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FOR SPACE STANDARDIZATION

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Radio frequency and modulation

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Foreword

This Standard is one of the series of ECSS Standards intended to be applied together for the management, engineering and product assurance in space projects and applications. ECSS is a cooperative effort of the European Space Agency, national space agencies and European industry associations for the purpose of developing and maintaining common standards.

Requirements in this Standard are defined in terms of what shall be accomplished, rather than in terms of how to organize and perform the necessary work. This allows existing organizational structures and methods to be applied where they are effective, and for the structures and methods to evolve as necessary without rewriting the standards.

The formulation of this Standard takes into account the existing ISO 9000 family of documents.

This Standard has been prepared by the ECSS-E-50-05 Working Group, reviewed by the ECSS Technical Panel and approved by the ECSS Steering Board.

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Introduction

The purpose of this Standard is to ensure the following:

- Compatibility of frequency usage and modulation schemes between space agencies' spacecraft and Earth stations for the Space Operation, Space Research and Earth Exploration Satellite services.
- As far as possible, compatibility between the spacecraft and other networks with which they can work.
- Standardization of frequency usage and modulation schemes within the space projects.
- Conformity of spacecraft and Earth station parameters to international radio regulatory provisions (Radio Regulations of the International Telecommunication Union (ITU)) and with national regulatory provisions (e.g. national frequency plans).
- That the parameters of spacecraft and Earth stations are properly chosen and listed in advance of their use, thus permitting coordination with other interested parties.
- That, within the above limitations, the frequency usage and modulation schemes are optimized.

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Scope

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

- frequency allocation, assignment and use;
- requirements on transmitted signals concerning, for example, spectral occupation, RF power levels, protection of other radio services;
- definition of the permissible modulation methods and parameters;
- specification of the major technical requirements that are relevant for the interface between spacecraft and Earth stations;
- operational aspects, such as acquisition;
- cross-support.

This Standard is applicable to all spacecraft supported by Earth stations [1] and to all controlled Earth stations operating in the space operation, Space Research and Earth Exploration Satellite services as defined in the ITU Radio Regulations.[2]

Other space telecommunication services are not covered in this issue.

The requirements specified by this Standard supersede any similar requirements contained in any of the related standards published prior to this issue. Consequently, in the case of conflict this Standard takes precedence.

When viewed from the perspective of a specific project context, the requirements defined in this Standard should be tailored to match the genuine requirements of a particular profile and circumstances of a project (see annex G).

NOTE Tailoring is a process by which individual requirements or specifications, standards and related documents are evaluated and made applicable to a specific project, by selection and, in some exceptional cases, modification of existing or addition of new requirements.
[ECSS-M-00-02A, clause 3]

[1] This Standard is not applicable for spacecraft supported by data relay satellites.

[2] This Standard is not applicable to the Meteorological Satellite service.

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Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this ECSS Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this ECSS Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the publication referred to applies.

ECSS-P-001	Glossary of terms
ECSS-E-50 [3)]	Space engineering — Communications
ITU/RR [4)]	ITU Radio Regulations, Geneva
CCSDS 401.0-B	CCSDS Radio Frequency and Modulation Systems, Part 1: Earth Stations and Spacecraft, Blue Book

3) To be published.

4) In this Standard the relevant articles are specified after the reference name. For example, ITU/RR/S1.23 refers to Article S1.23.

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3

Terms, definitions and abbreviated terms

3.1 Terms and definitions

The following terms and definitions are specific to this Standard in the sense that they are complementary or additional with respect to those contained in ECSS-P-001 and ECSS-E-50.

3.1.1
category A
category of those spacecraft having an altitude above the Earth's surface of less than 2×10^6 km

3.1.2
category B
category of those spacecraft having an altitude above the Earth's surface of equal to, or greater than, 2×10^6 km

3.1.3
Deep Space
space at distances from the Earth of equal to, or greater than, 2×10^6 km

[ITU/RR/S1.177]

3.1.4
Earth Exploration Satellite service
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

NOTE This service may also include feeder links necessary for its operation.

[ITU/RR/S1.51]

3.1.5
frequency coordinator

manager responsible for ensuring conformity with ITU/RR

3.1.6
necessary bandwidth

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

[ITU/RR/S1.152]

> NOTE For the purpose of this Standard, the necessary bandwidth shall be taken to be equal to the occupied bandwidth.

3.1.7
occupied bandwidth

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 $\beta/2$ of the total mean power of a given emission

[ITU/RR/S1.153]

> NOTE For the purpose of this Standard, the value of $\beta/2$ is 0,5 %.

3.1.8
out-of-band emission

emission on a frequency or frequencies immediately outside the necessary bandwidth, which results from the modulation process, but excluding spurious emissions

[ITU/RR/S1.144]

> NOTE For the purpose of this Standard, the boundary between out-of-band emissions and spurious emissions shall be taken as ±2,5 times the occupied bandwidth.

3.1.9
Space Operation service

a radiocommunication service concerned exclusively with the operation of spacecraft, in particular space tracking, space telemetry and space telecommand (TTC)

> NOTE These functions will normally be provided within the service in which the spacecraft is operating.

[ITU/RR/S1.23]

3.1.10
Space Research service

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

[ITU/RR/S1.55]

3.1.11
spurious emission

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

[ITU/RR/S1.145]

NOTE For the purpose of this Standard, the boundary between out-of-band emissions and spurious emissions shall be taken as ±2,5 times the occupied bandwidth.

3.1.12
symbol rate
reciprocal of the duration of the NRZ symbol at the modulator input

3.1.13
unwanted emissions
consists of spurious emissions and out-of-band emissions

[ITU/RR/S1.146]

NOTE For the purpose of this Standard, the boundary between out-of-band emissions and spurious emissions shall be taken as ±2,5 times the occupied bandwidth.

3.2 Abbreviated terms

The following abbreviated terms are defined and used within this Standard.

Abbreviation	Meaning
$2B_L$	double-sided phase-lock loop noise bandwidth
8PSK	phase shift keying of 8 states
BPSK	binary phase shift keying (see PSK)
BT	product of bandwidth and symbol duration
BW	bandwidth
CCSDS	Consultative Committee for Space Data Systems
CLCW	command link control word
dB	decibel
dBi	dB with respect isotropic emission
dBc	dB with respect to the unmodulated carrier
DRS	data relay satellite
DS	deep space
DSN	Deep Space Network of NASA
EES	Earth Exploration Satellite service
EHF	extremely high frequency NOTE EHF ranges from 30 GHz to 300 GHz.
EIRP	equivalent isotropically radiated power
ESA	European Space Agency
E/S	Earth station
f_t	ranging tone frequency
GMSK	Gaussian minimum shift keying
GSO	geostationary orbit
G/T	ratio of antenna gain to system noise temperature
ITU	International Telecommunication Union
ITU-R	radiocommunication sector of the ITU
ITU/RR	ITU radio regulations
LHC	left hand circular
NASA	National Aeronautics and Space Administration of the United States

NASDA	National 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 locked loop
PM	phase modulation
PSK	phase shift keying
QPSK	quadrature phase shift keying
RF	radio frequency
RFI	radio frequency interference
RHC	right hand circular
r.m.s.	root-mean-square
R_s	symbol rate
RSS	root-sum-square
Rx	receiver
SFCG	Space Frequency Co-ordination Group
SHF	super high frequency

NOTE SHF ranges from 3 GHz to 30 GHz.

SP-L	split phase-level
SO	Space Operation service
SR	Space Research service
SRC	square-root raised-cosine
TC	telecommand
TCM	trellis-coded modulation
TDRSS	Tracking and Data Relay Satellite System of NASA
TM	telemetry
TR	tracking
TTC	telemetry, tracking and telecommand
Tx	transmitter
UHF	ultra high frequency

NOTE UHF ranges from 300 MHz to 3 000 MHz.

UQPSK	unbalanced quadrature phase shift keying

4

Frequency allocations, assignment and use

4.1 Frequency allocations to the Space Operation, Space Research and Earth Exploration Satellite services

4.1.1 General

4.1.1.1

The use of frequencies by radiocommunication services is governed by the provisions of the Radio Regulations of the International Telecommunication Union (ITU/RR), which

- define the various radiocommunication services (see subclause 3.1),
- allocate frequency bands to them (see subclause 4.1.2),
- lay down procedures to be followed for a frequency assignment and the frequency notification with the Radiocommunications Bureau of the ITU (see subclause 4.3),
- specify technical conditions for the frequency use (see clause 5).

4.1.1.2

Any frequency assignment made to a particular user (spacecraft) shall be made in conformity with the ITU/RR.

4.1.2 Frequency bands allocated to the Space Radiocommunications services

4.1.2.1 General

Table 1 lists the available frequency bands, and their allocated radiocommunication service, direction and status.

Table 1: Frequency allocations to the Space Operation, Space Research and Earth Exploration services

Frequency band (MHz) (see 4.1.2.2 and 4.1.2.3)	Allocated service (see 4.1.2.4)	Direction (see 4.1.2.5)	Allocation status (see 4.1.2.6)
2 025 – 2 110	SR, SO, EES	Earth-space	Primary
2 110 – 2 120	SR (DS)	Earth-space	Primary
2 200 – 2 290	SR, SO, EES	Space-Earth	Primary
2 290 – 2 300	SR (DS)	Space-Earth	Primary
7 145 – 7 190 [a]	SR (DS)	Earth-space	FN (ITU/RR/S9.21)
7 190 – 7 235 [a]	SR	Earth-space	FN (ITU/RR/S9.21)
8 025 – 8 400	EES	Space-Earth	Primary
8 400 – 8 450	SR (DS)	Space-Earth	Primary
8 450 – 8 500	SR	Space-Earth	Primary
14 000 – 14 300 [a]	SR	Space-Earth [b]	Secondary
14 400 – 14 470 [a]	SR	Space-Earth	Secondary
14 500 – 15 350 [a]	SR	Space-Earth [b]	Secondary
16 600 – 17 100 [a]	SR	Earth-space	Secondary
25 500 – 27 000 [a]	EES	Space-Earth	Primary
31 800 – 32 300 [a]	SR (DS)	Space-Earth	Primary
34 200 – 34 700 [a]	SR (DS)	Earth-space	Primary
37 000 – 38 000 [a]	SR	Space-Earth	Primary
40 000 – 40 500 [a]	SR	Earth-space	Primary
	EES	Earth-space	Primary

[a] Implementation of frequency bands can be incomplete.

[b] Direction indicator recommended by SFCG.

4.1.2.2 Frequency band implementation

Users interested in frequency bands should contact the network operation manager in charge of the ground network.

NOTE Implementation of frequency bands can be incomplete. When this is the case, it is stated in Table 1.

4.1.2.3 Special conditions governing the use of particular frequency bands

4.1.2.3.1
The use of certain frequency bands is governed by specific conditions, which are laid down in Recommendations of the SFCG and CCSDS RF and Modulation Sub-panel (see clause 2 and Bibliography).

4.1.2.3.2
The frequency coordinator shall inform applicants for frequency assignments about any evolution of the conditions stated in 4.1.2.3.1, which can have occurred since the issue of this Standard.

NOTE See also subclause 4.3.

4.1.2.4 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.

4.1.2.5 Direction indicator

a. Frequency bands shall be used in conformity with the direction indicated in the Table 1.

b. If no direction indicator is present, the bands may be used in either direction (Earth-space, space-Earth, space-space), unless the SFCG or CCSDS specify otherwise.

4.1.2.6 Allocation status

Frequency allocations are made on the following basis (see ITU/RR/S5, Section II):

a. Primary allocation

   1. The one responsible for a service with a primary allocation status shall only share and coordinate with other co-primary services, which can be allocated in the same band, and

   2. A service with a primary allocation status has priority over other allocations, such as secondary, and therefore it need not protect them or accept interference caused by them or to coordinate with them.

b. Secondary allocation

   A service with a secondary allocation status shall not:

   1. cause harmful interference to any station of a primary service allocated in the same band, or

   2. claim protection from interference caused by stations of a primary service allocated in the same frequency band.

c. Allocation by footnote

   All additional regulatory conditions for the use of the frequency band, such as supplementary coordination in accordance with ITU/RR/ S9.21, or limits to the allocation to less than an entire ITU region contained in an allocation by footnote in ITU/RR, shall be adhered to at all times.

d. Allocation under the special procedure of ITU/RR/S9.21

   The supplementary (coordination) procedure of ITU/RR/S9.21, which stipulates a prior agreement with one or more administrations operating primary services in the bands, shall be applied.

   NOTE In this Standard, allocation is only applicable to the 7 145 MHz – 7 235 MHz band.

