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SINGLE SPACE SEGMENT

-oOo-

HRPT / LRPT DIRECT BROADCAST SERVICES SPECIFICATION

OPS/PREP Y2.6

esa / EUMETSAT	MetOp **CCB Directive**	Ref.: MO-CCB-ESA-SY-0050 Date: 1 November, 2000 Page 1 of 1

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Box 2: Description

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Participants: J. Bosma, S. Carlier, E. Neri, I. Stojkovic, C. Fransen

Decision: : ● Approve ❍ Do not approve

Comments:

The document reflects earlier agreements with Eumetsat and Industry.

Paragraph 3.3 has been updated for IASI. The IASI updates have been approved by Industry by means of DCR 0231.

Paragraph 3.3 has <u>not</u> been updated for GRAS as consensus has not yet been reached in Industry.

Industry will need to raise a formal request to update this document once the GRAS figures are agreed.

Issue of CCN ref.:

Box 4: Approval

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Issue 2	**15/05/96**		**All pages**
Issue 3	**04/02/97**		**All pages**
Issue 4	**14/11/97**		**page 7:** GOME packetised data rate increased to 400 kbit/s max; Satellite housekeeping packet and GRAS pos. & timing packet size adjusted to reflect the constraint of the size being multiple of 32 octets; DCS-2 packet data rate modified. **page 14:** Data rate budget updated **page 30:** The HRPT EIRP has been decreased by 1 dB over the whole coverage. **page 36/37:** The HRPT link budget has been modified to consider the variation in the HRPT EIRP.
Issue 5 Draft	**01/02/98**	MO-DS-ESA-SY0048 EPS/SYS/SPE/95413	**page 1:** Reference to document AD01 removed; cosmetic. **page 2:** Reference to AD01 and RD01 removed. **page 3:** Compression scheme referred to Annex 2. **page 4:** Packet structure format modified; Application process identifier set always to 1; Sequence flag set always to 11. **page 5:** Packet secondary header description modified; Ancillary data field description. **page 6:** Packet data rate table updated. **page 7:** Reference to RD01 removed. **page 11:** Insert zone is always present; cosmetic. **page 13:** Data rate budget table updated. **page 14/15/16:** LRPT physical layer description modified. **page 20:** Level required to demodulate

Issue / Revision	Date:	DCN No.	Changed Pages / Paragraphs
			LRPT data stream modified; cosmetic **page 22/23/24/28:** Cosmetic. **page 31/33:** Link budget updated; cosmetic. **page 34:** Cosmetic. **page 35:** Depth of compression and selection of transmitted channels modified. **page 38:** Packet sequence modified. **page 39:** Packet structure modified. **page 41:** Packet structure modified. **page 43:** Cosmetic.
Issue 5	**1/10/98**		**page 5:** Update to UTC and SBT field description; **page 36-40:** Detailed changes for compatibility with 'Reference Compressor/Decompressor'.
Issue 6	**20/9/99**		**page 7:** Corrected errors in data table; data rates presented as bps (not kbps) to avoid ambiguous definition of 1kb (1000 or 1024). **page 11:** Definition of M_PDU Header Spare. **page 14:** Update to data rate table. **pages 22, 30:** Axial ratio **at nadir**. **page 42:** Corrections to calibration packet description.
Issue 7	**20/10/99**		Final version for C/D Contract, agreed at MMS 15-10-99. **page 7, 14:** Table updates.
Issue 8	**30/6/00**		**All pages:** Minor editorial and typographical changes. **§ 3.3:** Table update, resolved TBD's. **§ 6.3:** Synchronisation marker defined. **§ 6.5.3:** Changes in the description of the LRPT group delay and requirements for compensation. **§ 7.2.3:** Changes in the description of the HRPT group delay and requirements for compensation.

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1 INTRODUCTION

This document defines the specification of the High Resolution Picture Transmission (HRPT) and the Low Resolution Picture Transmission (LRPT) services provided by the METOP satellite.

The HRPT and LRPT direct broadcast services are characterised by the implementation of the CCSDS Recommendations [AD03 and AD04] and the encryption of selectable virtual channels. The on-board encryption mechanism, based on the DES algorithm, is described in [AD02]. The encryption is addressed in this document, only to specify the content of the Insert zone in the VCDU data structure in the Data Link Layer.

This document covers the implementation of the data communication model on METOP spacecraft.

The structure of this document is as follows:

Chapter 1 - This chapter.

Chapter 2 - Lists the applicable and reference documents.

Chapter 3 - Details the Application Layer implementation specific to EPS / METOP.

Chapter 4 - Deals with the Network Layer implementation details.

Chapter 5 - Deals with the Data Link Layer implementation details.

Chapter 6 - Describes the LRPT Physical Layer and the main requirements for the Ground Stations.

Chapter 7 - Describes the HRPT Physical Layer and the main requirements for the Ground Stations.

Annex 1 - Provides an overview of the link budget for HRPT and LRPT.

Annex 2 - Describes the algorithm used to compress the AVHRR High Rate and the packet format of the resulting AVHRR Low rate application.

Annex 3 - Lists the acronyms used in this document.

2 DOCUMENTATION

2.1 *Applicable Documents*

AD01 Deleted

AD02	EPS/SYS/SPE/95424 MO/DS/ESA/SY/0049	EUMETSAT Polar System / METOP Programme: Encryption System Specification
AD03	CCSDS 701.0-B-2	Advanced Orbiting Systems, Networks and Data, Blue Book, Issue 2.
AD04	CCSDS 101.0-B-3	Telemetry Channel Coding, Blue Book, Issue 3.

2.2 *Reference Documents*

RD01 Deleted

3 APPLICATION LAYER

The Application layer defines the information exchange between the METOP payload and the user specific applications.

The NOAA procured instruments (AVHRR, AMSU-A1, AMSU-A2, HIRS, SEM, DCS) will generate raw data which will be time-tagged and formatted by the spacecraft NOAA Interface Unit (NIU). This NIU will also provide data compression of the AVHRR data for transmission on the LRPT link.

The IASI, MHS, GRAS, GOME and ASCAT instruments provide data in the form of CCSDS source packets.

The satellite provides housekeeping data, GRAS positioning and timing data and administrative messages in the form of CCSDS source packets.

The Application Process Identifiers relevant to each instrument are defined in 3.3.

3.1 *Application Data*

3.1.1 Application Data provided with LRPT

The application data provided by the LRPT link are as follows:

- Compressed resolution imagery on selected channels of the AVHRR instrument (the data compression scheme is defined in Annex 2).
- Infrared and microwave sounding data from the Meteorological Payload: AMSU-A1, AMSU-A2, MHS, HIRS.
- SEM data.
- Spacecraft Housekeeping data.
- GRAS positioning and timing data.
- Administrative messages.

3.1.2 Application Data provided with HRPT

The application data provided by the HRPT link are as follows:

- Full resolution AVHRR imagery.
- Infrared and microwave sounding data from the Meteorological Payload: AMSU-A1, AMSU-A2, MHS, HIRS and IASI.
- SEM data.
- DCS data.
- Data provided by ASCAT, GOME.
- Spacecraft Housekeeping data.
- GRAS positioning and timing data.
- GRAS sounding data.
- Administrative messages.

3.2 *Source Packet structure*

In addition to the source data, the source packet carries information needed for the acquisition, storage, distribution and exploitation of the source data by the end user.

The source packet structure is as follows:

Packet Primary Header (48 bits)							Secondary header	User data		
Packet identifier 2 octets				Packet sequence control 2 octets		Packet length 2 octets	8 octets	variable		
Version No 3 bits "000"	Type 1 bit "0"	Secondary Header Flag 1 bit	APID 11 bits	Sequence flag 2 bits	Packet Sequence Count 14 bits	16 bits	Time stamp 64 bits	Ancillary data var.	Application data var.	PEC 16 bits

The utilisation of the fields within the primary header is as follows:

Packet identifier

- Version number	000 (CCSDS packet Version number 1)
- Type	0 (This bit is not used within AOS)
- Secondary Header Flag	This bit shall be always set to 1 to indicate the presence of a secondary header.
- Application Process Identifier	This field defines the data route between two user application endpoints: the APIDs are listed in 3.3.

Packet sequence control

- Sequence Flag	This flag is set to 11 indicating that the packet contains un-segmented User Data. The maximum length of the packet is 65542 octets.
- Packet name/sequence count	This field is a modulo 16384 counter, which numbers the packets.
- Packet length	This field contains a sequential binary count "C" that expresses the length of the Secondary Header and the User Data. The value of "C" is the length (in octets) minus 1.

The Packet secondary header contains the time stamp. The time stamp is associated to a known time preceding the event measured. The time stamp is compliant with CCSDS 301-B2 "level 1" Time Code.

