Z-Corrections for DSN 70-Meter Antenna Ranging Calibration

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This article documents the Z-corrections of the DSN 70-m dual-shaped reflector antennas. These corrections to the group delay time measured by the translator are required before the 70-m antennas can be used for ranging.

I. Introduction

This article summarizes the Z-corrections needed for 70-m DSS ranging calibration. According to [1],[1] the Z-corrections consist of four terms: τ_c, τ_d, τ_3, and τ_4, as shown in Fig. 1 and Eq. (1). These numbers come from three separate sources. The τ_4 X-band corrections are discussed in a separate article in this issue [2]. The τ_3 and τ_4 S-band corrections are discussed in [1] and [3]. Details on the derivations of τ_c and τ_d are presented in Section III.

$$Z_{\text{Correction}} = Z_{\text{Translator}} - (\tau_3 + \tau_4 + (\tau_c - \tau_d)_{\text{Up}} + (\tau_c - \tau_d)_{\text{Down}}) \tag{1}$$

II. Derived Group Delay Time

Tables 1 (X-band) and 2 (S-band) summarize the derived group delay time for the 64-m and 70-m antenna configurations.

[1] Also refer to *DSN/Flight Project Interface Design Handbook*, TDA 810-5, Vol. 2 TRK-30 (internal document), Jet Propulsion Laboratory, Pasadena, Calif., to be published 1987.

III. One-Way Ranging Equation for τ_c and τ_d Corrections

With reference to Fig. 2, a theoretical one-way ranging equation can be written that does not involve a detailed ranging system configuration and hardware. The terminology used in this article follows that of [1] and [4]; range is distance and delay is the group delay time.

A. Phase Delay

Figure 2 shows a Cassegrainian antenna in a microwave system. Point A is the reference location for ranging. Point B is the target location. The distance R is the topocentric range of the target [1]. The phase of a continuous carrier wave received at Point B is exp $[j(\omega t + \Phi)]$. Following [5] and [6],

$$\Phi = \Phi_{wg} + \Phi_{\text{ant}}(\omega) + kL - kR \tag{2}$$

where $\omega = 2\pi f$, and f is the frequency. The meanings of each term on the right side of Eq. (2) are as follows. The first term is the phase delay from the RF transmitter (uplink) or receiver (downlink) to the feedhorn phase center. The second term is the phase delay in the Cassegrainian antenna from the feedhorn phase center to the aperture plane. The third term is the phase correction term needed when the aperture plane does not contain the reference location. These are the three correctional terms to the fourth term, which corresponds to the topocentric range R, the distance from the reference point of the ground antenna to the referenced point of the spacecraft antenna.

B. Group Delay Time

The Group delay of the RF signal from the RF transmitter to the target location B is (from [5])

$$t = -\frac{d\Phi}{d\omega}$$

$$= -\frac{d\Phi_{wg}}{d\omega} - \frac{d\Phi_{\text{ant}}}{d\omega} + \frac{R-L}{V_c} \tag{3}$$

where V_c is the free space light velocity and is 2.9979×10^{10} cm/s. The first term in Eq. (3) is the group delay time from the RF transmitter (or receiver) to the feedhorn phase center. The second term is the group delay time in the Cassegrainian antenna.

C. Air Path in Cassegrainian Antennas

A ranging path length may be artificially defined as the product of group delay time in Eq. (3) and free space light velocity.

$$\text{Path length} = -V_c \frac{d\Phi_{wg}}{d\omega} - V_c \frac{d\Phi_{\text{ant}}}{d\omega} + R - L \tag{4}$$

The second term in Eq. (4) is commonly referred to as the air path in the Cassegrainian antenna. For convenience "equivalent path length" is similarly defined in this article for any waveguide component in the ranging system as the product of group delay time and free space light velocity. This will be applied to the dichroic delay at the X-band later. Next, the air path for 64-m and 70-m antennas is derived using geometric optics and aperture theory. The theoretical analysis was made in [5] and [6]. Only the results are applied in this article.

