***Deep Space Network***

# 104
# Calibration and Modeling Services

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## *Review Acknowledgment*

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# *Document Change Log*

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| A | 07/03/2018 | Dong Shin | All | This is a new title and content due to the restructuring of the document series. |
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# *Table of Contents*

# Section 1
# Introduction

## 1.1 PURPOSE

This document describes the capabilities and data interfaces provided by the Deep Space Network (DSN) calibration and modeling services for all missions using the DSN.

The DSN calibration and modeling services include platform parameters, ionosphere and troposphere media calibrations, and DSN timing calibrations. These services support Delta Differential One-way Range (delta-DOR), Doppler, and ranging measurements that enable missions to establish and maintain knowledge of spacecraft position and motion.

## 1.2 REVISION AND CONTROL

This document is maintained by DSN System Engineering and will be revised to reflect new capabilities as they are approved by the DSN Project Office.

This document is approved for publication under the authority of the cover page signatories. Revisions are indicated by a revision letter following the module designator. Changes are appropriately marked and recorded in a Change Log at the front of this document.

This document is primarily concerned with the ground data and interfaces between the mission and the DSN. It is principally organized around the DSN Service Catalog [1] and includes references to DSN external interface specifications [3] through [9].

Documents controlling this version include:

[1] 820-100, Rev. F *Deep Space Network Services Catalog*, 2/24/2015
JPL D-30531

## 1.3 RELATIONSHIP TO OTHER SERVICES

The Service Management (SMS) system delivers a delivery mechanism and delivering support data needed for ionosphere media calibration.

## 1.4 CCSDS COMPLIANCE

The troposphere media calibration and ionosphere media calibration service are compliant with Consultative Committee for Space Data Systems (CCSDS) standards CCSDS 503.0-B-1 Tracking Data Message (TDM) [2] for delivering media calibrations. The CCSDS standards do not apply to platform services.

## 1.5 TERMINOLOGY AND NOTATION

Abbreviations and acronyms used in this document are defined with the first textual use of the term. Appendix A contains a list of abbreviations and acronyms used in this document. The definitions provided here are intended to clarify the use of certain terms as they apply to this module.

| | |
|---|---|
| Mission | Flight project teams including flight operations and project navigation, sequencing, and scheduling |
| Mission Interface Manager (MIM) | The DSN manager responsible for DSN customer interfaces |

## 1.6 REFERENCE DOCUMENTS

| | | | |
|---|---|---|---|
| [2] | CCSDS 503.0-B-1 | Blue Book | *Tracking Data Message (TDM)*, 11/2007 |
| [3] | 820-013, JPL D-16765 | TRK-2-21, Rev. C | *Deep Space Network External Interface Specification, DSN Tracking System Earth orientation Parameter Data Interface*, 7/22/2015 |
| [4] | 820-013, JPL D-76506 | TRK-2-23, Rev. D | *Deep Space Network External Interface Specification, Media Calibration Interface*, 10/25/2013 |
| [5] | 820-013, JPL D-16765 | TRK-2-33, Rev. A | *Tracking and Navigation SPK File Interface, 1/31/2006* |
| [6] | 820-013, JPL D-76497 | 0168-ServiceMgmt, Rev. D | *DSN Web Portal Services*, 4/20/2016 |
| [7] | 820-013, JPL D-76502 | 0194-Navigation-OEM, Rev. A | *Tracking and Navigation Orbit Ephemeris Message (OEM) File Interface*, 10/11/2013 |
| [8] | 820-013, JPL D-16765 | 0212-Tracking-TDM, Rev. D | *DSN Tracking Data Message (TDM) Interface*, 10/22/2015 |
| [9] | 820-013, JPL D-16765 | 0220-Tracking-FTS, Rev. A | *Deep Space Network External Interface Specification, DSN Complex Clock and Frequency Offset Interface*, 7/07/2016 |
| [10] | 820-016, JPL D-10 | 0389-GIMCAL-SPS, Initial | *Global Ionospheric Model-Based Calibration (GIMCAL) and Service Preparation Subsystem (SPS) Interface*, 4/30/2008 |
| [11] | 810-005 JPL D-19379 | Module 107 Rev. D | *DSN Telecommunications Link Design Handbook*, *X-Band Radio Source Catalog*, 10/22/2015 |
| [12] | 810-005 JPL D-19379 | Module 301, Rev. K | *DSN Telecommunications Link Design Handbook, Coverage and Geometry*, 9/13/2016 |
| [13] | 810-005 JPL D-19379 | Module 304, Rev. B | *DSN Telecommunications Link Design Handbook, Frequency and Timing*, 12/15/2014 |
| [14] | 810-007 JPL D-81599 | Module 203, Rev. A | *Emergency Control Center (ECC) Capabilities and Services Support*, 9/13/2016 |