The time stamp consists of

- 2 octets indicating the number of days with reference to 1/1/2000;
- 4 octets indicating the millisecond of the day;
- 2 octets indicating the microsecond of the millisecond.

The time stamp will be synchronised to UTC with an accuracy of 4 milliseconds.

The User Data field contains the following fields:

- Ancillary Data field: this field contains a secondary time stamp in the first six octets and optionally, other information required for the processing of the application data - i.e. instrument mode, instrument telemetry and calibration data, redundancy. Its size - an even number of octets - depends on the instrument requirement.

The secondary time stamp consists of:

- one octet filled with "0";
- 3 octets of coarse time (second);
- 2 octets of fine time (2^{-16} second). Within this field, a number of the LSB's (depending on the source) up to a maximum of 8 may be set to "0".

The reference time of the secondary time stamp (epoch) is known and defined by the Satellite Control Centre. A counter rollover happens every 2^{24} seconds (half a year). This is equivalent to a modification of the epoch. The secondary time stamp is synchronised with the time stamp in the Packet secondary header.

- Application Data field: this field contains information provided by the source; its length shall be an even number of octets.

- Packet Error Control field: this field is optional: if required by the user it shall contain one of the following checksums:

  a) Cyclic Redundancy Checksum (CRC) computed over all other octets that constitute the packet. The polynomial generator shall be:

  $$G(x) = x^{16} + x^{12} + x^{5} + 1.$$

  Both encoder and decoder shall be initialised with all ones ("1") state for each packet.

  b) Vertical Parity Checksum calculated by performing an exclusive-OR on all the other octet pairs that constitute the packet.

3.3 *Application data overview: APID and Source Packets size - data rates*

The following table provides an overview of the METOP application data: It shows the reserved APIDs, the packetised data rate, the size of the whole packet, the Ancillary data, the Application data length and eventually the packet rate for each application.

Application	APID	Packetised Data Rate [bps]	Packet Size [octet]	Ancillary Data OBT / Addit. Inform. [octet]	Application Data Length [octet]	PEC [octet]	Rate [pkt/sec]
AVHRR/3 HR	103, 104	622368	12966	6 / 0	12944	2	6
AVHRR/3 LR	64 ... 70	39900 (max)	var.	6 / 0	var.	2	4/1.3333
MHS	34	3924	1308	6 / 0	1286	2	3/8
A-DCS	35	7462	7462	6 / 0	7440	2	1/8
SEM	37	165.5	662	6 / 0	640	2	1/32
HIRS/4	38	2907.5	2326	6 / 0	2304	2	1/6.4
AMSU-A1	39	2102	2102	6 / 0	2080	2	1/8
AMSU-A2	40	1142	1142	6 / 0	1120	2	1/8
IASI Spectrum							
Pixel 1	130		<8960	6 / 300	<8638	2	30/8
Pixel 2	135		<8960	6 / 300	<8638	2	30/8
Pixel 3	140		<8960	6 / 300	<8638	2	30/8
Pixel 4	145		<8960	6 / 300	<8638	2	30/8
IASI Image	150	1500000 (average over 8s)	<6202	6 / 30	<6150	2	34/8
IASI Verif.	160		<59400 >5200	6 / 60	<59318 >5118	2	5/8
IASI Aux.	180		1024 (max)	6 / 120	<882	2	1/8
ASCAT	192 ... 255	60000 (max)	660 (nom)	6 / 126	512 (nom)	2	<11.36
GOME-2	384 ... 447	400000 (max)	18738	6 / 956	17490	2	8/3
GRAS Occultation / Tracking	448 ... 511	60000 (max)	TBD	6 / TBD	TBD	TBD	TBD
Satellite Pkt	1	4352	544	6 / 0	524	0	1
GRAS Nav RT	2	80	160	6 / 0	140	0	1/16
GRAS Nav Red	3	32	64	6 / 0	44	0	1/16
Admin Msg	6	2008	8032	6 / 0	8012	0	1/32

3.4 *Instruments Source Packet Description*

Although the instrument data follows the CCSDS recommendation together with the specific requirements listed in chapter 3.3, the packet data field structure is specific to each instrument and detailed in a dedicated document.

4 NETWORK LAYER

The Network layer is represented by the path layer in the CCSDS standard. In this case, the only function of the path layer shall be to generate the VCDU-Id and to forward CP-PDUs to the multiplexing service.

The VCDU-ID is a 14-bit data structure, consisting of a spacecraft identifier (8 bits) and a virtual channel identifier (6 bits).

Spacecraft identifiers shall be assigned as follows:

Spacecraft	Identifier
METOP1	00001011
METOP2	00001100
METOP3	00001101
METOP SIMULATOR	00001110

The virtual channel identifiers are given by the subsequent table:

LRPT:

Instruments	Virtual Channel Identifier
Spacecraft Housekeeping	34
MHS	12
AMSU A1/2, SEM, HIRS	3
AVHRR low rate	5
GRAS positioning and timing data	34
Administration message	34
Fill VC	63

HRPT:

Instruments	Virtual Channel Identifier
Spacecraft Housekeeping	34
MHS	12
AMSU A1/2, SEM, HIRS	3
DCS	27
AVHRR High rate	9
IASI	10
ASCAT	15
GOME	24
GRAS positioning and timing data	34
GRAS sounding data	29
Administration messages	34
Fill VC	63

5 DATA LINK LAYER

The Data Link Layer is organised into two sublayers: a Virtual Channel Link Control sublayer (VCLC) and a Virtual Channel Access sublayer (VCA). The VCLC sublayer receives CCSDS packets from the Network layer, while the VCA sublayer forwards the physical channel access protocol data unit (PCA_PDU) to the physical layer.

The virtual channel procedures are functions required to generate virtual channel data units (VCDUs) from VCA_SDUs and vice versa. One of the channel access procedures is to handle Reed-Solomon check symbols. A VCDU with attached check symbols is called coded virtual channel data unit (CVCDU). The PCA_PDU consists of a succession of CVCDU prefixed by a Synchronisation Marker.

The structure of one CVCDU is shown in the following figure:

VCDU Primary Header (6 octets)						VCDU insert zone	VCDU Data Unit Zone			CVCDU Check symbols
Version N°	VCDU Id		VCDU counter	Signalling Field 1 octet			M_PDU header 2 octets		M_PDU packet zone	
	S/C id 8 bits	Type 6 bits	3 octets	Replay flag "0"	spare "0000000"	2 octets	M_PDU header spare	M_PDU first header pointer	882 octets	128 octets
"01"										

The elements of the CVCDU are as follows:

VCDU primary header	Contains a six-octet header structure
VCDU insert zone	Contains one IN_SDU having a length of 2 octets
VCDU data unit zone	Contains one VCA_SDU in case of a valid VCDU or all zeros in case of a fill VCDU. The size of this field is 884 octets
Reed-Solomon check symbols	Contain Reed-Solomon (255, 223) encoded check symbols, calculated over the VCDU primary header and the VCDU data unit zone.

5.1 *VCDU Primary Header*

The VCDU primary header consists of the following elements:

version number	Set to "01" specifying version-2 CCSDS structure.
VCDU-ID	Virtual channel data unit identifier as specified in Chapter 4, consisting of spacecraft identifier and virtual channel identifier.
VCDU counter	Sequential count (modulo 16777216) of VCDUs on each virtual channel.
signalling field	Set to "0" specifying real-time VCDUs.

5.2 *VCDU Insert Zone*

The insert zone is always present and used for encryption control (AD02).

The structure of the IN_SDU used with LRPT or HRPT is as follows:

The insert service data unit (IN_SDU) is used for data encryption: this field is composed of:

- Encryption flag (1 octet): set to 00_{HEX} when encryption is off; set to FF_{HEX} when encryption is on.

- Key number (1 octet): this octet indicates which message key is used to encrypt the VC. It is set to 00_{HEX} when encryption is off.

In case of failure of the encryption mechanism, the system shall not prevent data transmission to the ground; data shall be transmitted without encryption.

5.3 *VCDU Data Unit Zone*

The CVCDU data unit zone contains the multiplexing protocol data unit; this field consists of:

- M_PDU Header Spare bits (5 bits) : all set to "0". If the VCDU data zone does not contain any packet header the bits shall all be set to "1".
- M_PDU Header First Pointer (11 bits): it contains a binary count P, which, when incremented by one, points directly to the number of the octet that contains the first octet of the first CCSDS packet header. If the VCDU data zone does not contain any packet header the bits shall be set to "1".
- M_PDU Packet Zone (882 octets): it contains part, parts or complete CCSDS packets.

5.4 *Fill VCDU*

In the event that there are no valid M_PDU available for transmission, a fill VCDU will be generated. The content of the VCDU Data Unit Zone will be all "0".

