GAIA Space/Ground Interface Control Document Volume1 RF Interface

prepared by	GAIA Operations Team
reference	GAIA-ESC-ICD-00515
issue	2
revision	0
date of issue	18-Dec-2006

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Title *titre*	GAIA Space/Ground Interface Control Document Volume1 RF Interface	issue *issue*	2	revision *revision*	0

Prepared by: *auteur*	GAIA Operations Team	Date *date*	12-Dec-2006

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CHANGE LOG

date	issue	revision	Pages	reason for change
12-Dec-2006	2	0	all	Update request from GAIA project in line ESTEC-ESOC PM #9, GAIA-ESC-MIN-0009 to align document with agreements with industry and GAIA SRR outcome: • Up/downlink frequencies updated as per frequency coordination request • Ranging tone frequency specified • Option for GMSK modulation at medium bit rate removed • Doppler and sweep range & rates updated in line with LEOP worst case conditions and transponder capabilities • Concatenated coding table updated for selectable punctured coding rates • Villafranca replaced by Maspalomas 15m as LEOP station • Station characteristics updated in line with OPS-ON inputs • Atmospheric attenuation curves added to annex • Bit and Frame error rates vs. Eb/N0 added to annex

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1 INTRODUCTION AND SCOPE

1.1 Scope

The ESA Radio Frequency and Modulation Standard [AD-5], requires to control the spacecraft/ground station interface a) in a definitive and formal specification of the RF interface; b) by means of Link Budget Tables regularly updated to keep track of the development of the spacecraft and ground stations(s). The hardware interface compatibility will be demonstrated by Spacecraft/Ground station compatibility tests, to be documented by the Compatibility Test Plan and the related Compatibility Test Results Report.

This Space/Ground Interface Control Document (SGICD) defines the relevant parameters for the interface between the GAIA spacecraft and the ground stations, as well as the list of standards and other documents applicable to this interface, and shall act as the source document for all data to be used in the preparation of the Link Budget Tables.

The Packet Telemetry and Telecommand Standards ([AD-1], [AD-2]) address the transport of telemetry and telecommand data between user applications on the ground and user applications on-board the satellite, and the intermediate transfer of this data through the different elements of the ground and space segments. This detail is covered in SGICD Volume2 [RD-5].

The document will be agreed between the ESA GAIA Project Manager, the appointed ESOC representative and the Prime Contractor. Upon approval the document will be controlled by the ESA GAIA Project Manager, to whom, any updates or changes to any parameters contained in it shall be submitted.

For each of the major project reviews, the Prime Contractor (in association with his subcontractors) shall supply ESA with updated information concerning the spacecraft performance or confirmation that no change has occurred from the previous review. This shall be achieved through submittal of respective compliance tables.

1.2 Operations Scenario

1.2.1 Nominal Mission Operations

The mission operations of the GAIA spacecraft and its payload will be conducted under control of the GAIA Mission Operations Centre (MOC) at the European Space Operations Centre (ESOC). This task includes spacecraft operations required for all phases of the mission: LEOP, transfer phase to the final operational orbit around L2 including commissioning and performance verification phases, injection in the low amplitude Lissajous orbit, and the satellite and payload operations during the operational orbit. Throughout the complete mission duration (from launch up to the end of the mission, when ground contact to the spacecraft /payload is terminated), facilities and services will be provided to the GAIA Scientific Community for planning and execution of astronomical observations, and provision of the necessary data sets.

Interaction with the spacecraft will be by monitoring and analysis of telemetered data and the uplink of commands to effect the necessary operations. Most commands will be stored on-board for later execution at a defined time, other may be intended for execution in near real-time. In both cases, it may also be necessary to control subsystem and experiment equipment using low-level commands or high-level commands (i.e. via on-board applications or On-Board Control Procedures).

Telemetry and telecommands will also be required for on-board software management functions, including:

- control of, and communication with, on-board processes (such as an on-board telemetry monitor)
- loading and dumping of on-board memories
- control of on-board Mission Time-Line

All telecommands must be appropriately verified by telemetry at acceptance and execution.

Telemetry data will be required in order to verify the execution of all mission operations and will also be required for:

- routine on ground health monitoring of the subsystems and the payload;
- reporting to the ground any anomalous events detected on-board and any actions taken autonomously by the on-board systems;
- performance evaluation on the ground for the purposes of long term trend analysis and feed back into the mission planning cycle.

1.2.2 Contingency Operations

In the event of unforeseen on-board events, actions will be necessary to investigate and correct anomalies utilising the available telemetry and command functions. In addition it may be necessary to modify on-board software in order to compensate for on-board failures or anomalous performance.

1.2.3 Packet Distribution

The following telemetry and telecommand packet categories exist:

- Those generated on-ground and up-linked to the spacecraft
- Those generated by on-board applications and down linked to the ground
- Those generated on-board and routed to other on-board applications (and to the ground if necessary)

1.3 Applicable Documents

AD-1 Telemetry Space Link Protocol, CCSDS 132.0-B-1 Issue 1 September 2003.
AD-2 Telecommand Space Link Protocol, CCSDS 232.0-1-1 Issue 1 September 2003.
AD-3 Telemetry Channel Coding Standard, CCSDS 131.0-B-1, September 2003.
AD-4 Ranging Standard, PSS-04-104, Vol. I, Issue 2, March 1991.
AD-5 ECSS Radio Frequency and Modulation Standard, ECSS E-50-05A, 24 January 2003.[1]
AD-6 CCSDS Packet Telemetry, CCSDS 102.0-B-4, November 1995.
AD-7 Telecommand, Command Operations Procedures, CCSDS 232.1-B-1, Sept 2003.
AD-8 Telecommand, Part 1 Channel Service, CCSDS 201.0-B-3 June 2001.
AD-9 Telecommand, Part 2 Data Routing Service, CCSDS 202.0-B-3, June 2001.
AD-10 Space Packet Protocol, CCSDS 133.0-B-1 Issue 1 September 2003.
AD-11 File Delivery Protocol, CCSDS 727.0-B-2, Issue 2 October 2002.

Note : It is expected that ECSS-E50-03 and ECSS-E50-04 (pending release) will become applicable early in the development of GAIA.

1.4 Reference Documents

RD-1 GAIA Operations Interface Requirements Document, GAIA-ESC-RD-00514.
RD-2 ESA Telecommand Decoder Specification, PSS-04-151.
RD-3 GAIA SOW GAIA-EST-SOW-00444.
RD-4 GAIA Transponder Specifications. TBW.
RD-5 GAIA SGICD Volume2, GAIA-GS-ICD-1002-OPS-OA.
RD-6 GAIA Radio Frequency Test procedure and Report, TBW.
RD-7 IEEE Standard, 149, 1979.
RD-8 GAIA consolidated Report on Mission Analysis. Draft, Issue 0.1. GAIA-MA-RP-0010-TOS/GA.
RD-9 Telemetry & Telecommand Packet Utilization ECSS E-70-41A.
RD-10 GAIA Mission Requirement Document, GAIA-EST-RD-00553

[1] Note a new version of the standard, ECSS-E-50-05B, is in the approval process.

2 TELECOMMUNICATION SYSTEM

The telecommunication system supports the functions of tracking, telecommand and telemetry for each phase of the mission.

The spacecraft telecommunication subsystem consists of a redundant set of transponders using X-Band for the uplink, and X-Band for the downlink. Depending on the mission phase, the transponder can be routed via RF switches to different antennas. The telecommunication subsystem provides hot redundancy for the receiving function and cold redundancy for the transmitting function.

The associated ground network consists of a number of stations, which support some or all of the mission phases. A full description of the station utilisation will be found in Section 4 together with the appropriate specification of spacecraft and ground stations.

The satellite telecommunication subsystem is allocated with its dedicated frequency in the X-Band frequency range. The frequency assignments have been agreed with the ESA Frequency Management Office.

2.1 Down Link

2.1.1 Frequencies

A frequency is allocated for GAIA as a Category A (non Deep Space) Mission and its telecommunication subsystem shall support a downlink frequency in the 8450-8500 MHz frequency band (X-Band). The selected down link carrier frequency for GAIA is 8459.0000 MHz (spanning 8454-8464 MHz when 10 Msps transmitted).

The antenna polarisation sense shall be LHC (Left Hand Circular) in accordance with [RD-7].

2.1.2 Telemetry Channel Formats

The telemetry shall follow the Packet Telemetry Standard [AD-1] without Source Packet segmentation as mentioned in [AD-6].

2.1.3 Ranging Signal

The ranging signal is defined in section 2.2.3.

2.1.4 Modulation

The telemetry modulation scheme and the bit rates to be transmitted shall be as follows (See section 2.1.5 for details on bit rates):

Rate	Information rate	Modulation Scheme	Subcarrier Frequency
Low-1	62.5 bps	PCM(NRZ-L)/PSK/PM	0.1 to 1000 kHz
Low-2	2 kbps	PCM(NRZ-L)/PSK/PM	0.1 to 1000 kHz
Medium	250 kbps	PCM(SP-L)PM	Not applicable
High	5 Mbps	GMSK	Not applicable

The modulation scheme to be used for high rate transmission to New Norcia (NNO) is GMSK (with BT=0.25) as defined in [AD-5]. GMSK modulation is not compatible with ranging. PCM(SP-L)PM modulation is compatible with ranging. This modulation scheme could be used at the beginning and at the end of the ground station passes in order to perform ranging.

High rate telemetry transmissions have to comply with the emission masks stipulated by the Space Frequency Co-ordination Group (SFCG) in recommendation REC 17-2R1 which are reported in § 6.3 of [AD-5].

The ranging signal in the ranging channel of the transponder directly phase modulates (PM) the downlink carrier. When simultaneous ranging and telemetry is performed, the two signals are added prior to phase modulation of the downlink carrier. Ranging is not possible simultaneously with GMSK modulation. During these phases, Doppler tracking only will be used instead of ranging.

2.1.5 Telemetry Bit Rates

The information rates (fb) and transmitted symbol rates (fs') listed below shall be supported. The information rates refer to the transfer layer with the associated data structure (Transfer Frames). The symbol rates results from the applied concatenated encoding.

Concatenated encoding

fb = information rate [bps]
fs = data rate at convolutional encoder input [bps]
fs'= transmitted symbol rate [sps]
fsc = subcarrier frequency [Hz]
N = subcarrier frequency/transmitted symbol rate ratio

Rate = Selected punctured convolutional code rate (see section 2.1.6 and Appendix C).