# *Section 2*
# *Services Description*

This section describes the DSN calibration and modeling services that enable a mission to establish and maintain accurate knowledge of spacecraft position and motion. Accurate navigation of interplanetary spacecraft requires accurate platform parameters and media, and timing calibrations.

## 2.1 PLATFORM PARAMETERS

The platform parameters service provides a celestial reference frame, DSN station coordinates, and Earth Orientation Parameters (EOP).

### 2.1.1 Celestial Reference Frame

The celestial reference frame is the quasi-inertial reference frame used for spacecraft navigation. It is based on the positions of extragalactic radio sources, which are determined from Very Long Baseline Interferometry (VLBI) measurements from DSN and non-DSN sites.

Key parameters are:

- Source catalog name and ID number of extragalactic radio source with observation epochs
- Angular position in the form of Right Ascension (RA) and Declination (DEC) angular coordinates
- Angular position uncertainty
- Correlated flux density
- Structure index

### 2.1.2 DSN Station Coordinates

The DSN station coordinates specify the locations of the DSN and other supported antennas in a terrestrial reference frame. They refer to a specific point on each antenna, which is located at the intersection of the antenna primary and secondary (elevation and azimuth) axes, in the terrestrial reference frame. They are determined from VLBI measurements and GPS (Global Positioning System) surveying.

Key parameters are:

- Cartesian coordinates
- Geodetic coordinates
- Geocentric coordinates
- Estimated DSN site velocities
- Station location uncertainties

### 2.1.3 Earth Orientation Parameters

The Earth orientation parameters provide information needed to rotate Deep Space Station (DSS) locations from the Earth-fixed frame to the inertial (radio) frame. Earth's orientation varies unpredictably at the level of accuracy required. Therefore it must be measured frequently and delivered rapidly to maintain adequate real-time knowledge.

The Earth orientation parameters are determined from VLBI measurements from DSN and non-DSN sites, atmospheric angular momentum information from the National Oceanic and Atmospheric Administration (NOAA), National Center for Environmental Prediction (NCEP), GPS measurements, Lunar Laser Ranging (LLR) measurements, and Satellite Laser Ranging (SLR) measurements.

Key parameters are:

- The spin parameter, which is the angle through which Earth has rotated about its spin axis (offset from International Astronomical Union (IAU) standard model)
- X Coordinate of Polar Motion (PMX) and Y Coordinate of Polar Motion (PMY) parameters, which specify the location of the spin axis in the terrestrial reference frame
- Precession-nutation parameters $\Delta\psi$ and $\Delta\varepsilon$, which specify the location of the spin axis in the celestial reference frame (offset from IAU standard model)

## 2.2 MEDIA CALIBRATION

Media calibrations quantify the delays that are experienced by radio signals traveling through the Earth's atmosphere. They are used by navigation to improve the accuracy of spacecraft orbit determination by compensating for the media transmission effects. They consist of troposphere calibrations and ionosphere calibrations, which are described below.

### 2.2.1 Ionosphere Calibrations

Radio signals traveling through the Earth's atmosphere are delayed by the presence of charged particles in the electrically-charged upper atmosphere, or ionosphere. The charged particle content and distribution is inhomogeneous and can vary rapidly in time and space. Ionosphere calibrations provide the ionospheric range delay along the target (spacecraft or quasar) line-of-sight over each tracking pass. The ionospheric delay is frequency-dependent; it varies with 1/f^2, where f is the carrier frequency. The calibrations are referenced to S-band. Each user must scale them to the actual frequency used.

Ionosphere calibrations are determined from Global Ionospheric Maps (GIMs) that are based on analysis of contemporaneous global GPS and GLONASS (Global Navigation Satellite System) measurements.