IV. 64-Meter Antenna Air Path and Delay

For classical Cassegrainian antennas consisting of a parabolic main reflector and a hyperbolic subreflector, the air path from the feedhorn phase center to the aperture is given by

$$-V_c \frac{d\Phi_{\text{ant}}}{d\omega} = \text{Air path} = f + 2a + d \tag{5}$$

where

f = Focal length of the paraboloid

$2a$ = Distance between vertices of the two branches of the hyperbola used in defining the Cassegrainian subreflector

d = Distance from main reflector vertex to aperture plane (Fig. 2)

It is shown in [5] and [6] that Eq. (5) is exact in the context of geometric optics (GO) and aperture theory. Equation (5) holds equally in the tricone feed geometry, where the feed and subreflector are tilted relative to the main reflector axis.

When applied to 64-m and 70-m antennas, Eq. (5) must be supplemented by the additional air path of the horn/ellipsoid/dichroic at S-band and delay through the dichroic plate at X-band. These are worked out in [7]. This information is included in Table 3 for reference.

Figure 3 shows the relevant dimensions of the 64-m antenna for ranging. Traditionally, the 64-m antenna aperture plane is taken as the plane defined by the rim of the parabolic main reflector. In this case the distances d and L are given by

$$d = \frac{\rho_{\text{main}}^2}{4f} \tag{6}$$

$$L = d + 807.72 \text{ cm} \tag{7}$$

In Eq. (6), ρ_{main} is the radius of the main reflector. Note that d and L are dependent on ρ_{main}. The radius of the 64-m antenna is taken to be 3200.4 cm to be consistent with [7].

V. The 70-Meter Antenna Air Path and Delay

The 70-m antenna geometry relevant to ranging is shown in Fig. 3. The information is extracted from Figs. 3-1, 3-3, and 3-4 of another document.[2] The air path of the shaped 70-m antenna is not given by such simple algebraic expression as Eq. (5). However, from geometric optics synthesis of the antenna, the air path from feedhorn to plane 2 (Fig. 3) is

$$\text{Air path} = 4835.96 \text{ cm } (1903.92 \text{ in.})$$

[2] A. G. Cha and W. A. Imbriale, "Computer Programs for the Synthesis and Interpolation of 70-Meter Antenna Reflector Surfaces," JPL D-1843 (internal document), Jet Propulsion Laboratory, Pasadena, Calif., Nov. 1984.

The plane 2 is a reference used in the geometric optics synthesis program of the 70-m antenna and is seen from Fig. 3 to be 1893.2 cm above the intersection point A of elevation and azimuth axes. Note, as shown in Fig. 3, plane 2 is not defined by the rim of the 70-m antenna main reflector.

The 64-m antenna and aperture plane are shown in Fig. 3. In the following, the 64-m aperture plane, plane 1 in Fig. 3, is also used as the 70-m aperture plane. This simplifies comparisons of the air path and delay of the 64-m and 70-m antennas, as the group delay from the aperture plane to the ground reference point for the two antennas would then be the same. This is shown in Table 3. If other ground reference points and/or aperture planes are preferred, the antenna air path and group delay from the aperture plane to the ground reference point would then be different for 64-m and 70-m antennas. The new 70-m numbers can be worked out in a straightforward manner from Eqs. (3) and (4).

At press time, it appears that the main reflector surface of DSS 63 is 1.2 cm (0.5 in.) higher than originally designed. Since this variation is not exactly known at present and will be different for each of the three 70-m antennas, future revisions will be issued for each of the antennas when the exact information is available.

Acknowledgment

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References

[1] T. Komarek and T. Otoshi, "Terminology of Ranging Measurements and DSS Calibrations," *DSN Progress Report 42-36*, pp. 35–40, Jet Propulsion Laboratory, Pasadena, Calif., Dec. 1976.

[2] R. Hartop, "Microwave Component Time Delays for the 70-Meter Antennas," *TDA Progress Report 42-89*, Vol. January–March, Jet Propulsion Laboratory, Pasadena, Calif., May 15, 1987.