4.2 Specific conditions for the use of certain frequency bands

4.2.1 2 025 MHz – 2 120 MHz and 2 200 MHz – 2 300 MHz bands

4.2.1.1 2 025 MHz – 2 120 MHz band

4.2.1.1.1 2 025 MHz - 2 110 MHz band

The 2 025 MHz – 2 110 MHz band is allocated to Earth-space and space-space transmissions.

a. 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 to allow for a margin of 3 dB on the link budget.

b. The use of a higher value shall be analyzed and justified.

c. Earth station transmitters shall allow adjustable RF output power by steps of 3 dB or less.

d. With a view to alleviating the frequency sharing situation, operators shall not activate the Earth-space links during periods when no tracking and telecommand operations are performed.

NOTE Excessive Earth station EIRP not only complicates frequency co-ordination with other users, but can also prevent operations totally at some sites. As a means of RFI mitigation, if requested by priority users, ITU/RR specifies the interruption of Earth-space transmissions during the periods when they cause RFI.

4.2.1.1.2 2110 MHz - 2120 MHz band

New assignments in the 2 110 MHz – 2 120 MHz band shall only be considered after consultation with the frequency coordinator.

NOTE The 2 110 MHz – 2 120 MHz band is part of the IMT-2000 or UMTS core band for third generation mobile telecommunication systems. Given the importance of this band for mobile telecommunications, administrations have imposed extremely severe limitations on the use of this band for Earth-space transmissions of the Space Research, Deep Space service. Therefore, new assignments in this band are formally discouraged.

4.2.1.2 2 200 MHz – 2 300 MHz band

4.2.1.2.1 2 200 MHz - 2 290 MHz

The devices on spacecraft used to switch-off emissions shall be designed with high reliability and be qualified for a large number of switching cycles during the spacecraft lifetime. (See also 5.5.2.)

NOTE The 2 200 MHz – 2 290 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.

4.2.1.2.2 2290 MHz - 2300 MHz

New assignments in this band shall only be considered after consultation with the frequency coordinator.

4.2.2 8 025 MHz – 8 400 MHz band

The same RFI mitigation methods specified in 4.2.1.2.1 for the 2 200 MHz – 2 290 MHz band shall be applied to the 8025 MHz – 8400 MHz band.

NOTE The 8 025 MHz – 8 400 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 2 200 MHz – 2 290 MHz band; additionally the interference situation is aggravated by the fact that most of the Earth Exploration Satellites use very similar (polar) orbits.

4.2.3 8 450 MHz – 8 500 MHz band

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

NOTE In the use of this band, priority is given to libration point missions.

4.2.4 16,6 GHz – 17,1 GHz and 14,0 GHz – 15,35 GHz bands

a. The 16,6 GHz – 17,1 GHz (Earth-space) and 14,0 GHz – 15,35 GHz (space-Earth) bands shall be used only for transmission of wideband data, with an occupied bandwidth larger than 10 MHz.

b. 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.

NOTE 1 The 16,6 GHz – 17,1 GHz band is currently still allocated to Space Research (Deep Space). SFCG is seeking regulatory action from a future competent WRC to remove the limitation to Deep Space.

NOTE 2 Currently, no modulation standard has been established to be used in these two frequency bands.

4.2.5 40,0 GHz – 40,5 GHz and 37,0 GHz – 38 GHz bands

Users interested in the use of this band shall contact the frequency coordinator for further guidance.

NOTE Future use of the 40,0 GHz – 40,5 GHz and 37,0 GHz – 38,0 GHz bands is still under consideration in the SFCG.

4.3 Frequency assignment procedure

4.3.1 Choice of frequencies

a. The project manager shall seek guidance from the frequency coordinator on the selection and use of frequency bands, for the assignment of individual frequencies in the selected band or bands, to be in conformity with the frequency management procedure established by the frequency coordinator.

b. Prior to the design phase of any spacecraft project, the project shall request the frequency assignments for the spacecraft. For this purpose it shall:

1. provide to the frequency coordinator with the information in conformity with the specifications established by him/her; and

2. indicate which of the information supplied is still in a preliminary state and is to be confirmed at a later date.

c. The entire procedure shall be carried out under the management of the frequency coordinator, who has the exclusive authority to assign frequencies.

d. All requests for frequency assignments or inquiries regarding frequency management matters shall be addressed to the frequency coordinator.

4.3.2 Advance publication, coordination and notification of frequencies

a. Not later than three years before the planned launch date, the project manager shall provide to the frequency coordinator the data regarding the frequencies used by the spacecraft, to allow the advance publication, coordination and notification procedures of ITU/RR/S9 and ITU/RR/S11.

b. The format established by the frequency coordinator shall be used for this purpose.

c. At this stage, the data supplied as per 4.3.1 above shall be the final.

d. The procedures of ITU/RR/S9 and ITU/RR/S11 shall be carried out in a timely manner by the frequency coordinator for the satellites and Earth stations, in conformity with frequency management procedures.

5

Transmitted signals

5.1 Turnaround frequency ratio for coherent transponders

5.1.1 Generation of the transmitted carrier

Transponders, flown on the spacecraft for the purpose of coherent Doppler tracking, may generate the transmitted carrier from the received carrier by means of phase-lock techniques.

5.1.2 Band pairs

a. Band pairs should be selected from Table 2 together with the applicable turnaround ratio.

b. In case the turnaround ratios in Table 2 cannot be used, the ratios in Table 3 shall be used instead.

Table 2: Turnaround frequency ratios for coherent transponder operation

	Earth-space (MHz)	Space-Earth (MHz)	Turnaround ratio (f_{up}/f_{down})
Cat. A	2 025,833 333 – 2 108,708 333	2 200 – 2 290	221/240
	7 192,102 273 – 7 234,659 091	8 450 – 8 500	749/880
Cat. B	2 110,243 056 – 2 117,746 142 [a]	2 291,666 667 – 2 299,814 815	221/240
	2 110,243 056 – 2 119,793 438 [a]	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
	7 147,286 265 – 7 188,897 377	31 909,913 580 – 32 095,691 358	749/3 344 [b]
	34 354,343 368 – 34 554,287 799	8 400,061 729 – 8 448,950 615	3 599/880 [b]
	34 365,451 396 – 34 487,639 661	31 930,555 562 – 32 044,086 420	3 599/3 344 [b]

[a] See subclause 4.2.1.1.2.

[b] Additional turnaround ratios are currently under consideration for a full use of the allocated bandwidths at 32 GHz and 34 GHz.

Table 3: Alternative turnaround frequency ratios for coherent transponder operation

	Earth-space (MHz)	Space-Earth (MHz)	Turnaround ratio (f_{up}/f_{down})
Cat. A	2 074,944 444 – 2 087,222 222	8 450 – 8 500	221/900
	7 190 – 7 235	2 255,686 275 – 2 269,803 922	765/240
	7 190 – 7 225,000 000	8 458,823 529 – 8 500	765/900 749/880 [b]
Cat. B	2 110,243 056 – 2 119,792 438 [a]	31 930,555 556 – 32 075,049 383	221/3 344 [c]
	34 343,235 339 – 34 487,639 661	2 290,185 185 – 2 299,814 815	3 599/240 [c]

[a] See subclause 4.2.1.1.2.

[b] Ratio 765/900 is only applicable in the case of fully coherent systems with 2 GHz, or 7 GHz, or 8 GHz links; otherwise, ratio 749/880 is applicable.

[c] Additional turnaround ratios are currently under consideration for a full use of the allocated bandwidths at 32 GHz and 34 GHz .

5.2 Carrier frequency stability

5.2.1 Spacecraft transmitter

The frequency stability of the transmitted RF carriers shall be within the limits specified in Table 4.

Table 4: Frequency stability for spacecraft transmitters

Frequency band (MHz)	Maximum frequency instability
2 200 – 2 290 8 450 – 8 500	$\pm 2 \times 10^{-5}$ under all conditions and for the lifetime of the spacecraft.
8 025 – 8 400 25 500 – 27 000	$\pm 2 \times 10^{-5}$ under all conditions and for the lifetime of the spacecraft.
2 290 – 2 300 8 400 – 8 450 31 800 – 32 300	$\pm 2 \times 10^{-5}$ under all conditions and for the lifetime of the spacecraft. $\pm 1{,}5 \times 10^{-6}$ at any one temperature of transmitter in the range +10 ° to +40 ° in any 15 h following 4 h of warm-up. $\pm 0{,}2 \times 10^{-6}$/°C within the transmitter temperature range +10 °C to +40 °C. Ageing $\pm 2{,}5 \times 10^{-6}$ per year

5.2.2 Spacecraft receiver

The frequency stability of spacecraft receivers shall be within the limits specified in Table 5.

NOTE For phase lock loop receivers the frequency referred to is the best lock frequency.

Table 5: Frequency stability for spacecraft receivers

Frequency band (MHz)	Maximum frequency instability
2 025 – 2 110 7 190 – 7 235	$\pm 2 \times 10^{-5}$ under all conditions including $\pm 4{,}8 \times 10^{-6}$ initial setting error. Ageing over seven years $\pm 7{,}1 \times 10^{-6}$.
2 110 – 2 120 7 145 – 7 190 34 200–34 700	$\pm 2 \times 10^{-5}$ under all conditions including $\pm 4{,}8 \times 10^{-6}$ initial setting error. $\pm 1{,}7 \times 10^{-5}$ at any one temperature in the range +10 ° to +40 °C in any 15 h after a warm-up period of 4 h. $\pm 2{,}4 \times 10^{-7}$/°C over the temperature range + 10 °C to +40 °C. Ageing $\pm 2{,}5 \times 10^{-6}$ per year.

5.2.3 Ground station equipment

The RF carriers transmitted by the Earth station shall be phase locked to a reference frequency standard having an accuracy of at least $\pm 5 \times 10^{-9}$ under all conditions.

5.2.4 Requirements for Doppler tracking

For any special stability requirements concerning ranging and Doppler tracking, the relevant Agency dependent standard shall be consulted until the new ECSS-E-50-02 Standard is approved.

5.3 Polarization

a. Earth-space and space-Earth links shall be circularly polarized.

NOTE For a right-hand circularly-polarized wave, the sense of polarization determined by the electric field vector rotates with time in a right-hand or clockwise direction when observed in any fixed plane, normal to the direction of propagation, whilst looking in the direction of propagation.

b. Earth stations shall be capable of transmitting right-hand or left-hand circular polarization at the choice of the user.

NOTE 1 For practical reasons, spacecraft generally use the same sense of polarization for the Earth-space link and the space-Earth link.

NOTE 2 Most Earth stations have the capability of combining 2 orthogonal circular polarizations on the space-Earth link.

5.4 Bandwidth considerations

5.4.1 Occupied bandwidth

The occupied bandwidth shall not be wider than the maximum values given in Table 6, where f_t is the ranging tone frequency and R_s the symbol rate.

NOTE The values given in Table 6 represent the maximum, but it is specified in ITU/RR/S3.9 that all efforts are made to restrict the occupied bandwidth.

5.4.2 Special case of bandwidth efficient modulations

For bandwidth efficient modulation, subclause 6.3 shall be applied.

Table 6: Occupied bandwidth

Frequency band (MHz)	Function	Category	Maximum occupied bandwidth
2 025 – 2 120 and 7 145 – 7 235	Telecommand (8 kHz subcarrier)	A & B	50 kHz
	Telecommand (16 kHz subcarrier)	A & B	100 kHz
	Telecommand (direct modulation)	A & B	$12 \times R_s$
	Ranging	A & B	$2{,}5 \times f_t$
2 200 – 2 290 and 8 450 – 8 500	Telemetry (symbol rate < 10 ksymbols/s)	A	300 kHz
	Telemetry PCM/PSK/PM (10 ksymbols/s ≤ symbol rate ≤ 60 ksymbols/s)	A	1 200 kHz or $30 \times R_s$, whichever is smaller [a]
	Telemetry (60 ksymbols/s < symbol rate < 2 Msymbols/s)	A	1 200 kHz or $12 \times R_s$, whichever is larger, up to 5 MHz at 2 GHz and 10 MHz at 8 GHz
	Telemetry (symbol rate ≥ 2 Msymbols/s)	A	$1{,}1 \times R_s$, up to 5 MHz at 2 GHz and 10 MHz at 8 GHz
	Ranging space-Earth	A	$2{,}5 \times f_t$
8 025 – 8 400	Telemetry	-	$1{,}6 \times R_s$
2 290 – 2 300 and 8 400 – 8 450	Ranging space-Earth Telemetry (symbol rate ≥ 2 Msymbols/s)	B	$2{,}5 \times f_t$ $1{,}2 \times R_s$ [b]

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

[b] No special requirement exists for symbol rates less than 2 Msymbols/s.