Because ionosphere calibrations are spacecraft-dependent, each mission must request them in advance and provide a spacecraft ephemeris. The calibrations will cover all possible Doppler/Range tracking passes, but delta-DOR calibrations will require the mission to provide the specific observing schedule.

Key parameter is:

- Ionospheric range delay, 1-way line-of-sight at S-band in meters

### 2.2.2 Troposphere Calibrations

Radio signals traveling through the Earth's atmosphere are delayed by dry air and water vapor in the electrically-neutral lower atmosphere, or troposphere. The *dry delay* component is much larger. In the absence of extreme winds, it is azimuthally-symmetric and vertically-stratified at any given location. The *wet delay* component is much smaller, but more variable due to the irregular distribution of atmospheric water vapor. The tropospheric delay is not frequency dependent.

Troposphere calibrations provide the wet and dry delays in the zenith direction at each Deep Space Communications Complex (DSCC) or other supported tracking station. They cover all 24 hours of each day at each DSCC. The user must apply elevation mapping functions to perform the slant-range correction to the spacecraft elevation.

The vertical dry delay is determined quite accurately from the barometric pressure. The vertical wet delay is determined by estimating the total zenith delay from Global Navigation Satellite System (GNSS) measurements and subtracting the dry delay.

Key parameter is:

- Zenith wet and dry delays in meters

## 2.3 DSN TIMING

DSN timing calibrations provide clock offsets between the clocks at each DSN complex and those at each complex traceable to United States Naval Observatory (USNO), to Universal Time Coordinated (UTC). The offset is measured from several GPS in common view. The DSN then performs the post processing of the measurement data and provides a mean offset value for each day and each DSN complex.

Navigation and VLBI principal investigators uses DSN timing calibration data to:

- Correct data time-tags (if offset is large) for Doppler, range and delta-DOR measurements
- As an a priori value when searching for VLBI clock offset between stations
- To synchronize 3-way Doppler and 3-way range measurements for spacecraft orbit determination

The DSN timing synchronization, adjustment, and performance are described in 810-005, Module 304 [13].

Key parameters are:

- Clock offset relative to USNO UTC

- Clock offset between DSN complex
- Frequency offset in terms of fractional frequency deviation
- Uncertainty of the frequency offset in the measurements

# *Section 3*
# *Service Interfaces*

This section describes mission interfaces with the DSN calibration and modeling services. The MIM is responsible for these interfaces.

## 3.1 MISSION-TO-DSN

### 3.1.1 Ionosphere Calibrations

Of all the calibration and modeling services, only ionosphere calibrations are spacecraft dependent, and only the ionosphere calibration service requires information from the mission.

To obtain ionosphere calibrations for Doppler/Range tracks the mission must:

1. Negotiate any special calibration delivery requirements with the MIM.
2. Provide a spacecraft ephemeris in the format described in 820-013, TRK-2-33 [5] or 0194-Navigation-OEM [7] and update it as needed to obtain accurate line-of-sight calibrations. The mission uploads these files utilizing the SPS web portal service as described in 820-13, 0168-Service-Mgmt [6].

To obtain ionosphere calibrations for a delta-DOR track, the mission makes an initial request for this service through the MIM. Then, for each tracking pass, the DSN engineering team deposits a 'DeltaDOR Schedule File' to the SPS, and then the SPS provides a 'DeltaDOR Schedule File' to the Radio Metric Modeling and Calibration (RMC) Subsystem. The 'DeltaDOR Schedule File' provides the quasar names and observing sequence in the format specified by DSN internal interface 820-016, 0389-GIMCAL-SPS [10]. The delivery of this file triggers the generation of ionosphere calibrations by the RMC Subsystem. The SPS updates the DeltaDOR Schedule File if the schedule changes.

## 3.2 DSN-TO-MISSION

All calibrations are delivered as files. The file transfer protocols are Secure File Transfer Protocol (SFTP) and Secure Shell (SSH). Access requires users to have proper network and authentication configuration to the DSN flight operations and Jet Propulsion Laboratory (JPL) networks. The customer obtains access authorization through the MIM.

