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RADIO FREQUENCY AND MODULATION
Reference Document

Prepared by:
The Standards Approval Board (STAB)
for Space Data Communications

SPACE DATA COMMUNICATIONS
PROCEDURES, SPECIFICATIONS & STANDARDS

Space Data Communications is the subject of the PSS-04 branch of the ESA Procedures, Specifications & Standards (PSS) series. This branch is further divided into two subbranches:

- the Space Link Standards and Protocols subbranch (document reference nos.: ESA PSS-04-1XX);

- the Spacecraft Data Interfaces and Protocols subbranch (document reference nos.: ESA PSS-04-2XX).

This document has the purpose of ensuring the compatibility of spacecraft TT&C subsystems with the relevant ESA infrastructure (i.e. the ESA (ESOC) tracking and data-communication network and the ESA (ESTEC) satellite check-out facilities).

DOCUMENT CHANGE RECORD

Date	Issue	Chapter	Description of Changes
April 1995	Draft Issue 2.1	all chapters	Changes in agreement with the Rationale for updating the currently applicable Issue 1 of December 1989
Dec. 1995	Draft Issue 2.2	all chapters	Changes in agreement with decisions taken by Panel members
June 1996	Draft Issue 2.3	chapter 5, App. B and D	Changes in agreement with decisions taken by Panel members
Nov. 1996	Draft Issue 2.4	chapter 6 and 7	Changes in agreement with decisions taken by Panel members

REFERENCES

[1] Ranging Standard (ESA PSS-04-104), Issue 2 of Volume 1, March 1991, European Space Agency.

[2] Telemetry Channel Coding Standard (ESA PSS-04-103), Issue 1, September 1989, European Space Agency.

[3] Packet Telemetry Standard (ESA PSS-04-106), Issue 1, January 1988, European Space Agency.

[4] Packet Telecommand Standard (ESA PSS-04-107), Issue 2, April 1992, European Space Agency.

[5] ITU Radio Regulations, Edition 1994, Geneva

[6] CCSDS Radio Frequency and Modulation Systems, Part 1, Earth Stations and Spacecraft, Blue Book, CCSDS 401.0-B, November 1994

[7] Handbook of the Space Frequency Coordination Group, Edition October 1996

CONTENTS

1. PURPOSE AND SCOPE

1.1 PURPOSE

The purpose of this Document is to:

- Ensure compatibility of frequency usage and modulation schemes between ESA spacecraft and ESA-controlled Earth stations (ESTRACK) for the SPACE OPERATION, SPACE RESEARCH and EARTH EXPLORATION SATELLITE services;

- Ensure, so far as possible, compatibility between the Agency's spacecraft and other networks with which they may have to work;

- Ensure standardisation of frequency usage and modulation schemes within the Agency;

- Ensure the compliance of ESA spacecraft and Earth station parameters with international radio regulatory provisions (Radio Regulations of the International Telecommunication Union (ITU)) and with national regulatory provisions (e.g. national frequency plans);

- Ensure that the parameters of ESA spacecraft and Earth stations are properly chosen and listed in advance of their use, thus permitting coordination with other interested parties;

- Ensure that, within the above limitations, the frequency usage and modulation schemes of the Agency are optimised.

1.2 SCOPE

This Document defines the radio communication techniques to be used for the transfer of information between spacecraft and Earth stations in both directions, and for the tracking systems required for orbit determination. It comprises the following subjects:

- Frequency allocation, assignment and use.

- Requirements on transmitted signals concerning spectral occupation, RF power levels, protection of other radio services, etc.

- Definition of the permissible modulation methods and parameters.

- Specification of the major technical requirements which are relevant for the interface between spacecraft and Earth stations.

- Operational aspects, e.g. acquisition.

- Cross-support.

2. APPLICABILITY

This Document is applicable to all ESA spacecraft which are supported by Earth-stations[1] and to all ESA controlled Earth stations (ESTRACK) operating in the SPACE OPERATIONS, SPACE RESEARCH and EARTH EXPLORATION SATELLITE services as defined in the ITU Radio Regulations.[2]

Other space telecommunication services are not covered in the present issue. Standards for these services will be added as and when they are developed.

The requirements specified by this document supersede any similar requirements contained in any of the related standards published prior to this Issue. In the case of conflict, this Document shall take precedence.

For particular cases where compliance with this Document is not feasible, owing to mission-specific requirements, deviations may be warranted. Waivers to requirements defined in this Document may be obtained when:

- the technical and/or operational need for such deviations has been demonstrated and
- it has been demonstrated that the intended change can be supported by existing systems.

Waivers to provisions of the ITU Radio Regulations cannot be granted.

Requests for waivers should be addressed by the Project manager to the ESA Standards Approval Board (STAB) for Space Data Communications. Such requests should be submitted as early as possible, preferably during the study phase of the project.

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1 For ESA spacecraft supported by data relay satellites, RD-04-109 is applicable.

2 This Document is not applicable to the Meteorological Satellite service.

3. FREQUENCY ALLOCATIONS, ASSIGNMENT AND USE

3.1 FREQUENCY ALLOCATIONS TO THE SPACE OPERATION, SPACE RESEARCH AND EARTH EXPLORATION SATELLITE SERVICES

3.1.1 General

The use of frequencies by radiocommunication services is governed by the provisions of the Radio Regulations of the International Telecommunication Union (ITU/RR) Consequently, any frequency assignment made to a particular user (spacecraft) has to be made in accordance with the ITU/RR, which

- define the various radiocommunication services (see Subsection 3.1.2),
- allocate frequency bands to them (see Subsection 3.1.3),
- lay down procedures to be followed for a frequency assignment and the frequency notification with the Radiocommunications Bureau of the ITU (see Subsection 3.3),
- specify technical conditions for the frequency use (see Section 4).

3.1.2 Definitions of the Space Radio Communication Services

Space Operation Service (SO), (ITU/RR/25 [5])

"A radiocommunication service concerned exclusively with the operation of spacecraft, in particular space tracking, space telemetry and space (tele)command (TTC). These functions will normally be provided within the service in which the spacecraft is operating".

Earth Exploration Satellite Service (EES), (ITU/RR48 [5])

"A radiocommunication service between Earth stations and one or more space stations, which may include links between space stations, in which:

- information relating to the characteristics of the Earth and its natural phenomena, including data relating to the state of the environment, is obtained from active sensors or passive sensors on Earth satellites;
- similar information is collected from airborne or Earth-based platforms;
- such information may be distributed to Earth stations within the system concerned;
- platform interrogations may be included.

This service may also include feeder links necessary for its operation"

Space Research Service (SR), (ITU/RR/52 [5])

"A radio communication service in which spacecraft and other objects in space are used for scientific and technological research".

Deep Space (DS) (ITU/RR/169 [5])

"Space at distances from the Earth of equal to, or greater than, 2×10^6 kilometers".

The following terminology will be used in this document:

Category A: Those spacecraft having an altitude above the Earth's surface of less than 2×10^6 km.

Category B: Those spacecraft having an altitude above the Earth's surfaceof equal to, or greater than, 2×10^6 km.

3.1.3 Frequency Bands Allocated to the Space Radiocommunications Services in the Framework of this Document

The following frequency bands, allocated to the above listed radiocommunication services, are available to ESA satellites operating in one or several of the above radiocommunications services (see Table 3.1):

Frequency Band (MHz) (1),(2)	Allocated Service (3)	Direction	Allocation Status (5)
2025 - 2110	SR, SO, EES	Earth-space	PRIMARY
2110 - 2120	SR (DS)	Earth-space	PRIMARY
2200 - 2290	SR, SO, EES	Space-Earth	PRIMARY
2290 - 2300	SR (DS)	Space-Earth	PRIMARY
7145 - 7190 *	SR (DS)	Earth-space	FN (Art.14)
7190 - 7235 *	SR	Earth-space	FN (Art. 14)
8025 - 8400	EES	Space-Earth	FN (Art. 14)
8400 - 8450	SR (DS)	Space-Earth	PRIMARY
8450 - 8500	SR	Space-Earth	PRIMARY
14000 - 14300*	SR	Space-Earth (4)	secondary
14400 - 14470*	SR	Space-Earth	secondary
14500 - 15350*	SR	Space-Earth (4)	secondary
16600 - 17100*	SR	Earth-space	secondary
	SR (DS)	space-Earth	PRIMARY
31800 - 32300*	SR (DS)	Earth-space	PRIMARY
34200 - 34700*			
37000 - 38000*	SR	Space-Earth	PRIMARY
40000 - 40500*	SR	Earth-space	PRIMARY

TABLE 3.1: Frequency Allocations to the Space Operation, Space Research and Earth Exploration Services (6)

Explanatory Notes:

(1) Frequency Band Implementation Status

The frequency bands marked by an asterisk are notyet implemented in the ESTRACK Network. Any potentially interested user is invited to contact the responsible department for operations in ESA.

(2) Special Conditions Governing the Use of Particular Frequency Bands

The use of certain frequency bands is governed by specific conditions (see 3.2), which are laid down in SFCG and CCSDS RF and Modulation Subpanel Recommendations [6][7]. The ESA Frequency Management Office will inform applicants for frequency assignments (see 3.3 below) about any evolution of these conditions, which may have occurred since the issue of this Document.

(3) Use of Frequency Bands Allocated to the Space Research (Deep Space) Service

The frequency bands allocated to the Space Research (Deep Space) service shall only be used by category B spacecraft.

(4) Direction Indicator

SFCG recommends that these bands be used in the space-Earth direction [7].

(5) Allocation Status

The ITU RR define a number of different modes of allocations: PRIMARY, secondary, allocation by Footnote and allocations under Article 14.

Primary allocation:
A service with a primary allocation status

- must only share with other co-primary services, which may be allocated in the same band, under defined conditions.
- has priority over other allocations, such as secondary; it is not obliged to protect them or to accept interference caused by them.

Secondary allocation:
A service with a secondary allocation status

- shall not cause harmful interference to any station of a service allocated in the same band with a primary status.
- cannot claim protection from interference caused by stations of a primary service sharing the same frequency band.

Allocation by Footnote:
An allocation by footnote in the ITU/RR may contain additional regulatory conditions for the use of the frequency band, such as supplementary co-ordination in accordance with Art. 14, or limit the allocation to less than an entire ITU Region.

Allocation under Article 14:
In the context of this Document, this Article is only applicable to a few frequency bands; it contains a supplementary (co-ordination) procedure which stipulates a prior agreement with (an) administration(s) operating primary services in the band.

3.2 SPECIFIC CONDITIONS FOR THE USE OF CERTAIN FREQUENCY BANDS

3.2.1 2025 - 2110 MHz / 2200 - 2290 MHz

3.2.1.1 2025 - 2110 MHz

The 2025 - 2110 MHz band is allocated to Earth-space and space-space transmissions. In order to minimise interference to Earth-space links of other spacecraft or to space-space links from data relay satellites to user satellites, which are particularly susceptible to RFI, the EIRP transmitted from the Earth station shall be selected in such a way as to allow for the smallest practicable link margin. Earth station transmitters shall be equipped with adjustable RF output power.

Excessive Earth station EIRP not only complicates frequency coordination with other users, but may also prohibit operations totally at some sites. As a means of RFI mitigation, Earth-to-space transmissions may have to be interrupted during those periods, when they cause RFI to other (priority) users. With a view to alleviating the frequency sharing situation, operators shall abstain from activating the Earth-to-space links during periods when no ranging and/or telecommand operations are required.

3.2.1.2 2200 - 2290 MHz

The 2200 - 2290 MHz band is one of the most densely occupied bands allocated to the space science services, with an average occupation density in excess of 25 MHz assigned per each 1 MHz allocated. Frequently the only efficient means of RFI mitigation is to limit emissions from a spacecraft in this band to those periods, when it is over the coverage area of a receiving Earth station. Consequently the devices on spacecraft used to switch-off emissions shall be designed with the highest practicable level of reliability and be qualified for a large number of switching cycles during the spacecraft lifetime (see also 4.5.2).

3.2.2 8025 - 8400 MHz

The 8025 - 8400 MHz band is the only direct data transmission band allocated to the Earth Exploration Satellite service below 20 GHz. Its occupation density is similar to that of the 2200 - 2290 MHz band; additionally the interference situation is aggravated by the fact that most of the Earth exploration satellites use very similar (polar) orbits Consequently the same RFI mitigation methods specified for the 2200 -2290 MHz band, i.e. limitation of emissions, shall be applicable in the 8025 - 8400 MHz band.

