet for 301N”. These horizon mask charts should be considered valid beginning May 1, 2020, until further notice, and are presently being used for planning mission telecom sequences. Figures 11 through 24 show the receive and transmit horizon mask limits for all DSN stations.

For this revision (Rev. N) the masks for the MDSCC (Madrid) stations have not been updated to show the effects (masks plus blockages) due to the updated 2-meter lower DSS-53 location. The effects on the DSS-53 mask are believed to be small (horizon mask less than 0.1 deg higher, and blockage by other antennas less than 0.7 degrees higher). As seen from other antennas, DSS-53 will appear to be less than 0.7 degrees lower.

The receive limits are governed generally by the physical terrain surrounding the antenna and blockage by neighboring antennas, or by the mechanical lower limit of approximately 6 degrees elevation. The transmitter limits are governed by statutory restrictions of approximately 10 degrees for low power (typically 20 kW) transmission, and approximately 13.5 degrees (by analysis) for high power (typically 80 kW) transmission. Most antenna horizon masks differ slightly from these values.

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. DSS-65 has a lower transmit limit of 10.8 degrees, which includes 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 neither the 100-kW S-band transmitter nor the 80-kW X-band transmitter can be used below 17.4-degrees elevation angle at any power level above 20 kW.

The receive horizon masks for DSS-34, DSS-35, and DSS-36, Figures 15 thru 17, 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 (the transmit horizon) by lowering that profile by 2 degrees.

The transmit horizon masks for the Canberra BWG antennas were determined by the azimuth profile where the system noise temperature increase was +2.5 K, where it is thought the lower edge of the beam is just touching the terrain. An additional 0.5 degrees in azimuth and elevation was added to account for interlock position uncertainties. The transmit profile for DSS-35 was 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 masks for DSS-34 and DSS-36 were also measured by radiometric means, but the transmit mask is now a continuous function of azimuth, and the transmitter lower limits are defined by a set of polynomials, each over a small range of azimuth. These polynomial transmit masks are used in the ATMC (Antenna Transmit Mask Controller).

A DSS-26 high-power (80 kW) transmit horizon mask at 13.5 degrees elevation has been added to Figure 14, in addition to the low-power mask at 10.5 degrees.

Transmit and receive horizon masks for the Madrid antennas (DSS-53, -54, -55, -56, -63, and -65) have been calculated from SRTM (Shuttle Radar Topography Mission) data.

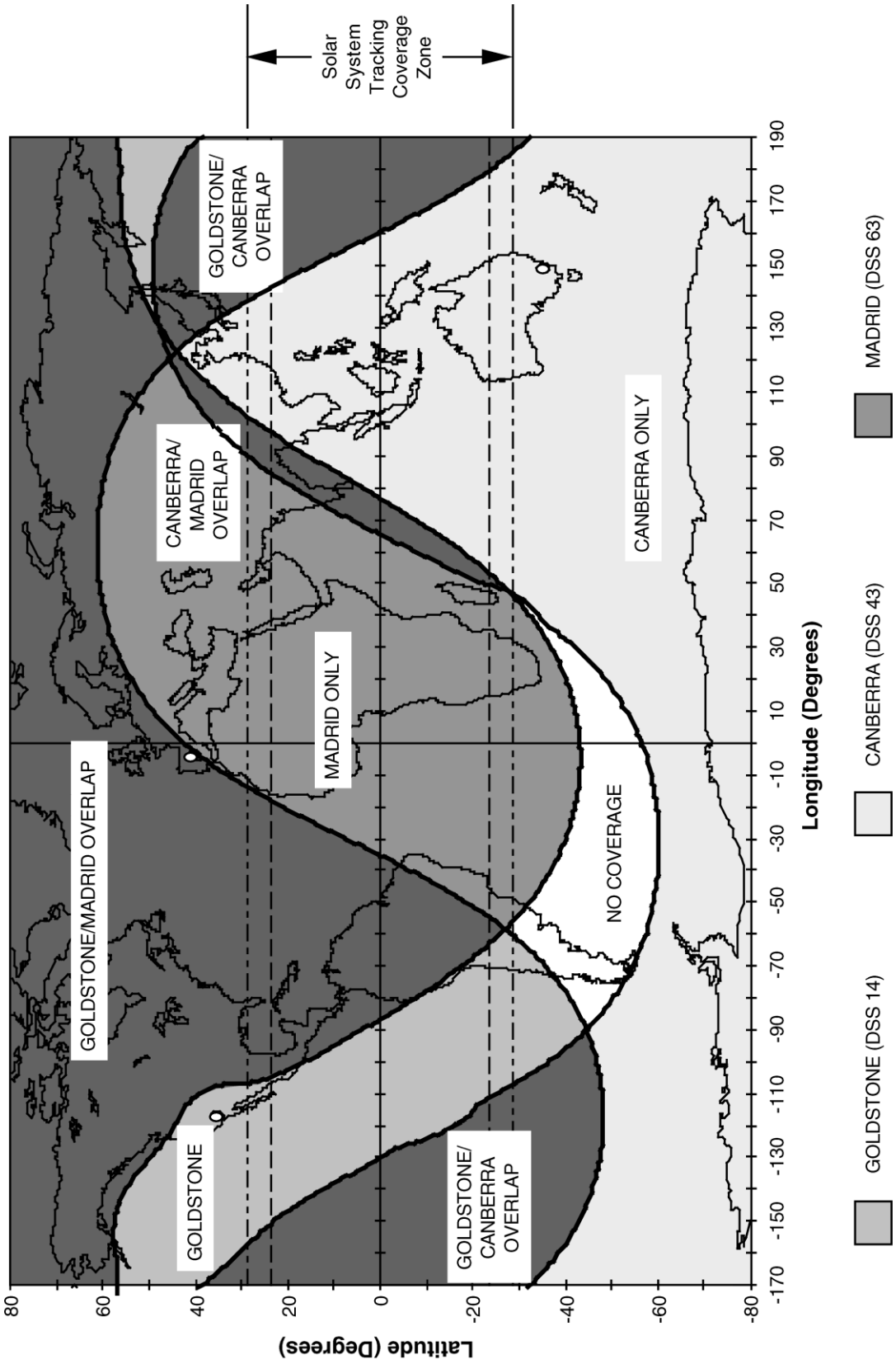


Figure 2. DSN 70-m Subnet Receive Coverage, Planetary Spacecraft

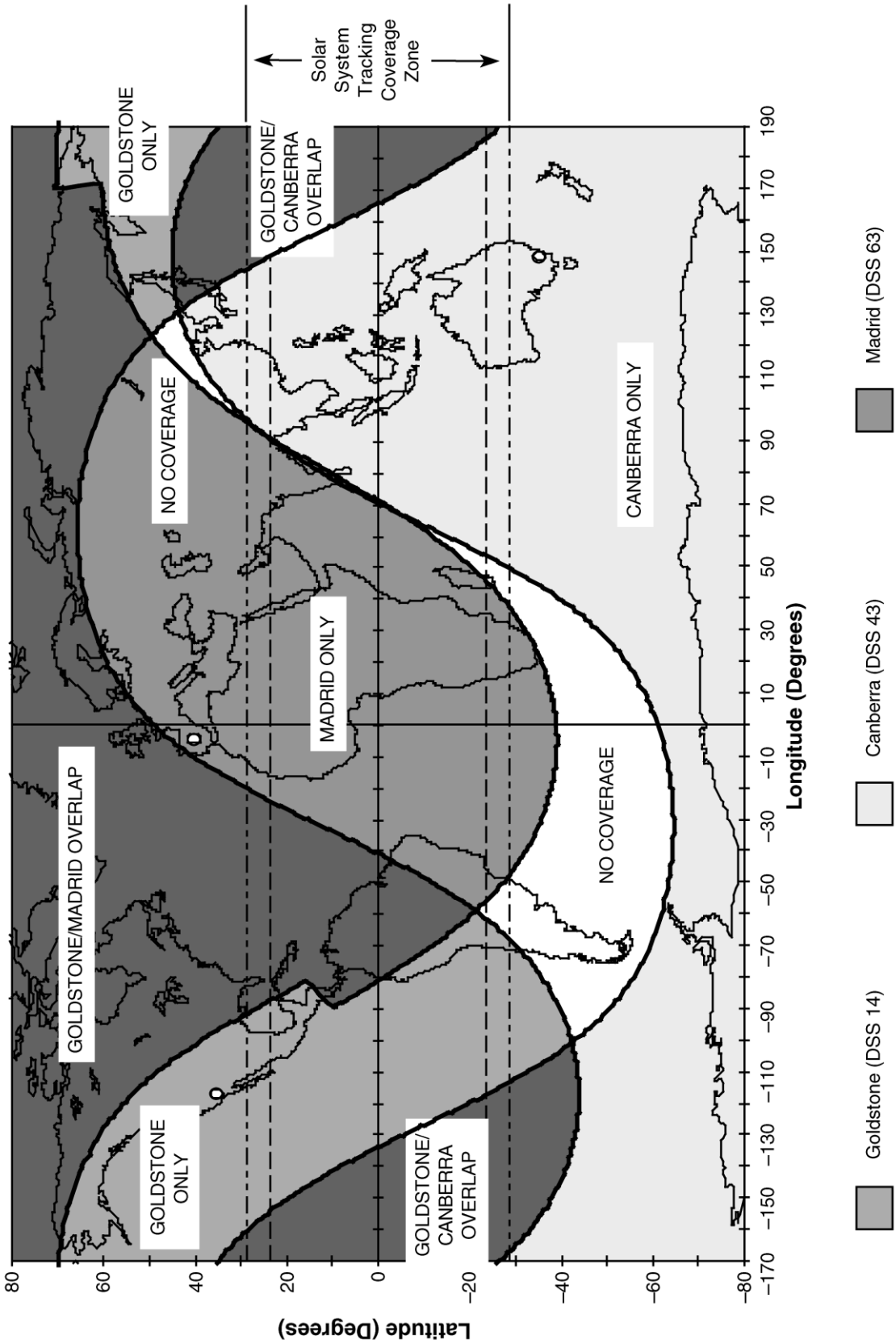


Figure 3. DSN 70-m Subnet Transmit Coverage, Planetary Spacecraft.