5.5 Emissions

5.5.1 Unwanted emission power level

5.5.1.1 Transmitter spurious emissions and harmonics

The spurious emissions including harmonics generated by spacecraft and Earth station transmitters shall not exceed the levels given in Table 7.

Table 7: Maximum level of spurious emissions

Carrier frequency (MHz)	Case	Maximum spurious level
100 – 40 500	Modulated and unmodulated transmissions. [a]	-60 dBc, measured in a reference bandwidth of 4 kHz [b]
	Carrier harmonics of category B spacecraft transmitters	-30 dBc

[a] Though ITU/RR/AP S3, Table II, Footnote 17 in principle exempts Deep Space missions from limits on unwanted emissions. Nevertheless the maximum value given in this Table is made applicable for all these missions, since they may travel frequently for long periods of time below the 2 000 000 km limit of Deep Space.

[b] See ITU/RR/SM.329.

5.5.1.2 Protection of radio astronomy bands

Unwanted emissions falling into frequency bands allocated to the Radio Astronomy service shall be kept to power flux spectral density values less than those detrimental to radio astronomy reproduced in Tables 8 and 9.

NOTE 1 ITU/RR/A.769-1 outlines protection criteria for radio astronomy measurements and lists in its annex interference thresholds detrimental to radio astronomy.

NOTE 2 Radio astronomy measurements are done in two modes: as spectral line observations using narrow bandwidths and as continuum observations using large bandwidths. This information is reproduced in Tables 8 and 9 for each of the modes from ITU/RR/A.769-1. In accordance with ITU/RR/A.769-1, power levels in excess of these values are considered harmful when illuminating a specific terrestrial radio astronomy site.

NOTE 3 For continuum observations, an integration of the interference power over the specified observation bandwidth given in Table 8 may be performed.

Table 8: Threshold levels of interference detrimental to radio astronomy spectral line (i.e. narrow bandwidth) observations at the surface of the Earth

Centre frequency (MHz)	Assumed observation bandwidth of spectral line (kHz)	Power flux spectral density (dBW/m²/Hz)
327	10	-244
1 420	20	-239
1 665	20	-237
4 830	50	-230
14 500	150	-221
22 200	250	-216
23 700	250	-215
43 000	500	-210
48 000	500	-209
88 600	1 000	-204
98 000	1 000	-203
115 000	1 000	-201

Table 9: Threshold levels of interference detrimental to radio astronomy continuum (i.e. wide bandwidth) observations at the surface of the Earth

Centre frequency (MHz)	Assumed 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	-55
611	6,0	-253
1 413,5	27	-255
1 665	10	-251
2 695	10	-247
4 995	10	-241
10 650	100	-240
15 375	50	-233
23 800	400	-233
31 550	500	-228
43 000	1 000	-227
89 000	6 000	-222
110 500	11 000	-222

5.5.1.3 Protection of Deep Space Research bands

a. Unwanted emissions falling into the frequency bands of Deep Space Research should be kept to power flux spectral density values less than those given in Table 10.

b. Whenever the limits of Table 10 cannot be met, coordination shall be initiated between the offending satellite and the Space Research (Deep Space) users, via the frequency coordinator.

NOTE This is consistent with SFCG Recommendation 14-1 and SFCG Administrative Resolution A12-1.

Table 10: Harmful interference levels at Deep Space antenna sites

Frequency band	Power flux spectral density at antenna location (dBW/m^2/Hz)
2 290 MHz – 2 300 MHz	-257
8 400 MHz – 8 450 MHz	-255
31,8 GHz – 32,3 GHz	-251
37,0 GHz – 38,0 GHz	-251

5.5.1.4 Protection of launcher RF systems

Spurious emissions from spacecraft which are active during the launch shall conform to the RF interface requirements of the launcher.

NOTE For Ariane-5 the interface requirement document is A5-SG-1-X-35-ASAI.
For 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 annex C can be used. This annex also gives some examples of typical requirements for Ariane-5. Note that the conversion method is 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.

5.5.2 Cessation of emissions

a. Each spacecraft shall be fitted with devices to ensure immediate cessation of its radio emissions by telecommand whenever such a cessation is requested. (See ITU/RR/S22.1.)

b. Since the temporary cessation of emissions is an efficient means of RFI mitigation in densely occupied bands, the design of devices used for the switch-off of emissions shall be done with high reliability, and be qualified for a large number of switching cycles during the mission lifetime. See SFCG Recommendation 12-4R2.

5.5.3 Power flux density limits

a. The power flux density (PFD) at the Earth's surface produced by emissions from a spacecraft, for all conditions and all methods of modulation, should not exceed the values given in Table 11. (See ITU/RR/S21.16.)

NOTE In all cases, the limits relate to the PFD, which are obtained under assumed free-space propagation conditions.

b. The PFD limits should be applied during all mission phases.

NOTE This can involve means for reducing EIRP on board the spacecraft. However, during certain phases of missions (e.g. the launch phase) it may not be practical to meet the PFD limits at all times.

c. When it is not feasible to comply with the PDF limits given in a. above, the advice of the frequency coordinator shall be sought.

Table 11: Power flux density limits at the Earth's surface

Frequency (MHz)	Angle of incidence (δ) above horizontal plane (degrees)	Power flux density ($dBW/m^2/4$ kHz)
1 525 – 2 300	0 – 5	-154
	5 – 25	-154 + 0,5 × (δ-5)
	25 – 90	-144
8 025 – 8 500	0 – 5	-150
	5 – 25	-150 + 0,5 × (δ-5)
	25 – 90	-140
Frequency (MHz)	**Angle of incidence (δ) above horizontal plane (degrees)**	**Power flux density ($dBW/m^2/1$ MHz)**
31 800 – 32 300	0 – 5	-120
	5 – 25	-120 + 0,75 × (δ - 5)
	25 – 90	-105
37 000 – 38 000 (non-GSO satellites)	0 – 5	-120
	5 – 25	-120 + 0,75 × (δ - 5)
	25 – 90	-105
37 000 – 38 000 (GSO satellites)	0 – 5	-125
	5 – 25	-125 + (δ - 5)
	25 – 90	-105

5.5.4 Power limits for Earth station emissions

5.5.4.1 Frequency bands between 1 GHz and 15 GHz

a. Except as specified in point b., the equivalent isotropically radiated power (EIRP) transmitted in any direction towards the horizon by an Earth station operating in the frequency bands between 1 GHz and 15 GHz shall not exceed:

1. +40 dBW in any 4 kHz band for $\theta \leq 0°$
2. $+40 + 3 \times \theta$ dBW in any 4 kHz band for $0° \leq \theta \leq 5°$

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.

b. As an exception to the limits specified in point a., 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, regardless of the horizon elevation.

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

5.5.4.2 Frequency bands above 15 GHz

a. Except as specified in point b., the EIRP transmitted in any direction towards the horizon by an Earth station operating in the frequency bands above 15 GHz shall not exceed:

1. +64 dBW in any 1 MHz band for $\theta \leq 0°$;
2. $(+64 + 3 \times \theta)$ dBW in any 1 MHz band for $0° \leq \theta \leq 5°$;

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.

b. As an exception to the limits specified in point a., the EIRP towards the horizon for an Earth station in the Space Research service, Deep Space shall not exceed +79 dBW in any 1 MHz band, regardless of the horizon elevation.

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

5.5.4.3 Limits to elevation angles

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

1. 3° for the Space Operation service;
2. 5° for the Space Research service, Category A;
3. 10° for the Space Research service, Category B;

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

b. Since host administrations for Earth stations may specify tighter minimum elevation limits, the advice of the frequency coordinator shall be sought.

5.5.5 Time limitations on transmissions

a. Transmissions from Earth stations to spacecraft shall be limited in time to the periods during which actual Earth-space link telecommunications (e.g. telecommand) and/or tracking operations are carried out (see also 4.2.).

b. Spacecraft telecommunication system designs which rely on the presence of a continuous Earth-space carrier outside the periods stated in point a. shall be avoided.

c. Spacecraft shall limit their transmission of RF power towards the Earth to those periods where telecommunications (e.g. reception of telemetry and data) or tracking operations are carried out. (See also 4.2.)

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6

Modulation

6.1 Phase modulation with residual carriers

6.1.1 Application

Phase modulation shall be used for:

a. Telemetry in the UHF (2 200 MHz – 2 300 MHz), SHF (8 400 MHz – 8 500 MHz) and EHF (31,8 GHz - 32,3 GHz) bands, unless modulation in accordance with subclause 6.2 of this Standard is adopted.

b. Telecommand in the UHF (2 025 MHz – 2 120 MHz), SHF (7 145 MHz – 7 235 MHz) and EHF (34,2 GHz - 34,7 GHz) bands.

c. Ranging Earth-space in the UHF (2 025 MHz – 2 200 MHz), SHF (7 145 MHz – 7 235 MHz) and EHF (34,2 GHz - 34,7 GHz) bands.

d. Ranging space-Earth in the UHF (2 200 MHz – 2 300 MHz), SHF (8 400 – 8 500 MHz) and EHF (31,8 GHz - 32,3 GHz) bands.

6.1.2 Modulating waveforms

a. The following modulating waveforms may be used:

   1. Telemetry, a subcarrier modulated by PCM data.
   2. Telemetry, PCM data, SP-L encoded.
   3. Telecommand, a subcarrier modulated by PCM data.
   4. Telecommand, SP-L encoded (see point b. below).
   5. Ranging, the appropriate ranging baseband signal.

   NOTE For improving link performance, or for controlling transition density or spectral occupancy of the telemetry signal, see ESA PSS-04-103.

b. Telecommand SP-L encoded, specified in point a.4. above, should not be used together with simultaneous ranging and telemetry.

6.1.3 PCM waveforms and data rates

a. PCM data signals shall be limited to the waveforms and symbol rates given in Table 12, with the following limitations:

1. For the RF carrier bands of 2 025 MHz – 2 120 MHz, 7 145 MHz – 7 235 MHz, 3 4200 MHz – 34 700 MHz and 40 000 MHz – 40 500 MHz (telecommand):
   (a) NRZ-M shall not be used for category B;
   (b) a symbol rate n = 0 shall only be used with 16 kHz subcarrier;
   (c) no subcarrier shall be used together with SP-L waveform.
2. For the RF carrier bands of 2 200 MHz – 2 300 MHz, 8 400 MHz – 8 500 MHz and 31 800 MHz – 32 300 MHz (telemetry):
   (a) NRZ–M shall not be used for category B;
   (b) NRZ waveforms shall only be used when modulated on a subcarrier.

   NOTE For the definition of the PCM waveforms and symbol duration, reference is made to Figure 1.

Table 12: PCM waveforms and rates

RF carrier (MHz)	Function	Symbol rate (symbol/s)	PCM waveform	Special limitations
2 025 – 2 120 7 145 – 7 235 34 200 – 34 700 40 000 – 40 500	Telecommand	$4\,000/2^n$ n = 0,1..9	NRZ-L NRZ-M	1) See 6.1.3.a.1.(a) 2) See 6.1.3.a.1.(b)
		$4\,000 \times 2^n$ n = 1 .. 6 [c]	SP-L	See 6.1.3.a.1.(c)
2 200 – 2 300 8 400 – 8 500 31 800 – 32 300	Telemetry [a,b]	10^2 - 10^7	NRZ-L SP-L NRZ-M	1) See 6.1.3.a.2.(a) 2) See 6.1.3.a.2.(b)
37 000 – 38 000 [d]	Telemetry	Up to 6×10^8		-

[a] Symbol rates below 100 symbols/s may be supported on a case by case basis. For such support, contact the relevant engineering services.

[b] The range of symbol rates is indicative only. For the rate used, the provisions in Tables 6 and 13 are applicable.

[c] The implementation of this capability can be still incomplete. For telecommand data rates in excess of 4 ksymbols/s, contact the relevant engineering services.

