The Consultative Committee for Space Data Systems

Report Concerning Space Data Systems Standards

CCSDS PROTOCOLS OVER DVB-S2 – SUMMARY OF DEFINITION, IMPLEMENTATION AND PERFORMANCE

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FOREWORD

This document is a CCSDS Report which contains background and explanatory material to support the CCSDS Recommendation *CCSDS Space Link Protocols over ETSI DVB-S2 standard* (reference [1]).

Through the process of normal evolution, it is expected that expansion, deletion, or modification of this document may occur. This Report is therefore subject to CCSDS document management and change control procedures, which are defined in *Organization and Processes for the Consultative Committee for Space Data Systems* (CCSDS A02.1-Y-3). Current versions of CCSDS documents are maintained at the CCSDS Web site:

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DOCUMENT CONTROL

Document	Title	Date	Status
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1 INTRODUCTION

1.1 BACKGROUND

The Recommended Standard “CCSDS Space Link Protocols over ETSI DVB-S2 standard” [1] is an adaptation profile describing how to use the ETSI DVB-S2 telecom standard [2] to transmit CCSDS Transfer Frames [5][6] for telemetry purpose.

1.2 PURPOSE

This report has been developed to help missions interested in using the Recommended Standard [1]. It provides some useful material for engineers to define systems, or equipment manufacturers to develop products, according to this Recommended Standard [1].

1.3 SCOPE

This document provides supporting and descriptive material only: it is not part of the Recommended Standard [1]. In the event of any conflict between the Recommended Standard [1] and the material presented herein, the Recommended Standard [1] shall prevail.

1.4 ORGANIZATION

Section 2 presents the relative roles of the Recommended Standard [1] and the ETSI DVB-S2 standards.

Section 3 provides an introduction to DVB-S2 terminology and some protocol management considerations when using [1].

Section 4 deals with implementation of the interface between CCSDS protocols and DVB-S2 when using [1].

Section 5 provides some DVB-S2 performance material.

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2 RELATIVE ROLES OF CCSDS RECOMMENDED STANDARDS AND ETSI DVB-S2 STANDARDS

2.1 RATIONALE OF CCSDS PROTOCOLS OVER DVB-S2

The ETSI DVB-S2 [2] telecom standard was developed with the views of achieving high power efficiency and bandwidth efficiency, both criteria being also of very high value for telemetry applications.

The use of the ETSI DVB-S2 telecom standard for telemetry makes it possible the use of generic VHDL (Very High Scale Integrated Circuits – VHSIC – Hardware Description Language) Intellectual Property (IP) cores – initially dedicated to the telecom market – for the development of telemetry equipment. The use of an already widely implemented standard simplifies the task of finding a transmitter or receiver for early compatibility tests. Regarding the ground part, some DVB-S2 receivers or ASICs (Application Specific Integrated Circuits) developed for the telecom mass market (and consequently with very competitive costs) could be reused for telemetry.

The DVB-S2 standard is consequently a technically-efficient and cost-effective solution in particular for High Data Rate Telemetry (HDRT) applications, such as Earth Exploration Satellite Services (EESS) payload telemetry.

Actually, the DVB-S2 standard is already used for many telemetry applications [13], and the added value of the Recommended Standard [1] is mainly to provide a formalization of the interface between CCSDS and DVB-S2 for interoperability issues.

2.2 CCSDS AND ETSI DVB-S2 VERSIONS

The CCSDS Recommended Standard [1] being an adaptation profile of the ETSI DVB-S2 standard, it is worth reminding the roles of the CCSDS Recommended Standard [1] and of the different versions of the ETSI DVB-S2 standard.

The different versions of the ETSI EN 302307 DVB-S2 standard are the following:

- V1.1.1, March 2005;
- V1.2.1, August 2009;
- V1.3.1, March 2013.

In 2014, the ETSI EN 302307 was split in two parts:

- Part 1: DVB-S2, reference ETSI EN 302307-1 V1.4.1 (July 2014);
- Part 2: DVB-S2 Extensions (DVB-S2X), reference ETSI EN 302307-2V1.1.1 (October 2014).

The CCSDS Recommended Standard 131.3-1 (March 2013) [1] is an adaptation profile referring to ETSI EN 302307 V1.2.1 (August 2009) [2].

Because of the backward compatibility of the ETSI EN 302307 standard versions, the CCSDS Recommended Standard 131.3-1 (Mars 2013) [1] is also compatible with ETSI EN 302307 V1.3.1 (March 2013) and ETSI EN 302307-1 V1.4.1 (July 2014). Actually, all new versions of ETSI EN 302307 include the previous version with new options. Possible new versions of ETSI EN 302307 after 2014 are beyond the scope of this document.

2.3 ETSI DVB-S2 USER GUIDELINES

The CCSDS Recommended Standard [1] being an adaptation profile of the ETSI DVB-S2 standard [2], it is worth noting that some ETSI user guidelines [3] are available. The first release of these user guidelines is ETSI TR 102376 V1.1.1 (February 2005).

A refreshment of these guidelines with ETSI EN 302307-1 was proposed in 2015 (*DVB BlueBook A171-1, DVB-S2 Implementation Guidelines, March 2015*), simultaneously with user guidelines for ETSI EN 302307-2 (*DVB BlueBook A171-2, DVB-S2X Implementation Guidelines, March 2015*).

For the sake of clarity, we refer all along this document to the first release of ETSI user guidelines [3] (the refreshment being very close to the first release).

It is worth noting that the technical content of these user guidelines is very significant.

These user guidelines include in particular DVB-S2 reference performance over AWGN channel (see 5.2.1 of this document), or some results with power amplifier non-linearity. Moreover, these user guidelines include substantial material concerning DVB-S2 VCM/ACM receivers and constitute an essential basis for people interested in detailed implementation of DVB-S2 receivers.

References to sections in [3] possibly useful for the CCSDS Recommended Standard [1] are listed in ANNEX C of this document.

2.4 CCSDS AND ETSI VCM / ACM MODE

The ETSI DVB-S2 standard includes a CCM mode (Constant Coding and Modulation) but also a VCM (Variable Coding and Modulation) and an ACM (Adaptive Coding and Modulation) mode.

The CCSDS Recommended Standard [1] being an adaptation profile of the ETSI DVB-S2 standard, the CCSDS Recommended Standard [1] can accommodate DVB-S2 CCM as well as VCM and ACM modes.

All along this document, VCM and ACM should be understood as DVB-S2 VCM or ACM.

3 DVB-S2 TERMINOLOGY AND PROTOCOL MANAGEMENT CONSIDERATIONS

3.1 INTRODUCTION

3.1.1 DVB-S2 VCM PRINCIPLE

It is well known that the propagation conditions are changing during a Low Earth Orbit (LEO) satellite pass above an Earth station. Figure 3-1 shows the two main parameters that greatly influence the link budget and consequently the signal-to-noise ratio at the receiver input:

- the distance between the satellite and the Earth station (d1, d2 and d3), depending on the elevation;
- the tropospheric propagation conditions (clouds, rain …).

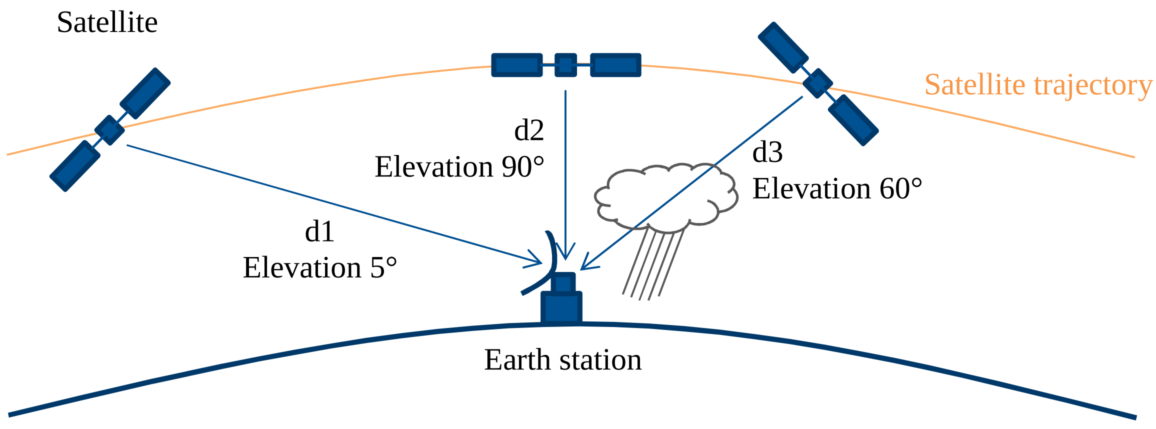


Figure 3-1: Illustration of variable conditions of propagation

When the distance decreases with higher elevation (d2 < d1), the free-space loss also decreases and the link budget is improved. The achievable gain is significant: typically 12 dB for a satellite with 700 km orbit altitude. The better signal-to-noise ratio at the receiver allows using more spectrally efficient modulation and/or coding rate.