5.5 *Reed Solomon Check Symbol Field*

The Reed Solomon Check Symbol Field contains the check symbols which allow error correction. They are generated according to AD04 with an interleaving depth of I= 4.

5.6 *Randomisation*

Each commutated sequence of CVCDUs is converted into a sequence of channel access data units (CADUs). For this purpose each CVCDU is randomised and subsequently preceded by a synchronization marker.

Randomization is performed by multiplying all 8160 bits of the CVCDU with a pseudo-noise pattern. The pseudo-noise sequence is generated by the following polynomial:

$$h(x) = x^8 + x^7 + x^5 + x^3 + 1$$

This sequence repeats after 255 bits with the sequence generator being reinitialized to "all-ones" state. The resulting PN pattern begins with $FF480EC09A_{HEX}$.

5.7 *Synchronisation Marker*

The synchronisation marker is defined as a unique word (UW). This unique word is:

$$1ACFFC1D_{HEX}$$

which describes a 32-bit pattern to precede each CVCDU.

Each CADU has a length of 8192 bits.

5.8 *CVCDUs Commutation Algorithm*

Commutation of CVCDUs shall not be performed on the basis of a priority system.

5.9 *Data Rate Budget*

The data rate budget for the LRPT and HRPT channels is given, for information only, herebelow:

Application	**HRPT [bps]**	**LRPT [bps]**
IASI	1500000	0
AVHRR	622368	39900
HIRS	2907.5	2907.5
AMSU A1	2102	2102
AMSU A2	1142	1142
MHS	3924	3924
SEM	165.5	165.5
A-DCS	7462	0
ASCAT	60000	0
GRAS Occultation	60000	0
GOME	400000	0
Satellite housekeeping packet	4352	4352
GRAS time and real-time position	80	80
Admin messages	2008	2008
subtotal	534072	6610
Capacity reserved	348132	5435
sub-total	3014643	62016
RS-coding (+16.1%)	485357	9984
total	3500000	72000

6 LRPT PHYSICAL LAYER

The LRPT physical layer shall perform the following operations (see the modulator block diagram in figure 6.1):

1) Convolutional encoding
2) Interleaving of the convolutionally encoded signal
3) Insertion of a unique word (UW) for interleaving synchronisation and delimitation
4) Serial to parallel conversion
5) QPSK modulation
6) Amplification of the modulated signal
7) Transmission from the LRPT antenna

6.1 *Convolutional Encoding*

The input data stream shall be convolutionally encoded.

The characteristics of the encoder are the following

Code rate:	½
Constraint length:	7 bits
Connection vectors:	G1= 1111001 / G2=1011011
Symbol inversion:	No
Puncturing:	No

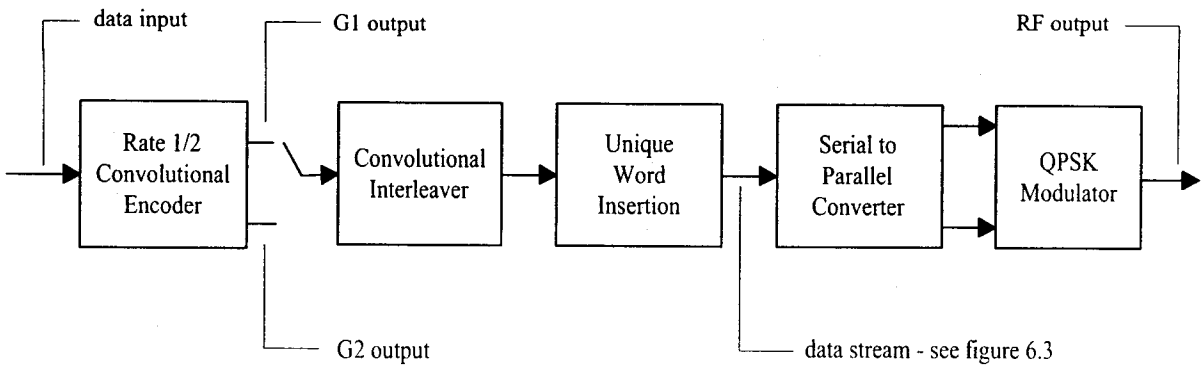


Figure 6.1 - Modulator block diagram

6.2 *Interleaving*

In this section encoded data units will be called bits.

The bits delivered by the convolutional encoder are shifted sequentially into a bank of registers. With each new encoded bit, the commutator switches to a new register and the new bit is shifted in, while the old encoded bit in that register is shifted out to the following stage (see figure 6.2).

The output G1 of the encoder shall feed the odd branches, whereas the output G2 shall feed the even branches.

The number of the interleaver branches (B) shall be 36.
The number of the elementary delay (M) in each branch shall be 2048 bits.

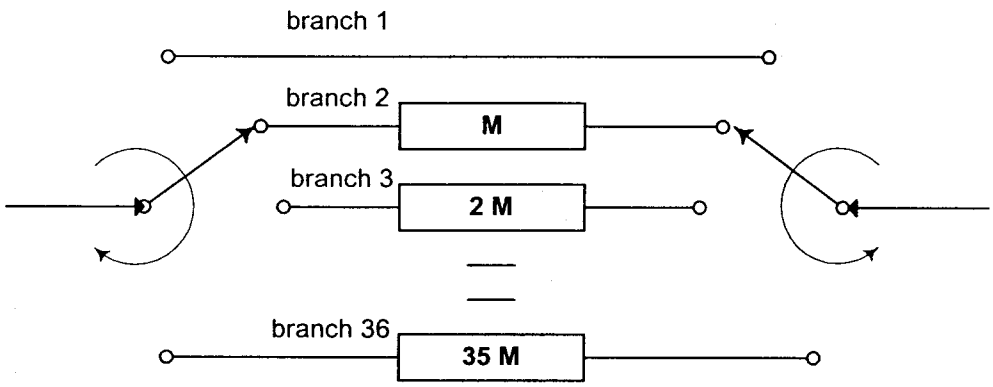


Figure 6.2 - Interleaver block diagram

6.3 *Synchronisation Marker Insertion*

A synchronisation marker shall be inserted every 72 bits of the data stream delivered by each interleaving process. The synchronisation marker is 8 bits long and is defined as 27_{HEX}.

A synchronisation marker is inserted at the output of the convolutional interleaver after the bit supplied by the last (36th) branch every two frames. The frame is structured as shown in figure 6.3.

The bit rate after the synchronisation marker insertion is 160 kbit/s.

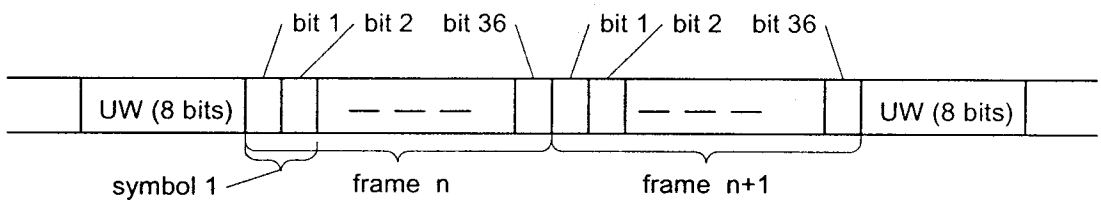


Figure 6.3 - Frame structure

6.4 *Serial to Parallel Conversion*

The grouping of pairs of bits for the QPSK modulator shall be obtained from the 1st and 2nd, the 3rd and 4th etc. branches of the convolutional interleaver output.

6.5 *QPSK Modulation*

6.5.1 Modulation Mapping

The mapping onto the QPSK constellation shall be according the Gray encoding scheme (see figure 6.4).