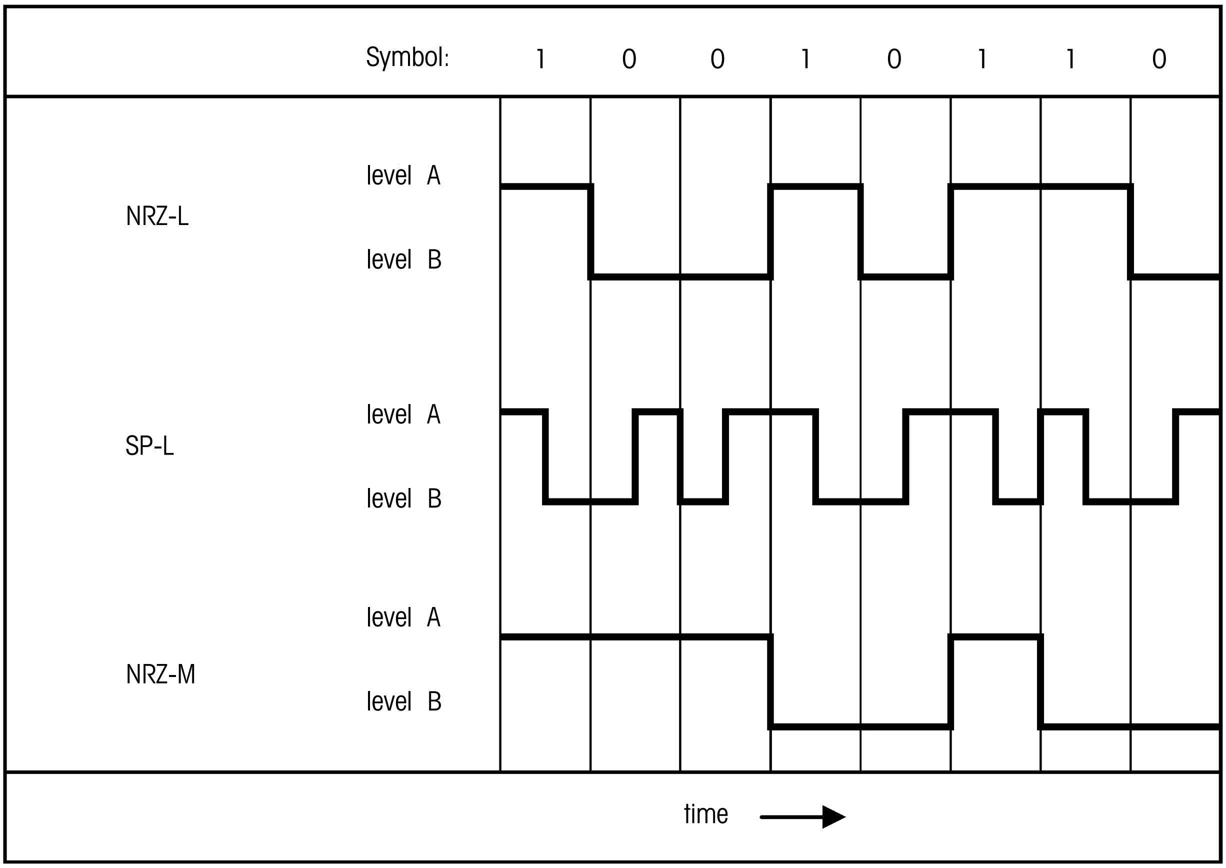
[d] The use of this band is going to be defined in later versions of this Standard.

b. For all data signals producing a square wave baseband PCM waveform, the symmetry shall be such that the mark-to-space ratio ranges from 0,998 to 1,002.

   NOTE In case of a combined PCM/SP-L/PM telecommand, the spectral overlap from the telecommand signal can cause degradation of the telemetry performance. Users are encouraged to take this into consideration.

c. SP-L shall not be used except for direct modulation of the RF carrier.

d. NRZ waveforms shall only be used when modulated onto a subcarrier.



NRZ-LV	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”

Figure 1: PCM waveforms

6.1.4 Use of subcarriers

6.1.4.1 Subcarriers

6.1.4.1.1 General

The subcarriers and modulating waveforms listed in Table 13 shall be used.

Table 13: Subcarriers used with phase-modulated rf carriers

RF Carrier (MHz)	Function	Subcarrier (kHz)	Modulation waveform	Subcarrier waveform	References
2 025 – 2 110 7 190 – 7 235	Telecommand (Category A)	8 or 16	NRZ-L NRZ-M	sine	See 6.1.4.1.2
2 110 – 2 120 7 145 – 7 190 34 200 – 34 700	Telecommand (Category B)	8 or 16	NRZ-L	sine	See 6.1.4.1.2
2 200 – 2 290 8 450 – 8 500	Telemetry (Category A)	0,1 – 1 000	NRZ-L NRZ-M	sine	See 6.1.4.1.3
2 290 – 2 300 8 400 – 8 450 31 800 – 32 300	Telemetry (Category B)	0,1 – 1 000	NRZ-L	square	See 6.1.4.1.3 d.

6.1.4.1.2 Telecommand

a. For telecommand transmission using a subcarrier, only two subcarrier frequencies shall be used.

b. In the case specified in point a., the subcarrier frequency should be 8 kHz. Only in cases where the 4 ksymbols/s symbol rate is used or where supported by the frequency coordinator, may the 16 kHz subcarrier be used.

c. For telecommand symbol rates in excess of 4 ksymbols/s, the symbols shall be SP-L encoded and directly modulated onto the carrier.

6.1.4.1.3 Telemetry

a. For NRZ telemetry symbol rates above 60 ksymbols/s (or above 30 ksymbols/s for SP-L data formats) subcarriers shall not be used and either one of the following modulation schemes shall be used:

1. SP-L encoded symbols and direct modulation on the carrier;
2. modulation in accordance with subclause 6.2 of this Standard.

b. For telemetry subcarrier frequencies above 60 kHz, a subcarrier frequency-to-highest symbol rate ratio not exceeding 4 (for category A missions) or 5 (for category B missions) shall be used.

c. In case a ratio of 4 or 5 leads to spectral overlap with other signal components, the subcarrier frequency-to-highest symbol rate ratio shall be the smallest integer achieving less than 0,3 dB degradation (category A) or less than 0,1 dB degradation (category B) in the symbol detection process.

NOTE For missions with multiple symbol rates, the subcarrier frequency used for the highest symbol rate may be also used for the lower symbol rates.

d. Telemetry subcarrier frequencies shall conform to the requirements of:

1. carrier acquisition by the ground receivers, as specified in annex A.1;
2. occupied bandwidth, as specified in subclause 5.4.1.;
3. compatibility between ranging and telemetry.

NOTE For compatibility between ranging and telemetry, see PSS-04-104.

6.1.4.2 Subcarrier frequency stability

a. Telecommand subcarriers

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

b. Telemetry subcarriers

1. The telemetry subcarrier shall have a frequency within $\pm 1 \times 10^{-4}$ of its nominal value at all times.
2. The medium-term frequency variation due to power-supply voltage, temperature and other spacecraft influences shall be less than $\pm 1 \times 10^{-5}$.
3. The short-term frequency stability shall be at least $\pm 1 \times 10^{-6}/T$, where T is less than or equal to 100 times the subcarrier's waveform period.

c. Subcarrier modulation

Modulation of subcarriers used for telemetry and telecommand shall be PSK and conform to the following requirements:

1. The subcarrier frequency shall be an integer multiple of the symbol rate.
2. At each transition in the PCM waveform, the subcarrier shall be reversed in phase.
3. The transitions in the PCM waveform shall coincide with a subcarrier zero crossing to within ±2,5 % of a subcarrier period.
4. At all times, for more than 25 % of a subcarrier period after a phase reversal, the phase of the modulated subcarrier shall be within ±5° of that of a perfect PSK signal.
5. For NRZ waveforms, the beginning of the symbol intervals shall coincide:
   (a) in the case of NRZ-M waveforms, with a subcarrier zero crossing;
   (b) in the case of NRZ-L waveforms, with a positive-going subcarrier zero crossing for symbols “1” and with a negative-going zero crossing for symbols “0”.

d. SP-L waveforms in combination with a subcarrier shall not be used. (See also 6.1.3c.)

6.1.5 Data transition density

a. To ensure recovery of the symbol clock by the ground demodulators, the transition density in the transmitted PCM waveform shall not be less than:

1. 125 in any sequence of 1 000 consecutive symbols for category A;
2. 275 in any sequence of 1 000 consecutive symbols for category B.

b. The maximum string of either ones or zeros shall be limited to 64 bits.

NOTE Symbol randomization is required unless a sufficient bit transition density is ensured for the channel by other methods.

6.1.6 Carrier modulation index

a. The peak modulation index shall be between the minima and the maxima stated in Table 14.

b. These limits shall take into account the worst case.

NOTE When two or more channels are transmitted simultaneously on the Earth-space link, existing equipment generally limits the peak modulation index to a value of about 1,75 rad.

Table 14: Limits of the peak modulation index

Function	Min. (radians peak)	Max. (radians peak)
Telecommand (PCM/NRZ/PSK/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 [a]
Ranging Earth-space	0,1	1,4
Ranging space-Earth	0,01	0,7

[a] A maximum of 1,39 rad may be used provided that the carrier tracking loop's signal-to-noise ratio remains above 15 dB.

6.1.7 Sense of modulation

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

b. 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, and a symbol “0” in a delay.

6.1.8 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 rad peak.

6.1.9 Residual amplitude modulation

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

6.1.10 Carrier phase noise

a. Phase noise of the unmodulated carrier, integrated between 0,1 Hz and 1 kHz, shall be less than:

   1° r.m.s. at UHF (2 110 MHz – 2 120 MHz and 2 290 MHz – 2 300 MHz)

b. Phase noise of the unmodulated carrier, integrated between 1 Hz and 10 kHz, shall be less than:

   4° r.m.s. at SHF (7 145 MHz – 7 190 MHz, and 8 400 MHz – 8 450 MHz)

c. 10° r.m.s. at EHF (31,8 GHz - 32,3 GHz and 34,2 GHz - 34,7 GHz).

6.1.11 Residual carrier and discrete spectral lines[5)]

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

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

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

5) Additional limitations on the telemetry modulation spectrum can be specified by the project manager to ensure the cleanliness of the ranging signals when simultaneous ranging and telemetry are used.

1. ±60 kHz for UHF (2 200 MHz – 2 300 MHz),
2. ±220 kHz for SHF (8 400 MHz – 8 500 MHz),
3. ±850 kHz for EHF (31,8 GHz – 32,3 GHz).

6.2 Suppressed carrier modulation[6)]

6.2.1 Application and modulation schemes[7)]

a. Modulation with suppressed carrier shall be used rather than residual carrier phase modulation for telemetry in the UHF (2 200 MHz – 2 290 MHz), and SHF (8 025 MHz – 8 400 MHz and 8 450 MHz – 8 500 MHz) bands in the following cases:
   1. Where application of subclause 6.1 would lead to power flux densities at the carrier frequency in excess of the limits specified in subclause 5.5.3.
   2. In any case for channel symbol rates in excess of 2 Msymbols/s.

b. In the case specified in point a.2., only TCM 8PSK (for the 8 025 MHz - 8 400 MHz band), filtered-OQPSK (for all bands) or GMSK (for all bands except 8 025 MHz - 8 400MHz) shall be used,

   NOTE Users are encouraged to also use modulation with suppressed carrier in the range of symbol rates from 60 ksymbols/s to 2 Msymbols/s.

c. Data signals shall be PCM. The following modulation schemes may be used:
   1. BPSK (binary phase shift keying);
   2. QPSK (quadrature phase shift keying);
   3. UQPSK (unbalanced quadrature phase shift keying);
   4. OQPSK (offset quadrature phase shift keying);
   5. Filtered OQPSK;
   6. GMSK;
   7. TCM 8PSK.

d. In the case of new projects, modulations 1 to 4 may only be used for symbol rates of less than 2 Msymbols/s.

6.2.2 Modulating waveforms

The basic modulating PCM waveforms shall be used as per Table 15, with the following limitations:

a. Q-DNRZ should be used for QPSK, OQPSK, and filtered (O)QPSK.

   NOTE For definition and principle of Q-DNRZ, see subclause 6.2.3.3.

b. From a spectrum efficiency point of view, in the case of NRZ-L, when QPSK or filtered (O)QPSK are used, OQPSK should be used instead.

c. The original data stream in NRZ-L format:
   1. Shall be encoded differentially and convolutionally according to the principle described in subclause 6.2.3.7 where a constellation mapper addresses the phase modulation of the carrier either with a non-linear 8PSK modulator or a linear I/Q modulator.
   2. Shall undergo a data-precoding in order to encode the source symbols dk = ±1 prior to GMSK modulation, as described in annex E.

6) Ranging in accordance with ESA PSS-04-103 is not compatible with this type of modulation.

7) Users are encouraged to consult the engineering service with regard to the capability of Earth stations to support this type of modulation and the range of symbol rates available.

NOTE This feature suppresses the need for differential decoding at the receiver side and improves the receiver performances.

Table 15: PCM waveforms

	NRZ-L	NRZ-M	Q-DNRZ
BPSK	-	Y [a]	-
QPSK	Y (see 6.2.2.b.)	-	See 6.2.2.a.
OQPSK	Y (see 6.2.2.b.)	-	See 6.2.2.a.
UQPSK	-	Y	-
Filtered (O)QPSK	Y (see 6.2.2.b.)	-	See 6.2.2.a.
GMSK	Y (see 6.2.2.c.2.)	-	-
TCM 8PSK	Y (see 6.2.2.c.1.)		

