ESA RD-04-109, Draft Issue 1.6
January 1996

european space agency
agence spatiale européenne

RADIO FREQUENCY AND MODULATION
Reference Document

FOR THE DATA RELAY SYSTEM

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

DOCUMENT CHANGE RECORD

Date	Issue	Chapter	Description of Changes
June 1993	Draft Issue 1.1	1.1 - 4.1.4.2	Changes in agreement with RF & Modulation Panel meeting decisions have been implemented Annex 1 of App. B, App. D and App. H have been added
June 1994	Draft Issue 1.2	all chapters	Changes in agreement with RF & Modulation Panel meeting decisions have been implemented
Feb. 1995	Draft Issue 1.3	all chapters	Changes in agreement with RF & Modulation Panel meeting decisions have been implemented
May 1995	Draft Issue 1.4	all chapters	Changes in agreement with RF & Modulation Panel meeting decisions have been implemented
July 1995	Draft Issue 1.5	all chapters	Final modifications as suggested in writing and agreed at the RF & Modulation Panel meeting
Nov. 1995	Draft Issue 1.6	all chapters	Final modifications as suggested in writing and agreed at the RF & Modulation Panel meeting
Jan. 1996	Draft Issue 1.6	some chapters	Editorial comments as suggested and agreed at the RF & Modulation Panel meeting

REFERENCES

[1] ITU Radio Regulations
Edition of 1990, Revised in 1994

[2] DRS Characteristics for Users
CD/201/AD/dv, DRTM Programme Office

[3] Telemetry Channel Coding Standard
ESA PSS-04-103, Issue 1, September 1989

[4] SNIP S-Band Communications Services and Requirements
for Interoperability, SNIP, June 1994

[5] SNIP Ka-Band Interoperability Recommendations
Rev. 1, SNIP, June 1995

CONTENTS

1 PURPOSE AND SCOPE

1.1 PURPOSE

This Document addresses the RF and modulation requirements of the ESA Data Relay System (DRS). The purpose of the Document is to:

- Ensure compatibility of frequency usage and modulation schemes between the elements of the ESA DRS comprising the Data Relay System Satellites (DRSSs), the Earth Terminals and the User Spacecraft Terminals (USTs);
- Ensure, wherever possible, the compatibility of these UST's with interoperable data relay satellite systems of other agencies;
- Ensure the compliance of UST and Earth Terminal parameters with international regulatory provisions (Radio Regulations of the International Telecommunication Union [1]) and with national regulatory provisions (e.g. national frequency plans);
- Ensure that the parameters of UST's and Earth Terminals are properly chosen and listed in advance of their use, thus permitting coordination with other interested parties.

This Document does not address the transmitter powers, noise performance and other requirements applicable to UST's and Earth Terminals and does not give link budgets for links via the DRS, which are presented in [2].

1.2 SCOPE

This Document defines the radio communication techniques to be used for the communications through DRS to provide forward and return channels for digital signals which can be used for audio, video, digital data and tracking. [1] [2]

It comprises the following subjects:

- Frequency usage and frequency assignment;
- Requirements on transmitted signals concerning spectral occupation, power levels, protection of other radio services, etc.;
- Modulation methods, allocation and assignment of spreading codes;
- The major technical requirements which are relevant for the IOL and the space-to-Earth interfaces.
- Operational aspects, e.g. acquisition.

Note 1 The RF and modulation requirements concerning TTC of the DRSSs are not addressed in this document.

Note 2 Direct communication between ESA spacecraft and ESA controlled Earth Terminals in the bands allocated to the SPACE OPERATION SERVICE and the SPACE RESEARCH SERVICE is the subject of the Radio Frequency and Modulation Document (ESA RD-04-105).

2 APPLICABILITY

This Document is applicable to all ESA USTs and Earth Terminals to be used for communications via the DRS. The document comprises two distinct classes of requirements:

A. Those imposed by international regulations and those necessary for the protection of other users of the DRS, users of other data relay systems and other users of the radio spectrum:

- Frequency allocations,
- Power and PFD limits,
- Spectrum occupancy,
- Unwanted emission limits,
- Code assignments

Waivers against Class A requirements will not normally be granted.

B. Those which ensure compatibility between the elements of the DRS, including:

- Frequency stability,
- Modulation schemes,
- Turnaround ratios

Waivers against Class B requirements may be considered where specific mission requirements prevent compliance with this document. A Waiver may be obtained when:

- the technical and/or operational need for such deviations has been demonstrated,
- it has been shown that all class A requirements are satisfied,
- it has been shown that the intended changes are compatible with the existing systems

Requests for waivers should be addressed by the Project manager to the ESA Standards Approval Board (STAB) for Space Data Communications. Such requests should be submitted as early as possible, preferably during the study phase of the project. All waivers and consequent agreements will be incorporated into the relevant RF Interface Control Document (see Appendix D).

3 FREQUENCY ALLOCATION, ASSIGNMENT AND USE

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

3.1.1 General

The use of frequencies by radiocommunication services is governed by the provisions of [1]. Consequently, any frequency assignment made to a particular user (spacecraft) has to be made in accordance with [1], which:

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

3.1.2 Definitions

Inter-Satellite Service [1]
"A radiocommunication service providing links between artificial satellites."

Space Operation Service [1]
"A radiocommunication service concerned exclusively with the operation of spacecraft, in particular space tracking, space telemetry and space (tele)command (TTC). These functions will normally be provided within the service in which thespacecraft is operating."

Earth Exploration Satellite Service [1]
"A radiocommunication service between earth stations and one or more space stations, which may include links between space stations, in which:

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

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

Space Research Service [1]
"A radiocommunication service in which spacecraft and other objects in space are used for scientific and technological research".

Fixed Satellite Service [1]
"A radiocommunication service between earth stations at specified fixed points when one or more satellites are used; in some cases this service includes satellite-to satellite links, which may also include feeder links for other space radiocommunication services".

3.1.3 Frequency Bands allocated to the Space Radiocommunication Services, used by the European DRS Satellites

3.1.3.1 Inter-Orbit Links (IOL)

The following frequency bands allocated with a primary status to space services will be used by the DRSS (Table 3.1):

Frequency Band	Direction	Space Radiocommunication Service
2025 - 2110 MHz	space-space (Forward IOL)	Space Research, Space Operation and Earth Exploration Satellite
2200 - 2290 MHz	space-space (Return IOL)	Space Research, Space Operation and Earth Exploration Satellite
23.12 - 23.55 GHz	space-space (Forward IOL)	Inter-Satellite
25.25 - 27.50 GHz	space-space (Return IOL)	Inter-Satellite *

TABLE 3.1 - FREQUENCY ALLOCATIONS TO SPACE RADIOCOMMUNICATION SERVICES USED FOR DRS INTER-ORBIT LINKS

* The use of the 25.25-27.5 GHz band is limited to space research and Earth exploration satellite applications and also transmissions of data originating from industrial and medical activities in space [1].

3.1.3.2 Feeder Links

The following frequency bands, allocated with a primary status to the Fixed Satellite service, will be used for DRS feeder links (Table 3.2.)

Frequency Band	Direction
18.1 - 20.2 GHz	space-Earth (return link)
28.5 - 30.0 GHz	Earth-space (forward link)

TABLE 3.2 - FREQUENCY ALLOCATIONS TO THE FIXED SATELLITE SERVICE USED FOR DRS FEEDER LINKS

3.2 FREQUENCY PLAN FOR DRS INTER-ORBIT AND FEEDER LINKS

3.2.1 Inter-Orbit Links in the 2 GHz Bands

User spacecraft requiring DRS IOL's in the 2 GHz bands will be assigned nominal carrier frequencies listed in Table 3.3.

Forward Frequency (MHz)	Return Frequency (MHz)
$F_r \cdot \frac{221}{240}$	$F_r = 2200 + \frac{n}{2} \quad (1 \le n \le 179)$

TABLE 3.3 - NOMINAL CARRIER FREQUENCIES FOR INTER-ORBIT LINKS IN THE 2 GHz BANDS

For operational reasons it may not be possible to assign all of these frequencies in practice.

3.2.2 Inter-Orbit Links in the 23/26 GHz Bands

User spacecraft requiring DRS IOL's in the 23/26 GHz bands will be assigned one of the forward IOL centre frequencies listed in Table 3.4 and one or more of the return IOL centre frequencies listed in Table 3.5.

FORWARD INTER-ORBIT LINK CENTRE FREQUENCY (GHz)
23.205
23.265
23.325
23.385
23.445
23.505[3]

TABLE 3.4 - CHANNEL CENTRE FREQUENCIES FOR DRSS FORWARD INTER-ORBIT LINKS IN THE 23 GHz BAND

RETURN INTER-ORBIT LINK CENTRE FREQUENCY (GHz)
25.600
25.850
26.100
26.350
26.600
26.850
27.100
27.350

TABLE 3.5 - CHANNEL CENTRE FREQUENCIES FOR DRSS RETURN INTER-ORBIT LINKS IN THE 26 GHz BAND

3.2.3 Beacons

Each DRSS will transmit a wide-beam beacon, which can be used by all User Spacecraft at all times to determine the direction of the DRSS at one of the frequencies listed in Table 3.6.

FORWARD BEACON FREQUENCY (GHz)
23.530
23.535
23.540[4]
23.545[5]

TABLE 3.6 - FREQUENCIES FOR FORWARD BEACONS

Note 3 Not currently supported by DRSS

Note 4 Beacon frequency of ARTEMIS

Note 5 Beacon frequency of DRS-1

3.2.4 Feeder Links

All DRSS will provide a European feeder link, covering most of the western part of Europe. Some DRSS will also provide a steerable spot feeder link, able to cover any location on that part of the Earth visible from these DRSS. Earth Terminals outside the DRS European Feeder Link coverage but within visibility of a DRS Satellite may be served by the DRS Steerable Spot Feeder Link. Steerable spot feeder links are not provided by ARTEMIS.

A User will be assigned one of the forward carrier centre frequencies listed in Table 3.7. The forward feeder link frequency will be the same, for that User, for all DRS Satellites and will not be changed during the mission (see also section 4.3.4.5).

A User will also be assigned one or more of the return carrier centre frequencies listed in Table 3.8. Only a subset of Table 3.8 will be available for the steerable spot return feeder link. The return feeder link frequencies will be different fordifferent DRS Satellites and may also be changed from time to time, so all Earth Terminals shall be designed to be able to receive any return channels.

FORWARD FEEDER LINK CENTRE FREQUENCY (GHz)
28.650
28.750
28.850
28.950
29.050
29.150
29.250
29.350
29.450
29.550
29.650
29.750

TABLE 3.7 - CHANNEL CENTRE FREQUENCIES
FOR FORWARD FEEDER LINKS

RETURN FEEDER LINK CENTRE FREQUENCY (GHz)
18.350
18.600
18.850
19.100
19.350
19.600

TABLE 3.8 - CHANNEL CENTRE FREQUENCIES
FOR RETURN FEEDER LINKS

3.2.5 Pilot Signals

Earth Terminals in the DRS European feeder link coverage will be able to receive an unmodulated Pilot Signal, transmitted by each DRSS at one of the frequencies listed in Table 3.9.

PILOT SIGNAL FREQUENCY (GHz)
20.110[6]
20.150
20.190

TABLE 3.9 - CARRIER FREQUENCIES FOR EUROPEAN FEEDER LINK PILOT SIGNALS

Earth Terminals inside the steerable spot feeder link coverage will be able to receive an unmodulated Pilot Signal, transmitted by each DRSS at one of the frequencies listed in Table 3.10.

PILOT SIGNAL FREQUENCY (GHz)
20.100[7]
20.140
20.180

TABLE 3.10 - CARRIER FREQUENCIES FOR STEERABLE SPOT FEEDER LINK PILOT SIGNALS

Note 6 ARTEMIS and DRS-1

Note 7 only DRS-1

3.3 FREQUENCY ASSIGNMENT PROCEDURE

3.3.1 Choice of Frequencies

Prior to the Phase C/D of any User Spacecraft project using the DRS, the User Spacecraft Project Manager shall provide the information listed in Appendix B and shall request a frequency assignment from the ESA Frequency Management Office.