This is where the Variable Coding and Modulation – VCM – mode, available when using the DVB-S2 standard, fully benefits. The distance change can be predicted for each pass and the transmission can be planned to change the modulation and the coding rate when the link budget is more favorable to increase the useful bit rate.

Thus, the VCM mode allows maximizing the HDRT downloading throughput, keeping the same on-board power consumption.

As an example and following values of table 13 in [2], a gain of 12 dB on the link budget allows to go from QPSK with coding rate 3/4 (E_s/N_0 = 4 dB) at 5° elevation to 32APSK with coding rate 9/10 (E_s/N_0 = 16 dB) at 90° elevation. The spectral efficiency of 32APSK 9/10 (4.45 bits/symbol) is 3 times the spectral efficiency of from QPSK 3/4 (1.48 bits/symbol).

In practice, VCM will be used taking into account the change of the free-space-loss (depending on the elevation) and also the change of the margin to cope with tropospheric propagation (also depending on the elevation).

3.1.2 DVB-S2 ACM PRINCIPLE

If the distance can be easily anticipated, some tropospheric propagation events may be more difficult to predict. The impact of these events on the link budget may be very significant, in particular when using the highest frequencies (such as Ka-band EESS). To cope with these events at the highest frequencies, the Adaptive Coding and Modulation – ACM – mode, available when using the DVB-S2 standard, can be considered.

This ACM mode consists in updating in quasi real-time the modulation and the coding rate to the best operating tuning, based on the received signal-to-noise ratio measurement by the receiver. Consequently, a quasi real-time telecommand link to the satellite is required. The principle is illustrated in Figure 3-2.

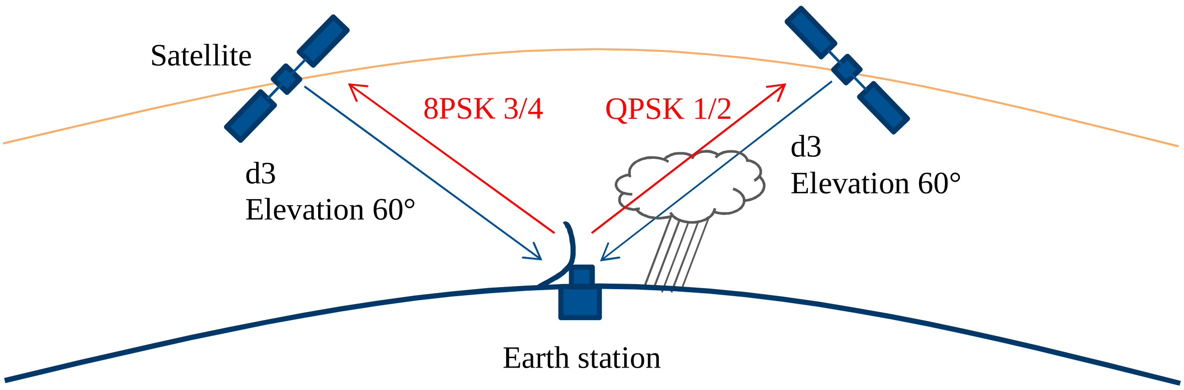


Figure 3-2: Illustration of variable conditions of propagation

3.1.3 ABOUT THE USE OF DVB-S2 VCM AND ACM

Both VCM and ACM modes allow optimizing the on-board resources to offer the highest available useful bit rate according to the propagation conditions, thus maximizing the HDRT throughput.

The VCM mode can be typically considered with X-band EESS (8.025-8.4 GHz) transmissions, where the tropospheric losses remain low in the link budget.

The ACM mode can be typically considered for Ka-band EESS (25.5-27 GHz) transmissions, because of the atmospheric losses highly changing with time.

Some examples of achievable system performance using DVB-S2 VCM or ACM are proposed in ANNEX B.

In the ETSI DVB-S2 standard [2], and consequently in the CCSDS Recommended Standard [1], the protocol is identical for VCM or ACM.

The difference between VCM and ACM is related to operation of the HDRT (which is beyond the scope of this document or of the scope of [1]).

3.1.4 OBJECTIVES OF SECTION 3

The objectives of section 3 are:

- to introduce the terminology used in the ETSI DVB-S2 standard [2], in particular for VCM and ACM management (section 3.2),
- to present some technical material in support to the selection of CCSDS managed parameters in [1] (section 3.3),
- to present possible solutions to properly use the CCSDS Recommended Standard [1] (sections 3.4 and 3.5).

3.2 MODCOD AND TYPE

The combination of a modulation and a coding rate is called a MODCOD as per DVB-S2 terminology. A MODCOD field can thus be coded using a decimal value between 0 and 28 (see [2] section 5.5.2.2), or 5 bits.

A TYPE field is added to the MODCOD field. This TYPE field is constituted of 2 bits. One bit indicates the FECFRAME size (normal or short). The other bit indicates the pilot insertion status (ON or OFF).

When using DVB-S2 VCM or ACM modes, the MODCOD and TYPE can be changed by the transmitter on a frame-by-frame basis. Consequently, the MODCOD, the FECFRAME size and the pilot insertion status are variable managed parameters as per CCSDS terminology. 7 bits are required to encode these variable managed parameters.

It is worth reminding here that these variable managed parameters are indicated in the PLHEADER of the transmitted signal; it is consequently not needed to provide them to the receiver working in VCM/ACM mode.

The useful data rate (defined as the data rate at the CADU level) depends on the MODCOD and the TYPE. It is equal to the product of the selected spectral efficiency listed in Table 3-1 by the symbol rate used on the physical link.

MODCOD	modulation	LDPC code identifier	spectral efficiency [bits/symbol]			
			Short FECFRAME with pilots	short FECFRAME without pilots	normal FECFRAME with pilots	normal FECFRAME without pilots
1	QPSK	1/4	0.3575	0.3653	0.4786	0.4902
2	QPSK	1/3	0.6155	0.6291	0.6408	0.6564
3	QPSK	2/5	0.7446	0.7609	0.7706	0.7894
4	QPSK	1/2	0.8306	0.8488	0.9653	0.9889
5	QPSK	3/5	1.1317	1.1565	1.1600	1.1883
6	QPSK	2/3	1.2607	1.2884	1.2908	1.3223
7	QPSK	3/4	1.3897	1.4203	1.4521	1.4875
8	QPSK	4/5	1.4757	1.5082	1.5494	1.5872
9	QPSK	5/6	1.5618	1.5961	1.6153	1.6547
10	QPSK	8/9	1.6908	1.7280	1.7244	1.7665
11	QPSK	9/10	N/D	N/D	1.7460	1.7886
12	8PSK	3/5	1.6920	1.7253	1.7396	1.7800
13	8PSK	2/3	1.8850	1.9220	1.9357	1.9806
14	8PSK	3/4	2.0779	2.1188	2.1775	2.2281
15	8PSK	5/6	2.3351	2.3811	2.4223	2.4786
16	8PSK	8/9	2.5280	2.5778	2.5859	2.6460
17	8PSK	9/10	N/D	N/D	2.6184	2.6792
18	16APSK	2/3	2.5052	2.5488	2.5746	2.6372
19	16APSK	3/4	2.7616	2.8097	2.8963	2.9667
20	16APSK	4/5	2.9326	2.9836	3.0905	3.1656
21	16APSK	5/6	3.1035	3.1575	3.2219	3.3002
22	16APSK	8/9	3.3599	3.4184	3.4395	3.5231
23	16APSK	9/10	N/D	N/D	3.4827	3.5673
24	32APSK	3/4	3.4192	3.4931	3.6233	3.7033
25	32APSK	4/5	3.6308	3.7093	3.8662	3.9516
26	32APSK	5/6	3.8424	3.9255	4.0306	4.1195
27	32APSK	8/9	4.1599	4.2498	4.3029	4.3979
28	32APSK	9/10	N/D	N/D	4.3569	4.4530

Table 3-1: DVB-S2 spectral efficiency as a function of MODCOD and TYPE

3.3 TYPICAL SIMPLIFIED CONFIGURATION

For most of HDRT applications, there is no need to change the TYPE field. It is consequently suggested to set these two bits to an unvarying value within a Mission Phase. Actually, this TYPE field is kept as a CCSDS variable managed parameter only for the sake of coherency between CCSDS Recommended Standard [1] and ETSI DVB-S2 standard [2].

