

# ***ROSETTA***

# ***MARS EXPRESS***

# ***VENUS EXPRESS***

## **Radio Science Experiments**

## **RSI / MaRS / VeRa**

### IFMS Ranging Processing and Calibration Software: Level 1a 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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## 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
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

## Contents

<b>1</b>	<b>INTRODUCTION</b> .....	<b>12</b>
1.1	Scope .....	12
1.2	Referenced Documents.....	12
1.3	Software Configuration Control.....	12
1.4	Action Item List.....	13
<b>2</b>	<b>MAIN PROGRAM SPECIFICATIONS</b> .....	<b>15</b>
2.1	Modules .....	15
2.2	Input Files.....	16
2.2.1	Data file types.....	16
2.2.2	File names.....	16
2.2.3	File formats.....	16
2.3	Definition of constants.....	17
2.4	Flow Diagram .....	19
<b>3</b>	<b>SPECIFICATIONS OF MODULES</b> .....	<b>20</b>
3.1	Module M_PREDICT.....	20
3.2	MODULE M_READ_INPUT_DATA.....	21
3.3	Module M_RTLT .....	22
3.4	Module M_Calibration.....	23
3.5	MODULE M_IONO_CAL.....	26
3.6	Module M_OUTPUT.....	30
3.7	RANGE Calibration output .....	35
3.8	RANGE LOGFILE output .....	36
<b>4</b>	<b>PERL GRAPHICAL USER INTERFACE PERL_FIMS.PL</b> .....	<b>38</b>
<b>5</b>	<b>ANNEX A</b> .....	<b>41</b>

<b>5.1</b>	<b>MEX transponder Group Delay values .....</b>	<b>41</b>
<b>6</b>	<b>ANNEX B .....</b>	<b>43</b>
<b>6.1</b>	<b>Earth Klobuchar Ionosphere Model .....</b>	<b>43</b>
<b>7</b>	<b>ANNEX C .....</b>	<b>45</b>
<b>7.1</b>	<b>Klobuchar File Format Description .....</b>	<b>45</b>

# 1 INTRODUCTION

## 1.1 SCOPE

This document specifies the requirements for the development of the IFMS ranging processing software, transferring Level 1a IFMS range data towards Level 2. The software shall analyze radio ranging tracking data, recorded at the IFMS receiving systems of the ground stations New Norcia (NNO). AGC and meteo data are handled via the IFMS labeling software.

## 1.2 REFERENCED DOCUMENTS

	Reference Number	Title	Issue Number	Date
[1]	MEX-MRS-IGM-IS-3016 ROS-RSI-IGM-IS-3087 VEX-VRA-IGM-IS-3009	Radio Science File naming Convention	5.1	17.07.2003
[2]	IFMS_OCCFTP_10_3_1.PDF	IFMS-to-OCC	9.3	
[3]	M32ESOCL1B_RCL_030522_00.PDF	MEX transponder Group delay values	1.0	17.02.2003
[4]	VEX-VERA-UBW-TN-3040	Reference Systems and Techniques Used for the Simulation and Prediction of Atmospheric and Ionospheric Sounding Measurements at Planet Venus	3.2	12.11.2003

## 1.3 SOFTWARE CONFIGURATION CONTROL

This document addresses the software package

### IFMS\_PROC\_RNG\_L1A\_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	

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## 2 MAIN PROGRAM SPECIFICATIONS

The software shall read the IFMS level 1a range data either at S-band or X-band depending on the used uplink frequency band, and computes from the delay the RTLT. The RTLT will be calibrated and range residuals will be computed using the predicted RTLT from subroutine PREDICT.

### 2.1 MODULES

The MAIN program consists of a number of modules:

1. M\_READ\_INPUT\_DATA
2. M\_PREDICT
3. M\_GOLBAL\_VAR
4. M\_RTLT
5. M\_OUTPUT
6. M\_CALIBRATION with M\_IONO\_CAL
7. M\_RANGE\_CALC
8. M\_RANGE\_OUTPUT

and a lot of utility modules:

9. M\_WIN\_UTILITY
10. M\_INTERPOL
11. M\_SEARCH
12. M\_FILE\_MOD
13. M\_FILE\_UTILITIES
14. M\_ERROR
15. M\_READ\_HEADER
16. M\_LABEL
17. M\_LabelNameIFMS
18. M\_FileNamingConvention
19. M\_SPICE

The flow diagram is shown in section 2.1.4.

## 2.2 INPUT FILES

### 2.2.1 Data file types

**IFMS-SPEC-2210:** the following table defines the input file types and the logical file names used in this specification and within the program:

File type	Logical name within program
IFMS level 1a range X-band	IFMS_RANGE
SPICE Kernels	SPICE_MEX_S/C SPICE_NNO_G/S
Range calibration file	IFMS_RANGE_CAL
Transponder calibration table	TRANSPONDER_CAL Defined in IFMS-DEF-1040
Geometric G/S calibration	GS_GEO_CAL Defined in IFMS-DEF-1050
IFMS Meteo file level 1b	IFMS_METEO
IFMS AGC file level 1b	IFMS_AGC
Klobuchar coefficients for Earth ionosphere calibration	ION_COEFF