FS’	**Rate**	**fs**	**Fb**	**fsc**	**N**
143.385625	1/2	71.6928125	62.5	N*fs’	TBD
4588.34	1/2	2294.17	2000	N*fs’	TBD
22941.7	1/2	11470.85	10000	N*fs’	TBD
573542.5	1/2	286771.25	250000	N/A	N/A
9084914	**1/2**	**4542457**	**3960000**	**N/A**	**N/A**
	2/3	**6056609**	**5280000**	**N/A**	**N/A**
	3/4	**6813686**	**5939999**	**N/A**	**N/A**
	5/6	**7570762**	**6599999**	**N/A**	**N/A**
	7/8	**7949300**	**6929999**	**N/A**	**N/A**
	NC	**9084914**	**7919999**	**N/A**	**N/A**
10000000	1/2	5000000	4358874	N/A	N/A
	2/3	6666667	5811832	N/A	N/A
	3/4	7500000	6538311	N/A	N/A
	5/6	8333333	7264790	N/A	N/A
	7/8	8750000	7628030	N/A	N/A
	NC	10000000	8717748	N/A	N/A
11470850	1/2	5735425	4999999	N/A	N/A
	2/3	7647233	6666665	N/A	N/A
	3/4	8603138	7499999	N/A	N/A
	5/6	9559042	8333332	N/A	N/A
	7/8	10036994	8749998	N/A	N/A
	NC	11470850	9999998	N/A	N/A

Table 2-1: TM Bit Rates for concatenated encoding (note values for high bit rates rounded). Note values in table are TBC and will be updated with exact bit rates implemented on-board once these are known.

For details on the above mentioned bit/symbol rate definition, see Appendix D.

2.1.6 Coding

The baseline coding shall be concatenated encoding (Reed Solomon R-S 255,223 with interleaving depth I = 5, and selectable punctured convolutional code rate 1/2, 2/3, 3/4, 5/6, 7/8 or No Coding (NC) with constraint length k = 7) in accordance with [AD-3].

The transfer frame has a maximum length of 223*I=1115 octets.

For achievable bit and frame error rates, see Appendix D.

2.1.7 Frame Synchronisation

In order to allow a proper frame synchronisation on ground, a synchronisation marker 1ACFFC1D (Hex) shall be inserted at the first bit of the code block of each transfer frame in line with [AD-3].

2.1.8 Bitstream Pseudo Randomiser

An on-board pseudo randomiser shall be implemented. The requirements for the pseudo randomiser are given in [AD-3].

2.2 Up-link (on-Board Reception)

2.2.1 Frequencies

A frequency will be allocated for GAIA as a Category A (non Deep Space) Mission and its telecommunication subsystem shall support an uplink frequency in the 7190-7235 MHz frequency band (X-Band). The selected uplink link carrier frequency for GAIA is 7199.7625 MHz (spanning 7198.2-7201.2 MHz when ranging transmitted).

The ratio for uplink and downlink frequencies for the transponders shall be as follows: fuplink/fdownlink = 749/880 (X-/X-Band).

The maximum Rx Doppler rate shall be 1500 Hz/sec (LEOP worst case).

The antenna polarisation sense shall be the LHC (Left Hand Circular) according to [RD-7].

2.2.2 Telecommand Format Standard

The telecommand format shall follow the Packet Telecommand Standard, [AD-6].

2.2.3 Ranging Signal

For the ESA ground stations the ranging signal is in accordance with the Ranging Standard [AD-4].
The selected tone frequency shall be 1 MHz from the carrier, ± 100kHz to ensure adequate offset from SP-L null (see [AD-5]).

2.2.4 Modulation

The telecommand modulation scheme shall be PCM(NRZ-L)/PSK/PM on a sinusoidal sub-carrier. The selected subcarrier frequency is 16 kHz.

The ranging signal directly phase modulates (PM) the uplink carrier. For simultaneous ranging and telecommand, the two signals are added prior phase modulation of the uplink carrier.

2.2.5 Telecommand Bit Rates

The following telecommand bit rates shall be used. These bit rates refer to the digital bit stream at the physical layer, consisting of CLTUs and Idle/Acquisition sequences.

- 125 bps,
- 4 kbps.

2.2.6 Uplink Sweep

The uplink sweep shall be implemented according to the following limitations:

- The range shall cover the maximum Doppler shift of +/- 220 kHz (LEOP worst case)
- The rate shall be 3500 Hz/s (TBC)
- The telecommand sweep shall be possible to complete within 2-3 minutes (TBC)
- The maximum sweep discontinuity shall be 1 Hz

2.2.7 Telecommand Specific Requirements

The following requirements have been based on the telecommand rejections observed in orbit with previous missions, namely related to:

- Telecommand chain selection with multiple channels
- Loss of bit synchronisation with telecommands containing long series of “zeroes”

2.2.7.1 Telecommand Chain Selection

When the on-board telecommand chain features multiple input channels, the selection process of the active input channel shall insure that the probability of maximum length frame rejection (or abandonment of CLTU) is less than 10^{-3}. This probability of rejections is defined:

- In worst case conditions (spacecraft attitude, distance from ground station);
- When the Bit Error Rate at any input of the telecommand decoder is less than 10^{-5};
- When the same valid CLTU is arriving quasi-simultaneously at several inputs of the telecommand decoder, with different signal to noise ratios;
- When the A/D commanding service is enabled.

2.2.7.2 Loss of Bit Synchronization

Telecommands with a minimum bit transition density of 3% at code block level (coding layer) and uplinked at the GAIA bit rates of section 2.2.5 shall be decoded and distributed on-board with a rejection rate of less than 10^{-3}, in worst case conditions (spacecraft attitude, distance from ground station, etc.)

3 OPERATIONAL UTILISATION

3.1 Operational Modes

3.1.1 Modulation Modes

The telecommunication subsystem shall support the following modes for the up-link:

- Carrier only (unmodulated carrier)
- Telecommand
- Ranging
- Simultaneous telecommand and ranging

The following operational modes shall be supported for the downlink:

- Carrier only (unmodulated carrier)
- Telemetry
- Ranging
- Simultaneous telemetry and ranging

3.1.2 Transponder Modes

It shall be possible to command the transponder to operate in either coherent or non-coherent mode as described below.

In the coherent mode, the transmitter shall operate coherent to the receiver as soon as the receiver is locked (see section 2.2.1 for ratio between up- and downlink frequency). This is referred to as coherent state. If the receiver loses lock, the transmitter shall go to non-coherent state and return to the coherent state, after the receiver locks.

In the non-coherent mode, the transmitter shall remain in non-coherent state irrespective of the receiver lock status, until switched to coherent mode.

3.1.3 Antenna Switching

Requirements for the on-board design are included in the GAIA Mission Requirements Document [RD-10].

3.1.4 Command Operations Procedure (COP-1)

The Command Operations Procedure COP-1 [AD-7] shall be supported. Within COP-1, the packet telecommand services AD (Sequence Controlled Service) and BD (Expedited Service) shall be supported in parallel.

4 PERFORMANCE

4.1 Spacecraft

4.1.1 Transponder Requirements

The requirements to be satisfied by the transponder are comprised in the Radio Frequency and Modulation Standard [AD-5] and the Ranging Standard [AD-4]. The detailed requirements to be applied to the transponder shall be agreed with the ESA project office.

4.2 RF Suitcase

RF suitcase requirements are contained in the GAIA Statement Of Work [RD 3].

4.3 Ground Stations

The performance characteristics together with the foreseen equipment configurations for the ESA ground stations are depicted in Table 4-1 to Table 4-4.

4.3.1 Kourou 15m, French Guyana

The Kourou ground station parameters are summarised in Table 4-1.

Kourou 15m, French Guyana				
Geographical Co-ordinates	Longitude [deg]	-52.80		
	Latitude [deg]	5.25		
Uplink	Antenna Polarisation	LHC or RHC		
	Antenna Gain [dB]	56.7 X-Band		
Downlink	Antenna Plarisation	any		
	Antenna Gain [dB]	59.3 X-Band		
Timing System Synchronisation to UTC [microsec]		5.0		
		NOM	ADV	FAV
	Atmospheric Loss * [dB]	1.00	1.20	0.80
	Ionospheric Loss [dB]	0.00	0.00	0.00
Uplink				
EIRP (300-W HPA)	X-Band [dBW]	82.0	81.0	82.8
	Pointing Loss [dB]	0.05	0.12	0.00
	Axial Ratio [dB]	0.90	1.25	0.00
Downlink **				
Effective G/T at 10° elevation	X-Band [dB/K]	37.5	37.0	38.0
Pointing Loss	X-Band [dB]	0.10	0.40	0.00
Axial ratio	[dB]	0.90	1.25	0.00
Carrier Lop Bandwidth $2B_L$ continuous 0.3-3000 [Hz]		NOM	+20%	-20%
TM demodulation technological losses [dB] Tx Rate >2730 [sps]		0.90	1.0	0.80
Ranging Tone Loop Bandwidth [rad/sec]		10^{-3} to 1.5		
Required Ranging Loop S/N [dB]		19.00	19.00	19.00
Required C/N in $2B_L$ for no data degradation [dB]		Residual carrier: 17		
Required C/N in $2B_L$ for no data degradation [dB]		Suppressed carrier: 25		
Required TM E_b/N_0	[dB]	AD[3]		
Station Equipment	Low Noise Amplifier	80-K FET X-Band		
	Receiver / Demod / Tracking	IFMS		
	Telemetry	TMTCS		
	Decoders	TCDS		
	Telecommand	TMTCS		
	Data Communications	TCP-IP		
	Timing System	H-Maser + GPS		
	Station Control	STC2, FEC/NT, MCM4		

* 95% probability at 10° elevation, for 99% probability the losses are defined in Appendix C.
** X-band downlink upgrade to LNAs planned for improved performance. Values to be updated once measurements available.

Table 4-1. Kourou Ground Station Parameters.

4.3.2 Maspalomas 15m, Spain

The Maspalomas ground station parameters are summarised in Table 4-2.

