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DSN ODF (Orbit Data File) Calibration Software:
Ranging Level 1b to Level 2
Software Design Specifications

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Prepared by

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Martin Pätzold

Approved by

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Martin Pätzold (MaRS Principal Investigator)

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Document Change Record

Issue	Rev	Sec	Date	Changes	author
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1	1	2.2.2 2.2.3 3	24.10.2004	2220 revised 2240 new 1150 new Section 3 completely revised New output file formats	mpa
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ACRONYMS

A/D	Analog/Digital
AGC	Automatic Gain Control
AGVTP	Archive Generation, Validation and Transfer Plan
AOL	Amplitude Open Loop
ATDF	Archival Tracking Data Format
CD-ROM	Compact Disk - Read Only Memory
CL	Closed-Loop
DDS	Data Delivery System
DSN	Deep Space Network
DVD	Digital Versatile Disk
ESA	European Space Agency
ESOC	European Space Operation Center
ESTEC	European Space Technology Center
FOL	Frequency Open Loop
G/S	Ground Station
HGA	High Gain Antenna
IFMS	Intermediate Frequency Modulation System
JPL	Jet Propulsion Laboratory
LCP	Left Circular Polarization
LGA	Low Gain Antenna
LOS	Line Of Sight
MaRS	Mars Express Radio Science Experiment
MGA	Medium Gain Antenna
MGS	Mars Global Surveyor
NASA	National Aeronautics and Space Administration
ODF	DSN Original Data File
ODR	Original Data Record
OL	Open-Loop
ONED	one-way dual-frequency mode
ONES	One-way single-frequency mode
PDS	Planetary Data System
POL	Polarization Open Loop
RCP	Right Circular Polarization
RSR	Radio Science Receiver
RX	Receiver
S/C	Spacecraft

SIS	Software Interface Specification
S-TX	S-Band Transmitter
SPICE	Space Planet Instrument C-Matrix Events
TBC	To Be Confirmed
TBD	To Be Determined
TWOD	Two-way dual-frequency mode
TWOS	Two-way single-frequency mode
USO	Ultra Stable Oszillator
X-TX	X-band Transmitter

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1 INTRODUCTION

1.1 SCOPE

This document specifies the requirements for the development of the Orbit data File (ODF) calibration software, transferring Level 1b ODF data towards Level 2. The software shall analyze radio ranging tracking data recorded at the DSN ground stations.

1.2 REFERENCED DOCUMENTS

	Reference Number	Title	Issue Number	Date
[1]	MEX-MRS-IGM-IS-3016	Radio Science File naming Convention	9.6	22.10.2004
[2]	TRK-2-18	Orbit Data File Interface	change 3	15.06.2000
[3]	MEX-MRS-IGM-DS-3037	ODF Processing Software: L1a to L1b	3.2	23.10.2004

1.3 SOFTWARE CONFIGURATION CONTROL

This document addresses the software package

DSN_ODF_PROC_RNG_L1B_TO_L02
Version 1.0

After release, the software is under configuration control which will be documented in this section.

Version number	Changes/Action	New version	Release date

1.4 ACTION ITEM LIST

Action item	Description	Due date	actioneer	closed
1	Correct range output format	04.04.2005	MF	Closed
2	Create web interface to select individually tracking ranges from the L1B input file	04.04.2005	MF/TA	Closed
3	Include Data Flow Diagram	04.05.2005	MF/TA	
4	Observe new L1b input format	04.05.2005	MF	

2 SPECIFICATIONS FOR LEVEL 1B TO LEVEL 2 CALIBRATION

2.1 MAIN PROGRAM SPECIFICATIONS

2.1.1 General specifications

ODFRNG-SPEC-2110: This software shall

- Read Level 1b ODF data
- Apply Earth troposphere calibration to the range data
- Compute differential range values if two frequencies are available
- Apply plasma calibration to the range data by using differential frequency data
- Apply the range predicts in order to compute residuals
- Output the results as level 2 data
- Generate PDS label files for the output files

ODFRNG-SPEC-2120: the software language is FORTRAN.

ODFRNG-SPEC-2122: The kind of data processing as
(a) gravity,
(b) solar corona

is selected via a web interface.