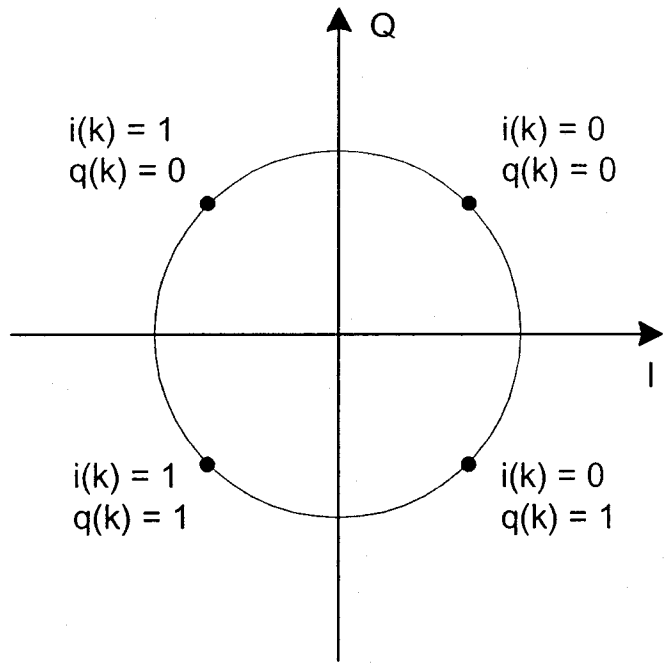


Figure 6.4 - QPSK constellation diagram

6.5.2 Modulation Waveform

The data stream shall be modulated according to the QPSK format.
The QPSK format can be expressed in complex notation as:

$$\tilde{s}_T(t) = \sum_{i=-\infty}^{\infty} \sqrt{2P_T}\,[\cos(\phi_i)\; g_T(t - iT_s) + j\,\sin(\phi_i)\; g_T(t - iT_s)]$$

The baseband square-root raised-cosine filter impulse response is given by:

$$g_T(t) = \frac{1}{\pi}\left\{\left[\frac{16\sqrt{T_s}\,\alpha^2 t}{(4\alpha t + T_s)(4\alpha t - T_s)} - \frac{\sqrt{T_s}}{t}\right]\sin\left(\frac{(\alpha-1)\pi t}{T_s}\right) - \frac{4\alpha\sqrt{T_s^3}\cos\left(\frac{(\alpha+1)\pi t}{T_s}\right)}{(4\alpha t + T_s)(4\alpha t - T_s)}\right\}$$

where T_s is the symbol duration, ϕ_i is the information bearing phase (ϕ_i belongs to the 4-ary alphabet $\{\pm\pi/4; \pm 3\pi/4\}$), α is the roll-off factor, P_T is the transmitter power.

6.5.3 RF Parameters

The transmitted signal will be with QPSK modulation. The modulation is achieved by two synchronous NRZ filtered data streams, modulating the carrier on orthogonal axes.

The two pulse streams shall be filtered in baseband by a network approximating the square-root raised cosine Nyquist filter, defined as follows:

$$|H(j\omega)| = \begin{cases} \dfrac{\omega T_s/2}{\sin(\omega T_s/2)} & 0 \le \omega \le \dfrac{\pi}{T_s}(1-\alpha) \\[2ex] \dfrac{\omega T_s/2}{\sin(\omega T_s/2)}\cos\left[\dfrac{T_s}{4\alpha}\left(\omega - \dfrac{\pi(1-\alpha)}{T_s}\right)\right] & \dfrac{\pi}{T_s}(1-\alpha) \le \omega \le \dfrac{\pi}{T_s}(1+\alpha) \\[2ex] 0 & \omega \ge \dfrac{\pi}{T_s}(1+\alpha) \end{cases}$$

The roll-off factor, α, shall be 0.6.

The approximation for the amplitude shape and the group delay caused by the filtering network shall be within the masks shown in Tables 6.1 and 6.2, respectfully.

Frequency [kHz]	Rel. Maximum Power [dB]	Rel. Minimum Power [dB]
0	0.4	-0.4
16	0.4	-0.4
40	0.2	-5
48	-2	-9
56	-8	-17
80	-30	-
92	-30	-
120	-35	-

Table 6.1 Pulse-shaping filter power mask

Frequency Range [kHz]		Group Delay Variation [μs]
0	40	±2
40	60	±5

Table 6.2 Maximum group delay variation

The receiver shall filter with a square-root raised cosine Nyquist filter and no further amplitude or group delay compensation at the receiving end is required.

The LRPT physical layer shall generate a signal which requires an Eb/No of 4.5 dB to be coherently demodulated with a BER of 10^{-3} at the output of the Viterbi decoder.
The loss introduced by the demodulator (used for the test) shall be considered part of the requirement.

The loss associated to the synchronisation insertion - which is 10·log(80/72) dB; 0.5 dB - shall not be taken into account in this figure.

This requirement shall be met at the maximum allowed compression point of the amplifier and for a random data pattern.

The nominal carrier frequency shall be either: 137.1 MHz
or 137.9125 MHz

The bandwidth of the signal (99% of total power) shall not exceed 150 kHz.

The carrier frequency deviation from the nominal or back-up frequency, including initial accuracy and drift due to ageing and temperature, shall not exceed $\pm 15 \cdot 10^{-6}$.

6.6 *Amplification*

The QPSK modulated signal shall be amplified in order to achieve the EIRP defined in para 6.7.

The working point of the amplifier shall be selected in order to meet the requirements defined in section 6.5.3.

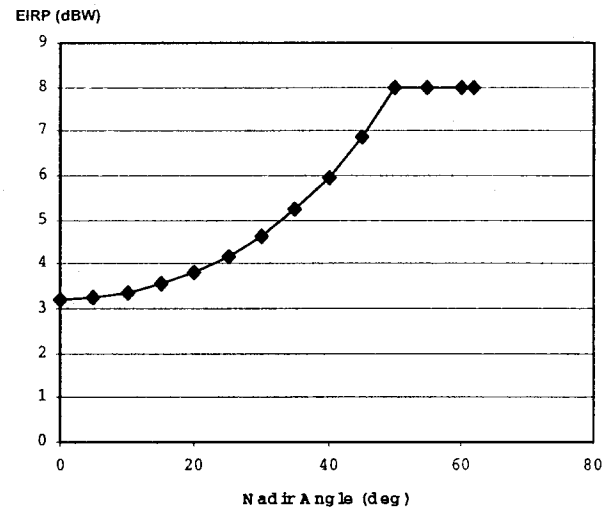
6.7 *Transmission*

The LRPT subsystem shall radiate at the S/C interface as a minimum the EIRP defined in table 6.3.

Angle w.r.t. Nadir	EIRP (dBW)
0	3.21
5	3.24
10	3.36
15	3.55
20	3.82
25	4.19
30	4.65
35	5.23
40	5.95
45	6.85
50	8.00
55	8.00
60	8.00
62	8.00

Table 6.3

Fig 6.5 EIRP vs Nadir Angle



The polarisation shall be RHCP.

The axial ratio shall be less than 4.5 dB at nadir.

6.8 *LRPT Ground Stations*

The LRPT link shall serve two different types of ground station equipment:

- with steerable antennas having a minimum elevation angle of 5°.
- with omni-directional antennas with coverage above the minimum elevation angle of 13°.

The assumed ground station G/T and corresponding minimum elevation angles (used for link margin calculation provided in Annex 1) are as follows:

Antenna type	System G/T	min. S/C Elevation
Steerable YAGI antenna	-22.4 dB/K	5°
Omni-directional antenna	-30.4 dB/K	13°

Axial ratio: less than 3.5 dB.
Pointing losses: less than 0.2 dB (YAGI antenna).

The assumptions taken for the ground stations modulation loss and receiver degradation, for the link budget calculation, are given in Annex 1.

7 HRPT PHYSICAL LAYER

The HRPT physical layer shall perform the following operations:

1) Convolutional encoding
2) Modulation according to the QPSK format
3) Amplification of the modulated signal
4) Transmission from the HRPT antenna

7.1 *Convolutional Encoding*

The input data stream shall be convolutionally encoded.

The characteristics of the encoder shall be the following

Code rate:	3/4
Constraint length:	7 bits
Connection vectors:	G1= 1111001 / G2=1011011
Phase relationship:	G1 is associated with the first symbol
Symbol inversion:	No
Puncturing:	Yes

Puncturing scheme:

- The 3/4 rate code is realised by puncturing the output of a ½ rate encoder (see figure 7.1).
- The output streams from the 3/4 rate Viterbi encoder - labelled i(k) and q(k) - consist of the output streams of the ½ rate encoder - labelled l(k) and m(k) and associated with the G1 and G2 vectors - with the exception of two out of six bits, which are deleted in a repeating pattern.

- The bits to be deleted are shown struck out:

i(k) = ..., l(k), ~~l(k+1)~~, l(k+2), l(k+3), ~~l(k+4)~~,

l(k+5) ..., l(k+6),

q(k) = ..., m(k), m(k+1), ~~m(k+2)~~, m(k+3), m(k+4), ~~m(k+5)~~, m(k+6),

- Therefore the two streams i(k) and q(k) are composed by the following bits:

i(k) = ..., l(k), l(k+2), l(k+3), l(k+5), l(k+6),

q(k) = ..., m(k), m(k+1), m(k+3), m(k+4), m(k+6),

The output of the Viterbi encoder has a rate of 4666.667 kbit/s and is provided to the modulation section.

