820-013
Deep Space Network (DSN)
External Interface Specification

JPL D-16765

TRK-2-23
Media Calibration Interface

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Change Log

Rev.	Check if Minor Rev.	Issue Date	Affected Sections	Change Summary
--		05/01/1983	All	This is a new document.
1		02/15/1999	1	Clarification of 2-digit year
2		05/31/2000	All	Update troposphere and solar plasma calibration specifications and reformat.
A			All	Remove solar plasma calibration specifications, update and reformat
B	X	02/29/2008	Section 1	Minor changes to update footer tags, change 'DSMS' references to 'DSN', Section 1 sequence
C		Xx/xx/2008	1.1, 1.2, 1.6, 2, 3.1.4, 3.1.10, 3.3, 3.4, 3.6, Table 3-1, Figures 3-1, 3-2, 3-3	Update subsystem name and spacecraft trajectory interface reference, correct calibration start and end time format, clarify allowed placement of comments in CSP commands, describe "quick-look" calibration files, update data flow description

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Section 1
Introduction

1.1 Purpose

This Deep Space Network (DSN) interface module specifies the format and content of the media calibration data that are provided by the Radiometric Modeling and Calibration Subsystem (RMC). These calibrations are used by project navigation and radio science teams, multi-mission spacecraft navigation, and other investigators (hereafter collectively referred to as users) to improve the accuracy of spacecraft orbit determination and radio science investigations by compensating for the media transmission effects of the Earth's troposphere and ionosphere on the propagation of radiometric signals.

1.2 Applicability

This module is revision C. It supersedes TRK-2-23 Revision B, released March 7, 2008. The content of the calibrations and their delivery location remain unchanged. This revision reflects the new name for the subsystem that creates the calibrations, updates the reference to the interface by means of which users provide spacecraft trajectory information, corrects the description of the format used for calibration start and end times, and clarifies where comments may occur in calibrations. It also describes new "quick-look" calibration deliveries and a new calibration delivery data flow within JPL, both of which are effective with the OP-G release of the Calibration Data Base (CALDB) software NOK-6036.

1.3 Revision Control

Revisions or changes to the information herein presented may be initiated according to the procedure specified in the *Introduction* to Document 820-013.

Documents controlling this version include

DSN 813-109, D-17818	*Preparation Guidelines and Procedures for Deep Space Mission System (DSMS) Interface Specifications.* October 19, 1999 [DSN internal]

1.4 Relationship to Other Documents

None.

1.5 Terminology and Notation

None.

1.6 References

Documents

The following documents are referenced within this module:

DSN 810-047	*DSN Antenna and Facility Identifiers, DSN Standard Practice* [DSN internal document].
DSN 820-013, D-16765	*DSN External Interface Specification*
	OPS-6-21 *Standard Code Assignments*
	0168-Service-Mgmt. *DSN Web Portal Services*
	VLB-13-4 *Radio Source Position Catalog Interface*
Chao	DSN Progress Report, Vol XIV, April 15, 1973, *A New Method to Predict Wet Zenith Range Correction from Surface Measurements,* C.C. Chao.
Fortran	IEEE Standard 1003.9-1992, *Posix Fortran-77 Language Interface*.
Niell	Journal of Geophysical Research, Vol, 101, No. B2, 1996, *Global Mapping Functions for the Atmospheric Delay at Radio Wavelengths,* A.E. Niell.

Web Sites

NAV	http://eis.jpl.nasa.gov/nav/doc
	[DSN internal document].
SSH	http://www.openssh.com

1.7 Abbreviations

Abbreviations used in this document are defined with the first textual use of the term. Abbreviations appearing in this module are provided below:

ASCII	American Standard Code for Information Interchange
CSP	Control Statement Processor (of the Orbit Determination Program)
DSCC	Deep Space Communications Complex
DSN	Deep Space Network
DSS	Deep Space Station

GPS	Global Positioning System
IP	Internet Protocol
ODP	Orbit Determination Program
OMC	DSN Operations and Maintenance Contract
RMC	Radiometric Modeling and Calibration Subsystem
SFTP	Secure File Transfer Protocol
SPS	Service Preparation Subsystem
SSH	Secure Shell
TCP	Transmission Control Protocol
ΔDOR	Delta Differenced One-way Ranging

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Section 2
Functional Overview

Media calibrations are created by the Radio Metric Modeling and Calibration (RMC) Subsystem and delivered to a central repository on the flight operations network by the DSN Operations and Maintenance Contract (OMC) Media Analyst. Calibrations that have been validated visually by the Media Analyst are delivered at daily-to-weekly intervals that are negotiated by the user with the Media Analyst. "Quick-look" calibrations that have not been validated in this way are delivered daily.