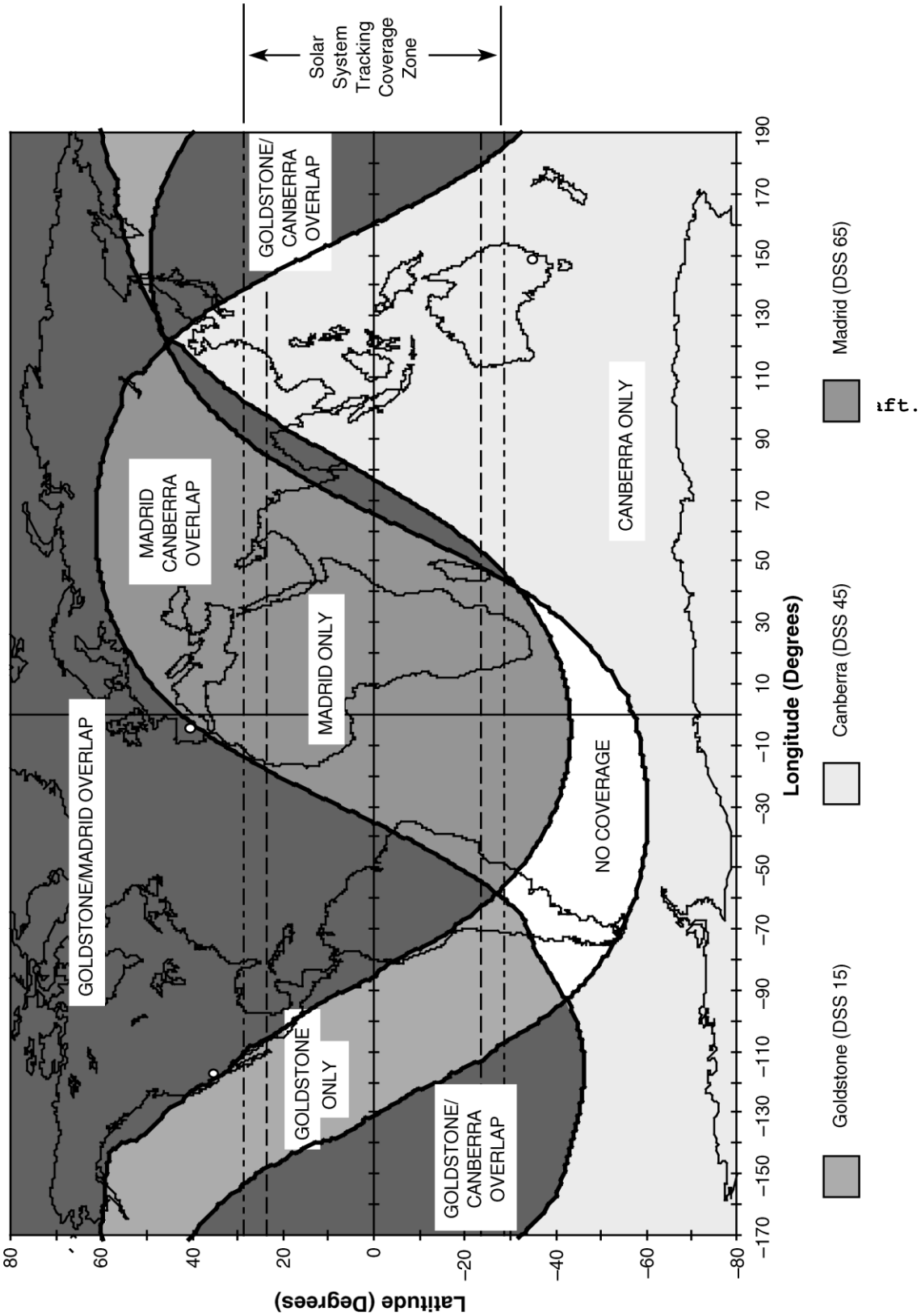


Figure 4. DSN 34-m HEF Subnet Receive Coverage, Planetary Spacecraft.

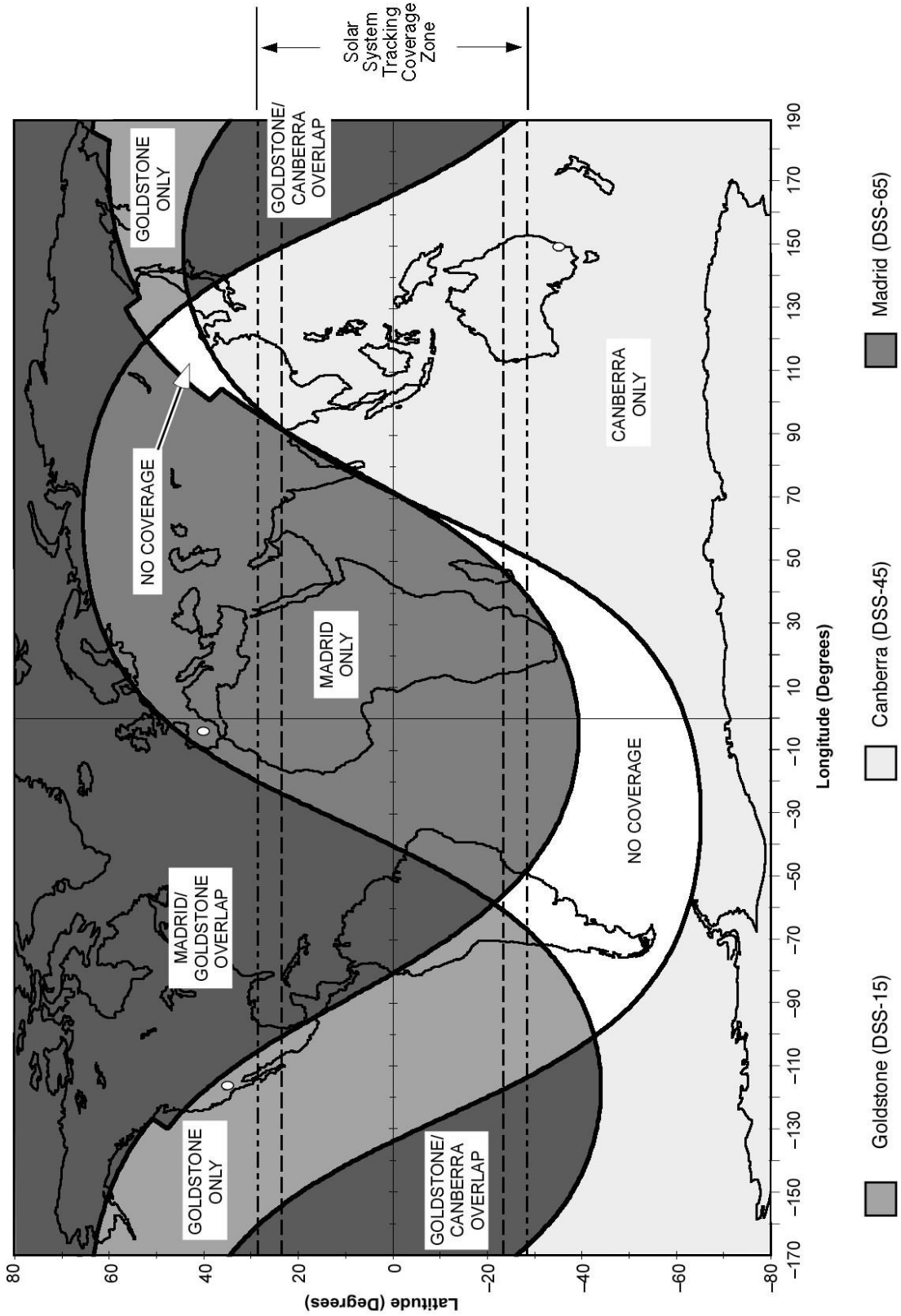


Figure 5. DSN 34-m HEF Subnet Transmit Coverage, Planetary Spacecraft

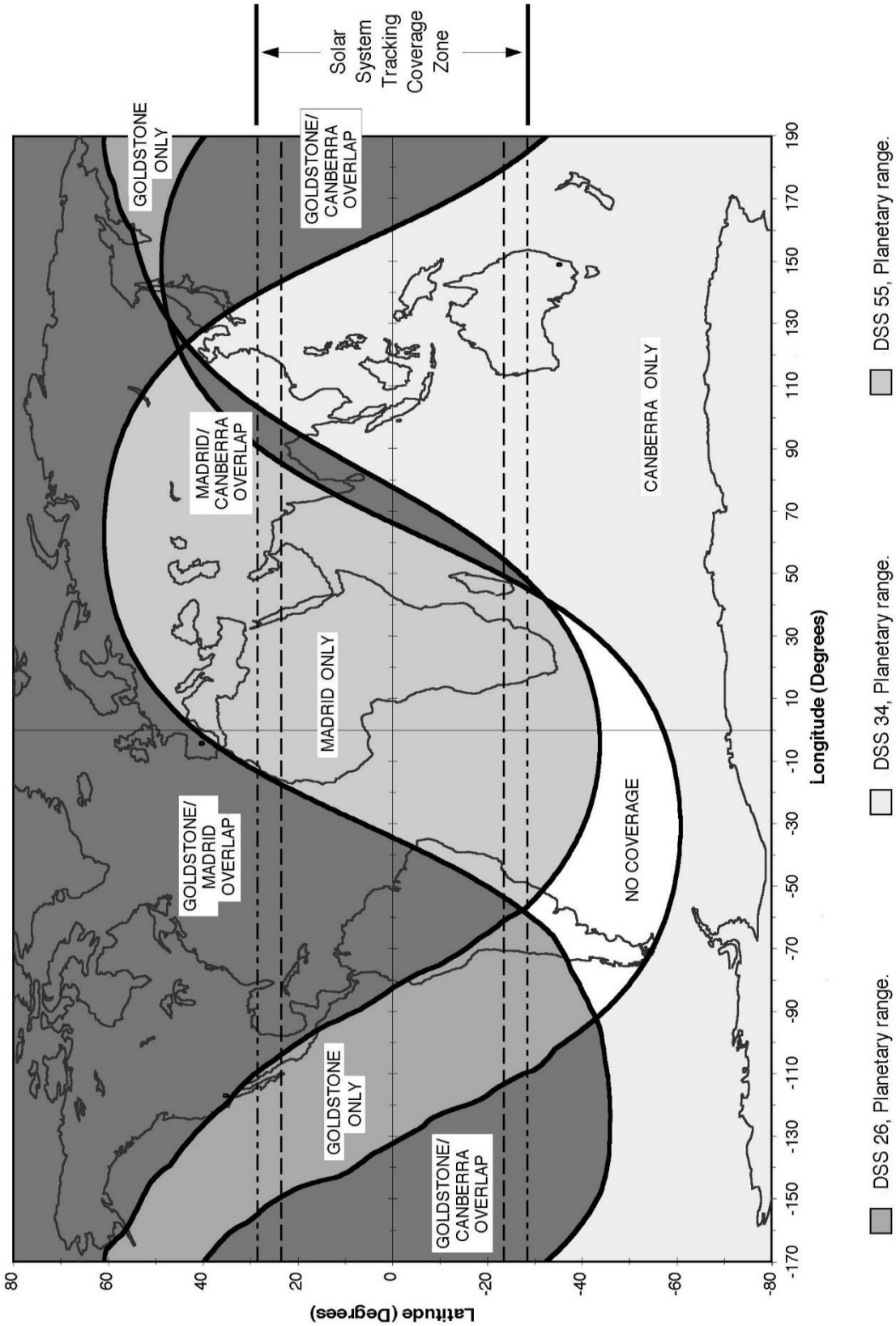


Figure 6. DSN 34-m BWG Antennas Receive Coverage, Planetary Spacecraft, Using DSS 26, 34, and 55