3.2.3 8450 - 8500 MHz

The maximum occupied bandwidth for spacecraft in this band shall not exceed 10 MHz.

3.2.4 16.6 - 17.1 GHz / 14.0 - 15.35 GHz

The 16.6 - 17.1 GHz (Earth-space) and 14.0 - 15.35 GHz (space-Earth) bands are to be used for transmission of wideband data only, with an occupied bandwidth larger than 10 MHz. Because of the difficult sharing environment prevailing in these bands, spacecraft shall use on both the Earth-space and space-Earth links spread spectrum types of modulations.

The 16.6 - 17.1 GHz band is currently still allocated to space Research (Deep Space). SFCG is seeking regulatory action from ITU/WRC-97 to remove the limitation to Deep Space.

3.2.5 40.0 - 40.5 GHz / 37.0 - 38 GHz

Future use of the 40.0 - 40.5 GHz and 37.0 - 38.0 GHz bands is still under consideration in the SFCG. Any project, which is potentially interested in the use of this band shall contact the ESA Frequency Management Office for further guidance.

3.3 FREQUENCY ASSIGNMENT PROCEDURE

3.3.1 Choice of Frequencies

Prior to Phase B of any spacecraft project, the project manager shall request the frequency assignments required for the spacecraft. For this purpose he shall provide to the ESA Frequency Management Office the information listed in Appendix B; he shall indicate which of the information supplied is still in a preliminary state and will have to be confirmed at a later date.

The entire procedure is carried out under the responsibility of the Frequency Management Office, which has the exclusive authority within the Agency to assign frequencies.

All requests for frequency assignments and/or inquiries regarding frequency management matters shall be addressed to:

Frequency Management Office
ESA
8 - 10 rue Mario-Nikis
F - 75738 PARIS CEDEX 15
Telephone: + 33-1-53697302
Telefax: + 33-1-53697286

3.3.2 Notification of Frequencies

Not later than 3 years before the planned launch date, the project manager shall provide to the ESA Frequency Management Office the data required to coordinate and notify to the Radiocommunications Bureau of the ITU the frequencies used by the spacecraft. The format of Appendix B shall be used for this purpose. At this stage the data supplied as per Appendix B must be the final.

The ESA Frequency Management Office is responsible for the procedural steps required by the ITU Radio Regulations, for both the spacecraft and all associated Earth stations.

4. REQUIREMENTS ON TRANSMITTED SIGNALS

4.1 TURNAROUND FREQUENCY RATIO FOR COHERENT TRANSPONDERS

Transponders, flown on the spacecraft for the purpose of coherent Doppler tracking, shall generate the transmitted carrier from the received carrier by means of phase-lock techniques. Band pairs shall be selected from table 4.1 together with the applicable turnaround ratio.

	Earth-Space (MHz)	Space-Earth (MHz)	Turnaround ratio (f_{up}/f_{down})
CATEGORY A	2025.833 333 - 2108.708 333	2200 - 2290	221/240
	2074.944 444 - 2087.222 222	8450 - 8500	221/900
	7190 - 7235	2255.686 275 - 2269.803 922	765/240
	7192.102 273 - 7234.659 091	8450 - 8500	749/880
	7190 - 7225.000 000	8458.823 529 - 8500	765/900 [3]
CATEGORY B	2 110.243 056 - 2 117.746 142	2 291.666 667 - 2 299.814 815	221/240
	2 110.243 056 - 2 119.793 438	8 402.777 780 - 8 440.802 468	221/880
	7 147.286 265 - 7 177.338 735	2 290.185 185 - 2 299.814 815	749/240
	7 149.597 994 - 7 188.897 377	8 400.061 729 - 8 446.234 569	749/880
	2 110.243 056 - 2 119.792 438	31 930.555 556 - 32 075.049 383	221/3344
	7 147.286 265 - 7 188.897 377	31 909.913 580 - 32 095.691 358	749/3344
	34 343.235 339 - 34 487.639 661	2 290.185 185 - 2 299.814 815	3599/240
	34 354.343 368 - 34 554.287 799	8 400.061 729 - 8 448.950 615	3599/880

TABLE 4.1: TURNAROUND FREQUENCY RATIOS FOR COHERENT TRANSPONDER OPERATION

[3] This ratio should only be used for fully coherent systems with 2/7/8 GHz links. Otherwise the ratio 749/880 is preferred.

4.2 CARRIER FREQUENCY STABILITY REQUIREMENTS

4.2.1 Spacecraft Transmitter

The frequency stability of the transmitted RF carriers shall be better than the values given in Table 4.2.

Frequency band (MHz)	Frequency stability requirement
2200 - 2290 8450 - 8500	$\pm 2\times10^{-5}$ under all conditions and for the lifetime of the spacecraft
8025 - 8400	$\pm 2\times10^{-5}$
2290 - 2300 8400 - 8450	(I) $\pm 2\times10^{-5}$ under all conditions and for the lifetime of the spacecraft (ii) $\pm 1.5\times10^{-6}$ at any one temperature of transmitter in range +10° to +40° in any 15 hrs following 4 hrs warm-up (iii) $\pm 0.2\times10^{-6}$/°C within the transmitter temperature range +10°C to +40°C (iv) Ageing $\pm 2.5\times10^{-6}$ per year

TABLE 4.2: FREQUENCY STABILITY REQUIREMENTS FOR SPACECRAFT TRANSMITTERS

4.2.2 Spacecraft Receiver

The frequency stability of spacecraft receivers shall be better than the values given in Table 4.3. For phase lock loop receivers the frequency referred to is the best lock frequency.

Frequency band (MHz)	Frequency stability requirement
2025 - 2110 7190 - 7235	$\pm1.7\times10^{-5}$ (2 GHz band) $\pm2\times10^{-5}$ (7 GHz band) under all conditions including $\pm4.8\times10^{6}$ initial setting error. Ageing over seven years $\pm7.1\times10^{6}$
2110 - 2120 7145 - 7190	(i) $\pm1.7\times10^{-5}$ (2 GHz band) $\pm2\times10^{-5}$ (7 GHz band)under all conditions including $\pm4.8\times10^{-6}$ initial setting error (ii) $\pm1.7\times10^{-6}$ at any one temperature in the range +10° to +40°C in any 15 hrs after a warm-up period of 4 hrs (iii) $\pm2.4\times10^{-7}$/°C over the temperature range + 10°C to +40°C (iv) Ageing $\pm3.0\times10^{-6}$ per year

TABLE 4.3: FREQUENCY STABILITY REQUIREMENTS FOR SPACECRAFT RECEIVERS

4.2.3 Ground Station Equipment

The RF carriers transmitted by the Earth station shall be phase locked to a reference frequency standard having an accuracy better than $\pm5\times10^{9}$ under all conditions.

4.2.4 Requirements for Doppler Tracking

Special requirements on frequency stabilities for Ranging and Doppler tracking are specified in [1].

4.3 POLARISATION

Earth-to-space links shall be circularly polarised.[4] Earth stations shall be capable of transmitting right- or left-hand circular polarisation at the choice of the user.

For practical reasons, spacecraft generally use the same sense of polarisation for the Earth-to-space link and the space-to-Earth link.

ESA Earth stations have the capability of combining 2 orthogonal circular polarisations on the space-to-Earth link.

4 The sense of polarisation shall be defined as follows: For a right-hand circularly -polarised wave, the electric field vector, observed in any fixed plane, normal to the direction of propagation, whilst looking in the direction of propagation, rotates with time in a right-hand or clockwise direction [5].

4.4 BANDWIDTH CONSIDERATIONS

4.4.1 Definitions

OCCUPIED BANDWIDTH (ITU/RR/147)

The width of a frequency band such that, below the lower and above the upper frequency limits, the mean powers emitted are each equal to a specified percentage ß/2 of the total mean power of a given emission. [5]

For the purpose of this Document, the value of ß/2 shall be 0.5%.

NECESSARY BANDWIDTH (ITU/RR/146)

For a given class of emission, the width of the frequency band which is just sufficient to ensure the transmission of information at a rate and with the quality required under the specified conditions. [5]

UNWANTED EMISSIONS (ITU/RR/140)

Consists of spurious emissions and out-of-band emissions. [5]

SPURIOUS EMISSION (ITU/RR/139)

Emissions on a frequency, or frequencies, which are outside the necessary bandwidth and the level of which may be reduced without affecting the corresponding transmission of information. Spurious emissions include harmonic emissions, parasitic emissions, intermodulation products and frequency conversion products but exclude out-of-band emissions. [5]

OUT-OF-BAND EMISSION (ITU/RR/138)

Emission on a frequency or frequencies immediately outside the necessary bandwidth which results from the modulation process, but excluding spurious emissions. [5]

SPECTRAL MASK

A radio-frequency spectral mask is a definition of the upper limits to the emitted spectral power density where the reference bandwidth shall be 1 kHz, the 0 dB reference shall be the maximum spectral density and the frequency band shall extend at least to the -60 dB points.

4.4.2 Requirements on Occupied Bandwidth

All efforts should be made to restrict the occupied bandwidth. A standard approach to achieve the desired bandwidth, cannot be specified, since the different modulation schemes will require different techniques (ITU/RR/2612).

Specific requirements on occupied bandwidth are listed in Table 4.4 with f_t being the ranging tone frequency and R_s being the symbol rate.

Frequency Band (MHz)	Function		Maximum Occupied Bandwidth (kHz)
2025 - 2120 and 7145 - 7235	Telecommand (8 kHz subcarrier)	Category A & B	50
	Telecommand (16 kHz subcarrier)		100
	Telecommand (direct modulation)		$12 \times R_s$
	Ranging		$2.5 \times f_t$
2200 - 2290 and 8450 - 8500	Telemetry (symbol rate < 10 ks/s) Category A		300
	Telemetry PCM/PSK/PM (10 ks/s ≤ symb. rate ≤ 60 ks/s) Category A		1200 or $30 \times R_s$, whichever is smaller[5]
	Telemetry (symbol rate > 60 ks/s) Category A		1200 or $12 \times R_s$ whichever is larger, up to 5 MHz at 2 GHz and 10 MHz at 8 GHz
	Ranging space-to-Earth Category A		$2.5 \times f_t$
8025 - 8400	Telemetry		TBD
2290 - 2300 and 8400 - 8450	Ranging space-to-Earth Telemetry Category B		[6]

TABLE 4.4: REQUIREMENTS ON OCCUPIED BANDWIDTH

[5] For missions with several data rates, the occupied bandwidth for the highest data rate may also be applied to lower rate modes

[6] No special requirement exists

4.5 REQUIREMENTS ON EMISSIONS

4.5.1 Spurious Emission Power Level

4.5.1.1 Transmitter Spurious Emissions and Harmonics

The spurious emissions including harmonics generated by spacecraft transmitters shall not exceed the levels given in Table 4.5.

Frequency band (MHz)	Maximum spurious level
100 - 10000 (Category A)	The spurious emissions generated by spacecraft shall not exceed [-60 dBc][7] measured in a reference bandwidth of 100 Hz at all frequencies. They are applicable to both modulated and unmodulated transmissions.
100 - 10000 (Category B)	As above for energy associated with the carrier frequency, with the exception that carrier harmonics shall be less than -10 dBc with respect to the fundamental.

TABLE 4.5: MAXIMUM LEVEL OF SPURIOUS EMISSIONS

4.5.1.2 Protection of Radio Astronomy Bands

Unwanted emissions falling into frequency bands of the Radio Astronomy service shall be kept to power flux spectral density values inferior to those given in Tables 4.6 and 4.7.

Centre frequency (MHz)	Observation bandwidth of spectral line (kHz)	Power flux spectral density (dBW/m²/Hz)
327	10	-244
1420	20	-239
1665	20	-237
4830	50	-230
14500	150	-221
22200	250	-216
23700	250	-215
43000	500	-210
48000	500	-209
88600	1000	-204
98000	1000	-203
115000	1000	-201

TABLE 4.6: HARMFUL INTERFERENCE LEVELS
FOR RADIOASTRONOMY LINE OBSERVATIONS

Note 7 This requirement shall be reviewed to ensure compliance with a future revision of ITU-R SM.329 expected during 1997.