2.1.2 Definition of constants

ODFRNG-DEF-2130: ASTRONOMICAL UNIT (AU)

1 AU = 149,597,870 kilometers

ODFRNG-DEF-2140: SPEED OF LIGHT

c = 299,792,458 m/s

ODFRNG-DEF-2150: RANGE UNIT (RU)

1 RU = 0.30 m

ODFRNG-DEF-2152: PHYSICAL CONSTANTS

Constant		Value	SI units
Electron charge	e	$1.6022\ 10^{-19}$	A s
Electron mass	m_e	$9.1094\ 10^{-31}$	kg
Electric field constant	ε_0	$8.8542\ 10^{-12}$	$s^4\ A^2\ m^{-3}\ kg^{-1}$
Plasma constant	$\frac{1}{2}\frac{1}{4\pi^2}\frac{e^2}{m_e\varepsilon_0}$	40.30924	$m^3\ s^{-2}$

ODFRNG-DEF-2160: CARRIER FREQUENCIES Mars Express

Mars Express:

frequency band	uplink	downlink
S-band	2114.676 MHz	2296.482 MHz
X-band	7116.936 MHz	8420.432 MHz

ODFRNG-SPEC-2170: Transponder constants and ratios

Mars Express:

frequency band uplink	transponder ratios downlink/uplink	
	S-band	X-band
S-band	240/211	880/211
X-band	240/749	880/749

ODFRNG-SPEC-2180: Transponder delay values
This is defined as Table TRANSPONDER_CAL

Transponder 1: at 25°C Temperature

frequency band uplink	transponder range delay (nanoseconds)	
	S-band	X-band
S-band	2025	2013
X-band	2018	2010

Transponder 2:

frequency band uplink	**transponder range delay (nanoseconds)**	
	S-band	**X-band**
S-band	2032	2015
X-band	2025	2015

ODFRNG-DEF-2190: DSN station range calibration
The ODF range values Level 1b are already calibrated with respect to the equipment delay and the antenna z-correction.

2.2 INPUT FILES

2.2.1 Data file types

ODFRNG-SPEC-2210: the following table defines the input file types and the logical file names used in this specification and within the software:

File Description	Logical name within program
S-band ranging	ODF_RNG_S
X-band ranging	ODF_RNG_X
DSN Media calibration	DSN_MET_MOD
Doppler and range predict file	PREDICT_FILE

ODFRNG-SPEC-2212: input file names will be accepted via a Windows interface.

2.2.2 File names

ODFRNG-SPEC-2220 Level 1b file names are defined in [1] section 4.1

For the range files:

r00ODF0L1B_RNS_yydddhhmm_qq.TAB
r00ODF0L1B_RNX_yydddhhmm_qq.TAB

for the meteorological file:

rggDSN0L1B_MET_yydddhhmm_qq.TAB

For the predicit file:

rggUNBWL02_RTW_yydddhhmm_qq.TAB

2.2.3 File formats

ODFRNG-SPEC-2230: File formats are defined in [1] and [3].

ODFRNG-SPEC-2240: DSN station ID
A DSN ODF file contains data of several days and from different DSN ground stations.

DSN station: the DSN station ID is stored in column 6 of ODF_RNG_S and ODF_RNG_X. It is transferred as DSN_STATION_ID to M_RANGE_OUTPUT and used to create the output file name defined in ODFRNG-SPEC-2760

ODFRNG-SPEC-2050: selection of DSN tracking times
A DSN ODF file contains data of several days and from different DSN ground stations.
One or more input data time ranges from one or several specific and individual DSN ground stations are selected via a web-interface. Only these data are read in, analyzed according to this specification and transferred to M_RANGE_OUTPUT.
As many output files are created as many individual tracking time ranges have been selected. The start date and time of the input data are used as the time in the output file name defined in ODFRNG-SPEC-2760.
The individual tracking time ranges are selected in Modul M_TRACKING_TIME and specified in ODFRNG-SPEC-2310.

2.3 LEVEL 1B TO LEVEL 2 SOFTWARE SPECIFICATIONS

2.3.1 MODULE M_PREDICT

PREDICT accepts two Doppler predict files: (a) the predict file PREDICT_FILE considering all possible perturbing forces like the best known gravity field and radiatation pressure and (b) the predict file considering radiation pressure and the gravity field up to degree and order 10 PREDICT_FILE_10. PREDICT interpolates for a given time stamp between the predicted or reconstructed parameters and returns a predicted or reconstructed parameter for each observed time stamp. This is done for each frequency band.
PREDICT will also being used for the reconstructed orbit file, replacing then PREDICT_FILE in the processing.

ODFRNG-SPEC-2210: PREDICT accepts input data from PREDICT_FILE and PREDICT_FILE_10 with the file name format defined in [1] section 8.1 or in [1] section 8.2 for the predicted orbit or the reconstructed orbit file, respectively. PREDICT_FILE is either a two-way or an one-way file, PREDICT_FILE_10 is always a two-way file.