Maspalomas 15m, Spain				
Geographical Co-ordinates	Longitude [deg]	15.63		
	Latitude [deg]	27.78		
Uplink	Antenna Polarisation	LHC or RHC		
	Antenna Gain [dB]	56.7 $_{X\text{-Band}}$		
Downlink	Antenna Plarisation	any		
	Antenna Gain [dB]	59.5 $_{X\text{-Band}}$		
Timing System Synchronisation to UTC [microsec]		5.0		
		NOM	ADV	FAV
	Atmospheric Loss * [dB]	0.60	0.50	0.70
	Ionospheric Loss [dB]	0.00	0.00	0.00
Uplink**				
EIRP (300-W HPA)	X-Band [dBW]	81.5	81.5	81.5
	Pointing Loss [dB]	0.28	1.14	0.00
	Axial Ratio [dB]	0.90	1.25	0.00
Downlink				
Effective G/T at 10° elevation	X-Band [dB/K]	37.5	37.0	37.5
Pointing Loss	X-Band [dB]	0.1	0.4	0.0
Axial ratio	[dB]	0.90	1.25	0.0
Carrier Lop Bandwidth $2B_L$ continuous 0.3-3000 [Hz]		NOM	+20%	-20%
TM demodulation technological losses [dB] Tx Rate >2730 [sps]		0.90	1.0	0.80
Ranging Tone Loop Bandwidth [rad/sec]		10^{-3} to 1.5		
Required Ranging Loop S/N [dB]		19.00	19.00	19.00
Required C/N in $2B_L$ for no data degradation [dB]		Residual carrier: 17		
Required C/N in $2B_L$ for no data degradation [dB]		Suppressed carrier: 25		
Required TM E_b/N_0	[dB]	AD[3]		
Station Equipment	Low Noise Amplifier	80-K FET$_{X\text{-Band}}$		
	Receiver / Demod / Tracking	IFMS		
	Telemetry	TMTCS		
	Decoders	TCDS		
	Telecommand	TMTCS		
	Data Communications	TCP-IP		
	Timing System	Cesium		
	Station Control	STC2, FEC/NT, MCM4		

* 95% probability at 10° elevation, for 99% probability the losses are defined in Appendix C.
** The station is to be upgraded for X-Band uplink. The values have to be confirmed after completion of upgrade and test

Table 4-2. Maspalomas Ground Station Parameters

4.3.3 New Norcia 35m, Australia

The New Norcia ground station parameters are summarised in Table 4-3:

New Norcia 35m, Australia				
Geographical Co-ordinates	Longitude [deg]	116.19		
	Latitude [deg]	-31.05		
Uplink	Antenna Polarisation	LHC or RHC		
	Antenna Gain [dB]	65.5 $_{\text{X-Band}}$		
Downlink	Antenna Plarisation	any		
	Antenna Gain [dB]	67.8 $_{\text{X-Band}}$		
Timing System Synchronisation to UTC [microsec]		5.0		
		NOM	ADV	FAV
	Atmospheric Loss * [dB]	0.50	0.60	0.40
	Ionospheric Loss [dB]	0.00	0.00	0.00
Uplink				
EIRP (2-kW HPA at 10° elevation)	X-Band [dBW]	97.0	96.0	97.0
EIRP (20-kW HPA at 10° elevation) In emergency or for Deep Space missions	X-Band [dBW]	107.0	106.0	107.0
	Pointing Loss [dB]	0.80	0.80	0.00
	Axial Ratio [dB]	1.00	1.50	0.50
Downlink				
Effective G/T at 10° elevation	X-Band [dB/K]	49.8	49.3	50.0
Pointing Loss (inc in G/T value)	X-Band [dB]	0.0	0.0	0.0
Axial ratio	[dB]	1.0	1.5	0.5
Carrier Lop Bandwidth $2B_L$ continuous 0.3-3000 [Hz]		NOM	+20%	-20%
TM demodulation technological losses [dB] for Tx rate >2730 [sps]		0.90	1.0	0.80
Ranging Tone Loop Bandwidth [mHz]		10 to 1880		
Required Ranging Loop S/N [dB]		19.00	19.00	19.00
Required C/N in $2B_L$ for no data degradation [dB] **		Residual carrier: 17		
Required C/N in $2B_L$ for no data degradation [dB] **		Suppressed carrier: 25		
Required TM E_b/N_0	[dB]	AD[3]		
Station Equipment	Low Noise Amplifier	20-K HEMT		
	Receiver / Demod / Tracking	IFMS		
	Telemetry	TMTCS		
	Decoders	TCDS		
	Telecommand	TMTCS		
	Data Communications	TCP-IP		
	Timing System	H-Maser + GPS		
	Station Control	STC2, FEC/NT, MCM4		

* 95% probability at 10° elevation, for 99% probability the losses are defined in Appendix C.
** assuming concatenated coding

Table 4-3. New Norcia Ground Station Parameters

4.3.4 Cebreros 35 M, Spain

The Cebreros ground station parameters are summarised in Table 4-4.

Cebreros 35m, Spain				
Geographical Co-ordinates	Longitude [deg]	-4.36		
	Latitude [deg]	+40.45		
Uplink	Antenna Polarisation	LHC or RHC		
	Antenna Gain [dB]	66.0 $_{X\text{-}Band}$		
Downlink	Antenna Plarisation	any		
	Antenna Gain [dB]	68.0 $_{X\text{-}Band}$		
Timing System Synchronisation to UTC [microsec]		5.0		
		NOM	ADV	FAV
	Atmospheric Loss * [dB]	0.50	0.60	0.40
	Ionospheric Loss [dB]	0.00	0.00	0.00
Uplink				
EIRP (400-W SSA at 10^o elevation)	X-Band [dBW]	91.4	91.0	91.4
EIRP (2-kW HPA at 10^o elevation)	X-Band [dBW]	98.4	98.00	98.4
EIRP (20-kW HPA at 10^o elevation) In emergency or for Deep Space missions	X-Band [dBW]	108.4	108.0	108.4
	Pointing Loss [dB]	0.7	0.7	0.7
	Axial Ratio [dB]	1.00	1.50	0.50
Downlink				
Effective G/T at 10^o elevation	X-Band [dB/K]	50.80	50.3	50.8
Pointing Loss (inc in G/T values)	X-Band [dB]	0.0	0.0	0.0
Axial ratio	[dB]	1.0	1.5	0.50
Carrier Lop Bandwidth $2B_L$ continuous 0.3-3000 [Hz]		NOM	+20%	-20%
TM demodulation technological losses [dB] for Tx rate >2730 [sps]		0.90	1.0	0.80
Ranging Tone Loop Bandwidth [mHz]		10 to 1880		
Required Ranging Loop S/N [dB]		19.00	19.00	19.00
Required C/N in $2B_L$ for no data degradation [dB] **		Residual carrier: 17		
Required C/N in $2B_L$ for no data degradation [dB] **		Suppressed carrier: 25		
Required TM E_b/N_0	[dB]	AD[3]		

Station Equipment	Low Noise Amplifier	20-K HEMT
	Receiver / Demod / Tracking	IFMS
	Telemetry	TMTCS
	Decoders	TCDS
	Telecommand	TMTCS
	Data Communications	TCP-IP
	Timing System	H-Maser + GPS
	Station Control	STC2, FEC/NT, MCM4

* 95% probability at 10° elevation, for 99% probability the losses are defined in Appendix C.
** assuming concatenated coding

Table 4-4. Cebreros Ground Station Parameters

4.4 Required Links

4.4.1 Required Link Performance

The links budgets shall be computed as defined in [AD-5], that means including nominal, adverse, favourable, mean - 3 sigma and worst case RSS (Root Sum Square). The minimum values of those margins shall be:

- nominal: $\geq$ 3 dB
- RSS worst case: $\geq$ 0 dB
- mean - 3 sigma: $\geq$ 0 dB

The link budget margins shall be computed under the following assumptions:

- Telemetry:
  Telemetry bit error rate associated with 99.999% of transfer frame delivery for concatenated coding (probability of frame loss = 10^{-5}); the required E_b/N_0 for obtaining the above specified probability of frame loss is 2.7 dB for concatenated encoding compliant with [AD-3].
- Telecommand:
  The requirements of [AD-2] are applicable
- Ranging:
  See Vol1 [AD-4].

4.4.2 Ground Station Network

The ground station network to support the required telemetry, telecommand and tracking links shall be as shown in Table 4-5:

Station	LEOP	L_2 Trans-fer	Commissioning	Science
Kourou 15m	Yes	Yes	No	No (only emergency TT&C support including Medium bit rate downlink)
Maspalomas 15m	Yes	No	No	No
New Norcia 35m	Yes	Yes	Yes	Yes
Cebreros 35 m	Yes	Yes	Yes	Yes

Table 4-5. Ground Station Network Utilisation.

4.4.3 Link Budget Formats and Definitions

Any link budget calculations shall be presented in a standard format as specified in Appendix B, and shall further include summary tables and graphical presentations for both uplink and downlink.

The following link budgets for maximum up/down link distances shall be verified for both ranging on (with exception of high rate telemetry) and off for the following information rates:

The link budgets should follow the format shown in Appendix B considering a minimum elevation of 5° for downlink. Atmospheric attenuation profiles are provided in Appendix C.

Uplink	**X-band**	
	LGA	
Kourou 15m	125 bps	
Maspalomas 15 m	125 bps	
Cebreros 35m	4 kbps	
New Norcia 35 m	4 kbps	
Downlink	**X-Band**	
	LGA	**MGA**
Kourou 15m	62.5 bps	250 kbps
Maspalomas 15 m	62.5 bps	250 kbps
Cebreros 35m	2 kbps	5 Mbps
New Norcia 35 m	2 kbps	5 Mbps

Appendix A Acronyms and Glossary of terms

Acronym	Description
AD	Sequence-Controlled Service
AD	Applicable Document
BD	Expedited Service
BT	Bandwidth Symbol Duration
CCSDS	Consultative Committee for Space Data Systems
CLCW	Command Link Control Word
CLTU	Command Link Transfer Unit
C/N	Carrier to Noise ratio
COP1	Command Operation Procedure 1
CPDU	Command Pulse Distribution Unit
E_b/N_0	Energy per bit/ Noise Power density
EIRP	Equivalent isotropic Radiated Power
FAV	Favourable
FEC 4	Front End Controler Ggeneration 4
FER	Frame Error Rate
FET	Field Effect Transistor
GMSK	Gaussian Minimum Shift Keying
GPS	Global Positioning System
HEMT	High Electron Mobility Transistor
HK	House Keeping
HPA	High Power Amplifier
ICD	Interface Control Document
IFMS	Intermediate Frequency and Modem System
ISS	Internet Service System
LGA	Low Gain Antenna
LHC	Left Hand Circular
MCM3	Monitor and Control Module Generation 3
MGA	Medium Gain Antenna
MOC	Mission Operations Centre
N/A	Not Applicable
NOM	Nominal
NRZ-L	Non-Return to Zero-Level
OBCP	On Board Control Procedure
PCM	Pulse Code Modulation
PM	Phase Modulation
PSS	Procedures, Specifications and Standards
PSK	Phase Shift Keying
RF	Radio Frequency
RHC	Right Hand Circular

Acronym	Description
S/N	Signal to Noise
SP-L	Split Phase-Level
STC2	Station Computer Generation 2
TBC	To Be Confirmed
TBD	To Be Defined
TBW	To Be Written
TC	Telecommand
TCDS	Telemetry Concatenated Decoding System
TCE	Telecommand Encoder
TM	Telemetry
TMP4	Telemetry Processor Generation 4.

Appendix B Link Budget Format

Link budgets are given for information only, the examples are based on assumptions below.