Centre frequency (MHz)	Observation bandwidth (MHz)	Power flux spectral density (dBW/m²/Hz)
13.385	0.05	-248
25.610	0.120	-249
73.8	1.6	-258
151.525	2.95	-259
325.3	6.6	-258
408.05	3.9	-255
611	6.0	-253
1413.5	27	-255
1665	10	-251
2695	10	-247
4995	10	-241
10650	100	-240
15375	50	-233
23800	400	-233
31550	500	-228
43000	1000	-227
89000	6000	-222
110500	11000	-222

TABLE 4.7: HARMFUL INTERFERENCE LEVELS FOR RADIOASTRONOMY CONTINUUM OBSERVATIONS

In accordance with CCIR Report 224-7 excess of these values is considered harmful when illuminating a specific terrestrial radio astronomy site.

For continuum observations, it is acceptable to integrate the interferencepower over the specified observation bandwidth of table 4.7.

4.5.1.3 Protection of Deep Space Research Bands

Unwanted emissions falling into frequency bands of the Deep Space Research should be kept to power flux spectral density values inferior to those given in Tables 4.8 Whenever the limits of Table 4.8 cannot be met, coordination shall be initiated with the space research (deep space) users via the ESA FMO.

Frequency Band	Power Flux Spectral Density at Antenna Location (dBW/m²/Hz)
2290 - 2300 MHz	-257
8400 - 8450 MHz	-255
31.8 - 32.3 GHz	-251

TABLE 4.8: HARMFUL INTERFERENCE LEVELS AT DEEP SPACE ANTENNA SITES

4.5.1.4 Protection of Ariane RF systems

Spurious emissions from spacecraft which are active during the launch by Ariane must comply with the requirements given in the Ariane documentation (in particular the User Manual).

In order to give guidance on the levels to be met by the spacecraft equipment in terms of directly measurable parameters (e.g. power, frequency in an antenna feed cable), the conversion method given in Appendix C may be used. This appendix also gives typical Ariane requirements. It should be noted that the conversion method may be used to derive an estimate of the values, but that the real requirement is on the actual field strength at the Vehicle Equipment Bay antennas.

4.5.2 Cessation of Emissions

In accordance with the provisions of the ITU Radio Regulations each spacecraft shall be fitted with devices to ensure immediate cessation of its radio emissions by telecommand whenever such a cessation is required.

4.5.3 Power Flux Density Limits

In accordance with the provisions of the ITU Radio Regulations Art. 28 the power flux density (PFD) at the Earth's surface produced by emissions from a spacecraft, for all conditions and all methods of modulation, shall not exceed the values given in Table 4.9. In all cases, the limits relate to the PFD which would be obtained under assumed free-space propagation conditions.

The PFD limits shall be applicable during all mission phases. This may require means on board the spacecraft for reducing EIRP. However, during certain phases of missions (e.g. the launch phase) it may not be practical to meet the PFD limits at all times. In these cases, the satellite may have to be operated on a non-interference basis for which the FMO has to be consulted.

Frequency (MHz)	Angle of incidence (δ) above horizontal plane (degrees)	Power flux density ($dBW/m^2/4$ kHz)
1525 - 2300	0 - 5	- 154
	5 - 25	- 154 + 0.5 (δ-5)
	25 - 90	- 144
8025 - 8500	0 - 5	- 150
	5 - 25	- 150 + 0.5 (δ-5)
	25 - 90	- 140

TABLE 4.9: POWER FLUX DENSITY LIMITS AT THE EARTH'S SURFACE

4.5.4 Power Limits for Earth Station Emissions

In accordance with the provisions of the ITU Radio Regulations, the equivalent isotropically radiated power (EIRP) transmitted in any direction towards the horizon by an Earth station operating in the frequency bands between 1 and 15 GHz shall not exceed:

+40 dBW in any 4 kHz band for $\theta \leq 0^o$
+40 + 3 θ dBW in any 4 kHz band for $0^o \leq \theta \leq 5^o$

where θ is the angle of elevation of the horizon viewed from the centre of radiation of the antenna of the Earth station and measured in degrees as positive above the horizontal plane and as negative below it.

The EIRP towards the horizon for an Earth station in the space research service (deep space) shall not exceed +55 dBW in any 4 kHz band.

For angles of elevation of the horizon greater than 5 degrees, there is no restriction for the EIRP transmitted by an Earth station towards the horizon.

No transmission shall be effected by Earth station antennas at elevation angles of less than:

3 degrees for the Space Operation Service
5 degrees for the Space Research Service, Cat. A
10 degrees for the Space Research Service, Cat. B

where the elevation angles are measured from the horizontal plane to the direction of maximum radiation (i.e. antenna main beam direction).

It should be noted that the administration of a country hosting an Earth station may modify the above limits for a particular frequency or frequency band. The Head of the Frequency Management Office must, therefore, be consulted in each case, in order to ensure that the above limits are valid or, if not, whether other, more stringent, limits are applicable.

4.5.5 Time Limitations on Transmissions

Transmissions from Earth stations to spacecraft should be limited in time to the periods during which actual Earth-to-space link telecommunications (e.g. telecommand) and/or ranging operations are carried out (see also 3.2).

Spacecraft telecommunication system designs which rely on the presence of a continuous Earth-to-space carrier outside the above periods should be avoided.

It is also strongly recommended that spacecraft limit their transmission of RF power towards the Earth to those periods where telecommunications (e.g.reception of telemetry and data) and/or ranging operations are carried out (see also 3.2).

5. MODULATION REQUIREMENTS

5.1 PHASE MODULATION WITH RESIDUAL CARRIERS

5.1.1 Application

Phase modulation shall be used for:

- Telemetry in the UHF (2200 - 2300 MHz), SHF (8400 - 8500 MHz) and EHF (31.8 - 32.3 GHz) bands, unless modulation in accordance with Subsection 5.2 of this document is adopted.

- Telecommand in the UHF (2025 - 2120 MHz), SHF (7145 - 7235 MHz) and EHF (342 - 34.7 GHz) bands.

- Ranging Earth-Space in the UHF (2025 - 2120 MHz), SHF (7145 - 7235 MHz) and EHF (34.2 - 34.7 GHz) bands.

- Ranging Space-Earth in the UHF (2200 - 2300 MHz), SHF (8400 - 8500 MHz) and EHF (31.8 - 32.3 GHz) bands.

5.1.2 Modulating Waveforms

The following modulating waveforms are permitted:

- Telemetry
  - a subcarrier modulated by PCM data.

- Telemetry
  - PCM data, SP-L encoded

- Telecommand
  - a subcarrier modulated by PCM data.

- Telecommand
  - SP-L encoded (this mode is not recommended for use together with simultaneous ranging and telemetry)

- Ranging
  - the appropriate ranging baseband signal compliant with Reference [1].

To improve link performance, or to control transition density or spectral occupancy of the telemetry signal, encoding may be employed in accordance with Reference [2].

5.1.3 PCM Waveforms and Data Rates

PCM data signals shall be limited to the waveforms and symbol rates given in Table 5.1. For the definition of the PCM waveforms and symbol duration, reference is made to Figure 5.1.

RF carrier (MHz)	Function	Symbol rate (s/s)	PCM waveform	Special requirements
2025 - 2120 7145 - 7235 34200 - 34700	Telecommand	$4000/2^n$ n=0,1..9	NRZ-L NRZ-M	1) NRZ-M is not allowed for Category B 2) n=0 is limited for use with 16 kHz subcarrier
		$4000*2^n$ n=1 .. 6 [8]	SP-L	no subcarrier
2200 - 2300 8400 - 8500 31800 - 32300	Telemetry [9]	10^2 - 10^6	NRZ-L SP-L [10] NRZ-M	NRZ-M is limited to Category A

TABLE 5.1: PCM WAVEFORMS AND RATES

For all data signals producing a square wave baseband PCM waveform, the symmetry shall be such that the mark-to-space ratio will be between 0.998 and 1.002.

The symbol rate is defined as the reciprocal of the duration of the NRZ symbol at the modulator input.

Special precautions must be taken in case of combined PCM/SP-L/PM telecommand, ranging and telemetry to avoid degradation of the telemetry performance by spectral overlap from the telecommand signal.

8 This capability may not be fully implemented yet. Missions requiring telecommand data rates in excess of 4 ks/s are invited to contact the relevant engineering services of ESA.

9 Support of symbol rates below 100 s/s may be feasible on a case by case basis. Missions requiring such support are invited to contact the relevant engineering services of ESA.

10 The use of SP-L is only permitted for direct modulation of the RF carrier; the NRZ waveforms are only permitted when modulated on a subcarrier.

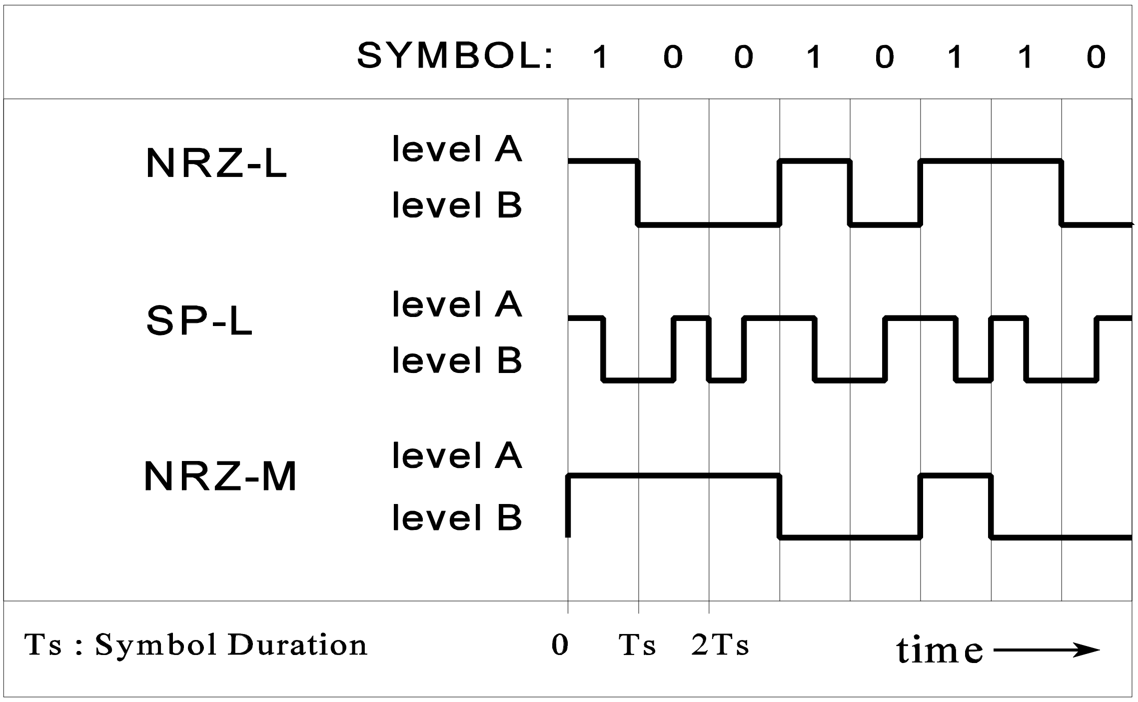

Figure 5.1 PCM WAVEFORMS

NRZ-L
- level A signifies symbol "1"
- level B signifies symbol "0"

SP-L
- level A during the first half-symbol followed by level B during the second half-symbol signifies symbol "1"
- level B during the first half-symbol followed by level A during the second half-symbol signifies symbol "0"

NRZ-M
- level change from A to B or B to A signifies symbol "1"
- no change in level signifies symbol "0"

5.1.4 Use of Subcarriers

5.1.4.1 Permitted Subcarriers

The subcarriers and modulating waveforms that are to be used are listed in Table 5.2.

RF Carrier (MHz)	Function	Subcarrier (kHz)	Modulation waveform	Subcarrier waveform	Notes
2025 - 2110 7190 - 7235	Telecommand (Category A)	8 or 16	NRZ-L NRZ-M	sine	(1)
2110 - 2120 7145 - 7190 34200-34700	Telecommand (Category B)	8 or 16	NRZ-L	sine	(1)
2200 - 2290 8450 - 8500	Telemetry (Category A)	0.1 - 1000	NRZ-L NRZ-M	sine	(2),(3)
2290 - 2300 8400 - 8450 31800-32300	Telemetry (Category B)	0.1 - 1000	NRZ-L	square	(3)

TABLE 5.2 SUBCARRIERS USED WITH PHASE-MODULATED RF CARRIERS

NOTES:

(1) For telecommand transmission using a subcarrier, only two subcarrier frequencies are permitted. Generally, the subcarrier frequency should be 8 kHz. Only in cases where the 4000 s/s symbol rate is needed or where support by other agencies requires this, may the 16 kHz subcarrier be used. For telecommand symbol rates in excess of 4 ks/s, the symbols shall be SP-L encoded and directly modulated onto the carrier.