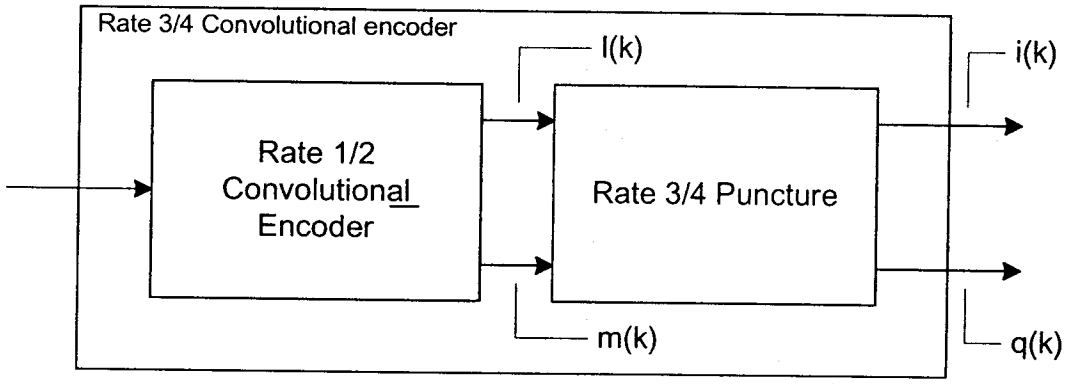


Figure 7.1 - Rate 3/4 convolutional encoder

7.2 *QPSK Modulation*

7.2.1 Modulation Mapping

The mapping onto the QPSK constellation shall be according the Gray encoding (see figure 7.1).

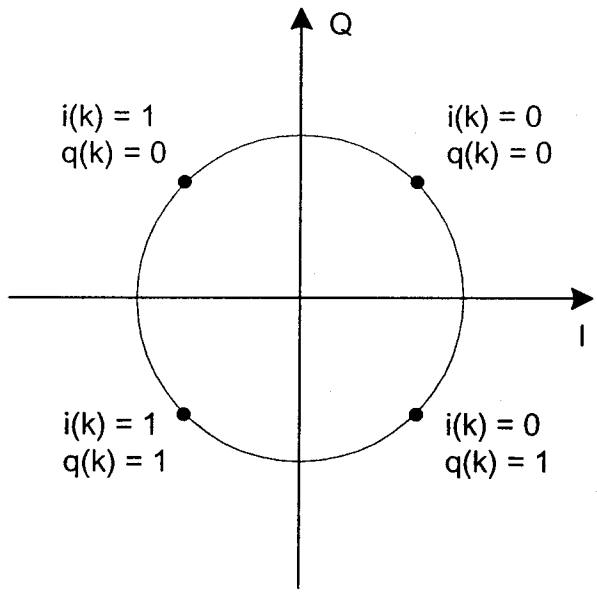


Figure 7.2 - QPSK constellation diagram

7.2.2 Modulation Waveform

The data stream shall be modulated according to the QPSK format.
The QPSK format can be expressed in complex notation as:

$$\tilde{s}_T(t) = \sum_{i=-\infty}^{\infty} \sqrt{2P_T}\,[\cos(\phi_i)\; g_T(t - iT_s) + j\,\sin(\phi_i)\; g_T(t - iT_s)]$$

The baseband square-root raised-cosine filter impulse response is given by:

$$g_T(t) = \frac{1}{\pi}\left\{\left[\frac{16\sqrt{T_s}\,\alpha^2 t}{(4\alpha t + T_s)(4\alpha t - T_s)} - \frac{\sqrt{T_s}}{t}\right]\sin\left(\frac{(\alpha-1)\pi t}{T_s}\right) - \frac{4\alpha\sqrt{T_s^3}\cos\left(\frac{(\alpha+1)\pi t}{T_s}\right)}{(4\alpha t + T_s)(4\alpha t - T_s)}\right\}$$

where T_s is the symbol duration, ϕ_i is the information bearing phase (ϕ_i belongs to the 4-ary alphabet $\{\pm\pi/4; \pm 3\pi/4\}$), α is the roll-off factor, P_T is the transmitter power.

7.2.3 RF Parameters

The transmitted signal will be QPSK modulated. The modulation is achieved by two synchronous NRZ filtered data streams, modulating the carrier on orthogonal axes.

The two pulse streams shall be filtered in baseband by a network approximating the square-root raised cosine Nyquist filter, defined as follows:

$$|H(j\omega)| = \begin{cases} \dfrac{\omega T_s/2}{\sin(\omega T_s/2)} & 0 \le \omega \le \dfrac{\pi}{T_s}(1-\alpha) \\[2ex] \dfrac{\omega T_s/2}{\sin(\omega T_s/2)}\cos\left[\dfrac{T_s}{4\alpha}\left(\omega - \dfrac{\pi(1-\alpha)}{T_s}\right)\right] & \dfrac{\pi}{T_s}(1-\alpha) \le \omega \le \dfrac{\pi}{T_s}(1+\alpha) \\[2ex] 0 & \omega \ge \dfrac{\pi}{T_s}(1+\alpha) \end{cases}$$

The roll-off factor, α, shall be 0.6.

The approximation for the amplitude shape and the group delay caused by the filtering network shall be within the masks shown in Tables 7.1 and 7.2, respectfully.

Frequency [MHz]	Rel. Maximum Power [dB]	Rel. Minimum Power [dB]
0	0.4	-0.4
0.466	0.4	-0.4
1.165	0.2	-5
1.398	-2	-9
1.631	-8	-17
2.33	-30	-
2.679	-30	-
3.495	-35	-

Table 7.1 Pulse-shaping filter power mask

Frequency Range [MHz]		Group Delay Variation [ns]
0	1.17	±50
1.17	1.755	±200

Table 7.2 Maximum group delay variation

The receiver shall filter with a square-root raised cosine Nyquist filter and no further amplitude or group delay compensation at the receiving end is required.

The HRPT physical layer shall generate a signal which requires an Eb/No of 5.0 dB to be coherently demodulated with a BER of 10^{-3} at the output of the Viterbi decoder. The loss introduced by the demodulator (used for the test) shall be considered part of the requirement.

This requirement shall be met at the maximum allowed compression point of the amplifier and for a random data pattern.

The Nominal carrier frequency shall be:

either 1701.300 MHz, being the nominal bandwidth 1698.75 - 1703.25 MHz

or 1707.000 MHz; being the nominal bandwidth 1704.75 - 1709.25 MHz.

The nominal bandwidth shall contain 99% of the total signal power.

The carrier frequency deviation from the nominal or back-up frequency, including initial accuracy and drift due to aging and temperature, shall not exceed $\pm 25 \cdot 10^{-6}$.

7.3 *Amplification*

The QPSK modulated signal shall be amplified in order to achieve the EIRP defined in section 7.4. The working point of the amplifier shall be selected in order to meet the requirements defined in section 7.2.3.

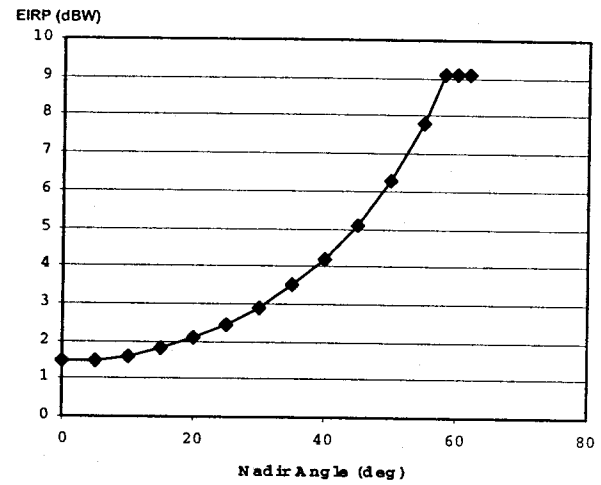
7.4 *Transmission*

The HRPT subsystem shall at least radiate at the S/C interface the EIRP defined in table 7.3.

Angle w.r.t. nadir	EIRP (dBW)
0	1.46
5	1.49
10	1.61
15	1.8
20	2.07
25	2.44
30	2.9
35	3.48
40	4.2
45	5.1
50	6.25
55	7.8
58	9.1
60	9.1
62	9.1

Table 7.3

Fig 7.3 EIRP vs Nadir Angle



The gain of the antenna shall be such that the following PFD limitations are met:

- -154 dBW/(m^2·4 kHz) for elevation angle (δ) lower than 5°
- -154 + 0.5 (δ -5) dBW/(m^2·4 kHz) for elevation angle (δ) between 5° and 25°
- -144 for elevation angle (δ) greater than 25°
- -133 dBW/(m^2·1.5 MHz) at any elevation angle (from 1670 to 1700 MHz).

The following assumptions shall be used in the PFD calculation:

- Peak of TX spectrum density including possible residual carrier.
- Typical values for TX power and antenna gain over elevation.
- Average values for antenna gain along azimuth.

The polarisation shall be RHCP. The axial ratio shall be less than 4.5 dB at nadir.