ODFRNG-SPEC-2220: PREDICT accepts predicted Doppler data from PREDICT_FILE and PREDICT_FILE_10 (file name specified in ODFRNG-SPEC-2210) formatted as defined in [1] section 8.1 or or in [1] section 8.2 for the predicted orbit or the reconstructed orbit file, respectively.

ODFRNG-SPEC-2225: PREDICT_FILE and PREDICT_FILE_10 cover tbd days of data. Predicts or orbit reconstruction shall be provided

- at steps of one degree true anomaly along the planetary orbit.
- At steps of one hour for the interplanetary cruise phase

ODFRNG-SPEC-2230: PREDICT accepts from DOPPLER the array TIME_DOPPLER representing the observed Doppler time stamps. PREDICT interpolates between each predicted or reconstructed parameter of PREDICT_FILE and PREDICT_FILE_10 for each observed time stamp given as TIME_DOPPLER. This is done for each frequency band.

ODFRNG-SPEC-2240: The interpolated results will be available as the arrays DOPPLER_PRE and DOPPLER_PRE_10 for subroutine RESIDUAL_DOPPLER. The arrays are transferred to the subroutine DOPLLER_OUTPUT and are stored in column 7 and 8, respectively. This is done for each frequency band.

2.3.2 Modul M_TRACKING_TIME

ODFRNG-SPEC-2310 : ordering of input files
A DSN ODF file contains data of several days and several DSN antennas. The input files ODF_RNG_X and ODF_RNG_S are ordered sequentially after

1. Ground station
2. recording time
3. sample rate

ODFRNG-SPEC-2320: selection of tracking times
The number of DSN activities, the ground stations and associated tracking times are selected via a web interface.

ODFRNG-SPEC-2330: output files
For each selected individual activity an output file is created (for each downlink frequency). The format of the output files is specified in ODFRNG-SPEC-2780 and 2781.

2.3.3 Module M Range

2.3.3.1 Subroutine Calibration

RANGE_CALIBRATION uses as calibrations the media propagation delay in the Earth troposphere and the path propagation delay through the plasma.

ODFRNG-SPEC-2610: Troposheric calibration

The path delay (unit is meter) of the dry and wet component of the Earth troposphere is (Hofmann-Wellenhoff et al., Global Positioning System, 4th Ed.):

$$\Delta_{dry}(E) = \frac{10^{-6}}{5}\frac{77.64\frac{p}{T}}{\sin\left(\sqrt{E^2+6.25}\right)}\left[40136+148.72(T-273.16)\right]$$
$$\Delta_{wet}(E) = \frac{10^{-6}}{5}\frac{-12.96T+3.718\cdot 10^5}{\sin\left(\sqrt{E^2+2.25}\right)}\frac{e}{T^2}11000 \qquad (1.1)$$

where *p*, *T* and *e* are the atmospheric pressure, Temperature and humidity, respectively, as observed at the ground station site. These values are given in the DSN_MEDIA file. The elevation angle *E* (unit in degrees) is provided by PREDICT_FILE.

The total tropospheric calibration expressed as delay time in seconds is:

$$\tau_{tropo} = \frac{1}{c}\left\{\Delta_{dry}(E)+\Delta_{wet}(E)\right\} \qquad (1.2)$$

where *c* is the speed of light with definition given in ODFRNG-DEF-1020.

ODFRNG-SPEC-2620: plasma calibration

Let

$$\delta\tau = \tau_S - \tau_X = \frac{1}{2}\frac{1}{4\pi^2}\frac{e^2}{m_e\varepsilon_0}\frac{1}{c}\left\{\frac{1}{f_S^2}-\frac{1}{f_X^2}\right\}I$$

be the differential range, where I is the total electron content and fs and fx are the downlink carrier frequencies as defined in ODFRNG-DEF-2160. Then

$$I = c\left[\frac{1}{2}\frac{1}{4\pi^2}\frac{e^2}{m_e\varepsilon_0}\right]^{-1}\left\{\frac{1}{f_S^2}-\frac{1}{f_X^2}\right\}^{-1}\delta\tau$$

ODFRNG-SPEC-2621: plasma correction

The plasma correction for each frequency band is then

$$\tau_{plasma,S} = \frac{1}{2c}\frac{1}{4\pi^2}\frac{e^2}{m_e\varepsilon_0}\frac{1}{f_S^2}I$$

$$\tau_{plasma,X} = \frac{1}{2c}\frac{1}{4\pi^2}\frac{e^2}{m_e\varepsilon_0}\frac{1}{f_X^2}I$$

ODFRNG-SPEC-2625: relativistic group delay calibration

If no dual frequency measurements using the differential method are performed the ranging data must be corrected for the effects of the theory of General Relativity (GRT). Figure 2.3-1 shows the geometric constellation relevant for our analysis.