(2) For telemetry symbol rates above:

- 60 ks/s for the UHF (2200 - 2290 MHz) band,
- 125 ks/s for the SHF (8450 - 8500 MHz) band,

subcarriers shall be avoided and either one of the following modulation schemes shall be used:

(a) the symbols shall be SP-L encoded and modulated directly on the carrier;

(b) modulation shall be in accordance with Subsection 5.2 of this document.

For spectrum and power efficiency reasons it is recommended that subcarriers only be used if a valid technical requirement exists and that the subcarrier to symbol rate ratio be as small as possible. Generally, a subcarrier frequency-to-symbol rate ratio of 4 be selected for subcarrier frequencies above 60 kHz. In case a ratio of 4 leads to spectral overlap with other signal components, the subcarrier frequency-to-symbol rate ratio shall be the smallest practicable integer and shall in any case not exceed ~~(TBD~~ 10~~)~~. For missions with multiple data rates, the subcarrier frequency used for the highest data rate may be also used for the lower data rates.

(3) The choice of the telemetry subcarrier frequency should take into account the requirements of:

- carrier acquisition by the ground receivers (see also Section 6);
- compatibility between ranging and telemetry (see Reference [1]);
- occupied bandwidth (see Subsection 4.4.2).

5.1.4.2 Subcarrier Frequency Stability

Telecommand Subcarriers

The telecommand subcarrier shall have a frequency within $\pm 1 \times 10^{-5}$ of its nominal value. The frequency stability shall be better than $\pm 5 \times 10^{-6}$ over 24 hours and better than $\pm 1 \times 10^{-6}$/s.

Telemetry Subcarriers

The telemetry subcarrier shall at all times have a frequency within $\pm 1 \times 10^{-4}$ of its nominal value.

The medium-term frequency variation due to power-supply voltage, temperature and other spacecraft influences shall be less than $\pm 1 \times 10^{-5}$.

The short-term frequency stability shall be better than $\pm 1 \times 10^{-6}/T$, where T is less than or equal to 100 times the subcarrier's waveform period.

5.1.4.3 Subcarrier Modulation [11]

Modulation of subcarriers used for telemetry and telecommand shall be PSK. The following requirements shall be met:

- the subcarrier frequency shall be a multiple (integer) of the symbol rate from 4 to 1024 and shall be as small as practicable (see 5.1.4.1, note 2);
- at each transition in the PCM waveform, the subcarrier shall be reversed in phase;
- the transitions in the PCM waveform shall coincide with a subcarrier zero crossing to within ±2.5% of a subcarrier period;
- at all times, for more than 25% of a subcarrier period after a phase reversal, the phase of the modulated subcarrier shall be within $\pm 5^\circ$ of that of a perfect PSK signal;
- for NRZ-M waveforms, the beginning of the symbol intervals shall coincide with a subcarrier zero crossing;

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11 SP-L waveforms in combination with a subcarrier are not permitted

- for NRZ-L waveforms, the beginning of the symbol intervals shall coincide witha positive-going subcarrier zero crossing for symbols "1" and with a negative-going zero crossing for symbols "0".

5.1.5 Data Transition Density

To ensure recovery of the symbol clock by the ground demodulators, the transition density in the transmitted PCM waveform shall not be less than 125 in any sequence of 1000 consecutive bits. Convolutional coding conforming to Reference [2] may be used to meet this requirement.

5.1.6 Carrier Modulation Index

Minima and maxima to the modulation index are stated in Table 5.3. These limits shall take into account worst case [12]

Function	Min. (radians peak)	Max. (radians peak)
Telecommand (PCM/NRZ/PM)	0.1	1.4
Telecommand (PCM/SPL/PM)	0.1	1.0
Telemetry (sinewave subcarrier)		1.5
Telemetry (squarewave subcarrier or PCM/SPL/PM)		1.25[13]
Ranging Earth-to-space	0.1	1.4
Ranging space-to-Earth	0.01	0.7

TABLE 5.3 MODULATION INDICES

[12] When two or more channels are transmitted simultaneously on the earth-to-space link, currently installed equipment limits the peak modulation index to 1.75 radians.

[13] A maximum of 1.39 radians is permissible provided that the carrier tracking loops signal-to-noise ratio remains above 15 dB

5.1.7 Sense of Modulation

A positive-going video signal shall result in an advance of the phase of the radio frequency carrier.

For directly modulated SP-L waveforms a symbol "1" shall result in an advance of the phase of the radio frequency carrier at the beginning of the symbol interval, a symbol "0" in a delay.

5.1.8 Modulation Linearity

The phase deviation, as a function of the video voltage applied to the modulator, shall not deviate from the ideal linear response by more than ±3% of the instantaneous value for deviations up to 1.5 radians peak.

5.1.9 Residual Amplitude Modulation

Residual amplitude modulation of the phase modulated RF signal shall be less than 2%.

5.1.10 Carrier Phase Noise

Phase noise of the unmodulated carrier, integrated between 10 Hz and 100 kHz shall be less than:

(a) 1° RMS at UHF (2025 - 2120 MHz and 2200 - 2300 MHz),
(b) 4° RMS at SHF (7145 - 7235 MHz and 8400 - 8500 MHz),
(c) 10° RMS at EHF (31.8 - 32.3 GHz).

5.1.11 Requirements on Residual Carrier and Spurious Lines [14]

The residual power in the modulated carrier shall always be greater than -15 dBc for space-to-earth and -10 dBc for earth-to-space links.

Modulation shall not introduce power greater than -30 dBc in the receiver bandwidth.

Modulation shall not introduce discrete spectral lines greater than -30 dBc in the following frequency ranges around the carrier:

(a) ±60 kHz for UHF (2200 - 2300 MHz),
(b) ±220 kHz for SHF (8400 - 8500 MHz),
(c) ±850 kHz for EHF (31.8 - 32.3 GHz).

[14] Additional limitations on the telemetry modulation spectrum will be imposed to ensure the cleanliness of the ranging signals, when simultaneous ranging and telemetry are required (see Reference [1]).

5.2 SUPPRESSED CARRIER MODULATION [15]

5.2.1 Application and Modulation Schemes [16]

- Modulation with suppressed carrier shall be used for Telemetry in the UHF (2200 - 2290 MHz), and SHF (8025 - 8400 MHz and 8450 - 8500 MHz) bands in cases where application of Subsection 5.1 (Phase Modulation) would lead to power flux densities at the carrier frequency in excess of the limits specified in Subsection 4.5.3. It shall also be used in other cases, where a subcarrier is not desirable.

- Data signals shall be PCM. The following modulation schemes may be used:

  (a) BPSK (binary phase shift keying)
  (b) QPSK (quadrature phase shift keying)
  (c) UQPSK (unbalanced quadrature phase shift keying).
  (d) OQPSK (offset quadrature phase shift keying).

5.2.2 Modulating Waveforms

The basic modulating PCM waveforms shall be:[17]

(a) for BPSK:
NRZ-L
or NRZ-M

(b) for QPSK [18]
DNRZ (4 level differentially encoded NRZ)

(c) for UQPSK:
NRZ-L
or NRZ-M

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15 Ranging in accordance with Reference [1] is not compatible with this type of modulation. It is recommended that each case be investigated to determine how far the mission requirements on orbital accuracy can be met if Doppler tracking only is used.

16 The responsible engineering service of ESA should be consulted concerning the capability of Earth stations to support this type of modulation and the range of symbol rates available.

17 For BSPK and UQPSK, NRZ-M will be preferred. In convolutionally encoded systems requiring conversion between NRZ-L and NRZ-M, the conversion from NRZ-L takes place before the input to the Viterbi encoder, and the conversion from NRZ-M to NRZ-L takes place after the output from the Viterbi decoder in order to maximise performance.

18 The use of OQPSK is preferred from a spectrum efficiency point of view. However, DNRZ creates an ambiguity problem and the responsible engineering department in ESA should be consulted for the appropriate data encoding scheme to be used with OQPSK.

5.2.3 Carrier Modulation

The modulation shall be defined as follows

(a) BPSK:

- The carrier shall be reversed in phase at each data signal transition

(b) QPSK/OQPSK:

- The modulation is defined as phase reversal keying of two phase quadrature carriers of equal amplitude by data channels with equal symbol rates.
- The phase angle between the two quadrature carriers shall be π/2 radians ±2%.
- Modulation shall be such that for each channel, the suppression of the signal from the other channel is more than 30 dB.
- The symbol clocks shall be synchronised to within ± 2% of the symbol period or 1 nanosecond, whichever is larger.
- The DNRZ coding convention for QPSK shall be as follows:

Carrier phase advance (Rad.)	Symbol Values
0	0 0
π/2	0 1
π	1 1
3π/2	1 0

The two columns for the symbol value represent the two data channels. For single-channel transmissions the left-hand column shall be the most significant symbol.

(c) UQPSK [19]

- The data shall consist of two channels with different symbol rates. The modulation shall be phase-reversal keying of two-phase quadrature RF carriers with different amplitude.
- The phase angle between two quadrature carriers shall be π/2 radians ±2%.
- Modulation shall be such that for each channel, the suppression of the signal from the other channel is more than 30 dB.

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19 If the symbol rate ratio is unequal to the power ratio in the two channels, care must be taken not to exceed the power flux density limits given in Subsection 4.5.3.

- The symbol rate imbalance, defined as

$$\frac{f_{s1} - f_{s2}}{f_{s1} + f_{s2}}$$

shall be more than 0.05.
(f_{s1} = symbol rate channel 1; f_{s2} = symbol rate channel 2)

- The power imbalance shall not be more than 10 dB.

5.2.4 Data Transition Density [20]

For NRZ waveforms, the transition density shall exceed 125 in any 1000-bit sequence.

5.2.5 Residual Amplitude Modulation

Residual amplitude modulation of the transmitted RF carrier shall be less than 2%.

5.2.6 Carrier Phase Noise

Phase noise of the unmodulated carrier, integrated between 10 Hz and 1 MHz shall be:

(a) less than 2° RMS at UHF (2200 - 2300 MHz)

(b) less than 6° RMS at SHF (8025 - 8500 MHz).

(c) less than 10° RMS at EHF (31.8 - 32.3 GHz).

5.2.7 Requirements on Spectral Lines and Residual Carrier

- Discrete lines in the transmitted RF signal spectrum, caused by baseband or RF bandwidth limitations, nonlinearity of the channel, or any other effect shall be less than:

  (a) -30 dBc inside the occupied bandwidth
  (b) -60 dBc (TBC) outside the occupied bandwidth [21]

- The residual carrier shall always be less than -30 dBc.

- The power flux density at the Earth surface shall always be below the limit specified in Subsection 4.5.3.

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20 Convolutional coding in accordance with the Reference [2] may be used to ensure that this requirement is met.

21 This requirement shall be reviewed to ensure compliance with a future revision of ITU-R SM.329 expected during 1997.

6. LINK ACQUISITION PROCEDURES

6.1 SPACE-EARTH

Under normal operation, the spacecraft transmitter will be switched on by on-board automaton at the time of scheduled commencement of the satellite "pass", the Space-Earth link shall then be modulated with the telemetry signal, containing at least the satellite housekeeping data.

Several methods are being used for acquisition of the Earth station receivers and demodulators; for safe acquisition a period of time shall be allowed commensurate with triangular frequency search in the worst case condition on link margin.

As a secondary mode of operation, it shall be possible to activate the spacecraft transmitter by telecommand; such a command should then be issued after the frequency sweep referred to in section 6.2 below.

If the coherent mode of the spacecraft transmitter is required, this shall be activated by telecommand, after acquisition of the Earth-Space link has been confirmed. Execution of this command will normally entail a frequency step in the Space-Earth link causing loss of data acquisition. A new acquisition of the Space-Earth link will then be required.