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

All aspects for frequency assignments and/or enquiries regarding frequency management matters shall be addressed to:

Frequency Management Office
ESA
8-10 rue Mario-Nikis
F-75738 PARIS CEDEX 15
Telephone: +33-1-5369-7302
Fax: +33-1-5369-7286

3.3.2 Notification of Frequencies

Not later than 2.5 years before the planned launch date, the User Spacecraft Project Manager shall provide to the ESA Frequency Management Office the data required to coordinate and notify the frequencies used with the Radiocommunications Bureau of the ITU. The format of Appendix B shall be used for this purpose.

In the case of ESA spacecraft, the ESA Frequency Management Office is responsible for the procedural steps required by [1] for the user spacecraft, the DRS and the associated ESA Earth Terminal.

In the case of non-ESA User spacecraft, the ESA Frequency Management Office is responsible only for the procedural steps regarding the DRS. The coordination and notification of the User Spacecraft and possibly associated non-ESA Earth Terminals will be carried out under the authority and responsibility of the owner space agency.

4 TRANSMISSION REQUIREMENTS

4.1 DEFINITIONS

OCCUPIED BANDWIDTH [1]

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

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

NECESSARY BANDWIDTH [1]

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.

UNWANTED EMISSIONS [1]

Consist of spurious emissions and out-of-band emissions.

SPURIOUS EMISSION [1]

Emission 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.

OUT-OF-BAND EMISSION [1]

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

4.2 INTER-ORBIT LINKS

4.2.1 Turnaround frequency ratio for coherent UST Transponders

4.2.1.1 2 GHz UST Transponders

In the case when Spacecraft two-way Doppler tracking is needed, the UST transponder shall generate a carrier at a frequency which is coherently related to the received carrier frequency. The ratio of forward (f_f) to return (f_r) carrier frequency shall be:

$$\frac{f_f}{f_r} = \frac{221}{240}$$

4.2.1.2 23/26 GHz UST Transponders

In the case when Spacecraft two-way Doppler tracking is needed, the UST transponder shall generate a carrier at a frequency which is coherently related to the received carrier frequency in conformance with Tables 3.4 and 3.5.

4.2.2 UST Carrier frequency stability requirements

4.2.2.1 UST Transmitter (non-coherent mode)

2 GHz Transmitter

$\pm 1\times10^{-5}$ of the assigned frequency over all operating conditions and lifetime
$\pm 3\times10^{-7}$ maximum uncertainty on frequency prediction for acquisition

26 GHz Transmitter

$\pm 1\times10^{-5}$ of the assigned frequency over all operating conditions and lifetime

4.2.2.2 UST Receiver

2 GHz Receiver

$\pm 1\times10^{-5}$ of the assigned frequency over all operating conditions and lifetime
$\pm 3\times10^{-7}$ maximum uncertainty on frequency prediction for acquisition

Calibration data shall be made available from the spacecraft so as to allow the ground operator to know the actual receiver frequency with an accuracy better than $\pm 3\times10^{-7}$.

23 GHz Receiver

$\pm 1\times10^{-5}$ of the assigned frequency over all operating conditions and lifetime

4.2.2.3 Requirements for Doppler Tracking (coherent UST transponders)

Coherent 2 GHz Transponders used for Doppler Tracking shall have an overall short term stability of better than 6×10^{-12} over 10 seconds.

Coherent 23/26 GHz Transponders used for Doppler Tracking shall have an overall short term stability of better than 1.5×10^{-12} over 10 seconds.

4.2.3 Polarization [8]

4.2.3.1 2 GHz Links

Forward and return links are either right or left hand circularly polarized. The sense of the polarization is at the choice of the user.

The User Spacecraft shall use the same polarization for both forward and return links.

4.2.3.2 23/26 GHz Links

Forward and return links are either right or left hand circularly polarized. The sense of the polarization is at the choice of the user.

The User Spacecraft requiring service from ARTEMIS shall use opposite polarization for forward and return links.

The User Spacecraft requiring service from DRS-1 may use either the same or opposite polarization for forward and return links.

All beacons are transmitted in left-hand circular polarisation.

Note 8 The sense of polarization shall be defined as follows: For a right-hand circularly-polarized wave, the electric field vector, observed in any fixed plane, normal to the direction of propagation, whilst looking in the direction of propagation, rotates with time in a right-hand or clockwise direction. [1]

4.2.4 UST Transmitted Spectrum

4.2.4.1 Transmitter Spectral Mask

The User shall submit, with his request for frequencies (see Section 3.3.1), a radio frequency spectral mask for the UST shall be submitted, below which the emitted spectral power density shall lie. This mask shall be expressed in dBW/Hz. It shall be averaged over 4 kHz for the 2 GHz IOL and over 1 MHz for the 26 GHz IOL. It shall extend to at least 60 dB below the maximum spectral density.

4.2.4.2 Requirements on Occupied Bandwidth

For all transmissions, every effort shall be made to minimise the occupied bandwidth in order to facilitate coordination with other users and to minimise interference into other systems.

Specific requirements on occupied bandwidth are shown in Figure 4.1 and Table 4.1. S denotes the transmitted symbol rate. In the case of QPSK modulation types, S is the maximum data rate (including coding if applied) on either the I-channel or the Q-channel. In case of spread spectrum modulation, S is the chip rate.

Users planning to operate a 2 GHz IOL should be aware of the severe congestion of this band and of the strong risk of difficult coordination procedures for occupied bandwidths in excess of 5 MHz.

Users planning to operate a 26 GHz IOL at different data rates at different times may select the occupied bandwidth corresponding to the highest data rate at any time.

FREQUENCY BAND (GHz)	TRANSMISSION MODES [9]	S_0 Ms/s	S_1 Ms/s	B_1 MHz	S_2 Ms/s	B_2 MHz
2.20 - 2.29	Return modes SR1, SR2 & SR3[10]	-	-	-	3	15
2.20 - 2.29	Return modes SR3[11]	-	-	-	6	15
2.20 - 2.29	Return modes SR4	0.5	0.5	5	6	15
25.25 - 27.5	Return mode (PSK modulation)	4	50	80	150	240

TABLE 4.1 - OCCUPIED BANDWIDTH REQUIREMENTS

Note 9 see chapter 5

Note 10 I/Q=1:1 and symbol rate on Q-channel < 3 Ms/s

Note 11 Symbol rate on Q-channel > 3 Ms/s

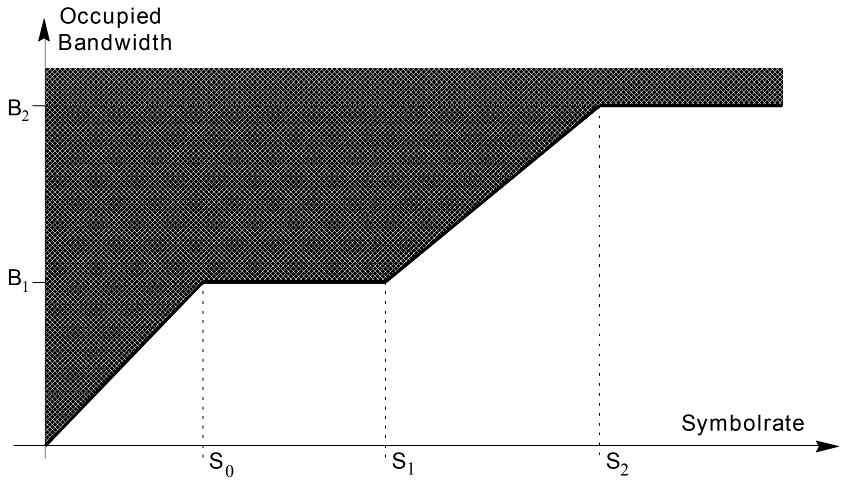


Figure 4.1 - IOL OCCUPIED BANDWIDTH LIMITS

4.2.5 Requirements on UST IOL Emissions

4.2.5.1 Power Flux Density Limits

In accordance with [1], the Power Flux Density (PFD) at the Earth's surface produced by emissions from a spacecraft, for all conditions and all methods of modulation, shall not exceed the values given in Table 4.2. In all cases, the limits relate to the PFD which would be obtained under assumed free-space propagation conditions.

Frequency	Angle of incidence (δ) above horizontal plane	Power flux density (dB(W/m^2))
2200 - 2290 MHz	0 - 5° 5 - 25° 25 - 90°	-154 -154 + 0.5 (δ-5) -144 in any 4 kHz bandwidth
25.25 - 27.50 GHz	0 - 5° 5 - 25° 25 - 90°	-115 -115 + 0.5 (δ-5) -105 in any 1 MHz bandwidth

TABLE 4.2 - POWER FLUX DENSITY LIMITS AT THE EARTH'S SURFACE

4.2.5.2 Spurious Emissions

The spurious emissions generated by spacecraft shall not exceed [-60 dBc][2] measured in a reference bandwidth of 100 Hz at all frequencies. They are applicable to both modulated and unmodulated transmissions.

Note 12 This requirement shall be reviewed to ensure compliance with a future revision of ITU-R SM.329 expected during 1997.

4.2.5.3 Protection of Radio Astronomy Bands

Unwanted emissions falling into frequency bands of the Radio Astronomy service shall be kept to power flux spectral density values inferior to those given in Tables 43 and 4.4.

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

TABLE 4.3 - HARMFUL INTERFERENCE LEVELS
FOR RADIOASTRONOMY LINE OBSERVATIONS

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

TABLE 4.4 - HARMFUL INTERFERENCE LEVELS
FOR RADIOASTRONOMY CONTINUUM OBSERVATIONS

Excess of these values is considered harmful when illuminating specific terrestrial radio astronomy sites. For continuum observations, it is acceptable to integrate the interference power over the specified observation bandwidth given in Table 4.4.

4.2.5.4 Protection of Deep Space Research Bands

Unwanted emissions falling into frequency bands of the Space Research (deep space) Service should be kept to power flux spectral density values inferior to those given in Tables 4.5. Whenever the limits of Table 4.5 cannot be met, coordination shall be initiated with the space research (deep space) users via the ESA Frequency Management Office.

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

TABLE 4.5 - HARMFUL INTERFERENCE LEVELS
AT DEEP SPACE ANTENNA SITES

4.2.5.5 Cessation of Emissions

In accordance with [1], each spacecraft shall be fitted with devices to ensure immediate cessation of its radio emissions by telecommand whenever such a cessation is required.

4.2.5.6 Time Limitations on IOL Transmissions

IOL transmissions shall be limited to the periods necessary for link acquisition, telemetry, telecommand and/or ranging.

4.2.5.7 In-Channel Signal Power Level at the DRSS

The maximum power flux density of the spectral main lobe of a transmitting UST at the DRSS shall be less than the levels defined in Table 4.6.

Frequency Band	Power Flux / Power Flux Density at DRSS	Symbol Rate Range
2200 - 2290 MHz	-160 dB(W/m².kHz)	
25.25 - 27.50 GHz	-136 dB(W/m²)	up to 100 ks/s
	-156 dB(W/m².kHz)	100 ks/s to 75 Ms/s
	-153 dB(W/m².kHz)	above 75 Ms/s

TABLE 4.6 - MAXIMUM IN-CHANNEL POWER FLUX DENSITY AT DRSS

4.2.5.8 Out of Channel Signal Power Level at the DRSS

The maximum out of channel power flux density of a transmitting UST at the DRSS shall be less than the levels defined in Table 4.7 at frequencies outside the channel bandwidth centered on the assigned channel centre frequency.