[a] In convolutionary encoded systems using conversion between NRZ-L and NRZ-M, the conversion from NRZ-L takes places before the input to the convolutional encoder, and the conversion from NRZ-M to NRZ-L takes place after the output from the Viterbi decoder in order to maximise performance.

6.2.3 Carrier modulation

6.2.3.1 General

The subclauses of 6.2.3 describe the provisions applicable to carrier modulation.

6.2.3.2 BPSK

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

6.2.3.3 QPSK

a. The modulation shall be phase reversal keying of two phase quadrature carriers of equal amplitude by data channels with equal symbol rates.

b. The phase angle between the two quadrature carriers shall be (90 ±2)°.

c. The amplitude imbalance between the two quadrature carriers shall be less than ±0,5 dB.

d. Modulation shall be such that for each channel, the suppression of the signal from the other channel is more than 30 dB.

e. The symbol clocks shall be synchronized to within ±2 % of the symbol period or 1 ns, whichever is larger.

f. The Q-DNRZ differential encoding convention for QPSK shall be as described in Tables 16 and 17.

NOTE 1 The two columns in Tables 16 and 17 for the symbol value represent the two data channels. For single-channel transmissions the left-hand column is the most significant symbol.

NOTE 2 For QPSK, differential encoding can be used to remove phase ambiguity and I/Q channel reversal at the receiver side. Differential encoding is described by the following equations, which correspond to Table 16 and Table 17:

$$A_n = \overline{E_1}\,\overline{E_2}A_{n-1} + E_1\overline{E_2}\,\overline{B_{n-1}} + \overline{E_1}E_2B_{n-1} + E_1E_2\overline{A_{n-1}}$$

$$B_n = \overline{E_1}\,\overline{E_2}B_{n-1} + E_1\overline{E_2}A_{n-1} + \overline{E_1}E_2\overline{A_{n-1}} + E_1E_2\overline{B_{n-1}}$$

where,
E_1 and E_2 represent the two data streams at the input of the differential coder;

A_n and B_n represent the data streams at the output of the differential coder at time n;
A_{n-1} and B_{n-1} represent the output data streams at time n-1 (one symbol time before).
The parameters with a "bar" above represent the Boolean inverse.

NOTE 3 The second mapping possibility, described in Table 17, corresponds to the following equations:

$$A_n = \overline{E_1}\,\overline{E_2}\,\overline{A_{n-1}} + E_1\overline{E_2}B_{n-1} + \overline{E_1}E_2\overline{B_{n-1}} + E_1E_2A_{n-1}$$

$$B_n = \overline{E_1}\,\overline{E_2}\,\overline{B_{n-1}} + E_1\overline{E_2}\,\overline{A_{n-1}} + \overline{E_1}E_2A_{n-1} + E_1E_2B_{n-1}$$

NOTE 4 The two streams A_n an B_n are used to drive a classical QPSK modulator using a Gray mapping (change of one bit only for two adjacent phase states, change of two bits for opposite phase states).

Table 16: Constellation mapping 1 for QPSK

Carrier phase advance (radians)	Symbol Values (input)	
	E_2	E_1
0	0	0
π/2	0	1
π	1	1
3π/2	1	0

Table 17: Constellation mapping 2 for QPSK

Carrier phase advance (radians)	Symbol Values (Input)	
	E_2	E_1
0	1	1
π/2	1	0
3π/2	0	1
π	0	0

6.2.3.4 UQPSK

a. The data shall consist of two channels with different symbol rates and the modulation shall be phase-reversal keying of two-phase quadrature RF carriers with different amplitude.

b. The phase angle between two quadrature carriers shall be (90 ±2)°.

c. The deviation from the theoretical amplitude imbalance between the two quadrature carriers shall be less than ±0,5 dB.

d. Modulation shall be such that for each channel, the suppression of the signal from the other channel is more than 30 dB.

e. The symbol rate imbalance shall be more than 0,05.

NOTE The symbol rate imbalance is given by the equation:

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

where f_{s1} is the symbol rate of channel 1 and f_{s2} the symbol rate of channel 2.

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

NOTE Attention is drawn to the user that the power flux density limits given in subclause 5.5.3 are normally more difficult to meet if the symbol rate is not equal to the power ratio in the two channels.

6.2.3.5 Filtered and unfiltered OQPSK

a. The modulation shall be phase reversal keying of two phase quadrature carriers of equal amplitude by data channels with equal symbol rates with the Q-channel delayed by half a symbol period with regard to the I-channel.

b. The phase angle between the two quadrature carriers shall be (90 ±2)°.

c. The amplitude imbalance between the two quadrature carriers shall be less than ±0,5 dB.

d. Modulation shall be such that for each channel, the suppression of the signal from the other channel is more than 30 dB.

e. The symbol clocks shall be synchronized to within ±2 % of the symbol period or 1 ns, whichever is larger.

f. The differential encoding convention for OQPSK shall be as follows:

$$p_{2n} = a_{2n} \oplus q_{2n} \qquad (p_{2n+1} = p_{2n})$$

$$q_{2n+1} = b_{2n+1} \oplus \overline{p_{2n+1}} \qquad (q_{2n+2} = q_{2n+1})$$

The stream of bits c_k, each one of duration T_b, is the input to the differential encoder. c_k is split into two different steams a and b. In this way:

$$a_{2k} = c_{2k}$$

$$b_{2k+1} = c_{2k+1}$$

The streams p_{2n} and q_{2n+1} are the outputs of the differential encoder and the inputs to the OQPSK modulator.

NOTE 1 In order to provide a better understanding on the implementation of the differential decoding, equations for the decoder are proposed below.
Decoder equations:

$$\hat{a}_{2n} = \hat{p}_{2n} \oplus \hat{q}_{2n} \qquad (\hat{a}_{2n+1} = \hat{a}_{2n})$$

$$\hat{b}_{2n+1} = \overline{\hat{p}}_{2n+1} \oplus \hat{q}_{2n+1} \qquad (\hat{b}_{2n+2} = \hat{b}_{2n+1})$$

where $\hat{p}_{2n}$ and $\hat{q}_{2n}$ are the outputs of the demodulator and the inputs to the differential decoder.

The stream of bits at the output of the differential decoder $\hat{c}_k$ is either given by:

$$\hat{c}_{2k} = \hat{a}_{2k} \text{ and } \hat{c}_{2k+1} = \hat{b}_{2k+1}$$

or

$$\hat{c}_{2k} = \hat{b}_{2k} \text{ and } \hat{c}_{2k+1} = \hat{a}_{2k+1}$$

depending on the ambiguity in the phase and sampling time delay in the receiver. In both cases the output data stream $\hat{c}_k$ is the same.

NOTE 2 The sign ^ denotes an estimate of the variable. If there are no transmission errors, then $\hat{c}_k = c_k$ (where c_k is the original bit stream input to the differential encoder).

g. Baseband square-root raised-cosine (SRRC) filtering shall be applied with roll-off $\alpha = 0{,}5$ such that the overall transfer function of the equivalent raised-cosine (R-C) channel filter shall be:

$$H(f) = 1 \qquad \text{if} \quad 0 \le |f| \le \frac{1-\alpha}{2T}$$

$$H(f) = \frac{1}{2}\left[1 + \cos\left(\frac{\pi T}{\alpha}\left(|f| - \frac{1-\alpha}{2T}\right)\right)\right] \qquad \text{if} \quad \frac{1-\alpha}{2T} \le |f| \le \frac{1+\alpha}{2T}$$

$$H(f) = 0 \qquad \text{if} \quad \frac{1+\alpha}{2T} \le |f|$$

where α is the roll-off factor and T is the time interval of the digital data stream on each I and Q channel. The impulse response of the R-C filter equals:

$$h(t) = \frac{\sin c(\pi t/T)\ \cos c(\pi \alpha t/T)}{1 - 4(\alpha t/T)^2}$$

h. The R-C filter shall be divided in two parts, one for the transmitting side and the other one for the receiving side (pre-detection matched filter): each side is the square root of the R-C channel filter frequency response for, which the corresponding impulse response is:

$$h(t) = \frac{4\alpha}{\pi\sqrt{T}} \ \frac{\cos\left((1+\alpha)\pi(t/T)\right) + \frac{\sin\left((1-\alpha)\pi(t/T)\right)}{4\alpha(t/T)}}{\left(1 - \left(4\alpha(t/T)\right)^2\right)}$$

i. In the case of digital implementation, the FIR filter impulse response shall be at least 16 bits long.

6.2.3.6 GMSK

a. The GMSK modulation format shall be as described in annex E.

b. For category A applications, a $BT = 0{,}25$ shall be used together with pre-coding where:

B = one-sided 3-dB bandwidth of the filter;

T = symbol duration (see Figure 1).

c. For category B applications, a $BT = 0{,}5$ shall be used together with precoding where:

B = one-sided 3-dB bandwidth of the filter;

T = symbol duration (see Figure 1).

d. In the case of impairments:

1. For an I-Q implementation of the modulator:
   (a) The phase angle between the two quadrature carriers shall be $(90 \pm 2)°$.
   (b) The amplitude imbalance between the two quadrature carriers shall be less than ±0,5 dB.
   (c) Modulation shall be such that for each channel, the suppression of the signal from the other channel is more than 30 dB.
2. For any implementation, the symbol clocks shall be synchronized to within ±2 % of the symbol period or 1 ns, whichever is larger.
3. For digital implementation:
   (a) The FIR filter impulse response shall be at least 4 bits long for category B applications and 5 bits long for category A applications.
   (b) The minimum number of bits for the FIR coefficient quantization shall be 12.

6.2.3.7 4 dimensional 8PSK-TCM

a. The modulation format shall be as described in Annex F.

b. The phase angle between any two adjacent phase states shall be $(45 \pm 1,5)^{\circ}$ peak.

c. The amplitude imbalance between any two adjacent phase states shall be less than $\pm 0,3$ dB peak.

NOTE The procedure[8)] for phase and amplitude imbalance measurement in the case of a linear I/Q modulator is as follows:

The I/Q modulator is tested with a sine and cosine wave on the I and Q ports as modulating signals. The frequency of the modulating signals is equal to the bit rate. The frequency spectrum at the output port of the modulator is observed. The power of the wanted signal, carrier signal and image signal (side-band) is measured. If C_{rej} is the rejection between the power of the wanted signal and the carrier and B_{rej} is the rejection between the power of the wanted signal and the image signal, the amplitude error δA and the phase error δΦ are given by:

$$\delta A < 20 \times \log\left(1 + C_{rej} + \sqrt{2} \times B_{rej}\right) \quad \text{in dB}$$

$$\delta \Phi < \arctan\left(C_{rej} + \sqrt{2} \times B_{rej}\right)$$

B_{rej} and C_{rej} are expressed in decimals in the above formulae.

d. The carrier rejection shall be at least 30 dB.

e. The side-band signal rejection shall be at least 30 dB, assuming, in the case of a linear modulator, a power variation of 6 dB in the modulating signal around the mean value.

6.2.4 Data transition density

a. For NRZ waveforms, the transition density shall exceed:

1. 125 in any 1 000-bit sequence for category A;
2. 275 in any 1 000-bit sequence for category B.

b. The maximum string of either ones or zeros shall be limited to 64 bits.

NOTE Symbol randomization is required unless a sufficient bit transition density is ensured for the channel by other methods.

6.2.5 Carrier phase noise

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

a. less than 2° r.m.s. at UHF for the 2 200 MHz – 2 300 MHz band;

b. less than 6° r.m.s. at SHF for the 8 025 MHz – 8 500 MHz band;

c. less than 10° r.m.s. at EHF for the 31,8 GHz – 32,3 GHz and 37 GHz – 38 GHz bands.

8) From "A 10 GHz - 14 GHz Linear MMIC Vector Modulator with less than 0,1 dB and 0,8° Amplitude and Phase Error", F.L.M. van den Bogaart, R. Pyndiah, 1990 IEEE MTT-S Digest.

6.2.6 Requirements on discrete spectral lines and residual carrier

a. Discrete lines in the transmitted RF signal spectrum, caused by baseband or RF bandwidth limitations, non-linearity of the channel, or any other effect shall be less than -30 dBc inside the occupied bandwidth.

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

c. The power flux density at the Earth surface shall always be below the limit specified in subclause 5.5.3.