### 2.2.2 File names

**IFMS-SPEC-2220:** File names of IFMS\_RANGE are defined in [2] and in [1] section 5.2

**IFMS-SPEC-2221:** File names of RANGE\_CAL, IFMS\_METEO, IFMS\_AGC are defined in [1] section 4.1

**IFMS-SPEC-2222:** File names of the SPICE kernels are defined in [1] section 11.

### 2.2.3 File formats

**IFMS-SPEC-2230:** File formats are defined in [2], in [1] in section 5.2, section 8 and section 9



## 2.3 DEFINITION OF CONSTANTS

### IFMS-DEF-1010: ASTRONOMICAL UNIT (AU)

$$1 \text{ AU} = 149,597,870 \text{ kilometers}$$

### IFMS-DEF-1020: SPEED OF LIGHT

$$c = 299,792,458 \text{ m/s}$$

### IFMS-DEF-1030: 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

### IFMS-DEF-1031: Transponder coherency 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

**IFMS-DEF-1040:** Transponder group delay values [3]. See also Annex A (4.1). This is defined as Table TRANSPONDER\_CAL

### Mars Express

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

**IFMS-DEF-1050:** Ground station geometric calibration

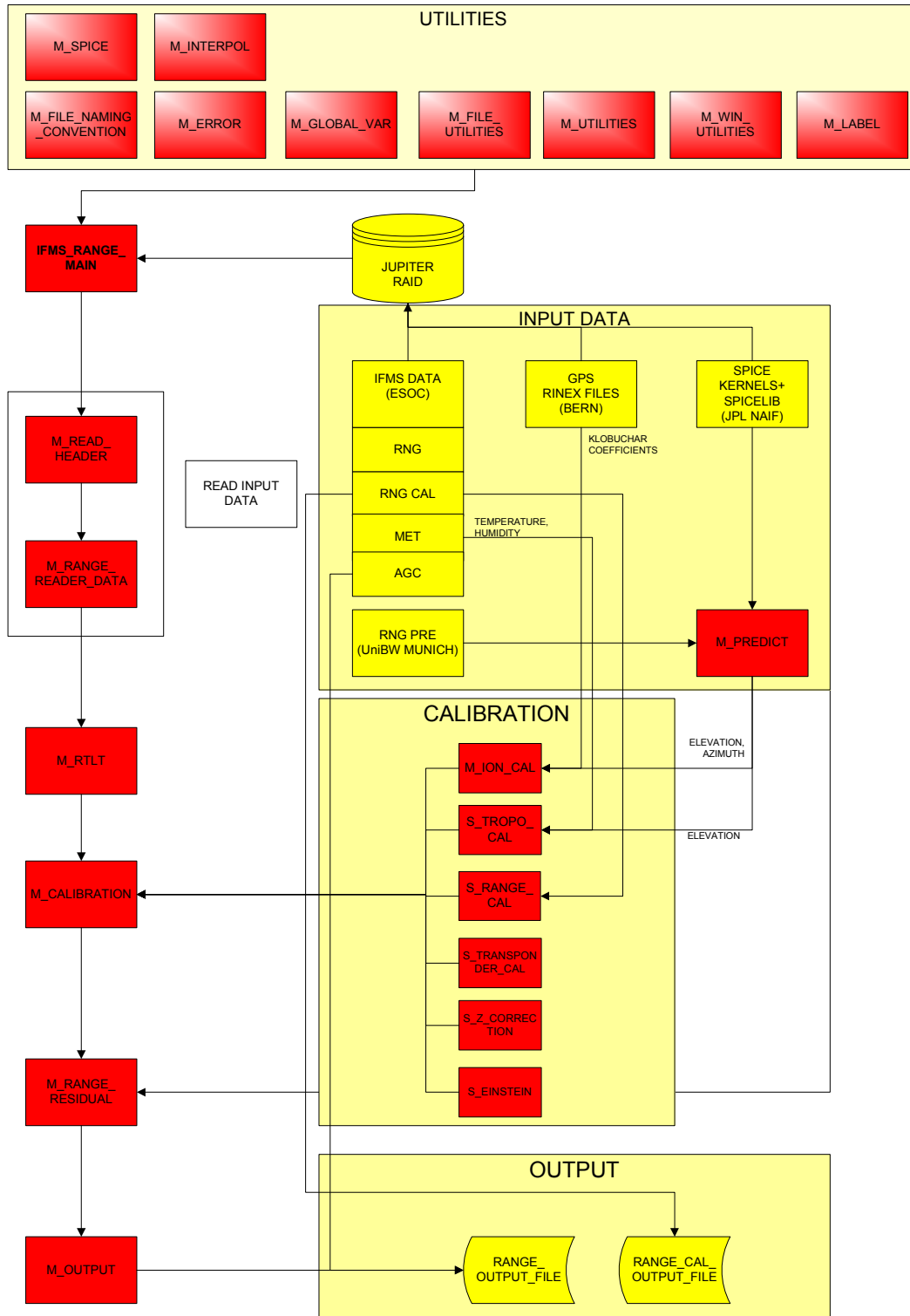
This is defined as GS\_GEO\_CAL

These values have to be subtracted from the measured calibration

### New Norcia

frequency band uplink	Ground station geometric calibration	
	S-band	X-band
S-band	59.47 nsec	59.77 nsec
X-band	59.58 nsec	59.87 nsec

## 2.4 FLOW DIAGRAM



### 3 SPECIFICATIONS OF MODULES

#### 3.1 MODULE M\_PREDICT

M\_PREDICT accepts the SPICE Kernels for the MEX spacecraft and the NNO ground station. PREDICT estimates for the given time stamp TIME\_RANGE the predicted range or OWLT and the ground station antenna elevation angles ELEVATION.

**IFMS-SPEC-2210:** M\_PREDICT accepts input data from the SPICE kernels SPICE\_MEX\_S/C and SPICE\_NNO\_G/S.

**IFMS-SPEC-2230:** M\_PREDICT accepts from Modules M\_READ\_INPUT\_DATA the array TIME\_RANGE, representing the observed range time stamps. M\_PREDICT computes the estimated OWLT using SPICE.

**IFMS-SPEC-2240:** The result will be available as the array RANGE\_PRE for modules M\_RTILT, M\_CALIBRATION and M\_DOPPLER\_OUTPUT.