Frequency Band	Power Flux Density at DRSS (dB(W/m².kHz))	channel bandwidth
2200 - 2290 MHz	-202	15 MHz
25.25 - 27.50 GHz	-196	250 MHz

TABLE 4.7 - MAXIMUM OUT OF CHANNEL POWER FLUX DENSITY AT DRSS

4.3 FORWARD FEEDER LINK TRANSMISSIONS

4.3.1 Carrier frequency requirements

4.3.1.1 Requirements for frequency compensation

In mode SF1 (see section 5.1), during acquisition of a 2 GHz user link and, on user request, following acquisition, the forward signal frequency as received by the User spacecraft shall be compensated by the Earth Terminal by up to ± 100 kHz, based on User spacecraft orbital information, to within ± 700 Hz of the estimated onboard receiver frequency.

The frequency error contribution from the system (Earth Terminal + DRSS) shall be less than ± 7 Hz. To achieve this accuracy, the Earth Terminal shall compensate the DRSS translation frequency drifts of up to ± 300 Hz by making use of the DRSS pilot.

The frequency compensation shall be phase-continuous such that the carrier phase is continuous during changes of frequency.

4.3.1.2 Requirements for Doppler Tracking

The Earth Terminal shall have an overall short term stability of better than 1×10^{11} over 10 seconds.

4.3.1.3 Requirements for Ranging

The Earth Terminal shall have a long term accuracy of better than 5×10^{11} over 10 seconds.

4.3.2 Polarization

The polarisation of the European Forward and Return Feeder Links will be linear, within 10° of vertical depending on the Earth Terminal location and the DRS orbital position.

The polarisation of Forward Feeder Links and Return Feeder Links via the Steerable Spot Feeder Link will be vertical at the DRS longitude (and therefore aligned to a direction at other locations dependent on the Earth Terminal location and the DRS orbital position).

The polarisation of the Pilot Signals will be the same as for the Feeder Links.

4.3.3 Bandwidth considerations

4.3.3.1 Transmitter Spectral Mask

The User shall submit, with his request for frequencies (see Section 3.3.1), a radio frequency spectral mask, below which the emitted spectral power density shall lie. This mask shall be expressed in dBW/Hz. It shall be averaged over 1 MHz. It shall extend to at least 60 dB below the maximum spectral density.

4.3.3.2 Requirements on Occupied Bandwidth

The definition of the occupied bandwidth is given in section 4.1.

For all transmissions, every effort shall be made to minimise the occupied bandwidth in order to facilitate coordination with other users and to minimise interference into other systems.

In any case, the occupied bandwidth of each forward feeder link shall not exceed 100 MHz.

4.3.4 Requirements on Earth Terminal Emissions

4.3.4.1 EIRP Limitations

In accordance with [1], the equivalent isotropically radiated power (EIRP) transmitted in any direction towards the horizon by an Earth station operating in the frequency bands above 15 GHz shall not exceed:

+ 64 dBW in any 1 MHz band for $\theta \leq 0°$
+ 64 + 3 θ dBW in any 1 MHz band for $0° < \theta \leq 5°$

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.

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

No transmission shall be effected by Earth Terminals at elevation angles of less than 3 degrees measured from the horizontal plane to the direction of maximum radiation (i.e. antenna main beam direction).

It should be noted that the administration of a country hosting an earth station may modify the above limits for a particular frequency or frequency band. The ESA Frequency Management Office must, therefore, be consulted in case of an ESA Earth Terminal whether the above or other, more stringent, limits are applicable.

4.3.4.2 Spurious Emissions

The spurious emissions generated by Earth Terminals shall not exceed [-60 dBc][13] measured in a reference bandwidth of 100 Hz at all frequencies. They are applicable to both modulated and unmodulated transmissions.

4.3.4.3 In-Channel Signal Power Level at the DRSS

The maximum power flux density of the spectral main lobe of a transmitting Earth Terminal at the DRSS shall range from less than -76 dB(W/m².kHz) for an Earth Terminal at the centre of the DRSS feeder link coverage increasing to -70 dB(W/m².kHz) towards the edge of coverage.

Note 13 This requirement shall be reviewed to ensure compliance with a future revision of ITU-R SM.329 expected during 1997.

4.3.4.4 Out of Channel Signal Power Level at the DRSS

The Out of Channel power spectral density of a transmitting Earth Terminal at the DRSS more than 50 MHz from the assigned channel centre frequency shall be less than -168 dB(W/(m².kHz)) for an Earth Terminal at the centre of the DRSS feeder link coverage and less than -156 dB(W/(m^2.kHz)) for an Earth Terminal at the edge of the DRSS feeder link coverage.

4.3.4.5 Forward link protection

The Earth Terminal shall be equipped with a bandpass filter and reflected power protection circuit in each transmit chain, such that it is physically impossible for the Operator to switch the Earth Terminal and transmit on any other frequency.

4.3.4.6 Turn-On EIRP

An Earth Terminal transmitting an EIRP of more than 73 dBW shall not transmit towards the DRSS at more than 73 dBW at turn on and shall then increase its EIRP towards the DRSS by not more than 10 dB/s.

4.3.4.7 Maximum transmitted power spectral density

The maximum transmitted power spectral density at the input of the Earth Terminal antenna shall not exceed -37 dBW/Hz averaged over 1 MHz within the specified channel bandwidth. This may be calculated as the ratio of the maximum average signal power and the signal symbol rate. The above specification is a requirement for coordination with other services in the assigned band.

4.3.4.8 Antenna Radiation Pattern

The Earth Terminal antenna gain $G_{(\varphi)}$ in dB for angles above φ_r shall not exceed:

$$G_{(\varphi)} = 29 - 25\log\varphi \quad \text{for} \quad \varphi_r < \varphi < 48^\circ$$

$$G_{(\varphi)} = -10 \quad \text{for} \quad 48^\circ < \varphi < 180^\circ$$

$$\varphi_r = 15.85\left(\frac{D}{\lambda}\right)^{-0.6} \quad \text{(degrees)}$$

where:

D = antenna diameter
λ = wavelength
φ = off-axis angle of the antenna, in degrees

5 SIGNAL REQUIREMENTS

5.1 MODULATION MODES

5.1.1 Modes for the 30/2 GHz and 2/20 GHz Links

The modulation modes listed below are available for communications between the UST and the Earth Terminal via a DRSS for a range of data rates. Data rates referred to in this document include the channel coding overhead whenever channel coding is applied. Some modulation modes support UST ranging. SF is the S-band Forward link (30 GHz/2 GHz) and SR is the S-band Return link (2 GHz/20 GHz).

	SF1	SF2	SR1	SR2	SR3	SR4
Data rate on I channel (kb/s)	0.1 - 300	300 - 2000	0.1 - 300	1 - 300	0.1 - 300	1 - 6000
Data rate on Q channel (kb/s)			0.1 - 300	1 - 300	1 - 6000	1 - 6000
Data rate increment (b/s)	1	1	1	1	1	1
Data format	NRZ-L NRZ-M	NRZ-L NRZ-M	NRZ-L NRZ-M	NRZ-L NRZ-M	NRZ-L NRZ-M	NRZ-L NRZ-M
PN code family I channel	Gold code		m-sequence	Gold code	m-sequence	
PN Code length I channel	$2^{10}-1$		$(2^{10}-1)$ 256	$2^{11}-1$	$(2^{10}-1)$ 256	
Code I epoch reference	none		received Q code of SF1	none	received Q code of SF1	
PN code family Q channel	m-sequence		m-sequence	Gold code		
PN Code length Q channel	$(2^{10}-1)$ 256		$(2^{10}-1)$ 256	$2^{11}-1$		
Code Q epoch reference	I code		x + ½ chips (x > 20000) delay to I of SR1	½ chip delay to I of SR2		
Spreading code rate (Mc/s)	$f_f \frac{31}{221 \cdot 96}$		identical to received code	$f_r \frac{31}{240 \cdot 96}$	identical to received code	
Modulation	UQPSK	BPSK	USQPSK	USQPSK	UQPSK BPSK	UQPSK SQPSK QPSK BPSK
I/Q power ratio	10:1		1:1 or 1:4	1:1 or 1:4	1:1 or 1:4	1:1 or 4:1
Ranging service	yes	no	yes	no	yes	no
Phase imbalance (deg)	< 2°	< 2°	< 5°	< 5°	< 5°	< 5°
Amplitude imbalance (dB)	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25	< 0.25
Data asymmetry	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03	< 0.03
Data bit jitter	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
PN code asymmetry	< 0.01		< 0.01	< 0.01	< 0.01	
PN code chip jitter	< 0.01		< 0.01	< 0.01	< 0.01	
Symbol transition time	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
I/Q symbol skew	< 0.01		< 0.01	< 0.01	< 0.01	< 0.01

TABLE 5.1 - 2 GHz INTER-ORBIT LINK MODULATION MODES

Appendix E contains definitions of the various specified parameters. Mode SF1 is a spread spectrum UQPSK modulated signal with the data and a short PN code on the I Channel and a long PN code on the Q channel. Mode SF2 is a directly modulated BPSK signal with the data modulating the transmitted carrier.

Mode SR1 is a spread spectrum USQPSK modulated signal with data on the Q channel and on the I channel. SR1 supports ranging by transmission of a long PN code on the I channel synchronized to the code received on the Q channel in transmission mode SF1. A delayed version of this code is transmitted on the Q channel. If data are transmitted on only one channel, the Q channel shall be selected for the data transmission in order not to deteriorate the ranging signal (long PN code) on the I channel.

Mode SR2 is a spread spectrum USQPSK modulated signal with the data on the Q channel and on the I channel. SR2 does not support ranging. A short PN code is transmitted on the I channel and a half chip delayed version of this code is transmitted on the Q channel. If data are transmitted on only one channel, the Q channel shall be selected for the data transmission in order to be compatible with SR1.

Mode SR3 is a UQPSK modulated signal with a direct data modulated signal on the Q channel and a spread spectrum signal plus data on the I channel. SR3 supports ranging by transmission of a long PN code on the I channel which is synchronised to the code received on the Q channel in transmission mode SF1.

Mode SR4 is a direct modulated PSK signal with the data on the I channel and/or the data on the Q channel modulating the transmitted carrier.

For all PN coded transmissions, the data shall be modulo-2 added asynchronously to the PN code before being applied to the carrier modulator. The modulation shall be based on switching. In modes SR1 and SR2, a single data stream may also be split between I and Q channels or transmitted simultaneously on both channels. Transmission of data rates above 2 Mb/s in SR3 and SR4 is strongly discouraged due to congestion of the 2 GHz bands.

For the spread spectrum 2 GHz Inter Orbit Links, the signal spectrum is spread by a PN (Pseudo Noise) code sequence to conform to power flux density limitations on the Earth. The same PN code sequence is used for UST localisation. The possible modulation mode combinations are listed in Table 5.2 where the choice of combination depends on the specific users requirements.

UST Localisation Forward & Return Link	No UST Localisation Forward Link only	No UST Localisation Return Link only	No UST Localisation Forward & Return Link
SF1 and SR1 SF1 and SR3	SF1 SF2	SR2 SR4	SF1 and SR2 SF1 and SR4 SF2 and SR2 SF2 and SR4

TABLE 5.2 - MODULATION MODE COMBINATIONS

5.1.2 Modes for the 30/23 and 26/20 GHz Links

The modulation modes listed below are available for communications between the UST and the Earth Terminal via a DRSS for a range of data rates including coding overheads where applicable. Some modulation modes provide the possibility to support UST ranging. KF is the Ka-band Forward link (30 GHz/23 GHz) and KR is the Ka-band Return link (26 GHz/20 GHz).