The assumed up-link parameters for GAIA (to be corrected at time of PDR and throughout Phase C/D as updated values become available):

Parameter		NOM	ADV	FAV
Antenna Gain [dBi]	LGA	-3 dBi	-3 dBi	-3 dBi
Polarisation		RHC	RHC	RHC
Axial ratio [dB]	LGA	<4 dB	<4 dB	<4 dB
Pointing losses	LGA	NA	NA	NA
Circuit losses [dB]	LGA	TBC	TBC	TBC
Antenna Noise Temperature [^{o}K]	LGA	100 TBC	100 TBC	100 TBC
Receiver Noise figure [dB]		2 TBC	2 TBC	2 TBC
Ranging on-board Channel bandwidth (double sided) [MHz]		1.4 TBC	1.4 TBC	1.4 TBC
Loop bandwidth at threshold (double sided) [Hz]		100 TBC	100 TBC	100 TBC
Input signal range [dBm]		-141 to -60	-141 to –60	-141 to -60
Receiver telecommand threshold at 300^{o}K [dBm]		-135 TBC	-135 TBC	-135 TBC
Implementation losses [dB]	Carrier	1 dB TBC	1 dB TBC	1 dB TBC
	Telecommand	1.3 dB TBC	1.3 dB TBC	1.3 dB TBC
	Ranging	1.3 dB TBC	1.3 dB TBC	1.3 dB TBC
Modulation index [rad]	Telecommand	1	+/- 5%	+/- 5%
	Ranging	>0.65	+/- 5%	+/- 5%

The down link parameters for GAIA :

Parameter		NOM	ADV	FAV
TT&C S/S output pover MGA (*) [dBW]		17.0	17.0	17.0
Circuit losses [dB]	LGA	TBC	TBC	TBC
	MGA	TBC	TBC	TBC
Antenna Gain [dBi]	LGA	-3 dBi TBC	-3 dBi TBC	-3 dBi TBC
	MGA	17.6 dBi TBC	17.6 dBi TBC	18.4 dBi TBC
Pointing losses [dB]	LGA	TBD	TBD	TBD
	MGA	TBD	TBD	TBD
Polarisation		RHC	RHC	RHC
Axial ratio [dB]	LGA	< 4dB	< 4dB	< 4dB
	MGA	3 dB	3 dB	2 dB
Modulation index [rad] (**)	Telemetry	1.2 TBC	+/- 10%	+/- 10%
	Ranging	0.7 TBC	+/- 10%	+/- 10%

(**) The Telemetry Modulation Index is not applicable for high rate telemetry.

LINK ID : P35GAIA

DATE : 17/06/2004 18:12

ORBIT : Lissajous L2

STATION : Perth 35-m

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ALTITUDE (1000km): 1680

ELEVATION (deg): 5

TELECOMMAND BIT RATE (kb/sec) : 2.00

TELEMETRY BIT RATE (kb/sec) : 5000.00

RS (1) or CONCAT. CODING (2) : 2

RANGING : No

BASIC UPLINK (1/2)

	NOM	ADV	FAV	MEAN	VAR	PDF
G/S TX POWER.........dBW	33.00	33.00	33.00	33.00	0.00	TRI
CIRCUIT LOSS..........dB	0.20	1.10	0.00	0.55	0.10	UNI
TX ANT GAIN..........dBi	64.30	64.30	64.30	64.30	0.00	UNI
G/S ANT TX AXIAL RAT..dB	0.50	1.00	0.00			
POINTING LOSS.........dB	0.10	0.20	0.00	0.10	0.00	UNI
EIRP G/S.............dBW	97.00	96.00	97.30	96.65	0.10	
FREQUENCY............GHz	7.24	7.24	7.24	7.24		
SLANT RANGE......1000*km	1686	1686	1686	1686		
PATH LOSS.............dB	234.17	234.17	234.17	234.17		
ATMOSPHERIC LOSS......dB	0.50	0.60	0.40	0.50	0.00	GAU
IONOSPHERIC LOSS......dB	0.00	0.00	0.00	0.00	0.00	GAU
COPOLAR ANT-GAINS(Y=1/N=0)?	0					
POLARISATION MISMATCH.dB	0.17	0.34	0.06	0.20	0.01	UNI
TOTAL PROPAG. LOSS....dB	234.84	235.11	234.62	234.87	0.01	
POW.-FLUX at S/C.dBm/m^2	-68.53	-69.53	-68.23	-68.88		
RX ANT GAIN..........dBi	-3.00	-3.00	-2.80	-2.93	0.00	TRI
POINTING LOSS (*)..dB	0.00	0.00	0.00	0.00	0.00	TRI
S/C ANT RX AXIAL RAT..dB	3.00	4.00	2.00			
ANTENNA NOISE TEMP.....K	100.00	100.00	100.00			
ANTENNA/FEED VSWR.....:1	1.10	1.20	1.00			
VSWR LOSS.............dB	0.01	0.04	0.00	0.02	0.00	TRI
CABLE PHYSICAL TEMP....K	290.00	330.00	240.00			
CABLE LOSS............dB	1.10	1.20	1.00	1.10	0.00	UNI
CIRCUITS TEMPERATURE...K	290.00	330.00	240.00			
RFDU CIRCUIT LOSS.....dB	1.10	1.40	1.00	1.20	0.01	UNI
TOTAL CIRCUIT & CABLE LOSS.....dB	2.21	2.64	2.00			
DIPL. CIRCUIT LOSS....dB	0.00	0.00	0.00	0.00	0.00	UNI
RECEIVER NOISE FIGURE.dB	2.00	2.00	1.80			
REF SYSTEM TEMP (**).K	459.62	459.62	438.93			
RX SYSTEM TEMP (***)..K	345.52	374.63	300.60			
RX SYSTEM TEMP (***)dBK	25.38	25.74	24.78	25.26	0.03	GAU
S/C RX G/T..........dB/K	-30.59	-31.37	-29.58			
RX POWER (***).....dBm	-113.05	-114.75	-112.12	-113.47	0.13	
THEOR CAR THRSH(**)dBm	-136.98					
CAR ACQ THRSH (**).dBm	-139.00	-139.00	-139.00			
THEOR TC THRSH(**).dBm	-123.00					
TC RX THRSH (**).dBm	-135.00	-135.00	-135.00			
REQ RX POWER (***).dBm	-135.00	-135.00	-135.00	-135.00		

RX POWER MARGIN.......dB	21.95	20.25	22.88	21.53	0.13
MEAN-3*SIGMA.......dB	20.45				
MARGIN - w.c. RSS..dB	20.97				

RX S/No.............dBHz	60.17	58.12	61.70	59.88	0.16

*) POINTING LOSS may be included in RX ANTENNA GAIN.

**) Reference at Diplexer/RFDU Interface, 290 K input noise temperature.

***) Reference at Diplexer/RFDU Interface.

LINK ID : P35GAIA
DATE : 17/06/2004 18:12
ORBIT : Lissajous L2 ALTITUDE (1000km): 1680
STATION : Perth 35-m ELEVATION (deg): 5

TELECOMMAND BIT RATE (kb/sec) : 2.00 RANGING : No
TELEMETRY BIT RATE (kb/sec) : 5000.00 with CONCAT. CODING : Yes

UPLINK (2/2)

	NOM	ADV	FAV	MEAN	VAR	PDF
RX S/No.............dBHz	60.17	58.12	61.70	59.88	0.16	
MODULATION INDICES (*)						
TELECOMMAND.......rad pk	1.00	1.05	0.95	(sine)		
RANGING (RNG).....rad pk	0.65	0.68	0.62			
RNG, sine(1) or sqre(2):	1					
CARRIER RECOVERY						
CARRIER SUPPRESSION...dB	3.27	3.63	2.93	3.27	0.02	TRI
BPL (1), non-coh AGC (2)						
or coherent AGC (3) ?	3					
AGC INPUT BNDWDTH..kHz	7.95	8.75	7.16			
PLL-BDW 2*Blo (**)...Hz	100.00	120.00	80.00			
THRSHD C/N in 2*Blo...dB	15.00	(common Definition)				
PLL DAMPING (**).....	0.99	1.09	0.89			
Effect PLL DAMPING......	0.99	1.09	0.89			
Effect PLL-BDW 2*Bl...Hz	100.00	120.00	80.00			
Max ACQ SWEEP RATE.kHz/s	0.50	0.36	0.64	0.50		
Effect PLL-BDW 2*Bl.dBHz	20.00	20.79	19.03	19.94	0.13	TRI
BP-LIMT SYSTEM LOSS...dB	0.00	0.00	0.00	0.00	0.00	TRI
IMPLEMENTATION LOSS...dB	1.00	1.00	1.00	1.00	0.00	TRI
REQ C/N in PLL-BDW....dB	10.00	10.00	10.00	10.00		
CARRIER MARGIN........dB	25.90	22.70	28.73	25.66	0.31	
MEAN-3*SIGMA.......dB	24.00					
MARGIN - w.c. RSS..dB	24.54					
TELECOMMAND RECOVERY						
MODULATION LOSS.......dB	5.06	5.50	4.66	5.07	0.03	TRI
IMPLMENT LOSS (***)..dB	1.30	1.30	1.30	1.30	0.00	TRI
BIT RATE............kb/s	2.000	2.000	2.000			
BIT RATE............dBHz	33.01	33.01	33.01	33.01		
REQ Eb/No (****)..dB	9.60	9.60	9.60	9.60		
TELECOMMAND MARGIN....dB	11.19	8.71	13.13	10.89	0.19	
MEAN-3*SIGMA.......dB	9.60					
MARGIN - w.c. RSS..dB	10.07					
TRANSPD RANGING-CHANNEL						
TC in RNG-Vdbd ? Y=1/N=0	1					
TONE MODULATION LOSS..dB	9.54	10.20	8.92			
RNG NOISE BNDWIDTH...kHz	1400.00	1540.00	1260.00			
RNG NOISE BNDWIDTH..dBHz	61.46	61.88	61.00			
IMPLEMENTATION LOSS...dB	1.30	1.30	1.30			
S(Tone)/N in Videobd..dB	-12.13	-15.26	-9.53			
S(TC)/N in RG-Videobd.dB	-7.66	-5.27	-10.56			

*) ADV and FAV Cases refer HERE to the Carrier Recovery !
Variation of the Preset Indices is +/- 5 % .
**) Reference at Carrier Acquisition Threshold.
***) Demod Loss until TC Video Output; TC Decoder Loss not included.
****) Includes TC Decoder Implementation Losses.

