# S/X-Band Experiment: Zero Delay Device Z Correction

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*A new dual-frequency (S-band and X-band) zero delay device (ZDD) was required for the MVM'73 S/X experiment at DSS 14. To properly utilize the "zero" calibration provided by the ZDD, an evaluation of the "Z" term in the ranging equations must be made. An equation for this term is derived, and values are determined for several configurations.*

## I. Introduction

A new dual frequency (S-band and X-band) zero delay device (ZDD) was required for the MVM'73 S/X experiment at DSS 14 (Refs. 1, 2).[1] To properly utilize the "zero" calibration provided by the ZDD, an evaluation of the Z term in the ranging equations must be made (Ref. 3). An equation for this term is derived and values are determined for several configurations.

[1]Discussions of the preliminary location tests and calibration of this ZDD are presented by C. T. Stelzried, et al. and by T. Y. Otoshi and C. T. Stelzried elsewhere in this issue.

## II. Discussion

By referring to Figs. 1 and 2, it is possible to write an equation for the ranging machine "gross indicated" value of round-trip light time (RTLT) while tracking the spacecraft:

$$A_{S/C\,(S)} = [B_U + B'_U + C_U - D + E_S] + F_S + [E_S - D + C_{DS} + B'_{DS} + B_{DS}] \qquad \text{(S-band)} \tag{1}$$

where

$A_{S/C}$ = ranging machine "gross indicated" round-trip light time while locked on the spacecraft (S/C), i.e., time for a signal to go from the ranging machine, through the complete system and back to the ranging machine[2]

$B_U$ = time for a signal to travel from the ranging machine to the uplink sampling point for the ZDD

$B'_U$ = time for a signal to travel from the uplink sampling point for the ZDD to the radio frequency (RF) $\phi$ center of the ground antenna feed horn

$C_U$ = time for a signal to travel from the feed-horn phase center, through the dichroic feed system, subreflector and parabolic surface to the aperture plane of the paraboloid

$D$ = distance (in equivalent time units) between the aperture plane and the antenna "bench mark"[3]

$E$ = time for a signal to travel between the ground antenna bench mark and the spacecraft antenna aperture plane

$F$ = two-way or round trip time for a signal to travel from the S/C antenna aperture plane, through the S/C radio subsystem and return to the S/C aperture plane

$B'_D$ = time for a signal to travel from the RF $\phi$ center of the ground antenna feed horn to the ZDD simulated downlink injection point

$B_D$ = time for a signal to travel from the ZDD simulated downlink injection point to the ranging machine

Subscripts $U$ and $D$ indicate uplink and downlink, respectively, and $S$ indicates S-band. $X$ will indicate X-band. Where no S or $X$ designation appears, the terms are identical for S- and X-band signals.

A similar equation may be written for X-band:

$$A_{S/C\,(X)} = [B_U + B'_U + C_U - D + E_S] + F_X + [E_X - D + C_{DX} + B'_{DX} + B_{DX}] \quad \text{(X-band)} \qquad (2)$$

[2]"Times" discussed here mean equivalent free-space light times.

[3]For DSS 14, the "bench mark" designated here is the intersection of the azimuth and elevation axes.

Similarly, equations can be written for the ranging machine "gross indicated" value of round-trip light time while "tracking" the ZDD:

$$A_{ZDD\,(S)} = [B_U + G_U] + H_S + [G_{DS} + B_{DS}] \qquad (3)$$

$$A_{ZDD\,(X)} = [B_U + G_U] + H_X + [G_{DX} + B_{DX}] \qquad (4)$$

where

$A_{ZDD}$ = ranging machine "gross indicated" round-trip light time while locked on ZDD, i.e., time for a signal to go from the ranging machine, through the complete system and back to the ranging machine

$G_U$ = time for a signal to travel from the uplink sampling point to the input port of the ZDD

$H$ = two-way or round-trip time for a signal to travel from the ZDD input port through the ZDD and back to the appropriate output port

$G_D$ = time for a signal to travel from the ZDD output port to the appropriate downlink injection point