	KF1	KF2	KR1	KR2	KR3	KR4
Data rate on I channel (kb/s) Data rate on Q channel (kb/s)	1 - 10000	1 - 10000	1 - 150 000	1 - 150 000	1 - 150 000 1 - 150 000	1 - 150 000 1 - 150 000
Data rate increment (b/s)	1	1	1000	1000	1000	1000
Data format	NRZ-L NRZ-M	NRZ-L NRZ-M	NRZ-L NRZ-M	NRZ-L NRZ-M	NRZ-L NRZ-M	NRZ-L NRZ-M
PN code family Q channel (see section 6.2)	[GHM code or PN code]		[GHM code or PN code]		[GHM code or PN code]	
PN code length Q channel	[24 2^{16} or (2^{10}-1) 256]		[24 2^{16} or (2^{10}-1) 256]		[24 2^{16} or (2^{10}-1) 256]	
Spreading code rate (Mc/s)	[10 Mc/s or 3 Mc/s]		[10 Mc/s or 3 Mc/s]		[10 Mc/s or 3 Mc/s]	
Modulation	UQPSK	BPSK	UQPSK	BPSK	SQPSK QPSK	SQPSK QPSK
I/Q power ratio	≤100:1 [14]		≤ 100:1 [15]		1:1	1:1
Ranging service	yes	no	yes	no	yes	no
Phase imbalance (deg)	< 6°	< 6°	< 6°	< 6°	< 6°	< 6°
Amplitude imbalance (dB)	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Data asymmetry Data bit jitter	< 0.03 < 0.01	< 0.03 < 0.01	< 0.03 < 0.01	< 0.03 < 0.01	< 0.03 < 0.01	< 0.03 < 0.01
PN code asymmetry PN code chip jitter	< 0.01 < 0.01		< 0.01 < 0.01			
Symbol transition time	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
I/Q symbol skew	< 0.01		< 0.01		< 0.01	< 0.01

TABLE 5.3 - 23/26 GHz INTER-ORBIT LINK MODULATION MODES

Transmission mode KF1 is a UQPSK modulated signal with direct data modulation on the I channel and a PN code on the Q channel for ranging purposes. An I channel to Q channel power ratio of 100:1 would have negligible impact on the data channel link budget and is appropriate for high data rates. A lower ratio (e.g. 10:1) would have noticeable impact on the data channel link budget but may be necessary for low data rates.

Note 14 For data rates less than 13 kb/s, the power on the Q channel shall not be reduced any further.

Note 15 For data rates less than 56 kb/s, the power on the Q channel shall not be reduced any further.

Transmission mode KF2 is a BPSK modulated signal with direct data modulation on the I channel.

Transmission mode KR1 is a UQPSK modulated signal with direct data modulation on the I channel and a PN code on the Q channel for ranging purposes. KR1 supports ranging by retransmitting the PN code (received on the Q channel in transmission mode KF1) on the Q channel. The I channel to Q channel power ratio is 100:1 or less as explained for KF1.

Transmission mode KR2 is a BPSK modulated signal with direct data modulation on the I channel.

Transmission mode KR3 is a QPSK/SQPSK modulated signal with direct data modulation on the I channel and the Q channel. KR3 could support ranging by superimposing the PN code (received on the Q channel in transmission mode KF1) on the Q channel. The data signal to PN code power ratio is 100:1 or less.

Transmission mode KR4 is a QPSK/SQPSK modulated signal with direct data modulation on the I channel and the Q channel.

For the 23/26 GHz Inter Orbit Links, the signal spectrum is not spread. To be able to support UST localisation, a PN code sequence is added on the Q channelfor transmission mode KF1 and KR1 and simply superimposed onto the data on the Q channel for transmission mode KR3. The possible transmission mode combinations are listed in Table 5.4 where the choice of combination depends on the specific users requirements.

UST Localisation Forward & Return Link	No UST Localisation Forward Link only	No UST Localisation Return Link only	No UST Localisation Forward & Return Link
KF1 and KR1 KF1 and KR3	KF2	KR2 KR4	KF2 and KR2 KF2 and KR4

TABLE 5.4 - TRANSMISSION MODE COMBINATIONS AT 23/26 GHz

5.2 MODULATION QUALITY REQUIREMENTS

The requirements in this section apply to transmitters in the Earth Terminal and in the UST. They include modulator imperfections and signal distortions up to and including the antenna and apply to all operational conditions.

5.2.1 Amplitude Attenuation Requirements

The amplitude attenuation, a, in the transmitter shall be within the generic mask of Figure 5.1, f_c being the channel centre frequency. The values a_1 and a_2 are as given in Table 5.5 for all bit or chip rates. For the maximum bit or chip rate f_1 and f_2 apply as defined in Table 5.5. For lower rates, f_1 and f_2 may be reduced in proportion to the bit rate.

The parameters f_3 and a_3 are defined by the maximum out of channel power levels specified in section 4.2.5.8 for the UST and in section 4.3.4.4 for the Earth Terminal.

	Earth Terminal 30 / 2 GHz	UST 2 / 20 GHz	Earth Terminal 30 / 23 GHz	UST 26 / 20 GHz
f_1	2.0 MHz	2.0 MHz	12.5 MHz	75 MHz
a_1	0.5 dB	0.5 dB	0.2 dB	0.5 dB
f_2	3.0 MHz	3.0 MHz	18.75 MHz	100 MHz
a_2	0.8 dB	0.8 dB	0.3 dB	1.0 dB

TABLE 5.5 - AMPLITUDE ATTENUATION REQUIREMENTS

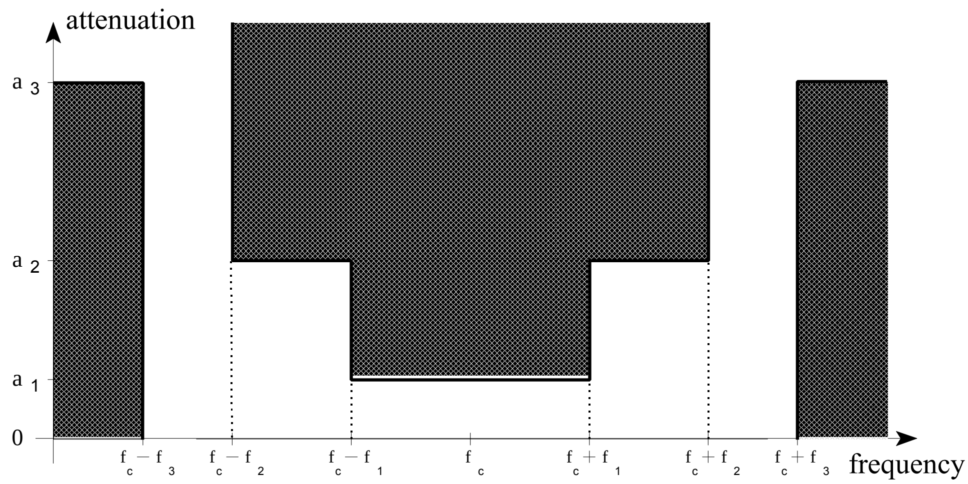


Figure 5.1 - AMPLITUDE MASK

5.2.2 Group Delay Requirements

The group delay variation, gd, in the transmitter shall be within the generic mask of Figure 5.2, f_c being the channel centre frequency. For the maximum bit or chip rate, f_1 and f_2 apply as defined in Table 5.6. For lower data and ranging rates, f_1 and f_2 may be reduced while gd_1 and gd_2 may be increased in proportion to this rate.

	Earth Terminal 30 / 2 GHz	UST 2 / 20 GHz	Earth Terminal 30 / 23 GHz	UST 26 / 20 GHz
f_1 gd_1	2.0 MHz 20 ns	2.0 MHz 20 ns	12.5 MHz 2.5 ns	75 MHz 3 ns
f_2 gd_2	3.0 MHz 40 ns	3.0 MHz 40 ns	18.75 MHz 3.5 ns	100 MHz 7 ns

TABLE 5.6 - GROUP DELAY REQUIREMENTS

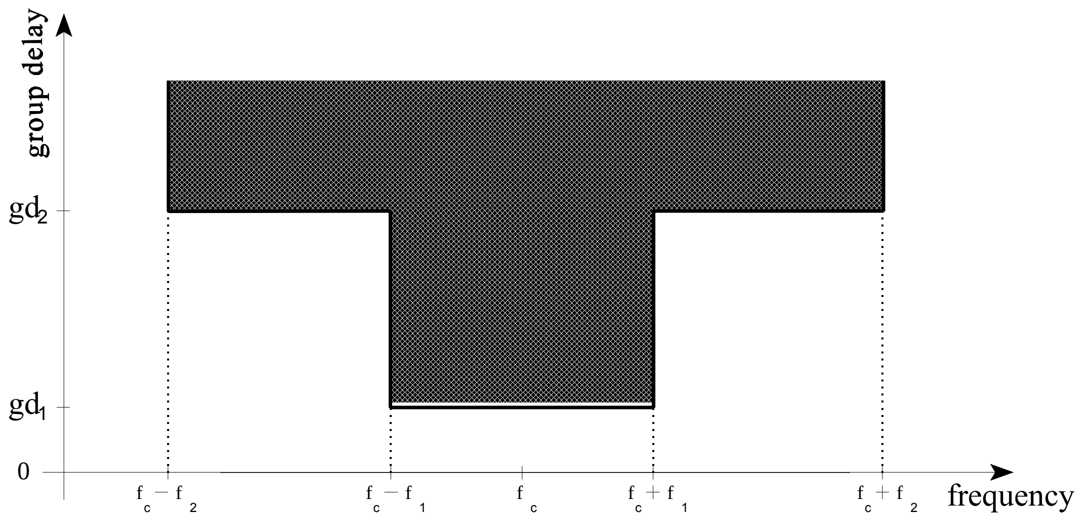


Figure 5.2 - GROUP DELAY MASK

5.2.3 Phase Noise Requirements

The single sideband phase noise, d, of the transmitted signal shall be less than the level specified in Table 5.7 and Figure 5.3, f being the offset frequency relative to the carrier. To meet data transmission performance requirements, the specification shall apply over the range from 0.001 to 1.0 times the transmitted symbol rate. To meet Doppler tracking requirements, the specification shall apply over the range from 0.5 Hz to 100 Hz.

	Earth Terminal 30 / 2 GHz	UST 2 / 20 GHz	Earth Terminal 30 / 23 GHz	UST 26 / 20 GHz
f_1	0.5 Hz		0.5 Hz	
d_1	-29 dBc/Hz		-29 dBc/Hz	
f_2	5.0 Hz		5.0 Hz	
d_2	-59 dBc/Hz		-59 dBc/Hz	
f_3	100 Hz	-33 - 10 log(f) dBc/Hz	100 Hz	-41 - 10 log(f) dBc/Hz
d_3	-67 dBc/Hz		-67 dBc/Hz	
f_4	1.0 kHz		1.0 kHz	
d_4	-67 dBc/Hz		-67 dBc/Hz	
f_5	5 MHz		5 MHz	
d_5	-103 dBc/Hz		-103 dBc/Hz	

TABLE 5.7 - PHASE NOISE REQUIREMENTS

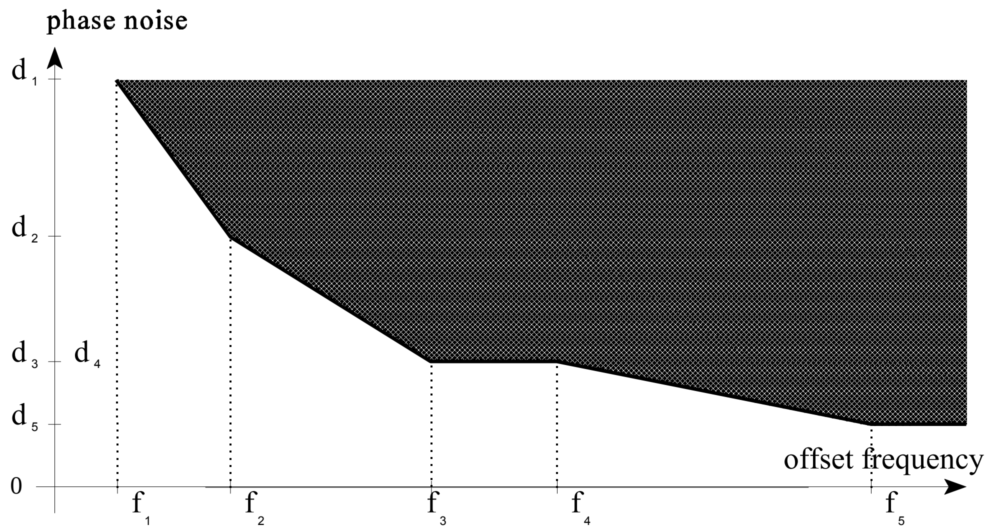


Figure 5.3 - PHASE NOISE SPECTRAL POWER DENSITY MASK

5.2.4 AM/PM Conversion Requirements

The AM/PM conversion factor shall be less than 3.5°/dB for all links considered above.