**IFMS-SPEC-2250:** M\_PREDICT computes the ground station elevation angles for each time stamp TIME\_RANGE. The result will be available as ELEVATION in module M\_CALIBRATION.

### 3.2 MODULE M\_READ\_INPUT\_DATA

READ\_INPUT\_RANGE\_DATA accepts IFMS level 1a range data at X-band or S-band (if available) from IFMS\_RANGE.

All IFMS RANGE data files with equal reference time tags and increasing sequence number are stored in one data array. For these data files only one IFMS RANGE output file is being created with the time stamp of the data file with the lowest sequence number.

**IFMS-SPEC-2310:** READ\_INPUT\_RANGE\_DATA accepts data from IFMS\_RANGE.

**IFMS-SPEC-2320:** The file name format is defined in [1] section 5.2 and [2].

**IFMS-SPEC-2330:** The ranging file format is defined in [2].

**IFMS-SPEC-2340:** Module M\_READ\_INPUT\_DATA extracts the parameter *actual\_tone\_indicator* from the IFMS\_RANGE data header and makes it available for M\_RTTL.

**IFMS-SPRE-2350:** Module M\_READ\_INPUT\_DATA accepts only those data as valid input from IFMS\_RANGE if *current\_code*  $\geq 14$  and *ambiguity* = "TRUE". *Current\_code* is made available for Module M\_RTTL.

**IFMS\_SPEC\_2360:** Module M\_READ\_INPUT\_DATA makes the time information as array TIME\_RANGE available for the module M\_PREDICT.

### 3.3 MODULE M\_RTLT

Module M\_RTLT computes the observed two-way round-trip light time from the actual measurement and the predicted range.

**IFMS-SPEC-2410:** Use the parameter *actual\_tone\_indicator* from the ranging file header (*actual\_tone\_indic*) and compute the actual tone frequency *tone\_freq* from:

$$tone\_freq = actual\_tone\_indic \cdot \frac{17.5 \cdot 10^6}{2^{32}} \text{ Hz}$$

**IFMS-SPEC-2420:** Compute the two-way light time ambiguity *amb* from

$$amb = \frac{2^{current\_code}}{tone\_freq} \text{ sec}$$

*Current\_code* is extracted from the IFMS\_RANGE file and shall be greater equal 14.

**IFMS-SPEC-2430:** The two-way light time is the sum of the measured *delay* and *n* times the ambiguity. The value *n* needs to be determined from an estimate of the OWLT:

$$n = \text{int} \left\{ \left[ \frac{\tau_{predicted, two-way} - delay}{amb} \right] \right\} + 1$$

*n* is an integer and is the predicted TWLT provided by Module M\_PREDICT for the observed time stamp.

**IFMS-SPEC-2440:** Compute the RTLTL from

$$\tau = n \cdot amb + delay$$

### 3.4 MODULE M\_CALIBRATION

Module M\_CALIBRATION uses the range calibration data obtained from the equipment propagation delay measurements before the tracking pass. The data are provided in IFMS\_RANGE\_CAL. An average calibration value and its r.m.s is computed. These calculated values together with the measured propagation delay are written into a RANG\_CAL\_OUTPUT outputfile with an appropriate PDS label. The format is specified in IFMS-SPEC-2730.

Further calibrations are the transponder delay time and the media propagation delay in the Earth troposphere and ionosphere.

**IFMS-SPEC-2530:** M\_CALIBRATION accepts range calibration data from IFMS\_RANGE\_CAL.

**IFMS-SPEC-2531:** the file name format is defined in [1] in section 9.

**IFMS-SPEC-2532:** the file format of IFMS\_RANGE\_CAL is defined in [1] in section 9.

**IFMS-SPEC-2540:** range calibration

M\_CALIBRATION computes the average equipment delay  $\langle \tau_{cal} \rangle$  and its standard deviation:

$$\langle \tau_{cal} \rangle = \frac{1}{n} \sum_{i=1}^n \tau_{cal_i}$$

$$\sigma_{cal} = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (\tau_{cal_i} - \langle \tau_{cal} \rangle)^2}$$

Only those data as valid input from IFMS\_RANGE\_CAL are accepted if *current\_code*  $\geq 14$  and *ambiguity* = "TRUE".

**IFMS-SPEC-2550:** transponder delay

The transponder delay time  $\tau_{transponder}$  is provided by the input table TRANSPONDER\_CAL.

**IFMS-SPEC-2555:** Antenna Correction (Z-Correction)

The delay time  $\tau_z$  caused by the G/S antenna geometry is provided by the input table by the input table GS\_GEO\_CAL

**IFMS-SPEC-2560:** Tropospheric 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, 4<sup>th</sup> Ed.):

$$\Delta_{dry}(E) = \frac{10^{-6}}{5} \frac{77.64 \frac{p}{T}}{\sin(\sqrt{E^2 + 6.25})} [40136 + 148.72(T - 273.16)]$$

$$\Delta_{wet}(E) = \frac{10^{-6}}{5} \frac{-12.96T + 3.718 \cdot 10^5}{\sin(\sqrt{E^2 + 2.25})} \frac{e}{T^2} 11000$$

where  $p$ ,  $T$  and  $e$  are the atmospheric pressure, Temperature and partial water vapour pressure, respectively, as observed at the ground station site.

These values are given in the IFMS\_METEO file. The elevation angle  $E$  (unit in degrees) is provided by M\_PREDICT.