LINK ID : P35GAIA PAGE 3/4
DATE : 17/06/2004 18:12
ORBIT : Lissajous L2 ALTITUDE (1000km): 1680
STATION : Perth 35-m ELEVATION (deg): 5

TELECOMMAND BIT RATE (kb/sec) : 2.00 RANGING : No
TELEMETRY BIT RATE (kb/sec) : 5000.00 with CONCAT. CODING : Yes

BASIC DOWNLINK (1/2)

	NOM	ADV	FAV	MEAN	VAR	PDF
S/C TX POWER.........dBW	17.00	17.00	17.00	17.00	0.00	TRI
DIPL. CIRCUIT LOSS....dB	0.00	0.00	0.00			
RFDU CIRCUIT LOSS.....dB	0.30	0.30	0.30			
CABLE LOSS............dB	0.26	0.30	0.26			
VSWR, overall.........:1	1.20	1.20	1.15			
VSWR LOSSES...........dB	0.04	0.04	0.02			
TOTAL LOSS............dB	0.60	0.64	0.58	0.61	0.00	UNI
S/C TX ANT GAIN......dBi	17.60	16.80	18.40	17.60	0.11	TRI
S/C ANT TX AXIAL RAT..dB	1.50	1.50	1.50			
POINTING LOSS (*)..dB	0.00	0.00	0.00	0.00	0.00	TRI
EIRP S/C.............dBW	34.00	33.16	34.82	33.99	0.11	
FREQUENCY............GHz	8.50	8.50	8.50	8.50		
SLANT RANGE......1000*km	1686	1686	1686	1686		
PATH LOSS.............dB	235.57	235.57	235.57	235.57		
ATMOSPHERIC LOSS......dB	0.50	0.60	0.40	0.50	0.00	GAU
IONOSPHERIC LOSS......dB	0.00	0.00	0.00	0.00	0.00	GAU
COPOLAR ANT-GAINS(Y=1/N=0)?	0					
POLARISATION MISMATCH.dB	0.06	0.09	0.03	0.06	0.00	UNI
TOTAL PROPAG. LOSS....dB	236.12	236.26	236.00	236.13	0.00	
FLUX at G/S......dBm/m^2	-131.52	-132.36	-130.71	-131.54	0.11	
POWER FLUX DENS..dBW/m^2	-164.99	-163.46	-166.66	(in 4 kHz)		
MAXIM FLUX DENS..dBW/m^2	-150.00	-150.00	-150.00	(S- or X-Bnd)		

FLUX MARGIN...........dB	14.99	13.46	16.66

G/S RX ANT GAIN......dBi	68.00	68.00	68.00	68.00	0.00	UNI
POINTING LOSS.........dB	0.30	0.40	0.00	0.20	0.01	UNI
G/S ANT RX AXIAL RAT..dB	0.50	1.00	0.00			
SYSTEM NOISE TEMP....dBK	17.90	18.40	17.90	18.15	0.01	GAU
RX G/T..............dB/K	50.10	49.60	50.10	49.85	0.01	

RX S/No.............dBHz	76.28	74.71	77.52	76.11	0.13

S/N in RANGING BANDWIDTH			
S(Tone)/N in Videobd..dB	-12.13	-15.26	-9.53
S(TC)/N in RG-Videobd.dB	-7.66	-5.27	-10.56

MODULATION INDICES (**)			
TELEMETRY (TM)....rad pk	1.20	1.32	1.08
TM, sine(1) or sqre(2) :	1		
RANGING (sine)....rad pk	0.00	0.00	0.00
RANG. TONE effec..rad pk	0.00	0.00	0.00
TC in RG-Videobd..rad pk	0.00	0.00	0.00
NOISE INDEX.............	0.00	0.00	0.00

*) POINTING LOSS may be included in TX ANTENNA GAIN.
**) ADV and FAV Cases refer HERE to the Carrier Recovery !
Variation of the Preset Indices is +/- 10 % .

LINK ID : P35GAIA **PAGE 4/4**
DATE : 17/06/2004 18:12
ORBIT : Lissajous L2 ALTITUDE (1000km): 1680
STATION : Perth 35-m ELEVATION (deg): 5

TELECOMMAND BIT RATE (kb/sec) : 2.00 RANGING : No
TELEMETRY BIT RATE (kb/sec) : 5000.00 with CONCAT. CODING : Yes

DOWNLINK (2/2)

	NOM	ADV	FAV	MEAN	VAR	PDF
RX S/No............dBHz	76.28	74.71	77.52	76.11	0.13	
CARRIER RECOVERY						
CARRIER SUPPRESSION...dB	3.46	4.30	2.75	3.50	0.10	TRI
PLL BANDWIDTH 2*Bl...Hz	*10.00*	12.00	8.00			
PLL BANDWIDTH.......dBHz	10.00	10.79	9.03	9.94	0.13	TRI
REQ LOOP S/N..........dB	*25.00*	25.00	25.00	25.00		
CARRIER MARGIN........dB	37.82	34.62	40.74	37.67	0.36	
MEAN-3*SIGMA.......dB	35.87					
MARGIN - w.c. RSS..dB	36.32					
TELEMETRY RECOVERY						
TLM MODULATION LOSS...dB	3.04	3.64	2.56	3.08	0.05	TRI
DEMODULATOR TECH LOSS.dB	*0.40*	*0.50*	*0.30*	0.40	0.00	TRI
BIT RATE............kb/s	5000.00	5000.00	5000.00			
BIT RATE............dBHz	66.99	66.99	66.99	66.99		
CONCAT CODING GAIN(*).dB	*9.70*	9.70	9.70			
CODING RATE 1/R.........	2.29					
REQ Eb/No ....dB	*2.80*	2.80	2.80	2.80		
TELEMETRY MARGIN......dB	3.05	0.78	4.87	2.84	0.18	
MEAN-3*SIGMA.......dB	1.57					
MARGIN - w.c. RSS..dB	1.92					
TONE RECOVERY						
TONE MODULATION LOSS..dB	No RG	No RG	No RG	No RG		
IMPLEMENTATION LOSS...dB	0.00	0.00	0.00	0.00		
REQ S(Tone)/N.........dB	*19.00*	19.00	19.00	19.00		
MAX REQ LOOP-BDW(**).mHz	No RG	No RG	No RG	No RG		
COMB. CARR. JITTER (***)						
RX TRSPD-PLL JITT...deg	0.65	0.94	0.47	0.67		
TRANSMT CARR. JITT...deg	2.00	*3.00*	*1.00*	2.00		
JITT BDW 2*B (****)...Hz	*5.00*	*10.00*	*3.00*	6.50		
RX COMBD CARR JITT...deg	1.09	1.91	0.60	1.60		

*) PFL=Probability of Frame Loss. Transfer Frame Length
is FS=1275 Octets, and Interleaving Depth is I=5.
**) The required MINIMUM Loop-Bandwith supported by MPTS is 1.25 mHz;
the MAXIMUM Loop-Bandwidth (two-sided) is 1880 mHz.
***) Coherent transponder mode assumed for RX COMBD CARR JITTer at G/S.
****) 2*B is the bandwidth of the jitter from the TX chain or a HPA.

Appendix C Atmospheric Attenuation Profiles

Atmospheric attenuation profiles for the various ground stations are provided for 5º and 10º elevation. These have been produced using the RAPIDS software implementing the relevant ITU recommendations.

