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

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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
OWLT	One Way Light Time
PDS	Planetary Data System
POL	Polarization Open Loop
RCP	Right Circular Polarization
RSR	Radio Science Receiver
RTLT	Round Trip Light Time
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

Content

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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 station New Norcia (NNO). AGC and meteo data are handeled via the IFMS labeling software.

1.2 REFERENCED DOCUMENTS

	Reference Number	Title
[1]	MEX-MRS-IGM-IS-3016 ROS-RSI-IGM-IS-3087 VEX-VRA-IGM-IS-3009	Radio Science File naming Convention
[2]	IFMS_OCCFTP_10_3_1.PDF	IFMS-to-OCC
[3]	M32ESOCL1B_RCL_030522_00.PDF	MEX transponder Group delay values
[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

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	Changes/Action	New	Release

number		version	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. In the following the process is described for the Mars Express spacecraft. For the Rosetta and Venus Express spacecraft the procedure is similar.

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_LableNameIFMS
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 _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

All spacecraft constants are similar for Mars Express, Venus Express and Rosetta.

IFMS-DEF-1010: ASTRONOMICAL UNIT (AU)

1 AU = 149,597,870 kilometers

IFMS-DEF-1020: SPEED OF LIGHT

c = 299,792,458 m/s

IFMS-DEF-1030: CARRIER FREQUENCIES Mars Express, Venus Express, Rosetta

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

frequency band uplink	transponder ratios downlink/uplink	
	S-band	X-band
S-band	240/221	880/221
X-band	240/749	880/749

IFMS-DEF-1040: Transponder group delay values [3].

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:

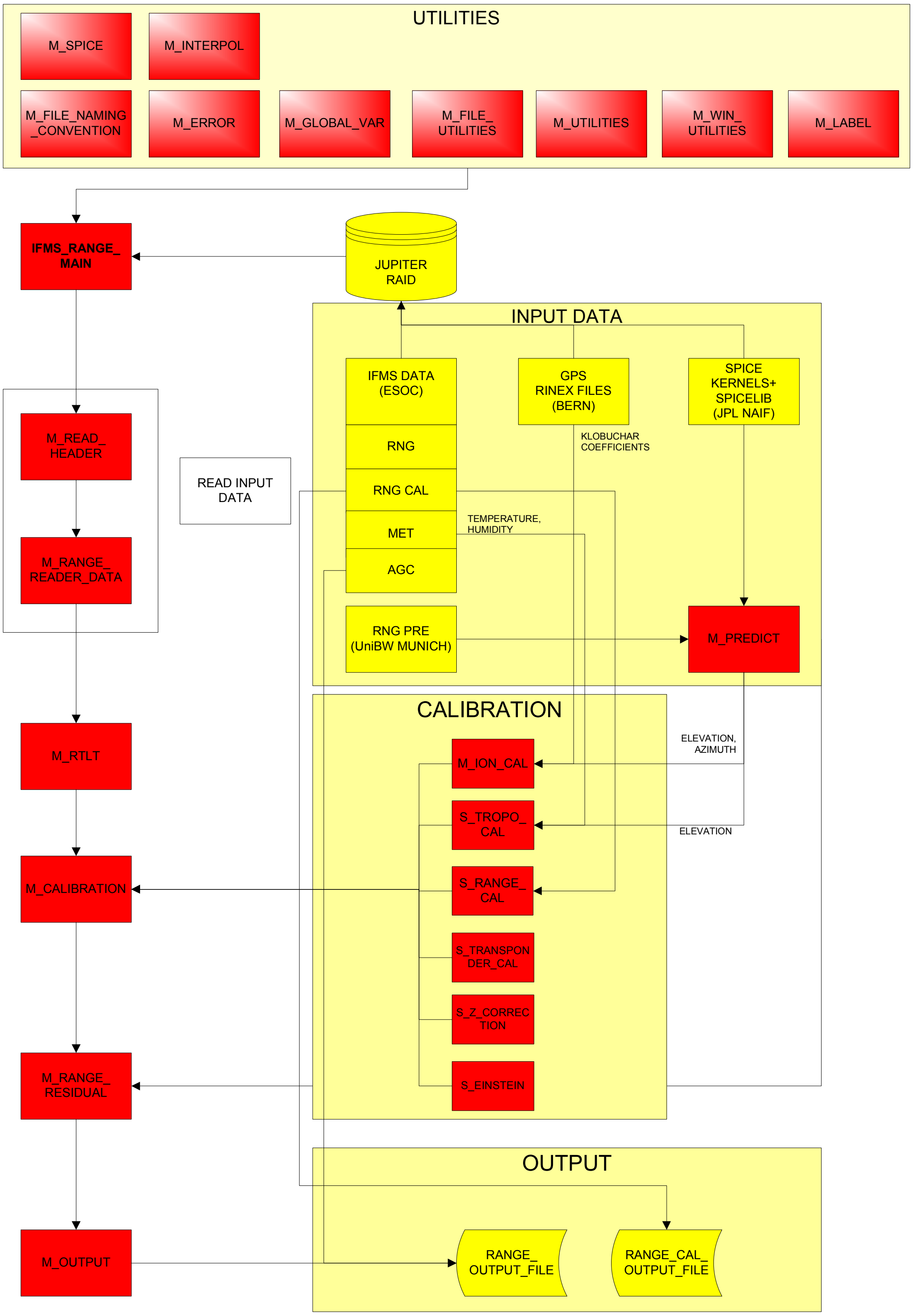
frequency band uplink	**transponder range delay (nanoseconds)**	
	S-band	**X-band**
S-band	2032	2015
X-band	2025	2015