The following transformations have to be applied:

	equation (20)	IFMS_METEO	M_PREDICT
<b>pressure <math>p</math></b>	mbar	hPascal	-
<b>Temperature <math>T</math></b>	Kelvin	°Celsius	-
<b>water vapour partial pressure <math>e</math></b>	hPascal	-	-
<b>humidity <math>h</math></b>	-	% humidity	-
<b>elevation <math>E</math></b>	degrees	-	radian

The relation between the water vapour partial pressure and the humidity given in IFMS\_METEO is:

$$e = 6.108 \cdot 10^{-2} \cdot \text{humidity} [\%] \cdot \exp \left\{ \frac{17.393(T - 272.15)}{T - 33.95} \right\}$$

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

$$\tau_{tropo} = \frac{2}{c} \{ \Delta_{dry}(E) + \Delta_{wet}(E) \}$$

where  $c$  is the speed of light with definition given in IFMS-DEF-1020. The factor 2 accounts for the two-way radio link.

**IFMS-SPEC-2565:** ionsospheric calibration  
described in module M\_IONO\_CAL.

**IFMS-SPEC-2566:** 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 3.4.1 shows the geometric constellation relevant for our analysis.

Assuming a generalized Schwarzschild metric (where  $\gamma$  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:



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

$\rho$ ,  $r_e$  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  $\gamma$  is set to 1.0, because of the fact that  $v_{s/c}$  is neglectible with respect to  $c_{\text{speed of light}}$ .

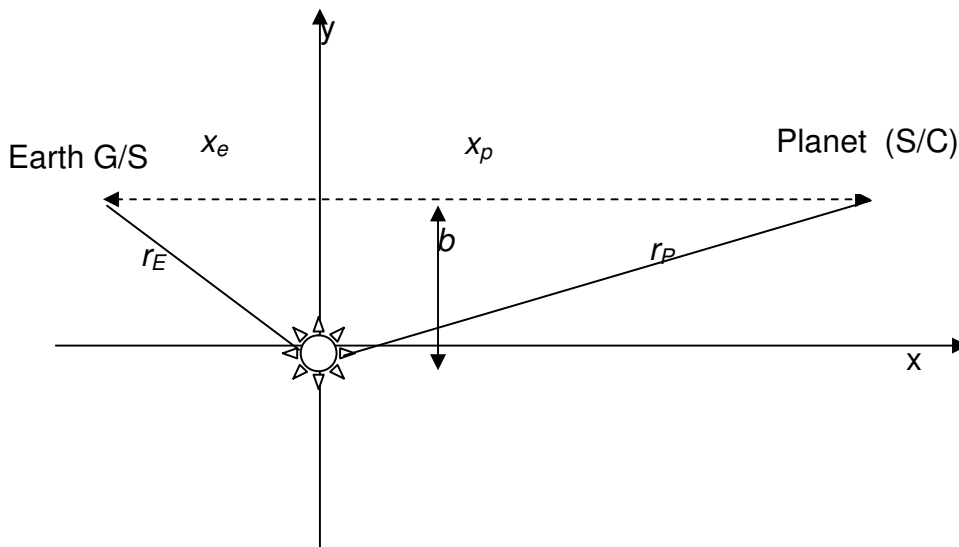


Figure 1: Radar echo at planet P (S/C)

### IFMS-SPEC-2570: total calibration

The calibrated RTLT  $\tau_{\text{calibrated}}$  is the observed RTLT  $\tau$  derived in subroutine RTLT (IFMS-SPEC-2440) minus the average equipment delay  $\langle \tau_{\text{cal}} \rangle$  as derived in IFMS-SPEC-2540 minus the transponder delay  $\tau_{\text{transponder}}$  as defined IFMS-SPEC-2550.

$$\tau_{\text{calibrated}} = \tau - \langle \tau_{\text{cal}} \rangle - \tau_{\text{transponder}} - \tau_z - \tau_{\text{iono}}$$

### 3.5 MODULE M\_IONO\_CAL

Module M\_IONO\_CAL models the electron content of the Earth ionosphere at any local time and pointing direction of the ground station antenna and determines the path delay. This is done using the Klobuchar model introducing the Klobuchar coefficients from GPS measurements of the International GPS Service (IGS). The IGS is based on about 200 globally distributed permanent GPS tracking sites. The coefficients used by Module M\_IONO\_CAL come from one of the seven IGS Analysis Center: the Center for Orbit Determination in Europe (CODE) of the Astronomical Institute of the University of Berne (AIUB), Switzerland.

CODE generates Global ionosphere maps (GIM) on a daily basis using data from about 200 GPS/GLONASS sites of the IGS and other institutions. The vertical total electron content (VTEC) is modelled in a solar-geomagnetic reference frame using a spherical harmonics expansion up to degree and order 15. Piece-wise linear functions are used for representation in the time domain. The time spacing of their vertices is 2 hours, conforming with the epochs of the VTEC maps. Instrumental biases, so-called differential P1-P2 code biases (DCB), for all GPS satellites and ground stations are estimated as constant values for each day, simultaneously with the 13 times 256, or 3328 parameters used to represent the global VTEC distribution. The DCB datum is defined by a zero-mean condition imposed on the satellite bias estimates. P1-C1 bias corrections are taken into account if needed. To convert line-of-sight TEC into vertical TEC, a modified single-layer model mapping (MSLM) mapping function approximating the JPL extended slab model mapping function is adopted. The global coverage of the GPS tracking ground stations considered at CODE is shown figure 3.5.1 including abbreviations for station identification.