6.2 EARTH-SPACE (2025-2110 MHz)

During acquisition, no data or subcarrier modulation shall be present on the RF carrier transmitted by the ground station.

The carrier shall be swept in frequency with a symmetrical triangular waveform, i.e. the frequency shall be linearly swept around a centre frequency, with a suitable amplitude After a single sweep the frequency shall return to the centre value.

The centre frequency may be offset from the assigned value to compensate for Doppler shift and, if this information is available, for drift of the transponder local oscillator. If Doppler compensation is required, then Doppler shift predictions with an effor of 5 kHz maximum shall be available at the station.

The sweep amplitude shall be large enough to ensure sweeping over the transponder best lock frequency. It shall, however, be small enough to remain inside the transponder tracking range.

The lock status of the transponder must be transmitted in the spacecraft telemetry data for operational use by the earth station.[22]

[22] A standard location of the transponder lock status telemetry is specified in the Command Link Control Word (CLCW) as described in References [3] and [4].

After reception of the confirmation of lock, the earth station shall bring the carrier frequency to the assigned value.

All frequency excursions shall take place at a constant rate, which shall be selected such that the transponder phaselock loop will have no difficulty acquiring the carrier and tracking the sweep. Any discontinuities, jumps, etc., shall be smaller than the transponder PLL lock-in range.

Preferred values consistent with a transponder phaselock loop bandwidth 2BL=800 Hz and a damping factor $0.7 < \xi < 1.2$ are:

Sweep rate:	± 30 kHz/s
Max. discontinuity:	100 Hz
Max. tracking range:	± 150 kHz

Onboard telecommand decoders shall not require a frequency sweep for subcarrier or bit clock acquisition, which shall be achieved using the preamble transmitted before all uplink messages.

To limit the power spectral density from the Earth transmitters, the idle sequence specified in Reference [4] shall be transmitted at all times (except during acquisitions when the transmitter is activated but no data or ranging signal needs to be transmitted (however, see section 3.2.1.1).

6.3 EARTH-SPACE (2110 - 2120 MHz)

The acquisition procedure shall be the same as that described in the previous section for 2025 to 2110 MHz, with the exception that Doppler compensation of the uplink carrier frequency is a necessary requirement and that the carrier frequency will not be brought to the assigned value after acquisition. The compensation for Doppler shift and transponder local oscillator drift shall be periodically corrected to ensure that the received frequency will be within ±5 kHz of the estimated best lock frequency. Other than this, no frequency corrections shall be required (such as the continuous compensation of Doppler shift).

To provide a means of estimating the best lock frequency, the transponder PLL error voltage (loop stress) shall be transmitted to the ground via the spacecraft telemetry. The resolution of this information shall correspond to frequency steps of the order of the PLL bandwidth ($2B_l$) or less.

The earth station shall be capable to support the following specifications:

Sweep rate:	1 Hz/s to 10 kHz/s
Sweep range:	±100 Hz to ±300 kHz
Max. discontinuity:	1 Hz

6.4 EARTH-SPACE (7190 - 7235 MHz)

The acquisition procedure shall be the same as that described in section 6.2. However, the sweep parameters to be used shall be :

Sweep rate:	500 Hz/s to 50 kHz/s
Max. discontinuity:	100 Hz
Max. tracking range:	± 550 kHz

6.5 EARTH-SPACE (7145 - 7190 MHz)

The acquisition procedure shall be the same as that described in section 6.3. The sweep parameters to be used shall be :

Sweep rate:	1 Hz/s to 10 kHz/s
Max. discontinuity:	1 Hz
Max. tracking range:	± 550 kHz

7. CROSS SUPPORT FROM OTHER NETWORKS

7.1 NETWORK COMPATIBILITY

Compatibility of RF modulation standards between ESA and other space agencies is the subject of the

- CCSDS Recommendations for Radio Frequency and Modulation Systems (Blue Book), CCSDS 401.0-B-1, November 1994, prepared by Panel 1 of the Consultative Committee for Space Data Systems (CCSDS).[23]

  This document gives a broad outline of the possibilities of cross support. However, prior to committing a mission to support from another space agency it is indispensable to check the detailed technical documentation on the network of this agency.

- A report from CCSDS Panel 1 on Telemetry, Tracking and Command, which compares systems for Radio Frequency and Modulation (30 August 1984).

  This report gives an overview of the existing support capabilities which are available from the participating CCSDS member agencies.

7.2 SHUTTLE/DETACHED-PAYLOAD COMPATIBILITY

The reference document for the Shuttle/detached-payload interface is

- ICD 2-19001 Shuttle Orbiter/Cargo Standard Interfaces Rev. 6, September 26, 1980 (Attachment 1 to JSC 07700 Vol XIV).

The main limitations that should be observed are:

Frequency (Category A)

Earth-Space:	2025.833400 - 2109.792438 MHz
Space-Earth:	2200 - 2290 MHz
Frequency ratio (f_{up}/f_{down}):	221/240
Channel carrier (Space-Earth):	2200.000 + N × 125 MHz with N = 0 ... 800 (integer) and N + 1 = channel number

23 This document may be consulted in the libraries of ESA establishments.

Frequency (Category B)

Earth-Space:	2110.243056 - 2119.792438 MHz
Space-Earth:	2290.185185 - 2299.814815 MHz
Frequency ratio (f_{up}/f_{down}):	221/240
Channel carrier (Space-Earth):	2295.000000 + N × 10/27 MHz with N = - 9 ... + 13 (integer) and N + 863 = channel number [24]

Polarisation

Both directions:	LHC or RHC, the same polarisation shall be used for Earth-Space and Space-Earth links.

Telecommand

Subcarrier:	16 kHz only

Telemetry

Bit rate:	1, 2, 4, 8 or 16 kHz
Subcarrier:	1024 kHz, sinewave, PSK
Coding:	not used

Ranging	No cross-supported ranging mode is available

7.3 NASA MK IVA DSN COMPATIBILITY

The reference document, that contains all necessary details on the spacecraft/Earth station interface is:

- Deep Space Network/Flight Project Interface Design Handbook (JPL document 810-5, Rev. D)

  Vol. I Existing DSN capabilities.
  Vol. II Proposed DSN capabilities.

The main limitations that should be observed for missions requiring cross-support are:

[24] For Space-Earth link only channels 850 to 853 are also available and for Earth-Space link only channels 877 to 882.

Frequency (Category A)

Earth-Space:	2025 - 2110 MHz 7190 - 7235 MHz
Space-Earth:	2200 - 2290 MHz 8450 - 8500 MHz

Frequency (Category B)

Earth-Space:	2100 - 2120 MHz 7145 - 7190 MHz
Space-Earth:	2290 - 2300 MHz 8400 - 8450 MHz 32.8 - 32.3 GHz
Frequency ratio (f_{up}/f_{down})	UHF/UHF: 221/240 UHF/SHF: 221/880 UHF/EHF: 221/3344 SHF/UHF: 749/240 SHF/SHF: 749/880 SHF/EHF: 749/3344 EHF/EHF: 3599/3344
Channel assignments:	see Table 7.1

Channel No	UHF Earth-Space frequency (MHz)	UHF Space-Earth frequency (MHz)	SHF Space-Earth frequency (MHz)
1	_	2290.185185	-
2	_	2290.555556	-
3	_	2290.925926	-
4	_	2291.296296	-
5	2110.243056	2291.666667	8402.777780
6	2110.584105	2292.037037	8404.135803
7	2110.925154	2292.407407	8405.493826
8	2111.266204	2292.777778	8406.851853
9	2111.607253	2293.148148	8408.209876
10	2111.948303	2293.518519	8409.567903
11	2112.289352	2293.888889	8410.925927
12	2112.630401	2294.259259	8412.282950

Channel No	UHF Earth-Space frequency (MHz)	UHF Space-Earth frequency (MHz)	SHF Space-Earth frequency (MHz)
13	2112.971451	2294.629630	8413.641977
14	2113.312500	2295.000000	8415.000000
15	2133.653549	2295.370370	8416.358023
16	2113.994599	2295.740741	8417.716050
17	2114.335648	2296.111111	8419.074073
18	2114.676697	2296.481481	8420.432097
19	2115.017747	2296.851852	8421.790124
20	2115.358796	2297.222222	8423.148147
21	2115.699846	2297.592593	8424.506174
22	2116.040895	2297.962963	8425.864197
23	2116.381944	2298.333333	8427.222220
24	2116.722994	2298.703704	8428.580248
25	2117.064043	2299.074074	8429.938271
26	2117.405092	2299.444444	8431.296294
27	2117.746142	2299.814815	8432.654321
28	2118.087191	_	8434.012344
29	2118.428241	_	8435.370371
30	2118.769290	_	8436.738395
31	2119.110339	_	8438.086418
32	2119.451389	_	8439.444445
33	2119.792438	-	8440.802468

TABLE 7.1 MK IVA DSN CHANNEL ASSIGNMENTS

Polarisation

Both directions: LHC or RHC, the Earth-to-space and space-to-Earth link may have different polarisations. [25]

[25] DSN 70 m stations offer also linear polarisations at UHF

Telemetry

Symbol rates

NRZ-L with subcarrier: 10 s/s - 250 ks/s

SP-L without subcarrier: 125 ks/s - 250 ks/s

Subcarrier: 10 kHz - 1 MHz, squarewave.

For PSK data rates > 500 s/s the subcarrier should be > 45 kHz.

Ranging

Transponder requirements: The DSN ranging system is different in many essential aspects from the ESA ranging system. For details, JPL document 810-5 should be consulted.

7.4 DATA RELAY SATELLITE COMPATIBILITY

Users planning mixed support from data-relay satellites and the ESA network, or planning missions wholly supported by data-relay satellites, must consult the relevant reference documents:

- for NASA TDRSS, the relevant NASA document is STDN 101.2;
- for ESA DRS, the corresponding document is ESA RD-04-109.

APPENDIX A

ACRONYMS AND ABBREVIATIONS USED IN THIS Document

BPSK	Bi-Phase Shift Keying (= PSK)
BW	Bandwidth
CCIR	Comité Consultatif International des Radiocommunications
CCSDS	Consultative Committee for Space Data Systems
dB	Decibel
dBc	dB with respect to the unmodulated carrier
DRS	Data Relay Satellite
DSN	Deep Space Network of NASA
DH	Data Handling
EES	Earth Exploration Satellite service
EHF	Extremely High Frequency (30GHz-300GHz)
EIRP	Equivalent Isotropically Radiated Power
ESA	European Space Agency
ESTEC	European Space Research and Technology Centre, Noordwijk, Netherlands
ESOC	European Space Operations Centre, Darmstadt, Germany
FN	Footnote in the ITU Radio Regulations
f_t	Ranging tone frequency
GHz	Gigahertz
G/T	Ratio of Antenna Gain to System Noise Temperature
Hz	Hertz
ISRO	Indian Space Research Organisation
ITU	International Telecommunication Union
ITU/BR	Radiocommunications Bureau of the ITU
kHz	Kilohertz
ks/s	kilosymbols per second
km	Kilometre
LHC	Left Hand Circular
m	Metre
MHz	Megahertz
ms	Millisecond
NASA	National Aeronautics and Space Administration (United States)

NASDA	Space Development Agency of Japan
NRZ	Non Return to Zero
NRZ-L	Non Return to Zero-Level
NRZ-M	Non Return to Zero-Mark
OQPSK	Offset Quadrature Phase Shift Keying
PCM	Pulse Code Modulation
PFD	Power Flux Density
PLL	Phase Lock Loop
PM	Phase Modulation
PSK	Phase Shift Keying (in this Document identical to Phase Reversal Keying)
P&T	Post and Telecommunications Administration
QPSK	Quadrature Phase Shift Keying
RF	Radio Frequency
RHC	Right Hand Circular
Rs	Symbol rate
RSS	Root Square Sum
Rx	Receiver
s	Second
s/s	symbols per second
SFCG	Space Frequency Coordination Group
SHF	Super High Frequency (3 GHz-30 GHz)
SP-L	Split Phase-Level
SO	Space Operation service
SR	Space Research service
STAB	Standards Approval Board for Space Data Communications of ESA
TC	Telecommand
TDRSS	Tracking and Data Relay Satellite System (NASA)
TM	Telemetry
TR	Tracking
TTC	Telemetry, Tracking and (Tele)Command
Tx	Transmitter
UHF	Ultra High Frequency (300 MHz-3000 MHz)
UQPSK	Unbalanced Quadrature Phase Shift Keying
$2B_L$	Double-Sided Phaselock Loop Noise Bandwidth

APPENDIX B

FREQUENCY ASSIGNMENT PROCEDURE

Several factors must be taken into consideration when proceeding to the choice of the most appropriate frequency bands for a particular mission and subsequently the assignment of discrete frequencies in the selected bands. Such factors are:

- frequency bands allocated to the radiocommunication service into which the mission under consideration falls;
- required bandwidth versus available bandwidth in the frequency bands that are allocated to the services;
- special conditions that may be applicable for the use of a frequency band;
- link budget for a particular mission;
- ground support aspects such as availability of general support capability, availability of frequency bands at the most favoured support Earth station(s);
- availability of technology and existing designs for spacecraft equipment in the frequency band.