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 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 _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_RTLT, 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_RTLT.

IFMS-SPRE-2350: Module M_READ_INPUT_DATA accepts only those data as valid input from IFMS_RANGE if *current_code >= 14* and *ambiguity = "TRUE". Current_code* is made available for Module M_RTLT.

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:

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

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

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

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:

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

n is an integer and is the predicted TWLT provided by Module M_PREDICT for the observed time stamp.
observed time stamp.

IFMS-SPEC-2440: Compute the RTLT 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 time delay 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 $<\tau_{cal}>$ and its standard deviation:

$$< \tau_{cal} > = \frac{1}{n}\sum_{i=1}^{n}\tau_{cal_i}$$

$$\sigma_{cal} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(\tau_{cal_i} - < \tau_{cal} >\right)^2}$$

Only those data as valid input from IFMS_RANGE_CAL are accepted if *current_code >= 14* and *ambiguity = "TRUE".*

IFMS-SPEC-2550: transponder delay

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

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

The time delay τ_z caused by the G/S antenna geometry is provided by the input table by the input table GS_GEO_CAL

.

IFMS-SPEC-2560: 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.):

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

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

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
pressure *p*	mbar	hPascal	-
Temperature *T*	Kelvin	°Celsius	-
water vapour partial pressure *e*	hPascal	-	-
humidity *h*	-	% humidity	-
elevation *E*	degrees	-	radian

The relation between the water vapour partial pressure and the humidity given in IFMS_METEO is:

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

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

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

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: ionsopheric 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 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 $c_{\text{speed of light}}$.

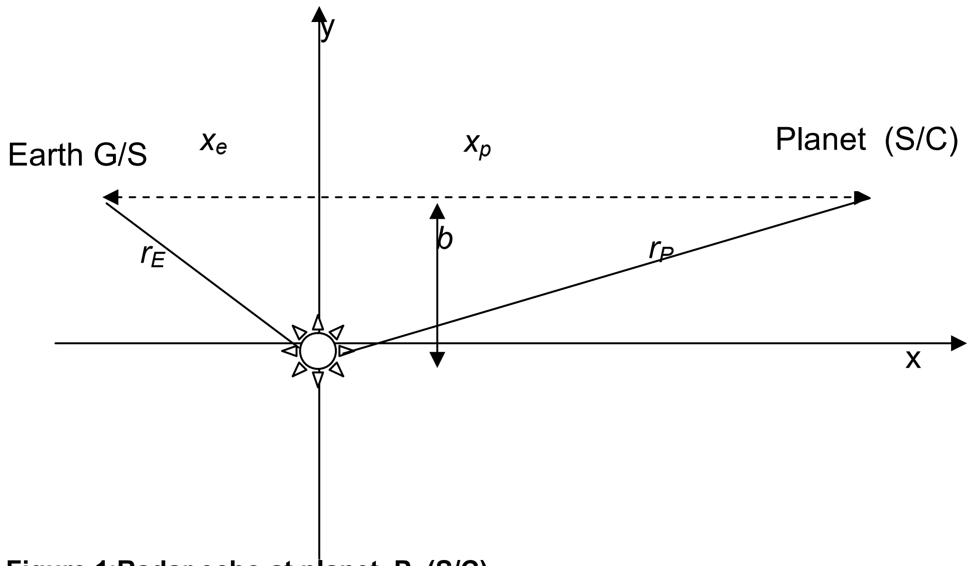


Figure 1:**Radar echo at planet P (S/C)**

IFMS-SPEC-2570: total calibration

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

$$\tau_{calibrated} = \tau - <\tau_{cal}> - \tau_{transponder} - \tau_z - \tau_{iono}$$