GPS Tracking Ground Stations Considered at CODE

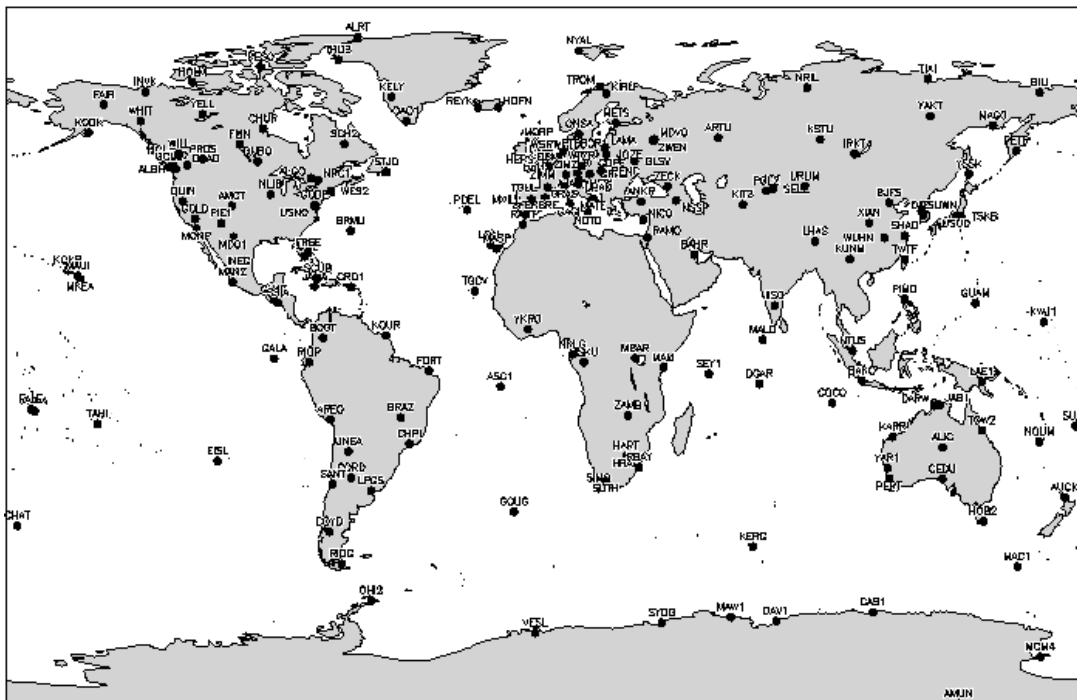


Figure 3.5-2:GPS Tracking Ground Stations

CODE computes Klobuchar-style ionospheric coefficients (alphas and betas) best fitting the IONosphere map EXchange data (IONEX) on a regular basis. The description how the Klobuchar coefficients are computed and on which ionospheric model they are based on can be found in ANNEX B.

The data files containing the Klobuchar coefficients are named CGIMddd0.yyN, where ddd and yy substitute doy and 2-digit year. Those coefficients derived from a final IONEX product are stored under <ftp://ftp.unibe.ch/aiub/CODE/> in yyyy-specific subdirectories as of 1995. For the few days where the final product is not yet available, rapid as well as predicted coefficients serving real-time applications may be found generally at <ftp://ftp.unibe.ch/aiub/CODE/>. CGIM2410.04N R contains the latest set of rapid coefficients; CGIM2420.04N P and CGIM2430.04N P2 contain the current 1-day and 2-day predicted coefficients, respectively.

Unlike the original Klobuchar ionosphere model which is based on a total of 370 possible sets of base coefficients and which is therefore of discrete nature, the model derived by CODE is not subject to a similar restriction. All the night-time TEC level of this type of ionosphere model is hard-wired to 5 nanoseconds of ionospheric delay on the first GPS frequency (corresponding to approximately 9 TECU). Because the Klobuchar-style TEC parameterization may be unpleasant at the polar caps and especially at the poles, CODE displays a corresponding warning in the RINEX navigation data files in case the TEC above a latitude of 75 degrees reaches day-time level. The format of RINEX data files is described in ANNEX C.

**IFMS-SPEC-2610:** Module M\_IONO\_CAL accepts the actual needed Klobuchar coefficients (described above) from input file ION\_COEFF. The input file can be downloaded from

[ftp.unibe.ch/aiub/CODE/](ftp://ftp.unibe.ch/aiub/CODE/)

M\_IONO\_CAL needs several input parameters, which are listed in the table below.

Parameter	Description	Unit
Phi	Geodetic latitude of receiver	Degree
Lambda	Geodetic longitude of receiver	Degree
TOW	Time of Week	Degree
Beta	The coefficients of a cubic equation representing the amplitude of the vertical delay	

Alpha	The coefficients of a cubic equation representing the period of the model	
-------	---	--

**IFMS-SPEC-2615:** The output of Module M\_IONO\_CAL is the ionospheric slant range correction **d\_tau\_iono**. The unit of **d\_tau\_iono** is seconds. The calculation of **d\_tau\_iono** is described in **IFMS-SPEC-2620**.

**IFMS-SPEC-2620:** The computation of the ionospheric slant range correction **d\_tau\_iono** depends on the local time at the ground station side. For the calculation of **d\_tau\_iono** the following parameters are used:

1. **Local Time t:**

$$t = 4.32 \cdot \text{long}_i + \text{TOW}$$

2. **Azimuth a (in radian):**

$$a = \text{azimuth} \cdot \pi / 180$$

3. **Elevation angle e (in semicircles):**

$$e = \text{elev} \cdot 1. / 180$$

4. **Earth Centered angle psi:**

$$\text{psi} = 0.0137 / (e + 0.11) - 0.022$$

5. **Subionospheric longitude long\_i :**

$$\text{long}_i = \text{lambda} \cdot 1. / 180. + (\text{psi} \cdot \text{DSIN}(a) / \text{DCOS}(\text{lat}_i \cdot \pi))$$

6. **Subionospheric latitude lat\_i :**

$$\text{lat}_i = \text{phi} \cdot 1. / 180 + \text{psi} \cdot \text{DCOS}(a)$$

7. **Time of the Week TOW (output of the subroutine S\_GPSTIME)**

$$t = \text{DMOD}(t, 86400.) \quad !$$

8. **Slant factor sf:**

$$\text{sf} = 1. + 16. \cdot (0.53 - e)^3 \quad !$$

9. **Period of model PER:**

If PER less than 72000.D0

PER = 72000.