The calibrations are provided as American Standard Code for Information Interchange (ASCII) text files that conform to the Control Statement Processor (CSP) language used by the Orbit Determination Program (ODP) software. A separate calibration file is provided for each medium (troposphere and ionosphere).

Troposphere calibration files are spacecraft-independent; their calibrations collectively cover all 24 hours of each day at each Deep Space Communications Complex (DSCC), in contiguous "passes" of approximately six hours each. Two troposphere calibrations are provided for each such pass: a "dry" tropospheric delay calibration and a "wet" tropospheric delay calibration. Since the troposphere calibrations are used for all spacecraft, new users do not need to specifically request that they be created.

Ionosphere calibration files are specific to one spacecraft or other user and provide one calibration per tracking pass or other time period of interest at each Deep Space Communications Complex (DSCC) or Deep Space Station (DSS). New projects or missions must contact the Media Analyst in advance to arrange for the creation of their ionosphere calibrations.

To receive spacecraft line-of-sight ionosphere calibrations, the user must first provide the Service Preparation Subsystem (SPS) with a spacecraft trajectory in one of the supported formats [820-013, 0168-Service-Mgmt.] and provide updated trajectories as often as necessary to maintain adequate knowledge of the spacecraft position. To receive line-of-sight ionosphere calibrations for Delta Differenced One-way Ranging (ΔDOR) tracking data, the user must provide the SPS with the quasar numbers [820-013, VLB-13-4] and the spacecraft and quasar observing schedules for the ΔDOR scans. The Media Analyst then downloads the trajectories and ΔDOR schedules from the SPS as needed.

The details of the media calibration interface are presented in the next section. Many users will be concerned only with the location of the calibration repository and its directory and file name conventions, which are given in section 3.4. However, since those specifics may change between revisions of this module, new users should confirm them with established users, the Media Analyst, or the RMC Subsystem Engineer.

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Section 3
Detailed Interface Description

Media calibrations conform to the Control Statement Processor (CSP) language used by the Orbit Determination Program (ODP) to adjust data points. The CSP language is described in detail in [NAV] under *Navigation Software; File Formats; Internal File Format Descriptions; Control Statement Processor (CSP) Command File*. Section 3.1 below identifies the CSP command elements that may be used in media calibrations. Section 3.2 provides further information and examples specific to ionosphere and troposphere calibrations. Section 3.3 describes the calibration data flow and file transfer protocols. Section 3.4 identifies the directories and file naming conventions used for the media calibration files on the central repository.

3.1 CSP Command Language

A CSP command consists of a command verb followed by optional scope limiters and computation specifiers, terminated by a period. Spaces are not significant. Most commands extend over multiple lines of text. The CSP language elements that may be used in media calibrations are listed in Table 3-1 and described in the following subsections.

Table 3-1: CSP Elements Used in Media Calibrations

Type of Element	Elements Used
Command Verbs	ADJUST
Data Types	DOPRNG ALL DOPPLER VLBI RANGE
Transmission Medium	MODEL(DRY NUPART) MODEL(CHPART) MODEL(WET NUPART)
Time Span	FROM TO
Network Complex or Station	DSN(C10) DSN(C40) DSN(C60) DSN(*dss*) for a specific DSS number
Source	SCID QUASAR
Computation Specifier	BY NRMPOW BY CONST BY TRIG BY DNRMPOW BY DCONST BY DTRIG
Comments	#

3.1.1 Command Verbs

The media calibrations use just one CSP command verb: ADJUST. The calibrations are ADJUST commands that specify corrections to one or more data types; e.g., ADJUST(DOPRNG).

3.1.2 Data Types

Data type limiters indicate the specific radiometric data type(s) to be adjusted; e.g., ADJUST(DOPRNG). The data type limiters currently used in the operational media calibrations are: DOPRNG for Doppler and range data, VLBI for Delta Differenced One-way Ranging (ΔDOR) data, and ALL for all radiometric data. The data type limiters DOPPLER (Doppler data) and RANGE (range data) may be used in some experimental calibrations.