Now, subtract Eq. (3) from Eq. (1) and combine terms

$$A_{S/C\,(S)} - A_{ZDD\,(S)} = B'_U + B'_{DS} + C_U + C_{DS} - 2D + E_S + E_S + F_S - [G_U + G_{DS} + H_S] \qquad (5)$$

Rearrange

$$(E_S + E_S) = A_{S/C\,(S)} - A_{ZDD\,(S)} - F_S + [-(B'_U + B'_{DS} + C_U + C_{DS}) + 2D + G_U + G_{DS} + H_S] \qquad (6)$$

The corresponding X-band equation is

$$(E_S + E_X) = A_{S/C\,(X)} - A_{ZDD\,(X)} - F_X + [-(B'_U + B'_{DX} + C_U + C_{DX}) + 2D + G_U + G_{DX} + H_X] \qquad (7)$$

Now, compare Eqs. (6) and (7) with the R/D S/X ranging equation (repeated here for convenience) of Ref. 3:

$$RTLT = RU \frac{1}{(128)\,(48)\,F_T} + M \frac{64 \times 2^N}{3F_T} - BIAS_{DSN} \frac{1}{(128)\,(48)\,F_T} - BIAS_{S/C} + Z \qquad (8)$$

The results of this comparison, term by term, are

$$(E + E) = \text{RTLT} \tag{9}$$

$$A_{S/C} = RU \frac{1}{(128)(48)F_T} + M \frac{64 \times 2^N}{3F_T} \tag{10}$$

$$A_{ZDD} = BIAS_{DSN} \frac{1}{(128)(48)F_T} \tag{11}$$

$$F = BIAS_{S/C} \tag{12}$$

and finally,

$$[-(B'_U + B'_D + C_U + C_D) + 2D + G_U + G_D + H] = Z \tag{13}$$

(The frequency subscripts $S$ and $X$ have been omitted for convenience as the comparison applies to both frequencies.)

Some comments on the terms comprising the expression for Z are in order:

(1) The term $C$ has the effect of moving the RF reference point from the ground antenna appropriate feed horn phase center to the aperture plane.

(2) Then, the term $D$ further moves the resulting RF reference from the aperture plane to the "bench mark."

(3) The terms $(-B'_U + G_U)$ and $(-B'_D + G_D)$ compensate for the fact that the ZDD is not at the ground antenna feed horn phase center when taking a "zero delay" reading.

(4) Finally, term $H$ is exactly analogous to the $S/C$ term $F$ where each corrects for the signal turnaround time of its appropriate device.

The differential (S) − ($X$) Z term can be determined simply by subtracting the S and $X$ forms of equation (13), the Z equation:

$$Z_S - Z_X = -(B'_{DS} - B'_{DX} + C_{DS} - C_{DX} - G_{DS} + G_{DX} - H_S + H_X) \tag{14}$$

Notice that since uplink terms are common to both S- and X-band signals, virtually all of them have dropped out of the differential (S) − ($X$) Z term.

## References


1. Otoshi, T. Y., and Batelaan, P. D., *S/X-Band Experiment: Zero Delay Device*, Technical Report 32-1526, Vol. XIV, pp. 78–80, Jet Propulsion Laboratory, Pasadena, Calif., Apr. 15, 1973.
2. Otoshi, T. Y., and Batelaan, P. D., *S/X Experiment: Preliminary Tests of the Zero Delay Device*, Technical Report 32-1526, Vol. XVII, pp. 68–77, Jet Propulsion Laboratory, Pasadena, Calif., Oct. 15, 1973.
3. DSN System Requirements Document 820-13, Rev. A, Detailed Interface Design, TRK-2-8, pg. 20, paragraph 3.
4. Otoshi, T. Y., and Stelzried, C. T., "S/X Experiment: A New Configuration for Ground System Range Calibrations with the Zero Delay Device," (this issue).
5. Private communication, D. Bathker to P. Batelaan, 1/11/74.
6. Private communication, Smoot Katow to P. Batelaan, 11/14/73.