6.3 Spectral roll-off

The emitted spectrum for all Space Science services projects, which utilize space-to-Earth link frequency assignments in the bands 2 200 MHz – 2 290 MHz, 2 290 MHz - 2 300 MHz, 8 025 MHz - 8 400 MHz, or 8 400 MHz - 8 500 MHz, shall adhere to the spectral emission masks of Figure 2.

NOTE The emitted spectrum is measured relative to the peak of the telemetry spectrum and excluding all spurious emissions.

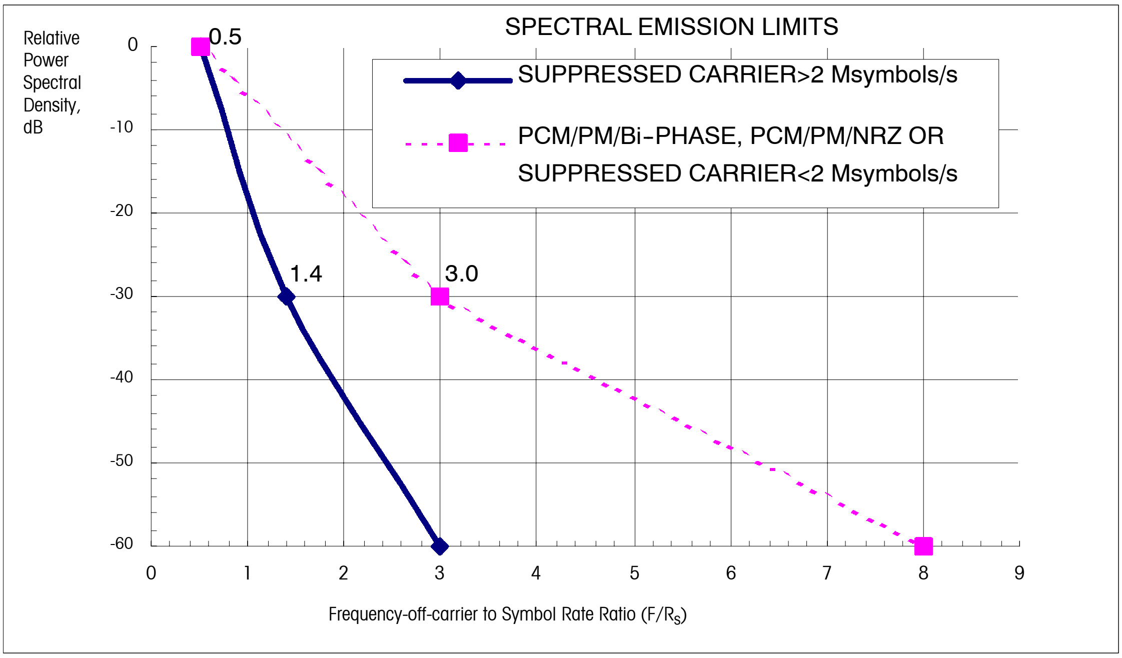


Figure 2: Spectral emission masks for transmissions at symbol rates equal to or above 2 Msymbols/s (continuous line) and below 2 Msymbols/s (dashed line)

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Annex A (normative)

Link acquisition procedures

A.1 Space-Earth

A.1.1 Normal operation

A.1.1.1

Under normal operation, the spacecraft transmitter is switched on by on-board automation at the time of scheduled commencement of the satellite “pass”, and the space-Earth link is modulated with the telemetry signal, containing at least the satellite housekeeping data.

A.1.1.2

For safe acquisition, a period of time commensurate with a triangular frequency search in the worst case condition on link margin, shall be allowed.

NOTE This applies regardless of the methods being used for the acquisition of the Earth station receivers and demodulators.

A.1.2 Alternative mode of operation

a. As a secondary mode of operation, the spacecraft transmitter shall be capable of being activated by telecommand.

b. Such a command should then be issued after the frequency sweep referred to in A.2.

A.1.3 Coherent mode

a. If the coherent mode of the spacecraft transmitter is used, this shall be activated by telecommand, after acquisition of the Earth-space link is confirmed.

b. When execution of this command entails a frequency step in the space-Earth link causing loss of data acquisition, a new acquisition of the space-Earth link shall be performed.

A.2 Earth-space

A.2.1 2025 MHz - 2110 MHz category A

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

b. 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 suitable amplitude.

c. After a single sweep the frequency shall return to the centre value.

d. If Doppler compensation is used, then Doppler shift predictions with an error of 5 kHz maximum shall be available at the station.

NOTE 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.

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

f. The lock status of the transponder shall be transmitted in the spacecraft telemetry data for operational use by the Earth station.

NOTE A standard location of the transponder lock status telemetry is specified in the Command Link Control Word (CLCW) as described in References ESA PSS-04-106 and ESA PSS-04-107.

g. After receipt of the confirmation of lock, the Earth station shall bring the carrier frequency to the assigned value.

h. All frequency excursions shall take place at a constant rate, selected such that the transponder phase-lock loop has no difficulty acquiring the carrier and tracking the sweep.

i. Any discontinuities and jumps shall be smaller than the transponder PLL lock-in range.

j. The following values, consistent with a transponder phase-lock loop bandwidth $2BL$ = 800 Hz and a damping factor $0{,}7 < \xi < 1{,}2$, should be used:

1. Sweep rate: ±30 kHz/s.
2. Maximum discontinuity: 100 Hz.
3. Maximum sweep range: ±150 kHz

k. The Earth station design should include flexibility on the parameters given in point j. in order to allow the support of transponders with other PLL loop bandwidths.

l. Onboard telecommand decoders shall not use frequency sweep for subcarrier or bit clock acquisition.

m. Subcarrier bit clock acquisition shall be achieved using the preamble transmitted before all uplink messages.

NOTE The idle sequence as specified in ESA PSS-04-107 is transmitted at all times (except during acquisitions when the transmitter is activated but no data or ranging signal needs to be transmitted) to limit the power spectral density from the Earth transmitters. However, see also subclause 4.2.1.1.

A.2.2 2 110 MHz - 2 120 MHz category B

a. The acquisition procedure shall be the same as that described in A.2.1 for 2 025 MHz - 2 110 MHz, except that Doppler compensation of the uplink carrier frequency shall be performed and that the carrier frequency shall not be brought to the assigned value after acquisition.

b. The compensation for Doppler shift and transponder local oscillator drift shall be periodically corrected to ensure that the received frequency remains within ±5 kHz of the estimated best lock frequency.

NOTE No further frequency corrections need to be performed (such as the continuous compensation of Doppler shift).

c. 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.

d. The resolution of this information shall correspond to frequency steps of the order of the PLL bandwidth ($2B_l$) or less.

e. The Earth station shall be capable of supporting the following specifications:

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

A.2.3 7 190 MHz – 7 235 MHz category A

a. The acquisition procedure shall be the same as that described in A.2.1, except that the sweep parameters are:

1. Sweep rate: ±500 Hz/s to ±50 kHz/s.
2. Maximum discontinuity: 100 Hz.
3. Maximum sweep range: ±500 kHz.

b. The Earth station design should include flexibility on the above parameters in order to allow the support of transponders with other PLL loop bandwidths.

A.2.4 7 145 MHz - 7 190 MHz category B

The acquisition procedure shall be the same as that described in A.2.1, except that the sweep parameters are:

a. Sweep rate: ±1 Hz/s to ±10 kHz/s.

b. Maximum discontinuity: 1 Hz.

c. Maximum sweep range: ±1 MHz.

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Annex B (informative)

Cross support from other networks

B.1 Network compatibility

Compatibility of RF modulation standards between worldwide space agencies and capabilities of their Earth stations support networks are the subjects of:

- CCSDS Recommendations for Radio Frequency and Modulation Systems (Blue Book), CCSDS 401.0-B-1, prepared by Panel 1 of the Consultative Committee for Space Data Systems (CCSDS);
- CCSDS Recommendations for Radio Frequency and Modulation Systems (Green Book), CCSDS 411.0-G-3.

These documents give a broad outline of the possibilities of cross support. However, in the case of support by an external space agency, provisions are given in Annex G d.

B.2 NASA MK IVA DSN compatibility

The reference document, which contains all 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.

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Annex C (informative)

Protection of Ariane-5 RF system

C.1 General

This annex does not replace the interface specifications with the Ariane-5 launcher nor the Ariane-5 launcher user guide and compatibility documentation.

C.2 Proposed conversion method for relating spurious radiation received at Ariane-5 vehicle equipment bay antennas to spurious emission requirements on payload transmitters

It is assumed 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, the approximation that the antennas have 0 dBi gain can be made.

Therefore $P = 0,1\dfrac{P_T}{G(\lambda^2/4\pi)}$, with $G = 1$ (0 dBi), having: $P = \dfrac{0,4\pi P_T}{\lambda^2}$

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

$4\pi D^2 P = \dfrac{E^2 D^2}{30}$, having $P = \dfrac{E^2}{120\pi}$

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 5 690 MHz the equivalent payload transmitter power is –72,3 dBm.

C.3 Operating constraints

The following requirements are extracted verbatim from A5‐SG‐1‐X‐35‐ASAI for spacecraft to be launched by an Ariane‐5 vehicle.

NOTE A5‐SG‐1‐X‐35‐ASAI provides the launcher susceptibility to radiated electrical field.

The launcher susceptibility is directly expressed in terms of spacecraft constraint on radiated electrical field: 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).

Table C‐1: Maximum radiated electrical field at bolted interface

Frequency range	Field (dBμV/m)
14 kHz - 420 MHz	120
420 MHz - 480 MHz	35
480 MHz - 1 GHz	120
1 GHz - 2 GHz	Linear evolution from 120 dBμV/m (1 GHz) to 150 dBμV/m (2 GHz)
2 GHz - 5,45 GHz	150
5,640 GHz – 5,670 GHz	70
5,825 GHz - 20 GHz	150

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

The field in the 5,640 GHz - 5,670 GHz band shall be measured in a resolution bandwidth of 10 MHz.

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

2 203 MHz	±250 kHz
2 206,5 MHz	±250 kHz
2 218 MHz	±500 kHz
2 227 MHz	±500 kHz
2 249 MHz	±500 kHz
2 254,5 MHz	±500 kHz
2 267,5 MHz	±250 kHz
2 284 MHz	±500 kHz

In case the spacecraft does not conform to the constraint provided here above, case by case studies shall be conducted to verify the compatibility between launcher and spacecraft.

Flight constraints during the powered phase of the launch vehicle and up to separation of the spacecraft + 20 s:

- no telecommand signal can be sent to the spacecraft,
- spacecraft emission can not be switched on or off.

Annex D (informative)

RF interface control

D.1 RF interface control documents

For the purpose of the RF interface control between spacecraft and Earth stations, the following two documents shall be used:

a. Spacecraft-Earth station interface control document.

b. Link budget tables.

NOTE These two documents are specified in more detail in the subsequent subclauses. The first document is the definitive and formal specification of the RF interface. The second document is updated regularly to keep track of the development of the spacecraft and Earth station. Hardware interface compatibility is demonstrated by spacecraft-Earth station compatibility tests, which are documented in the

- compatibility test plan, and
- compatibility test results.

D.2 Spacecraft-Earth station interface control document

D.2.1 General

The spacecraft-Earth station interface control document is the formal interface specification, containing all the relevant parameters describing the interface between the spacecraft and the Earth stations.

D.2.2 Process

a. The first draft of the document shall be prepared in the Phase B (preliminary definition) of the project by the responsible engineering department using inputs from the study or project manager.

b. The document referred in point a. shall contain top-level specifications for any new ground systems to be developed for the project.

c. When the spacecraft parameters are definitely specified, the document should reach its final form and be agreed upon by the project manager and the duly appointed representative of the network operations manager.

d. From this time on, the document shall be under the control of the project manager, who shall agree with the responsible engineering department any change to the parameters contained in it.

e. The document shall contain the following information:

1. Earth stations and time profile of use.
2. Configuration of the equipment in the Earth stations and links to the control centre.
3. Performances of Earth station (e.g. EIRP, G/T, and demodulation losses, with tolerances).
4. Configuration of equipment on-board the spacecraft.
5. Performances of spacecraft equipment (e.g. transmitter power, telecommand thresholds, and antenna gains, with tolerance).
6. TTC standards applicable and any waivers granted.
7. Choice of parameters for the links (i.e. which subsets of the parameters allowed by the standards are chosen), e.g. PCM data types, bit rates, formats, subcarriers and modulation indices.
8. Operational modes of the spacecraft TTC subsystem (e.g. combinations of bit rates, subcarriers, formats, and indices, and combination of ranging with telecommand or telemetry).

f. 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

D.3.1 General

a. Link budget tables shall be prepared by the spacecraft project responsible for the correct modelling of all aspects of the links between spacecraft and Earth stations.

b. 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 engineering department responsible.

c. Although the exact format may vary from application to application, the same terminology and parameters shall be used. For this purpose, the telecommunication link design control table in CCSDS RF & Modulation Blue Book, CCSDS 401, Recommendation 4.1.2 shall be used.