[3] T. Otoshi, K. B. Wallace, and R. B. Lyon, "Dual Coupler Configuration at DSS 14 for the Voyager Era," *DSN Progress Report 42-42*, pp. 184–192, Jet Propulsion Laboratory, Pasadena, Calif., Sept. 1977.

[4] T. Otoshi and K. R. Weld, "Updated Z-Corrections for 64-m DSS Ground Station Delay Calibrations," *DSN Progress Report 42-47*, Vol. July and August, pp. 77–84, Jet Propulsion Laboratory, Pasadena, Calif., 1978.

[5] A. G. Cha, W. V. T. Rusch, and T. Otoshi, "Microwave Delay Characteristics of Cassegrainian Antennas," *IEEE Trans. on Antennas and Propagation*, Vol. AP–26, No. 6, pp. 860–865, Nov. 1978.

[6] A. G. Cha, "Phase and Frequency Stability of Cassegrainian Antennas," *Radio Science*, pp. 156–166, Jan. and Feb. 1987.

[7] R. Hartop, "Microwave Time Delays in the DSN 34- and 64-Meter Antennas," *DSN Progress Report 42-51*, vol. Mar. and Apr. 1979, pp. 183–185, Jet Propulsion Laboratory, Pasadena, Calif., May 15, 1979.

Table 1. X-band delay, ns

Correction	64-m	70-m	Delta
τ_c	152.28	156.79	4.51
τ_d	58.45	58.45	–
τ_3	No X-band uplink at present. Use S-band number for S- uplink and X-downlink.		
τ_4	Straight path 5.986 Side path 6.417	Straight path 6.026 Side path 6.690	0.040 0.273

Table 2. S-band delay, ns

Correction	64-m	70-m	Delta
τ_c	161.16	165.68	4.52
τ_d	58.45	58.45	–
τ_3	22.18	22.18	–
τ_4	19.66	19.66	–

Table 3. Air path and group delay for 64-m and 70-m antennas

Parameter	64-m		70-m	
	S-band	X-band	S-band	X-band
f, cm (in.)	2711 (1067.294)	2711 (1067.294)	–	–
$2a$, cm (in.)	904 (356.057)	904 (356.057)	–	–
d, cm (in.)	945 (371.875)	945 (371.875)	–	–
Air path, horn to aperture plane,* in absence of reflex/dichroic feed, cm (in.)	4560 (1795.226)	4560 (1795.226)	4695 (1848.42)	4695 (1848.42)
Air path due to reflex/dichroic feed, cm (in.)	272 (106.963)	5.49† (2.16)	272 (106.963)	5.49† (2.16)
Air path total, cm (in.)	4832 (1902.189)	4565 (1797.39)	4967 (1955.51)	4700 (1850.58)
One-way group delay, horn to aperture plane, ns	161.16	152.28	165.68	156.79
One-way group delay, aperture plane to reference point, ns	58.45	58.45	58.45	58.45
Net downlink airpath delay, ns	102.71‡	93.83‡	107.23	98.34

*Aperture plane is plane 1, Fig. 3, for both antennas (64-m antenna aperture plane).
†Converted from group delay of 0.183 ns [6].
‡Agree closely with values for Z_6 in [3].