7.5 *HRPT Ground Stations*

The HRPT link shall serve ground stations, which may be located anywhere in the world, and which will have the following characteristics:

G/T:	6 dB/K
Pointing loss	0.5 dB
Ground station axial ratio	less than 1 dB

The assumptions taken on ground stations modulation and receiver degradation for link budget calculation, are given in Annex 1.

Annex 1. Typical worst Case LRPT/HRPT Link Budgets based on Specification Values

Link ID	METOP LRPT - High gain antenna receiver								
Ground station	LRPT (G/T=-22.4)								
Frequency		(MHz)	137.90	137.90	137.90	137.90	137.90	137.90	137.90
S/C altitude		(km)	850.00	850.00	850.00	850.00	850.00	850.00	850.00
Slant range		(km)	2,889	2,468	1,858	1,473	1,227	963	850
S/C view angle		(degree)	61.51	60.33	56.00	49.82	42.52	26.18	0.00
Data rate		(kb/s)	72.00	72.00	72.00	72.00	72.00	72.00	72.00
G/S view angle		(degree)	5.00	10.00	20.00	30.00	40.00	60.00	90.00
S/C EIRP	note 1	(dBW)	8.00	8.00	8.00	7.96	6.40	4.28	3.21
S/C antenna axial ratio		(dB)	4.50	4.50	4.50	4.50	4.50	4.50	4.50
Free space loss		(dB)	144.45	143.08	140.62	138.60	137.01	134.91	133.82
Atmospheric loss		(dB)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polarisation loss		(dB)	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Reflection & multipath	note 7	(dB)	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Total propagation loss		(dB)	145.90	144.53	142.07	140.05	138.46	136.36	135.27
Ground station G/T (reference)	note 2	(dB/K)	-22.40	-22.40	-22.40	-22.40	-22.40	-22.40	-22.40
G/S axial ratio		(dB)	3.50	3.50	3.50	3.50	3.50	3.50	3.50
G/S pointing loss		(dB)	0.20	0.20	0.20	0.20	0.20	0.20	0.20
C/KT at receiver input		(dB/Hz)	68.10	69.47	71.93	73.91	73.94	73.92	73.94
Boltzmann's constant		dBW/kHz	-228.60	-228.60	-228.60	-228.60	-228.60	-228.60	-228.60
Bit rate		(dBHz)	48.57	48.57	48.57	48.57	48.57	48.57	48.57
Eb/No at receiver input		(dB)	19.53	20.90	23.36	25.34	25.37	25.35	25.37
Required Eb/No	note 13	(dB)	3.50	3.50	3.50	3.50	3.50	3.50	3.50
Coding frame sync loss	note 11	(dB)	0.47	0.47	0.47	0.47	0.47	0.47	0.47
Modulation degradation	note 8	(dB)	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Receiver degradation	note 3	(dB)	2.00	2.00	2.00	2.00	2.00	2.00	2.00
System margin	note 4	(dB)	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Available link margin		(dB)	11.56	12.93	15.39	17.37	17.40	17.38	17.41

note 1: minimum EIRP at S/C interface.

note 2: reference G/T of the ground station; the actual figure depends mainly on the receiver, the level of man-made noise in the receiver location and the pointing of the antenna.

note 3: allowed deviation from theoretical performance of the demodulator.

note 4: minimum system margin required by ESA.

note 7: loss due to reflections from ground or from adjacent buildings.

note 8: deviation from theoretical performance due to the modulation process, requirement by ESA.

note 11: loss due the addition of the synchronisation marker in the interleaving protocol.

note 13: theoretical Eb/No required to obtain a BER of 1E-3 at the output of the Viterbi decoder. This BER requirement (due to the following R-S decoder) guarantees a virtually packet-loss-free link quality.

Link ID	METOP LRPT - Omnidirectional antenna receiver							
Ground station	LRPT (G/T=-30.4)							
Frequency		(MHz)	137.90	137.90	137.90	137.90	137.90	137.90
S/C altitude		(km)	850.00	850.00	850.00	850.00	850.00	850.00
Slant range		(km)	2,256	1,858	1,473	1,227	963	850
S/C view angle		(degree)	59.28	56.00	49.82	42.52	26.18	0.00
Data rate		(kb/s)	72.00	72.00	72.00	72.00	72.00	72.00
G/S view angle		(degree)	13.00	20.00	30.00	40.00	60.00	90.00
S/C EIRP	note 1	(dBW)	8.00	8.00	7.96	6.40	4.28	3.21
S/C antenna axial ratio		(dB)	4.50	4.50	4.50	4.50	4.50	4.50
Free space loss		(dB)	142.30	140.62	138.60	137.01	134.91	133.82
Atmospheric loss		(dB)	0.00	0.00	0.00	0.00	0.00	0.00
Polarisation loss		(dB)	0.47	0.47	0.47	0.47	0.47	0.47
Reflection & multipath	note 7	(dB)	2.00	2.00	2.00	2.00	2.00	2.00
Total propagation loss		(dB)	144.77	143.09	141.07	139.48	137.38	136.29
Ground station G/T (reference)	note 2	(dB/K)	-30.40	-30.40	-30.40	-30.40	-30.40	-30.40
G/S axial ratio		(dB)	3.50	3.50	3.50	3.50	3.50	3.50
G/S pointing loss		(dB)	0.00	0.00	0.00	0.00	0.00	0.00
C/KT at receiver input		(dB/Hz)	61.43	63.11	65.09	65.12	65.10	65.12
Boltzmann's constant		(dBW/kHz)	-228.60	-228.60	-228.60	-228.60	-228.60	-228.60
Bit rate		(dBHz)	48.57	48.57	48.57	48.57	48.57	48.57
Eb/No at receiver input		(dB)	12.86	14.54	16.52	16.55	16.53	16.55
Required Eb/No	note 13	(dB)	3.50	3.50	3.50	3.50	3.50	3.50
Coding frame sync loss	note 11	(dB)	0.47	0.47	0.47	0.47	0.47	0.47
Modulation degradation	note 8	(dB)	1.00	1.00	1.00	1.00	1.00	1.00
Receiver degradation	note 3	(dB)	2.00	2.00	2.00	2.00	2.00	2.00
System margin	note 4	(dB)	1.00	1.00	1.00	1.00	1.00	1.00
Available link margin		(dB)	4.89	6.57	8.55	8.58	8.56	8.58

note 1: minimum EIRP at S/C interface.

note 2: reference G/T of the ground station; the actual figure depends mainly on the receiver and the level of man-made noise in the receiver location.

note 3: allowed deviation from theoretical performance of the demodulator.

note 4: minimum system margin required by ESA.

note 7: loss due to reflections from ground or from adjacent buildings.

note 8: deviation from theoretical performance due to the modulation process, requirement by ESA.

note 11: loss due the addition of the synchronisation marker in the interleaving protocol.

note 13: theoretical Eb/No required to obtain a BER of 1E-3 at the output of the Viterbi decoder. This BER requirement (due to the following R-S decoder) guarantees a virtually packet-loss-free link quality.

Link ID	METOP HRPT								
Ground Station	HRPT (G/T=6.0)								
Frequency		(MHz)	1707.00	1707.00	1707.00	1707.00	1707.00	1707.00	1707.00
S/C altitude		(km)	850.00	850.00	850.00	850.00	850.00	850.00	850.00
Slant range		(km)	2889	2468	1858	1473	1227	963	850
S/C view angle		(degree)	61.51	60.33	56.00	49.82	42.52	26.18	0.00
Data rate		(kb/s)	3500.00	3500.00	3500.00	3500.00	3500.00	3500.00	3500.00
G/S view angle		(degree.)	5.00	10.00	20.00	30.00	40.00	60.00	90.00
S/C EIRP	note 1	(dBW)	9.10	9.10	8.23	6.21	4.65	2.55	1.46
S/C antenna axial ratio		(dB)	4.50	4.50	4.50	4.50	4.50	4.50	4.50
Free space loss		(dB)	166.30	164.93	162.47	160.45	158.86	156.76	155.67
Rain loss		(dB)	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Polarisation Loss		(dB)	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Reflection and multipath	note 7	(dB)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total propagation loss		(dB)	166.73	165.36	162.90	160.88	159.29	157.19	156.10
Ground station G/T	note 2	(dB/K)	6.00	6.00	6.00	6.00	6.00	6.00	6.00
G/S axial ratio		(dB)	1.00	1.00	1.00	1.00	1.00	1.00	1.00
G/S pointing loss		(dB)	0.50	0.50	0.50	0.50	0.50	0.50	0.50
C/KT at receiver input		(dB/Hz)	76.47	77.84	79.43	79.43	79.46	79.46	79.46
Boltzmann's constant		(dBW/kHz)	-228.60	-228.60	-228.60	-228.60	-228.60	-228.60	-228.60
Bit rate		(dBHz)	65.44	65.44	65.44	65.44	65.44	65.44	65.44
Available Eb/No		(dB)	11.03	12.40	13.99	13.99	14.02	14.02	14.02
Required Eb/No	note 9	(dB)	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Modulation degradation	note 3	(dB)	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Receiver degradation	note 8	(dB)	2.00	2.00	2.00	2.00	2.00	2.00	2.00
System margin	note 4	(dB)	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Available link margin		(dB)	3.03	4.40	5.99	5.99	6.02	6.02	6.02

note 1: minimum EIRP at S/C interface.

note 2: reference G/T of the ground station.

note 3: deviation from theoretical performance due to the modulation process; requirement by ESA.

note 4: minimum system margin required by ESA.

note 7: loss due to reflections from ground or from adjacent buildings.

note 8: allowed deviation from theoretical performance of the demodulator.

note 9: theoretical Eb/No required to obtain a BER of 10^{-3} at the output of the Viterbi decoder.
This BER requirement (due to the following R-S decoder) guarantees a virtually packet-loss-free link quality.

