# GEO-10, Rev. E
# DSN Coverage and Geometry

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# *1. Introduction*

## *1.1 Purpose*

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

## *1.2 Scope*

This module provides the DSN station coordinates which 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 whose 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 on the range observable is discussed in module TRK-30 of this handbook.

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 Standard (STD) | 42, 61 | HA/DEC | 6.706 m |
| 34-m High Efficiency (HEF) | 15, 45, 65 | Az/El | 0 |
| 34-m Beam Waveguide (BWG) | 24, 25, 26, 34, 54 | Az/El | 0 |
| 34-m High-speed Beam Waveguide (HSB) | 27, 28 | Az/El | 1.83 m |
| 26-m | 16, 46, 66 | X/Y | 6.706 m |
| 11-m OVLBI | 23, 33, 53 | Tilt/Az/El | 0.391 m |
| 9-m | 17 | X-Y | 2.44 m |

Az/El - Antenna's azimuth plane is tangent to the earth's surface and antenna at 90-degrees elevation is pointing at zenith.

HA/DEC - Antennas employ polar mounts where the primary axis (HA) is aligned parallel to the earth's rotational axis.

X/Y - Primary axis (X) is aligned horizontally in an east-west (26-m antennas) or north-south (9-m antenna) direction. Secondary axis is aligned vertically in a north-south (26-m antennas) or east-west (9-m antenna) plane.

Tilt/Az/El - The azimuth axis of the Az/El mount is tilted to avoid an overhead keyhole. The direction of tilt is fixed for each pass and results in an apparent shift in the actual station location from the specified station location.

The 11-m antennas are unique in that the azimuth axis is tilted from the local vertical by a 7-degree wedge that is rotated to a position with respect to north called the "train angle" before the start of each track. This has the effect of causing the station location to be displaced away from the train angle along a circular path having a radius equal to the axis offset. The vector ($\Delta\mathbf{r}_b$) which must be added to the station coordinates to compensate for this effect can be derived from the train angle which is supplied to the user as part of the tracking data (see module TRK-10) and the north and east station vectors (**N** and **E**) which are functions of the station geodetic coordinates.

$$\Delta \mathbf{r}_b = -0.391\cos\sigma\,\mathbf{N} - 0.391\sin\sigma\,\mathbf{E}$$

where:

$\sigma$ = the train angle

$$\mathbf{N} = \begin{bmatrix} -\sin\phi_g \cos\lambda \\ -\sin\phi_g \sin\lambda \\ \cos\phi_g \end{bmatrix}$$

$$\mathbf{E} = \begin{bmatrix} -\sin\lambda \\ -\cos\lambda \\ 0 \end{bmatrix}$$

$\phi_g$ = Station Geodetic Latitude (Table 5)

$\lambda$ = Station Longitude

### *2.1.2 IERS Terrestrial Reference Frame*

To use station locations with sub-meter accuracy, it is necessary to clearly define a coordinate system which is global is scope as opposed to the regional coordinate systems referenced in previous editions of this document. The International Earth Rotation 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 which 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 (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 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.

Until this change is fully adopted by the Earth orientation community, the DSN is delivering Earth orientation calibrations to navigation teams that are consistent with the earlier definition and using the ITRF93 reference frame. Users interested in precise comparison with other system should keep in mind the small systematic differences.

#### *2.1.2.1 ITRF Coordinates*

Figure 1 illustrates the ITRF coordinates and the relationship between the ITRF coordinates and geocentric coordinates discussed below. The Cartesian coordinates of the DSN station locations in the ITRF93 reference system are provided in Table 2. Table 2 also gives the characteristic position uncertainty for horizontal and vertical components.

#### *2.1.2.2 ITRF Site Velocities*

The locations given in Table 2 are for the epoch 1993.0. To transform these locations to any other epoch, the site velocities should be used. Table 3 gives the ITRF93 site velocities for the DSN stations, in both Cartesian and east-north-vertical components.

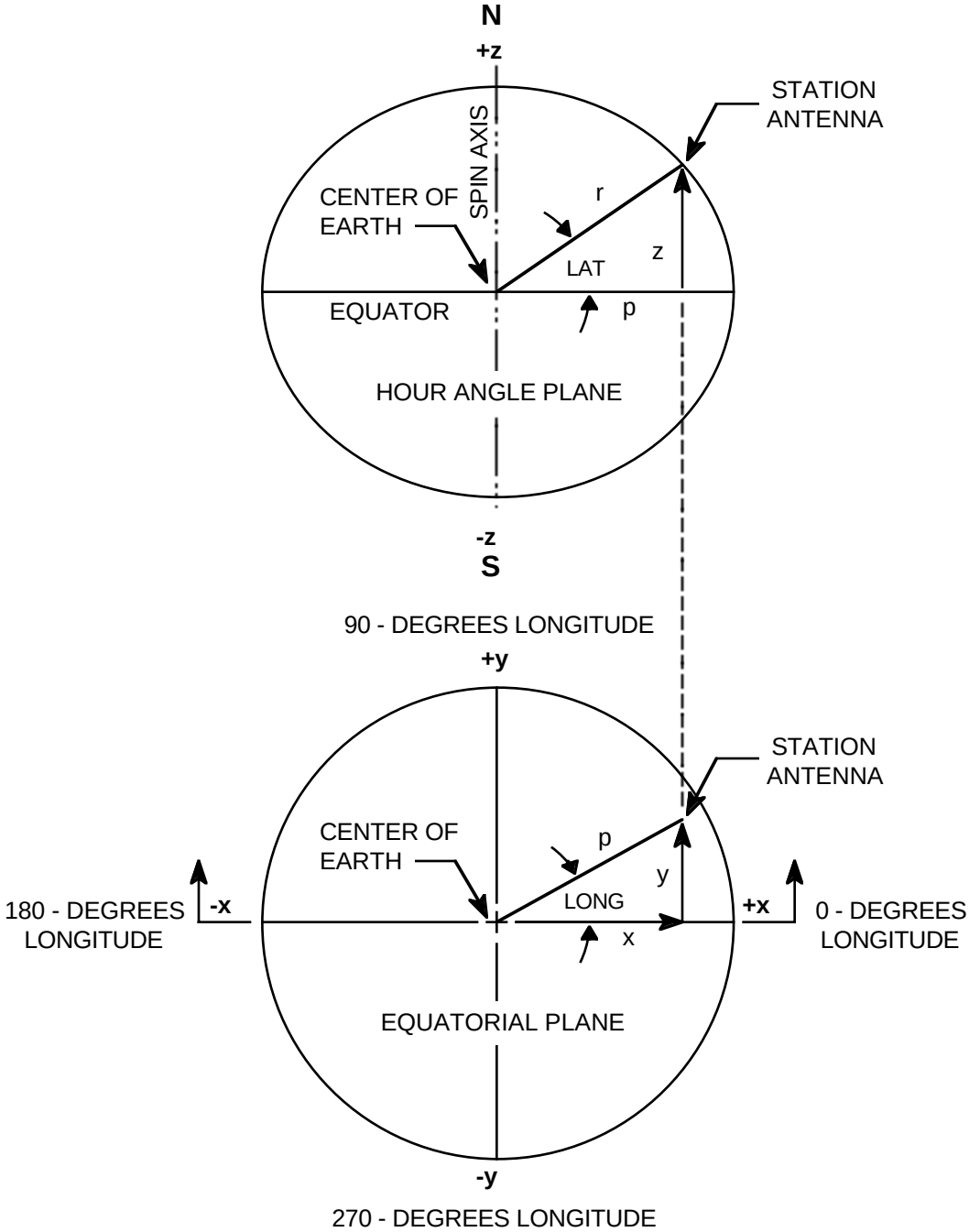
### *2.1.3 Geocentric Coordinates*

Geocentric coordinates are used for spacecraft tracking. 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 4.

### *2.1.4 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 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 having a semi-major (equatorial) axis and semi-minor (polar) axis that provides a best fit to the geoid in the area of interest. 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:

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




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. ITRF Cartesian and Geocentric Coordinate System Relationships

Table 2. ITRF93 Coordinates for DSN Stations

| Antenna | | Cartesian Coordinates | | | Uncertainty | |
|---|---|---|---|---|---|---|
| Name | Description | x(m) | y(m) | z(m) | h(m) | v(m) |
| DSS 13 | 34-m R & D | -2351112.491 | -4655530.714 | +3660912.787 | 0.04 | 0.05 |
| DSS 14 | 70-m | -2353621.251 | -4641341.542 | +3677052.370 | 0.03 | 0.03 |
| DSS 15 | 34-m HEF | -2353538.790 | -4641649.507 | +3676670.043 | 0.03 | 0.03 |
| DSS 16 | 26-m X-Y | -2354763.158 | -4646787.462 | +3669387.069 | 0.05 | 0.10 |
| DSS 17 | 9-m X-Y | -2354730.357 | -4646751.776 | +3669440.659 | 0.05 | 0.10 |
| DSS 23 | 11-m Tilt/Az/El | -2354757.567 | -4646934.675 | +3669207.824 | 0.05 | 0.10 |
| DSS 24 | 34-m BWG | -2354906.495 | -4646840.128 | +3669242.317 | 0.05 | 0.10 |
| DSS 25 | 34-m BWG | -2355022.066 | -4646953.636 | +3669040.895 | 0.05 | 0.10 |
| DSS 26 | 34-m BWG | -2354890.967 | -4647166.925 | +3668872.212 | 0.05 | 0.10 |
| DSS 27 | 34-m HSB | -2349915.260 | -4656756.484 | +3660096.529 | 0.05 | 0.10 |
| DSS 28 | Not in service | -2350101.849 | -4656673.447 | +3660103.577 | 0.05 | 0.10 |
| DSS 33 | 11-m Tilt/Az/El | -4461083.514 | +2682281.745 | -3674570.392 | 0.03 | 0.10 |
| DSS 34 | 34-m BWG | -4461146.756 | +2682439.293 | -3674393.542 | 0.05 | 0.10 |
| DSS 42 | 34-m HA -DEC | -4460981.016 | +2682413.525 | -3674582.072 | 0.04 | 0.05 |
| DSS 43 | 70-m | -4460894.585 | +2682361.554 | -3674748.580 | 0.03 | 0.03 |
| DSS 45 | 34-m HEF | -4460935.250 | +2682765.710 | -3674381.402 | 0.03 | 0.03 |
| DSS 46 | 26-m X-Y | -4460828.619 | +2682129.556 | -3674975.508 | 0.04 | 0.04 |
| DSS 53 | 11-m Tilt/Az/El | +4849330.129 | -0360338.092 | +4114758.766 | 0.05 | 0.10 |
| DSS 54 | 34-m BWG | +4849434.555 | -0360724.108 | +4114618.643 | 0.05 | 0.10 |
| DSS 61 | 34-m HA -DEC | +4849245.211 | -0360278.166 | +4114884.445 | 0.04 | 0.05 |
| DSS 63 | 70-m | +4849092.647 | -0360180.569 | +4115109.113 | 0.03 | 0.03 |
| DSS 65 | 34-m HEF | +4849336.730 | -0360488.859 | +4114748.775 | 0.03 | 0.03 |
| DSS 66 | 26-m X-Y | +4849148.543 | -0360474.842 | +4114995.021 | 0.05 | 0.10 |

Notes:

1. All antennas are AZ-EL type unless otherwise specified.
2. Horizontal (h) and vertical (v) uncertainties are 1-sigma.

Table 3. ITRF93 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) | -0.0191 | 0.0061 | -0.0047 | -0.0198 | -0.0057 | -0.0001 |
| Canberra (Stations 3x & 4x) | -0.0354 | -0.0017 | 0.0412 | 0.0197 | 0.0506 | 0.0001 |
| Madrid (Stations 5x & 6x) | -0.0141 | 0.0222 | 0.0201 | 0.0211 | 0.0255 | 0.0011 |

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

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

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

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

where:

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

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

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

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

Table 4. 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 | 5215524.535 | 35.0660185 | 243.2055430 | 6372125.125 |
| DSS 14 | 70-m | 5203996.955 | 35.2443527 | 243.1104638 | 6371993.286 |
| DSS 15 | 34-m HEF | 5204234.332 | 35.2403133 | 243.1128069 | 6371966.540 |
| DSS 16 | 26-m X-Y | 5209370.715 | 35.1601777 | 243.1263523 | 6371965.530 |
| DSS 17 | 9-m X-Y | 5209324.056 | 35.1608133 | 243.1264967 | 6371958.245 |
| DSS 23 | 11-m Tilt/Az/El | 5209499.503 | 35.1581932 | 243.1271390 | 6371967.603 |
| DSS 24 | 34-m BWG | 5209482.486 | 35.1585349 | 243.1252079 | 6371973.553 |
| DSS 25 | 34-m BWG | 5209635.978 | 35.1562594 | 243.1246384 | 6371983.060 |
| DSS 26 | 34-m BWG | 5209766.971 | 35.1543411 | 243.1269849 | 6371993.032 |
| DSS 27 | 34-m HSB | 5216079.244 | 35.0571456 | 243.2233516 | 6372110.269 |
| DSS 28 | Not in service | 5216089.176 | 35.0571462 | 243.2211109 | 6372122.448 |
| DSS 33 | 11-m Tilt/Az/El | 5205372.367 | -35.2189880 | 148.9830895 | 6371684.945 |
| DSS 34 | 34-m BWG | 5205507.750 | -35.2169868 | 148.9819620 | 6371693.561 |
| DSS 42 | 34-m HA-DEC | 5205352.432 | -35.2191772 | 148.9812650 | 6371675.396 |
| DSS 43 | 70-m | 5205251.579 | -35.2209234 | 148.9812650 | 6371689.033 |
| DSS 45 | 34-m HEF | 5205494.708 | -35.2169652 | 148.9776833 | 6371675.906 |
| DSS 46 | 26-m X-Y | 5205075.496 | -35.2235036 | 148.9830794 | 6371676.067 |
| DSS 53 | 11-m Tilt/Az/El | 4862699.481 | 40.2375043 | 355.7503453 | 6370014.595 |
| DSS 54 | 34-m BWG | 4862832.239 | 40.2357708 | 355.7459008 | 6370025.429 |
| DSS 61 | 34-m HA-DEC | 4862610.356 | 40.2388851 | 355.7509753 | 6370027.745 |
| DSS 63 | 70-m | 4862450.981 | 40.2413537 | 355.7519890 | 6370051.221 |
| DSS 65 | 34-m HEF | 4862717.238 | 40.2373325 | 355.7485795 | 6370021.697 |
| DSS 66 | 26-m X-Y | 4862528.530 | 40.2401197 | 355.7485798 | 6370036.713 |

Notes:
1. All antennas are AZ-EL type unless otherwise specified.

Table 5 provides geodetic coordinates derived by the preceding approach using an ellipsoid with a semi-major axis (a) of 6378136.3 m and a flattening (f) of 298.257.

## *2.2 Coverage and Mutual Visibility*

The coverage and mutual visibility provided for spacecraft tracking depends on the altitude of the spacecraft, the type or types of antennas being used, the blockage of the antenna beam by the landmask 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.

#### *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 on-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 and somewhat lower for antennas with polar (hour angle-declination) or X-Y mounts. The second area of non-coverage is the keyhole off the end or ends of the antenna's primary axis.