3.1.3 Transmission Media

Media calibrations refer to one of three media: ionospheric charged particles (MODEL(CHPART)), tropospheric wet delay (MODEL(WET NUPART)), or tropospheric dry delay (MODEL(DRY NUPART)). Only wet and dry tropospheric delay calibrations are typically mixed together in a single calibration file.

3.1.4 Time Spans

Each calibration applies to the particular time span that it specifies in the form FROM(*YY*/*MM*/*DD*,*HH*:*MM*:00.001) TO(*YY*/*MM*/*DD*,*HH*:*MM*). All times refer to Universal Time Coordinated (UTC). The year, month, day, hour, and minute values are two-digit integers. Years 69 through 99 refer to 1969 through 1999, and years 00 through 68 refer to 2000 through 2068. The TO time has no seconds field; all calibration time spans end on the minute. The FROM time seconds field is always 00.001, in order to prevent the ODP from interpreting time-contiguous calibrations as overlapping, except in the troposphere seasonal model calibrations (see Figure 3-2). Since the seasonal models never include time-contiguous calibrations, they dispense with the seconds field in the FROM time.

The time span limiter AT(*YY*/*MM*/*DD*,*HH*:*MM*:*SS.SSS*) may be used in experimental calibrations. Here the seconds field is a floating point number and the applicable time span is from one millisecond before the given time to one millisecond after it.

3.1.5 Network Complex or Station

The applicable tracking sites for media calibrations may be specified by DSCC number or by DSS number. DSCC specifications have the form DSN(C*nn*) where *nn* is the complex number; e.g., DSN(C10). These are the more common, since the media effects are essentially the same for all stations at a given complex. Individual stations are specified in the form DSN(*nn*) where *nn* is the DSS number; e.g., DSN(15). See module 810-047 for the DSS identifiers.

3.1.6 Data Source

Applicable data sources for media calibrations are specified by spacecraft or quasar number. Spacecraft are identified in the form SCID(*nn*) where *nn* is the decimal spacecraft number given in 820-013. Quasar sources of ΔDOR data are identified in the form QUASAR(*nn*) where *nn* is the quasar number. If no data source is specified, the calibration is applicable to any data source. Troposphere calibrations use no source specification since they do not refer to a specific spacecraft or quasar line-of-sight.

3.1.7 Computation Specifiers

Computation specifiers indicate how the data corrections are expressed in ADJUST commands. Media calibrations may be expressed by a constant (computation specifier BY CONST), by a normalized power series (BY NRMPOW), or by a Fourier series (BY TRIG). If the constant or the coefficients are expressed in double precision, the computation specifier is preceded by the letter "D" (e.g., BY DNRMPOW).

The computation specifier is followed by a parenthesized, comma-separated list of numerical coefficients. Up to 24 single-precision or 12 double-precision coefficients are allowed in one series. Their interpretation is described below for each type of computation that may be used. In these descriptions S and E refer to the start and end of the applicable time span, which are generally specified by the FROM and TO time span limiters.

A constant correction of size C is expressed in the form BY CONST(C).

A normalized power series is expressed in the form BY NRMPOW(C_O, C_1, ... ,C_N). The calibration at time T is computed as $C_O + C_1 * X + C_2 * X^2 + \ldots + C_N * X^N$, where T is replaced by the normalized, dimensionless argument $X = 2 * ((T - S) / (E - S)) - 1$, which is -1 at T = S and +1 at T = E.

A Fourier series is expressed in the form BY TRIG (P, A_O, A_l, B_1, A_2, B_2, …, A_N, B_N). The calibration at time T is $A_0 + A_l\cos X + B_1\sin X + A_2\cos 2X + B_2\sin 2X + \ldots + A_N\cos NX + B_N\sin NX$, where $X = 2\pi * (T - S) / P$ and P is the period of the fundamental mode, in seconds.

3.1.8 Sign of Calibration

Positive media calibrations indicate positive range delays. Media calibrations are (effectively) subtracted from ODP range observables. ODP Doppler observables are corrected by (effectively) subtracting troposphere calibrations while adding ionosphere calibrations, since the charged particle effect advances the Doppler phase.

3.1.9 Number Formats

The formats for single- and double-precision floating-point numbers are generally the same as the standard FORTRAN G format [Fortran]. However the sign of the exponent of a floating-point number may replace the letter D or E; for example, 1.234E-3 may be written 1.234-3.