Generally, ESA favours a restriction to the minimum number of frequency bands in order to avoid diversification of investments.

Once the most appropriate frequency band has been selected, the assignment for one or several frequencies within this band will be made. The frequency assignment process - because of its very complex nature - can be very lengthy, and consequently shall be started as early as possible in a project.

Step 1: Selection of mission frequency bands

Objective:

To select in accordance with the provisions of the ITU/RR, the frequency band(s) the mission will most likely use. The step does not yet include the selection of discrete frequencies.

Data:

(To be supplied by the Spacecraft Project to the ESA Frequency Management Office):

- general mission description;
- orbital parameters (general indications are sufficient, such as "geostationary", "circular/polar", "highly eccentric with apogee in NorthSouth", together with approximate values for apogee, perigee and inclination);

- ground support options envisaged;
- year of launch and approximate mission lifetime;
- indication of favoured band.

In many cases this request can be made informally, in order to save time in the frequency assignment process.

Deadline:

During feasibility study phase.

Step 2: Selection of Discrete Frequencies

Objective:

To select, within frequency bands chosen in Step 1, the discrete mission frequencies. This step which is frequently an iterative one, includes the frequency co-ordination with the national radio regulatory authorities concerned and those space agencies with whom ESA has concluded frequency coordination agreements (NASA, NASDA, ISRO). In exceptional cases it is possible to assign tentatively alternative frequencies to a mission to choose from in order to keep some flexibility in the spacecraft design and ground support. As soon as the spacecraft design and the design of the ground-support baseline are frozen, any alternative frequencies, that were tentatively assigned, shall be released by the project.

Data:

(To be supplied by the Spacecraft Project to the ESA Frequency Management Office.)
The form (Annex 1) shall be used for a request for frequency assignment.

Deadline:

During Phase B study.

NOTE: If preferred frequencies have been identified by the project, these may be proposed. However, it cannot be guaranteed that these will be finally assigned.

Step 3: Coordination and Notification of Frequencies with the Radiocommunications Bureau of the ITU (ITU/BR)

Objective:

To co-ordinate and inscribe the assigned frequencies into the International Frequency List of ITU/BR so that the frequency assignment becomes a formally recognized one vis-à-vis all Member States of the ITU. The procedure to be followed is found in the ITU Radio Regulations (i.e. in the provisions of Art. 11, 13 and 14 and App. 3 and 4).

In very exceptional cases, it may become necessary for a frequency assignment made in Step 2 to be modified as an outcome of this international coordination process; however, this possibility is a very small one and is virtually restricted to geostationary spacecraft.

Data:

(To be supplied by the Spacecraft Project Office to the ESA Frequency Management Office.)
The data required for the notification with ITU/BR shall be supplied in two consecutive steps:

- Advance Publication Information to be furnished for a satellite network (ITU/RR/1042 and App 4)

- Co-ordination and Notification Data (ITU/RR/1060, 1488 and App 3; plus ITU/RR/1611, f the band is allocated under the provisions of Art. 14)

Deadline:

Between 5 and 2.5 years before the launch date, at the request of the Head of the Frequency Management Office, who will establish the required documentation in co-operation with the project team.

ANNEX 1 TO APPENDIX B

REQUEST FOR FREQUENCY ASSIGNMENT

1. GENERAL INFORMATION

1.1 PROJECT NAME:

1.2 CONTACT PERSON (Name and Phone):

1.3 MISSION OBJECTIVES:

1.4 LAUNCH DATE:

1.5 MISSION LIFETIME

2. ORBIT PARAMETERS:

2.1 CATEGORY A

2.1.1 GEOSYNCHRONOUS ORBITS

- Position on GSO:	deg E
- Inclination:	deg

2.1.2 NON-GEOSYNCHRONOUS ORBITS

- Apogee:	km
- Perigee:	km
- Inclination:	deg
- Argument of Perigee:	deg
- Right Ascension of the Ascending Node:	deg
- Period:	min

2.2 CATEGORY B

Give general trajectory data (including mention of planets, comets or other mission destinations)

3. EARTH STATION SUPPORT BASELINE

Earth Station Name (N) and Geographical Location (L)	Earth - Space	Space - Earth	Remarks
N:			
L:			
N:			
L:			
N:			
L:			
N:			
L:			
N:			
L:			
N:			
L:			
N:			
L:			
N:			
L:			

Table AP/B 3.1

Note: This table is to be used only as a synoptic overview of the Earth station support baseline. Detailed technical data are to be supplied in subsequent Sections/Tables.

Use the following symbols:

Earth - Space:
- TC: Telecommand only
- RG: Ranging only
- TC/RG: Simultaneous Telecommand and Ranging

Space - Earth:
- TM: Telemetry only
- RG: Ranging only
- TM/RG: Simultaneous Telemetry and Ranging

4 EARTH-SPACE LINK [26]

4.1 SELECTED FREQUENCY BAND: ________________ MHz

4.2 PREFERRED FREQUENCY ________ MHz [27]

4.3 OCCUPIED BANDWIDTH (Maximum) ________ kHz

4.4 FIXED TURNAROUND FREQUENCY RATIO WITH SPACE/EARTH FREQUENCY REQUIRED? YES/NO

4.5 EARTH STATION TRANSMITTER OUTPUT POWER (see Table AP/B4.1)

4.6 MAXIMUM SPECTRAL POWER DENSITY (see Table AP/B4.1)

4.7 EARTH STATION ANTENNA GAIN DIAGRAM: (Including maximum gain, see Table AP/B4.2)

4.8 SPACECRAFT RECEIVER SYSTEM NOISE TEMPERATURE ________ K

4.9 SPACECRAFT ANTENNA GAIN AND DIAGRAM[28] ________ dBi

---

26 Use several forms for spacecraft requiring more than one frequency.

27 The preferred frequency is given as an indication only. There is no guarantee that it can be finally assigned to the project.

28 Use additional sheet(s) if required; particularly if several spacecraft receive antennas are used.

Transmission modes can be telecommand (TC) only, ranging (RG) only or simultaneous telecommand and ranging (TC/RG). Use one line per transmission mode:

Transmission Mode (TC, RG, TC/RG)	Modulation Scheme	TC Symbol Rate (ks/s)	TC Subcarrier Frequency (kHz)	TC Modulation Index (rad)	RG Tone Frequency (kHz)	RG Modulation Index (rad)	RF Power at Antenna Input (dBW)	Max. Power Density (dBW/Ref.BW)[29]

Table AP/B 4.1: EARTH-TO-SPACE TRANSMISSION MODES

[29] The maximum power density applied to the input of the antenna shall be expressed in dBW/Hz, averaged over the worst 4 kHz band for RF carrier frequencies below 15 GHz, or averaged over the worst 1 MHz band for carrier frequencies above 15 GHz. The value in dBW shall be referred to 1W (0 dBW).

Earth Station Name	Antenna Gain (dBi)	Antenna Diagram	RF Power at Antenna Input (dBW)

Table AP/B 4.2: TRANSMITTING EARTH STATION CHARACTERISTICS

5 SPACE-EARTH LINK [30]

5.1 SELECTED FREQUENCY BAND: ________________ MHz

5.2 PREFERRED FREQUENCY: ________ MHz [31]

5.3 OCCUPIED BANDWIDTH (Maximum): ________ kHz

5.4 SPACECRAFT TRANSMITTER POWER
(see Table AP/B5.1)

5.5 MAXIMUM SPECTRAL POWER DENSITY
(see Table AP/B5.2)

5.6 SPACECRAFT ANTENNA GAIN AND DIAGRAM [32] ________ dBi

5.7 EARTH STATION RECEIVER SYSTEM NOISE TEMPERATURE
(see Table AP/B5.2)

5.8 EARTH STATION ANTENNA GAIN DIAGRAM: ________ dB

5.9 SPACE-TO-EARTH TRANSMISSION MODES:

---

30 Use several forms for spacecraft requiring more than one frequency.

31 The preferred frequency is given as an indication only. There is no guarantee that it can be finally assigned to the project.

32 Use additional sheet(s) if required; particularly if several spacecraft transmit antennas are used.

Transmission modes can be telemetry (TM) only, ranging (RG) only or simultaneous telemetry and ranging (TM/RG). Use one line pe transmission mode:

Transmission Mode (TM, RG, TM/RG)	Modulation Scheme	TM Symbol Rate (ks/s)	TM Subcarrier Frequency (kHz)	TM Modulation Index (rad)	RG Tone Frequency (kHz)	RG Modulation Index (rad)	RF Power at Antenna Input (dBW)	Max. Power Density (dBW/Ref.BW)[33]

Table AP/B 5.1: SPACE-TO-EARTH TRANSMISSION MODES

33 The maximum power density applied to the input of the antenna shall be expressed in dBW/Hz, averaged over the worst 4 kHz band for RF carrier frequencies below 15 GHz, or averaged over the worst 1 MHz band for carrier frequencies above 15 GHz. The value in dBW shall be referred to 1W (0 dBW).

Earth Station Name	Antenna Gain (dBi)	Antenna Diagram	System Noise Temperature (K)

Table AP/B 5.2: RECEIVING EARTH STATION CHARACTERISTICS

APPENDIX C

PROTECTION OF ARIANE RF SYSTEM

C.1 A suggested Conversion Method for Relating Spurious Radiation Received at Ariane Vehicle Equipment Bay Antennas to Spurious Emission Requirements on Payload Transmitters

Assume that of the power produced by the payload transmitters P_T less than 10% is coupled into the vehicle equipment bay via its antennas. The rest of the power is either reflected back into the transmitter or escapes via the transparent sections of the fairing. To evaluate the relationship between the power flux density incident on the vehicle equipment bay antennas, P, and the power absorbed into the bay P_R we may make the approximation that the antennas have 0 dBi gain.

Therefore $P_R = \frac{\lambda^2 P}{4}$

If free space conditions are assumed, the incident power flux density P can be related to the electric field by:

$$P = \frac{E^2}{1204}$$

Therefore the value of P_T corresponding to a maximum permitted value of E is given by

$$P_T = \frac{\lambda^2 E^2}{48\pi^2}$$

For example, for 20 dB µV/m at 435 MHz, the equivalent payload transmitter power is -100 dBm and for 70 dB µV/m at 5690 MHz the equivalent payload transmitter power is -72.3 dBm.

C.2 Operating Constraints

The following requirements shall be met by spacecraft which are to be launched by an Ariane 5 vehicle.

The requirements mentioned below have been taken from:
A5-SG-1-X-35-ASAI Spécifications Générales de compatibilité Electromagnétique, Ed.3, Révision 1, 11 mai 1995

The spacecraft shall not radiate a narrow-band electrical field at 0.5 m below the bolted interface exceeding the limit set in table C.1 (including intentional transmission).

Frequency range	Field (dBµV/m)
10 kHz - 420 MHz	100
420 MHz - 480 MHz	35
480 MHz - 2 GHz	100
2 GHz - 5.45 GHz	145
5.450 GHz - 5.825 GHz	70
5.825 GHz - 20 GHz	145

Table C.1: Maximum Radiated Electrical Field at Bolted I/F

A 35dBµV/m level radiated by the spacecraft, in the launch vehicle telecommand receiver 420-480MHz band, shall be considered as the worst case of the sumof spurious level over a 100 kHz bandwidth.

The field in the 5.450 - 5.825 MHz band shall be measured in a resolution bandwidth of 10 MHz.

There is a restriction on spacecraft transmissions up to 20 s after separation of the spacecraft. Authorization to allow transmission during the countdown phase and/or flight phase and/or at spacecraft separation will be considered on a case-by-case basis.