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

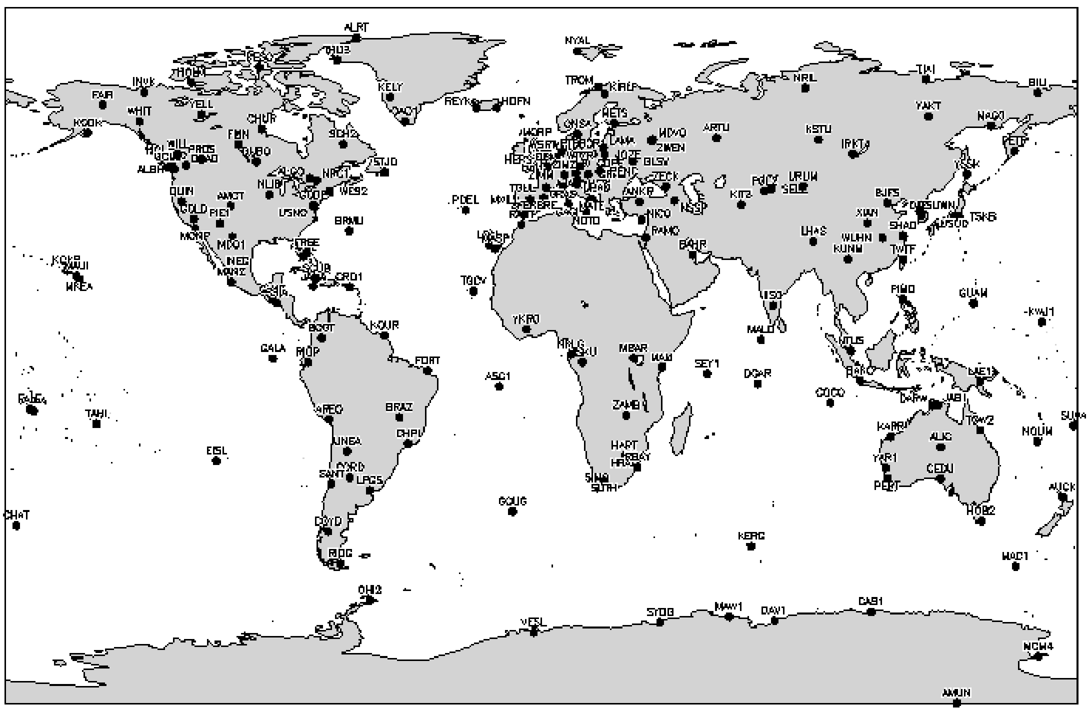


Figure 3.5-2:**GPS Tracking Ground Stations**

CODE computes Klobuchar-style ionospheric coefficients (alphas and betas) best fitting the IONosphere map EXchange data (IONEX) on a regular basis.

The 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.

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/

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·long_i + TOW

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

   a = azimuth·pi /180
   !

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

   e = elev·1./180
   !

4. **Earth Centered angle psi:**

   psi = 0.0137/ (e+0.11) - 0.022

5. **Subionospheric longitude long_i :**

   long_i = lambda·1./180.+ (psi·DSIN(a)/DCOS(lat_i·pi))

6. **Subionospheric latitude lat_i :**

   lat_i = phi·1./180+ psi·DCOS(a)

7. **Time of the Week TOW (output of the subroutine S_GPSTIME)**

   t = DMOD(t,86400.) !

8. **Slant factor sf:**

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

9. **Period of model PER:**

   If PER less than 72000.D0

   PER = 72000.

Else

$$PER = beta(1) + beta(2) \cdot lat\_m + beta(3) \cdot lat\_m^2 + beta(4) \cdot lat\_m^3$$

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

$x = 2. \cdot pi \cdot (t-50400.)\ /\ PER$!

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

$$AMP = alpha\ (1) + alpha\ (2) \cdot lat\_m + alpha\ (3) \cdot lat\_m^2 + alpha(4) \cdot lat\_m^3$$

12. **Ionospheric slant correction d_tau_iono:**

Night (DABS(x) greater Than 1.57):

$$d\_tau\_iono = sf \cdot (5.D\text{-}9)$$

Day:

$$d\_tau\_iono\ 1 = sf \cdot (5.D\text{-}9 + AMP^*(1.D0 - x^2/2. + x^4/24.))$$

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 troposheric 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 τ

IFMS-SPEC-2710: The RANGE_OUTPUT file name is defined as

rggIFMSL02_sss_yydddhhmm_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 . ll 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 *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*	day	10^{-10} day
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)*	second	10^{-6} sec
5	Distance *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*	kilometer	10^{-3} m
6	Observed TWLT X-band	second	0.1 nsec
7	calibrated TWLT X-band *corrected for the propagation in the Earth atmosphere, ionospshere and interplanetary plasma propagation*	second	0.1 nsec
8	TWLT delay X-band *Signal Round-Trip delay, modulo the maximum code ambiguity*	second	0.1 nsec
9	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*	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 *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*	day	10^{-10} day
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)*	second	10^{-6} sec
5	Distance *<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*	kilometer	10^{-3} m
6	Observed TWLT S-band	second	0.1 nsec
7	calibrated TWLT S-band *corrected for the propagation in the Earth atmosphere, ionospshere and interplanetary plasma propagation*	second	0.1 nsec
8	TWLT delay S-band *Signal Round-Trip delay, modulo the maximum code ambiguity*	second	0.1 nsec
9	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*	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_yydddhhmm_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_yydddhhmm_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^{-7} 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