3.1.10 Comments

Additional commentary may appear at the end of a CSP command, following the period ("."), if it is preceded by a number sign (#). All characters from a number sign to the end of the text line are ignored by the ODP.

3.2 Media Calibrations

3.2.1 Ionosphere Calibrations

The distribution of charged particles in the ionosphere is highly inhomogeneous. The magnitude of the ionospheric range delay at a given site depends on the spacecraft line-of-sight and on the observing frequency, time of day, season, and time since the start of the current solar cycle. At S-band, the zenith ionospheric delay ranges from less than 1 meter to more than 10 meters, and the delay at 0 degrees elevation is about 3.5 times as large.

Ionospheric calibrations are given by a normalized polynomial for each tracking pass at each DSCC or DSS. An example for a Doppler/range track is shown in Figure 3-1. The time span of the calibration is from spacecraft rise (0 degrees) to set (0 degrees) at the receiving station or complex. For ΔDOR tracks, the data type is VLBI, the data source is SCID(*nn*) for spacecraft scans and QUASAR(*nn*) for quasar scans, and the time spans correspond to the ΔDOR tracking schedule. The calibration represents the one-way line-of-sight ionospheric range delay to the spacecraft, in meters at a nominal S-band frequency of 2295 Mhz. The ODP adjusts the calibration to the tracking frequency that is used.

```
# FITSIG= .0254331
ADJUST(DOPRNG)BY NRMPOW(    1.3963,   -1.2750,    1.7128,   -1.3736,    3.3967,
    3.8142,   -8.1935,   -4.0516,    3.9466,    2.1107)               MODEL(CHPART)
FROM(06/05/01,03:01:00.001)TO(06/05/01,13:00)DSN(C40)SCID(82). #S01 ADJ 060504 15:31
```

Figure 3-1: Example Ionosphere Calibration

A comment before each calibration indicates the post-fit residual of the fitted polynomial, in meters at S-band. A comment at the end of each calibration indicates the date and time it was created and the source of the data used: S01 ADJ for final ionospheric models available after three days; S02 ADJ for prompt ionospheric models available after one day; or S03 PRE for predicted data.

3.2.2 Troposphere Calibrations

The tropospheric delay is comprised of a wet delay, caused by the permanent dipole in atmospheric water vapor, and a hydrostatic or dry delay, caused by induced dipoles in all atmospheric gasses. The zenith dry delay ranges from about 2 to 2.2 meters at the DSN sites. DSN zenith wet delays are smaller and more variable, ranging from a few centimeters to 25 centimeters or more. The slant-range factor is approximately 1 / sin(elevation), which is about 10 at 6 degrees elevation.

To a large degree, the troposphere is azimuthally symmetric. Therefore, tropospheric calibrations represent the zenith wet and dry delays and the ODP uses mapping functions [Niell] to perform the slant-range correction to the spacecraft elevation. Thus, troposphere calibrations are not specific to a particular spacecraft. They simply “cover the clock” at a given DSCC and apply to all data types and spacecraft by specifying data type ALL and omitting a spacecraft scope limiter.

First order calibration of the tropospheric delays is accomplished with seasonal models [Chao] which do not depend on real time data and need only be delivered once. These models represent the one-way zenith wet and dry delays, in meters, as Fourier series calibrations as shown in Figure 3-2. The zenith dry delay decreases about 0.25 mm for each additional meter of altitude. Dry delay calibrations refer to the altitude of the intersection of axes of the 70m antenna at each DSCC. The seasonal models include adjustments for the altitudes of each of the other DSN antennas.

```
ADJUST(ALL)BY TRIG(31557600.,   0.0870,  -0.0360,  -0.0336,   0.0002,
   0.0200,   0.0008,  -0.0021,  -0.0036,  -0.0002)                    MODEL
(WET NUPART)FROM(72/01/01,00:00)TO(48/01/01,00:00)DSN(C10).    #ADJ 920121 02:23
ADJUST(ALL)BY TRIG(31557600.,   2.0521,   0.0082,  -0.0005,  -0.0004,
   0.0033,  -0.0015,   0.0005,  -0.0011,   0.0036)                    MODEL
(DRY NUPART)FROM(72/01/01,00:00)TO(48/01/01,00:00)DSN(C10).    #ADJ 920121 02:23
…
ADJUST(ALL) BY CONST( 0.0094947) MODEL(DRY NUPART)
FROM(72/01/01,00:00) TO(48/01/01,00:00) DSN(012).  #ADJ
…
```