3.3.1 PILOT SYMBOLS INSERTION

Pilot symbols insertion in the transmitted signal may be useful to reinforce the robustness of the link.

A typical DVB-S2 receiver is shown in Figure 3-3. Pilots may be used for carrier phase interpolation by the receiver.

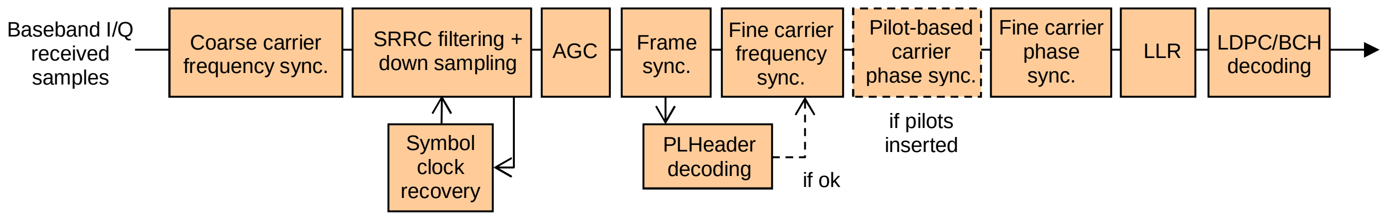


Figure 3-3: Typical DVB-S2 receiver

In presence of phase noise, this carrier phase interpolation allows using a phase lock loop (PLL) for fine carrier phase recovery with a narrower loop bandwidth than without pilots. Hence, degradation due to imperfect carrier recovery is reduced when using pilots. An example of comparison of DVB-S2 performance, with and without pilot insertion, and using the typical DVB-S2 receiver in Figure 3-3, is shown in Figure 3-4 (where BlT designs the normalized loop bandwidth used for carrier phase recovery).

Pilot symbols may also be useful to increase the robustness to the Doppler effects. Section B.2 of [3] points out that the DVB-S2 carrier recovery scheme (and thus the DVB-S2 pilot symbols structure) was conceived to cope with a frequency offset up to 5 MHz and with a frequency ramp up to 30 KHz/s (the target being telecom symbol rates, typically from 10 to 30 Mbauds). Maximum Doppler shift and Doppler rate values in LEO are typically less than 660 KHz and 17 KHz/s (worst case of a satellite with height 300 km and carrier frequency 26 GHz). Moreover, data rates considered for HDRT of LEO satellites are usually higher than those considered for telecoms (typically by a ratio from 5 to 20) then frequency recovery is easier for HDRT applications (thanks to this higher symbol rate). Therefore, it appears quite feasible to cope with Doppler effects in the frame of the use of [1][2].

Finally, since the cost of pilot symbols in terms of power/bandwidth efficiency is negligible, it is advised to consider the use of pilots, in particular in case of lack of fine technical evaluations.

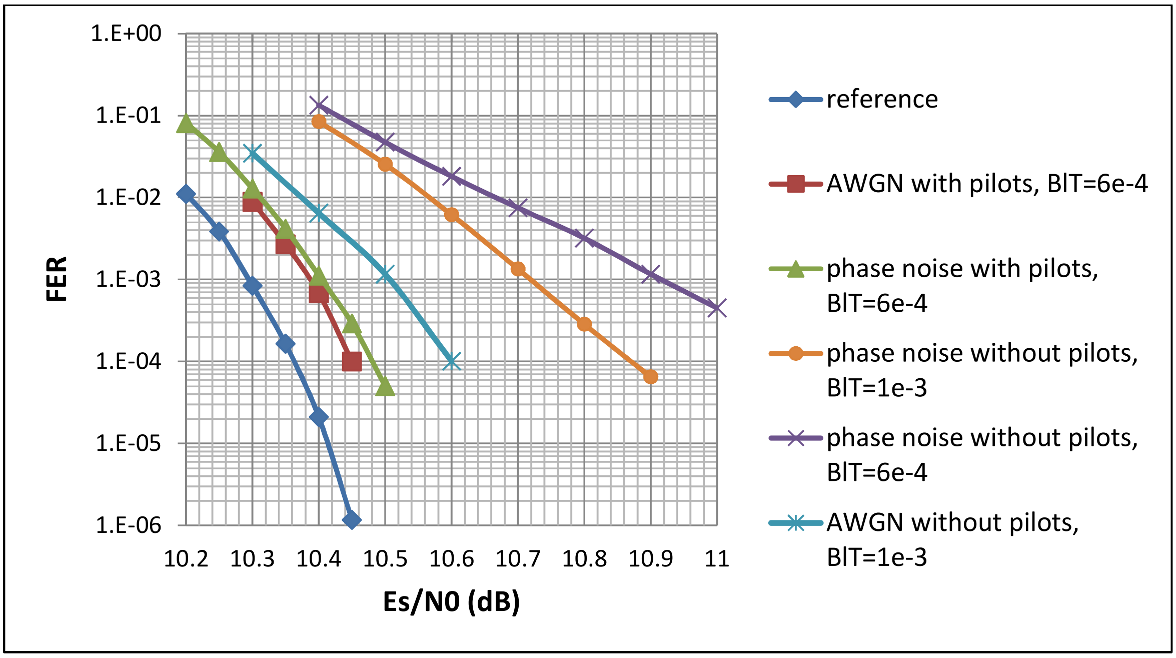


Figure 3-4: DVB-S2 typical receiver performance with and without pilot insertion (16APSK 3/4, short FECFRAME)

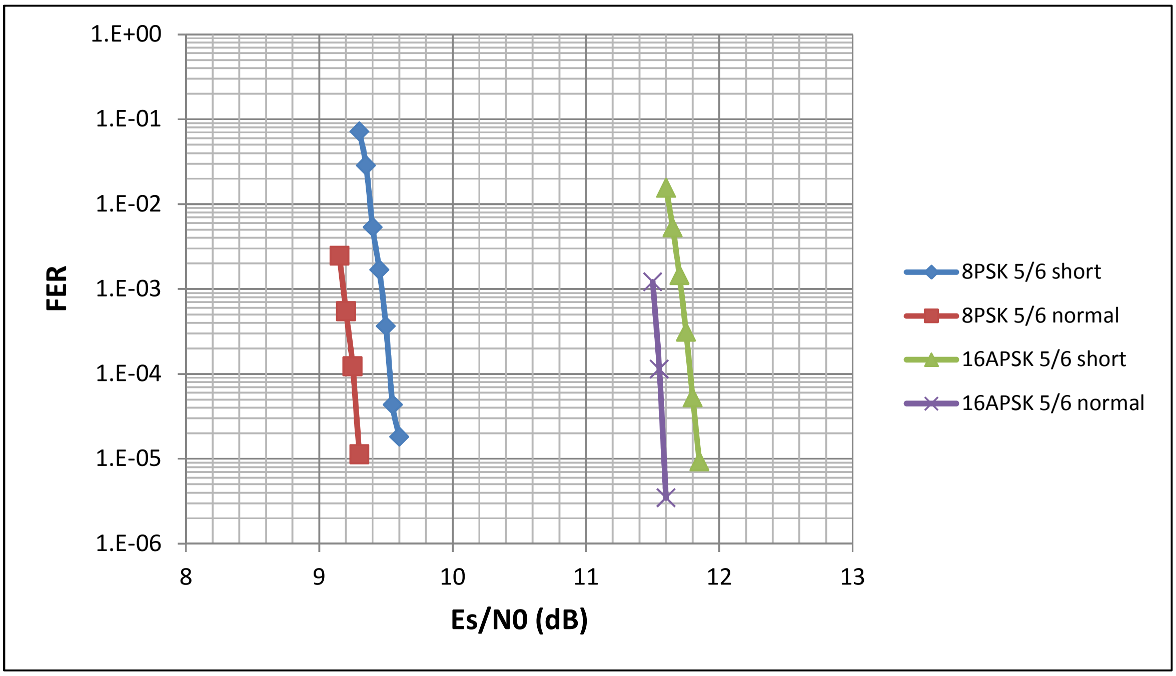


Figure 3-5: DVB-S2 performance with normal and short FECFRAME

3.3.2 NORMAL FECFRAME

The Bits Interleaved Coded Modulation (BICM) scheme used in the DVB-S2 standard is a pragmatic way to achieve performance close to the AWGN channel capacity, even for High Order Modulation, with dissociation of demodulation step and decoding step (by computing Log-Likelihood Ratio) to reduce receiver complexity (see [16][17]).