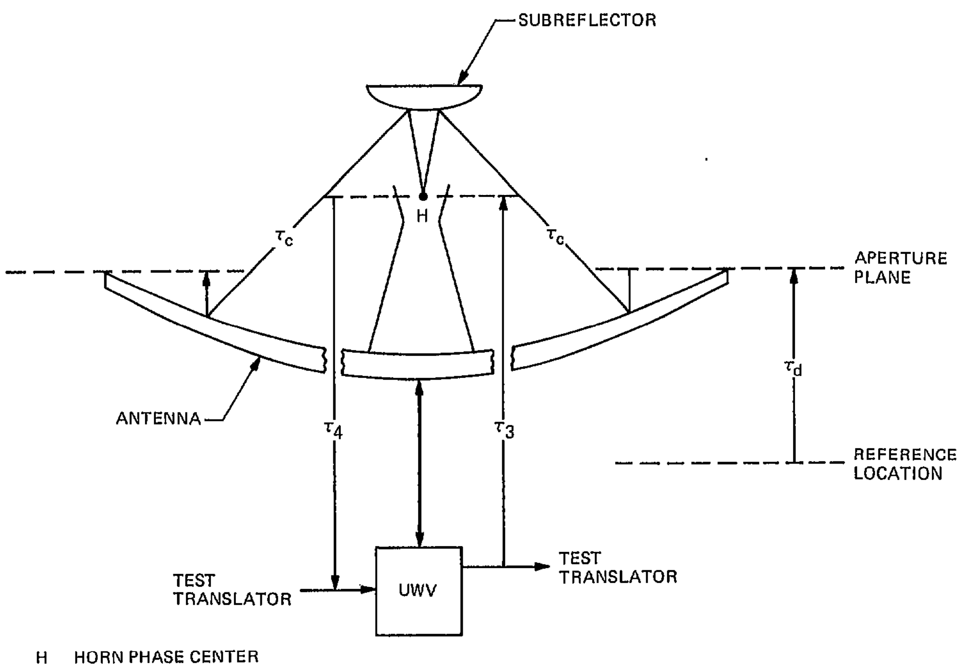

Fig. 1. Definitions of *Z* corrections

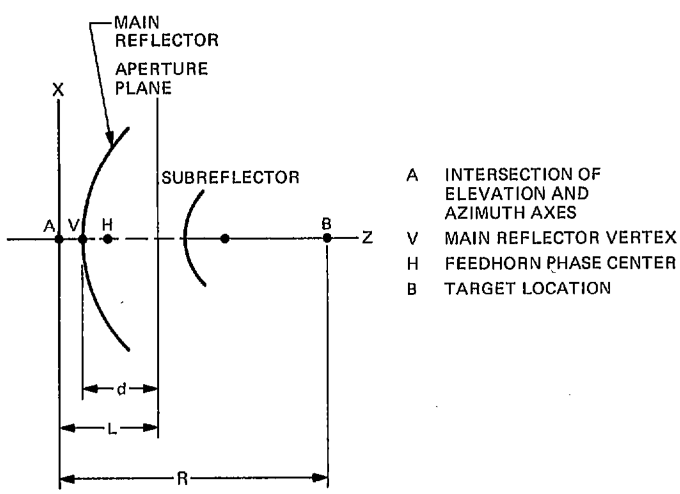

Fig. 2. Cassegrainian antenna in a microwave ranging system

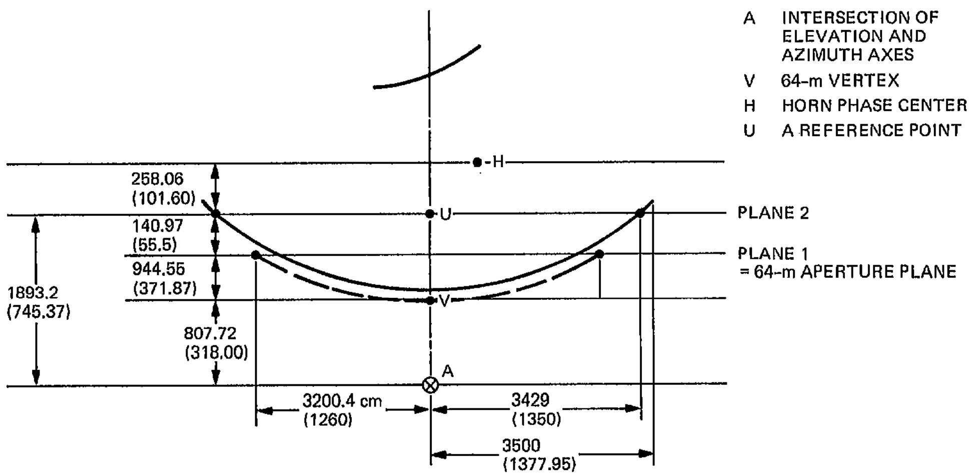

Fig. 3. Geometry of 64-m and 70-m antennas