Assuming a generalized Schwarzschild metric (where γ is the PPN parameter of General Relativity) the subroutine S_EINSTEIN calculates the additional two way delay $\tau_{einstein}$ caused by the gravity field of the sun by the following expression:

$$\tau_{\text{einstein}} = \frac{4GM}{c^3}\left[\frac{1+\gamma}{2}\ln\left(\frac{r_e + r_p + \rho}{r_e + r_p - \rho}\right)\right]$$

ρ, r_e and r_p are the coordinate distances between G/S and planet (satellite), the heliocentric distance of the G/S and the heliocentric distance of the planet (satellite), whereby *γ* is set to 1.0, because of the fact that $v_{s/c}$ is neglectible with rexpect to $c_{\text{speed of light}}$.

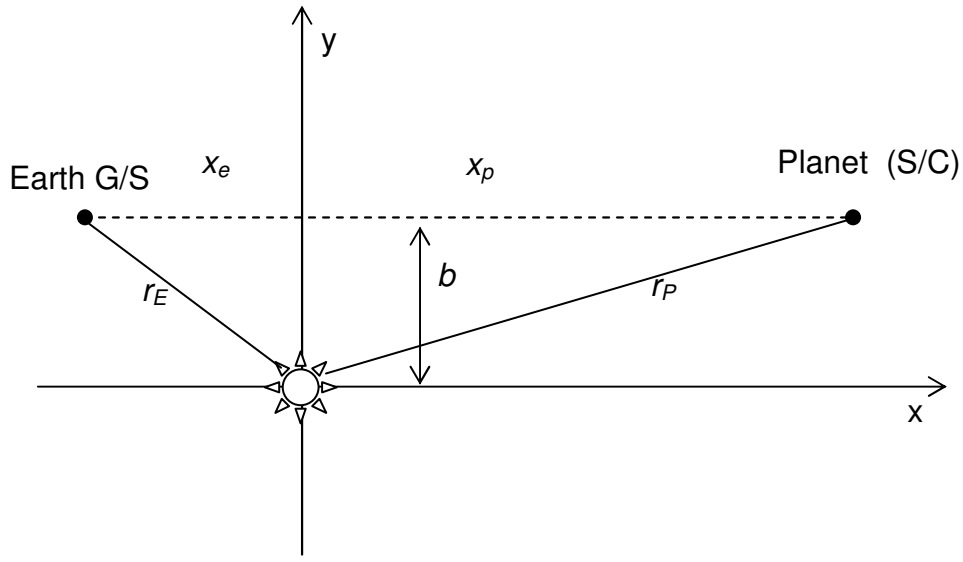

Figure 2.3-1:Radar echo at planet P (S/C)

ODFRNG-SPEC-2630: total calibration

The calibrated RTLT $\tau_{calibrated}$ is the observed RTLT τ minus the transponder delays defined in Table TRANSPONDER_CAL minus the tropospheric calibration defined in ODFRNG-SPEC-2610 minus the plasma correction defined in ODFRNG-SPEC-2621 minus the relativistic calibration defined in ODFRNG-SPEC-2622:

$$\tau_{calibrated} = \tau - \tau_{transponder} - \tau_{tropo} - \tau_{iono} - \tau_{einstein} \quad (1.3)$$

The DSN equipment path delay and the antenna z-correction are already substracted from the observed values. The ODF provides corrected values in this regard.

2.3.3.2 Subroutine RANGE_RESIDUAL

RANGE_RESIDUAL computes for each frequency band the ranging residuals, expressed as propagation time, between the observed TWLT and the predicted TWLT.

ODFRNG-SPEC-2640: RANGE_RESIDUAL accepts predicted RTLT as interpolated from PREDICT_FILE in MODULE PREDICT from the given array TIME_RANGE.