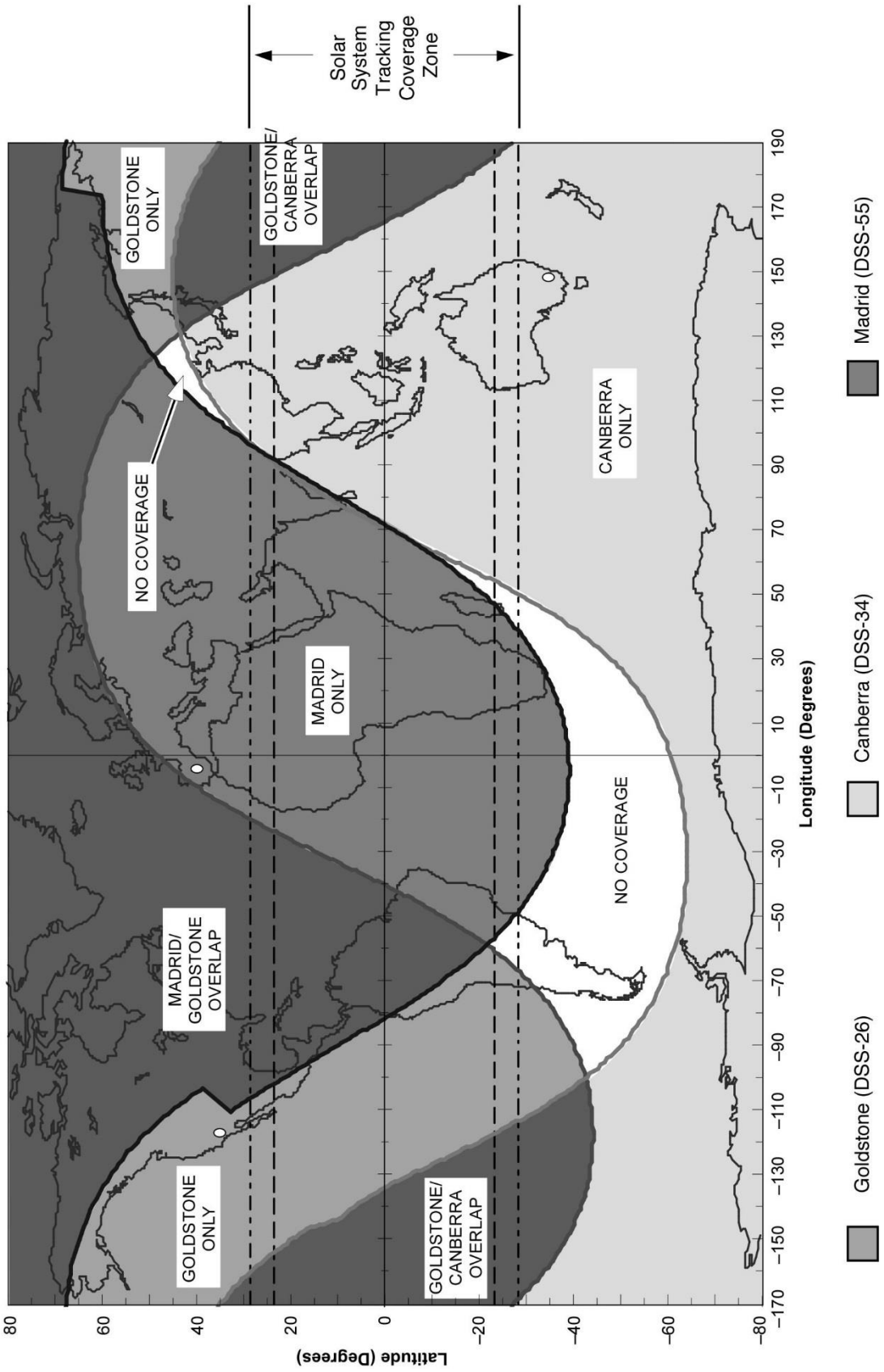


Figure 7. DSN 34-m BWG Antennas Transmit Coverage, Planetary Spacecraft, Using DSS 26, 34, and 55.

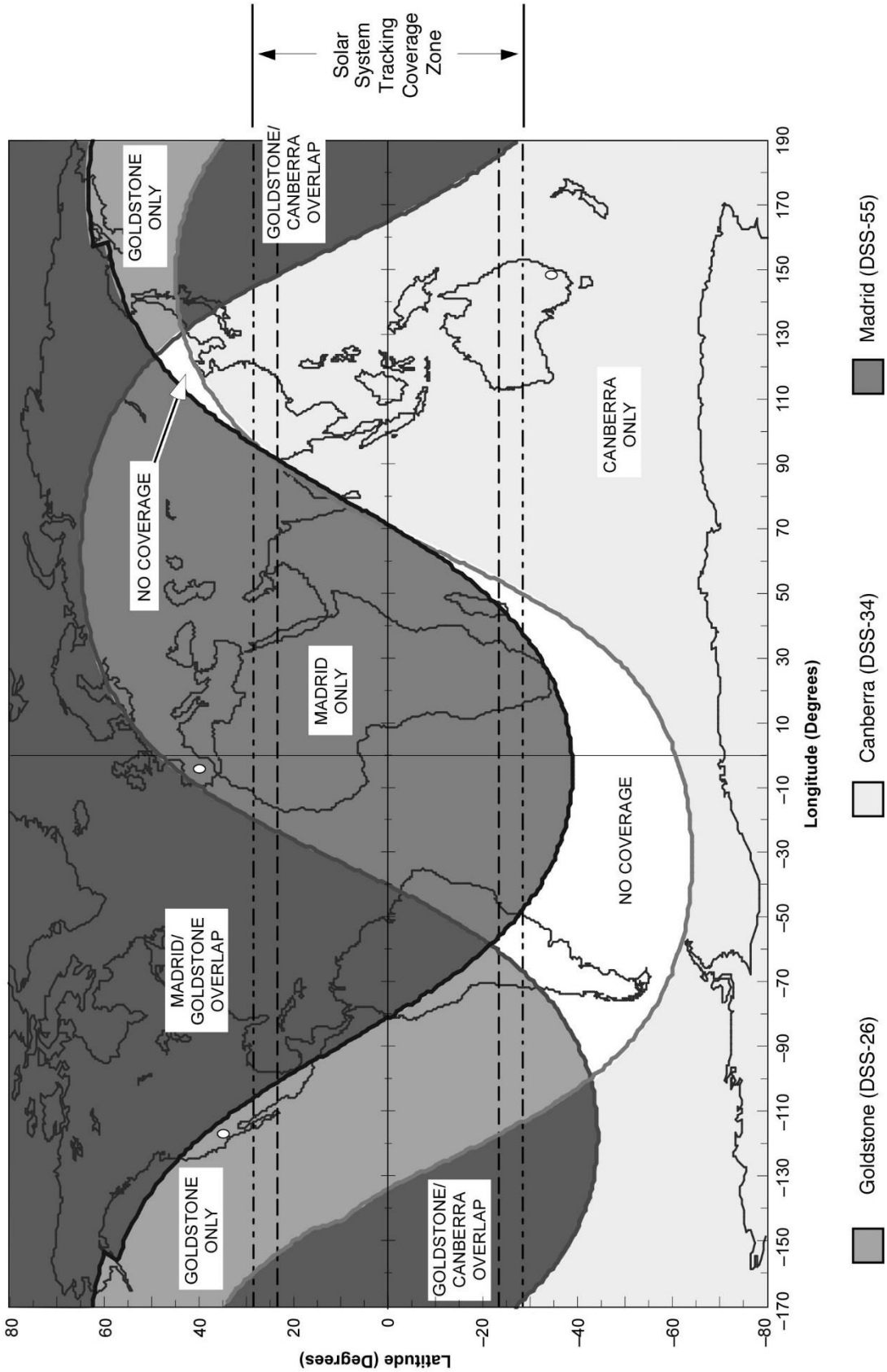


Figure 8. DSN 34-m BWG Antennas Transmit Coverage, Planetary Spacecraft, Using DSS 26, 34, and 54.