According to information theory, a long frame allows a more efficient Forward Error Correction (FEC). Hence, in the DVB-S2 standard, the normal FECFRAME is more efficient than the short FECFRAME from a power/bandwidth trade-off point of view. An example of comparison of DVB-S2 performance with normal and short FECFRAME is shown in Figure 3-5. It is consequently advised to use the normal FECFRAME whenever possible.

3.4 DUMMY PLFRAME

The DVB-S2 standard allows inserting a so-called Dummy PLFRAME (Physical Layer Frame) in the transmitted signal. This Dummy PLFRAME does not convey any information, and is identified and suppressed by all DVB-S2 receivers (i.e. it does not appear in the data flow at the receiver output).

For some applications or some technical implementation solutions, it can be more convenient to use this Dummy PLFRAME rather than CCSDS OID Transfer Frames encapsulated in DVB-S2. Typical utilizations of the Dummy PLFRAME include:

- opening of the link at the beginning of a satellite pass,
- maintenance of the link continuity when downloading is stopped for a link budget reasons,
- maintenance of the link continuity when data are not available at the DVB-S2 transmitter input (which is not possible with a system fully following the CCSDS standards, but can happen in practice),
- stand-by mode of the transmitter.

This Dummy PLFRAME is referenced as the MODCOD 0. The associated spectral efficiency is 0.

3.5 TRANSMISSION CLOSING

As described in [1], the encapsulation of CCSDS Transfer Frames in DVB-S2 frames is asynchronous (and the DVB-S2 padding is not used).

Consequently, the transmission of a non-useful data sequence (by the DVB-S2 transmitter itself, or by the data source feeding the transmitter) is required to flush the data in the DVB-S2 transmitter buffer and properly close the download without loss of useful data. The required minimum length of the data sequence of non-useful bits depends on the current MODCOD and TYPE. The worst case is obtained with the coding rate 9/10 and normal FECFRAME, and is (58192-80) bits.

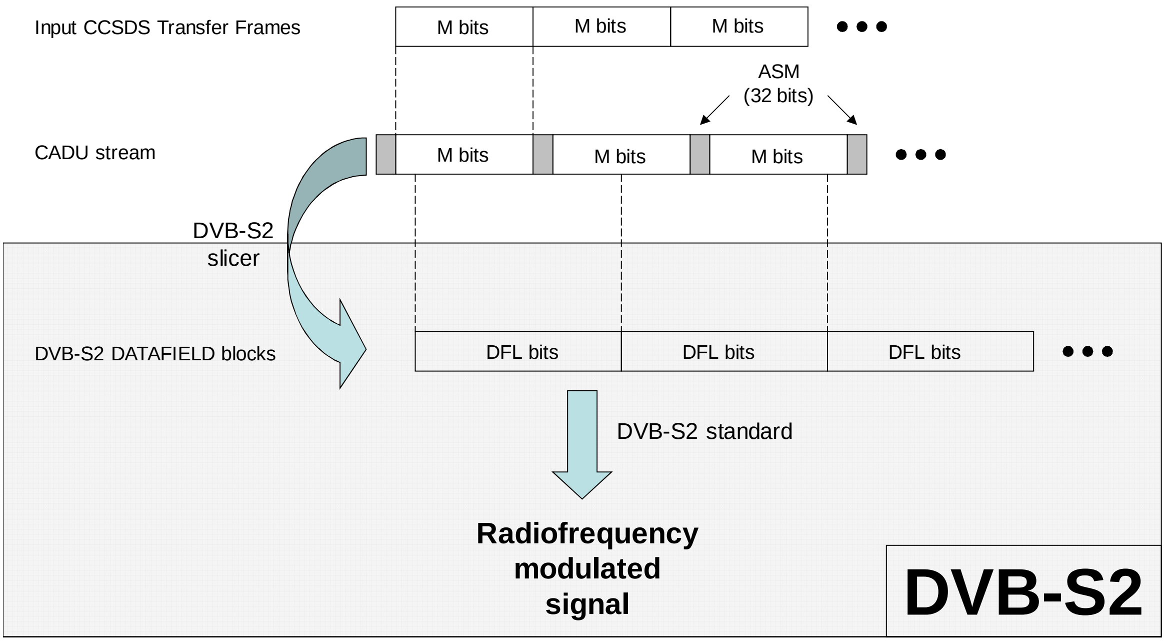


Figure 3-6: Stream Format while Transmitting CCSDS Transfer Frames Using DVB-S2 (extract from [1])

CCSDS OID Transfer Frames can be used for this non-useful data sequence rather than a pseudo-random data sequence. It allows maintaining the flow of the CADU stream at the receiver side during a temporary interruption of data transmission. It is useful when the transmission is not fully predicted on-ground (such as when using ACM). The minimum number of required OID Transfer Frames depends on the current MODCOD and TYPE and on the CCSDS Transfer Frame length. A worst case is obtained considering the coding rate 9/10 with normal FECFRAME. The number of OID Transfer Frames required in this worst case is at least (58192-80)/(CCSDS Transfer Frame Length in bits + 32 bits of ASM).

NOTE – It is suggested to choose the CCSDS Transfer Frame Length equal to (or close to) the maximal value of 2048 octets to minimize the overhead loss. When using this CCSDS Transfer Frame Length and DVB-S2 normal FECFRAME size, 4 OID Transfer Frames are required to properly close the transmission.

4 IMPLEMENTATION AT THE INTERFACE BETWEEN CCSDS PROTOCOLS AND DVB-S2

4.1 INTRODUCTION

The CCSDS Recommended Standard [1] being an adaptation profile of the ETSI DVB-S2 standard [2], the interface between CCSDS protocols and DVB-S2 is of particular interest.

It is worth reminding that all DVB-S2 telecom development can be considered for application to the CCSDS case (see section 2.1), the Recommended Standard [1] being fully compatible with the DVB-S2 standard [2].

However, some specific HDRT implementations (possibly not including DVB-S2 options useless for [1]) may be considered to reduce implementation complexity at the interface between CCSDS protocols and DVB-S2. Section 4.2 deals with such a simplified implementation.

Moreover, the classical “data-push” interface, originally conceived for low data rate telemetry, does not seem particularly suited to a VCM/ACM interface. Hence, a possible solution for a VCM/ACM interface at the transmitter input presented in section 4.3.

4.2 DVB-S2 BASEBAND HEADER SIMPLIFIED PROCESSING

In the DVB-S2 standard, a BaseBand Header (BBHEADER) of 10 octets length is inserted at the beginning of each BaseBand Frame (BBFRAME). This BBHEADER includes some signaling related to the DVB-S2 standard. The BBHEADER structure is fully described in [2] section 5.1.6.

Actually, this signaling is not essential for a telemetry transmission. However, this BBHEADER must not be bypassed in a transmitter, according to [1], for the sake of full DVB-S2 compatibility (to ensure the possible reuse of commercial telecom receivers). Moreover, the complexity added by this BBHEADER insertion is very limited (for the transmitter and the receiver), as explained hereunder.

According to [1], most of the BBHEADER content is fixed, in particular during a mission phase.

Indeed, during a mission phase, the potentially variable content is limited to the DVB-S2 DATA FIELD LENGTH (DFL) and the DVB-S2 CRC-8 (depending on the DFL value). According to section 4.2.3 of [1], this DFL only depends on the FECFRAME size (DFL=Kbch-80 bits) and the coding rate.

Actually, these two parameters (FECFRAME size and coding rate) are required by the receiver before FEC decoding, justifying that they are still indicated in the DVB-S2 PLHEADER. Additional content of the BBHEADER with respect to the PLHEADER is limited to the transmission mode (CCM or VCM/ACM) and the transmitted roll-off.

Thus, the telemetry receiver, designed according to [1], can bypass the BBHEADER interpretation because, on one hand, it knows the transmission roll-off or uses adaptive equalization and on the other hand, it knows the transmission mode or always assumes a VCM/ACM mode.

Concerning the DVB-S2 transmitter designed according to [1]:

- the BBHEADER does not change in CCM mode,
- the BBHEADER only changes with the FECFRAME size and coding rate during a mission phase with VCM/ACM mode.

It can be pointed-out that the 10th octet of the BBHEADER is a CRC upon the first 9 octets of the BBHEADER.