Else

PER = beta(1) + beta(2) ·lat\_m + beta(3) ·lat\_m<sup>2</sup> +beta(4) ·lat\_m<sup>3</sup>

**10. Phase of the model x (Maximum at 14.00 =! 50400 sec local time):**

$x = 2 \cdot \pi \cdot (t - 50400) / \text{PER}$  !

**11. Amplitude of the model AMP:**

AMP = alpha (1) + alpha (2) ·lat\_m + alpha (3) ·lat\_m<sup>2</sup> +alpha(4) ·lat\_m<sup>3</sup>

**12. Ionospheric slant correction d\_tau\_iono:**

Night (DABS(x) greater Than 1.57):

**d\_tau\_iono = sf · (5.D-9)**

Day:

**d\_tau\_iono 1 = sf · (5.D-9 + AMP\*(1.D0 - x<sup>2</sup>/2. + x<sup>4</sup>/24.))**

### 3.6 MODULE M\_OUTPUT

Module M\_OUTPUT generates the IFMS Range Outputfiles. Within the M\_OUTPUT the subroutine S\_RNG\_OUTPUT computes for each frequency band the ranging residuals, expressed as propagation time, between the observed TWLT and the predicted TWLT. This predicted TWLT includes the tropospheric correction (**IFMS-SPEC-2560**) and the relativistic correction (**IFMS-SPEC-2566:** ).

$$\tau_{predicted} = \tau_{TWLT,UBW} + \tau_{tropo} + \tau_{enstein}$$

**IFMS-SPEC-2640:** M\_OUTPUT accepts predicted RTLT as interpolated from PREDICT\_FILE in M\_MODULE PREDICT from the given array TIME\_RANGE.

**IFMS-SPEC-2645:** S\_RNG\_OUTPUT computes the range residuals (range delay) at S-band or X-band expressed as residual in the round-trip-light time  $\tau$

**IFMS-SPEC-2710:** The RANGE\_OUTPUT file name is defined as

**rggIFMSL02\_sss\_yyddhhmm\_qq.TAB**

The definitions are given in .

placeholder	description	example
r	spacecraft name M = MEX R = Rosetta V = VEX	M
gg	ground station xx = ESA Cerbreros 32 = ESA New Norcia (tbc)	32
IFMS	Data source IFMS = IFMS file	IFMS
L02	Data level L02	L02
sss	File type RGS = calibrated S-band ranging RGX = calibrated X-band ranging	RGX
yy	year	03
ddd	day of year	180
hhmm	start time of first data file in hour, minute	2345
qq	not used	00
TAB	Extension .TAB data file	TAB

**IFMS-SPEC-2720:** The format of the X-band RANGE\_OUTPUT file is defined in . II quantities not available for the appropriate output file are set to the INVALID CONSTANT=-999999.999999999.

column	description	unit	resolution
1	Sample number		
2	Ground received time <i>as UTC in ISO format</i>		
3	Ground received time <i>as UTC in fractions of day of year starting with the first day of the year the data was recorded at 00:00.000</i>	day	10 <sup>-10</sup> day
4	Ground received time <i>as elapsed terrestrial barycentric dynamic time (TDB) time since noon of the first calendar day of year 2000 (12:00 1 January 2000 TDB)</i>	second	10 <sup>-6</sup> sec
5	Distance <u>Propagation experiments:</u> <i>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</i> <u>Gravity observations:</u> <i>geometric distance of the s/c from the center of mass of referenced body</i>	kilometer	10 <sup>-3</sup> m
6	Observed TWLT X-band	second	0.1 nsec
7	calibrated TWLT X-band <i>corrected for the propagation in the Earth atmosphere, ionosphere and interplanetary plasma propagation</i>	second	0.1 nsec
8	TWLT delay X-band <i>Signal Round-Trip delay, modulo the maximum code ambiguity</i>	second	0.1 nsec
9	Differential TWLT <i>Computed from the S-band and X-band calibrated range in column 6</i> $\tau_s - \tau_x$ <i>If neither S-band or X-band is available the value is set to -99999.9</i>	second	0.1 nsec
10	X-band Range Calibration G/S Equipment Delay	second	0.1 nsec
11	X-band Range predict	second	0.1 nsec
12	X-band Range residual	second	0.1 nsec

13	X-band AGC Carrier level	DBM	0.1 DBM
----	--------------------------	-----	---------

**IFMS-SPEC-2721:** The format of the S-band RANGE\_OUTPUT file is defined in



All quantities not available for the appropriate output file are set to the INVALID CONSTANT=-999999.999999999.

column	description	unit	resolution
1	Sample number		
2	Ground received time <i>as UTC in ISO format</i>		
3	Ground received time <i>as UTC in fractions of day of year starting with the first day of the year the data was recorded at 00:00.000</i>	day	10 <sup>-10</sup> day
4	Ground received time <i>as elapsed terrestrial barycentric dynamic time (TDB) time since noon of the first calendar day of year 2000 (12:00 1 January 2000 TDB)</i>	second	10 <sup>-6</sup> sec
5	Distance <i>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</i> <i>Gravity observations: geometric distance of the s/c from the center of mass of referenced body</i>	kilometer	10 <sup>-3</sup> m
6	Observed TWLT S-band	second	0.1 nsec
7	calibrated TWLT S-band <i>corrected for the propagation in the Earth atmosphere, ionosphere and interplanetary plasma propagation</i>	second	0.1 nsec
8	TWLT delay S-band <i>Signal Round-Trip delay, modulo the maximum code ambiguity</i>	second	0.1 nsec
9	Differential TWLT <i>Computed from the S-band and X-band calibrated range in column 6</i> $\tau_S - \tau_X$ <i>If neither S-band or X-band is available the value is set to -99999.9</i>	second	0.1 nsec
10	S-band Range Calibration G/S Equipment Delay	second	0.1 nsec
11	S-band Range predict	second	0.1 nsec
12	S-band Range residual	second	0.1 nsec