Figure 3-2: Seasonal Troposphere Models for DSCC 10

The seasonal troposphere models are routinely used in all ODP runs. More accurate tropospheric calibrations are derived from real time weather and Global Positioning System (GPS) data. These calibrations are expressed as normalized polynomial corrections, in meters, to the one-way seasonal model delays, in order to avoid double-calibrating. Examples are shown in Figure 3-3. A comment before each calibration indicates the post-fit residual of the fitted polynomial. A comment at the end of each calibration indicates the date and time it was created, preceded by “PRE” if it is based on predicted data.

```
# FITSIG= .0008888
ADJUST(ALL)BY NRMPOW(   0.0197,  -0.0150,  -0.0212,   0.0786,   0.0789,
  -0.1863,  -0.0938,   0.1683,   0.0342,  -0.0518)                     MODEL
(WET NUPART)FROM(06/05/01,03:00:00.001)TO(06/05/01,09:00)DSN(C10). #  060502 15:40
# FITSIG= .0001873
ADJUST(ALL)BY NRMPOW(   0.0020,   0.0027,   0.0039,  -0.0014,  -0.0025)  MODEL
(DRY NUPART)FROM(06/05/01,03:00:00.001)TO(06/05/01,09:00)DSN(C10). #  060502 15:40
```

Figure 3-3: Example Troposphere Calibrations

3.3 Data Flow and File Transfer Protocols

The RMC Subsystem resides on the open JPLnet. Calibrations are delivered to the repository on the closed flight operations network in two steps. First, Secure File Transfer Protocol (SFTP) is used to copy them to the open network server nexus.jpl.nasa.gov, which is accessible from the flight operations network. Then software running in the Radio Metric Data Conditioning Subsystem copies the calibrations into the repository on the server oscarx.fltops.jpl.nasa.gov within a few minutes. (oscarx does not permit this to be done directly from the open network.) The file transfer protocols are Internet Protocol (IP), Transmission Control Protocol (TCP), Secure File Transfer Protocol (SFTP) [SSH] and Secure Shell [SSH]. The data are encrypted during transmission.

3.4 Calibration Repository Directory and File Name Conventions

Media calibrations are delivered to the server oscarx.fltops.jpl.nasa.gov. Spacecraft-specific ionosphere calibrations are placed in directory /fs1/oscarx/ftp/*name*/media, where *name* is chosen by the flight project (e.g., cassini for Cassini or odyssey for Mars Odyssey). Troposphere calibrations go in directory /fs1/oscarx/ftp/media/tropo. The troposphere seasonal models are found in the file seasonal.csp.

Media calibrations are normally organized in files that cover one calendar month. Each file is originally filled with predicted calibrations and is updated and redelivered throughout the month as calibrations based on real time data become available to replace the predictions. Validated troposphere calibration files are named ATC*yrmon*.csp where *yrmon* indicates the year and month in the form, e.g., 06may. Validated spacecraft-specific ionosphere calibration files for Doppler/range tracks are named gimcal_*no*_*yymm*_dopr.csp, where *no* is the spacecraft number (see 820-013, OPS-6-21) and *yymm* indicates the year and month in the form, e.g., 0605. Spacecraft-specific ionosphere calibration files for ΔDOR tracks are named gimcal_*no*_*yymm*_vlbi.csp. “Quick-look” calibration files whose latest calibrations have not been validated visually by the Media Analyst appear in the same directory as validated calibrations, but with “.ql” appended to the file name.

3.5 Calibration File Sizes

Each individual media calibration occupies approximately 240 to 320 bytes of storage. Ionosphere calibration files require about 22 to 29K bytes per spacecraft per month and troposphere calibration files require about 176 to 230K bytes per month.

3.6 Dependencies

The creation of ionosphere calibrations for a new spacecraft or other project depends on prior communication with the Media Analyst.

To receive spacecraft line-of-sight ionosphere calibrations, the user must first provide the SPS with a spacecraft trajectory in one of the supported formats [820-013, 0168-Service-Mgmt.] and provide updated trajectories as often as necessary to maintain adequate knowledge of the spacecraft position.

To receive line-of-sight ionosphere calibrations for ΔDOR tracking data, the user must provide the SPS with the quasar numbers [820-013, VLB-13-4] and the spacecraft and quasar observing schedules for the ΔDOR scans.