ODFRNG-SPEC-2645: RANGE_RESIDUAL computes the range residuals (range delay) at S-band or X-band expressed as residual in the round-trip-light time τ

$$\Delta\tau = \tau_{calibrated} - \tau_{predicted} \quad (1.4)$$

3 OUTPUT FILES

3.1 SUBROUTINE RANGE_OUTPUT

ODFRNG-SPEC-2760: The RANGE_OUTPUT file name is defined as

rggODF0L02_sss_yydddhhmm_qq.TAB

gg = DSN_STATION_ID as selected from the input file ODFRNG-SPEC-2240

yydddhhmm = start of output data time range as selected from the input data file

Table 3-1: file name parameter

Acronym	Description	Examples
r	Spacecraft (Raumsonde) name R = Rosetta M = Mars Express V = Venus Express	M
gg	Ground station ID: DSN complex Canberra 34 = 34 m BWG 43 = 70 m 45 = 34 m HEF DSN complex Goldstone: 14 = 70 m 15 = 34 m HEF 24 = 34 m BWG 25 = 34 m BWG 26 = 34 m BWG 27 = 34 m HSBWG DSN complex Madrid: 54 = 34 m BWG 55 = 34 m BWG 63 = 70 m 65 = 34 m HEF	43
tttt	data source identifier Level 2 ODF0 = DSN ODF closed-loop file	TNF0
lll	Data archiving level L02 = Level 2	L1a
sss	data type data level 2: RGS calibrated S-band ranging file	

	RGX calibrated X-band ranging file	
yy	Year	04
ddd	Day of the year	153
hhmm	Sample hour , minute (Start time)	1135
qq	Sequence or version number	01
eee	.TAB ASCII data files	

ODFRNG-SPEC-2780: The format of the X-band RANGE_OUTPUT file is defined in Table 3-2: .
If only one frequency is available for range observations, the differential TWLT is set to -99999.9.

column	description	unit	resolution
1	Sample number		
2	Ground received time *as UTC in ISO format*		
3	Ground received time *as UTC in fractions of day of year starting with the first day of the year the data was recorded at 00:00.000*	days	10^{-10} days
4	Ground received time *as elapsed terrestrial barycentric dynamic time (TDB) time since noon of the first calendar day of year 2000 (12:00 1 January 2000 TDB)*	sec	10^{-6} sec
5	Geometric impact parameter *<u>Propagation experiments:</u> approximate value of the closest approach of a downlink geometric ray path to the center of the reference body (Sun, planet, minor object). When two-way, the value is approximate average of uplink and downlink rays* *<u>Gravity observations:</u> geometric distance of the s/c from the center of mass of referenced body*	km	10^{-3} m
5	Observed TWLT X-band	Seconds	0.1 nsec
6	calibrated TWLT X-band *corrected for the propagation in the Earth atmosphere, ionospshere and interplanetary plasma propagation*	Seconds	0.1 nsec
7	TWLT delay X-band *Total correction applied to column 6*	nsec	0.1 nsec
8	Differential TWLT *Computed from the S-band and X-band calibrated range in column 6* $\tau_S - \tau_X$ *If neither S-band or X-band is available the value is set to -99999.9*	nsec	0.1nsec
9	Range calibration G/S equipment *Measured propagation delay of the*	nsec	0.1 nsec

	ground station equipment during pre- and/or post-pass calibration. *For the ODF this value is already containe din the value of column 5 and 6 and there set to -99999.9*		

Table 3-2: Definition of X-band RANGE_OUTPUT file format

ODFRNG-SPEC-2781: The format of the S-band RANGE_OUTPUT file is defined in .

If only one frequency is available for range observations, the differential TWLT is set to -99999.9.

column	description	unit	resolution
1	Sample number		
2	Ground received time *as UTC in ISO format*		
3	Ground received time *as UTC in fractions of day of year starting with the first day of the year the data was recorded at 00:00.000*	days	10^{-10} days
4	Ground received time *as elapsed terrestrial barycentric dynamic time (TDB) time since noon of the first calendar day of year 2000 (12:00 1 January 2000 TDB)*	sec	10^{-6} sec
5	Geometric impact parameter *Propagation experiments: approximate value of the closest approach of a downlink geometric ray path to the center of the reference body (Sun, planet, minor object). When two-way, the value is approximate average of uplink and downlink rays* *Gravity observations: geometric distance of the s/c from the center of mass of referenced body*	km	10^{-3} m
5	Observed TWLT S-band	Seconds	0.1 nsec
6	calibrated TWLT S-band *corrected for the propagation in the Earth atmosphere, ionospshere and interplanetary plasma propagation*	Seconds	0.1 nsec
7	TWLT delay S-band *Total correction applied to column 6*	nsec	0.1 nsec
8	Differential TWLT *Computed from the S-band and X-band calibrated range in column 6* $\tau_S - \tau_X$ *If neither S-band or X-band is available the value is set to -99999.9*	nsec	0.1nsec
9	Range calibration G/S equipment *Measured propagation delay of the*	nsec	0.1 nsec

	ground station equipment during pre- and/or post-pass calibration. *For the ODF this value is already contained in the value of column 5 and 6 and there set to -99999.9*		

Table 3-3: Definition of X-band RANGE_OUTPUT file format