Table 5. Geodetic Coordinates for DSN Stations

| Antenna | | latitude ($\phi$) | | | longitude ($\lambda$) | | | height($h$) |
|---|---|---|---|---|---|---|---|---|
| Name | Description | deg | min | sec | deg | min | sec | (m) |
| DSS 13 | 34-m R & D | 35 | 14 | 49.79342 | 243 | 12 | 19.95493 | 1071.178 |
| DSS 14 | 70-m | 35 | 25 | 33.24518 | 243 | 6 | 37.66967 | 1002.114 |
| DSS 15 | 34-m HEF | 35 | 25 | 18.67390 | 243 | 6 | 46.10495 | 0973.945 |
| DSS 16 | 26-m X-Y | 35 | 20 | 29.54391 | 243 | 7 | 34.86823 | 0944.711 |
| DSS 17 | 9-m X-Y | 35 | 20 | 31.83778 | 243 | 7 | 35.38803 | 0937.650 |
| DSS 23 | 11-m Tilt/Az/El | 35 | 20 | 22.38335 | 243 | 7 | 37.70043 | 0946.086 |
| DSS 24 | 34-m BWG | 35 | 20 | 23.61555 | 243 | 7 | 30.74842 | 0952.156 |
| DSS 25 | 34-m BWG | 35 | 20 | 15.40450 | 243 | 7 | 28.69836 | 0960.862 |
| DSS 26 | 34-m BWG | 35 | 20 | 08.48213 | 243 | 7 | 37.14557 | 0970.159 |
| DSS 27 | 34-m HSB | 35 | 14 | 17.78052 | 243 | 13 | 24.06569 | 1053.203 |
| DSS 28 | Not in service | 35 | 14 | 17.78136 | 243 | 13 | 15.99911 | 1065.382 |
| DSS 33 | 11-m Tilt/Az/El | -35 | 24 | 01.76138 | 148 | 58 | 59.12204 | 0684.839 |
| DSS 34 | 34-m BWG | -35 | 23 | 54.53995 | 148 | 58 | 55.06320 | 0692.750 |
| DSS 42 | 34-m HA -DEC | -35 | 24 | 02.44494 | 148 | 58 | 52.55396 | 0675.356 |
| DSS 43 | 70-m | -35 | 24 | 8.74388 | 148 | 58 | 52.55394 | 0689.608 |
| DSS 45 | 34-m HEF | -35 | 23 | 54.46400 | 148 | 58 | 39.65992 | 0675.086 |
| DSS 46 | 26-m X-Y | -35 | 24 | 18.05462 | 148 | 58 | 59.08571 | 0677.551 |
| DSS 53 | 11-m Tilt/Az/El | 40 | 25 | 38.48036 | 355 | 45 | 1.24307 | 0827.501 |
| DSS 54 | 34-m BWG | 40 | 25 | 32.23201 | 355 | 44 | 45.24283 | 0837.696 |
| DSS 61 | 34-m HA -DEC | 40 | 25 | 43.45508 | 355 | 45 | 03.51113 | 0841.159 |
| DSS 63 | 70-m | 40 | 25 | 52.34908 | 355 | 45 | 7.16030 | 0865.544 |
| DSS 65 | 34-m HEF | 40 | 25 | 37.86055 | 355 | 44 | 54.88622 | 0834.539 |
| DSS 66 | 26-m X-Y | 40 | 25 | 47.90367 | 355 | 44 | 54.88739 | 0850.582 |

Notes:

1. All antennas are AZ-EL type unless otherwise specified.

#### *2.2.2.1 Azimuth-Elevation Antennas*

The keyhole of the DSN azimuth-elevation antennas is directly overhead and results from the fact that the antennas can only be moved over an arc of approximately 85 degrees in elevation. In order to track a spacecraft which is passing directly overhead, it is necessary to rotate the antenna 180 degrees in azimuth when the spacecraft is at zenith in order to continue the track. 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 TRK-10. The location of the DSN antennas is such that overhead tracks are not required for spacecraft on normal planetary missions.

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 6 provides the approximate cable wrap limits for the DSN azimuth-elevation antennas.

Table 6. Approximate Cable Wrap Limits for Azimuth-Elevation Antennas

| Antenna | | Azimuth Position (Degrees) | | |
|---|---|---|---|---|
| Name(s) | Description | Center of Wrap | CW Limit | 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, 65 | 34-m BWG | 135 | 360 | 270 |
| DSS 34 | 34-m BWG | 45 | 270 | 180 |
| DSS 27 | 34-m HSB | 135 | 360 | 270 |
| DSS 23, 33, 53 | 11-m | 0 | 380 | (-) 380 |

#### *2.2.2.2 Hour Angle-Declination Antennas*

The DSN hour angle-declination antennas have a single keyhole caused by requirements for mechanical clearance in the antenna structure. The keyhole is located directly to the north of DSS 61 and directly to the south of DSS 42.

#### *2.2.2.3 X-Y Antennas*

The DSN 26 meter X-Y antennas (DSS 16, 46, and 66) and the DSN 9 meter antenna (DSS 17) have two keyholes caused by requirements for mechanical clearance in the antenna structure. The keyholes are located directly to the east and west of the 26-m antennas. The primary axis of the DSN 9-m antenna (DSS 17) runs north and south but the keyholes do not extend above the terrain mask.

#### *2.2.2.4 Tilt-Azimuth-Elevation Antennas*

The DSN 11-meter antennas (DSS 23, 33, and 55) have a keyhole above each antenna which is offset from zenith by 7-degrees. The location of this keyhole is set before each pass to a position that will provide clearance between the keyhole and the scheduled track.

### *2.2.3 Coverage Charts*

The following figures provide examples of coverage for various combinations of stations, spacecraft altitudes, and type of support. These figures were plotted by a program written as a collection of Microsoft Excel 5.0 macros which is available for download (1.7 Mbytes) from the 810-5 web site (http://deepspace1.jpl.nasa.gov/810-5/).

#### *2.2.3.1 70-m Subnet Receive Coverage of Planetary Spacecraft*

Figure 2 illustrates the receive coverage of planetary spacecraft by the DSN 70-m antenna subnet. The small circles (shown as ovals on the maps) above each antenna represent the 70-m antenna keyholes. Although not illustrated, the receive coverage from a subnet of 34-m BWG stations is approximately the same as that from the 70-m stations.

#### *2.2.3.2 70-m Subnet 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 circles (shown as ovals on the maps) above each station 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 north-west of the station.

#### *2.2.3.3 34-m HEF Subnet Receive Coverage of Planetary Spacecraft*

Figure 4 illustrates the receive coverage of planetary spacecraft by the DSN 34-m HEF antenna subnet. The keyholes above each 34-m HEF antenna are very small and are 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 of where it is observed from DSS 63.

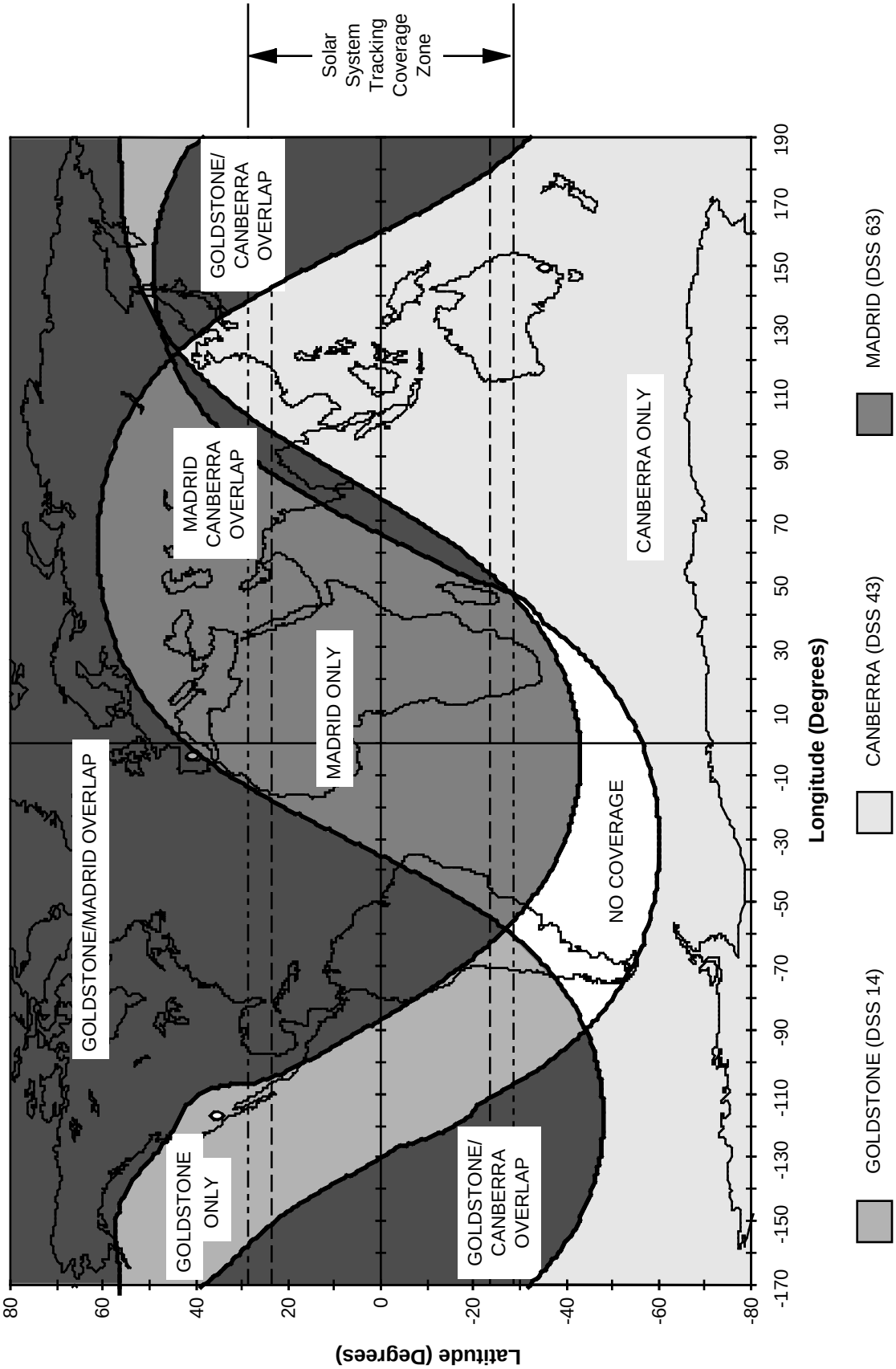



Figure 2. DSN 70-m Subnet Receive Coverage, Planetary Spacecraft.

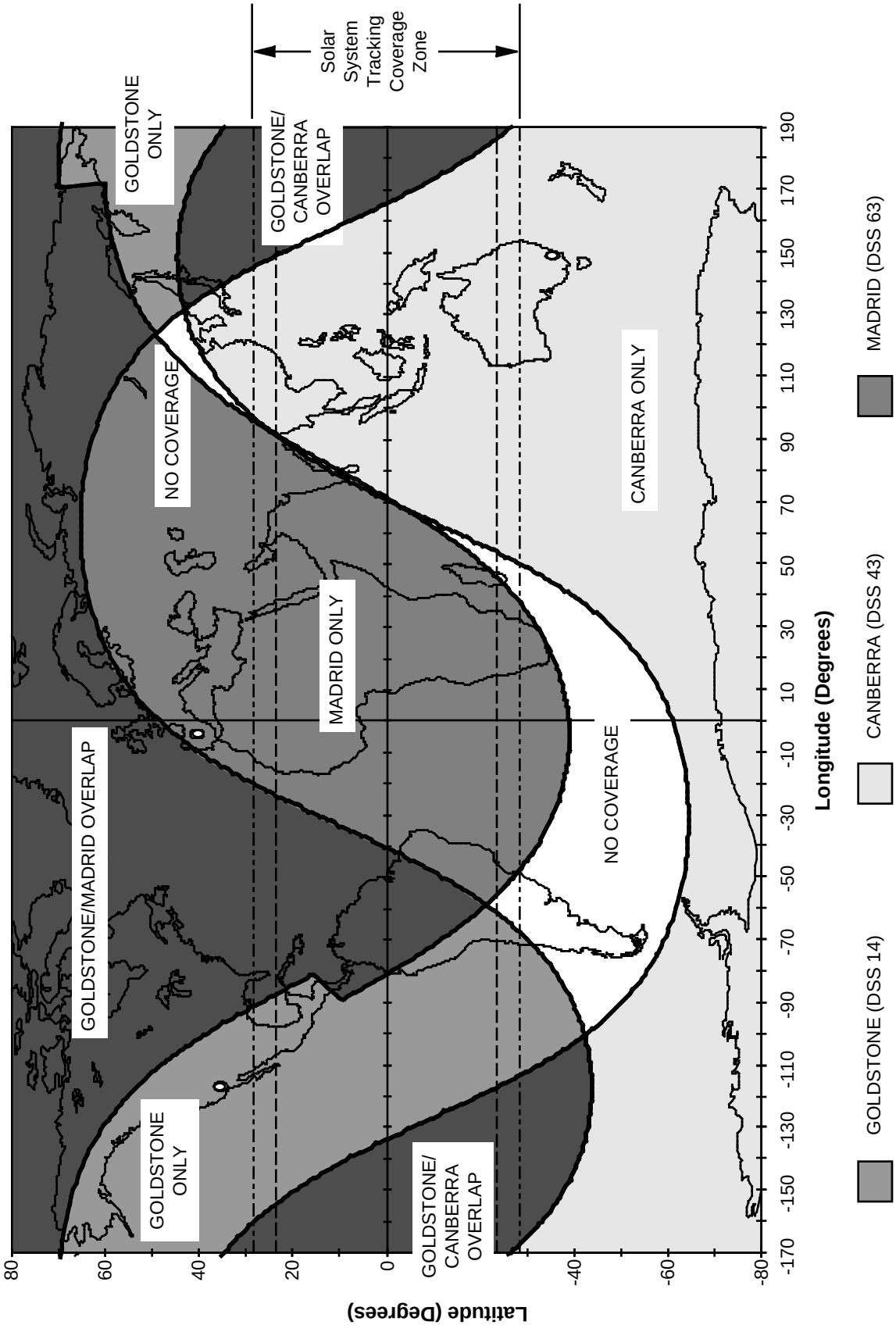



Figure 3. DSN 70-m Subnet Transmit Coverage, Planetary Spacecraft

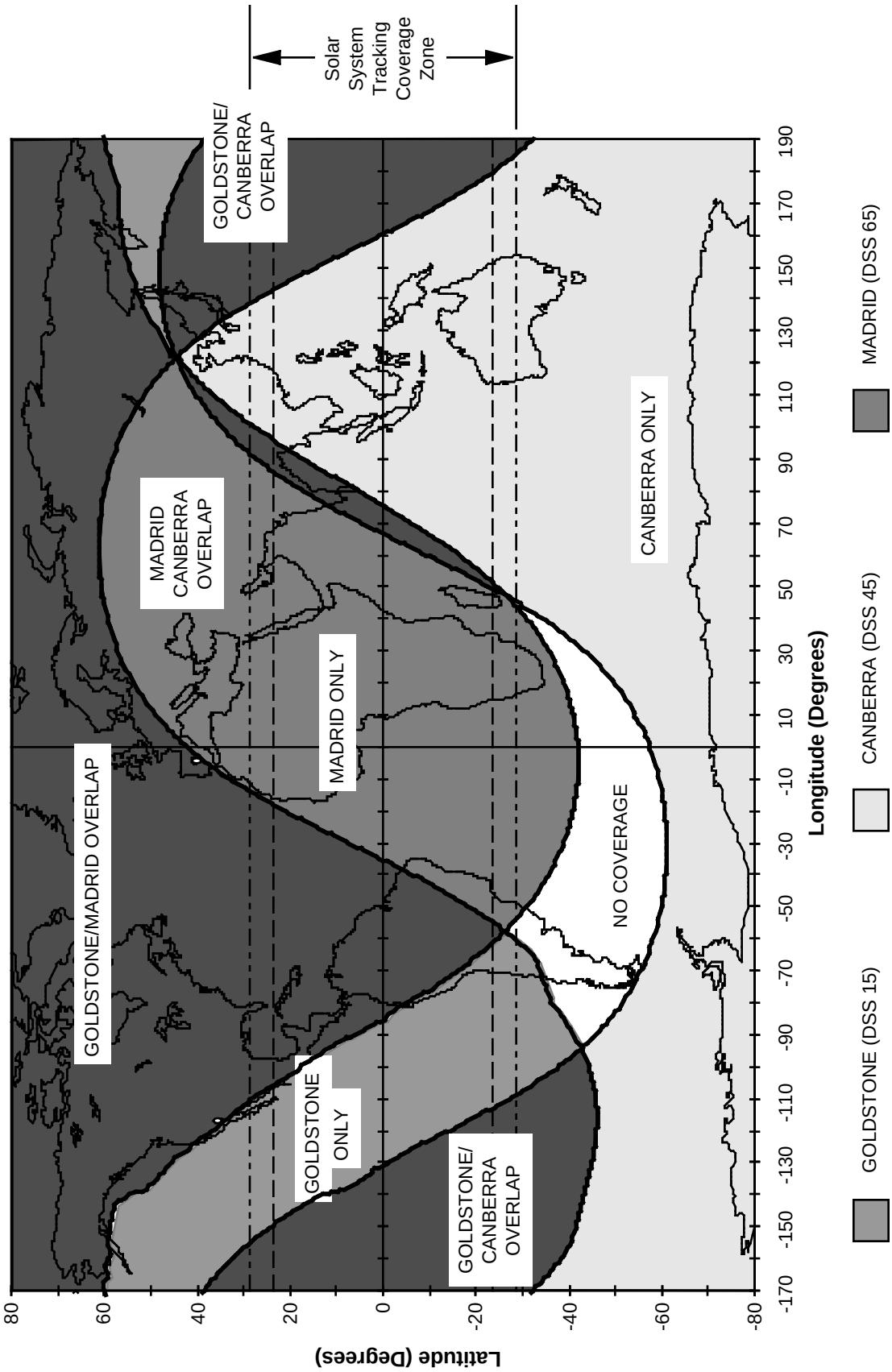



Figure 4. DSN 34-m HEF Subnet Receive Coverage, Planetary Spacecraft.