The spacecraft telemetry frequency band must not overlap the launch vehicle operational bands:

2203 MHz	± 250 kHz
2218 MHz	± 500 kHz
2227 MHz	± 500 kHz
2206.5 MHz	± 250 kHz
2267.5 MHz	± 250 kHz

Flight constraint: during the powered phase of the launch vehicle and up to separationof the spacecraft, no telecommand signal can be sent to the spacecraft.

APPENDIX D

RF INTERFACE CONTROL REQUIREMENTS

D.1 RF INTERFACE CONTROL DOCUMENTS

For each project that intends to use one or more of the ESTRACK stations, two documents shall be used to control the spacecraft/Earth-station interface. These will be the

- Spacecraft/Earth-station Interface Control Document
- Link Budget Tables

which are specified in more detail in the subsequent subsections.

The first document will be the definitive and formal specification of the RF interface. The second document will be updated regularly to keep track of the development of the spacecraft and Earth station. Hardware interface compatibility will be demonstrated by Spacecraft/Earth-station compatibility tests, documented by the

- Compatibility test plan
- Compatibility tests results

D.2 SPACECRAFT/EARTH-STATION INTERFACE CONTROL DOCUMENT

This document will be the formal interface specification, containing all the relevant parameters describing the interface between the spacecraft and the Earth stations(s).

The first draft of the document shall be prepared in the study phases of the project by the responsible engineering department in ESA using inputs from the ESA Study or Project Manager. It will also contain top-level specifications for any new ground systems to be developed for the project.

The document should achieve its final form, and be agreed on by the ESA Project Manager and the duly appointed representative of the Directorate of Operations, when the relevant spacecraft parameters are definitely specified.

From this time on, the document shall be under the control of the Project Manager, who shall consult the responsible engineering department in ESA before agreeing to changes to any parameters contained in it.

The document shall contain information on the following items:

- Earth stations and time profile of use.
- Configuration of equipment in Earth stations and links to control centre.
- Performances of Earth station (EIRP, G/T, demodulation losses etc. with tolerances).
- Configuration of equipment on board the spacecraft.
- Performances of spacecraft equipment (Transmitter powers, telecommand thresholds, antenna gains, etc. with tolerances).

- TTC standards applicable and any waivers granted.
- Choice of parameters for the links (i.e. which subsets of the parameters allowed by the standards are chosen). (PCM data types, bit rates, formats, subcarriers, modulation indices.)
- Operational modes of the spacecraft TTC subsystem. (Combinations of bit rates, subcarriers, formats, indices, etc. Combination of ranging with telecommand or telemetry.)

Thus the Spacecraft/Ground-network Interface Control Document shall act as a source document for all data to be used in the preparation of the Link Budget Tables.

D.3 LINK BUDGET TABLES

Link budget tables shall be prepared by the spacecraft project who shall be responsible for the correct modeling of all aspects of the links between spacecraft and Earth stations. These link budget tables shall be used throughout the course of the project to monitor the quality of the spacecraft /Earth network interface and be subject to verification by the responsible engineering department in ESA. Although the exact format may vary from application to application, it is of importance that the same terminology and parameters be used. For this purpose, an example link budget output table is provided in Annex 1 hereto.

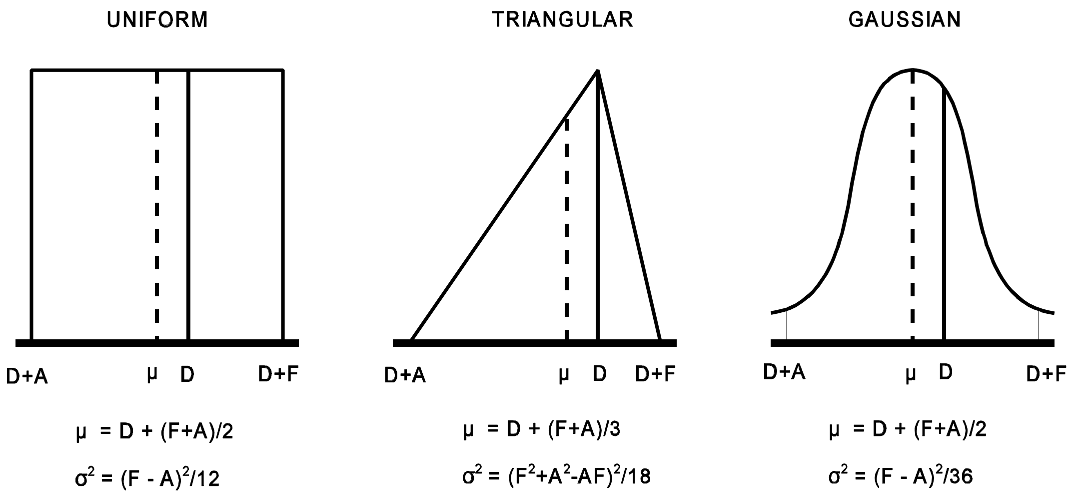
(a) Separate link budgets should be produced for all different parameter combinations (e.g. different Earth stations, different spacecraft antennas, bit rates).

(b) For a given set of parameters the link budget should be evaluated for the planned maximum distance of the spacecraft from the Earth for which these parameters will be used.

(c) For each parameter entering the link budget, three values should be used:

- The design value D, which is the value of the parameter expected to be achieved under nominal conditions.
- The adverse tolerance A, which is defined as the worst case of a parameter minus the design value in dB. Adverse conditions such as extreme temperatures, extreme voltages, end of life, end of maintenance period, etc shall be considered. Normally, the adverse tolerance would be the value given in a design specification.
- The favorable tolerance F, which is defined as the best case of a parameter minus the design value in dB. Best case conditions such as benign environment, beginning of life, equipment recently maintained, shall be considered. Often the favorable tolerance, particularly in the design phase of a project, must represent an intelligent guess as to how much better the equipment will turn out to be than the design value.

(d) From the design value, the adverse and the favorable tolerances, the mean value μ and the variance (σ_n^2), based on a particular probability density function for each parameter should be calculated according to the equations given below: In the absence of better statistical data on probability density functions, those given in Table D.1 should be used.



EARTH - SPACE	SPACE - EARTH
UNIFORM PROBABILITY DENSITY FUNCTIONS	
E/S Antenna Gain (TX) E/S Antenna Circuit Loss (TX) E/S Antenna Pointing Loss (TX) Polarisation Loss S/C Antenna Circuit Loss (RX) S/C Phase Jitter Loss (RX) Waveform Distortion Loss E/S Effective Antenna Gain (TX) S/C Effective Antenna Gain (RX)	S/C Antenna Circuit Loss (TX) Polarisation Loss E/S Antenna Gain (RX) E/S Antenna Pointing Loss (RX) E/S Antenna Circuit Loss (RX) E/S Phase Jitter Loss (RX) Waveform Distortion Loss S/C Effective Antenna Gain (TX) E/S Effective Antenna Gain (RX)
TRIANGULAR PROBABILITY DENSITY FUNCTIONS	
S/C Antenna Gain (RX) S/C Antenna Pointing Loss (RX) S/C Carrier Circuit Loss (RX) S/C Demodulator/Detector Loss (RX) S/C Ranging Demodulation Loss (RX) E/S Transmit Power (TX) E/S Transmit EIRP (TX) S/C Loop Bandwidth at Threshold (RX) S/C Ranging Transpond. Bandwidth (TX)	S/C Antenna Gain (TX) S/C Antenna Pointing Loss (TX) E/S Demodulator/Detector Loss (RX) E/S Ranging Demodulation Loss (RX) S/C Transmit Power (TX) S/C Transmit EIRP (TX) E/S Loop Bandwidth (RX) E/S Lock Threshold
GAUSSIAN PROBABILITY DENSITY FUNCTIONS	
Atmospheric Attenuation Ionospheric Loss S/C System Noise Temperature (RX)	E/S Effective System Noise Temp. (RX) Atmospheric Attenuation Ionospheric Loss

TABLE D.1: PROBABILITY DENSITY FUNCTIONS FOR LINK BUDGETS

(e) Margins for budgets based on the design value, favorable tolerance, adverse tolerance, mean value, mean - 3σ and worst-case RSS should be calculated.

- the margin for mean - 3σ is:

$$\text{margin for mean parameters} - 3\sqrt{\sum_{0}^{n}\sigma_n^2}$$

- the worst case RSS margin is:

$$\text{margin for design parameters} - \sqrt{\sum_{0}^{n}A_n^2}$$

(f) Note that the calculation of the variances of the margin from the sum of variances of its components which have different density functions is valid only if all the variances are of approximately the same magnitude. If a particular variance is dominant, its statistics must be treated separately.

(g) Unless specified otherwise, the required performance shall be in accordance with the selected standards:

- for packet telecommand, in accordance with Reference [4].
- for packet telemetry in accordance with Reference [3].
- for ESA standard ranging in accordance with Reference [1].

(h) The jitter performance of the restituted carrier shall be taken into account in the calculation of the degradation in the demodulation processes.

(i) Each project may choose its own criteria for acceptablity of link performance, using the various margins calculated in the link budget tables. Experience has shown, however, that margins based on design parameters should exceed 3 dB, and those on the RSS worst case and the mean -3σ should exceed 0 dB.

(j) The link budget tables should be kept updated during the evolution of the project. In particular, they should reflect new information coming from spacecraft unit, subsystem and system acceptance tests and from spacecraft/ground-network compatibility tests.

D.4 SPACECRAFT/GROUND-NETWORK COMPATIBILITY TEST;

Compatibility of the spacecraft with the ground network shall be demonstrated by means of compatibility tests. Such tests shall be made on spacecraft TTC equipment and Earth-station equipment to be finally used during the mission. However, where new developments or extensive modifications of existing equipment are involved, preliminary tests should be made in an early phase of the programme using engineering, development or even breadboard equipment.

The tests to be performed during compatibility testing will of necessity vary from project to project. Tests will always aim at establishing thresholds and limiting values so that a good assessment of available margins can be made.

A compatibility test plan, detailing the tests to be performed, the minimum required values for critical parameters, the spacecraft and Earth station equipment to be used etc, will be drawn up before commencement of the test activities.

At the conclusion of the tests, a Compatibility Test Report will be issued by the responsible engineering department in ESA. This will contain a formal statement on the compatibility of the spacecraft and the ground network.

ANNEX 1 TO APPENDIX D

For the purpose of the link budget example below the following equivalent definitions are applicable:

NOM = D
ADV = D+A
FAV = D+F

Project

LINK ID : *X111.2* **PAGE 1/4**
DATE : date
ORBIT : *Orbit* ALTITUDE (1000km): *255.00*
STATION : *Station* ELEVATION (deg): *90*

TELECOMMAND BIT RATE (kb/sec) : *2.00* RANGING : Yes
TELEMETRY BIT RATE (kb/sec) : *1.75*
RS (1) or CONCAT. CODING (2) : *2*

BASIC UPLINK (1/2)