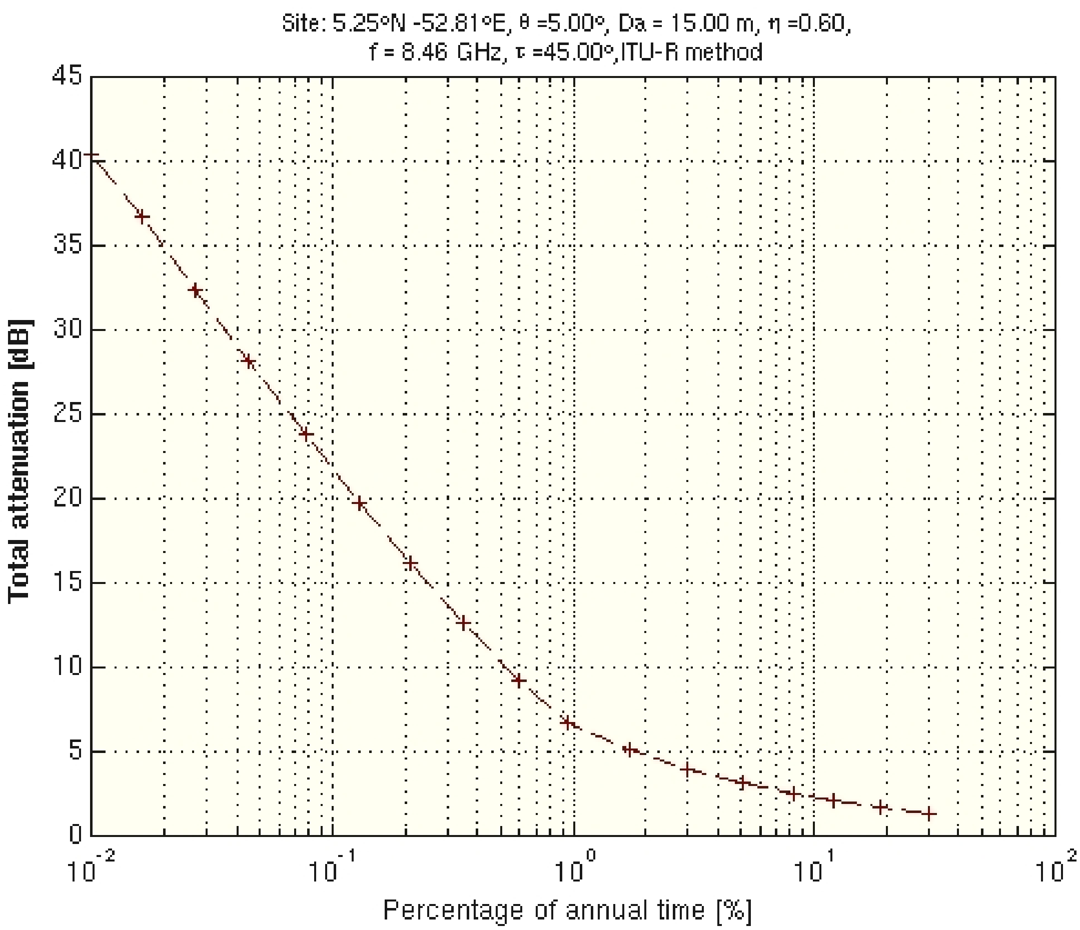

Figure 4-1 Atmospheric attenuation Kourou at 5 deg elevation

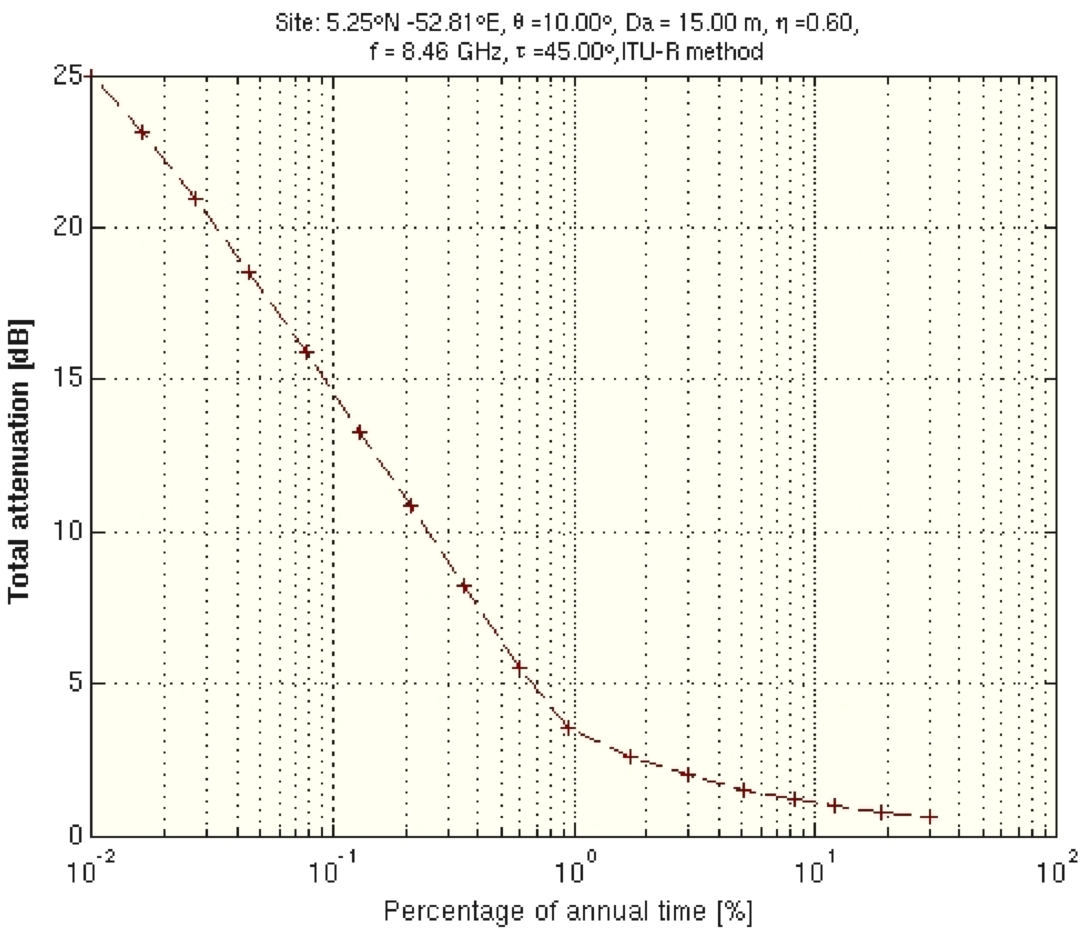

Figure 4-2 **Atmospheric attenuation Kourou at 10 deg elevation**

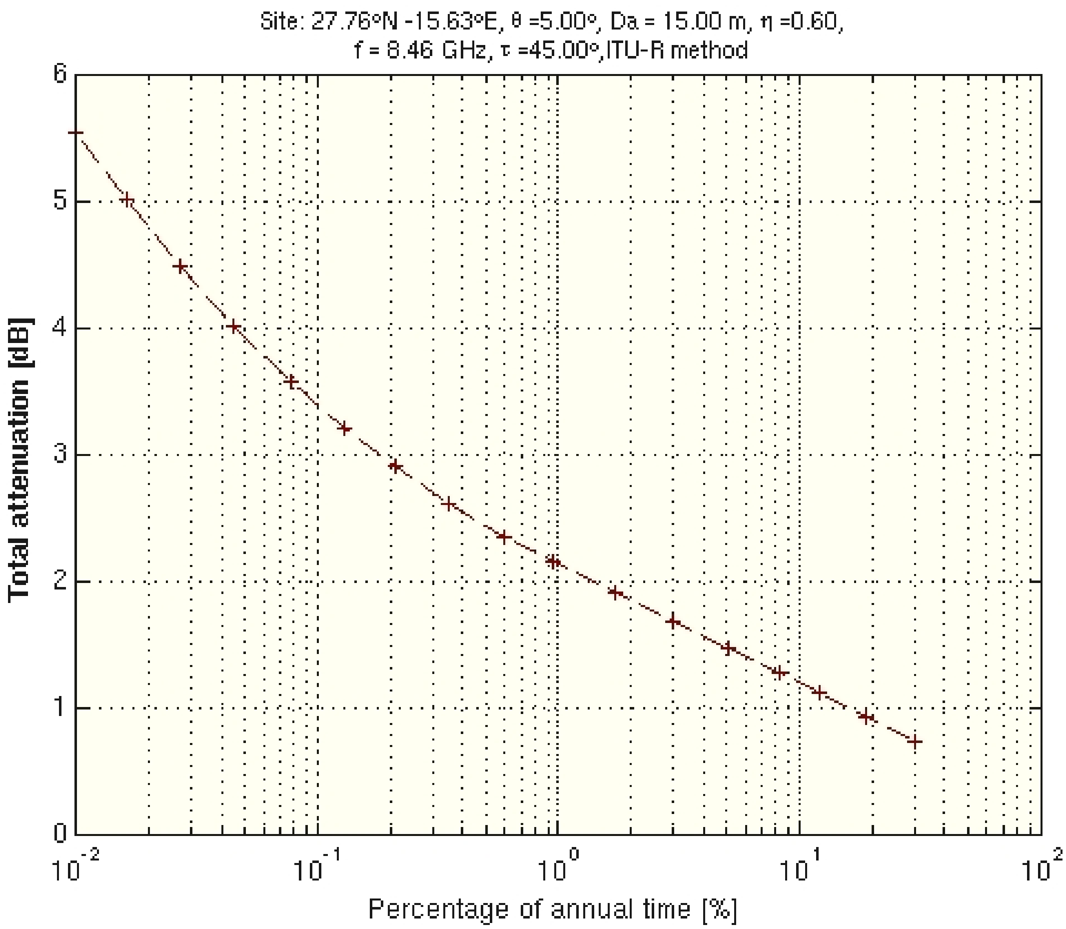

Figure 4-3 Atmospheric attenuation Maspalomas at 5 deg elevation

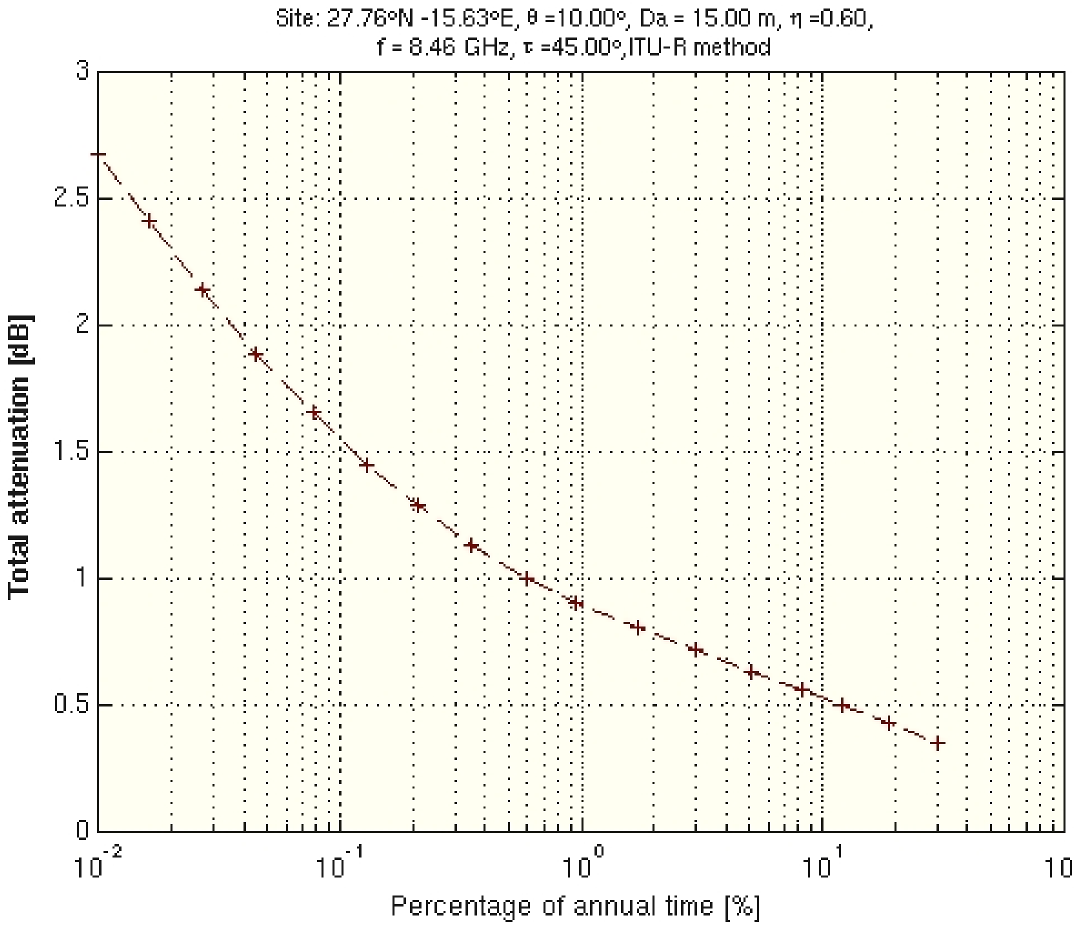

Figure 4-4 Atmospheric attenuation Maspalomas at 10 deg elevation

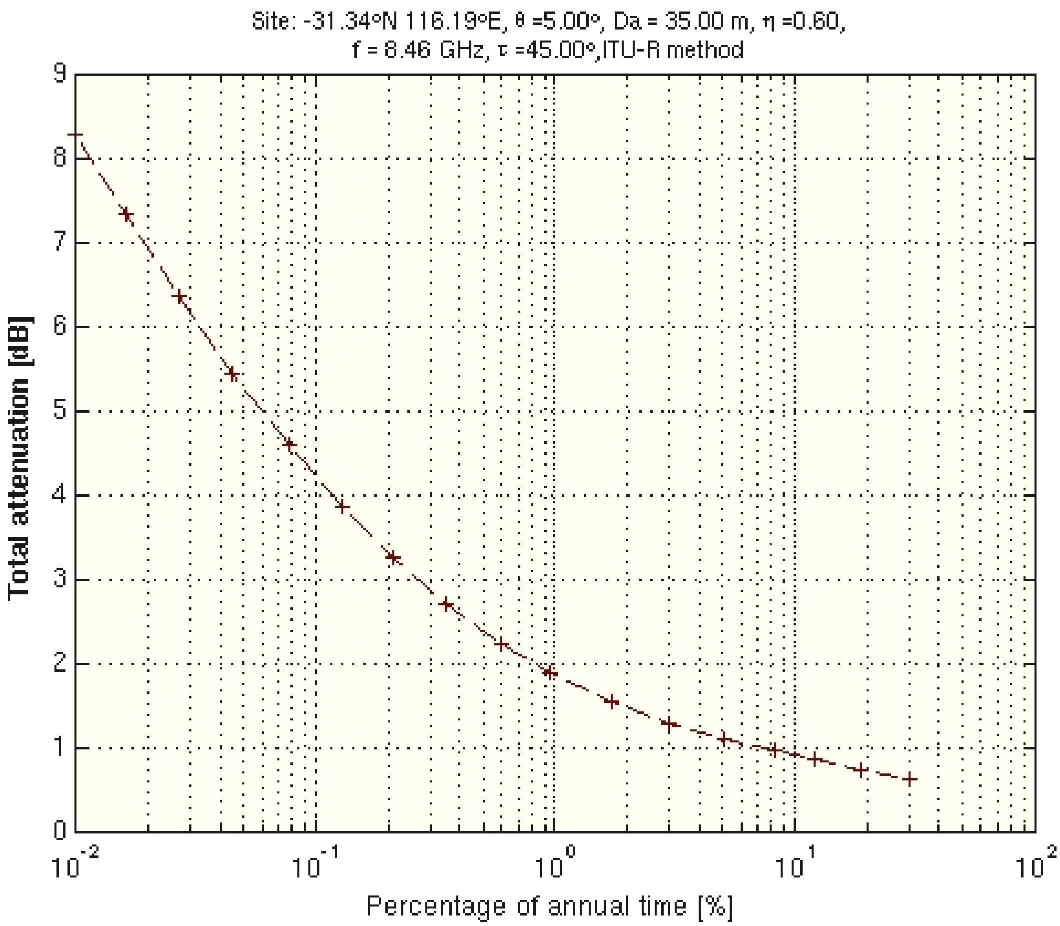

Figure 4-5 Atmospheric attenuation New Norcia at 5 deg elevation

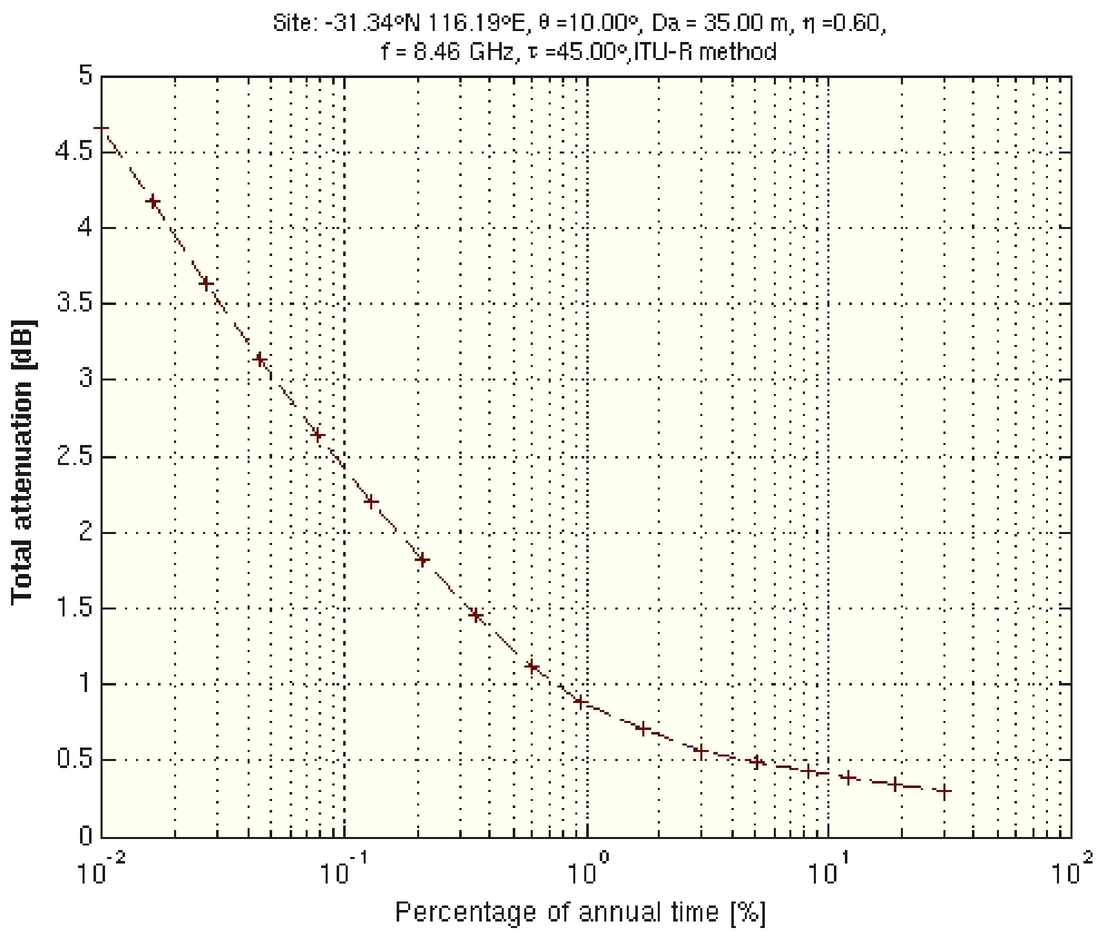

Figure 4-6 **Atmospheric attenuation New Norcia at 10 deg elevation**

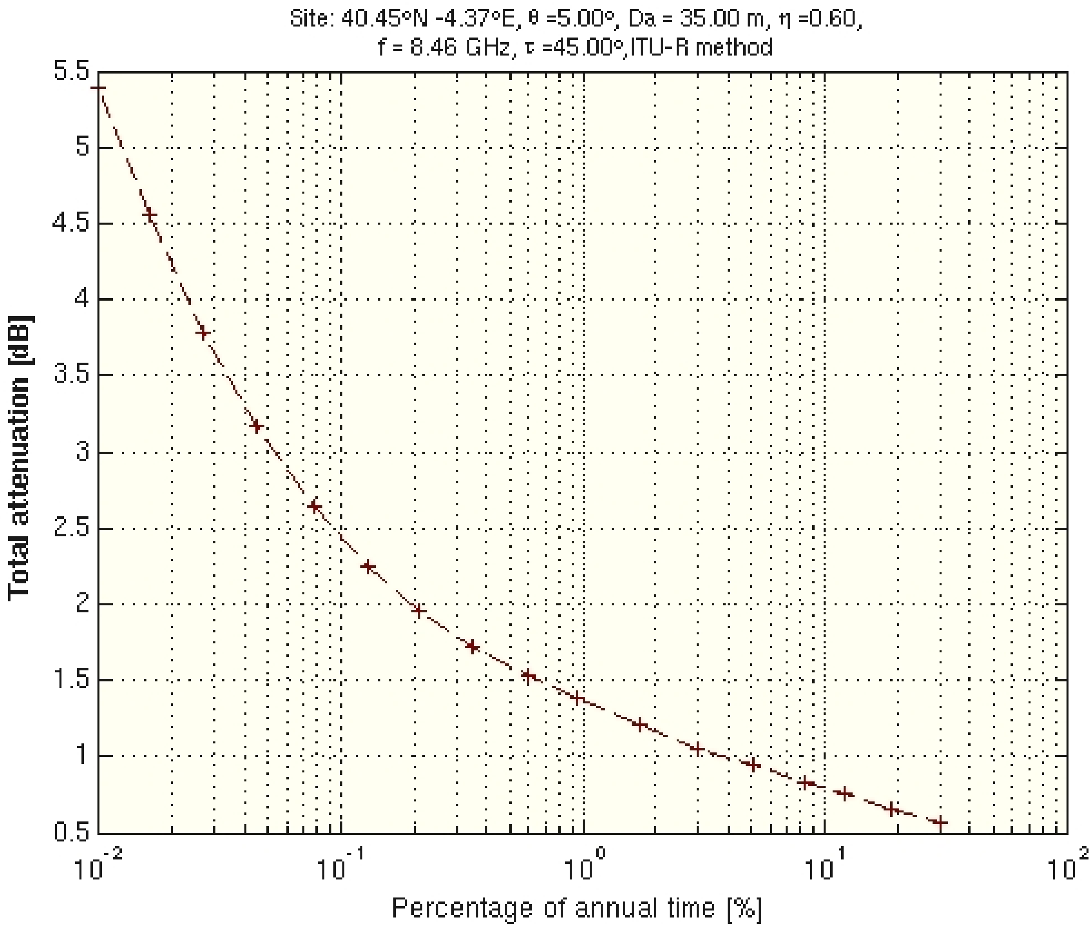

Figure 4-7 Atmospheric attenuation Cebreros at 5 deg elevation

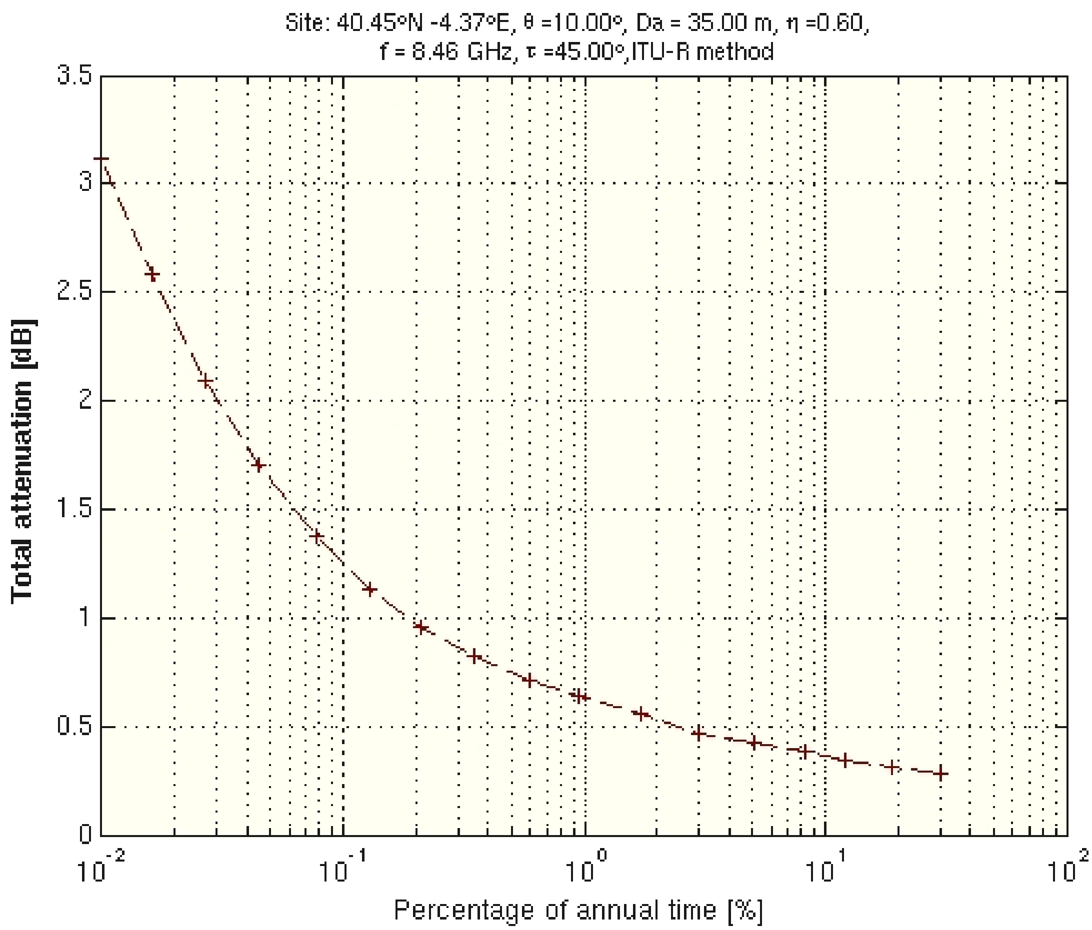

Figure 4-8 Atmospheric attenuation Cebreros at 10 deg elevation

Appendix D Telemetry Bit/Symbol Rate Definition & Bit Error Rates

The on-board functions that concur to the generation of the transmitted telemetry frame are shown below. Figure 4-9 and Figure 4-10 provide a summary of the encoding and decoding processes on-board and on-ground. In the second part of this appendix bit and frame error rates are shown.