Annex 2. AVHRR/LRPT Data Compression System

A2.1 General

The AVHRR is a multi-spectral imager able to scan the earth in six spectral bands covered by five channels. The AVHRR scanning rate is 360 rpm producing one line per channel of earth view samples and calibration data every 1/6th of second.

The AVHRR samples are 10 bits wide and each earth view line contains 2048 pixels corresponding to a data rate of 2048(samples) x 5 (channels) x 6 (lines per second) x 10 (bits per sample), thus yielding an overall data rate of about 600 kbit/s.

The compression will operate on 10-bit input data. The output data will have the same resolution as the input data, i.e. the JPEG extended DCT-based process using 12 bit samples will be used. The AVHRR/LRPT compression system will deliver to the ground user 3 compressed channel out of the 5 channel provided by the AVHRR. The compression will operate on the 10 bit samples. The three compressed channels may be any combination of the channels available on board.

The data compression algorithm used for the AVHRR/LRPT is a modified version of the standard JPEG to adapt to a fixed compression ratio option and a continuous instrument operation mode (neither header nor trailer in the compressed stream)

The fixed compression ratio option is used to reduce the on board smoothing buffer size and to cope with a fixed average output data rate and to avoid risks of overflow.
The baseline of the JPEG algorithm is maintained, including the 8*8 sub-block extraction, quantization, zigzag reordering and Huffman coding [see for reference: Digital Compression and Coding of Continuous-tone Still Images, ISO/IEC CD10918-1, part 1, Draft, June 1991].

A simple schematic of the algorithm is shown below:

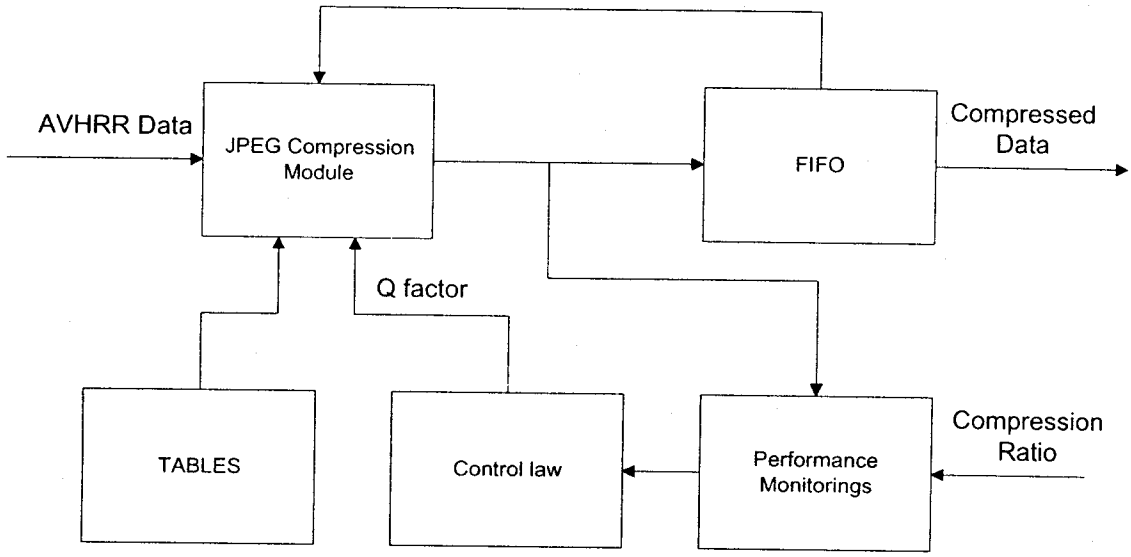


Figure A2.1.1 - Block diagram of the compression algorithm

The performance-monitoring block computes of the actual compression ratio and compares it with the desired one. The result of the comparison is used to feed a non-linear, empirical control law that controls the Q factor.

The details of the compression algorithm are given in MO-TN-ESA-SY-0124 "LRPT Reference Compressor and Decompressor Technical Note".

In order to achieve a fixed compression ratio, the compressed stream is divided into segments containing a number of MCUs. For every segment the difference between the actual compression ratio and the desired one is computed (Delta CR) and the new quality factor is computed according to the control law, thus having a constant Q factor within the segment.

The Q factor is communicated to the decoder by means of one of the spare JPEG markers, along with the compressed data stream just between two MCUs. To allow the restart after an error (re-synchronisation), the DC component of the first MCU of the first segment of every packet is not DPCM coded.

A2.2 Data Format

A2.2.1 CCSDS Packets

In the on board Compression Unit (CU), the earth view samples and calibration data are treated in two different ways: The earth view samples of each selected channel *i* are grouped into stripes of 8 lines * 2048 pixels; each stripe is then compressed and formatted in a CCSDS packet having an APID associated to the channel *i*; calibration data instead are sub-sampled once every stripe and formatted in a non-compressed format in a specific CCSDS packet.

There are seven different APIDs:

APID 64) coded data channel 1;

APID 65) coded data channel 2;

APID 66) coded data channel 3a;

APID 67) coded data channel 3b;

APID 68) coded data channel 4;

APID 69) coded data channel 5;

APID 70) calibration data.

The first three packets of the sequence will be any combination of the packets with APID 64, APID 65, either APID 66 or APID 67 (day or night), APID 68, APID 69. The sequence is closed by the packet with APID 70 and then is repeated continuously.

A2.2.1.1 Compressed image packets (APID 64-69)

The following drawing illustrates the packet structure.

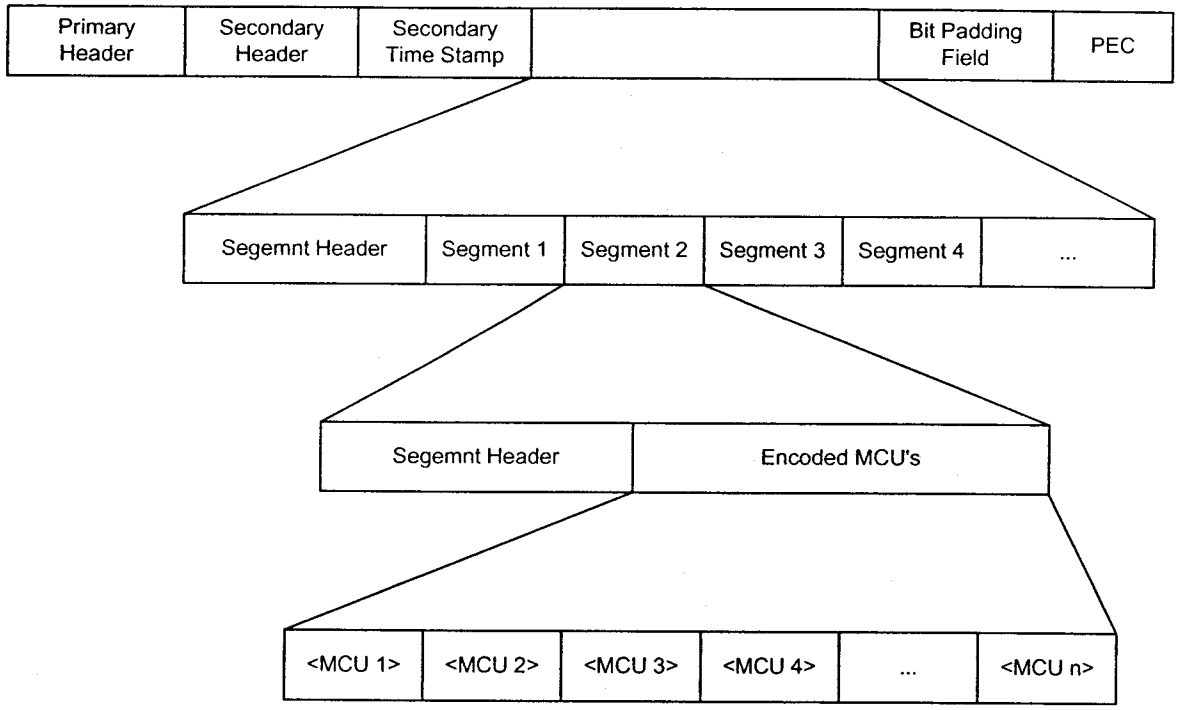


Figure A2.2.1.1.1 - Compressed packet structure

The Scan can contain any number (n) of Segments and each Segment can contain any number (m) of MCUs (Minimum Coded Units) provided that the global number of MCUs per packet is 2048 / 8 = 256 MCUs.