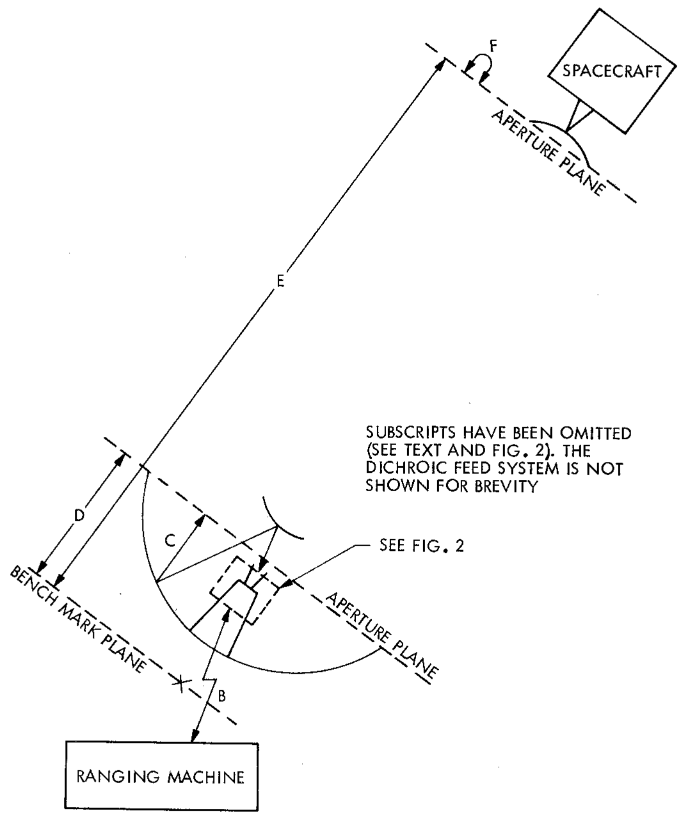


**Fig. 1. Overall ranging path**

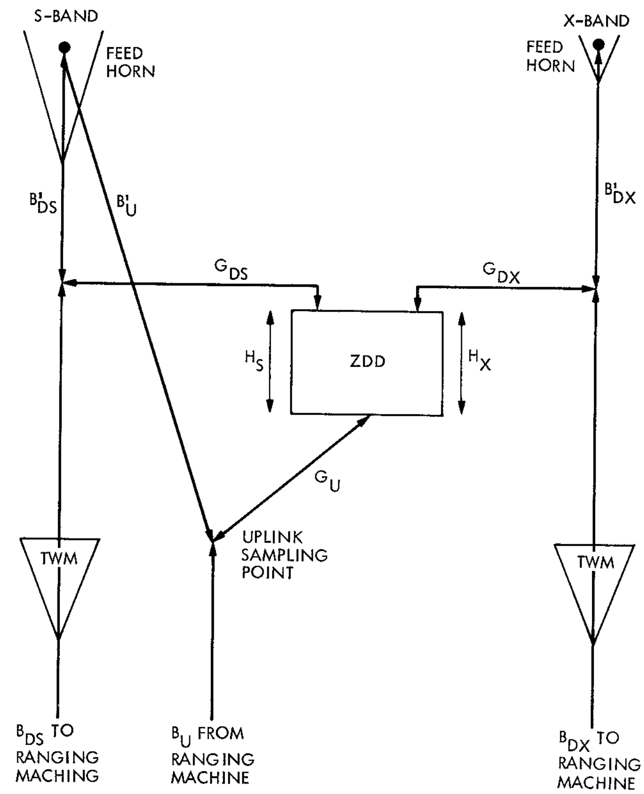


**Fig. 2. Detail ranging path**

# Appendix A
# Values of $Z_S$ and $Z_X$ for DSS 14 for the Period 12/21/73 Through 1/12/74

Values of $Z_S$ and $Z_X$ for DSS 14 for the period 12/21/73 through 1/12/74 are:

$$Z_S = -169.00 \pm 0.86 \text{ ns}, 1\sigma$$

$$Z_X = -137.58 \pm 0.86 \text{ ns}, 1\sigma$$

These numbers were arrived at by evaluating the appropriate forms of Eq. (13) with the values in Table A-1 substituted for the various indicated parameters (they do not, however, include the effects of the instabilities described in the articles of footnote 1)