A possible implementation scheme can be based on a tabulated function to compute the BBHEADER:

- input parameters: transmission mode (CCM or VCM/ACM), roll-off, FECFRAME size, coding rate,
- output parameters: possibly varying octets of the BBHEADER
  - Octet 1/10 (MATYPE),
  - Octets 5/10 and 6/10 (DFL=K_{bch}-80),
  - Octet 10/10 (CRC-8).

The other BBHEADER octets can be set to 0.

NOTE – This tabulated function can be further simplified for a given mission by considering unvarying transmission mode, roll-off and FECFRAME size as proposed in section 3.3.

4.3 EXAMPLE OF DATA INTERFACE AT THE TRANSMITTER INPUT TO WORK WITH DVB-S2 VCM/ACM

Let us recall that the DVB-S2 standard, being originally designed for telecom applications, implies a time-unvarying channel symbol rate. Similarly, in a High Data Rate Telemetry context, the symbol rate does not change during a mission phase. When using VCM or ACM transmission mode, the required data rate at the DVB-S2 transmitter input (input CADU stream data rate) depends on the MODCOD. Required input data rates can be derived from the channel symbol rate and the spectral efficiencies in Table 3-1.

A convenient solution to cope with this time-varying data rate is to use a “data-pull” interface. A typical implementation of this data interface using parallel LVDS wires, and used in [9], is shown in Figure 4-1. A functional diagram of the on-board downloading subsystem is shown in Figure 4-2.

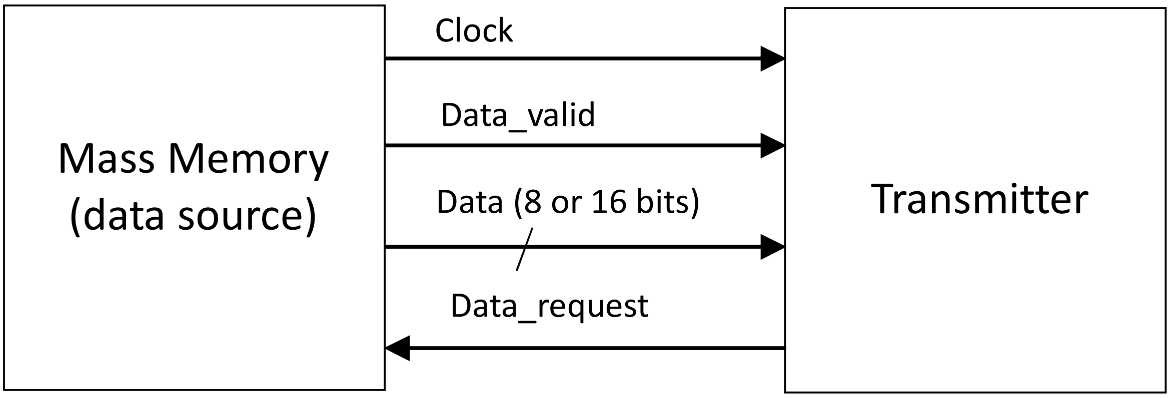


Figure 4-1: Data-pull interface with parallel LVDS wires

The data source at the transmitter input is here a mass memory (MM). The master equipment is the transmitter (TX) and the slave equipment is the data source. The transmitted symbol rate (and consequently the transmitted data rate) is proportional to the internal clock of the transmitter. The data rate at the interface between the data source and the transmitter is proportional to the internal clock of the data source. The transmitter has an internal buffer at its input to store data before processing (i.e. coding, modulation and filtering).

At the beginning of a downloading sequence, the transmitter sets the “data_request” signal to 1, thus the data source begins to send data to the transmitter. When using VCM/ACM modes, these data must be sent with a data rate higher than the maximum data rate achievable by the transmitter. Consequently, the buffer is filled. When the buffer filling reaches a maximum value, the “data_request” signal is set to 0, the data source stops sending data to the transmitter and the buffer is dumped. Then, when the buffer filling reaches a minimum value, it sets the “data_request” signal to 1, and so on. A proper choice of the buffer size and of the minimum and maximum filling values (taking into account response times of the data source and the transmitter) is required. This system is then able to cope with any transmitter data rate change.

The “data_valid” signal (equal to 1 when some data are transferred from the data source to the transmitter, else equal to 0) is used by the transmitter to detect when data are received.

This “data-pull” interface would allow exchanging an unframed stream of data between the data source and the transmitter. However, it is rather suggested to exchange entire CADU at the interface between the data source and the transmitter.

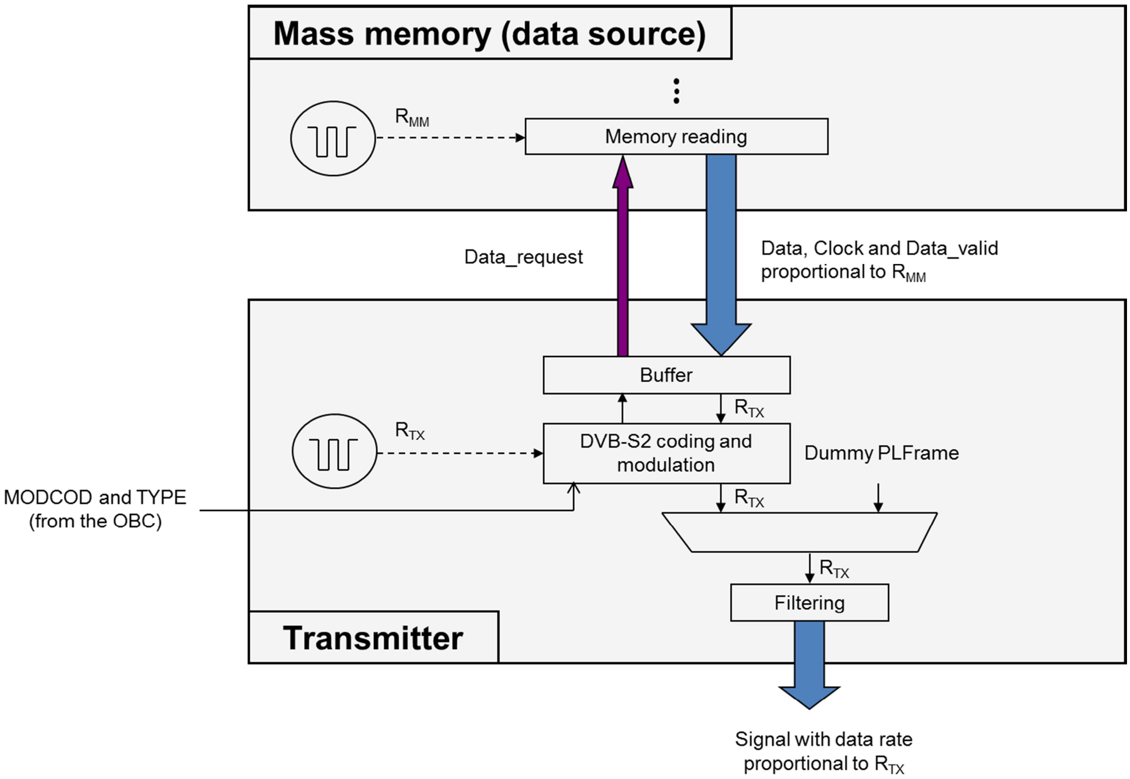


Figure 4-2: On-board downloading subsystem functional diagram with data-pull interface

The “data-pull” concept can be used with a “wizard link” or a HSSL (High speed Serial Link) for the data transfer between the data source and the transmitter. In such a case, the physical electric interface of the “data_request” signal can be different from the data interface.

If a ciphering device is inserted between the data source and the transmitter, this device may include a buffer at its input and transmit the “data_request” signal from the transmitter to the data source. By doing so, the system is able to work with VCM/ACM.

Finally, it can be pointed out that the use of a stuffing mechanism (for example using the DVB-S2 Dummy PLFrame) appears natural to secure the link continuity when using a “data-pull” interface.

5 PERFORMANCE OF DVB-S2

5.1 INTRODUCTION

The objective of this section is to present a synthesis of DVB-S2 performance useful for HDRT engineers.

Section 5.2 provides exhaustive references and results for theoretical DVB-S2 performance over AWGN channel.

Section 5.3 provides examples of DVB-S2 performance in a HDRT non-linear (due to power amplifier) channel, using software simulations with a fully emulated receiver and FER (FECFRAME Error Rate) measurements.