13	S-band AGC Carrier level	DBM	0.1 DBM
----	--------------------------	-----	---------

### 3.7 RANGE CALIBRATION OUTPUT

**IFMS-SPEC-2730:** The RANGE\_CAL\_OUTPUT file name is defined as

**rggIFMSL02\_sss\_yyddhhmm\_qq.TAB**

The definitions are given in Table 3-3-1.

placeholder	description	example
r	spacecraft name M = MEX R = Rosetta V = VEX	M
gg	ground station xx = ESA Cerbreros 32 = ESA New Norcia (tbc)	32
IFMS	Data source IFMS = IFMS file	IFMS
L02	Data level L02	L02
sss	File type RCS = S-band ranging calibration RCX = band ranging calibration	RCX
yy	year	03
ddd	day of year	180
hhmm	start time of data in hour, minute	2345
qq	not used	00
TAB	Extension .TAB data file	TAB

**Table 3-3-1:** RANGE\_CAL\_OUTPUT file name Definition

### 3.8 RANGE LOGFILE OUTPUT

**IFMS-SPEC-2735:** The RANGE\_LOG\_OUTPUT file name is defined as

**rggIFMSL02\_sss\_yyddhhmm\_qq.LOG**

The definitions are given in Table 3-3-15.

placeholder	description	example
r	spacecraft name M = MEX R = Rosetta V = VEX	M
gg	ground station xx = ESA Cerbreros 32 = ESA New Norcia (tbc)	32
IFMS	Data source IFMS = IFMS file	IFMS
L02	Data level L02	L02
sss	File type RCS = S-band ranging calibration RCX = band ranging calibration	RCX
yy	year	03
ddd	day of year	180
hhmm	start time of first data file in hour, minute	2345
qq	not used	00
TAB	Extension .TAB data file	TAB

**Table 3-5:** RANGE\_LOG\_OUTPUT file name Definition

**SCA-SPEC-2740:** The format of the X-band RANGE\_CAL\_OUTPUT file is defined in **Table 3-3-2**.

column	description	unit	resolution
1	Sample number		
2	time in ISO format		
3	fractions of day of year	days	10 <sup>-7</sup> days
4	MJD since 01.01.2000	MJD	
5	Mean average value of X-band equipment propagation delay	Seconds	nsec
6	X-band equipment propagation delay	Seconds	nsec
7	Root Mean Square of X-band equipment propagation delay	Seconds	nsec

**Table 3-3-2: Definition of X-band RANGE\_CAL\_OUTPUT file format**

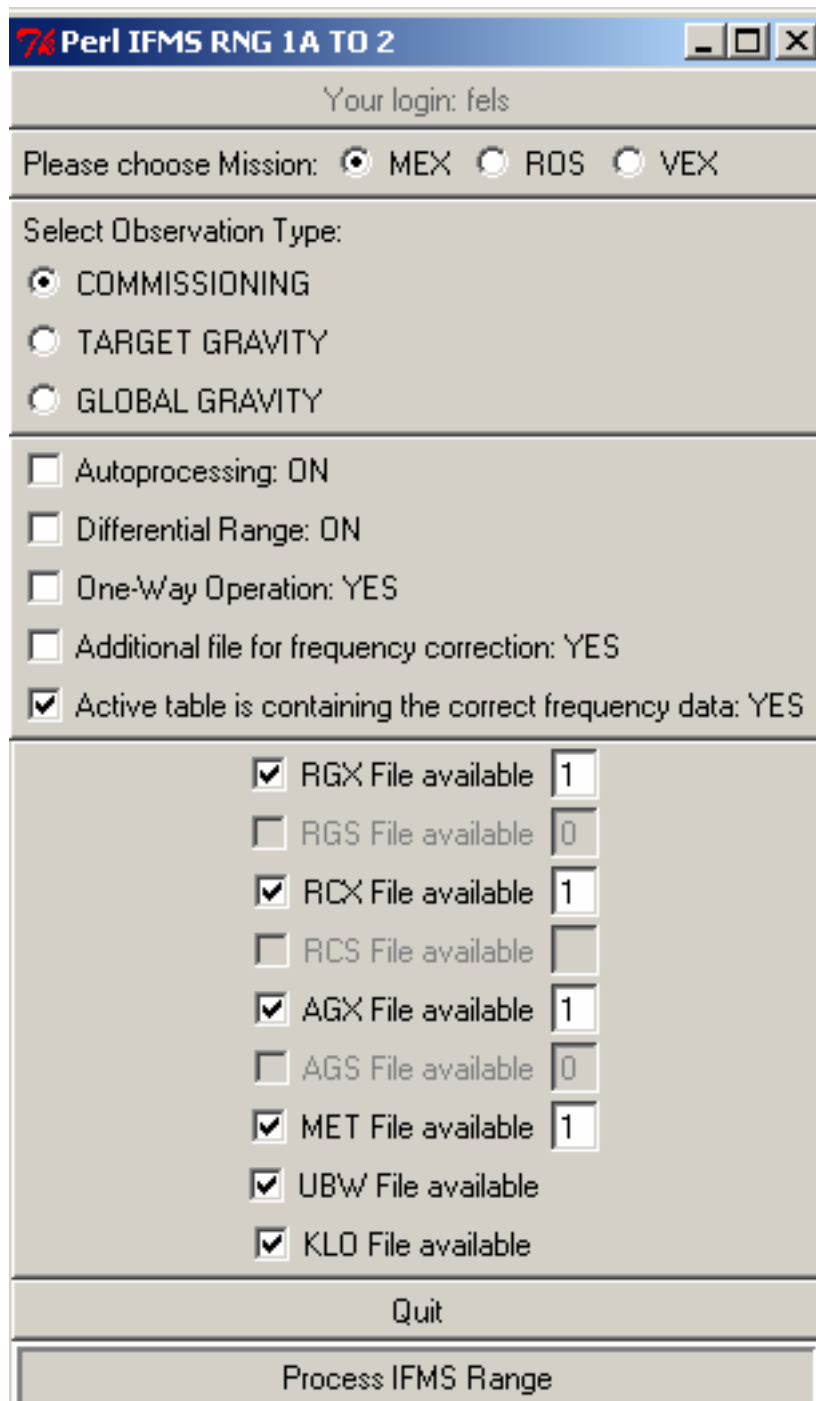
**SCA-SPEC-2741:** The format of the S-band RANGE\_CAL\_OUTPUT file is defined in **Table 3-3-3**