#### *2.2.3.4 34-m HEF Subnet Transmit Coverage of Planetary Spacecraft*

Figure 5 illustrates the transmit coverage of planetary spacecraft by the DSN 34-m HEF antenna subnet using a 10.6 degree transmit elevation limit at DSS 15, a 10.5 degree transmit limit at DSS 45, and a 10.3 degree limit at DSS 65. As is the case in Figure 4, the size of the circles on the map is larger than the actual size of the 34-m HEF antenna keyholes. Protection of the high ground at DSS 65 is provided by disabling the transmitter between 327.4 and 358.6 degrees azimuth.

#### *2.2.3.5 34-m STD/BWG Subnet Receive Coverage of Planetary Spacecraft*

Figure 6 illustrates the receive coverage of planetary spacecraft by a subnet composed of the 34-m STD antennas at Canberra and Madrid and the DSS 24 BWG antenna at Goldstone. The small circle above DSS 24 represents its keyhole. The keyholes for the STD antennas lie to the south (at DSS 42) and north (at DSS 61) but have no effect on coverage except near the poles. This set of antennas provides the significantly different coverage from that shown in either Figure 4 or 5.

#### *2.2.3.6 26-m Subnet Receive Coverage of Earth Orbiter Spacecraft*

Figure 7 illustrates the receive coverage of earth orbiter spacecraft at altitudes of 200 km, 1000 km, and 5000 km by the DSN 26-m antenna subnet. There are two additional antennas at the Goldstone complex which can be substituted for the 26-m antenna. There is a 9-m antenna, DSS 17, which has similar coverage to the collocated 26-m antenna but without the large keyholes to the east and west (DSS 17's primary axis runs north-south and there are no appreciable keyholes). There is also a 34-m BWG antenna, DSS 27, located approximately 14.5 km south-east of DSS 16. It is collocated with an inactive antenna (DSS 28) that blocks reception to the west in the same place and approximately to the same extent as the west keyhole of DSS 16.

#### *2.2.3.7 34-m STD/BWG Receive Coverage of Earth Orbiter Spacecraft*

Figure 8 illustrates the receive coverage of earth orbiter spacecraft at altitudes of 1000 km, 5000 km, and geosynchronous altitude (35789 km) using a subnet composed of the 34-m STD antennas at Canberra and Madrid and the DSS 24 BWG antenna at Goldstone. Note that the lowest altitude at which this configuration of antennas can be used is limited by the tracking rate of the STD antennas which is listed in module TRK-10.

#### *2.2.3.8 11-m Subnet Receive Coverage of Earth Orbiter Spacecraft*

Figure 9 illustrates the receive coverage of earth orbiter spacecraft at altitudes of 1000 km, 5000 km, and geosynchronous altitude (35789 km) using the 11-m Subnet. The irregular coverage outlines are the result of high ground to the east of DSS 33 and north-west of DSS 54 plus blockage due to other antennas and structures at each complex.

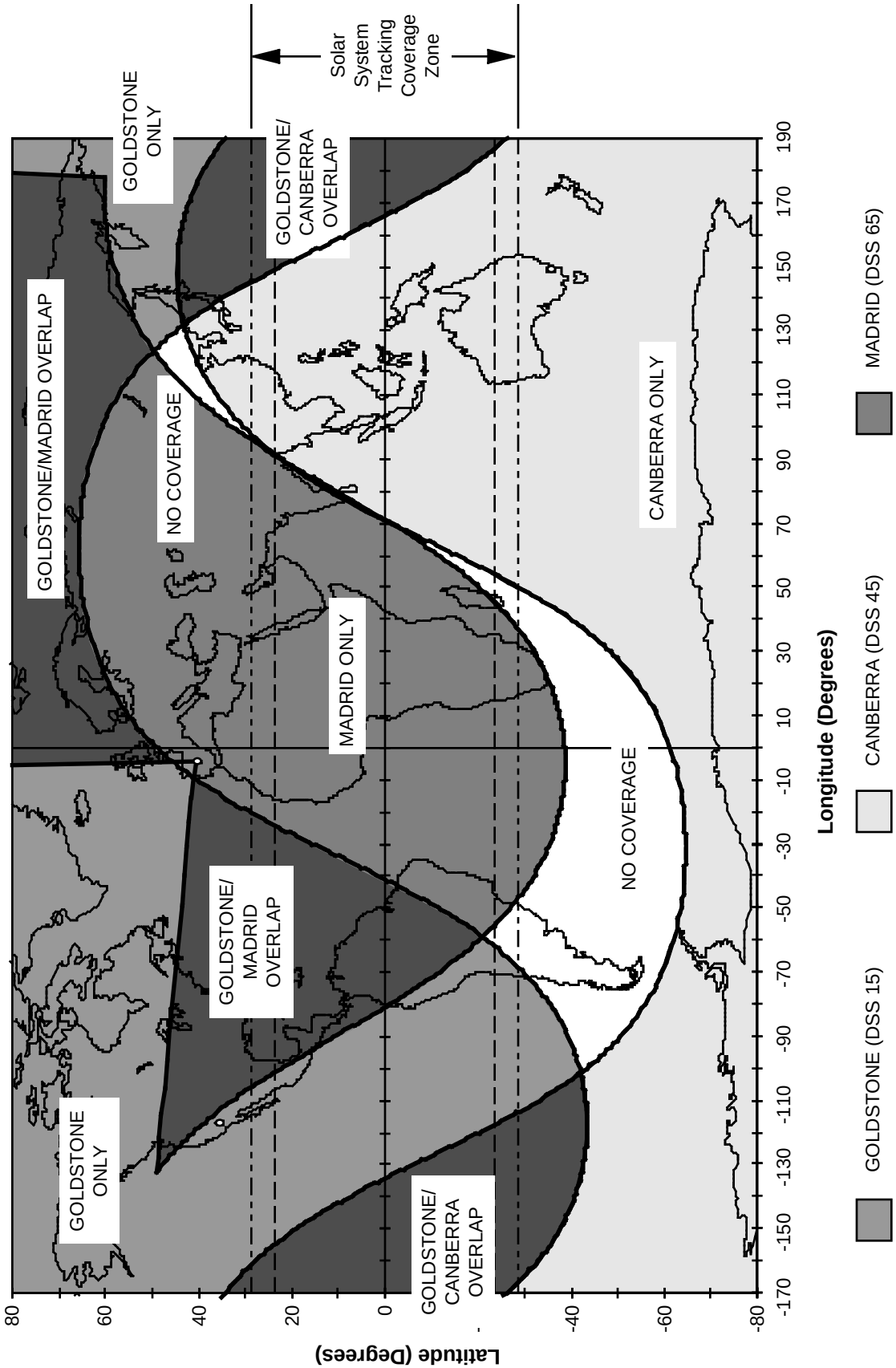



Figure 5. DSN 34-m HEF Subnet Transmit Coverage, Planetary Spacecraft.

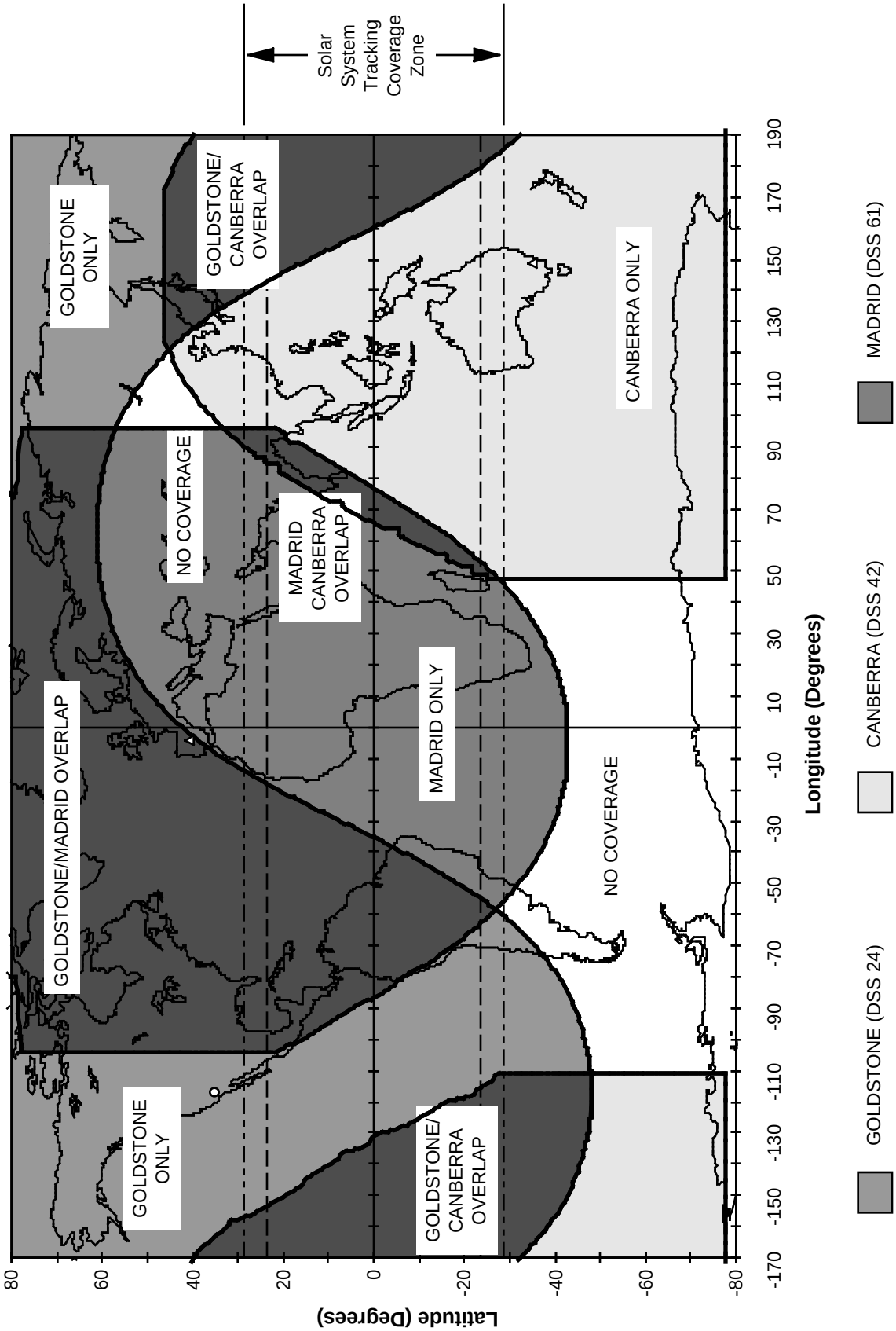



Figure 6. DSN 34-m STD/BWG Subnet Receive Coverage, Planetrary Spacecraft

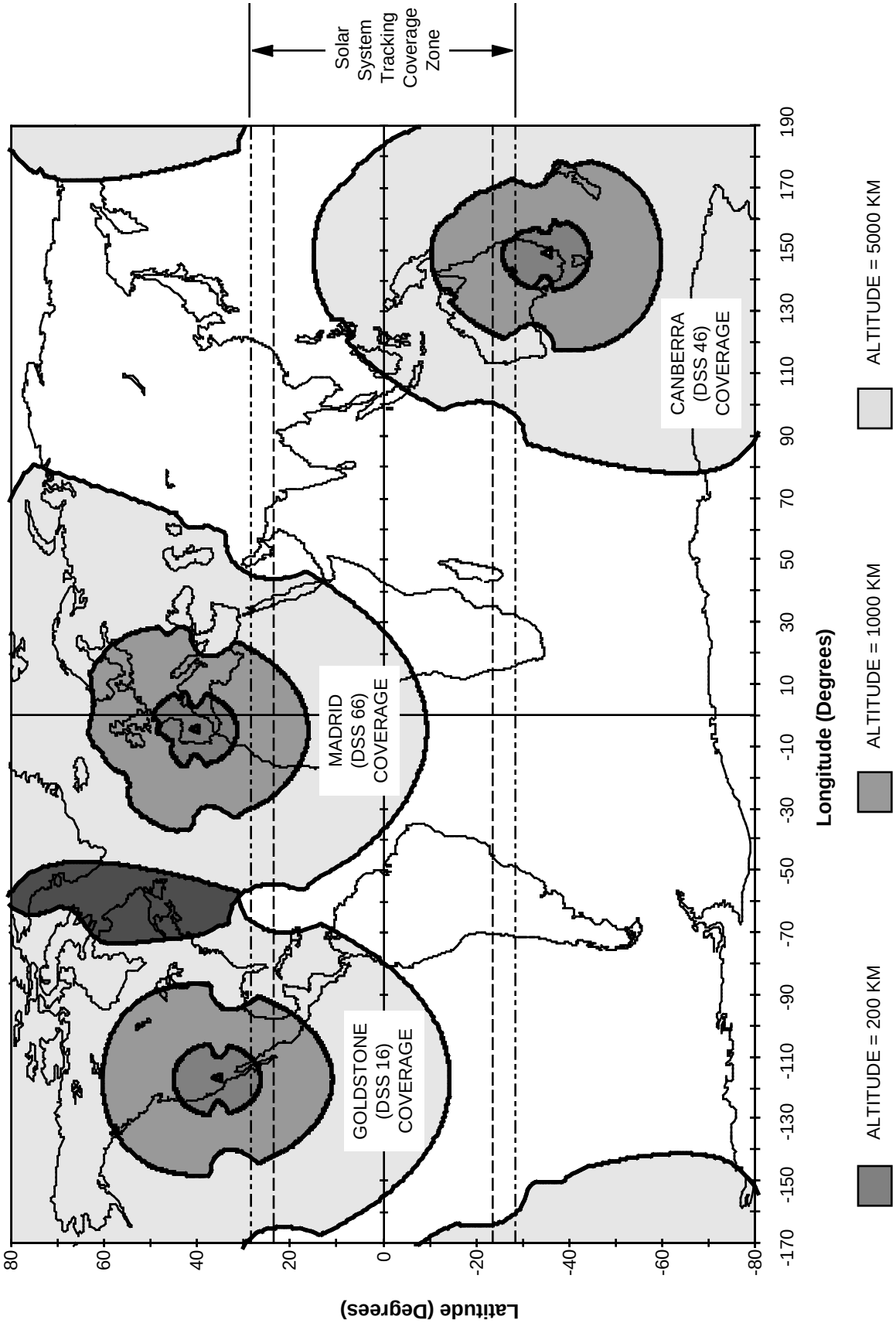



Figure 7. DSN 26-m Subnet Receive Coverage, Earth Orbiter Spacecraft.

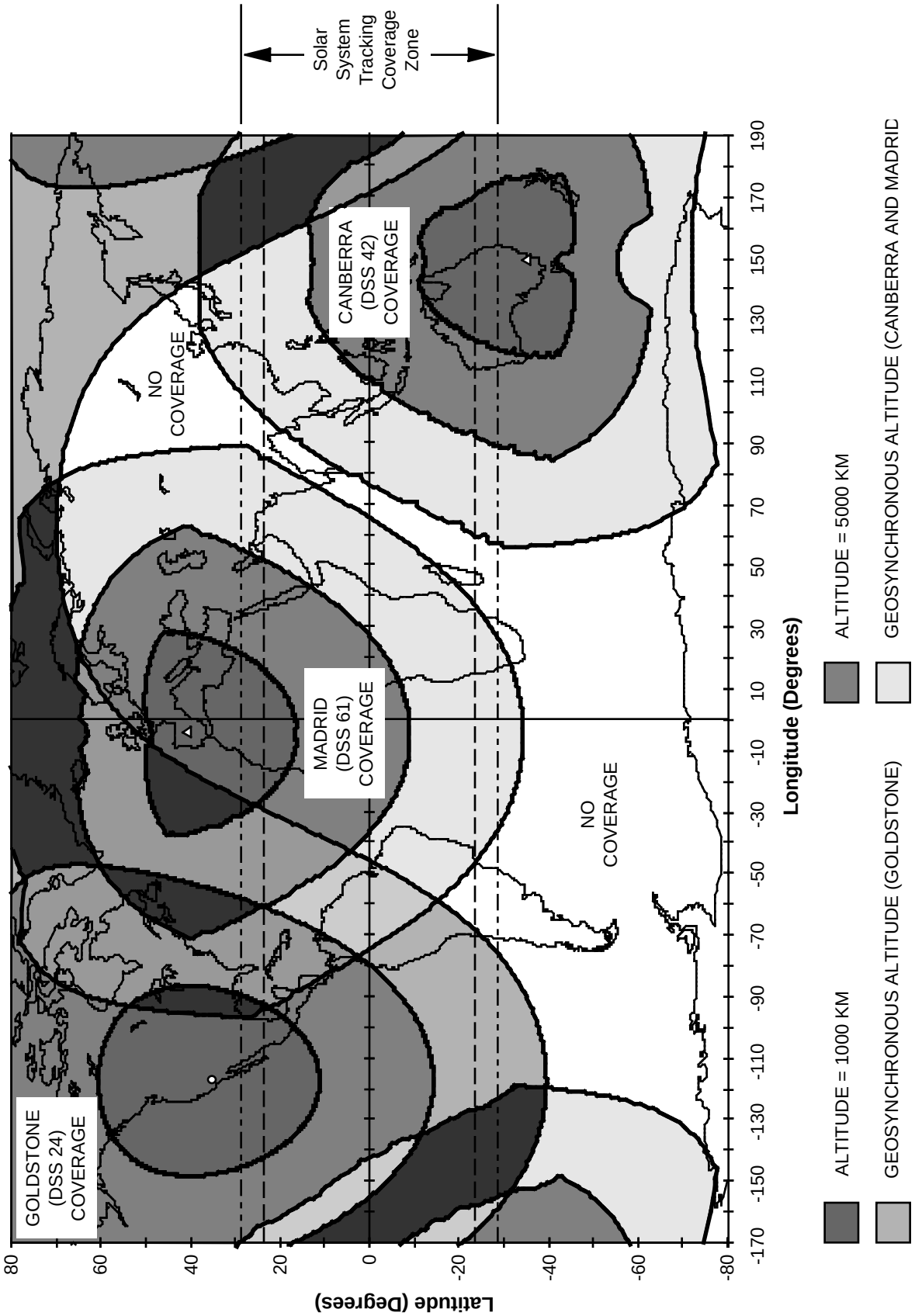



Figure 8. DSN 34-m Receive Coverage, DSS 24, 42, and 61, Earth Orbiter Spacecraft.