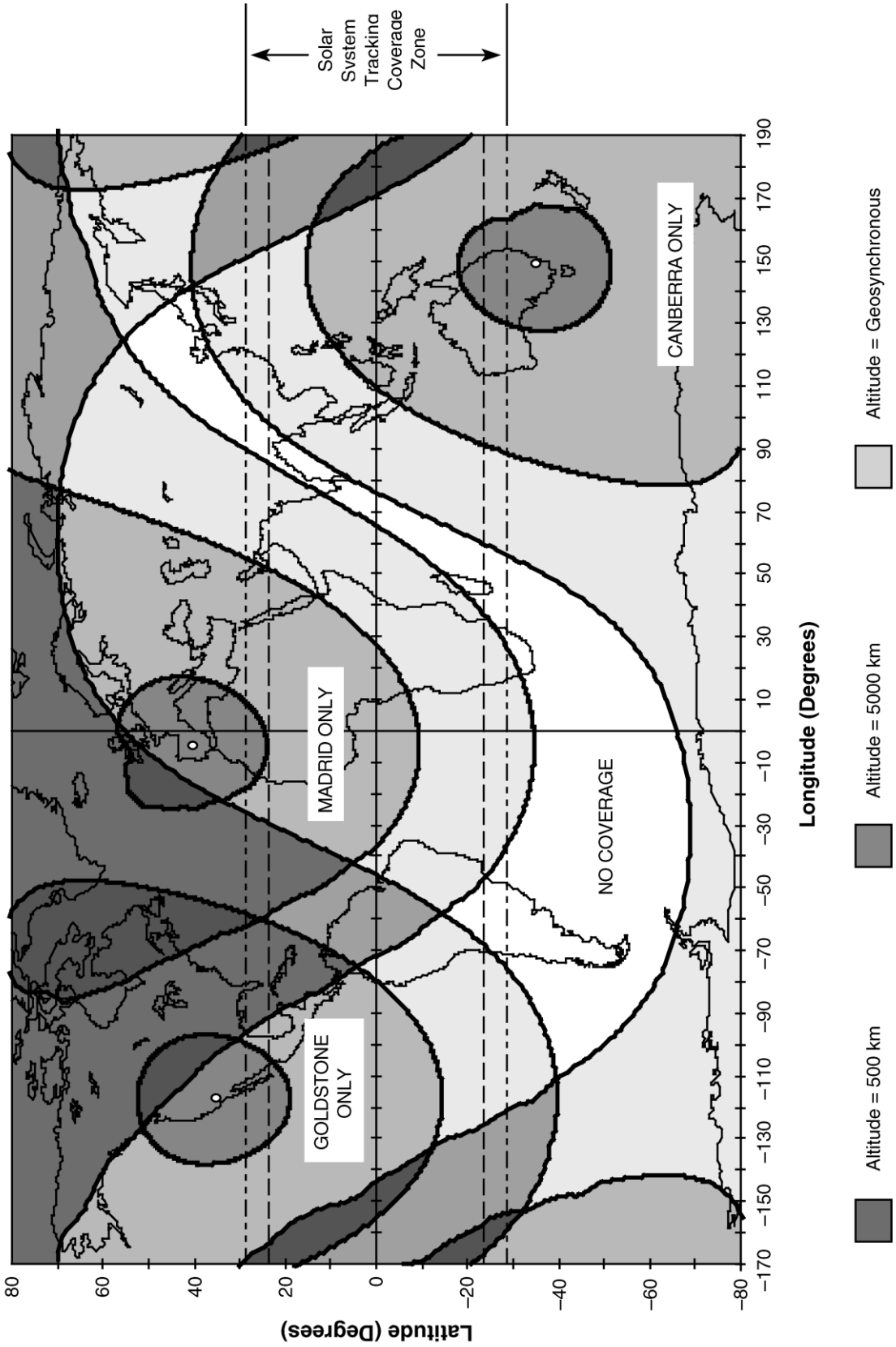


Figure 9. DSN 34-m BWG Antennas Receive Coverage, Near-Earth Spacecraft

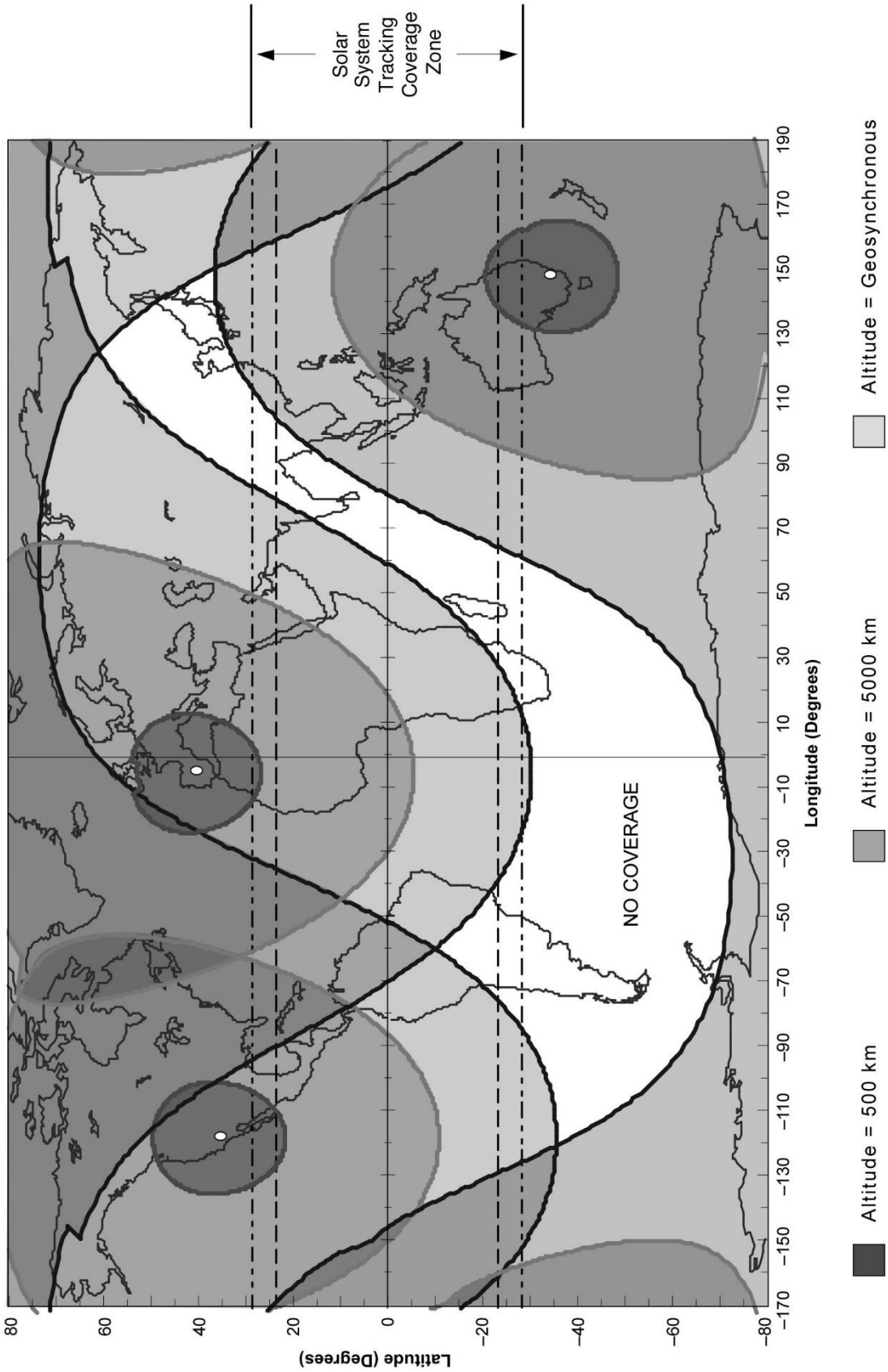


Figure 10 DSN 34-m BWG Antennas Transmit Coverage, Near-Earth Spacecraft

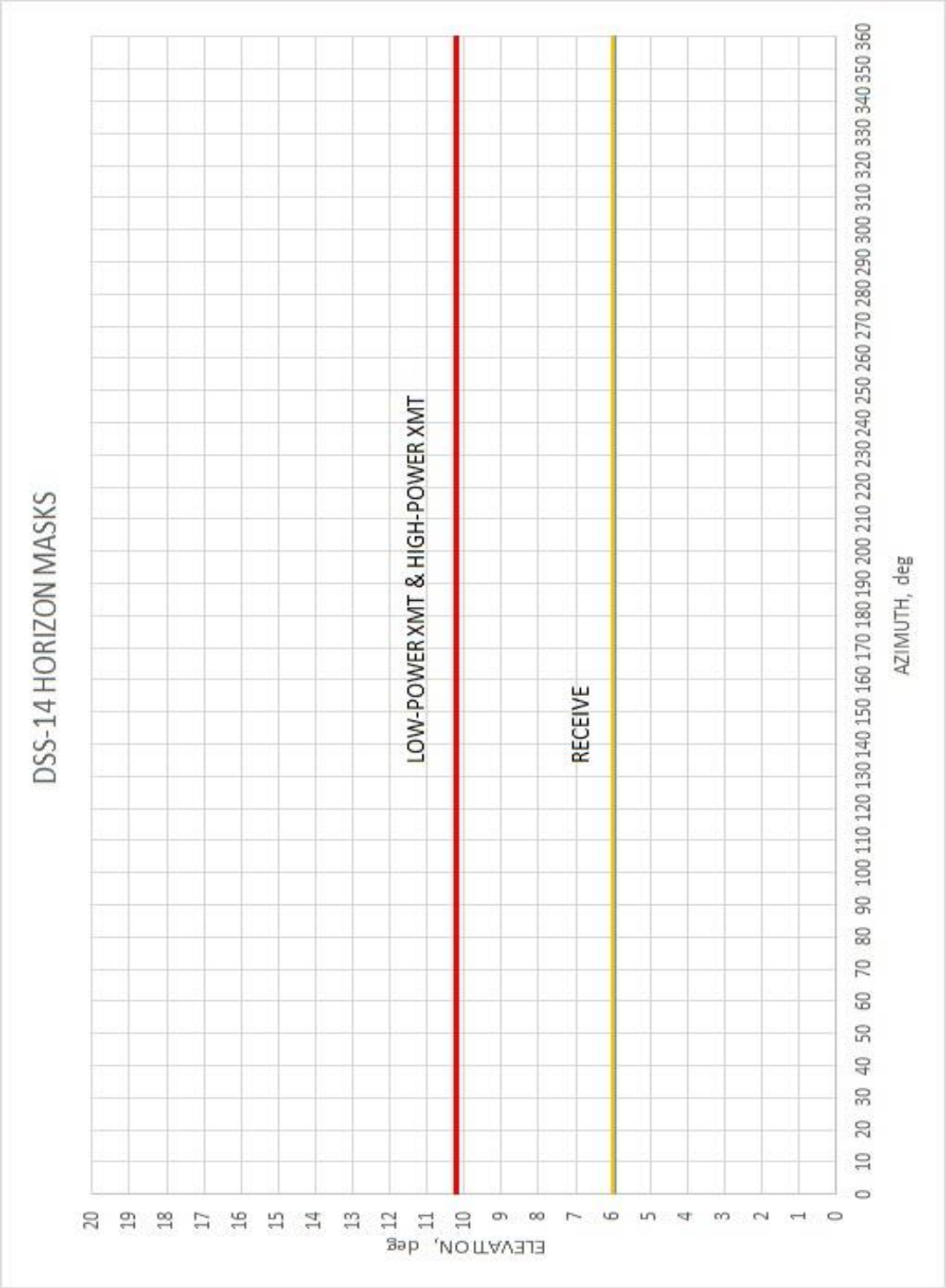


Figure 11. DSS-14, 70-m, Receive, Low-Power Transmit, and High-Power Transmit Horizon Masks