column	description	unit	resolution
1	Sample number		
2	time in ISO format		
3	fractions of day of year	days	10 <sup>-7</sup> days
4	MJD since 01.01.2000	MJD	
5	Mean average value of S-band equipment propagation delay	Seconds	nsec
6	X-band equipment propagation delay	Seconds	nsec
7	Root Mean Square of S-band equipment propagation delay	Seconds	nsec

**Table 3-3-3: Definition of S-band RANGE\_CAL\_OUTPUT file format**

#### 4 PERL GRAPHICAL USER INTERFACE PERL\_FIMS.PL

This section describes the structure and the usage of a PERL TK Graphical User Interface (GUI), named **perl\_ifms.pl**, with which the IFMS RANGE Software can be easily configured and executed. The GUI is shown in the figure below:



**Rosetta Radio Science Investigations RSI  
Mars Express Orbiter Radio Science Experiment MaRS  
Venus Express Radio Science Experiment VeRa**

**IFMS Ranging Processing and Calibration Software : Level 1a to Level 2**

Document number	Issue: 1	Revision:	10
MEX-MRS-IGM-DS-3036	Date: 23.09.2005	Page	39 of 45
ROS-RSI-IGM-DS-3119			
VEX-VRA-IGM-DS-3012			

The main function of this GUI is creating a so called **process\_option.txt** file, which includes all information needed for processing IFMS Range data. In case of autoproccessing a list of existing logfiles is opened and used as input parameters. After starting the Perl script the user have to enter his LOGIN. This LOGIN can be seen in the top widget of the GUI and it is stored as additional information in a logfile, which is being created during processing. This logfile mainly includes informations of the input and output data and the IFMS Range configuration. Together with this information the errors are listed, which occurred during the IFMS Range processing. An example logfile is shown below:

```
MEX

GLOBAL GRAVITY

FLAGS FROM PROCESS_OPTIONS FILE:
-----
F Differential Range ON
T Processing with UniBW Predict
F Processing with AGC
T Processing with CGIM
T Processing with RCL
F Processing with MET
F Additional file for frequency correction
F One-Way Mode
F Active table is containing the correct frequency data

NUMBER OF INPUT FILES:
-----
01 Number of RGX files
00 Number of RGS files
00 Number of AGX files
00 Number of AGS files
00 Number of MET files

FILES USED FOR PROCESSING:
-----
D:\data\mars_express\300\NN11_MEX1_2004_300_OP_RG_235105_0000.raw
D:\data\mars_express\300\NN11_MEX1_2004_300_CL_RG_202229_0000.raw
D:\data\mars_express\300\predict_300.txt
D:\data\mars_express\300\CGIM3000.04N\CGIM3000.04N

FILES CREATED DURING PROCESSING:
-----
D:\data\mars_express\300\M32ICL1L02_RGX_043002351_00.TAB
D:\data\mars_express\300\M32ICL1L02_RGX_043002351_00.LBL
D:\data\mars_express\300\M32ICL1L02_RCX_043002022_00.TAB
D:\data\mars_express\300\M32ICL1L02_RCX_043002022_00.LBL
```

**Rosetta Radio Science Investigations RSI**  
**Mars Express Orbiter Radio Science Experiment MaRS**  
**Venus Express Radio Science Experiment VeRa**

**IFMS Ranging Processing and Calibration Software : Level 1a to Level 2**

Document number

Issue: 1

Revision:

10

MEX-MRS-IGM-DS-3036

Date: 23.09.2005

Page

40 of 45

ROS-RSI-IGM-DS-3119

VEX-VRA-IGM-DS-3012

CONFIGURATION INFO:

-----  
UPLINK-FREQUENCY X-BAND: 7166758739.9976720809936523  
DOWNLINK-FREQUENCY X-BAND: 8420223886.7796421051025391  
SAMPLE-INTERVAL X-BAND: 1.000  
TRANSPONDER-RATIO X-BAND: 880/749

PROCESSING INFO:

-----  
PRODUCER ID: fels  
NO DIFFERENTIAL RANGE  
PLASMA-CORRECTION DONE WITH KLOBUCHAR-MODEL

ERRORS:

-----  
No Errors during processing



## **5 ANNEX A**

### **5.1 MEX TRANSPONDER GROUP DELAY VALUES**

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## **6 ANNEX B**

### **6.1 EARTH KLOBUCHAR IONOSPHERE MODEL**

Page Left Free

## **7 ANNEX C**

### **7.1 KLOBUCHAR FILE FORMAT DESCRIPTION**