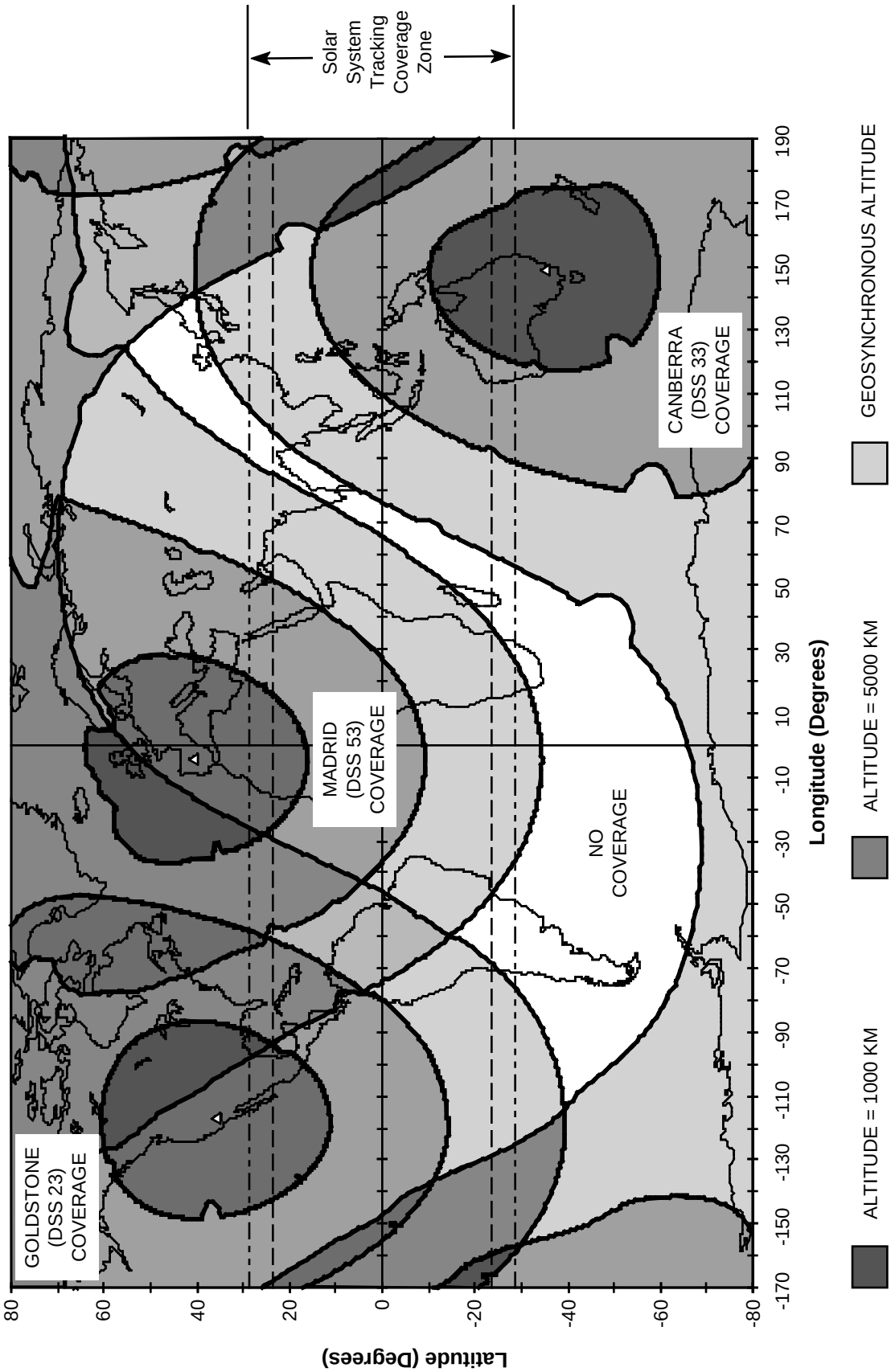



Figure 9. DSN 11-m Subnet Receive Coverage, Earth Orbiter Spacecraft.

### *2.2.4 Horizon Masks and Antenna Limits*

Figures 10 through 30 show the horizon mask and transmitter limits for all DSN stations. These masks and limits are the ones used to establish the coverage depicted in Figures 2 through 9. Each chart shows antenna coordinates in two coordinate systems. For all antennas except those with X-Y mounts, the coordinate systems are azimuth-elevation and hour angle-declination. The antennas with X-Y mounts show azimuth-elevation and X-Y coordinates.

Charts showing hour angle-declination coordinates can be used to provide an the 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 5.0 macros which is available for download (1.1 Mbytes) from the 810-5 web site (http://deepspace1.jpl.nasa.gov/810-5/). This file also contains the land mask data which can be used to accurately calculate spacecraft rise and set times.