6 CODE ALLOCATION, ASSIGNMENT AND GENERATION

6.1 CODES FOR THE 30/2 AND 2/20 GHz LINKS

6.1.1 Code Allocation

For transmissions at low to medium data rates Pseudo Noise (PN) codes are required for the 2 GHz space-to-space links between a DRSS and a User spacecraft. The codes are necessary in order to satisfy power flux density limitations in accordance with [1] and to enable ranging support via the data channels. They also help in reducing RF effects and multipath reception. Code and data are modulo-2 added asynchronously before modulation.

International agreements have led to an allocation of separate code libraries to ESA, NASA, and NASDA in order to minimize the probability of interference. The allocated code libraries comprise a full set of 85 codes for each agency. Additional codes are available for other agencies/users but the risk of interference may be higher than with the established sets.

6.1.2 Code Assignment

Relevant DRS users will be assigned at least one set of PN codes comprising a forward command channel code, a code pair for non-coherent return modes, a forward ranging channel PN code and a coherent return mode code. The ESA libraries are listed in Appendix C.

The user must request an assignment for a set of codes from the:

TBD
[for the time being: DRS Project Management (R Department) - see D.1]

Earth Terminals shall be designed such that every code set can be supported including the sets of the other agencies as defined in reference 3. This allows for a maximum degree of interoperability.

6.1.3 Code Generation

6.1.3.1 Forward In-Phase Channel

The codes for the forward link (Mode SF1) I channel are Gold codes with a length of 1023 chips. All codes are balanced, i.e. the number of ones is one more than the number of zeros, in order to assure a smooth spectrum distribution. A typical code generator is shown in Figure 6.1. For ESA, Register A, stages 9 and 10 are initially both set to 1.

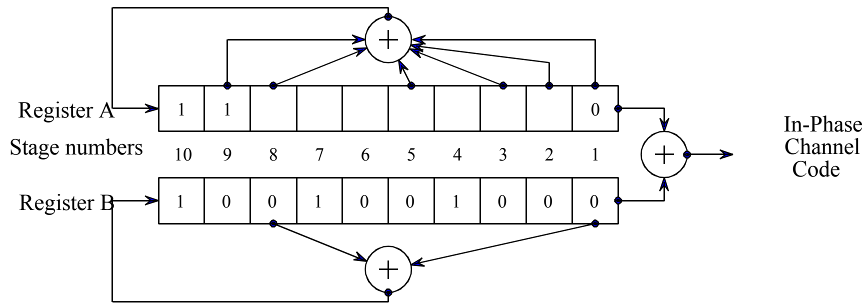


Figure 6.1 - I CHANNEL (COMMAND LINK) CODE GENERATOR

6.1.3.2 Data Channel (non - coherent)

The codes for the return link mode SR2 are Gold codes with a length of 2047 chips This mode is used for non-coherent transmissions. The codes are balanced and result in minimum cross-correlation values. A typical code generator is shown in Figure 6.2.

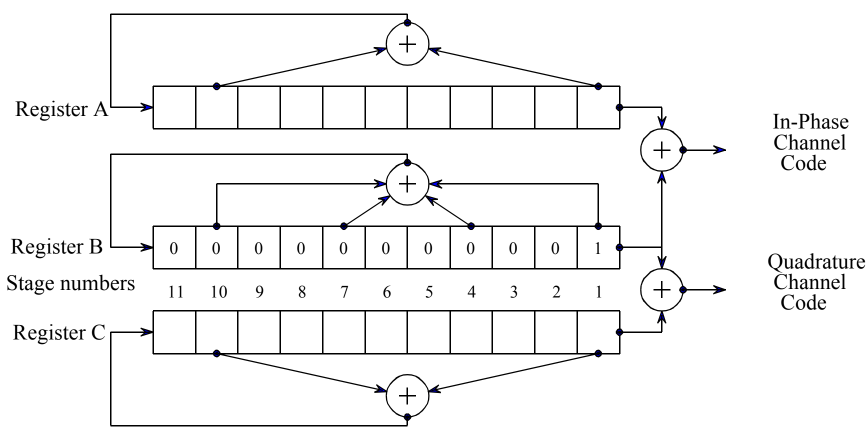


Figure 6.2 - MODE 2 RETURN LINK PN CODE GENERATOR

6.1.3.3 Forward Quadrature Channel

The codes for the forward link mode SF1 Q channel are maximum length sequences with a length of 262143 chips. The codes are truncated to 261888 chips (256 × 1023) in order to synchronise them to an integer number of forward code lengths. The all 1's condition of this code must be synchronous with the initial loading condition of the B register in Figure 6.1. Consequently, only 256 code positions have to be searched after synchronisation is achieved on the forward in-phase channel code. The codes are selected such that the number of feedback connections N is not higher than 6 to minimize on-board hardware and power consumption. Although truncated, the codes are essentially balanced. A typical code generator is shown in Figure 6.3.

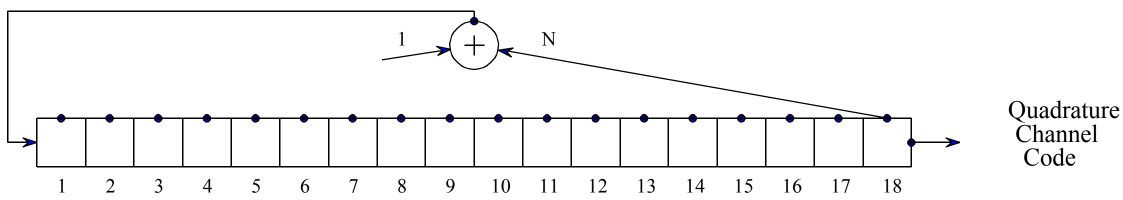


Figure 6.3 - Q CHANNEL (RANGING) CODE GENERATOR

6.1.3.4 Return Channels (coherent modes)

The codes for the return channel (modes SR1 and SR3) are maximum length sequences with a length of 262143 chips. The codes are truncated to 261888 chips (256 × 1023) and synchronised to the forward Q channel code. The number of feedback connections N is not higher than 8. Although truncated, the codes are essentially balanced. A typical code generator is shown in Figure 6.4.

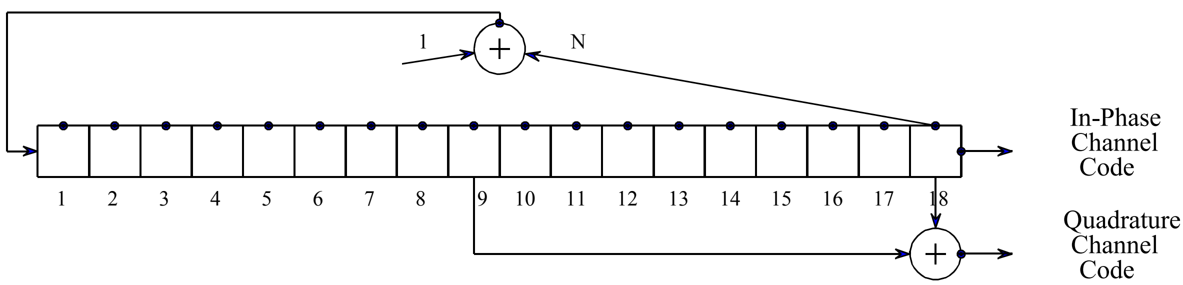


Figure 6.4 - MODES 1 AND 3 RETURN LINK CODE GENERATOR

6.2 CODES FOR 30/23 AND 26/20 GHz Links

At 23/26 GHz PN codes are required for ranging purposes. They are not required to satisfy power flux density limitations on the earth's surface. The interference environment is also less critical than at 2 GHz.

[A final decision on the codes to be used for ranging has not been made yet. An ESA study concluded that a 24×2^{16} GHM pseudo random code results in an optimum compromise between acquisition performance and code complexity. The time jitter performance is not affected by the choice of the code type. The chip rate is 10 Mc/s The code generator block diagram is given in Figure 6.5. The PN codes described in section 6.1 could also be used.]

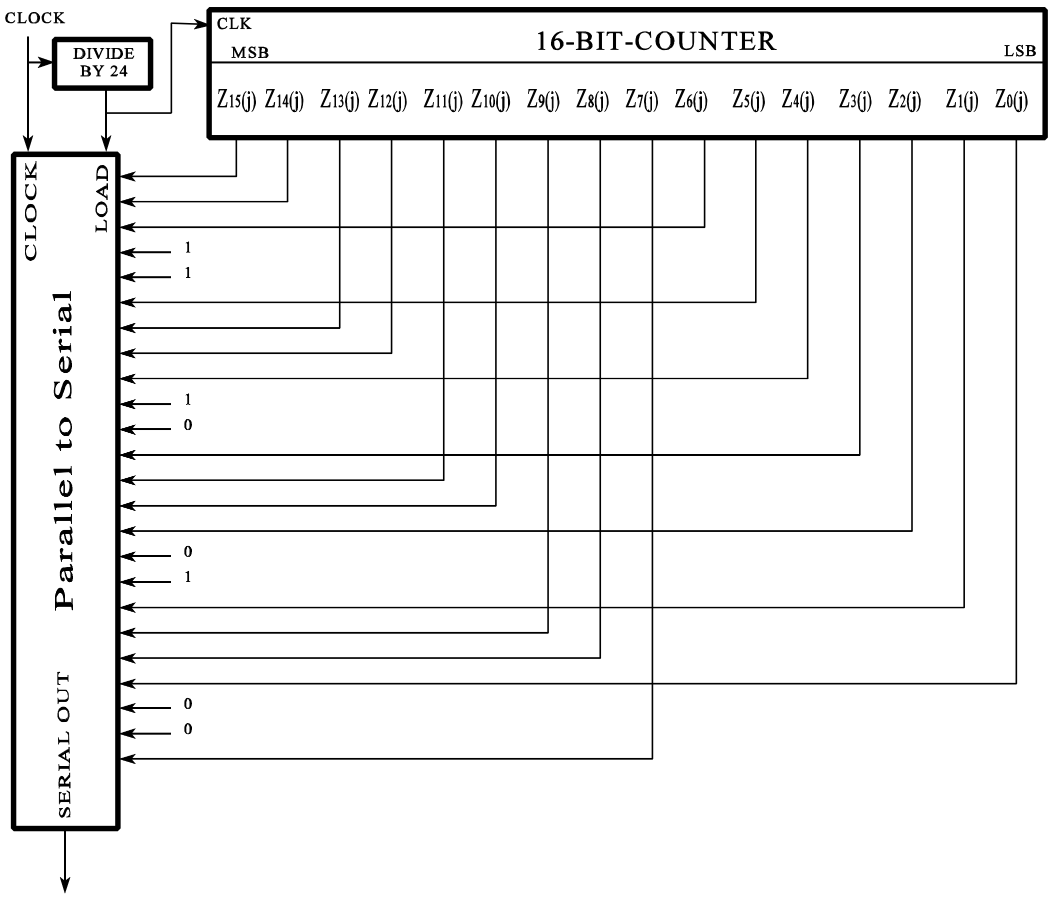


Figure 6.5 - GHM CODE GENERATOR

7 LINK ACQUISITION

7.1 GENERAL REQUIREMENTS

Link acquisition between an Earth Terminal and a User spacecraft via a DRSS comprises antenna pointing, frequency acquisition and in spread spectrum modes also code acquisition. Closed loop as well as open loop RF tracking systems can be used.

Two types of link with different requirements have to be considered. The feeder links between the Earth Terminal and the DRSS will operate with rather standard antenna pointing techniques whereas the IOL's will require more sophisticated pointing and tracking schemes, Doppler compensation and signal acquisition.