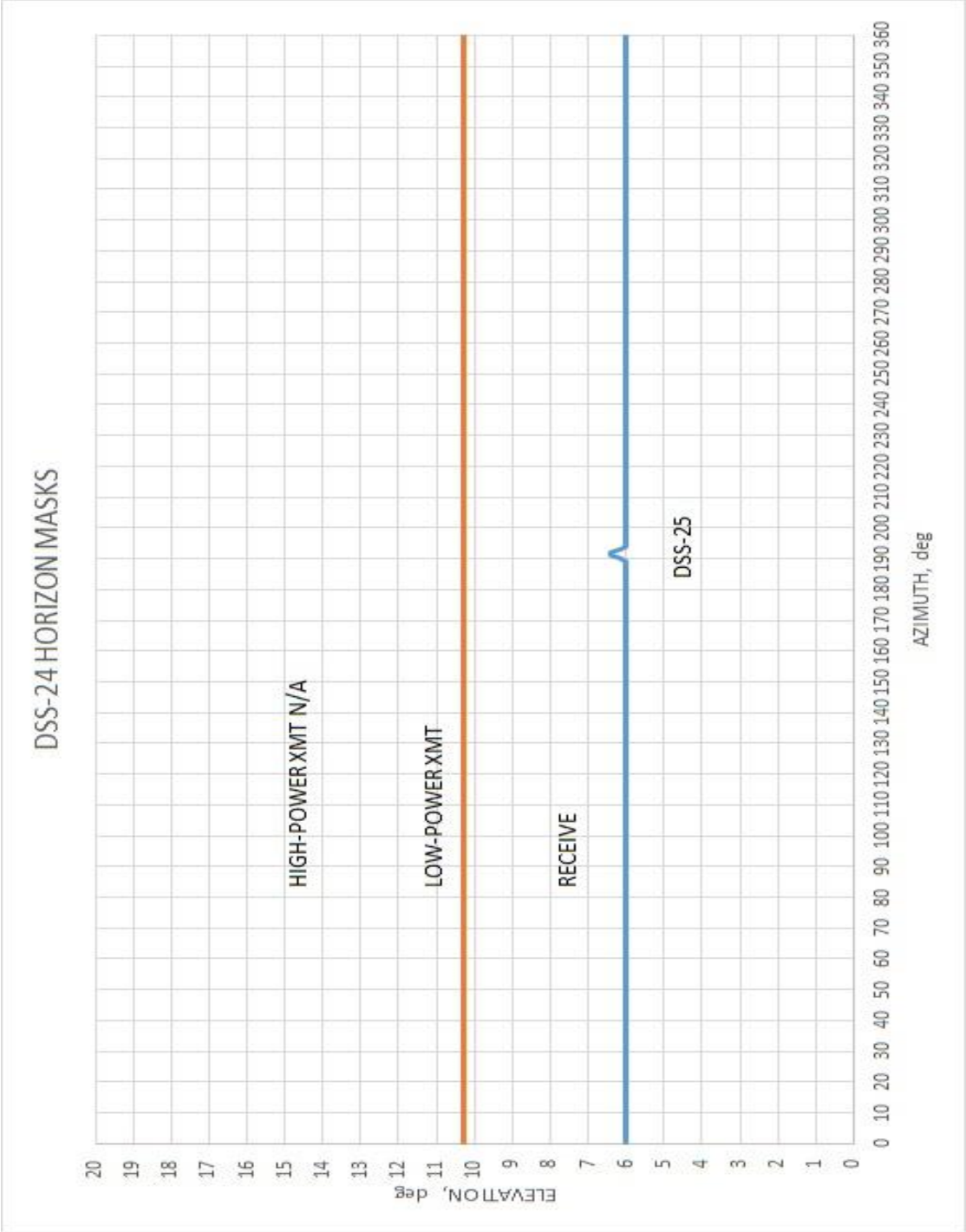


Figure 12. DSS-24, BWG, Receive and Low-Power Transmit Horizon Masks

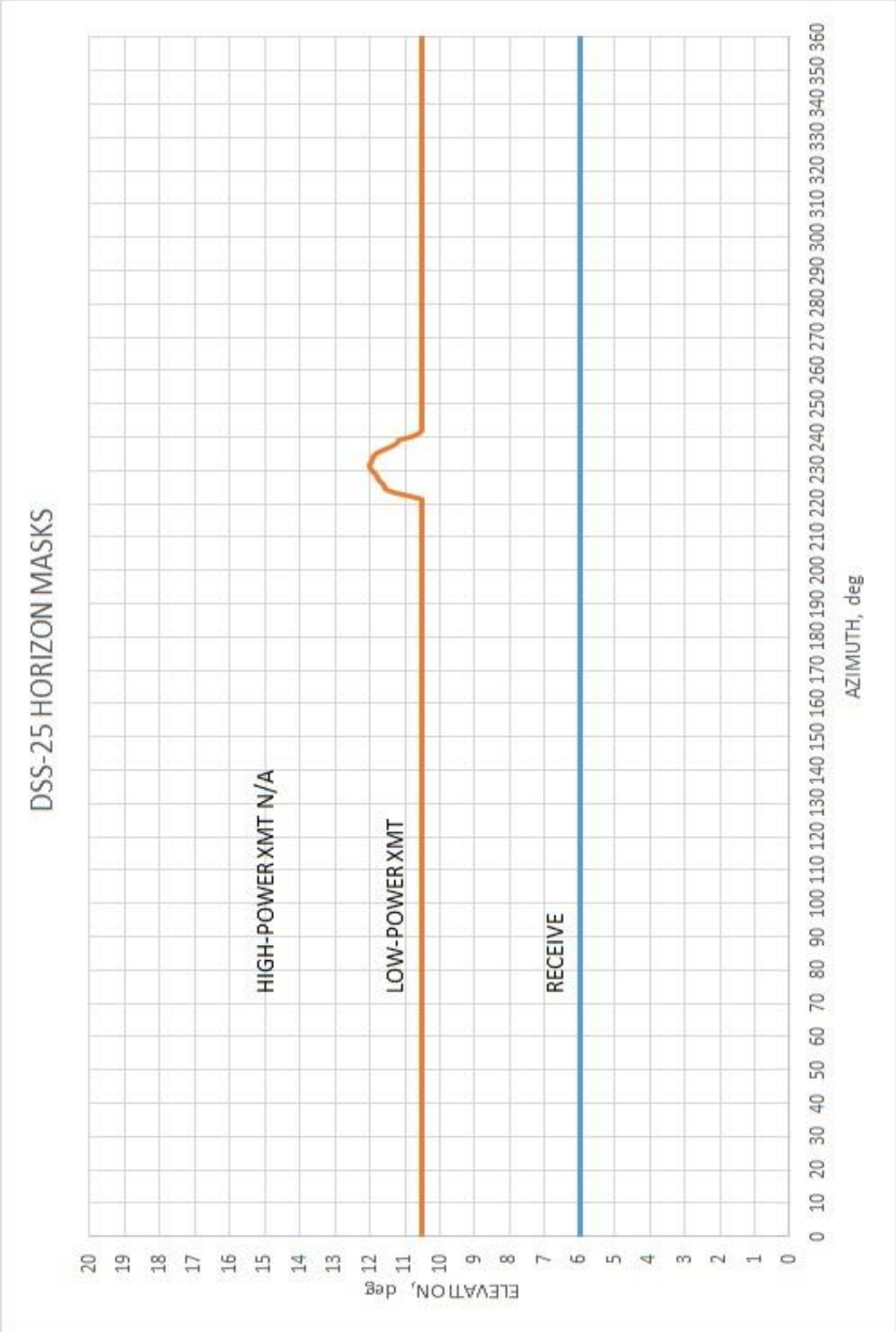


Figure 13. DSS-25, BWG, Receive and Low-Power Transmit Horizon Masks

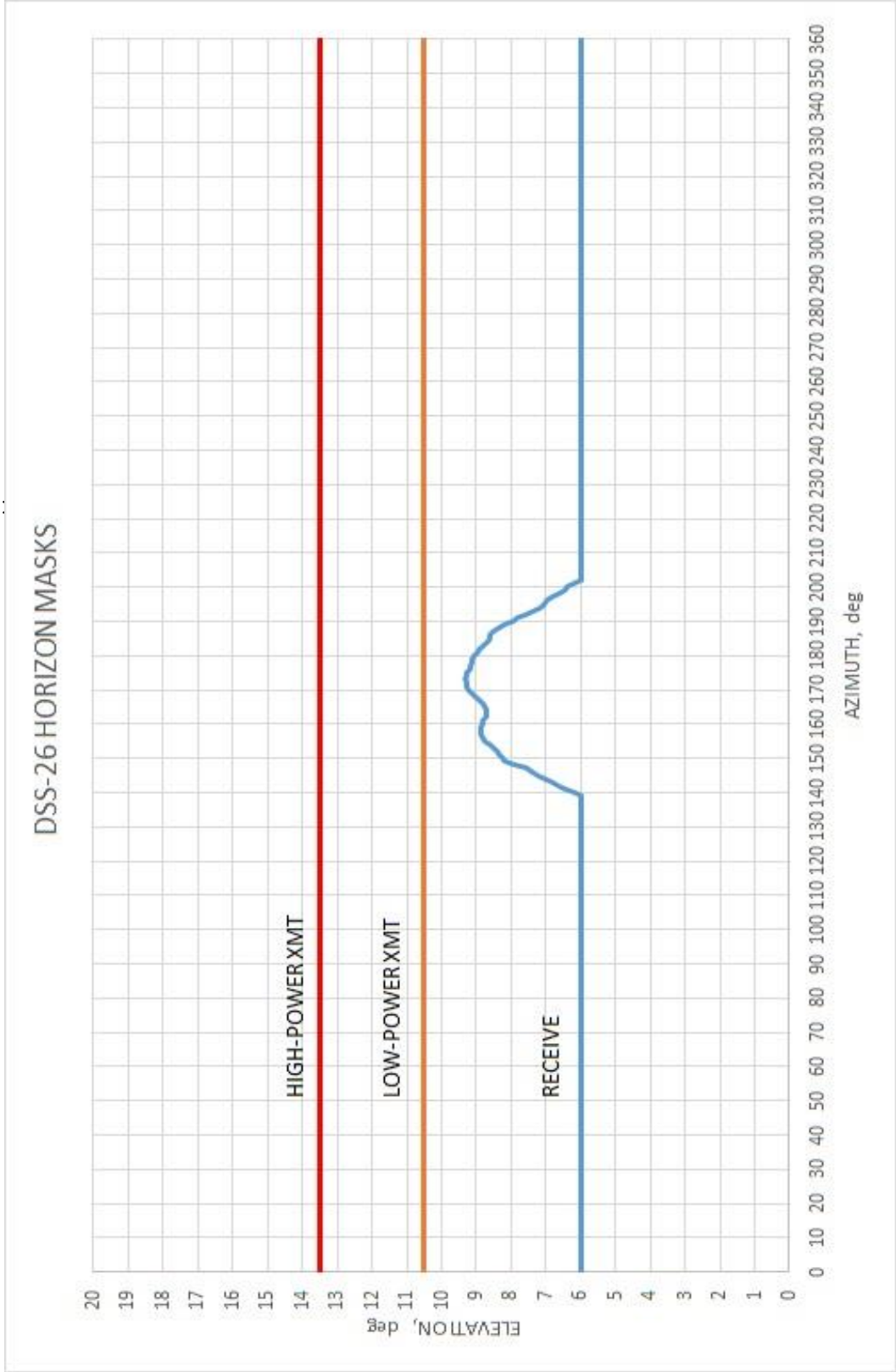


Figure 14. DSS-26, BWG, Receive, Low-Power Transmit, and High-Power Transmit Horizon Masks