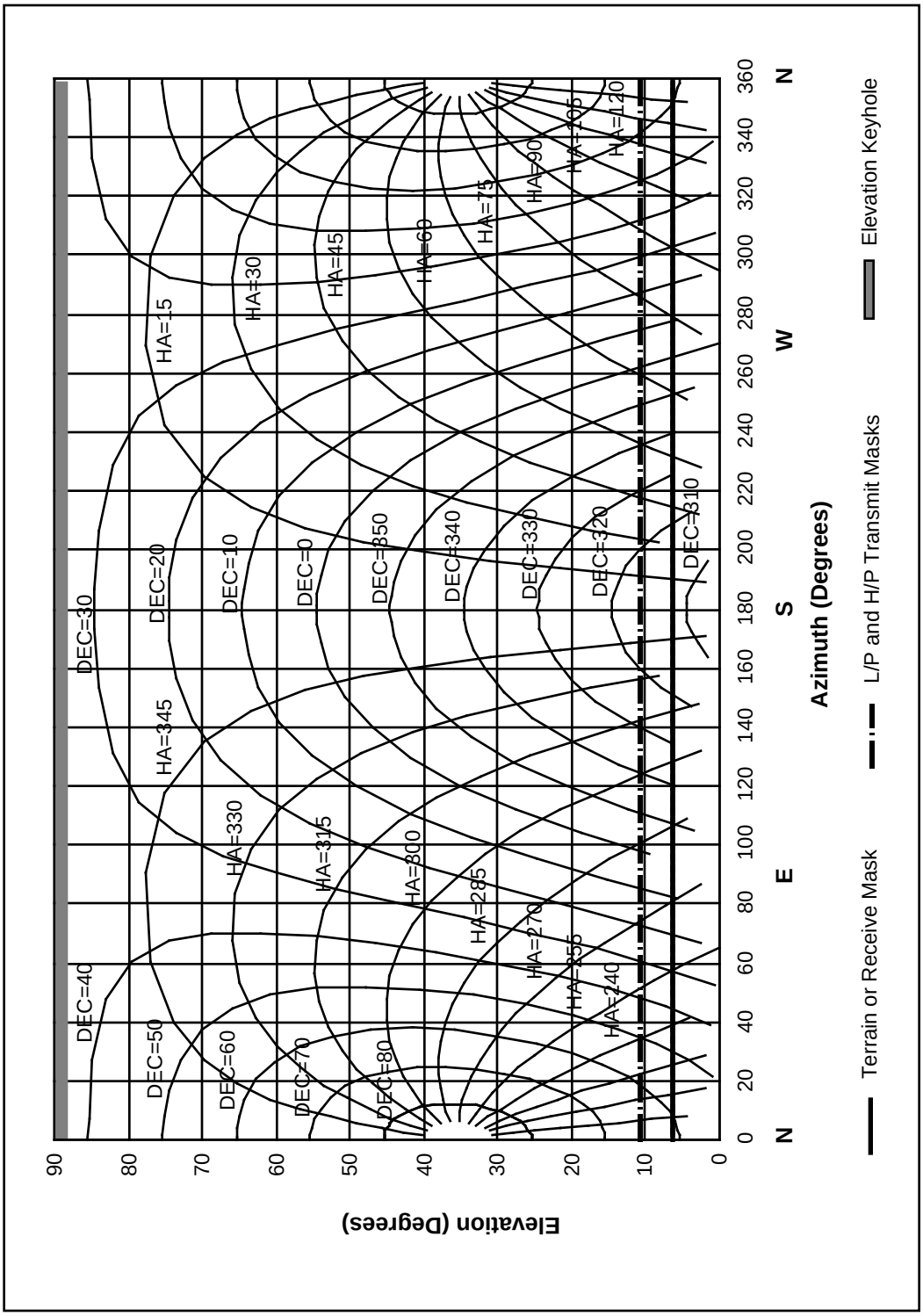



Figure 10. DSS 14 Hour Angle/Declination Profiles and Horizon Mask

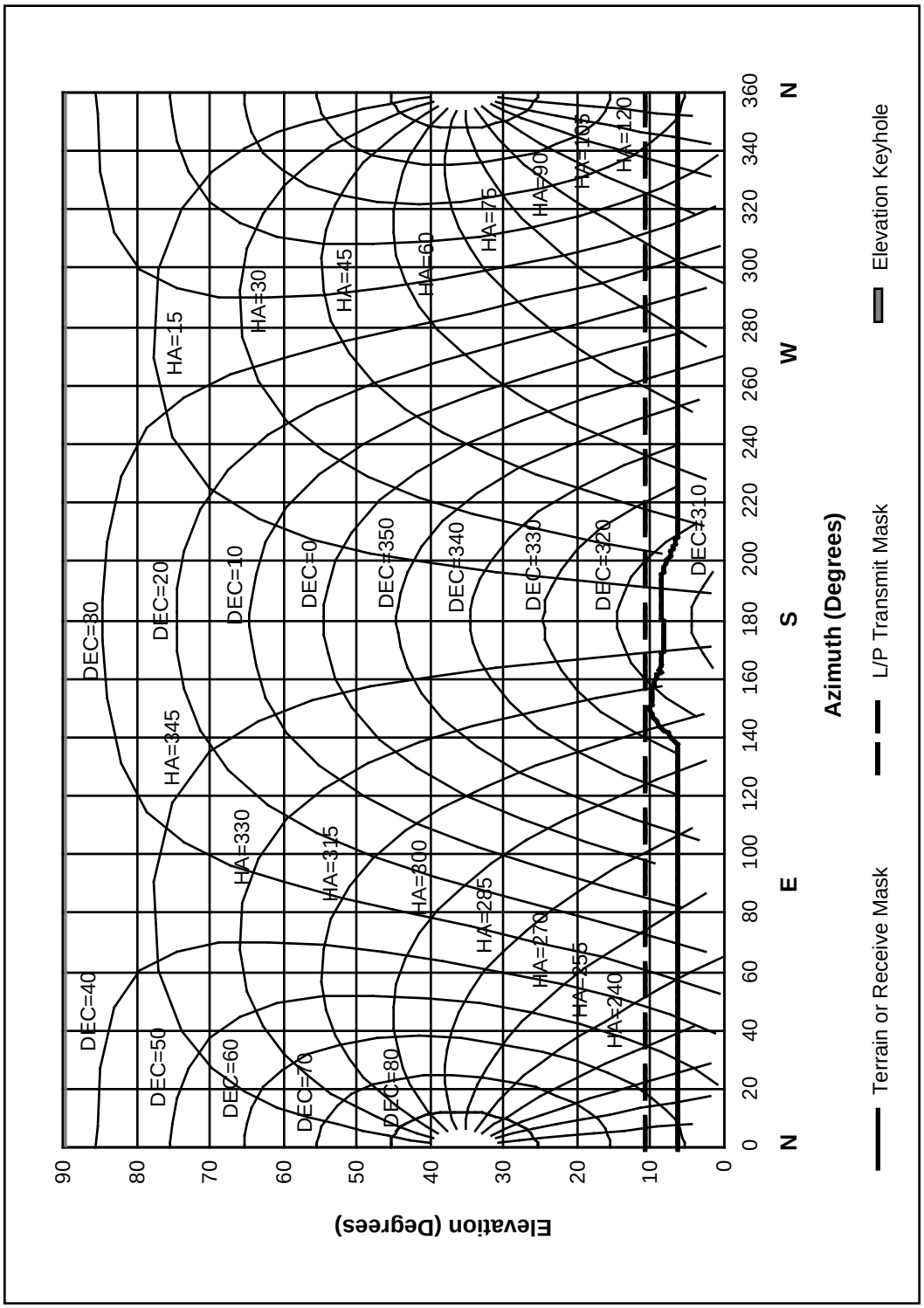



Figure 11. DSS 15 Hour Angle/Declination Profiles and Horizon Mask

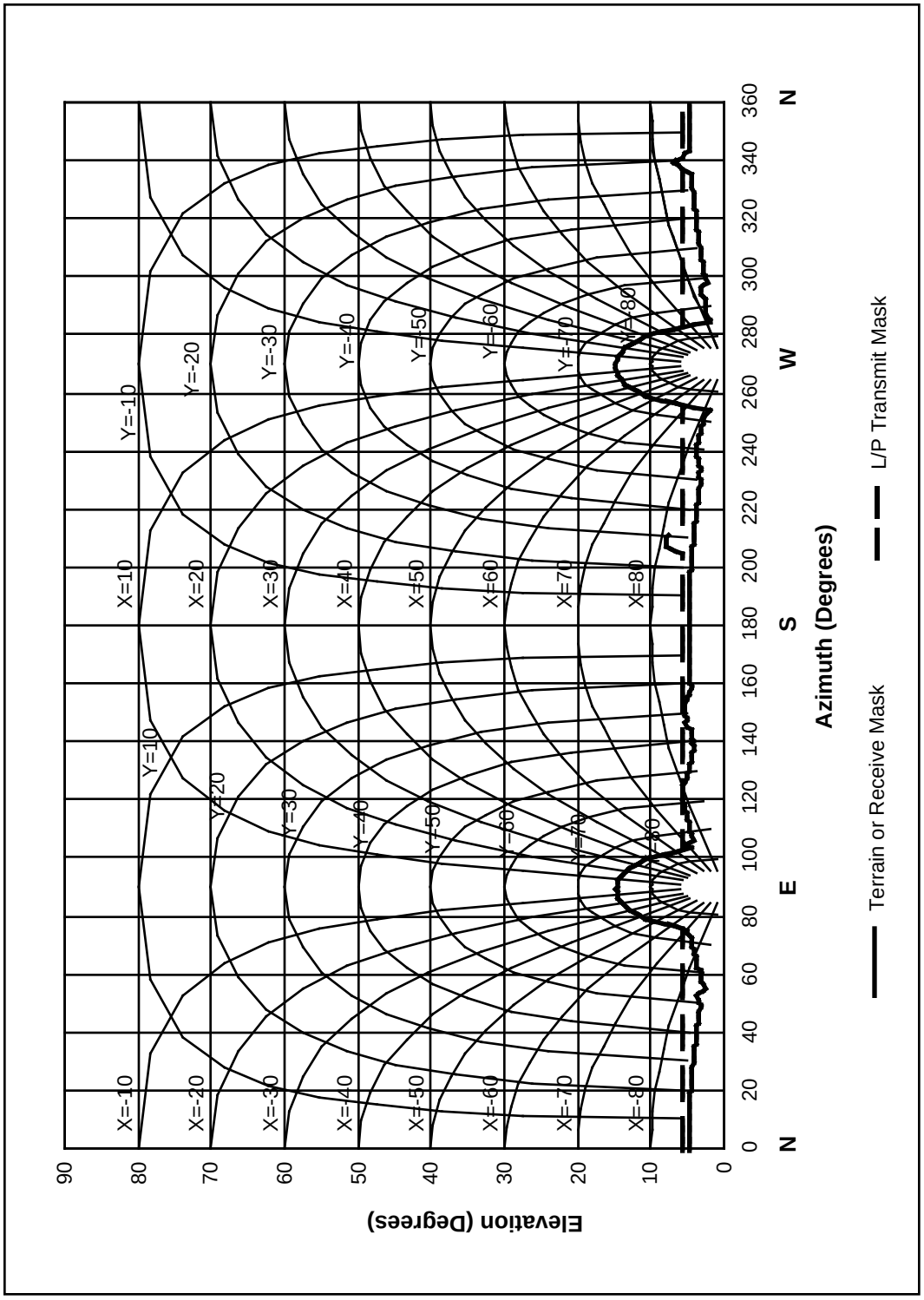



Figure 12. DSS 16 X-Y Profiles and Horizon Mask

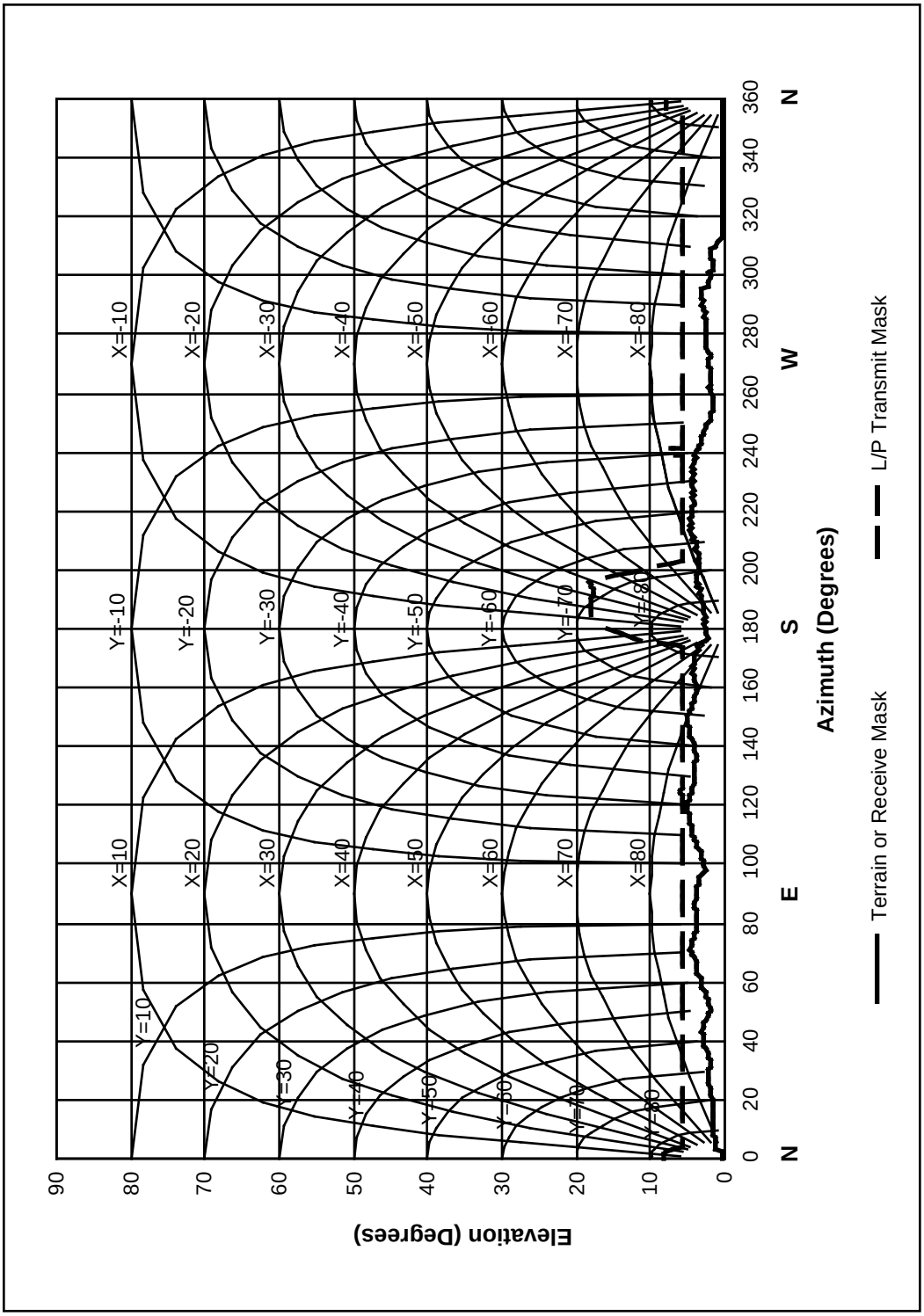



Figure 13. DSS 17 X-Y Profiles and Horizon Mask

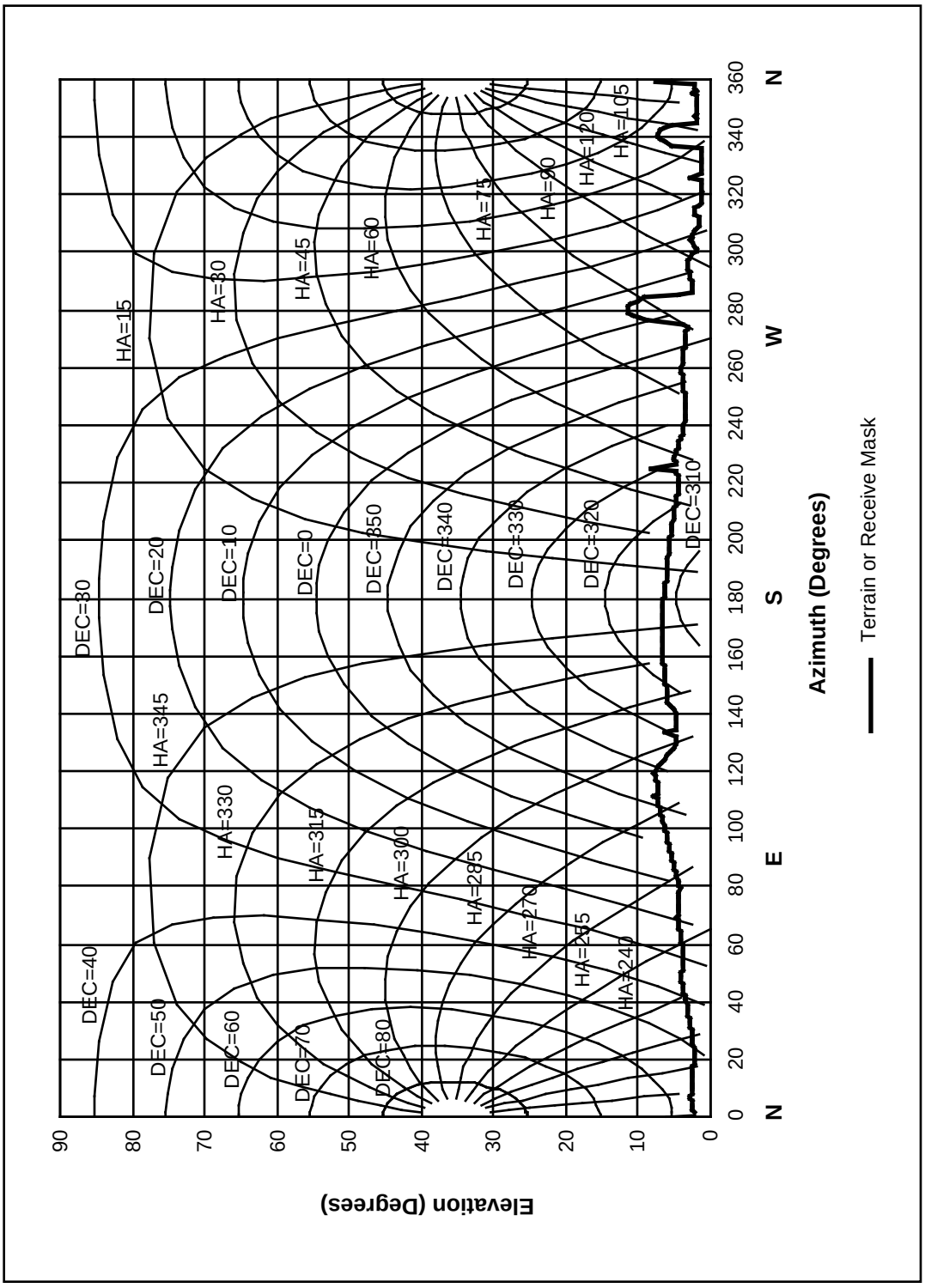



Figure 14. DSS 23 Hour Angle/Declination Profiles and Horizon Mask

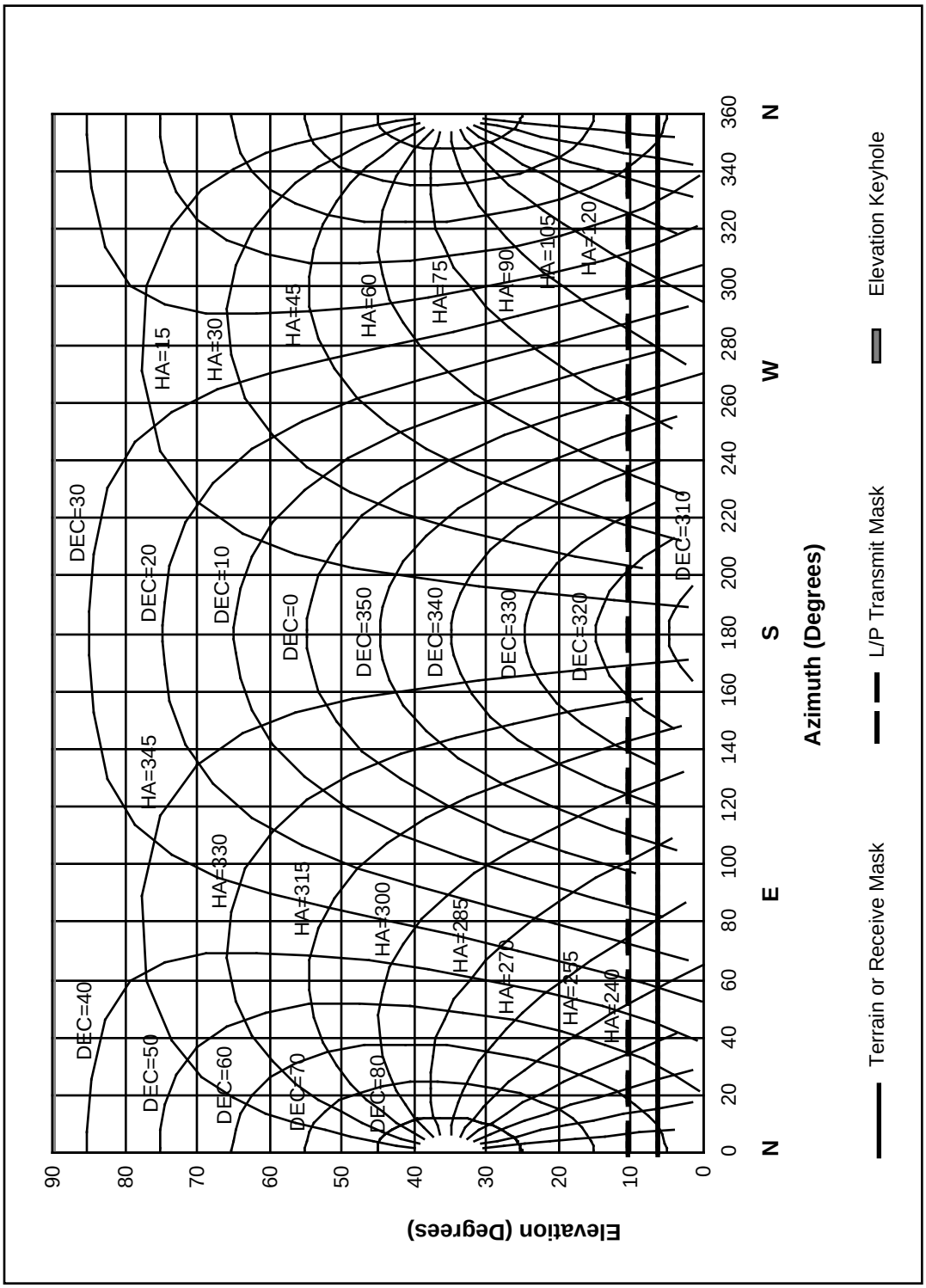



Figure 15. DSS 24 Hour Angle/Declination Profiles and Horizon Mask

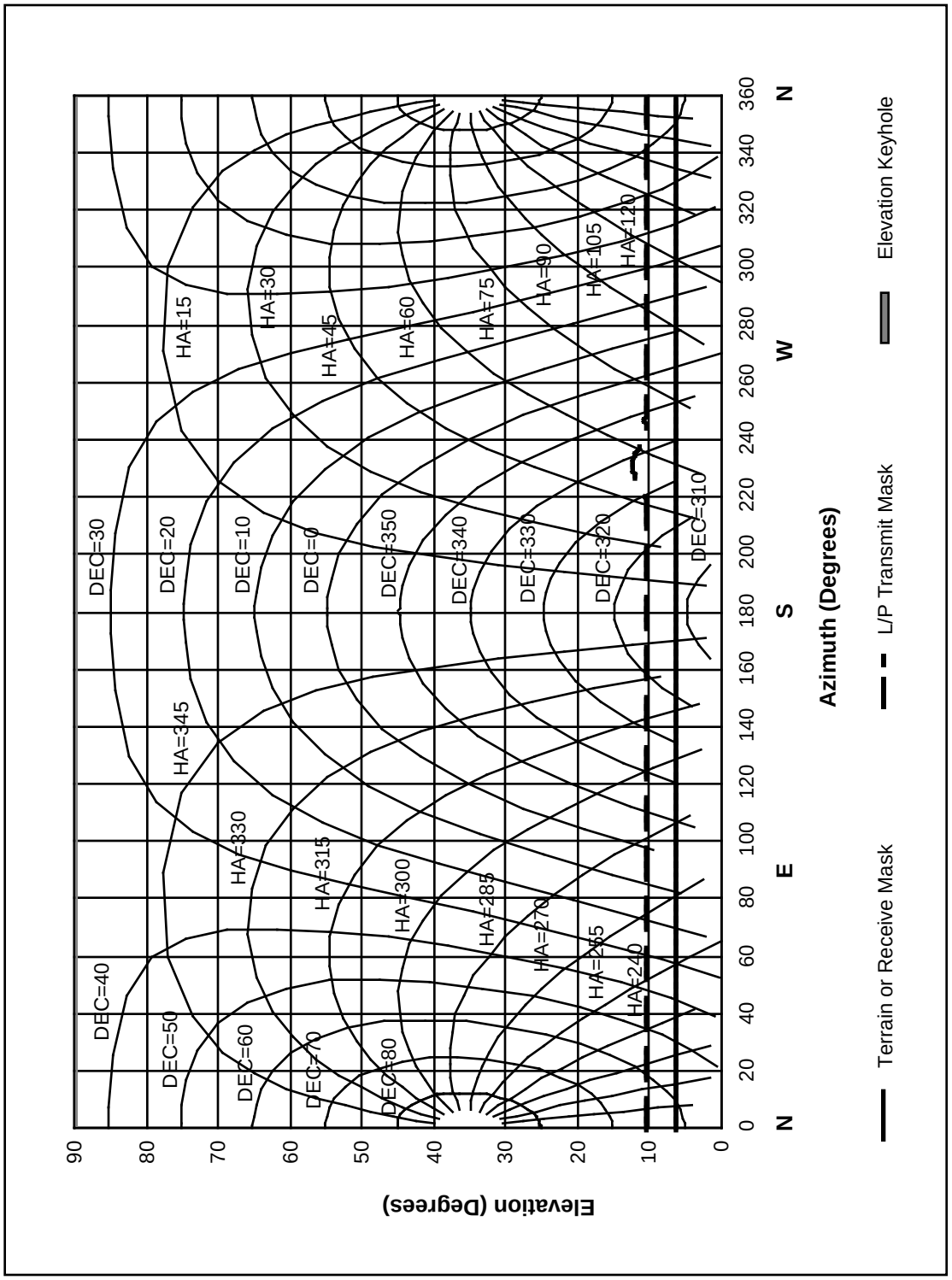



Figure 16. DSS 25 Hour Angle/Declination Profiles and Horizon Mask

Figure 17.
DSS 26 Hour Angle/Declination Profiles and Horizon Mask (To be Supplied)
(Landscape)