The Earth Terminal shall be pointed towards the DRSS in either an open or closed loop mode. The DRSS transmits a pilot (see section 3.2.5), which can be used for closed loop pointing. The DRSS translates signals incoherently in frequency but the pilot is coherent with the DRSS translation frequencies so that the Earth Terminal can apply corrections.

The DRSS IOL antenna is continuously open loop pointed towards the User spacecraft before start of the communication service period based on orbital information obtained from the user. The antenna is steerable within an angle of ±10° centered around the axis from the DRSS towards the earth centre.

The User Spacecraft shall point its antenna towards the DRSS with sufficient accuracy in order to achieve the minimum required signal level at the receiver input for acquisition and subsequent communications.

7.2 FORWARD LINKS

Doppler compensation is normally inhibited during tracking service periods requiring coherent two-way Doppler measurements upon reception of the transponder lock indication in the telemetry data stream. It may also be inhibited at the user's request. Doppler compensation shall be available for a relative velocity towards the DRS of up to 10 km/s.

7.2.1 30/2 GHz Links

The DRSS IOL antenna will be pointed towards the User spacecraft by open-loop predetermined tracking.

Forward 30/2 GHz and return 2/20 GHz links may be acquired independently or the return link may be acquired first to allow telemetry data, e.g. temperatures, to aid forward carrier frequency adjustment.

7.2.1.1 Earth Terminal Requirements for Mode SF1

Forward 30/2 GHz links must be pre-compensated at the start of the pass for frequency offsets in the UST receiver and Doppler shifts due to velocities of the User spacecraft relative to the DRSS of up to 10 km/s. The Earth Terminal shall provide frequency compensation as specified in section 4.3.1.1.

Following acquisition, the carrier frequency shall either continue to be compensated for Doppler shift or be fixed or be swept to the nominal channel centre frequency. During tracking service periods requiring coherent two-way Doppler measurements, the carrier frequency shall be kept fixed.

The Earth Terminal shall in addition be able to sweep the forward feeder link frequency linearly over a range of ± 3 kHz in 120 seconds. The forward frequency sweep shall be on top of on-going frequency compensation.

A change in frequency received by the UST shall not be higher than 250 Hz/s. The Doppler rate will contribute up to 80 Hz/s when the User spacecraft is at the DRSS subsatellite point. The DRSS frequency drift will contribute a negligible factor.

No data shall modulate the signal during the acquisition phase.

7.2.1.2 Earth Terminal Requirements for Mode SF2

The Earth Terminal shall be able to sweep the forward feeder link frequency at up to 5 kHz/s. Frequency precompensation is not required over a range of up to ± 100 kHz. The forward signal shall be modulated at all times.

7.2.1.3 UST Requirements for Mode SF1

The UST receiver shall acquire the frequency, the short command (I-channel) code and the long ranging (Q-channel) code as specified in section 7.2.1.1. Details are given in Appendix F.

7.2.1.4 UST Requirements for Mode SF2

The UST receiver shall acquire the swept signal as specified in section 7.2.1.2 and demodulate the data.

7.2.2 30/23 GHz Links

7.2.2.1 Earth Terminal Requirements

The Earth Terminal shall be able to sweep the forward link frequency at a rate of up to 50 kHz/s over a range of up to 1 MHz around a nominal frequency. The Earth Terminal shall be able to set the nominal frequency to the forward feeder link centre frequency specified in section 3.2.4. The Earth Terminal shall also be able to apply a frequency offset to compensate for a predicted Doppler shift in order to allow for a smaller search range.

7.2.2.2 UST Requirements

Each DRSS transmits a beacon at one of the frequencies listed in section 3.2.3 which may be used for User Spacecraft antenna pointing with the following characteristics:

EIRP:	24 dBW minimum
EIRP stability:	$\leq$ 0.2 dB/s
Frequency stability:	10^{-8} long term
Polarisation:	LHC

The risk of inadvertently locking onto a terrestrial signal should be noted.

The UST receiver shall acquire the swept signal as specified in section 7.2.2.1 and demodulate the data.

7.3 RETURN LINKS

7.3.1 2/20 GHz Links

7.3.1.1 UST Requirements

The User spacecraft antenna will be open loop pointed towards the DRSS.

It shall be possible to switch on the UST transmitter either at a prestored time or upon command from the Earth. When the forward link is established, the UST may switch to coherent mode either automatically or on command from Earth.

7.3.1.2 Earth Terminal Requirements

The Earth Terminal shall be able to receive a signal up to ± 150 kHz from the return feeder link centre frequency, which is normally achieved by estimating the receive frequency to ± 1500 Hz.

The received frequency may vary by up to 400 Hz/s due to Doppler shift variations.

The Earth Terminal shall acquire the signal and demodulate the data.

In coherent mode of operations, the return signal carrier will be locked by the UST to the forward signal frequency and for spread spectrum modes, the return PN code will be synchronized by the UST to the forward PN code so that the Earth Terminal can use its Doppler shift estimates to acquire the signal frequency and its user position estimate to acquire the long ranging code.

7.3.2 26/20 GHz Links

7.3.2.1 UST Requirements

The User spacecraft antenna may be open loop pointed towards the DRSS or may use the DRSS Beacon for closed-loop pointing. See section 7.2.2.2.

It shall be possible to switch on the UST transmitter either at a prestored time or upon command from the Earth. When the forward link is established, the UST may switch to coherent mode either automatically or on command from Earth.

7.3.2.2 Earth Terminal Requirements

The Earth Terminal shall be able to receive a signal up to ± 2 MHz from the return feeder link centre frequency. The received frequency may vary by up to 2 kHz/s due to Doppler shift variations.

The Earth Terminal shall acquire the signal and demodulate the data.

In coherent mode of operations, the return signal carrier will be locked by the UST to the forward signal frequency.

8 CROSS SUPPORT FROM OTHER NETWORKS

8.1 COMPATIBILITY WITH NASA TDRS AND NASDA DRTS

Within the frame of the Space Network Interoperability Panel (SNIP) ESA, NASA and NASDA have agreed to an interoperability concept which allows extensive mutual-support of User Spacecraft via each of their data relay systems.

All detailed specifications for supported modes and information on individual system capabilities in S-band can be found in the document "S-Band Interoperability Link Parameters" [4]. USTs compliant with this document should be RF- and modulation-compatible with NASA and NASDA data relay systems in the 2 GHz bands.

Recommendations on interoperability in the 23 GHz and 26 GHz bands can be found in the "SNIP Ka-Band Interoperability Recommendations" [5]. USTs compliant with this document should be RF-compatible with NASA and NASDA data relay systems in the 23 GHz and 26 GHz bands, subject to the limitations that NASA data relay systems will operate only on the same polarisation for transmit and receive signals and will not provide a wide-beam beacon. However, modulation and coding schemes in the Earth Terminals in USA or Japan may not be fully compatible with this document.

Users considering support by NASA or NASDA data relay systems as well as the ESA DRS should discuss this with the DRS Management Organisation (see Appendix D) at the earliest opportunity.

APPENDIX A - ACRONYMS AND ABBREVIATIONS

ARTEMIS	Advanced Relay and Technology Mission
BPSK	Binary Phase Shift Keying
BW	Bandwidth
CCSDS	Consultative Committee for Space Data Systems
dBc	dB with respect to the unmodulated carrier
DRS	European Data Relay System
DRS-1	European Data Relay Satellite number 1
DRSS	DRS Satellite
EIRP	Equivalent Isotropic Radiated Power
ESA	European Space Agency
Feeder Link	Link between the Earth Terminal and DRSS
Forward Link	Total communication link from Earth Terminal to UST via DRSS
GHz	Gigahertz
GHM	Gantz-Hiltgen-Massey
I (or I-channel)	In-Phase Channel
ICD	Interface Control Document
IOL	Inter Orbit Link between UST and DRSS
ITU	International Telecommunication Union
KF	30 GHz/23 GHz (Ka-band) forward link
KR	26 GHz/20 GHz (Ka-band) return link
LHC	Left Hand Circular
LSB	Least Significant Bit
Mc/s	Megachips per second
Ms/s	Megasymbols per second
MSB	Most Significant Bit
NASA	National Aeronautics and Space Administration (US)
NASDA	National Astronautics and Space Development Administration (Japan)

NRZ- L	Non Return to Zero- Level
NRZ -M	Non Return to Zero- Mark
OCC	Operations Control Centre
PFD	Power Flux Density
PN	Pseudo Noise
Q (or Q-channel)	Quadrature Channel
QPSK	Quadrature Phase Shift Keying
Return Link	Total communication link from UST to Earth Terminal via DRSS
RF	Radio Frequency
SF	30 GHz/2 GHz (S-band) forward link
SR	2 GHz/20 GHz (S-band) return link
STAB	ESA Standards Approval Board for Space Data Communications
SQPSK	Staggered Quadrature Phase Shift Keying
UQPSK	Unbalanced Quadrature Phase Shift Keying
UST	User Space Terminal accommodated on the User Spacecraft
USQPSK	Unbalanced Staggered Quadrature Phase Shift Keying

APPENDIX B - FREQUENCY ASSIGNMENT PROCEDURE

Several factors must be taken into consideration when proceeding to the choice of the most appropriate frequency bands for a particular mission and subsequently the assignment of discrete frequencies in the selected bands. Such factors are (not necessarily listed in order of priority):

- frequency bands implemented on the data relay satellite considered for mission support;
- required bandwidth versus available bandwidth in the frequency bands that are allocated to the services;
- link budget for a particular mission;
- availability of technology and existing designs for spacecraft equipment in the frequency band.

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

Step 1: Selection of mission frequency bands (ESA and non-ESA missions)

Objective:

To select the frequency band(s) the mission will most likely use. The step does not yet include the selection of discrete frequencies.

Data:

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

- general mission description;
- orbital parameters (general indications are sufficient together with approximate values for apogee, perigee and inclination);
- data relay satellite support options envisaged including feeder link Earth stations;
- year of launch and approximate mission lifetime;
- indication of favored frequency band for IOL including bandwidth requirements.

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

Deadline:

During feasibility study phase.

Step 2: Selection of Discrete Frequencies (ESA and non-ESA missions)

Objectives:

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

Data:

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

Deadline:

During Phase B study.

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

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

Objective:

For ESA missions, to coordinate and inscribe the assigned frequencies into the International Frequency List of ITU/BR so that the frequency assignment becomes a formally recognized one by all member states of the ITU. The procedure to be followed is found in [1].

For non-ESA missions, to coordinate and inscribe those assigned frequencies related to the DRS interface into the international frequency list of the ITU/BR so that the frequency assignment becomes a formally recognized one by all member states of the

ITU. The procedure to be followed is found in [1].

Data:

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

The data required for the notification with ITU/BR shall be supplied in two consecutive steps:

- Advance Publication Information for ESA missions to be furnished for a satellite network [1]
- Coordination and Notification Data for ESA and non-ESA missions (DRS interface only) [1]

The Frequency Management Office will assist the spacecraft project in the compilation of these data.

Deadline:

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

ANNEX 1 TO APPENDIX B

REQUEST FOR FREQUENCY ASSIGNMENT

1. GENERAL INFORMATION

1.1 PROJECT NAME:

1.2 CONTACT PERSON (Name and Phone):

1.3 MISSION OBJECTIVES:

1.4 LAUNCH DATE:

1.5 MISSION LIFETIME:

2. ORBIT PARAMETERS

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

Note: For circular orbits the first three parameters and for eccentric ones the first four parameters are mandatory in order to perform the RFI analysis vis-a-vis other satellites. The period should also be given.