The decoder can recognize the beginning of a new Segment by means of its header and to decode the MCUs belonging to a Segment the quality factor specified in the Segment header must be used.

The tables can change from one CCSDS compressed packet to the other but not inside a single Scan. Quantization and Huffman tables to be used within the Scan are specified in the Scan header.

To allow the restart (re-synchronization) after an error, the DC component of the first MCU of the first Segment of every packet is not coded. This corresponds to setting the resynch interval to 256 (the number of MCUs per packet) in the JPEG standard.

The Bit Padding field is a variable length field and will allow the entire packet length to be an even number of bytes. Padding bits are all set to ones.

The secondary header will contain 8 bytes for the Time Tag. The secondary time stamp will contain 6 bytes for the additional time stamp.

Scan Header

At the beginning of each packet the Scan Header indicates to the decoder which tables are to be used in the decompression of the stripe. This field - see next figure - contains 3 fields of 4 bits each, thus allowing to use up to 16 different tables.

Qt (4 bits)	DC Ht (4 bits)	AC Ht (4 bits)

Scan Header

Qt : index of the quantization table to be used in the scan;

DC Ht : index of the DC Huffman table to be used in the scan;

AC Ht : index of the AC Huffman table to be used in the scan.

The Qt field corresponds to the Tq field in the frame header as described in JPEG standard. Analogously, DC Ht and AC Ht correspond to the Td and Ta fields in the scan header.

Segment Header

The Segment Header can be found anywhere in the Scan stream, between two successive MCUs, and it is used to communicate to the decoder that a new quality factor is used in the following MCUs, until a new Segment Header is found.
As shown in the following drawing, the Segment Header is a JPEG marker used to allow the detection of this field by the decoder.

QFM (16 bits)	Q factor (8 bits)

Segment header

QFM : quality factor mark. Is one of the reserved JPEG markers, in this application it is set to 0xFFF0;

Q factor: it is the quality factor (or quantization factor) to be used within the Segment.

A2.2.1.2 Calibration Packet (APID 70)

The following drawing illustrates the calibration packet structure.

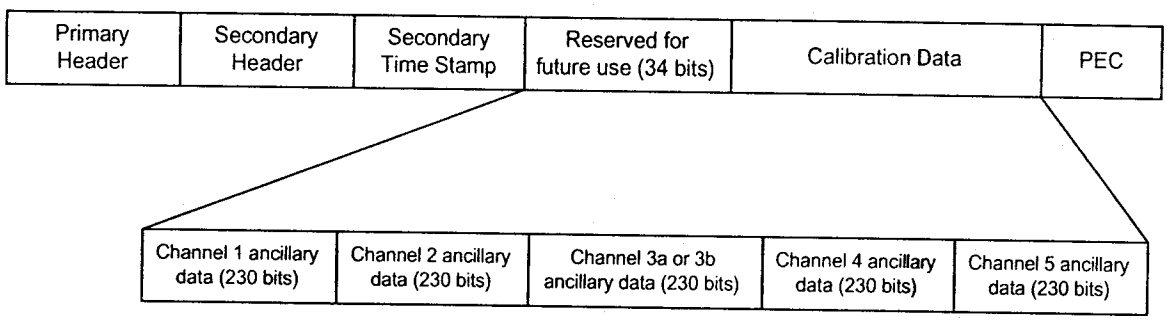


Figure A2.2.1.2.1 - Calibration packet structure

The secondary header contains a Time Stamp field of 8 octets.
The calibration data field follows a field reserved for future use and is composed by five fields of 230 bits for the ancillary data of each channel.

A2.3 System Architecture

The ground system is mainly composed of two subsystems: the Signal Conditioning subsystem and the Digital Processing subsystem.

The Signal Conditioning subsystem, given the frame synchronisation pattern and the frame length, can detect the CADUs and can then de-randomise the CVCDUs. The CVCDUs are then de-interleaved and R-S decoded to remove channel errors. The valid VCDUs are sent to the packet demultiplexer that sorts out the AVHRR packets that are stored in the host computer's hard disk either in DMA or under program control.

Administrative packets are first decoded to enable a correct setting of the decompression algorithm.
During the mission lifetime, it is possible that predefined quantisation and Huffman tables (available to both space and ground systems) are updated or expanded. These new tables are broadcast to the users by means of the Administrative messages.

Once the packets have been stored on the disk, the decompression process can take place off line for visualisation purposes.

A2.4 Software Decoding

CCSDS Packets will be first grouped and archived. After the packets have been properly conditioned visualisation can be performed by commercial or public domain tools.

The CCSDS packets conditioning process consists mainly in the decompression of several Encoded Channel Stripes belonging to packets having the same AP ID so that the raw data of a specific channel can be reconstructed. Then a conversion to a known image format can take place.

The conditioning consists primarily of:

- stripping-off the header and trailer information of CCSDS packets related to a specific channel and observation time. For instance, to create a 2048*2048 pixel image of the AVHRR channel 1, a set of 256 consecutive packets with APID 64 must be considered.

- reading the Administrative Messages to seek for new Quantization or Huffman tables.

- for every new packet the Scan Header is read out to select the proper tables to be used within the Scan. If the specified tables are different from the ones predefined they have already been defined in the Administrative Messages.

- detecting the Segment Headers so that a new Segment can be identified. The Segment Header contains the Q factor value which must be used to re-scale the quantisation table addressed by the Qt field in the Scan Header.

- decompressing the MCUs according to JPEG compression standard

Once the image has been reconstructed on ground it is not advisable to use of a lossy compressed format (such as JPEG) for further images transmission, because even with the highest quality setting, it would lead to further image-quality degradation, on top of that due to the on-board compression algorithm.

Annex 3. List of Acronyms

AM	Amplitude Modulation
AMSU	Advanced Microwave Sounding Unit
APid	Application Process identifier
ASCAT	Advanced Scatterometer
AVHRR	Advanced Very High Resolution Radiometer
BER	Bit Error Rate
CADU	Channel Access Data Unit
CCSDS	Consultative Committee for Space Data Systems
CRC	Cyclic Redundancy Checksum
CVCDU	Coded Virtual Channel Data Unit
DCS	Data Collection System
E_b/N_0	Bit energy / noise density
EIRP	Equivalent Isotropic Radiated Power
EPS	EUMETSAT Polar System
ESA	European Space Agency
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FEC	Forward Error Correction
GRAS	GNSS Receiver for Atmospheric Sounding
G/S	Ground Station
G/T	Figure of merit (antenna gain / system noise temperature)
HIRS	High resolution Infra-Red Sounder
HRPT	High Resolution Picture Transmission
IASI	Infrared Atmospheric Sounding Interferometer
IN_PDU	Insert service_ Protocol Data Unit
IN_SDU	Insert _Service Data Unit
JPEG	Joint Photographic Experts Group
LRPT	Low Resolution Picture Transmission
MHS	Microwave Humidity Sounder
M_PDU	Multiplex_ Protocol Data Unit
M_SDU	Multiplex _Service Data Unit
NOAA	National Oceanic and Atmospheric Administration
NRZ-L	Nonreturn-to-zero Type L

GOME	Global Ozone Monitoring Instrument
PCA_PDU	Physical Channel Access _Protocol Data Unit
PEC	Packet Error Control
PN	Pseudo Noise
QPSK	Quadrature Phase Shift Keying
RF	Radio Frequency
RHC	Right Hand Circular
SEM	Space Environment Monitor
S/C	Spacecraft
TBC	To Be Confirmed
TBUS	TIROS Bulletin United States
TBD	To Be Defined
UTC	Co-ordinated Universal Time
VC	Virtual Channel
VCA	Virtual Channel Access
VCA_SDU	Virtual Channel Access _Service Data Unit
VCLC	Virtual Channel Link Control
VCDU	Virtual Channel Data Unit
VCDU-ID	Virtual Channel Data Unit Identifier