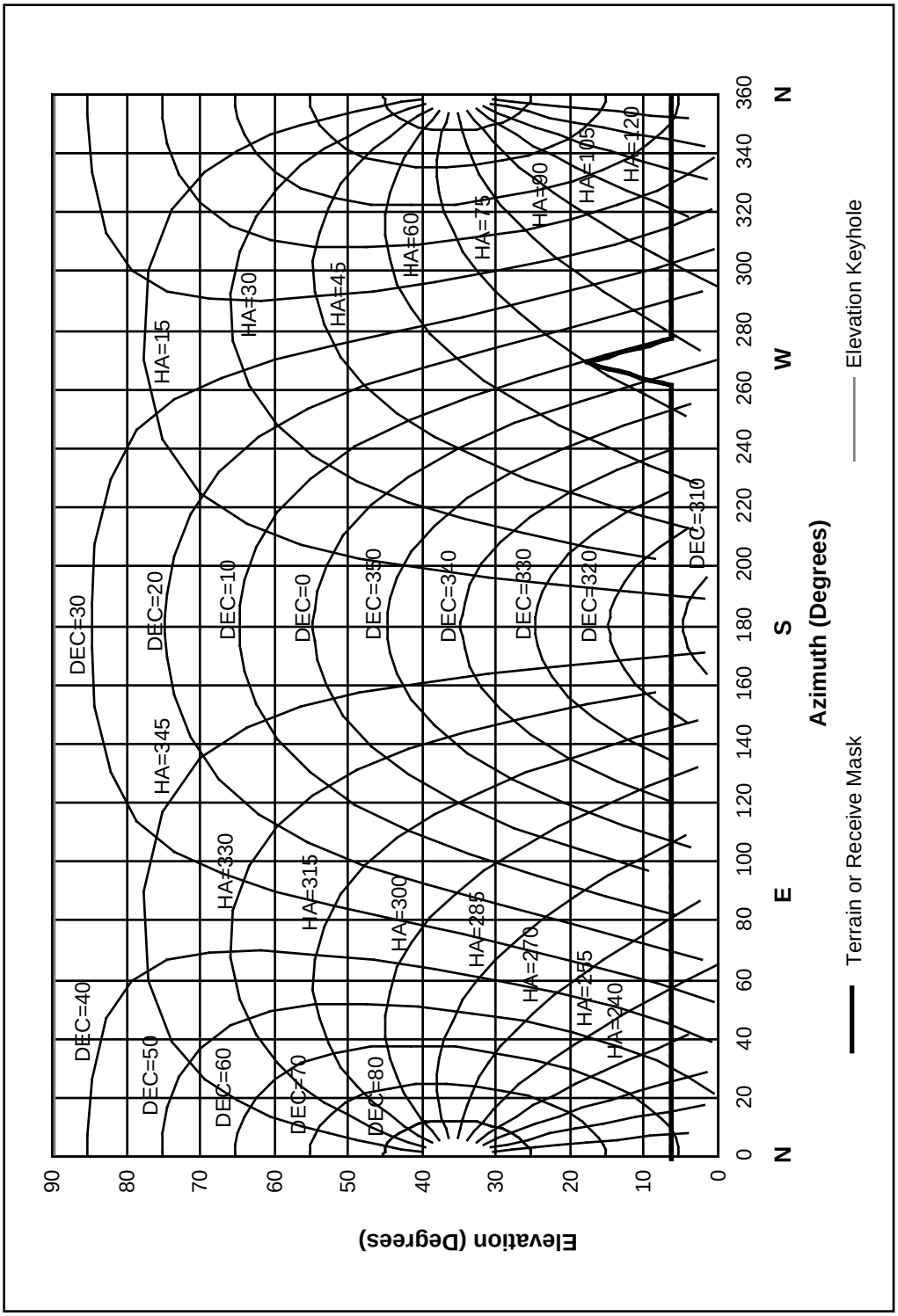



Figure 18. DSS 27 Hour Angle/Declination Profiles and Horizon Mask

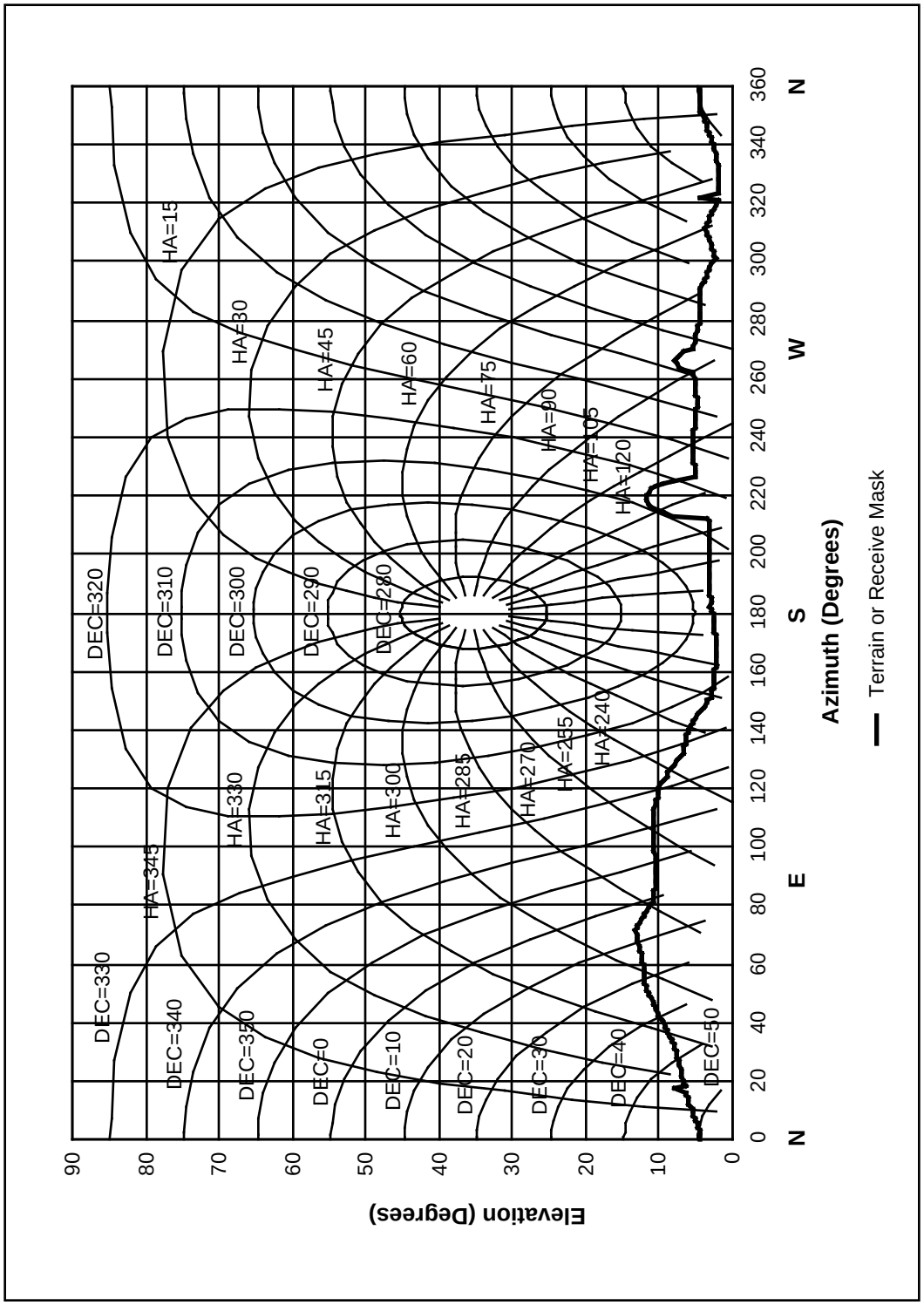



Figure 19. DSS 33 Hour Angle/Declination Profiles and Horizon Mask

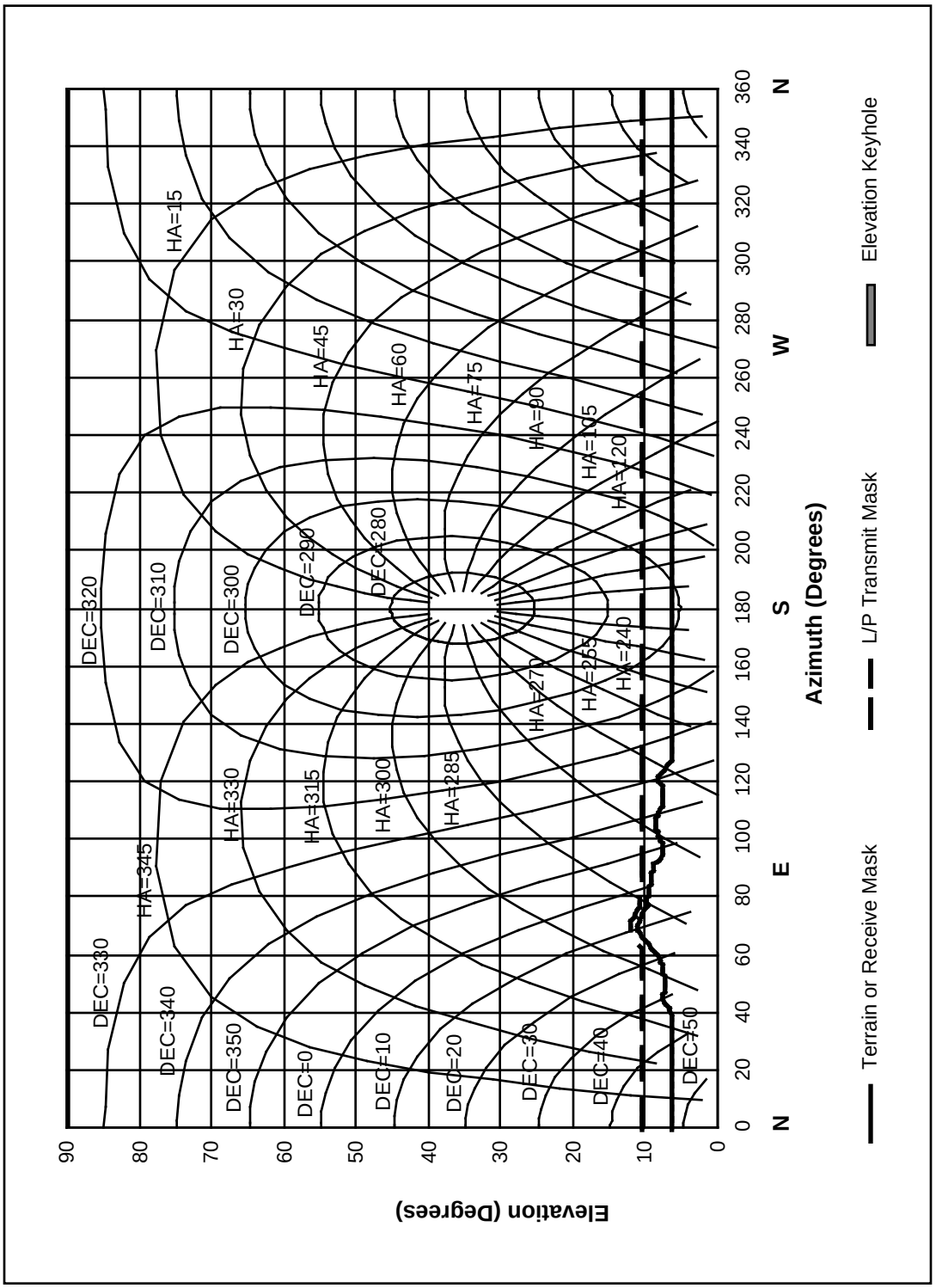



Figure 20. DSS 34 Hour Angle/Declination Profiles and Horizon Mask

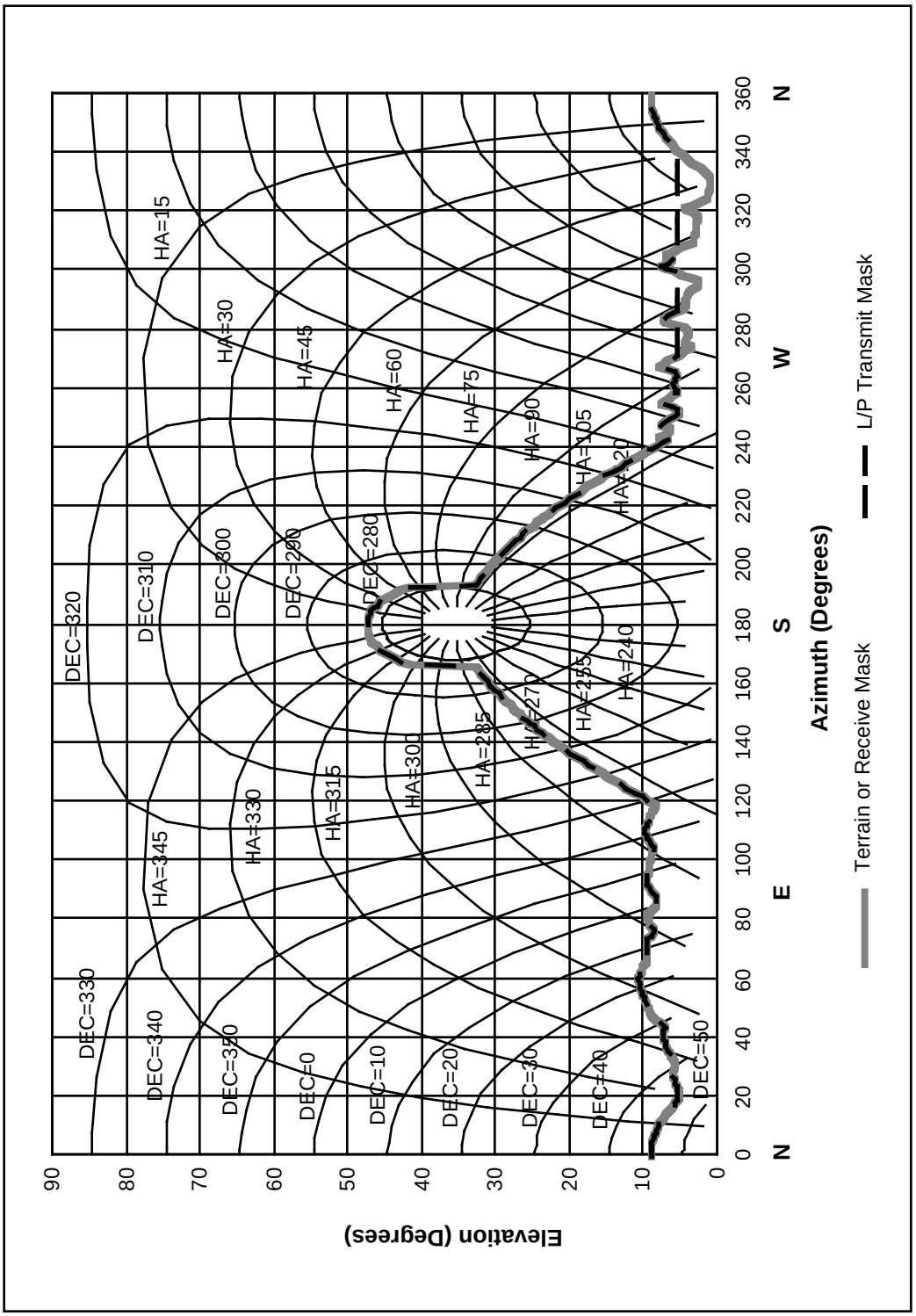



Figure 21. DSS 42 Hour Angle/Declination Profiles and Horizon Mask

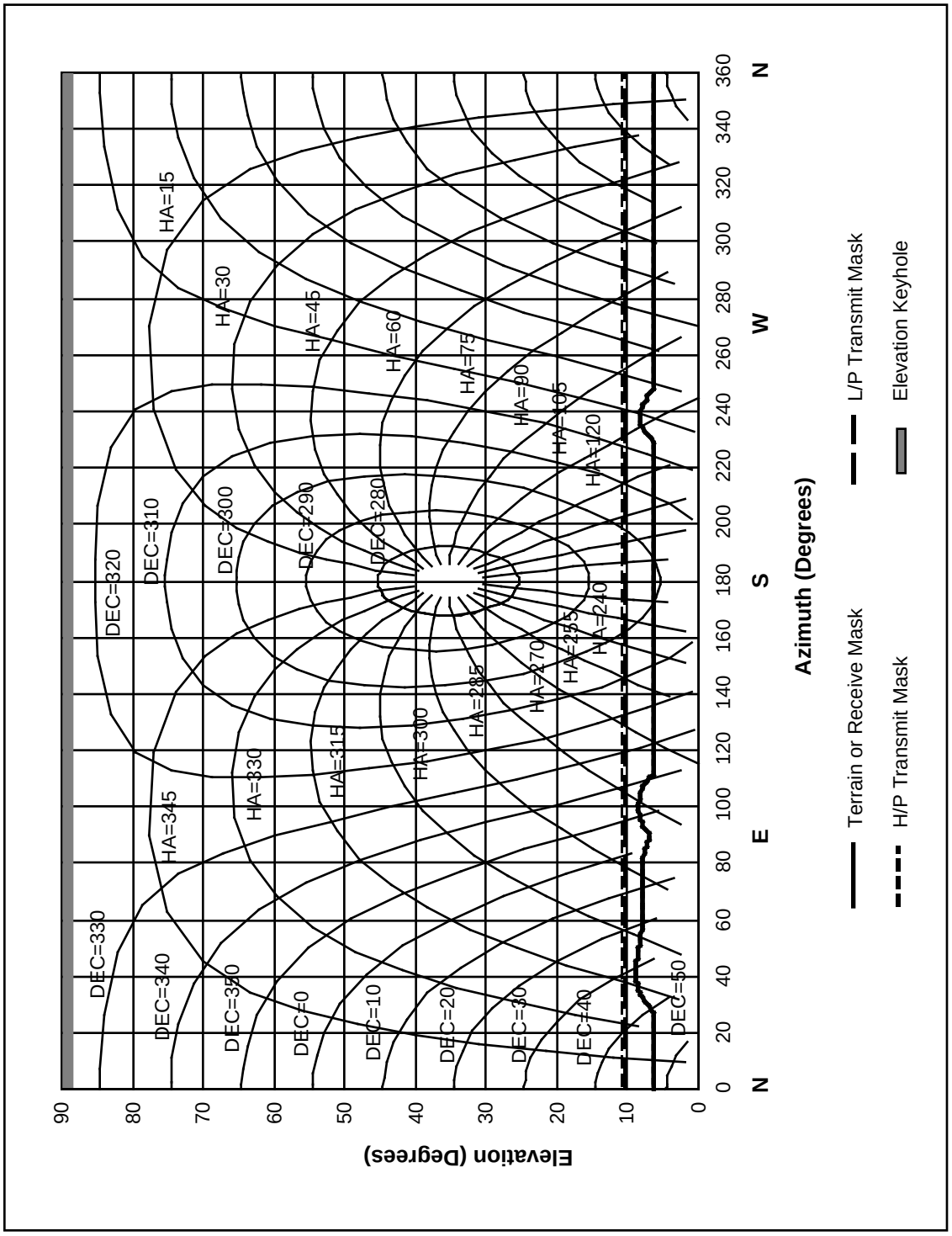



Figure 22. DSS 43 Hour Angle/Declination Profiles and Horizon Mask