### 3.2.1 Celestial Reference Frame

The celestial reference frame is documented in 810-005, Module 107 [11]. It is updated periodically to reflect improvements in the source positions and add new radio sources.

### 3.2.2 Station Coordinates

DSN station coordinates are available in 810-5, Module 301 [12].

### 3.2.3 Earth Orientation Parameters

The DSN provides the EOP data in the format specified by 820-013, TRK-2-21 [3].

EOP files are produced daily. The mission negotiates the data delivery time and frequency with the MIM if delivery at different intervals or times is needed. The EOP file can be obtained through the following locations, where access is restricted to authorized users.

- DSN server at oscarx.fltops.jpl.nasa.gov
- JPL web page at: https://eop.jpl.nasa.gov for JPL mission
  http://keof.jpl.nasa.gov for non-JPL mission

### 3.2.4 Ionosphere and Troposphere Calibrations

The DSN generally provides ionosphere and troposphere calibrations according to 820-013, TRK-2-23 [4]. If requested, the DSN provides them according to CCSDS compliant (503.0-B-1 TDM [2]) 820-013, 0212-Tracking-TDM [8]. The ionosphere calibrations are spacecraft dependent and cover each view period. The troposphere calibrations are spacecraft independent and cover all 24 hours of each day at each DSCC.

Media calibrations that have been visually validated by the DSN are delivered at daily-to-weekly intervals. "Quick-look" calibrations that have not been validated in this way are delivered daily. The customer may negotiate more frequent deliveries during critical periods with the MIM. Media calibration files can be obtained through the DSN server at oscarx.fltops.jpl.nasa.gov.

### 3.2.5 DSN Timing

The DSN provides timing calibration data according to 820-013, 0220-Tracking-FTS [9]. DSN timing calibration files are usually produced 2 to 3 times per week. Each file contains data for the last 10 days and 2 days in advance based on the prior observations. The DSN timing calibration file can be obtained through the following locations, where access is restricted to authorized users.

- DSN server at oscarx.fltops.jpl.nasa.gov
- Non-JPL web page at https://dsnweb.jpl.nasa.gov/zend/fts/.

## 3.3 AVAILABILITY IN CONTINUITY OF OPERATION PLAN (COOP) ENVIRONMENT

The DSN Continuity of Operations Plan (COOP) provides plans and tools needed to ensure continued spacecraft tracking operations during a natural disaster or other catastrophic event that disables JPL facilities, as described in 810-007, Module 203 [14].

DSN calibration and modeling services are not available in the COOP environment.

# *Appendix A - Abbreviations*

| | |
|---|---|
| IAU | International Astronomical Union |
| CCSDS | Consultative Committee for Space Data Systems |
| COOP | DSN Continuity of Operations |
| DEC | Declination |
| DSCC | Deep Space Communications Complex |
| DOR | Differential One-way Range |
| DSN | Deep Space Network |
| DSS | Deep Space Station |
| Delta-DOR | Delta Differential One-way Range |
| ECC | Emergency Control Center |
| EOP | Earth Orientation Parameter |
| GIMCAL | Global Ionospheric Model-Based Calibration |
| GIMs | Global Ionospheric Maps |
| GLONASS | Global Navigation Satellite System |
| GNSS | Global Navigation Satellite System |
| GPS | Global Positioning System |
| IP | Internet Protocol |
| JPL | Jet Propulsion Laboratory |
| LLR | Lunar Laser Ranging |
| MIM | Mission Interface Manager |
| NCEP | National Center for Environmental Prediction |
| NOAA | National Oceanic and Atmospheric Administration |
| OEM | Orbit Ephemeris Message |
| PMX | X Coordinate of Polar Motion |
| PMY | Y Coordinate of Polar Motion |
| RA | Right Ascension |
| RMC | Radio Metric Modeling and Calibration Subsystem |
| SFTP | Secure File Transfer Protocol |
| SLR | Satellite Laser Ranging |
| SMS | Service Management Services |
| SPS | Service Preparation Subsystem |
| SSH | Secure Shell |
| TCP | Transmission Control Protocol |
| TDM | Tracking Data Message |
| USNO | United States Naval Observatory |
| UTC | Universal Time Coordinated |
| VLBI | Very Long Baseline Interferometry |