3. SUPPORT REQUIREMENTS

DRSS Location	Earth Terminal Location	Telemetry	Telecommand	Tracking	Remarks

4. FORWARD LINK [16]

4.1 EARTH TERMINAL TRANSMIT

4.1.1 PREFERRED FREQUENCY [17] GHz

4.1.2 FORWARD FEEDER LINK MODULATION SCHEMES

Modulation Modes [18] (see section 5.1)	Symbol Rate (ks/s)	Occupied Bandwidth (kHz)	Remarks

4.1.3 EARTH TERMINAL DATA

Earth Terminal Location	Antenna Gain (dB)	Antenna Pattern	RF Power at Antenna Input (dBW)	Max. Spectral Power Density (dBW/Ref.BW)[19]

4.2 UST RECEIVE

4.2.1 SELECTED FREQUENCY BAND: 2 / 23 GHz

4.2.2 PREFERRED FREQUENCY: [17] MHz

4.2.3 SPACECRAFT ANTENNA MAXIMUM GAIN dBi

Note 16 Use several forms for spacecraft requiring more than one forward frequency.

Note 17 The PREFERRED FREQUENCY is given as an indication only. There is no guarantee that it can be finally assigned to the project.

Note 18 In case non-standard modes are used, a detailed description of the modulation mode shall be provided.

Note 19 The maximum spectral power density at the antenna input shall be expressed in dBW/Hz, averaged over the worst reference bandwidth of 4 kHz for RF carrier frequencies below 15 GHz, and over 1 MHz for those above 15 GHz.

4.2.4 SPACECRAFT ANTENNA GAIN PATTERN dBi

4.2.5 SYSTEM TEMPERATURE K

5. RETURN LINK [20]

5.1 UST TRANSMIT

5.1.1 SELECTED FREQUENCY BAND: 2 / 26 GHz

5.1.2 PREFERRED FREQUENCY: [17] MHz

5.1.3 SPACECRAFT TRANSMITTER POWER: dBW

5.1.4 MAXIMUM SPECTRAL POWER DENSITY: [19]

5.1.5 SPACECRAFT ANTENNA MAXIMUM GAIN: dBi

5.1.6 SPACECRAFT ANTENNA GAIN PATTERN: dBi

5.1.7 MODULATION SCHEMES:

Modulation Modes [21] (see section 5.1)	Symbol Rate (ks/s) I	Q	Occupied Bandwidth (kHz)	Remarks

5.1.8 TRANSMITTER SPECTRAL MASK

Note 20 Use several forms for spacecraft requiring more than one return frequency.

Note 21 In case non-standard modes are used, a detailed description of the modulation mode shall be provided.

5.2 EARTH TERMINAL RECEIVE

5.2.1 PREFERRED FREQUENCY (not applicable - see section 3.2.4)

5.2.2 EARTH TERMINAL DATA

Earth Terminal Location	Antenna Gain (dB)	Antenna Pattern	System Noise Temperature (K)

6. STRAPPING TABLE

FORWARD LINK			RETURN LINK	
Modulation Modes	Feeder Link (GHz)	IOL (GHz)	Modulation Modes	IOL (GHz)

APPENDIX C - PN CODE LIBRARIES

The numbers in the table are the initial register loadings and tab connections in octal presentation. The only exception is the forward in-phase channel, where binary representation was selected. For the command channel, stage 1 is always 0 and stages 9 and 10 are agency specific and both set to 1 for ESA.

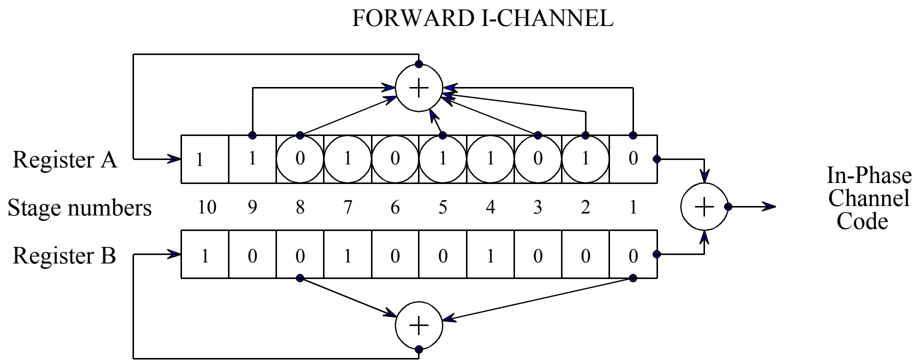
Code Set	Forward In-Phase Channel	Mode 2 Return Link Reg. A	Reg. C	Forward Quadrature Channel	Mode 1 and 3 Return Link
	Initial Register Loading			Feedback Tab Connections	
1	0101101	0514	0752	1124013	1320067
2	0100001	1231	1725	1624021	1105265
3	1011011	2462	3653	1524003	1062127
4	0011001	1144	3526	1550005	1211465
5	0010001	2310	3254	1011505	1036123
6	0110011	0621	2531	1240423	1406551
7	0011011	1443	1262	1006113	1146065
8	0110010	3107	2544	1221411	1023551
9	0011010	2176	3101	1502025	1041467
10	0100101	0375	2203	1014027	1071701
11	1111010	0772	0407	1110311	1126611
12	0010111	1765	1017	1001651	1442625
13	1000100	3753	2036	1500341	1430351
14	0001000	3726	0075	1200211	1720215
15	0011100	2604	3506	1634001	1423521
16	1000000	1410	3214	1401125	1201617
17	0000000	3021	2431	1402423	1070447
18	1101110	2043	1062	1400043	1003715
19	1011100	1625	1137	1101223	1433601
20	1000111	3453	2276	1242043	1443251
21	0001110	3032	0427	1004447	1470215
22	1101011	2065	1057	1114015	1626023
23	1010110	0153	2136	1111023	1247013
24	0010101	0326	0275	1010051	1244427
25	0011000	0654	0572	1101511	1264415
26	0111111	3161	2511	1214103	1500437

Code Set	Forward In-Phase Channel	Mode 2 Return Link Reg. A	Reg. C	Forward Quadrature Channel	Mode 1 and 3 Return Link
27	1110001	2343	1222	1021611	1203543
28	1100010	0707	2444	1602051	1065505
29	0001001	3076	0441	1104101	1161053
30	0001101	3666	0155	1111045	1620613
31	0101100	2613	1516	1210047	1500731
32	0001111	1335	1663	1056021	1446511
33	0101111	3247	2764	1321011	1331411
34	0011101	2517	1750	1224411	1076405
35	1010111	1703	1042	1406421	1136045
36	0101110	0714	0452	1132011	1111331
37	1001001	1776	3001	1442205	1222227
38	1011110	0022	0033	1016141	1125053
39	1100100	0044	0066	1420113	1530215
40	1001000	0550	0734	1220123	1342701
41	1111001	2114	3152	1014251	1311065
42	1110010	0231	2325	1001705	1472013
43	0010011	3604	0106	1306101	1120475
44	0110001	0414	0612	1054121	1217601
45	1010100	2247	1364	1206221	1341611
46	0010010	1536	3361	1604043	1073141
47	1111101	1366	3615	1506003	1534023
48	1110101	0366	0215	1424205	1710215
49	0000010	0754	0432	1232201	1442515
50	1101001	3771	2005	1204151	1544621
51	0100100	3762	0013	1300213	1603251
52	0111100	3440	0260	1550401	1641113
53	1001011	0403	2602	1360401	1056251
54	1011111	0035	2023	1224045	1460417
55	0111110	1676	3141	1402251	1225303
56	1110011	3575	2303	1440425	1122253
57	1100110	3372	0607	1760001	1024157
58	0001011	3250	0774	1212045	1101355
59	0111001	2504	3746	1046025	1502453
60	0010100	1040	3460	1262003	1165025
61	1000001	1204	3706	1120341	1042715

Code Set	Forward In-Phase Channel	Mode 2 Return Link Reg. A	Reg. C	Forward Quadrature Channel	Mode 1 and 3 Return Link
62	1101010	0450	0674	1142061	1071341
63	1111011	1213	1716	1500261	1047641
64	1110110	2426	3635	1013421	1506213
65	1101100	1235	1723	1203105	1443461
66	1011000	2350	3234	1120113	1303243
67	0110000	0721	2471	1210065	1204565
68	0110110	1643	1162	1461011	1054631
69	1100000	2435	1623	1404055	1055261
70	1001111	3513	2356	1464003	1546501
71	0011110	1514	3352	1244045	1532421
72	1000110	2314	3252	1401035	1432541
73	1110100	3147	2524	1604103	1422447
74	0110111	0525	2777	1111051	1061153
75	0111000	3225	2737	1441001	1160721
76	0000011	0603	2502	1401225	1026315
77	1011001	1761	1011	1305401	1206427
78	0010110	0157	2130	1642011	1651045
79	1010001	1647	1164	1502105	1660047
80	0000101	2735	1463	1452003	1146461
81	0100011	1240	3760	1040351	1742405
82	0000111	2500	3740	1021143	1563011
83	1111110	1200	3700	1200057	1730111
84	1111100	2400	3600	1005341	1574005
85	1111000	1000	3400	1404213	1072321

Note that the loading for the shift registers is given from left to right whereas the feedback tap connections are specified from right to left according to mathematical definitions. An example for the loading and for the tap connections is given below and in Figures C1 and C2 based on code set 1.

Gold Code on Forward I-Channel:	0101101	->	1101011010
Gold Codes on Return Channels:	I: 0514	->	[0]00101001100
	Q: 0752	->	[0]00111101010
Maximum Length Codes Forward Channel:	1124013	->	[00]100101010000000101[1]
Maximum Length Codes Return Channels:	1320067	->	[00]101101000000011011[1]



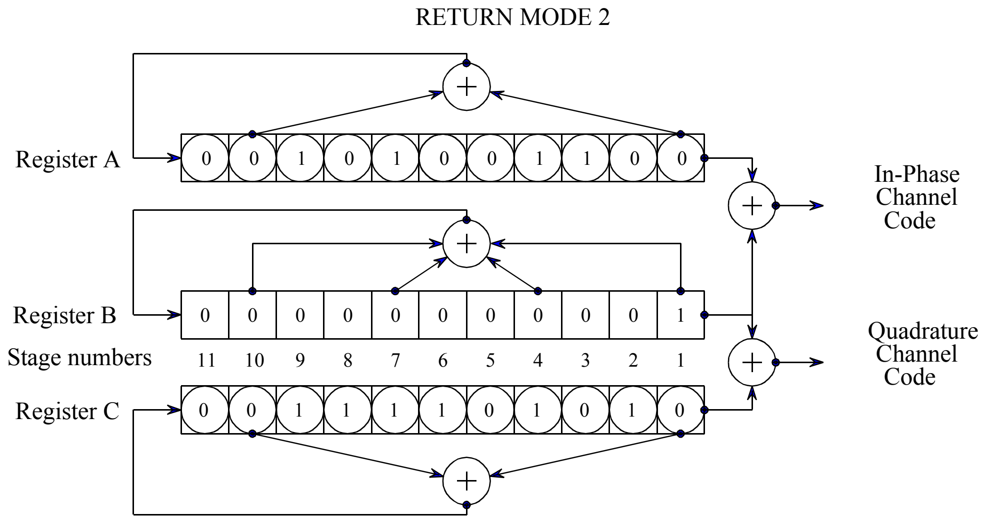


Figure C1 - EXAMPLES OF REGISTER LOADING FOR GOLD CODES BASED ON CODE SET 1
(circled positions can be programmed by the User)