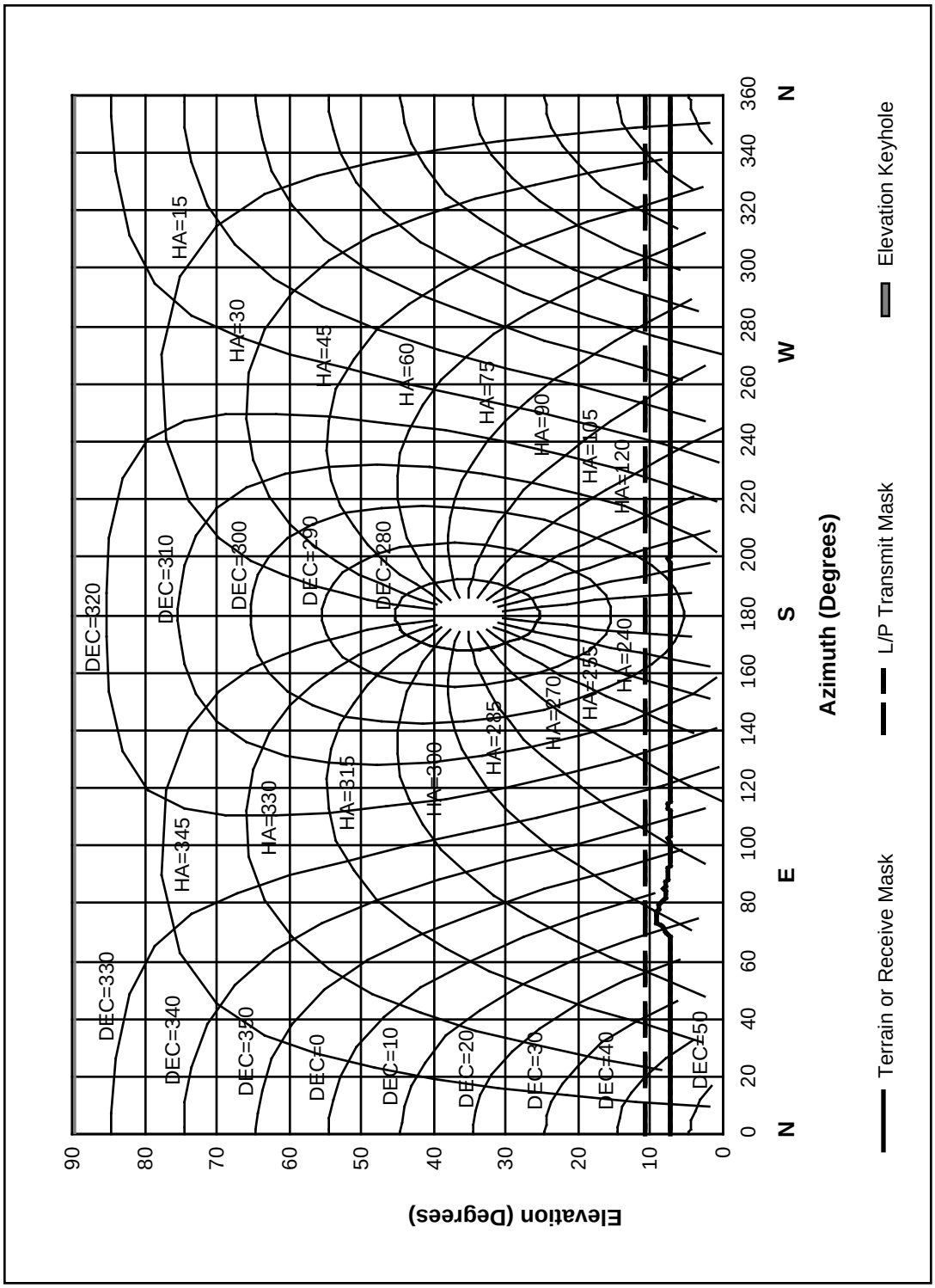



Figure 23. DSS 45 Hour Angle/Declination Profiles and Horizon Mask

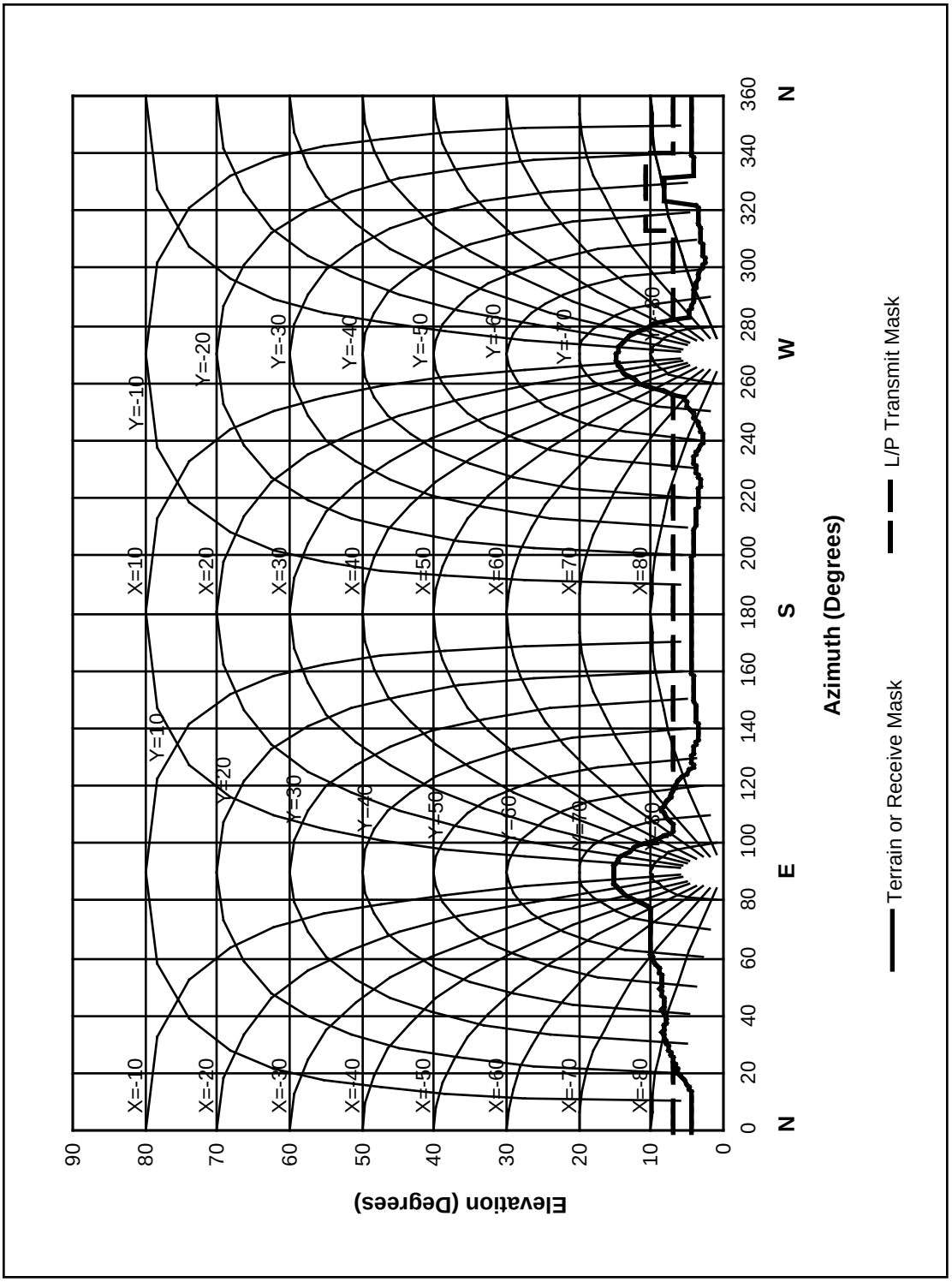



Figure 24. DSS 46 X-Y Profiles and Horizon Mask

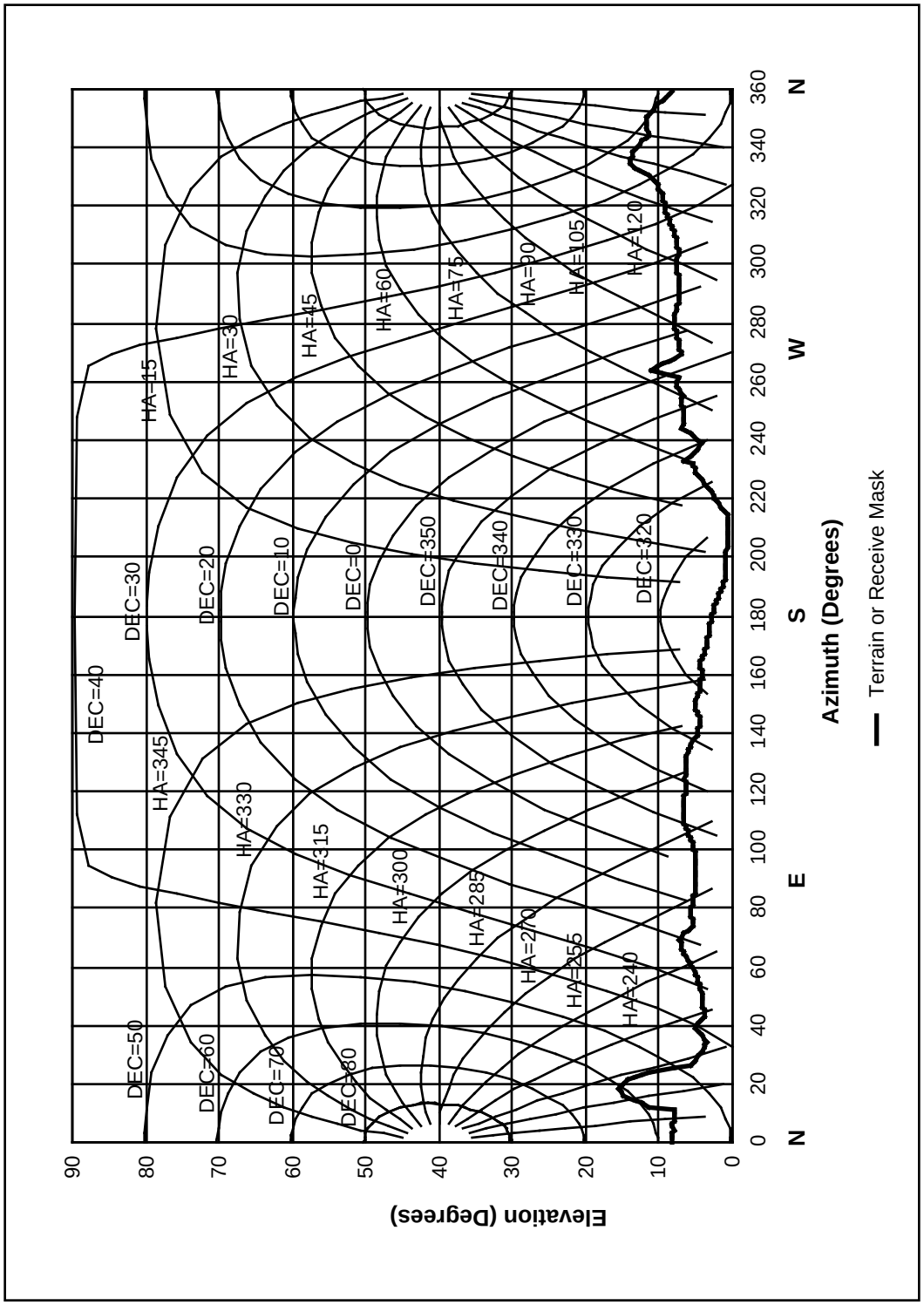



Figure 25. DSS 53 Hour Angle/Declination Profiles and Horizon Mask

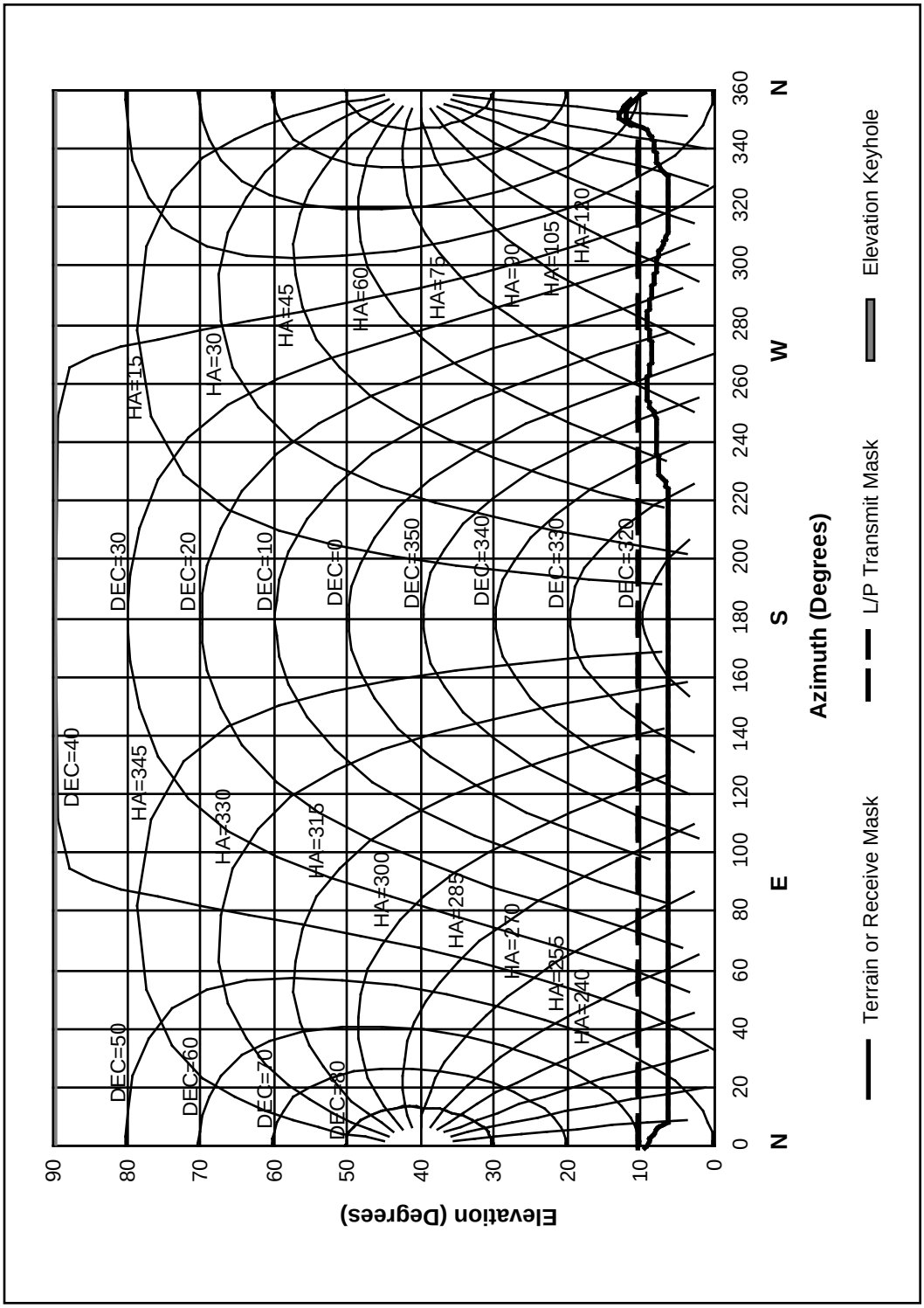



Figure 26. DSS 54 Hour Angle/Declination Profiles and Horizon Mask

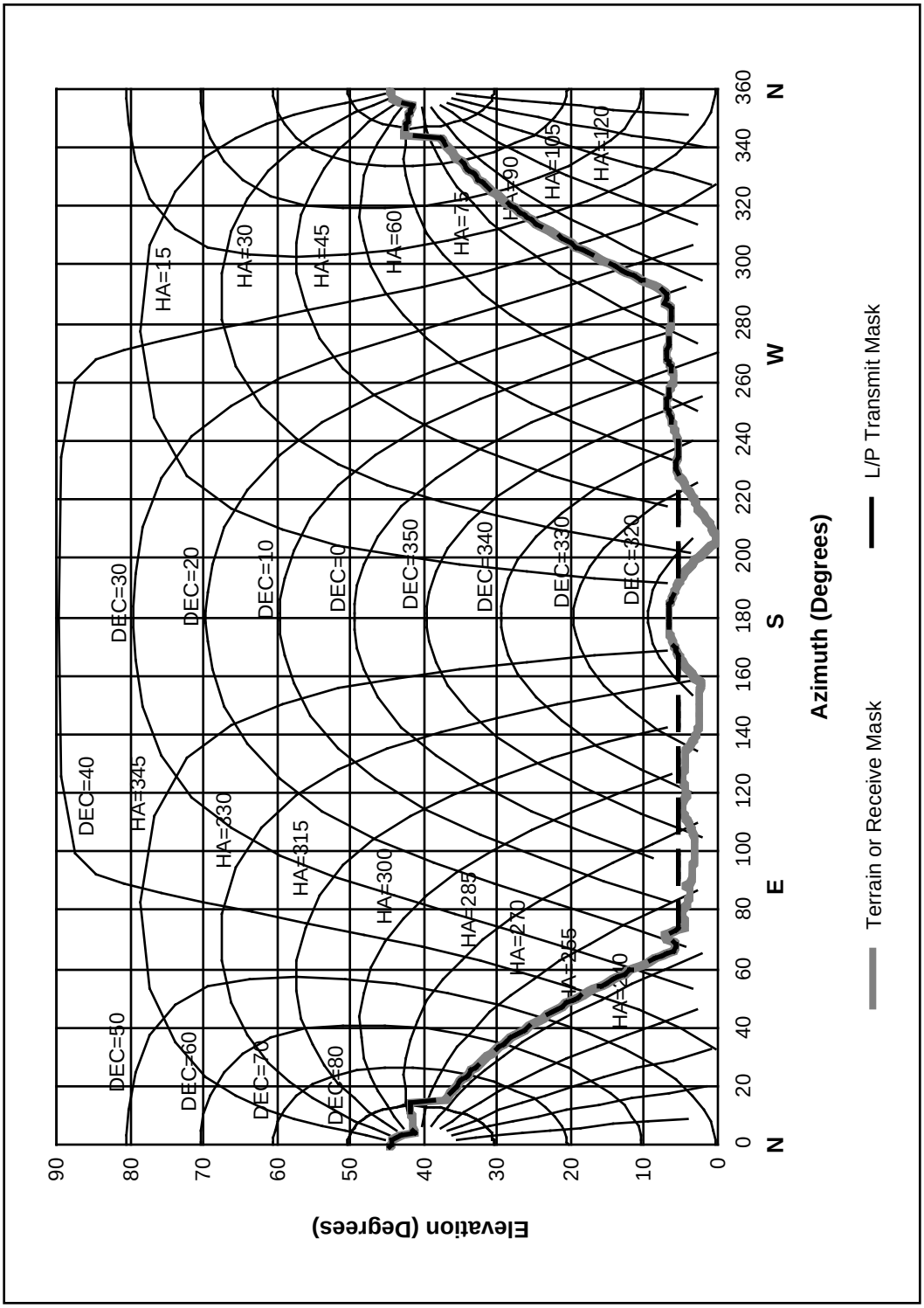



Figure 27. DSS 61 Hour Angle/Declination Profiles and Horizon Mask