Section 5.4 provides exhaustive DVB-S2 performance in a HDRT non-linear (due to power amplifier) channel, using software simulations with a simplified receiver and EVM measurements (allowing a considerable diminution of the simulation time with respect to section 5.3). This section also provides results concerning Power Spectrum Density (PSD).

Section 5.5 provides some hardware results measurements from a recent HDRT equipement.

5.2 PERFORMANCE OVER AWGN CHANNEL

The objective of this subsection is to provide references and results for theoretical performances of DVB-S2 over AWGN channel.

5.2.1 NORMAL FECFRAME

Some performances can be found in ETSI user guidelines [3], section A.3, page 66/67, in terms of MPEG Packet Error Rate (PER). Actually, simulations show that FECFRAME Error Rate (FER) and PER values are very close. Moreover, since the curve slopes are very steep, the difference in terms of E_s/N_0 is negligible (<0.05 dB).

Simulation results for MODCOD missing in [3] are presented in Figure 5-1.

5.2.2 SHORTFECFRAME

Some performances can be found in ETSI user guidelines [3], section A.3, page 68.

Simulation results for MODCODs missing in [3] are presented in Figure 5-2.

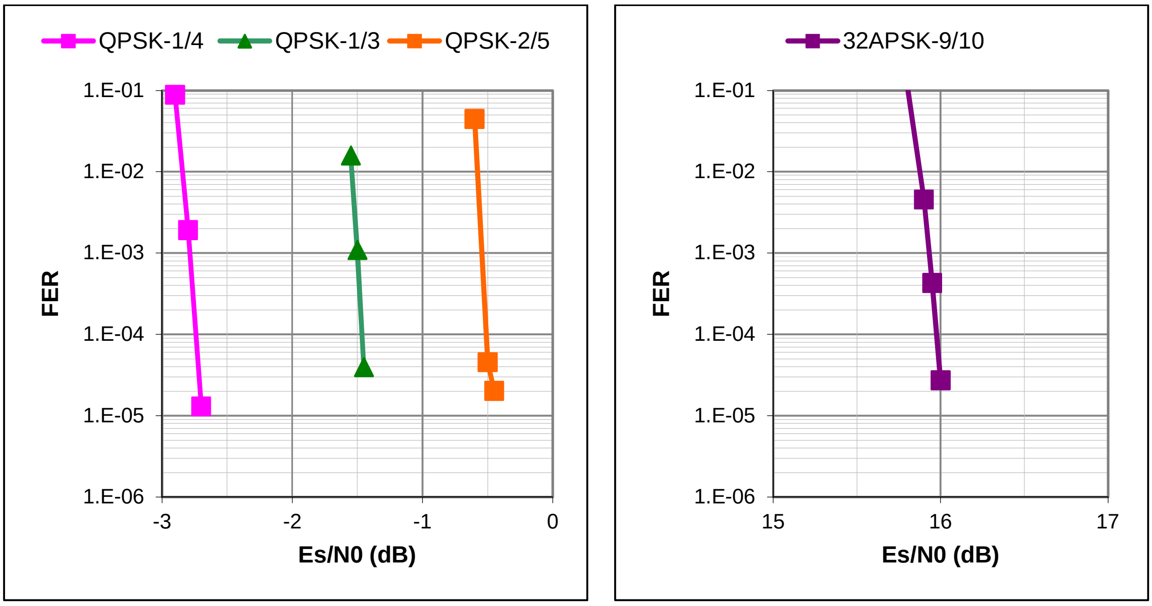
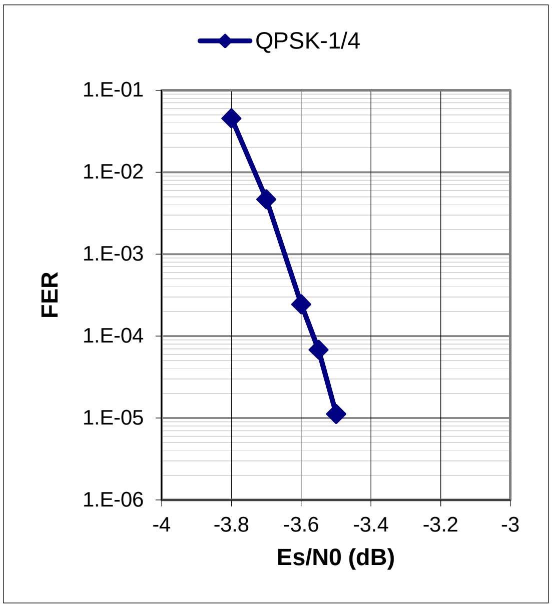


Figure 5-1: Performance over AWGN channel – DVB-S2 normal FECFRAME – additional results to ETSI user guidelines [3]



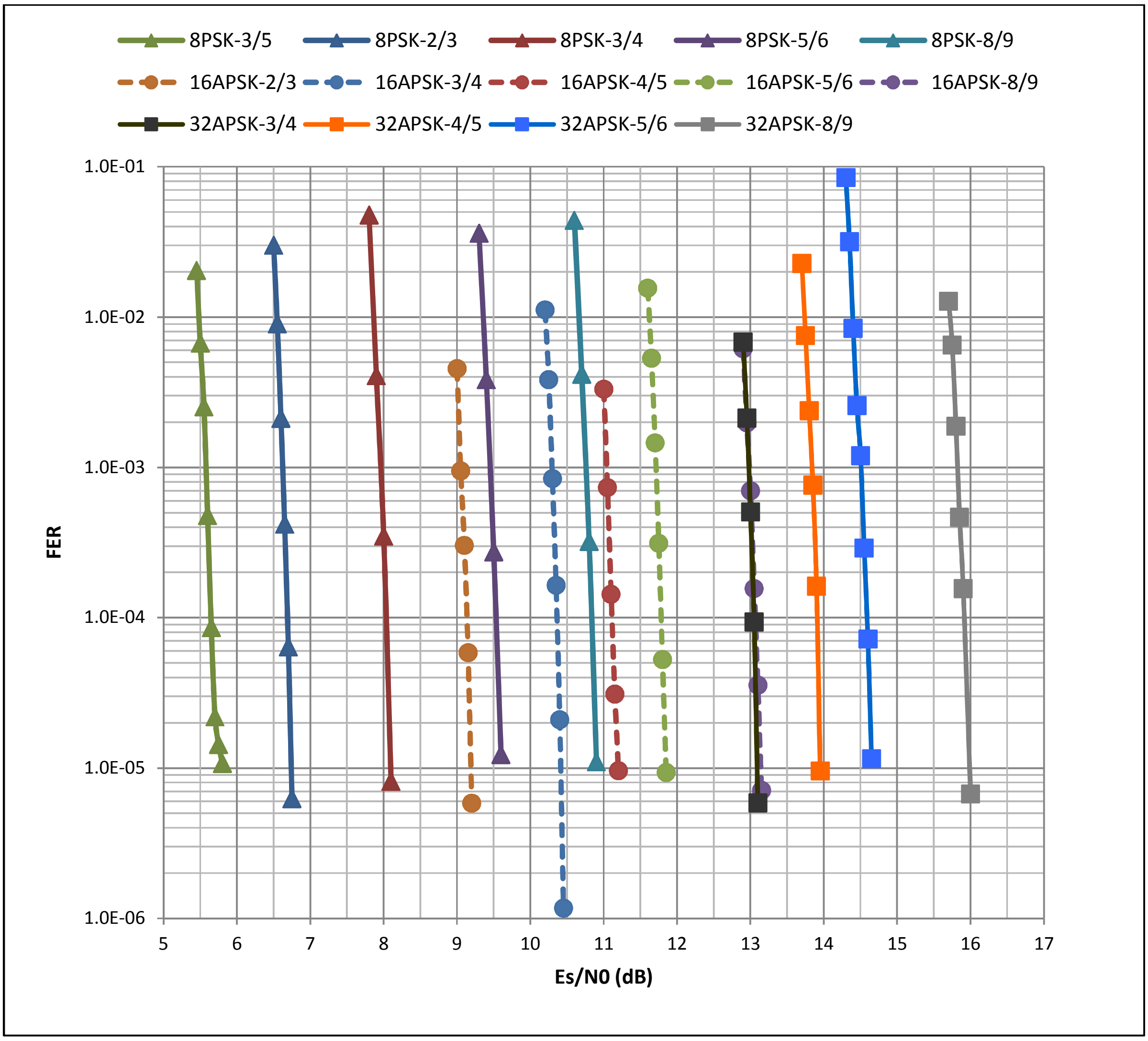


Figure 5-2: Performance over AWGN channel – DVB-S2 short FECFRAME – additional results to ETSI user guidelines [3]

5.3 EXAMPLE OF PERFORMANCE WITH NON-LINEAR CHANNEL IMPAIRMENT

The objectives of this subsection are:

- to present simulation results illustrating the behavior of DVB-S2 over a non-linear channel,
- to point out the interest of adapting the amplifier operating point according to the used MODCOD.