D.3.2 Parameters

a. Separate link budgets should be produced for all different parameter combinations (e.g. different Earth stations, different spacecraft antennas, and 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 are used.

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

1. The design value D, which is the value of the parameter expected under nominal conditions.

2. The adverse tolerance A, which takes into consideration adverse conditions such as extreme temperatures, extreme voltages, end of life, and end of maintenance period.

   NOTE The adverse tolerance is defined as the worst case of a parameter minus the design value in dB. Normally, the adverse tolerance is the value given in a design specification.

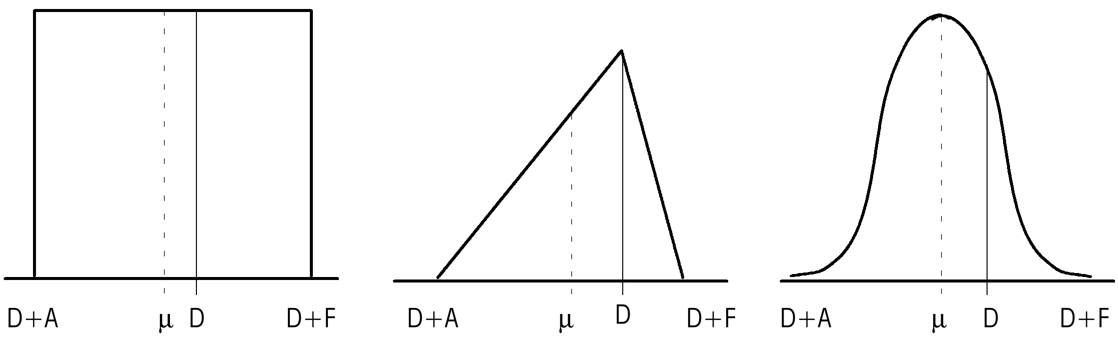
3. The favourable tolerance F, which takes into consideration best case conditions such as benign environment beginning of life, and equipment recently maintained.

   NOTE The favourable tolerance is defined as the best case of a parameter minus the design value in dB. Often the favourable tolerance, particularly in the design phase of a project, represents an informed estimate on how to improve the equipment over the original design.

d. From the design value, the adverse and the favourable tolerances, the mean value μ and the variance ($\sigma_n{}^2$), based on a particular probability density function identified in Table D-1 for each parameter should be calculated according to the equations given in Figure D-1 for each of the distributions represented.

Table D-1: Probability density functions for link budgets

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) Polarization Loss S/C Antenna Circuit Loss (RX) S/C Phase Jitter Loss (RX) Waveform Distortion Loss	S/C Antenna Circuit Loss (TX) Polarization 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
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 Transponder 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



$\mu = D + (F + A)/2$
$\sigma^2 = (F - A)^2/12$

$\mu = D + (F + A)/3$
$\sigma^2 = (F^2 + A^2 - AF)/18$

$\mu = D + (F + A)/2$
$\sigma^2 = (F - A)^2/36$

Figure D-1: Parameter distributions and their equations

e. Margins for budgets based on the design value, favourable tolerance, adverse tolerance, mean value, mean -3σ and worst case RSS should be calculated as follows:

1. The margin for mean - 3σ is:

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

2. The worst case RSS margin is:

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

NOTE 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.

f. If a particular variance is dominant, its statistics shall be treated separately.

NOTE For packet telecommand see ESA PSS-04-107 and for packet telemetry see ESA PSS-04-106.

g. The jitter performance of the recovered carrier shall be taken into account in the calculation of the degradation in the demodulation processes.

h. Each project may have its own criteria for acceptability of link performance, using the various margins calculated in the link budget tables. Margins based on design parameters should exceed 3 dB, and those on the RSS worst case and the mean -3σ should exceed 0 dB.

NOTE These recommendations have been derived from practical experience.

i. The link budget tables should:

1. be kept updated during the evolution of the project, and
2. reflect new information coming from the spacecraft unit, subsystem and system acceptance tests and from spacecraft-ground network compatibility tests.

D.4 Spacecraft-ground network compatibility test

a. Compatibility of the spacecraft with the ground network shall be demonstrated by means of compatibility tests.

b. Such tests shall be made with representative models of spacecraft TTC flight equipment and Earth station equipment.

c. 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 breadboard equipment.

NOTE The tests to be performed during compatibility testing vary from project to project. The purpose of the tests is always to establish thresholds and limiting values so that a good assessment of available margins can be made.

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

NOTE A proposed set of compatibility test procedures is given in CCSDS 412.0-G-1.

e. At the conclusion of the tests, a Compatibility Test Report, containing a formal statement on the compatibility of the spacecraft and the ground network, shall be issued by the engineering department responsible.

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Annex E (normative)

GMSK modulation format

The modulated RF carrier shall conform to the expression:

$$x(\tau) = \sqrt{2P}\cos(2\pi f\tau + \varphi(\tau) + \varphi_0)$$

where

P is the power of the carrier;

f is the centre frequency;

$\varphi(\tau)$ is the phase of the modulated carrier;

φ_0 is a constant random phase;

and,

$$\varphi(t) = \sum_k (a_k \frac{\pi}{2} \int_{-\infty}^{t-kT} g(\tau)d\tau)$$

where

a_k $= (-1)^k d_k d_{k-1}$ are the pre-coder output symbols;

$d_k \in \{ \pm 1 \}$ is the k-th information symbol to be transmitted.

The instantaneous frequency pulse $g(\tau)$ is obtained through a linear filter with impulse response defined by:

$$g(\tau) = h(\tau) * rect(\tau/T)$$

where

rect (τ/T) is the function:

rect $(\tau/T) = 1 / T$ for $|\tau| < T/2$,

rect $(\tau/T) = 0$, otherwise.

* means convolution,

$h(\tau)$ is the Gaussian density function:

$$h(\tau) = \frac{1}{\sqrt{2\pi}\sigma T} \exp\left(\frac{-\tau^2}{2\sigma^2 T^2}\right)$$

where

$$\sigma = \frac{\sqrt{\ln(2)}}{(2\pi BT)}$$

with ln (n) = natural logarithm (base = e);

B = one-sided 3-dB bandwidth of the filter with impulse response $h(\tau)$;

T = the duration of one input symbol as defined in Figure 1.

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Annex F (normative)

8PSK TCM modulation format

F.1 General principles

The MPSK-trellis coded modulation is based on the partitioning of one MPSK constellation into different subsets, each subset having a minimum Euclidian distance larger than the minimum distance of the original constellation.

With the use of a trellis coder prior to the modulator, the different phase states z_k of the constellation are not independent and belong to the coded sequences of the trellis.

The use of a maximum likelihood decoder that is sensitive to the minimum Euclidian distance d^c_{min} offered by these sequences, gives improved performances for the data recovery in the AWGN channel.

These performances are improved by the use of multidimensional trellis coded modulation, which also allows the automatic removal of carrier phase ambiguity at demodulator side, but in this case the performances are the same as for the mono-dimensional case.

F.2 4 dimensional 8PSK-TCM coder

a. The 4 dimensional-8PSK trellis coded modulator shall combine a serial to parallel converter, a trellis encoder, i.e. convolutional coder, a constellation mapper and a 8PSK modulator (see Figure F-1).

b. The trellis encoder shall be based on a 64 state systematic convolutional coder.

NOTE The trellis encoder is considered as the inner code if a block code is introduced.

c. Carrier phase ambiguity shall be resolved by the use of a differential coder located before the trellis encoder.

d. Spectral efficiency of 2 b/s/Hz and 2,5 b/s/Hz shall be achieved by one of the architectures of the constellation mapper described in F.5 a. and b.

NOTE If the input data stream is parallelled into b lines, for k multidimensional M-ary symbols ($k = 4$ in this case) the spectral efficiency of the modulation is $r = b/k$. Figure F-1 shows the general principle of the 4D-8PSK TCM modulator.

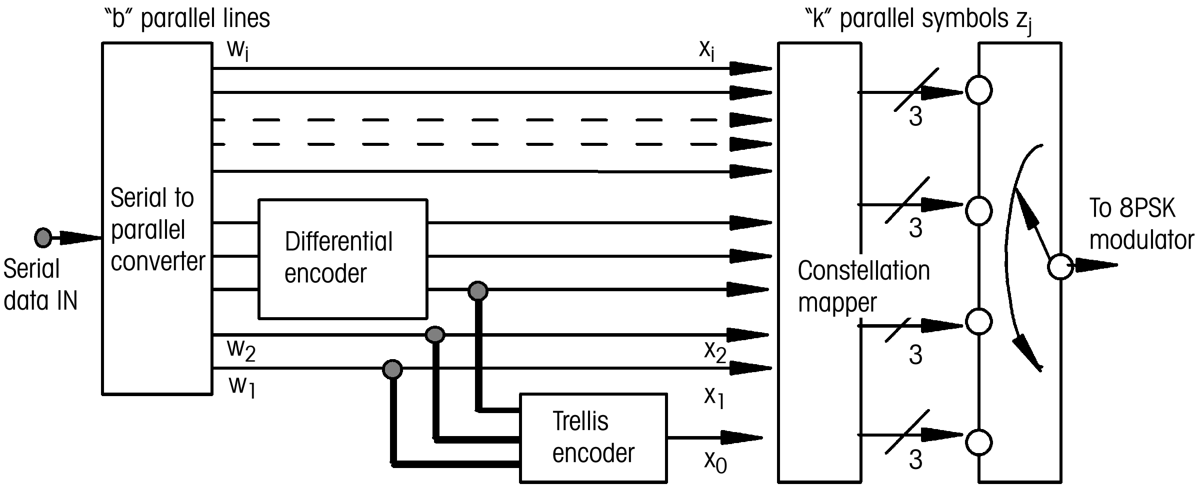

Figure F-1: General principle of the 4D-8PSK TCM modulator

e. The constellation mapper shall deliver 4 parallel symbols coded with three bits to perform 8PSK modulation.

f. The output switch shall address successively each of the four possible symbols to the 8PSK modulator. The four symbols shall be transmitted during "b" bit time.

NOTE The symbol rate (constellation rate) is therefore $b/4$. At 2 b/Hz, $b = i = 8$, at 2,5 b/Hz, $b = i = 10$. Due to the trellis encoder the number of lines at the input of the constellation mapper is $b + 1$ (either 9 or 11).

F.3 Trellis encoder structure

The 64 states $L = 7$, rate 3/4 systematic trellis encoder shall be as represented in Figure F-2, which is the same encoder at 2 b/Hz and 2,5 b/Hz spectrum efficiency.

NOTE 1 Efficiency defined at Nyquist bandwidth.

NOTE 2 The corresponding polynoms (in octal) are: $h^3 = 050$, $h^2 = 024$, $h^1 = 006$, $h^0 = 103$

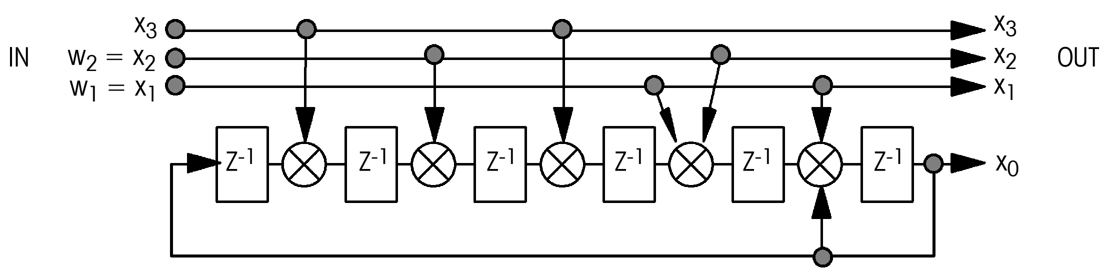

Figure F-2: Representation of a 64 state L=7, rate 3/4 systematic trellis encoder

F.4 Differential coders for 2 and 2,5 b/Hz case

To eliminate 22,5° phase ambiguity on carrier synchronization, the codes represented in Figure F-3 should be used.