	NOM	ADV	FAV	MEAN	VAR	PDF
G/S TX POWER.........dBW	*24.20*	*24.00*	*24.50*	24.23	0.01	TRI
CIRCUIT LOSS..........dB	*0.10*	*0.20*	*0.00*	0.10	0.00	UNI
TX ANT GAIN..........dBi	*47.30*	*47.30*	*47.30*	47.30	0.00	UNI
G/S ANT TX AXIAL RAT..dB	*0.50*	*1.00*	*0.00*			
POINTING LOSS.........dB	*0.05*	*0.12*	*0.00*	0.06	0.00	UNI
EIRP G/S.............dBW	71.35	70.98	71.80	71.37	*0.02*	
FREQUENCY............GHz	2.08	2.08	2.08	2.08		
SLANT RANGE......1000*km	255.00	255.00	255.00	255.00		
PATH LOSS.............dB	206.94	206.94	206.94	206.94		
ATMOSPHERIC LOSS......dB	*0.10*	*0.20*	*0.00*	0.10	0.00	GAU
IONOSPHERIC LOSS......dB	*0.05*	*0.10*	*0.00*	0.05	0.00	GAU
COPOLAR ANT-GAINS(Y=1/N=0)?	*1*					
POLARISATION MISMATCH.dB	0.06	0.13	0.00	0.06	0.00	UNI
TOTAL PROPAG. LOSS....dB	207.15	207.37	206.94	207.15	*0.00*	
POW.-FLUX at S/C.dBm/m^2	-77.77	-78.14	-77.32	-77.75		
RX ANT GAIN..........dBi	*-6.00*	*-6.50*	*-5.50*	-6.00	0.04	TRI
POINTING LOSS (*)..dB	*0.00*	*0.00*	*0.00*	0.00	0.00	TRI
S/C ANT RX AXIAL RAT..dB	*4.00*	*4.50*	*4.00*			
ANTENNA NOISE TEMP.....K	*40.00*	*50.00*	*35.00*			
ANTENNA/FEED VSWR.....:1	*1.00*	*1.00*	*1.00*			
VSWR LOSS.............dB	0.00	0.00	0.00	0.00	0.00	TRI
CABLE PHYSICAL TEMP....K	*290.00*	*330.00*	*240.00*			
CABLE LOSS............dB	*0.00*	*0.00*	*0.00*	0.00	0.00	UNI
CIRCUITS TEMPERATURE...K	*290.00*	*330.00*	*240.00*			
RFDU CIRCUIT LOSS.....dB	*2.10*	*2.70*	*2.12*	2.41	0.03	UNI
TOTAL CIRCUIT & CABLE LOSS.....dB	2.10	2.70	2.12			
DIPL. CIRCUIT LOSS....dB	*0.00*	*0.00*	*0.00*	0.00	0.00	UNI
RECEIVER NOISE FIGURE.dB	*5.00*	*5.00*	*5.00*			
REF SYSTEM TEMP (**).K	917.06	917.06	917.06			
RX SYSTEM TEMP (***)..K	762.91	806.69	741.24			
RX SYSTEM TEMP (***)dBK	28.82	29.07	28.70	28.88	0.00	GAU
S/C RX G/T..........dB/K	-36.92	-38.27	-36.32			
RX POWER (***).....dBm	-113.90	-115.59	-112.76	-114.19	*0.09*	
THEOR CAR THRSH(**)dBm	-129.95					
CAR ACQ THRSH (**).dBm	*-128.00*	-128.00	-128.00			
THEOR TC THRSH(**).dBm	-118.00					
TC RX THRSH (**).dBm	*-117.00*	-117.00	-117.00			
REQ RX POWER (***).dBm	-117.00	-117.00	-117.00	-117.00		

RX POWER MARGIN.......dB	3.10	1.41	4.24	2.81	0.09
MEAN-3*SIGMA.......dB	1.92				
MARGIN - w.c. RSS..dB	2.28				

RX S/No.............dBHz	55.88	53.95	57.14	55.53	*0.09*

*) POINTING LOSS may be included in RX ANTENNA GAIN.
**) Reference at Diplexer/RFDU Interface, 290 K input noise temperature.
***) Reference at Diplexer/RFDU Interface.

Project

LINK ID : X111.2 **PAGE 2/4**
DATE : date
ORBIT : Orbit ALTITUDE (1000km): 255.00
STATION : Station ELEVATION (deg): 90

TELECOMMAND BIT RATE (kb/sec) : 2.00 RANGING : Yes
TELEMETRY BIT RATE (kb/sec) : 1.75 with CONCAT. CODING : Yes

UPLINK (2/2)

	NOM	ADV	FAV	MEAN	VAR	PDF
RX S/No.............dBHz	55.88	53.95	57.14	55.53	*0.09*	
MODULATION INDICES (*)						
TELECOMMAND.......rad pk	*1.00*	1.05	0.95	(sine)		
RANGING (RNG).....rad pk	*0.40*	0.42	0.38			
RNG, sine(1) or sqre(2):	*1*					
CARRIER RECOVERY						
CARRIER SUPPRESSION...dB	2.68	2.97	2.40	2.68	0.01	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	*800.00*	960.00	640.00			
THRSHD C/N in 2*Blo...dB	*10.00*	(common Definition)				
PLL DAMPING (**).....	*0.71*	0.78	0.64			
Effect PLL DAMPING......	0.71	0.78	0.64			
Effect PLL-BDW 2*Bl...Hz	800.00	960.00	640.00			
Max ACQ SWEEP RATE.kHz/s	32.00	25.52	32.00	28.76		
Effect PLL-BDW 2*Bl.dBHz	29.03	29.82	28.06	28.97	0.13	TRI
BP-LIMT SYSTEM LOSS...dB	0.00	0.00	0.00	0.00	0.00	TRI
IMPLEMENTATION LOSS...dB	*1.10*	*1.50*	*0.80*	1.13	0.02	TRI
REQ C/N in PLL-BDW....dB	*14.00*	14.00	14.00	14.00		
CARRIER MARGIN........dB	9.07	5.65	11.88	8.74	0.26	
MEAN-3*SIGMA.......dB	7.23					
MARGIN - w.c. RSS..dB	7.80					
TELECOMMAND RECOVERY						
MODULATION LOSS.......dB	4.47	4.84	4.13	4.48	0.02	TRI
IMPLMENT LOSS (***)..dB	*1.50*	*1.60*	*1.10*	1.40	0.01	TRI
BIT RATE............kb/s	2.00	2.00	2.00			
BIT RATE............dBHz	33.01	33.01	33.01	33.01		
REQ Eb/No (****)..dB	*12.00*	12.00	12.00	12.00		
TELECOMMAND MARGIN....dB	4.90	2.49	6.90	4.64	0.12	
MEAN-3*SIGMA.......dB	3.58					
MARGIN - w.c. RSS..dB	3.96					
TRANSPD RANGING-CHANNEL						
TC in RNG-Vdbd ? Y=1/N=0	*1*					
TONE MODULATION LOSS..dB	13.47	14.15	12.82			
RNG NOISE BNDWIDTH...kHz	*3000.00*	3300.00	2700.00			
RNG NOISE BNDWIDTH..dBHz	64.77	65.19	64.31			
IMPLEMENTATION LOSS...dB	*1.46*	*1.60*	*1.20*			
S(Tone)/N in Videobd..dB	-23.82	-26.99	-21.19			
S(TC)/N in RG-Videobd.dB	-14.82	-12.50	-17.68			

*) 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.

Project

LINK ID : X111.2 **PAGE 3/4**
DATE : date
ORBIT : Orbit ALTITUDE (1000km): 255.00
STATION : Station ELEVATION (deg): 90

TELECOMMAND BIT RATE (kb/sec) : 2.00 RANGING : Yes
TELEMETRY BIT RATE (kb/sec) : 1.75 with CONCAT. CODING : Yes

BASIC DOWNLINK (1/2)

	NOM	ADV	FAV	MEAN	VAR	PDF
S/C TX POWER.........dBW	*3.70*	*3.70*	*5.70*	4.37	0.22	TRI
DIPL. CIRCUIT LOSS....dB	*0.10*	*0.20*	*0.00*			
RFDU CIRCUIT LOSS.....dB	*2.10*	*2.60*	*2.00*			
CABLE LOSS............dB	*0.10*	*0.20*	*0.00*			
VSWR, overall.........:1	*1.00*	*1.00*	*1.00*			
VSWR LOSSES...........dB	0.05	0.10	0.00			
TOTAL LOSS............dB	2.35	3.10	2.00	2.55	0.10	UNI
S/C TX ANT GAIN......dBi	*-6.00*	*-6.50*	*-5.50*	-6.00	0.04	TRI
S/C ANT TX AXIAL RAT..dB	*4.00*	*4.50*	*4.00*			
POINTING LOSS (*)..dB	*0.00*	*0.00*	*0.00*	0.00	0.00	TRI
EIRP S/C.............dBW	-4.65	-5.90	-1.80	-4.18	*0.36*	
FREQUENCY............GHz	2.26	2.26	2.26	2.26		
SLANT RANGE......1000*km	255.00	255.00	255.00	255.00		
PATH LOSS.............dB	207.65	207.65	207.65	207.65		
ATMOSPHERIC LOSS......dB	0.10	0.20	0.00	0.10	0.00	GAU
IONOSPHERIC LOSS......dB	*0.05*	*0.10*	*0.00*	0.05	0.00	GAU
COPOLAR ANT-GAINS(Y=1/N=0)?	*1*					
POLARISATION MISMATCH.dB	0.06	0.13	0.00	0.06	0.00	UNI
TOTAL PROPAG. LOSS....dB	207.86	208.08	207.65	207.87	*0.00*	
FLUX at G/S......dBm/m^2	-153.77	-155.02	-150.92	-153.31	*0.37*	
POWER FLUX DENS..dBW/m^2	-187.59	-183.94	-189.76	(in 4 kHz)		
MAXIM FLUX DENS..dBW/m^2	-144.00	-144.00	-144.00	(S- or X-Bnd)		

	NOM	ADV	FAV
FLUX MARGIN...........dB	43.59	39.94	45.76

	NOM	ADV	FAV	MEAN	VAR	PDF
G/S RX ANT GAIN......dBi	48.00	48.00	48.00	48.00	0.00	UNI
POINTING LOSS.........dB	*0.03*	*0.05*	*0.00*	0.03	0.00	UNI
G/S ANT RX AXIAL RAT..dB	*0.50*	*1.00*	*0.00*			
SYSTEM NOISE TEMP....dBK	21.10	21.40	20.80	21.10	0.01	GAU
RX G/T..............dB/K	26.90	26.60	27.20	26.90	*0.01*	
RX S/No.............dBHz	42.96	41.17	46.35	43.42	*0.38*	

S/N in RANGING BANDWIDTH			
S(Tone)/N in Videobd..dB	-23.82	-26.99	-21.19
S(TC)/N in RG-Videobd.dB	-14.82	-12.50	-17.68

MODULATION INDICES (**)			
TELEMETRY (TM)....rad pk	*1.13*	1.24	1.02
TM, sine(1) or sqre(2) :	*1*		
RANGING (sine)....rad pk	*0.60*	0.66	0.54
RANG. TONE effec..rad pk	0.04	0.06	0.02
TC in RG-Videobd..rad pk	0.11	0.15	0.07
NOISE INDEX............	0.59	0.65	0.52

*) 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 % .

Project

LINK ID : X111.2 **PAGE 4/4**
DATE : date
ORBIT : Orbit ALTITUDE (1000km): 255.00
STATION : Station ELEVATION (deg): 90

TELECOMMAND BIT RATE (kb/sec) : 2.00 RANGING : Yes
TELEMETRY BIT RATE (kb/sec) : 1.75 with CONCAT. CODING : Yes

DOWNLINK (2/2)

	NOM	ADV	FAV	MEAN	VAR	PDF
RX S/No.............dBHz	42.96	41.17	46.35	43.42	*0.38*	
CARRIER RECOVERY						
CARRIER SUPPRESSION...dB	3.81	4.73	3.02	3.86	0.12	TRI
PLL BANDWIDTH 2*Bl...Hz	*30.00*	36.00	24.00			
PLL BANDWIDTH.......dBHz	14.77	15.56	13.80	14.71	0.13	TRI
REQ LOOP S/N.........dB	*17.00*	17.00	17.00	17.00		
CARRIER MARGIN........dB	7.37	3.87	12.53	7.86	0.63	
MEAN-3*SIGMA.......dB	5.47					
MARGIN - w.c. RSS..dB	5.83					
TELEMETRY RECOVERY						
TLM MODULATION LOSS...dB	4.16	5.00	3.46	4.21	0.10	TRI
DEMODULATOR TECH LOSS.dB	*0.50*	*0.60*	*0.40*	0.50	0.00	TRI
BIT RATE............kb/s	1.75	1.75	1.75			
BIT RATE............dBHz	32.43	32.43	32.43	32.43		
CONCAT CODING GAIN(*).dB	*9.70*	9.70	9.70			
CODING RATE 1/R.........	2.29					
REQ Eb/No (PFL=1.E-5).dB	*2.80*	2.80	2.80	2.80		
TELEMETRY MARGIN......dB	3.07	0.34	7.25	3.49	0.48	
MEAN-3*SIGMA.......dB	1.41					
MARGIN - w.c. RSS..dB	1.79					
TONE RECOVERY						
TONE MODULATION LOSS..dB	35.24	40.33	30.94	35.63		
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	74.51	15.27	437.36	75.69		
COMB. CARR. JITTER (***)						
RX TRSPD-PLL JITT...deg	2.84	4.22	2.06	2.96		
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	3.93	5.93	2.57	4.16		

*) 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.