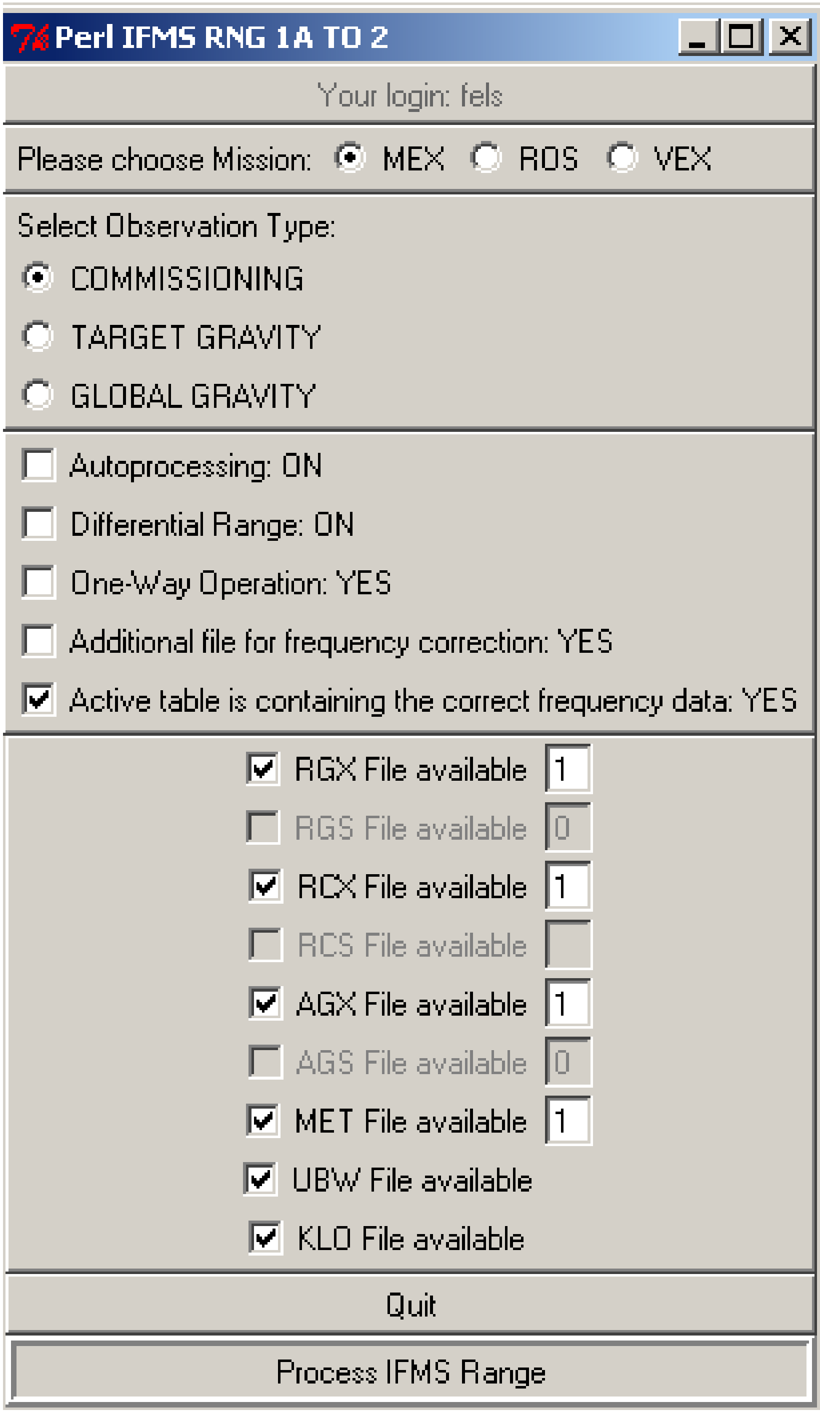
SCA-SPEC-2741: The format of the S-band RANGE_CAL_OUTPUT file is defined in **Table 3-3-3**

column	description	unit	resolution
1	Sample number		
2	time in ISO format		
3	fractions of day of year	days	10^{-7} 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:



The main function of this GUI is creating a so called **process_option.txt** file, which incudes all information needed for processing IFMS Range data. In case of autoprocessing 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
```

```
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
```