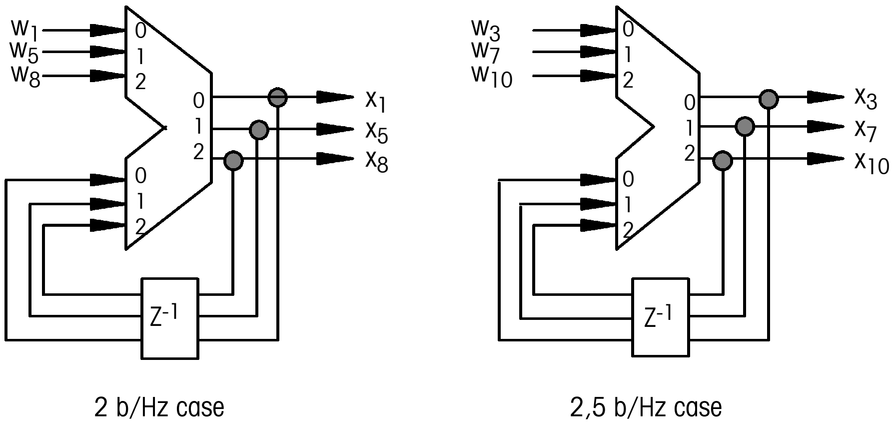

Figure F-3: Codes to eliminate 22,5° phase ambiguity on carrier synchronization

F.5 Constellation mapper for 4 dimensional 8PSK-TCM

a. The constellation mapper for a 2 b/Hz case shall conform to Figure F-4.

b. The constellation mapper for a 2,5 b/Hz case is given in Figure F-5.

c. The channel filtering shall be obtained according to the SRC shaping located before to the linear I/Q 8-PSK modulator.

d. A roll-off factor of 0,35 or 0,25 shall be used.

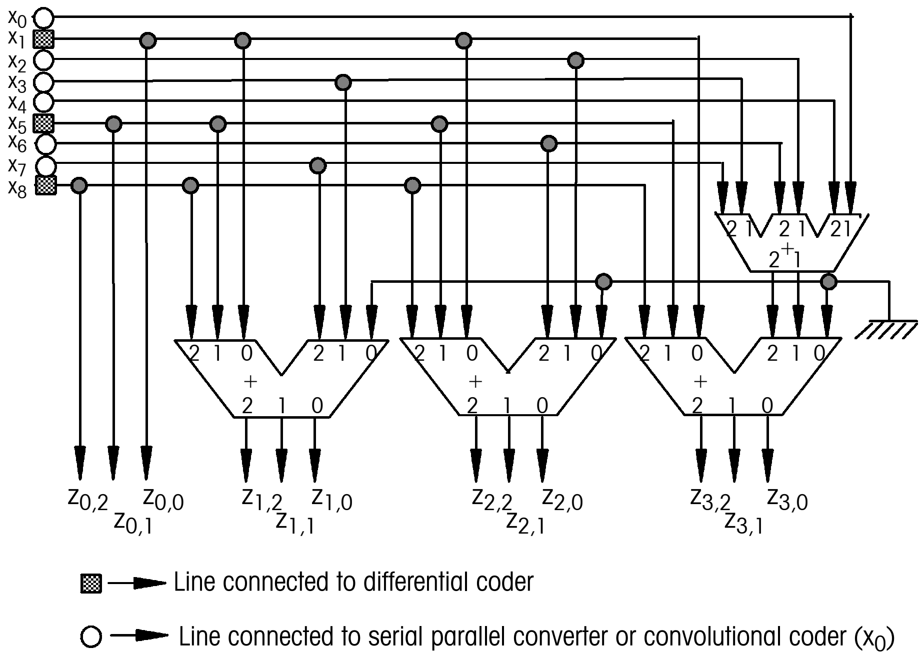

Figure F-4: Constellation mapper for a 2 b/Hz case

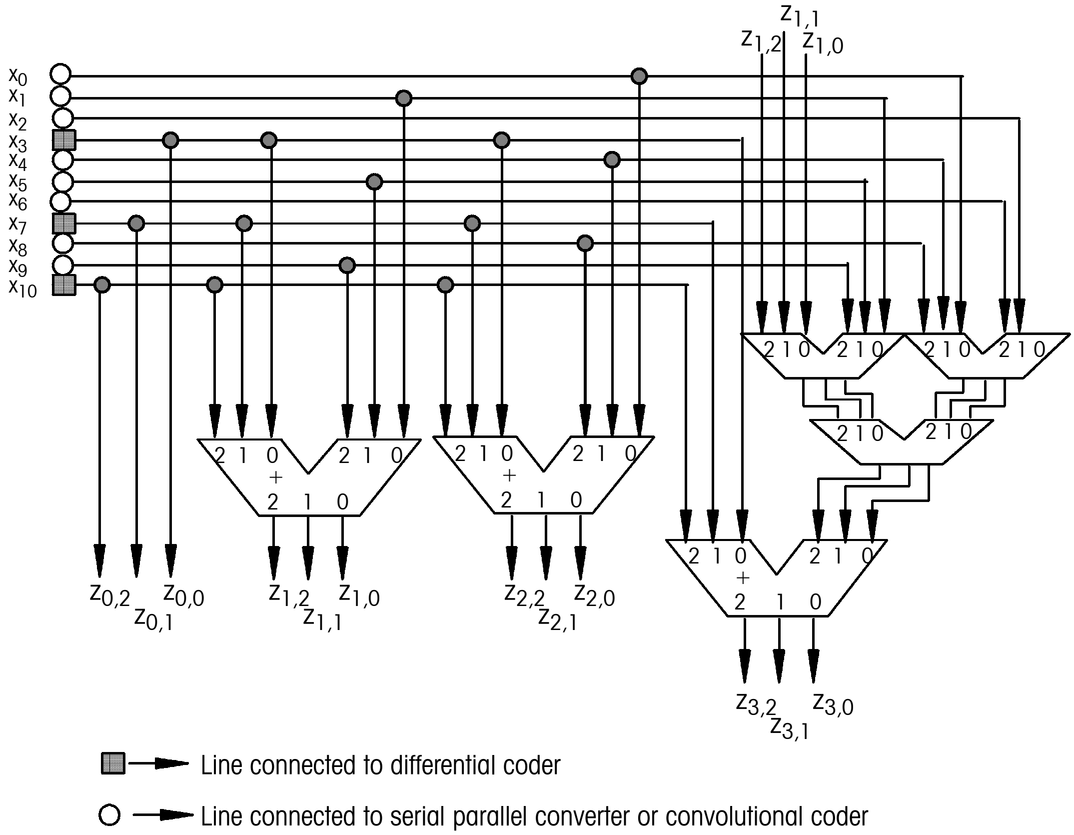

Figure F-5: Constellation mapper for a 2,5 b/Hz case

F.6 Channel filtering

a. General

1. Channel filtering shall be obtained by one of the following two methods:

   — Square root raised-cosine baseband shaping located prior to the modulator, with a channel roll-off factor α of 0,35 (or 0,25) as described in point b.

   NOTE This waveform shaping is used in association with a linear modulator and power amplifier.

   — Post-amplifier shaping using an output filter located at the output the non-linear power amplifier as described in point c.

   NOTE In this case a NRZ-like shaping is used in conjunction with a non-linear 8-phase modulator.

2. In both cases, the pre-detection filter (matched filter) in the receiver shall be a square root raised-cosine filter with the roll-off factor α of 0,35 or 0,25.

b. Baseband, square root raised-cosine shaping

1. This type of channel filtering should be used for linear amplifier conditions, or with amplifier linearization, when the symbol rate to central frequency ratio is low.

2. The transfer function of the SRRC filter shall be:

$H(f) = 1$ for $|f| < f_N (1 - \alpha)$

$$H(f) = \left[\frac{1}{2} + \frac{1}{2}\sin\left\{\frac{\pi}{2f_n}\left(\frac{f_n - |f|}{\alpha}\right)\right\}\right]^{\frac{1}{2}} \quad \text{for } f_N (1 - \alpha) \le |f| \le f_N (1 + \alpha)$$

$H(f) = 0$ for $f_N(1 + \alpha) < |f|$

where $f_N = 1/(2T_s) = R_s/2$ is the Nyquist frequency and α is the roll-off factor.

3. The corresponding transmit structure shall conform to Figure F-6.

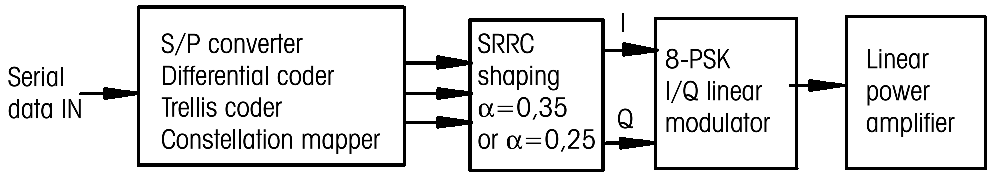

Figure F-6: Transmit structure for baseband, square root raised-cosine shaping

c. Post-amplifier shaping

1. This type of channel filtering should be used for nonlinear amplifier conditions or when the symbol rate to central frequency ratio is high.
2. The output filtering should be obtained with a 4 poles/2 zeros elliptic filter characterized with the transfer function given in Figure F-7.
3. The corresponding transmit structure should conform to Figure F-8.

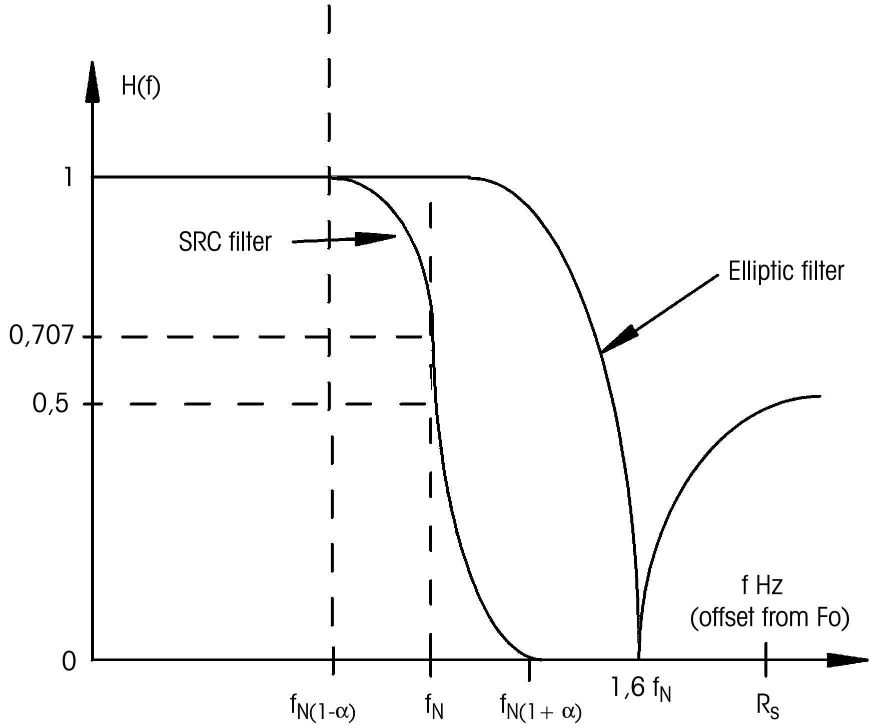

Figure F-7: Transfer function for a 4 poles/2 zeros elliptic filter

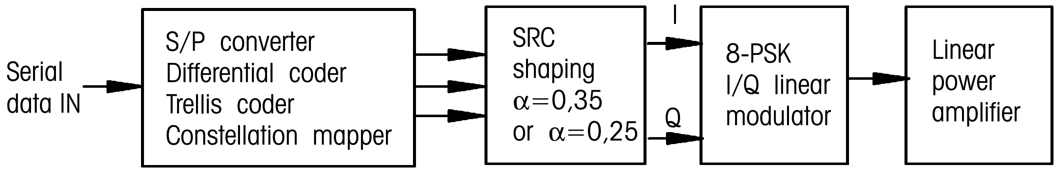

Figure F-8: Transmit structure for post-amplifier shaping

Annex G (normative)

Tailoring

a. If this Standard is in conflict with mission-specific requirements, deviations may be warranted, when the following is demonstrated:

- the technical or operational need for such deviations, and
- that the intended change can be supported by existing systems.

b. ITU/RR shall not be tailored.

c. The tailoring process shall be supported by the frequency coordinator.

d. The project manager, prior committing a mission to be supported by an external space agency, shall verify the detailed technical documentation on the network of that agency for potential tailoring-in.

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ECSS Document Improvement Proposal

1. Document I.D.	**2. Document date**	**3. Document title**
ECSS-E-50-05A	24 January 2003	Radio frequency and modulation

4. Recommended improvement (identify clauses, subclauses and include modified text or graphic, attach pages as necessary)

5. Reason for recommendation

6. Originator of recommendation

Name:	Organization:	
Address:	Phone: Fax: e-mail:	**7. Date of submission:**

8. Send to ECSS Secretariat

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