**Table A-1. Values of parameters**

| Parameter | | Value, ns | Source |
|---|---|---|---|
| $B'_U$ | = | 91.29 ±0.26 | $\tau_{23}$ (Ref. 4) + $\tau$ (2113 feed and components) (Ref. 5) |
| $B'_{DS}$ | = | 47.37 ±0.28 | $\tau_{34}$ (Ref. 4) + $\tau$ (2295 feed and components) (Ref. 5) |
| $B'_{DX}$ | = | 3.52 ±0.08 | $\tau_{67}$ (Ref. 4) + $\tau$ (8415 feed and components) (Ref. 5) |
| $C_U$ | = | 168.95 ±0.02 | Ray optics tracing of path from S-band feed horn to aperture plane via dichroic system, subreflector and paraboloid |
| $C_{DS}$ | = | 168.95 ±0.02 | Ray optics tracing of path from S-band feed horn to aperture plane via dichroic system, subreflector and paraboloid |
| $C_{DX}$ | = | 160.01 ±0.06 | Ray optics tracing of path from X-band feed horn to aperture plane via dichroic system, subreflector and paraboloid |
| $D$ | = | 58.62 ±0.01 | Ref. 6 and print 9437255 |
| $G_U$ | = | 88.83 ±0.09 | $\tau_{2A}$ (Ref. 4) |
| $G_{DS}$ | = | 87.38 ±0.12 | $\tau_{B4}$ (Ref. 4) |
| $G_{DX}$ | = | 70.63 ±0.10 | $\tau_{C7}$ (Ref. 4) |
| $H_S$ | = | 14.11 ±0.76 | $\tau_{AB}$ (Ref. 4) |
| $H_X$ | = | 9.49 ±0.80 | $\tau_{AC}$ (Ref. 4) |

# Appendix B
# Values of $Z_S$ and $Z_X$ for DSS 14 for 1/14/74 and Later

On 1/13/74 the uplink sampling point was moved from the 10/20 kW transmitter in the MOD II area to the junction of the megawatt transmitter filter (MTF) and the 4th harmonic filter in the MOD III area. This was done so that the sampling point would be independent of which transmitter was in use: 10, 20, 100 or 400 kW. Because of this relocation, the values of $Z_S$ and $Z_X$ have changed to:

$$Z_S = -166.50 \pm 0.86 \text{ ns}, 1\sigma$$

$$Z_X = -135.08 \pm 0.86 \text{ ns}, 1\sigma$$

These numbers were arrived at by evaluating the appropriate forms of Eq. (13) with the values in Table B-1 substituted for the various indicated parameters.

**Table B-1. Values of parameters**

| Parameter | | Value, ns | Source |
|---|---|---|---|
| $B'_U$ | = | 42.31 ±0.26 | $\tau_{2'3}$ (Ref. 4) + $\tau$ (2113 feed and components) (Ref. 5) |
| $B'_{DS}$ | = | 47.37 ±0.28 | $\tau_{34}$ (Ref. 4) + $\tau$ (2295 feed and components) (Ref. 5) |
| $B'_{DX}$ | = | 3.52 ±0.08 | $\tau_{67}$ (Ref. 4) + $\tau$ (8415 feed and components) (Ref. 5) |
| $C_U$ | = | 168.95 ±0.02 | Ray optics tracing of path from S-band feed horn to aperture plane via dichroic system, subreflector and paraboloid |
| $C_{DS}$ | = | 168.95 ±0.02 | Ray optics tracing of path from S-band feed horn to aperture plane via dichroic system, subreflector and paraboloid |
| $C_{DX}$ | = | 160.01 ±0.06 | Ray optics tracing of path from X-band feed horn to aperture plane via dichroic system, subreflector and paraboloid |
| $D$ | = | 58.62 ±0.01 | Ref. 6 and print 9437255 |
| $G_U$ | = | 42.35 ±0.09 | $\tau_{2'A}$ (Ref. 4) |
| $G_{DS}$ | = | 87.38 ±0.12 | $\tau_{B4}$ (Ref. 4) |
| $G_{DX}$ | = | 70.63 ±0.10 | $\tau_{C7}$ (Ref. 4) |
| $H_S$ | = | 14.11 ±0.76 | $\tau_{AB}$ (Ref. 4) |
| $H_X$ | = | 9.49 ±0.80 | $\tau_{AC}$ (Ref. 4) |