Channel impairment is thus limited in this subsection to the non-linear impairment without memory from the power amplifier.

5.3.1 PRINCIPLE OF AMPLIFIER OPERATING POINT OPTIMIZATION

To optimize the amplifier operating point for a given MODCOD, two effects have to be considered.

For a given OBO, the available RF power at the amplifier output is reduced with respect to the RF power available at saturation. Thus, a back-off implies a loss over the link budget and it appears interesting to reduce this OBO.

However, the non-linear effect of the power amplifier induces a demodulation loss. This degradation increases when reducing the OBO, as shown in Figure 5-3.

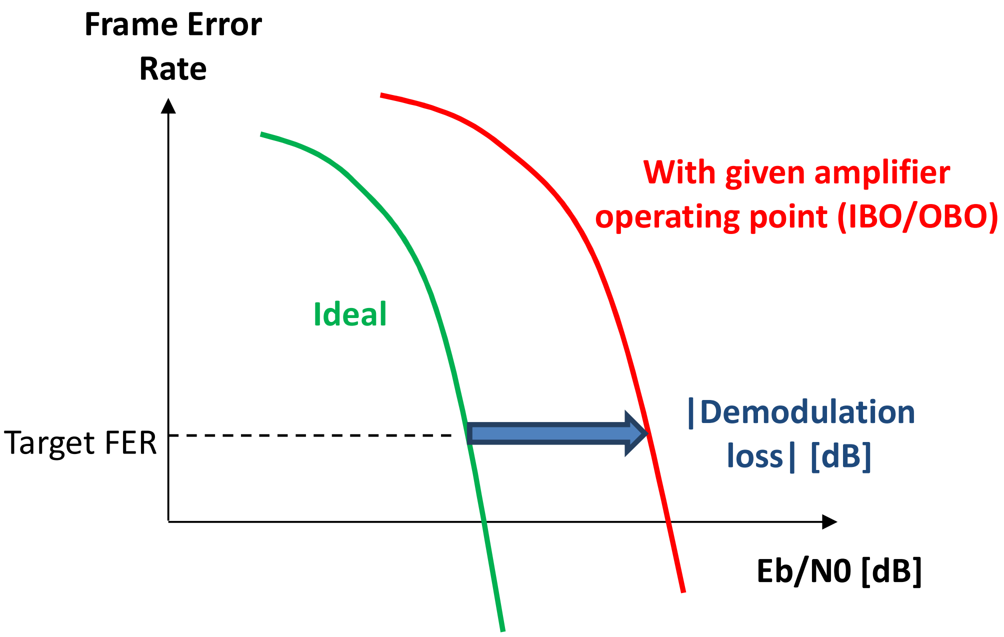


Figure 5-3: Demodulation loss measurement principle

Finally, an optimum OBO can be found – for a given MODCOD – as shown in Figure 5-4.

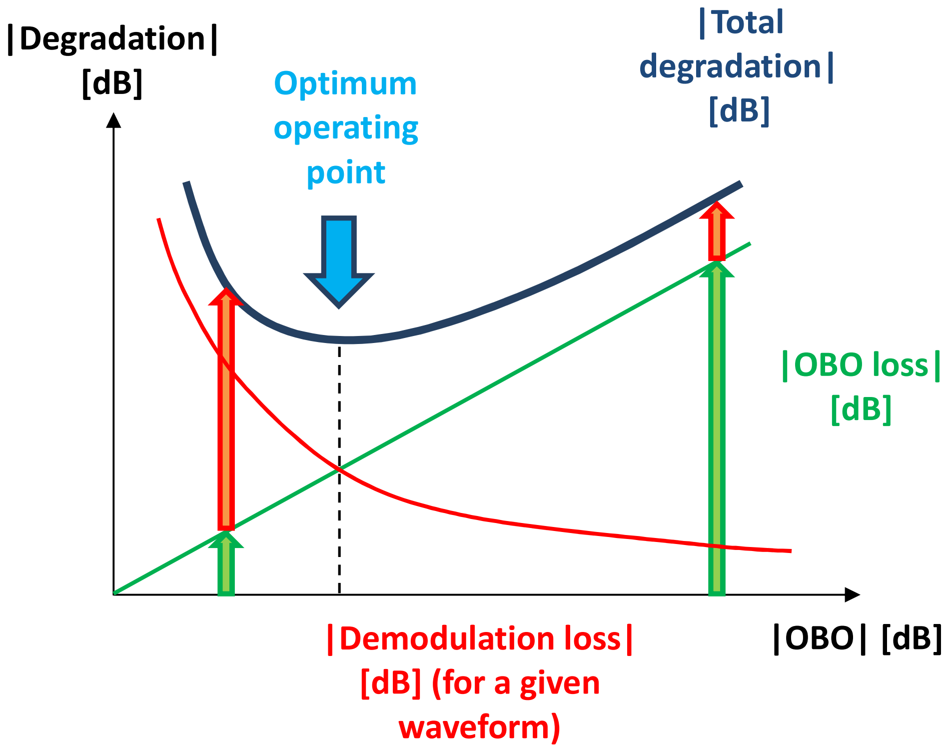


Figure 5-4: Principle of amplifier operating point optimization

5.3.2 SIMULATION HYPOTHESES

Results are obtained using the simulation tool presented in [7], in which the receiver shown in Figure 3-3 is used. This tool includes the receiver shown in Figure 3-3. Short FECFRAME is used to limit the simulation time. Pilot symbols are inserted. The rolloff is chosen equal to 0.2.

A typical European 26 GHz non-linearized Travelling Wave Tube Amplifier TWTA (used in [18] and with characteristics roughly similar to the ones in Figure H.12 of [2]) is assumed. It is fully characterized by CW (Continuous Wave) AM/AM and AM/PM responses shown in Figure 5-5. No digital predistorsion of the amplifier non-linearity is considered here. Other channel impairments are not considered for the sake of interpretability of results.

It can be noticed that usually, the relationship between IBO (Input Back-Off) and OBO (Output Back-Off) depends on the waveform. It is, for instance, different for CW and modulated signals. It also depends on the rolloff and the constellation of a modulated signal.

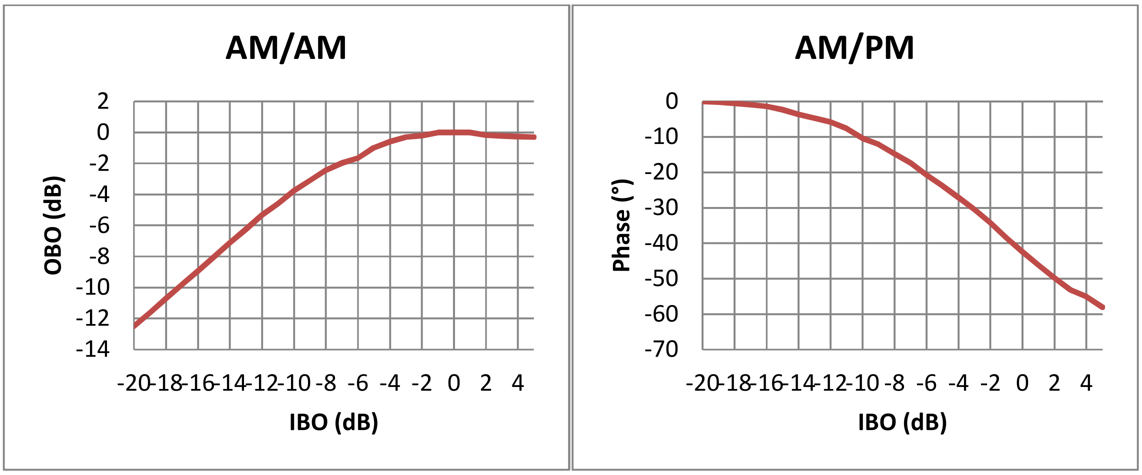


Figure 5-5: 26 GHz power amplifier AM/AM and AM/PM responses

5.3.3 OPTIMUM OPERATING POINT OPTIMIZATION FOR 16APSK 8/9

The optimization for 16APSK 8/9 is shown in Figure 5-6.

The optimal operating point is an |IBO| of 5.5 dB corresponding to an |OBO| of 1.75 dB.