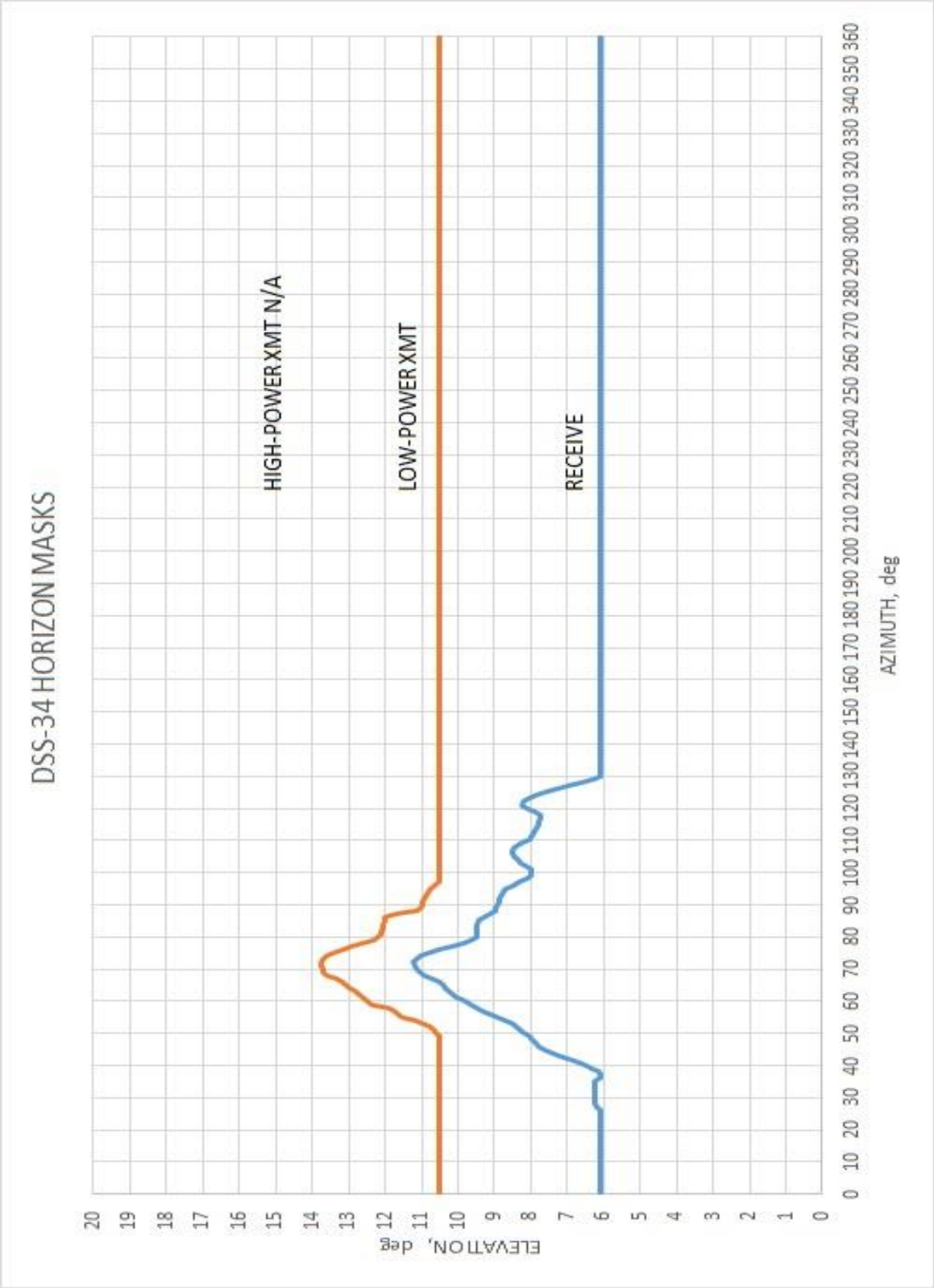


Figure 15. DSS-34, BWG, Receive and Low-Power Transmit Horizon Masks

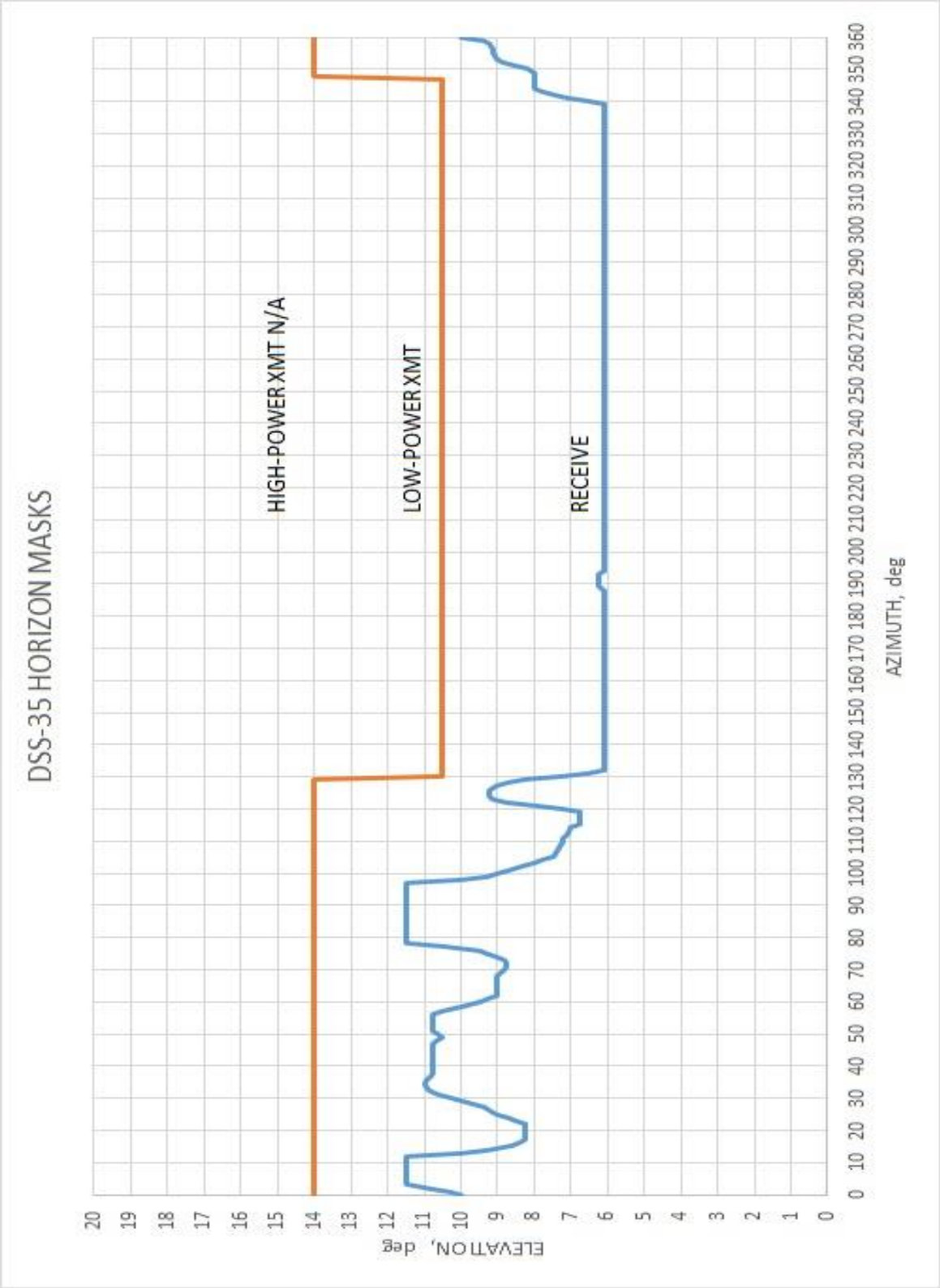


Figure 16. DSS-35, BWG, Receive and Low-Power Transmit Horizon Masks

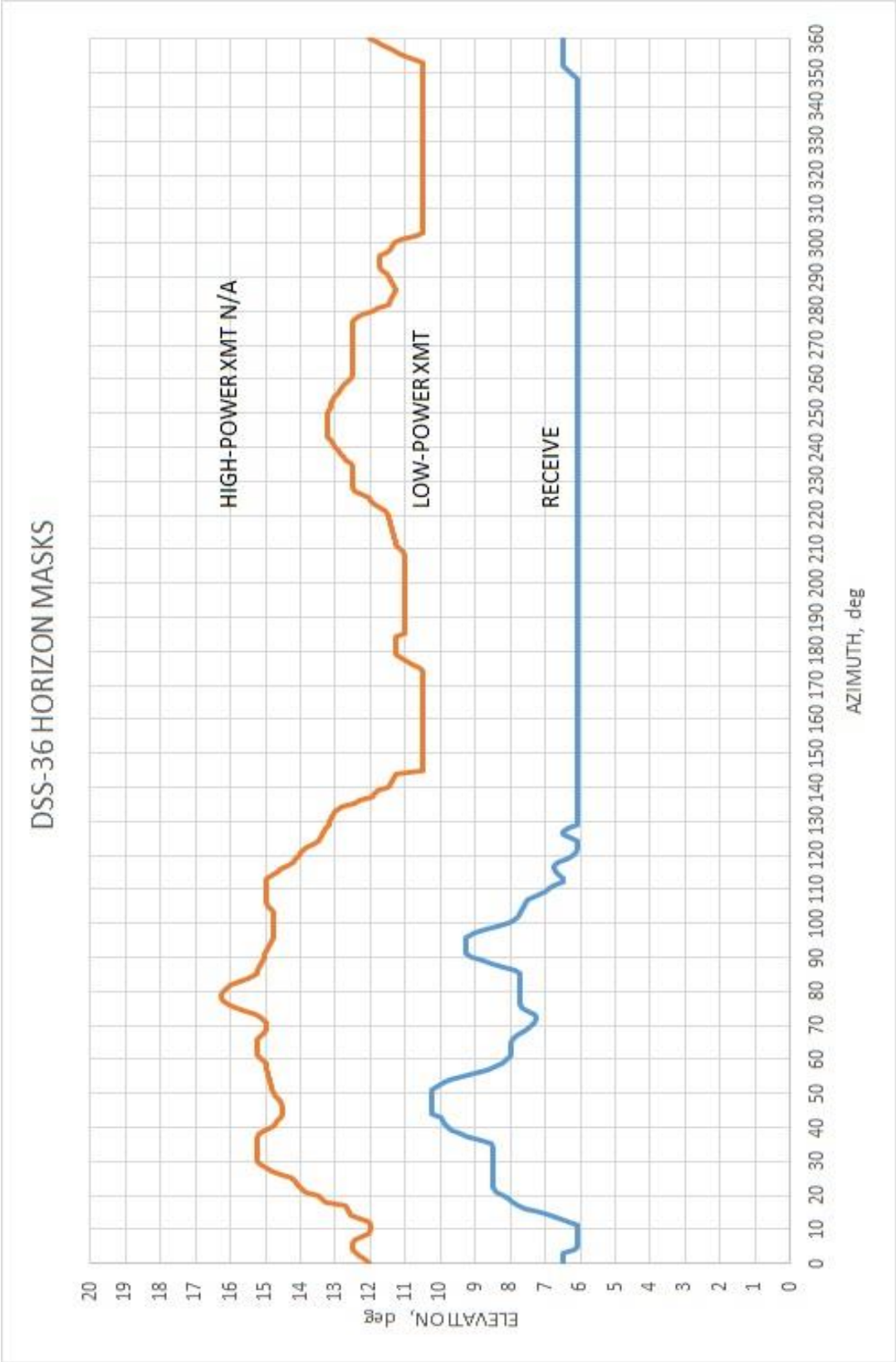


Figure 17. DSS-36, BWG, Receive and Low-Power Transmit Horizon Masks

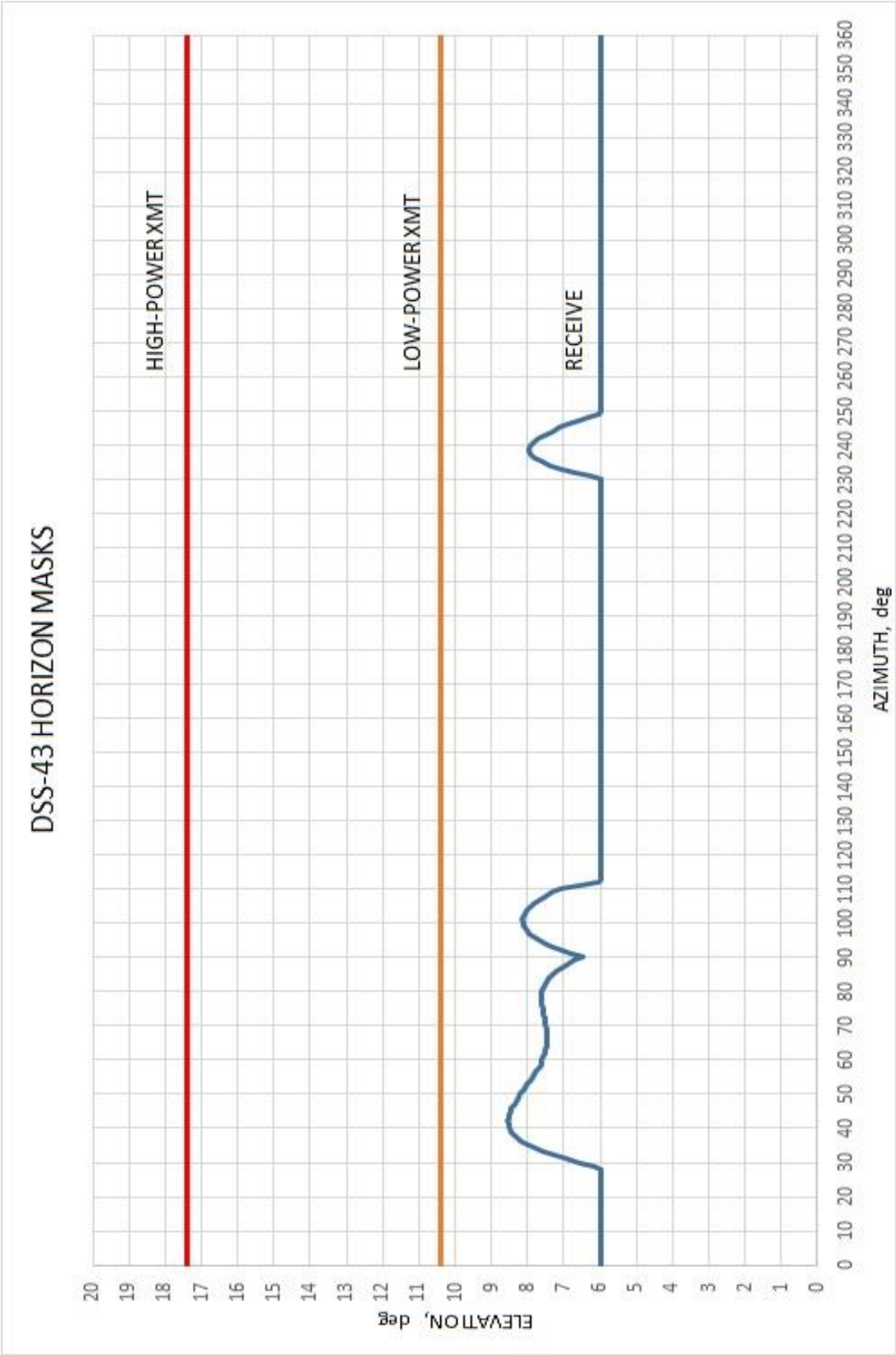


Figure 18. DSS-43, 70-m, Receive, Low-Power Transmit, and High-Power Transmit Horizon Masks