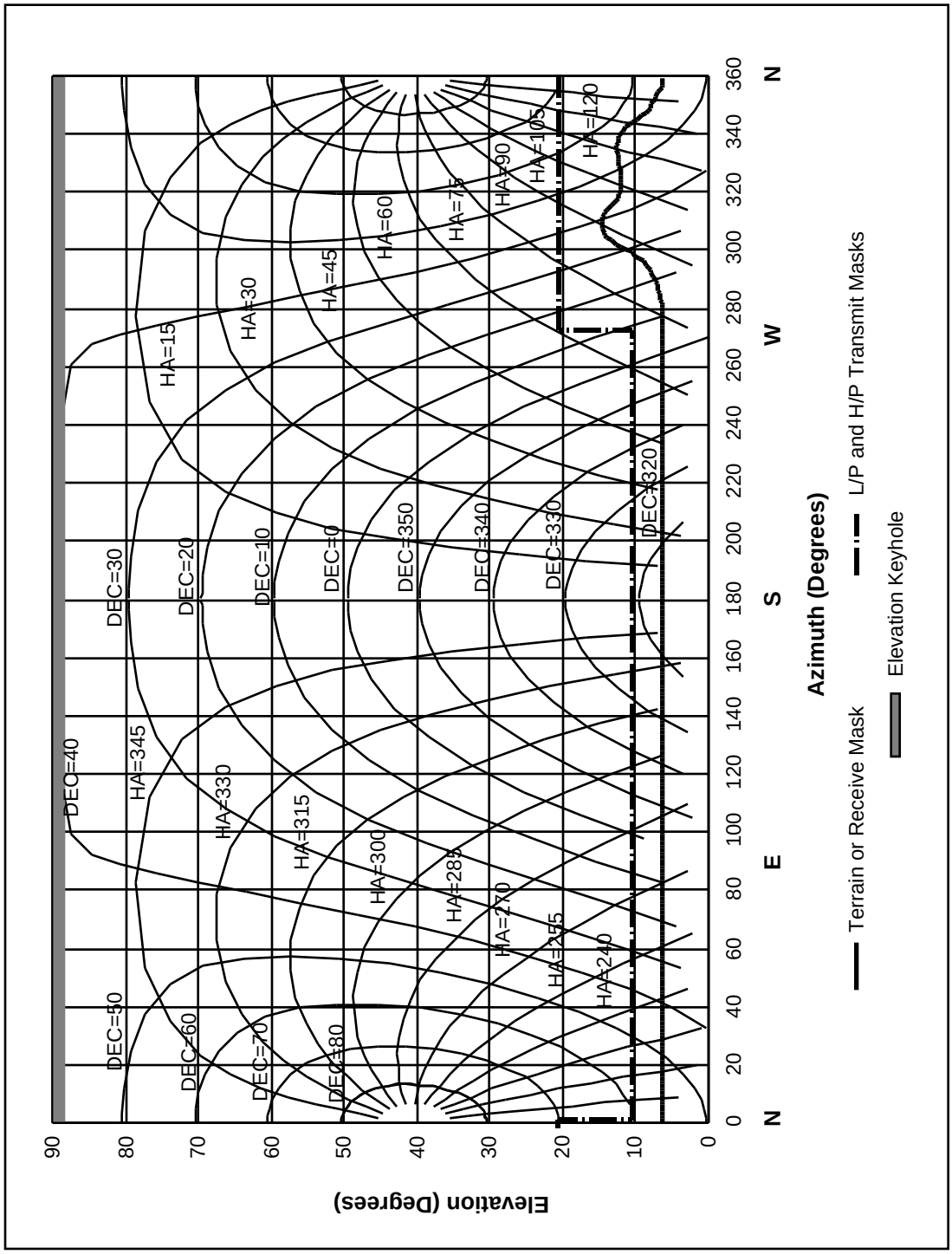



Figure 28. DSS 63 Hour Angle/Declination Profiles and Horizon Mask

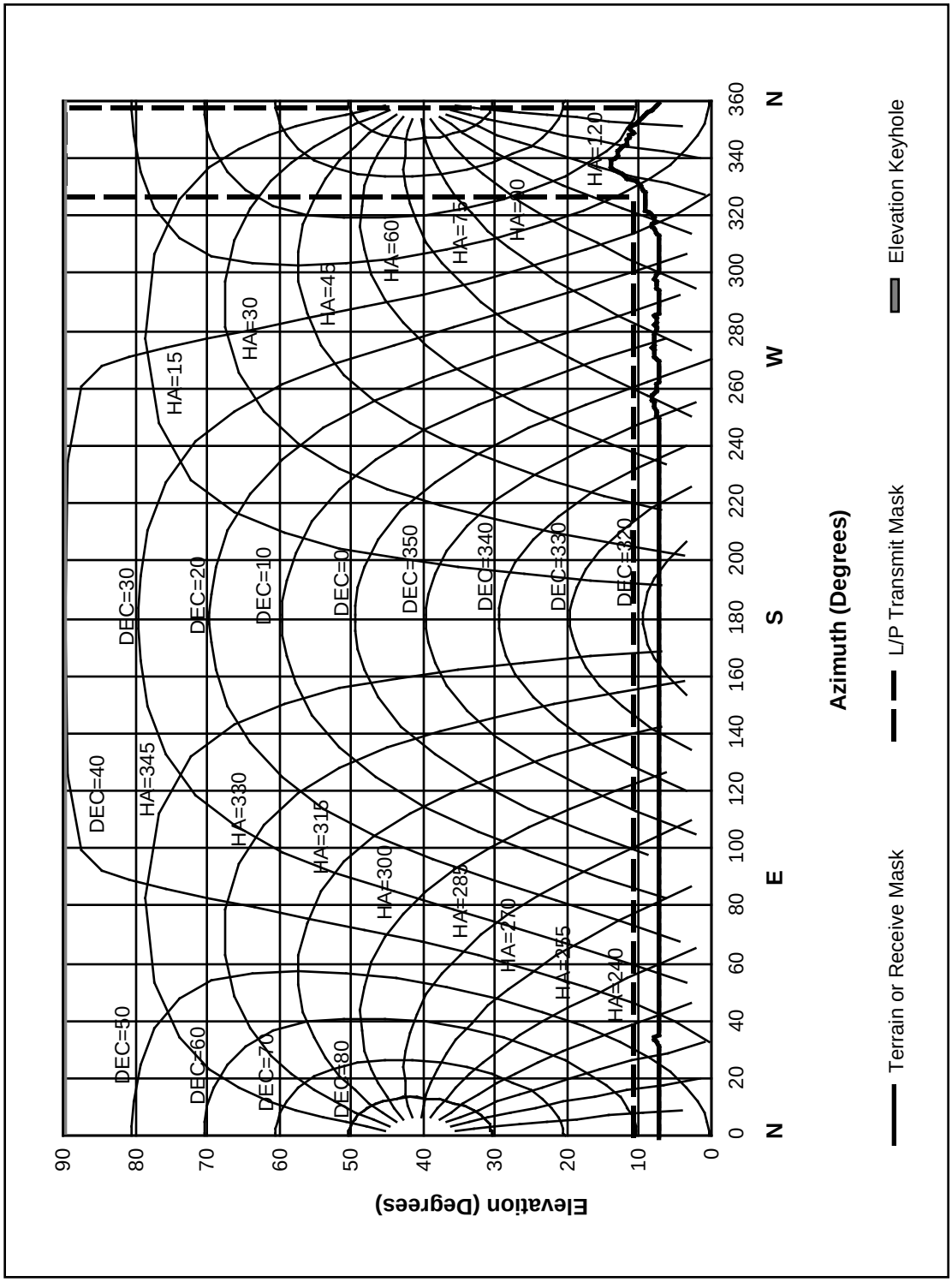



Figure 29. DSS 65 Hour Angle/Declination Profiles and Horizon Mask

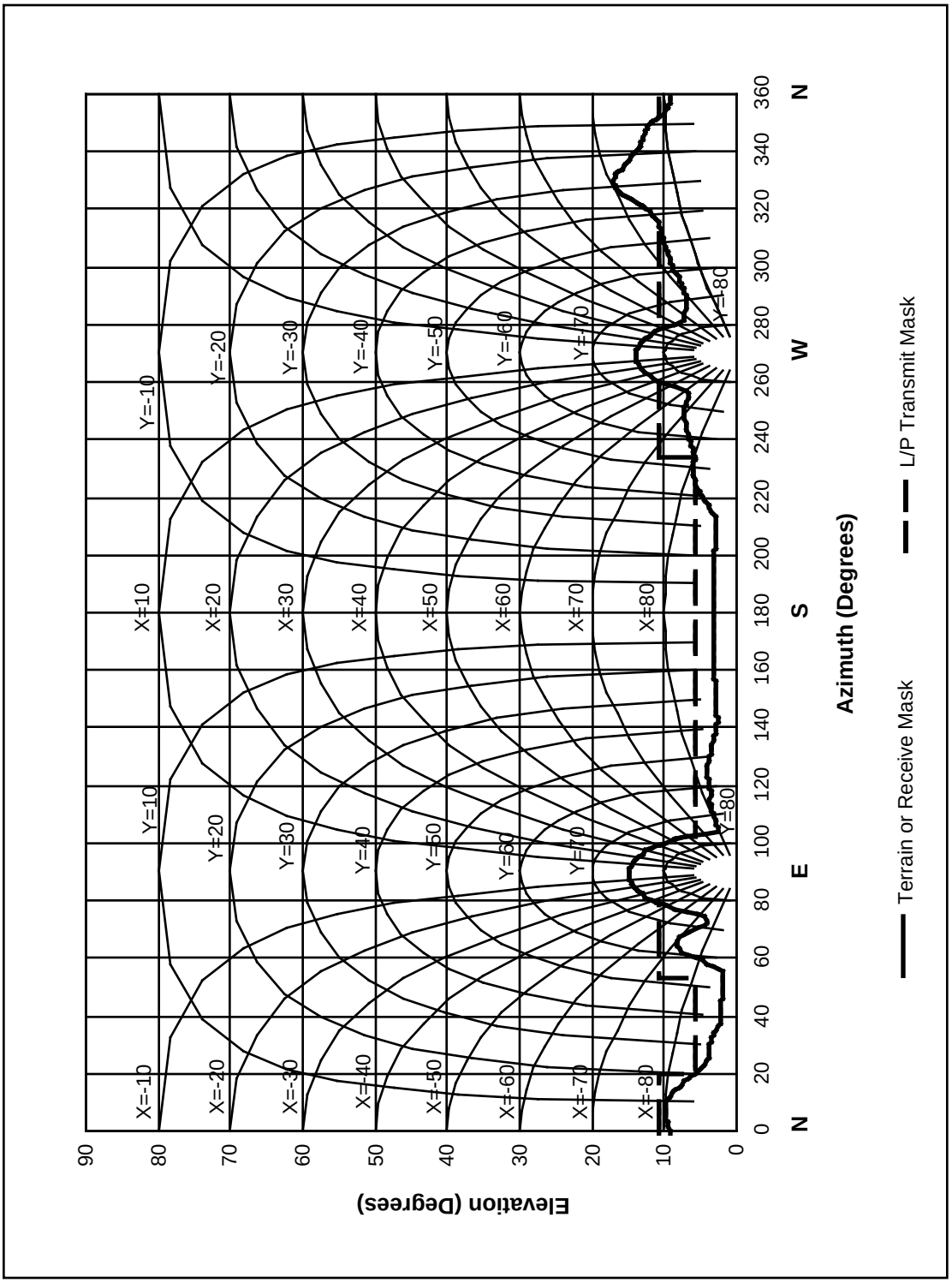



Figure 30. DSS 66 X-Y Profiles and Horizon Mask

# *Appendix A*
# *References*

1 C. Boucher, Z. Altamimi and L. Duhem, Results and analysis of the ITRF93, IERS Technical Note 18, Observatoire de Paris, October 1994

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