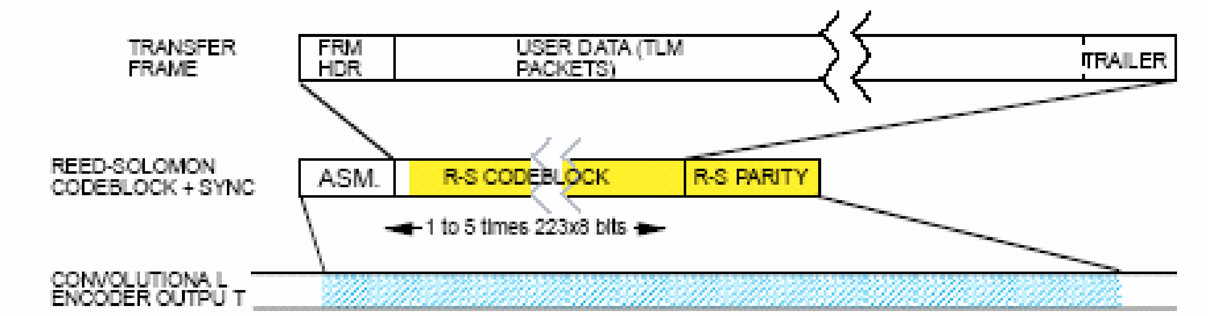

Figure 4-9 Encoding process

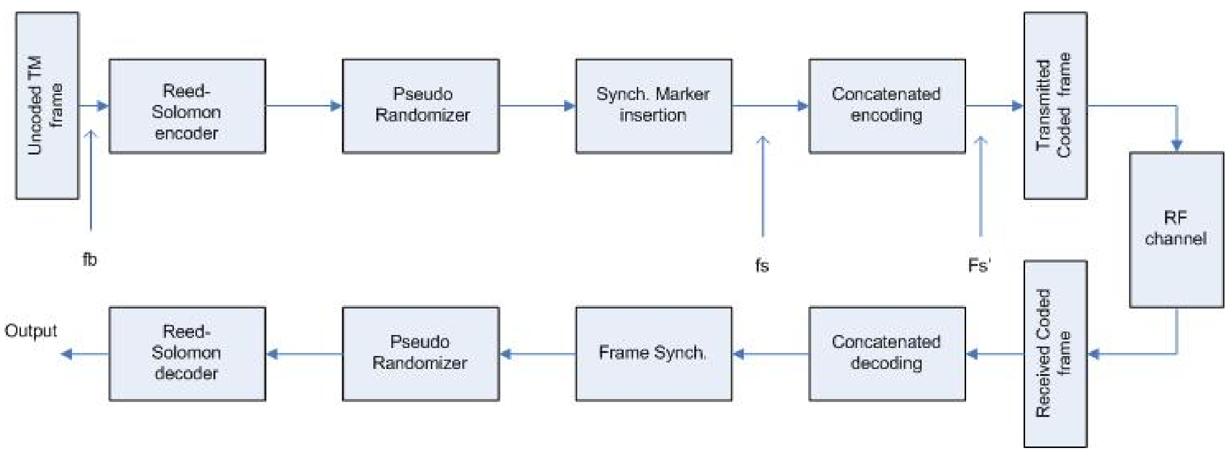

Figure 4-10 End-to-end Telemetry Coding and Decoding Scheme

Concatenated Encoding

<u>Frame structure before convolutional encoding:</u>

32	8920	1280

R-S plus header:
Synch. Marker = 32 bits Data Field = 8920 bits R-S trailer = 1280 bits

Defining: fs = data rate at convolutional encoder input
fb = information bit rate

yields:

$$\frac{f_s}{f_b} = \frac{32 + 8920 + 1280}{8920} = \frac{10232}{8920} \approx 1.147085$$

Example: f_s=32.768 kb/s corresponds to an information rate f_b=28.56632 kb/s

Frame structure after convolutional encoding:
The structure is the same as before. However, the concatenated encoder (convolutional and punctured) will add error correction bits depending on the selected rate to achieve the required Bit Error Rate (e.g. in the case of rate 1/2 the encoder will double every bit). Therefore, the frame length will be twice as long or 20464 symbols.