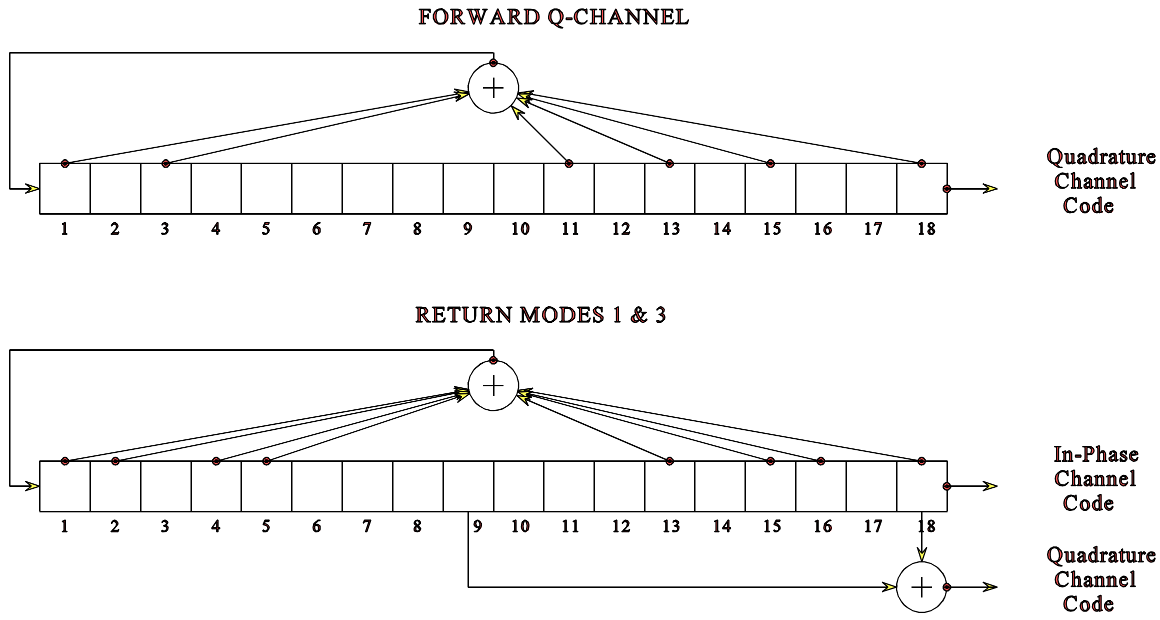


Figure C2 - EXAMPLES OF TAP CONNECTIONS FOR MAXIMUM LENGTH CODES BASED ON CODE SET 1

APPENDIX D - RF INTERFACE CONTROL REQUIREMENTS

D.1 INTERFACE CONTROL DOCUMENT

Management of the relations between DRS and each User will be based on an Interface Control Document (ICD), which will be issued by the DRS management organisation based on the Initial Request for Service provided by the User and other information requested by DRS.

The DRS Management Organisation is represented by:

DRS Project Management (R Department)
ESTEC
P. O. Box 299
NL - 2200 AG Noordwijk
Tel: +31-1719-83138
Fax: +31-1719-84093

Discussion and drafting of the ICD should commence before the User makes firm commitments for the design and construction of his UST and/or Earth Terminal.

The ICD will define and specify all RF and management interfaces between DRS and the Users to ensure their compatibility.

The ICD is approved by both the DRS management organisation and the User and is revised and maintained under formal configuration control until the conclusion of the User mission. After approval, the ICD becomes the basic technical and operational document between DRS and the User. A typical contents list for the ICD is shown in Table D.1.

The agreement of the ICD will allow the User to proceed with the detailed design and manufacture of his facilities with confidence that an agreed quality of DRS service can be achieved.

1. INTRODUCTION

   1.1 Structure of the ICD
   1.2 Definition of Responsibilities
   1.3 Documentation
   1.4 Change Control Procedure

2. SYSTEM DESCRIPTION

   2.1 Data Relay System Description
   2.2 User System Description

3. DRS SERVICES REQUESTED BY USERS

   3.1 User Mission Characteristics
   3.2 Requested Period of Service per Mission Phase
   3.3 Service Requirements per Mission Phase

4. USER SPACE TERMINAL CHARACTERISTICS

   4.1 Receive Characteristics
   4.2 Transmit Characteristics

5. DRS TRANSFER CHARACTERISTICS

   5.1 Forward Channel
   5.2 Return Channel
   5.3 Tracking Beacon Characteristics
   5.4 Frequency Pilot Characteristics

6. USER EARTH TERMINAL CHARACTERISTICS

   6.1 Forward Link Characteristics
   6.2 Return Link Characteristics

Table D.1. - TYPICAL CONTENTS LIST OF DRS/USER ICD

APPENDIX E - DEFINITION OF MODULATOR IMPERFECTIONS

E1 Phase Imbalance

The modulated signal, at the output of the modulator, is a sum of two signal components called In Phase Channel (I-channel) and Quadrature Phase Channel (Q-channel) respectively. The two signal components have the same carrier with an ideal phase difference of 90°.

The modulated signal has two signal states for BPSK modulation and four signal states for QPSK modulation. Each signal state, N, is characterised by an amplitude, $A_{(N)}$, and a phase, $\Phi_{(N)}$, where $\Phi_{(N)}$ is defined as the difference between the phase of the modulated carrier, when in state N, and the phase of the unmodulated carrier.

E1.1 BPSK Phase Imbalance

For BPSK the ideal phase between the two signal states, with phase $\Phi_{(1)}$ and $\Phi_{(2)}$ respectively, is 180°. The phase imbalance is defined as:

$$\text{Phase Imbalance} = |180° - (\Phi_{(2)} - \Phi_{(1)})|$$

where |argument| denotes the absolute value of the argument.

E1.2 QPSK Phase Imbalance

For QPSK the ideal phase between the four signal states depend on the ideal In Phase to Q channel power ratio. The ideal phase difference, θ_{ideal}, is provided in Table E1 versus In Phase to Q channel (I/Q) power ratio.

I/Q Power Ratio	θ_{ideal}
1:1	90°
1:4	53.1° and 126.9°
1:10	35.1° and 144.9°
1:100	11.4° and 168.6°

TABLE E1 - IDEAL SIGNAL STATE PHASE DIFFERENCES

Let $\theta_{(N)}$ denote the phase difference between the actual signal states. The phase imbalance is then defined as:

$$\text{Phase Imbalance} = \text{Maximum}(|\theta_{(N)} - \theta_{ideal}|, N = 1,2,3,4)$$

E2 Amplitude Imbalance

The modulated signal has two signal states for BPSK and four signal states for QPSK modulation. Each signal state, N, is characterised by an amplitude, $A_{(N)}$, and a phase, $\Phi_{(N)}$. The modulated signal from a Phase Shift Keying modulator, being either BSPK, QPSK, UQPSK or USQPSK, is ideally a constant envelope signal or the ratio between the maximum and minimum signal state amplitude is 1:1. Let A_{max} and A_{min} denote the actual amplitudes for the signal state with the maximum amplitude and the signal state with the minimum amplitude as follows:

$$A_{max} = \text{Maximum}(A_{(N)}, N = 1,2,3,4)$$
$$A_{min} = \text{Minimum}(A_{(N)}, N = 1,2,3,4)$$

The amplitude imbalance is then defined as:

$$\text{Amplitude Imbalance} = 20 \cdot \log(A_{max}/A_{min})$$

E3 Data Asymmetry

The data signal is a continuous sequence of symbols. For NRZ data format, two different symbols exist where one denotes logical zero and the other logical one. The length or duration of the symbol denoting logical zero is ideally equal to the length of the symbol denoting logical one.

The actual length of the symbol denoting logical zero might not be equal to the actual length of symbol denoting logical one. Let l_1 denote the average length of symbols denoting logical one in a data sequence and l_0 denote the average length of symbols denoting logical zero in the data sequence. The data asymmetry is defined as:

$$\text{Data Asymmetry} = \left|(l_0 - l_1)/(l_0 + l_1)\right|$$

E4 Data Bit Jitter

The data signal is a continuous sequence of symbols. For NRZ data format, two different symbols exist where one denotes logical zero and the other logical one. The length or duration of the symbol denoting logical zero is ideally equal to the length of the symbol denoting logical one.

The actual length of the symbol denoting logical zero might not be equal to the actual length of symbol denoting logical one. Let l_1 denote the average length of symbols denoting logical one in a data sequence and l_0 denote the average length of symbols denoting logical zero in the data sequence. Moreover, let vl_0 denote the variance of the length of symbols denoting logical zero, which is defined as the average of ((length of logical zero symbol – $l_1)^2$), and let vl_1 denote the variance of the length of symbols denoting logical one. The data bit jitter is defined as:

$$\text{Data Bit Jitter} = \frac{\sqrt{vl_1 + vl_0}}{l_1 + l_0}$$

E5 PN Code Asymmetry

Defined as in Section E3 with chips in place of bits.

E6 PN Code Chip Jitter

Defined as in Section E4 with chips in place of bits.

E7 Symbol Transition Time

The modulated signal has two signal states for BPSK modulation and four signal states for QPSK modulation. Each signal state, N, is characterised by an amplitude, $A_{(N)}$, and a phase, $\Phi_{(N)}$, where $\Phi_{(N)}$ is the steady state phase angle.

Ideally the phase $\Phi_{(N)}$ changes from the one signal state to the other signal state in an infinite short time. The actual transition time from the phase $\Phi_{(1)}$, for signal state 1, to change to the subsequent phase $\Phi_{(2)}$, for signal state 2, lasts a finite duration.

Symbol Transition Time = the time duration to switch from 90% of $\Phi_{(1)}$ to 90% of $\Phi_{(2)}$ divided by the average symbol duration.

E8 I/Q Data Bit Skew

When the data rate modulating the I channel and the data rate modulating the Q channel are the same, there is as ideal relative time delay between the instants of data transitions on the one channel and the instants of data transitions on the other channel. The I/Q data bit skew defines the deviation from this ideal relative time delay. For QPSK the ideal relative time delay is zero whereas for staggered QPSK the relative time delay is 0.5.

Let $t(I_i)$ and $t(Q_i)$ denote the actual data bit transition instants on the I channel and the Q channel respectively. Moreover, let l_d denote the average length of the data bits and let δ denote the ideal relative time delay. The I/Q data bit skew is defined as:

$$\text{I/Q Data Bit Skew} = \text{Average}((t(I_i) - t(Q_i))/l_d - \delta)$$

where I denotes the data bit number I in a data sequence and the average is taken over all data bits in the complete data sequence.

E9 I/Q PN Code Chip Skew

Defined as in Section E8 with chips in place of bits.

APPENDIX F - ACQUISITION FOR MODE SF1

The spread spectrum forward signal received by the onboard receiver is composed of 4 different constituents which are acquired sequentially by the receiver. They are:

1. the short PN code on the I-channel
2. the suppressed carrier
3. the long PN code on the Q-channel
4. the data on the I-channel

In order to avoid excessive complexity of the onboard receiver, no data are present in the forward link signal during the acquisition phase. The acquisition of the forward signal is performed in three steps:

- Acquisition of the short PN code: during this phase, the onboard receiver correlates an internally generated replica of the short code with the PN code on the received signal. The receiver searches sequentially each position of the 1024 chips code until the proper position is found. The signal-to-noise conditions determine the necessary integration time for each position. The result of the integration for each position is compared to a predefined threshold, chosen in such a way that only the peak of this correlation function will overcome the threshold. In practice, the two codes rates are not identical (frequency uncertainties, Doppler) and the result is a smoothing of the peak of the correlation function. The receiver is designed to tolerate a difference between the replica code and the received code rates of up to $\pm 6\times10^{-7}$. The choice for this figure is the result of a trade-off between complexity in the receiver and in the acquisition process. This code rate tolerance is equally shared as:

  $\pm 3\times10^{-7}$ uncertainty on the onboard receiver actual code rate
  $\pm 3\times10^{-7}$ uncertainty on the forward link code rate at the input to the receiver

- Acquisition of the carrier: the same uncertainty figures as for the short PN code apply to the carrier:

  $\pm 3\times10^{-7}$ uncertainty on the onboard receiver local carrier frequency
  $\pm 3\times10^{-7}$ uncertainty on the forward link signal carrier frequency

  The similarity between code rate and carrier frequency uncertainties stem from the fact that carrier and code at the input to the receiver are expected to be coherent or quasi-coherent.

- Acquisition of the long code: the received signal long code is synchronised with the received signal short code. When long code acquisition process begins, short code and carrier are already acquired and the receiver local frequency references are locked to the receive signal. Hence correlation process is performed with a long code replica at the exact rate of the received long code.

It is therefore evident that the ground operator must be able to predict the UST rest frequency variation, the IOL Doppler shift and the DRSS translation frequency in order to ensure that the frequency received by the UST is within the required acquisition range.