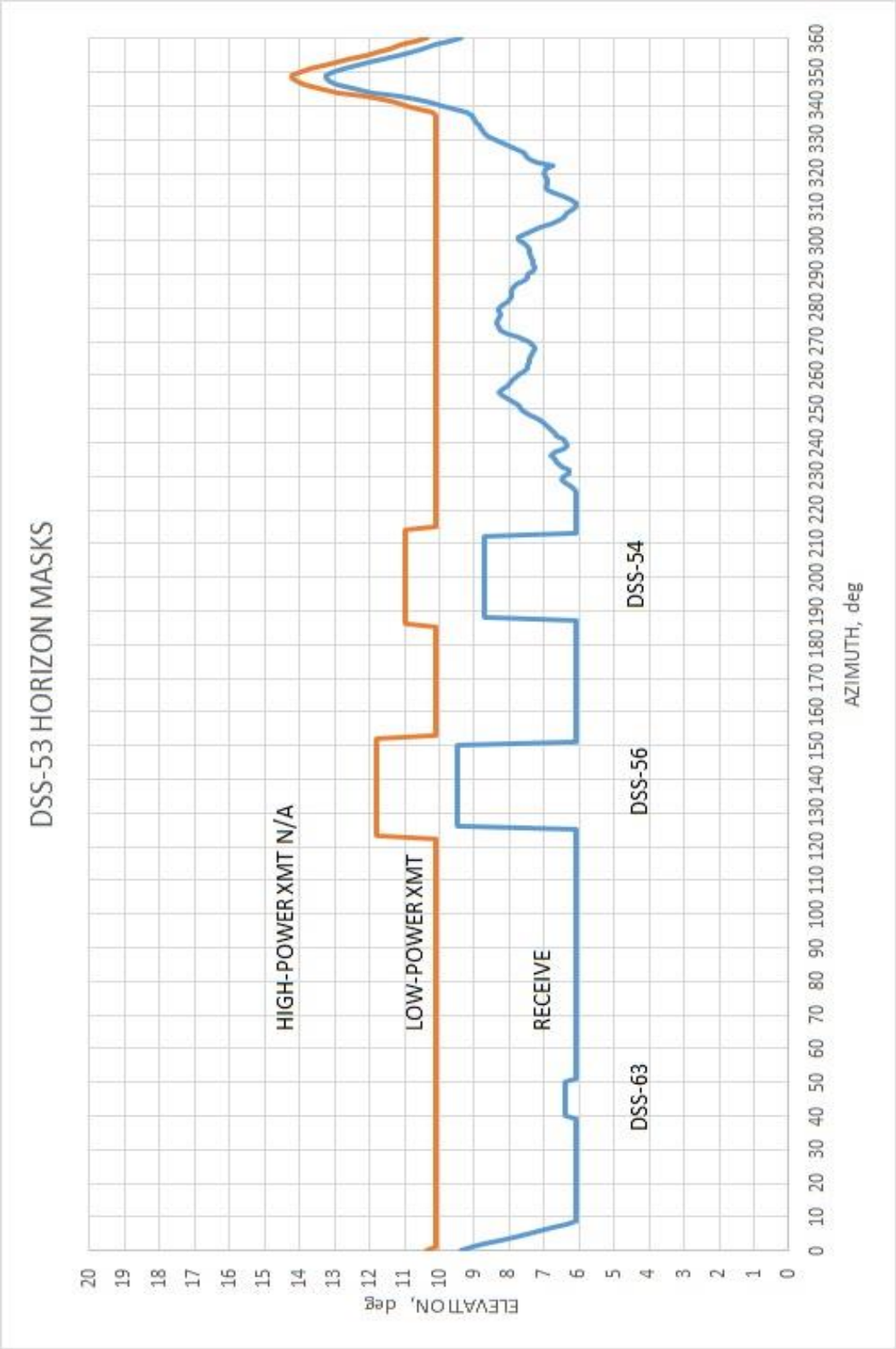


Figure 19. DSS-53, BWG, Receive and Low-Power Transmit Horizon Masks

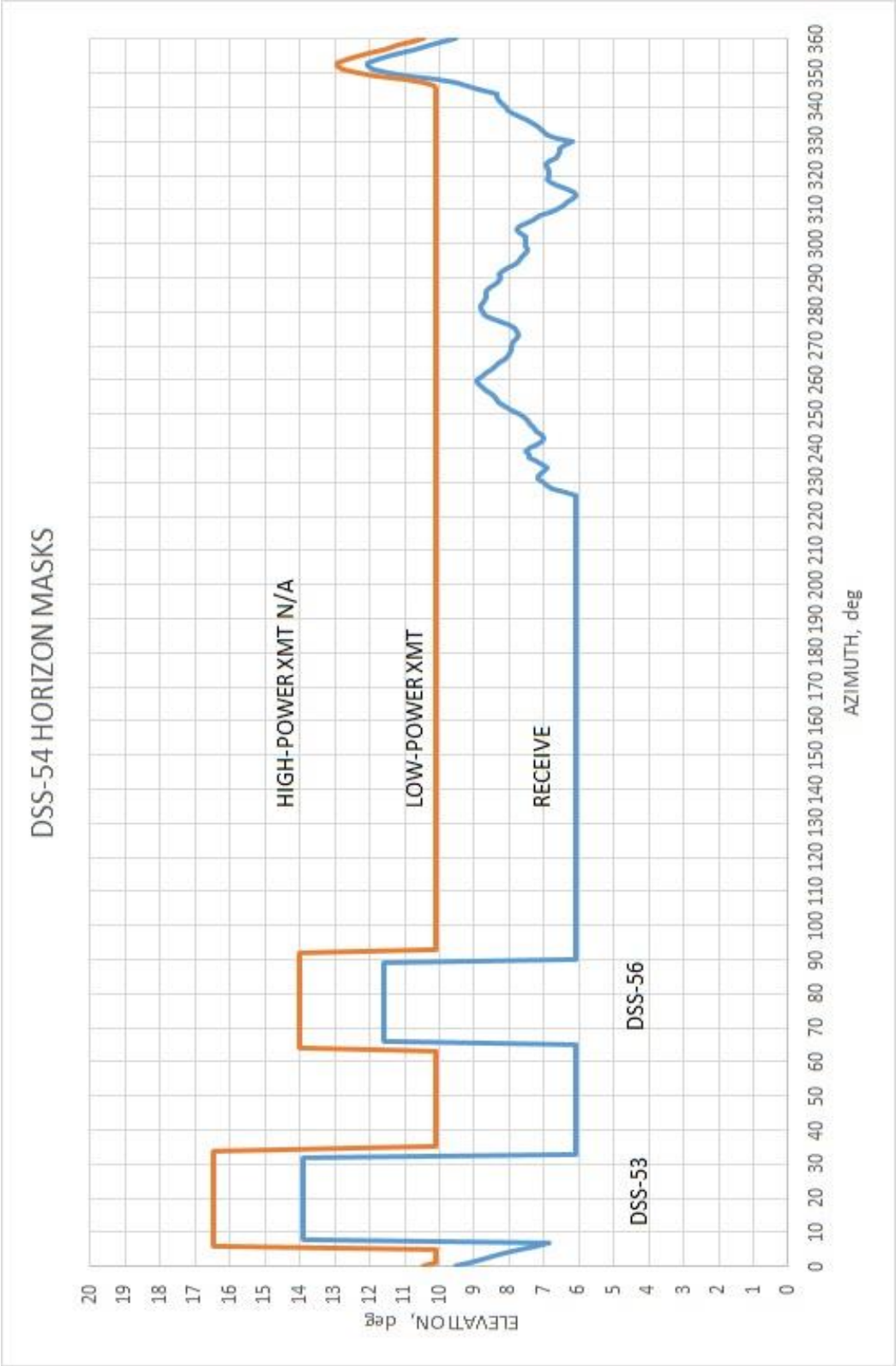


Figure 20. DSS-54, BWG, Receive and Low-Power Transmit Horizon Masks

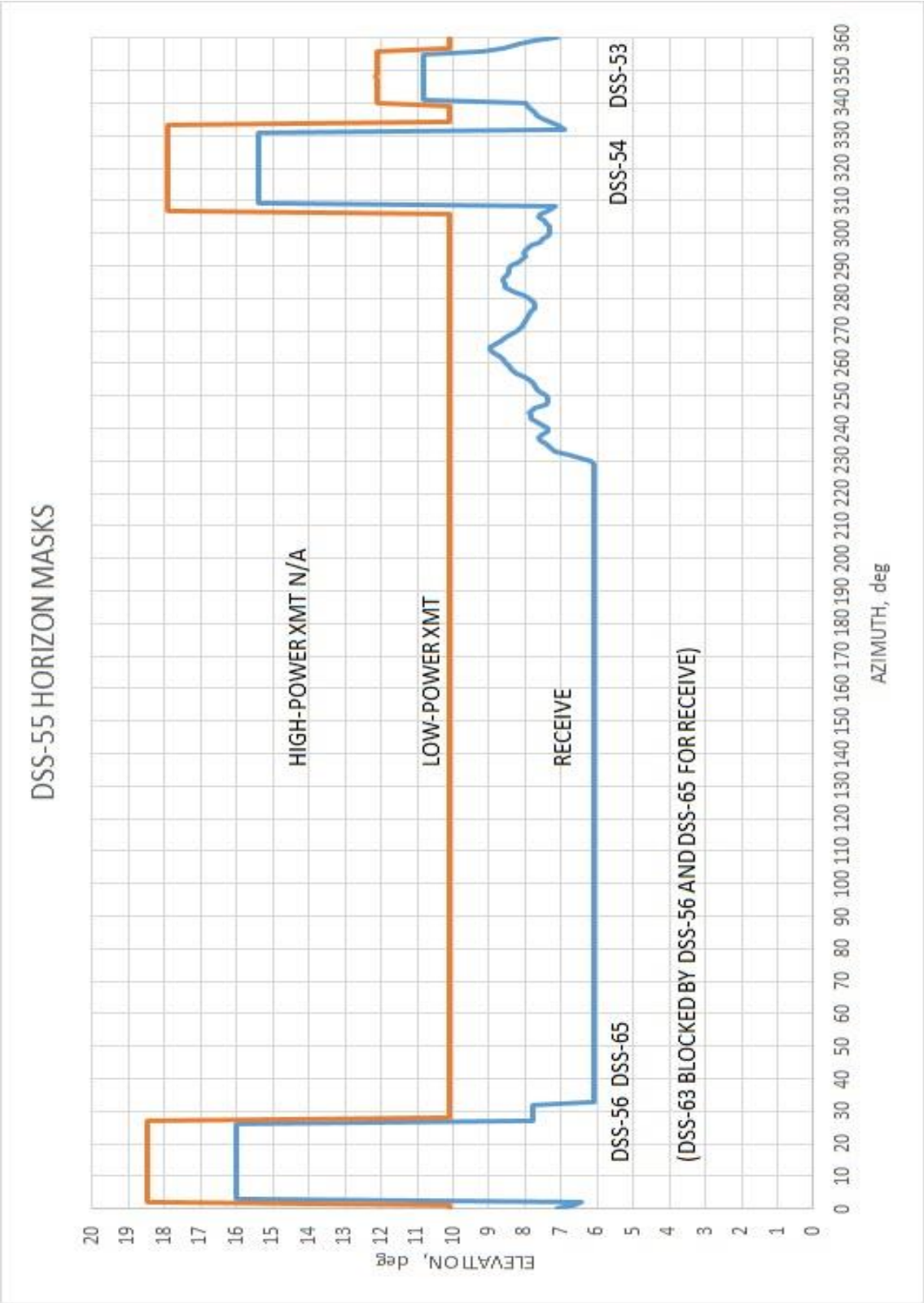


Figure 21. DSS-55, BWG, Receive and Low-Power Transmit Horizon Masks

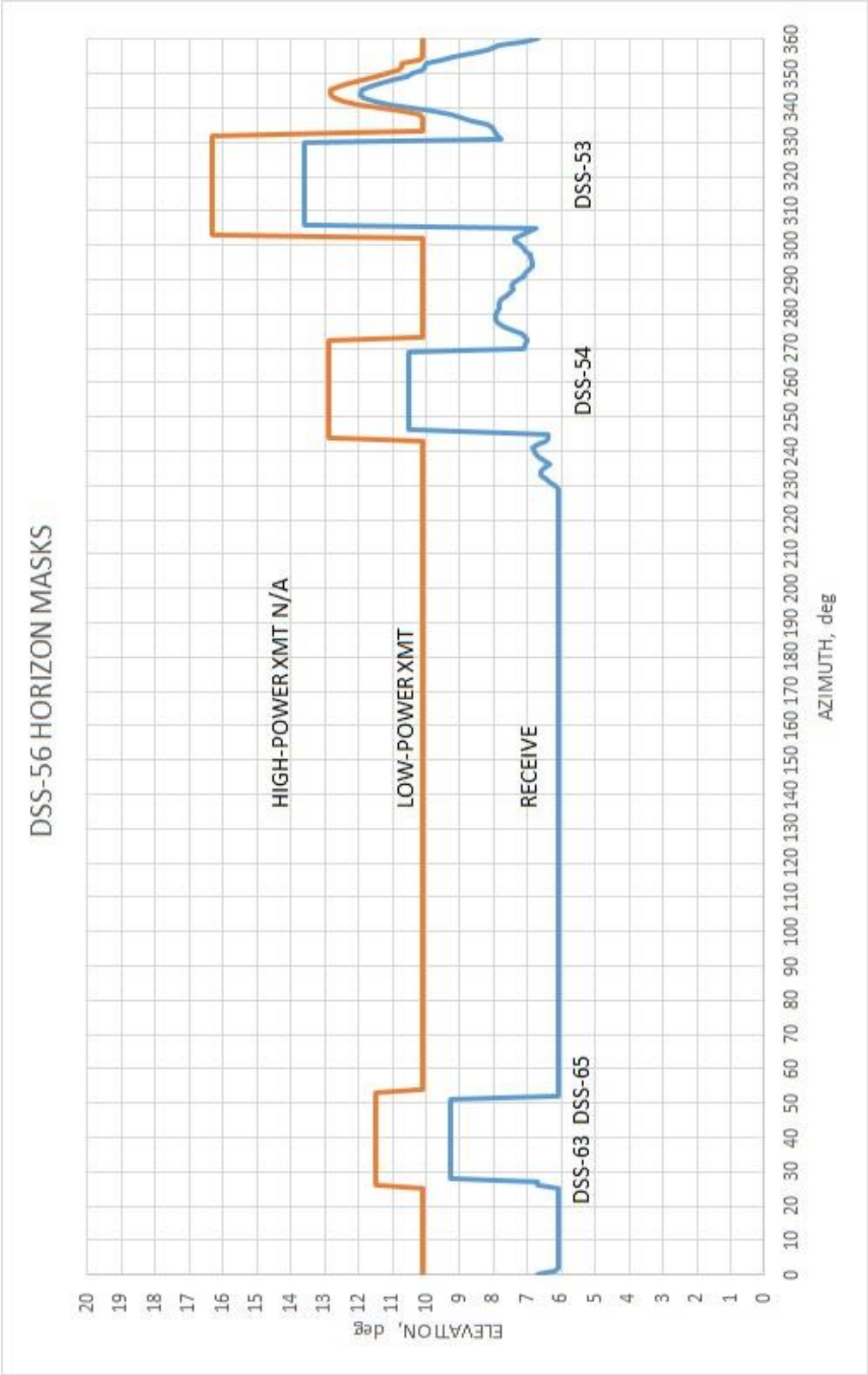