Moreover, what counts is the symbol rate at the modulator input or at the convolutional encoder output. For the standard rate ½ code, this is given by:

$$\frac{f_s'}{f_b} = 2\frac{f_s}{f_b} = 2\frac{10232}{8920} \approx 2.29417$$

where f_s' is the transmitted symbol rate.
Example: The information rate f_b=28.56632 kb/s above given corresponds to a transmitted symbol rate f_s'=65.536 ks/s.

Bit and Frame Error Rates for Punctured Coding Schemes

The following graphs present the simulated Bit and Frame error rates vs E_b/N_0 simulated performance for the CCSDS Concatenated Scheme with Outer *E*=16 Reed-Solomon Code (255,223) and Inner Punctured Convolutional Code, using finite interleaving with *I*=5 (courtesy of Prof. Chiaraluce, Universita' Politecnica delle Marche (Italy.)).

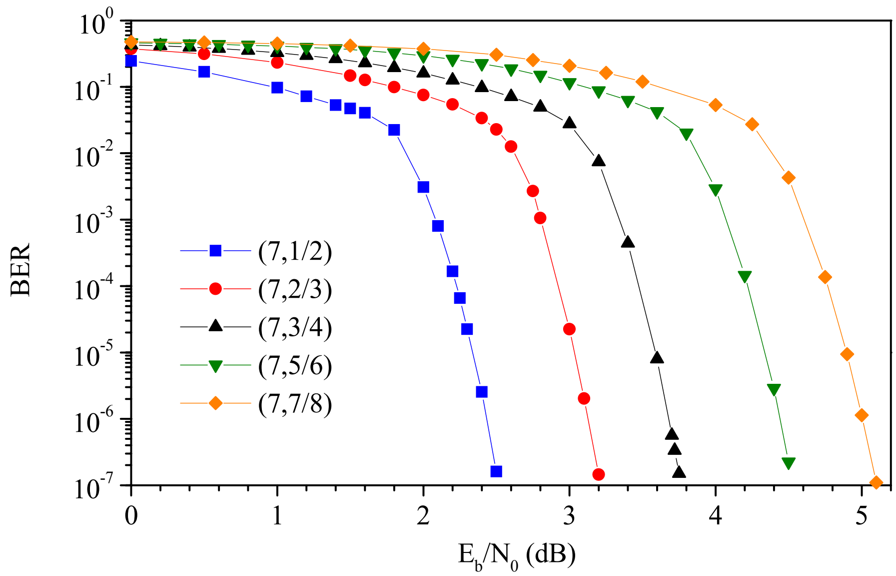

Figure 6-9 **Bit error rate over E_b/N_0 for punctured coding rates 1/2, 2/3, 3/4, 5/6, 7/8**

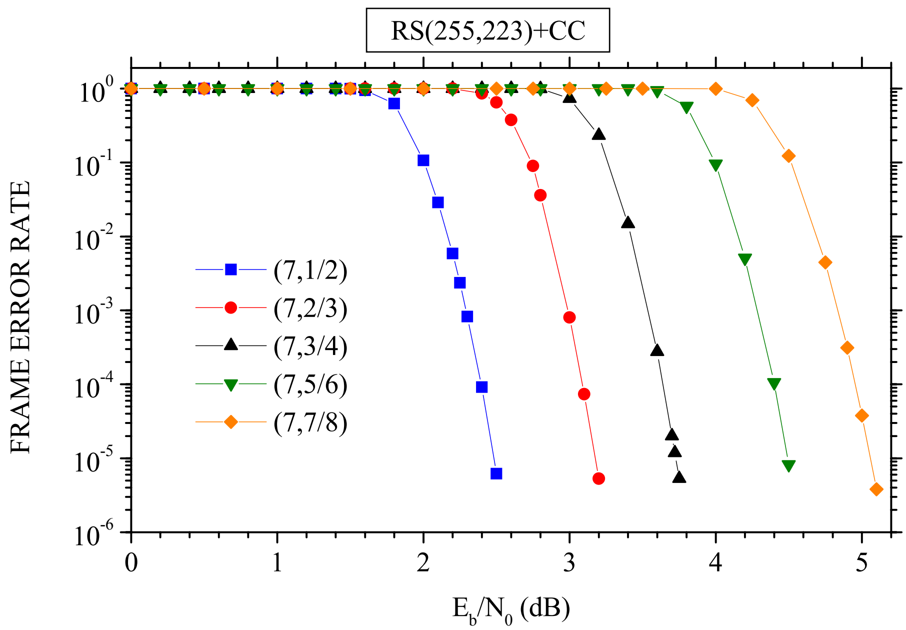

Figure 6-10 Frame error rate over E_b/N_0 for punctured coding rates 1/2, 2/3, 3/4, 5/6, 7/8

Appendix E Spectral Emission Masks.

See § 6.3 of [AD-5].