Figure 22. DSS-56, BWG, Receive and Low-Power Transmit Horizon Masks

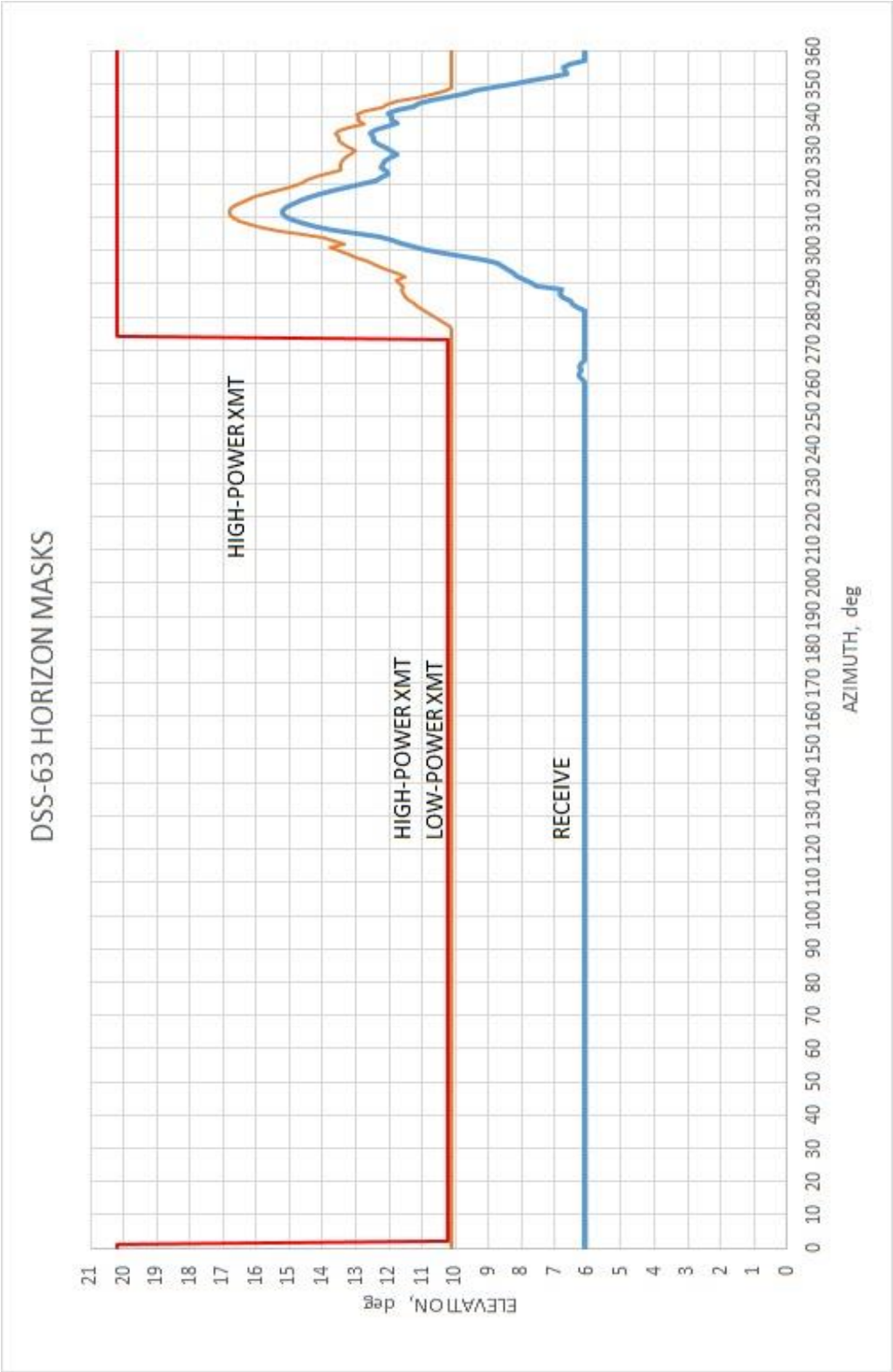


Figure 23. DSS-63, 70-m, Receive, Low-Power Transmit, and High-Power Transmit Horizon Masks

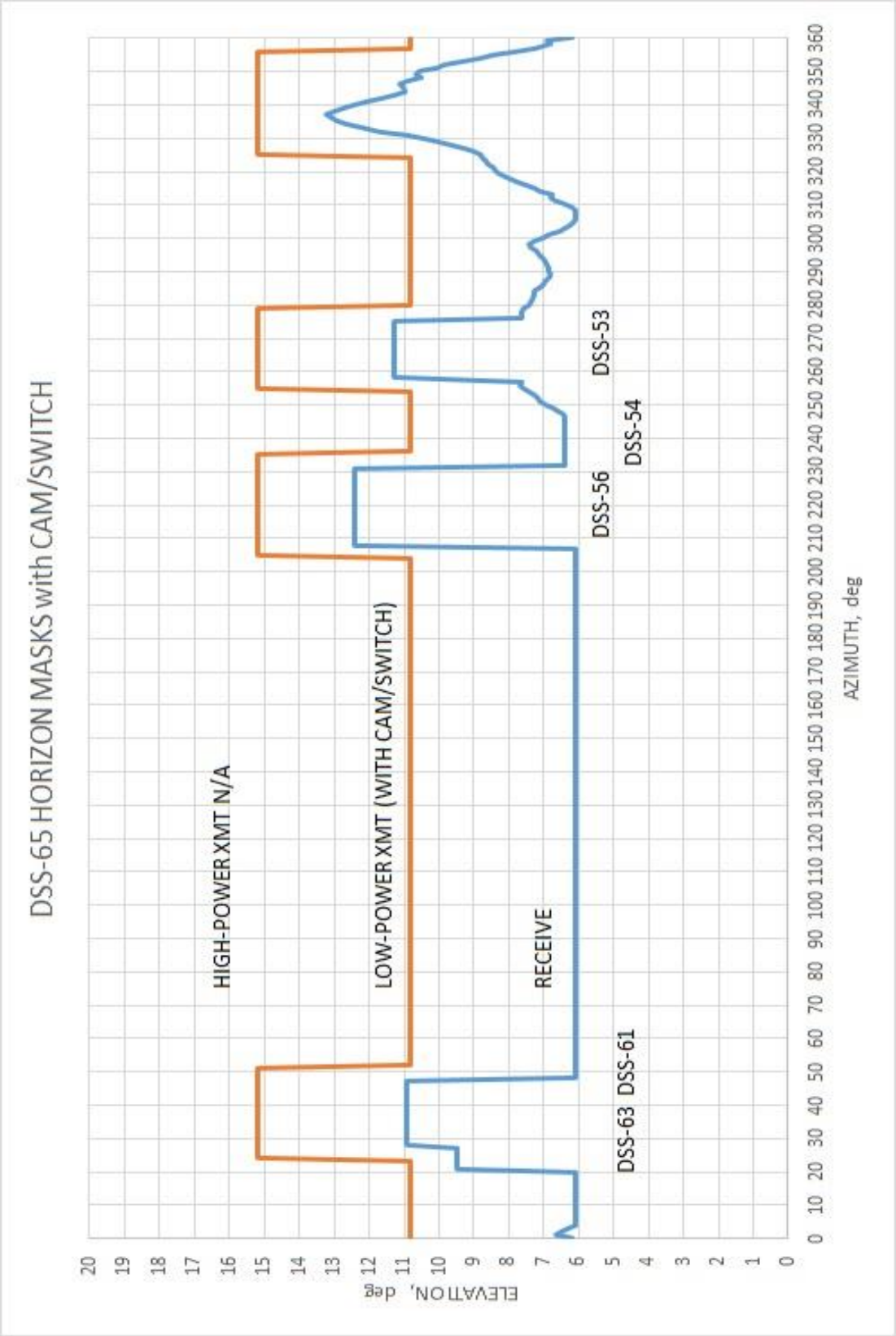


Figure 24. DSS-65, HEF, Receive and Low-Power Transmit Horizon Masks

Appendix A
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