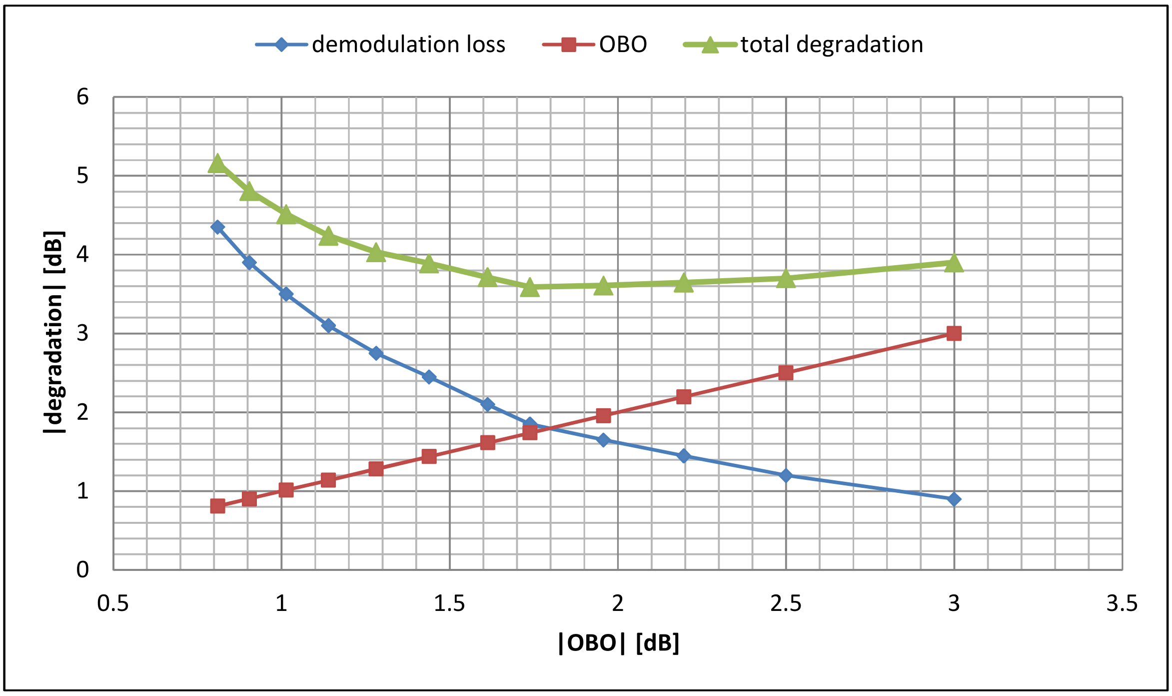


Figure 5-6: Amplifier operating point optimization for 16APSK 8/9

5.3.4 RESULTS WITH CONSTANT IBO

If a MODCOD change is required, the most straightforward way, though not optimum, may be in some cases to operate at the same IBO operating point over a mission range of MODCODs.

Results for different MODCOD from QPSK 1/3 to 16APSK 8/9 with the previous IBO are thus presented in Figure 5-7.

For a given constellation, the demodulation loss decreases with the coding rate, thanks to the decrease of the required Es/N0 over AWGN channel.

However, if high coding rate 8PSK and low coding rate 16APSK have similar required Es/N0 over AWGN channel, 16APSK shows a more important demodulation loss with non-linearity, due to its higher peak-to-average power ratio (PAPR).

Due to the even higher PAPR of 32APSK, it does not appear possible to reach the target FER with the considered IBO. For that reason, it is necessary to consider a specific IBO optimization for the case of the 32APSK MODCODs.

The optimization for 32APSK 8/9 is shown in Figure 5-8. The optimal operating point is an |IBO| of 11 dB corresponding to an |OBO| of 4.95 dB.

5.3.5 COMMENTS

The basis for optimization of the amplifier operating point was presented, considering DVB-S2 nominal constellations.

Another simple way to further increase performance is to use static digital pre-distortion of the amplifier non-linearity– for 16APSK and 32APSK – at the constellation mapping level in the transmitter. Such a pre-distortion is working at the symbol rate, thus its digital complexity is very limited. For a given MODCOD using 16APSK or 32APSK, a joint optimization of the pre-distorted constellation and of the operating point is then possible. Such an optimization is proposed in section 5.4.

When considering a VCM or even ACM transmission, a simple solution consists in optimizing the amplifier operating point for a median MODCOD, and then in keeping a constant IBO for the different MODCOD.

When considering a VCM or even ACM transmission, a full performance solution requires a dynamic adaptation of the amplifier operating point depending on the MODCOD (the implementation of such a solution being beyond the scope of this document).

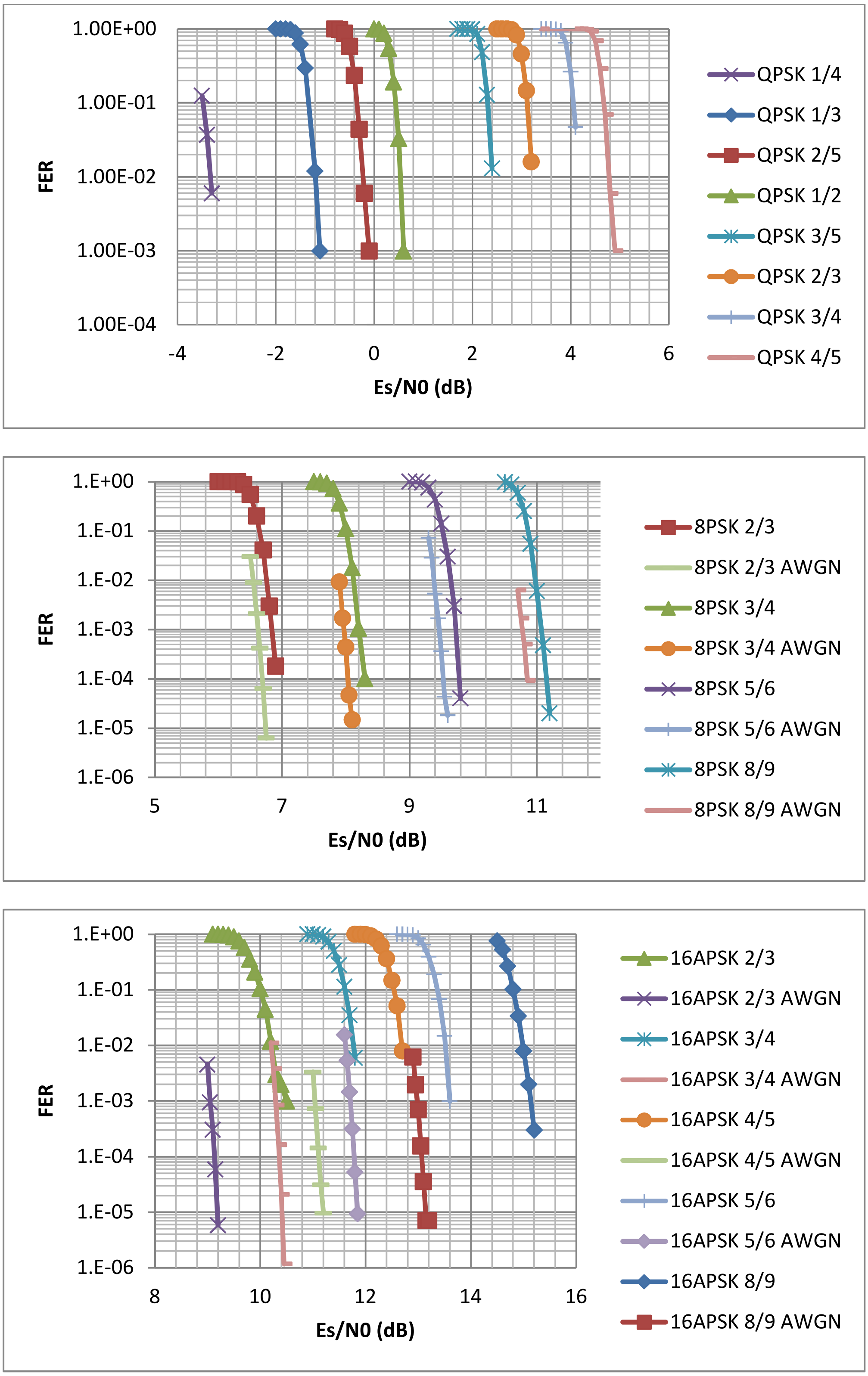


Figure 5-7: Performance with constant |IBO|= 5.5 dB

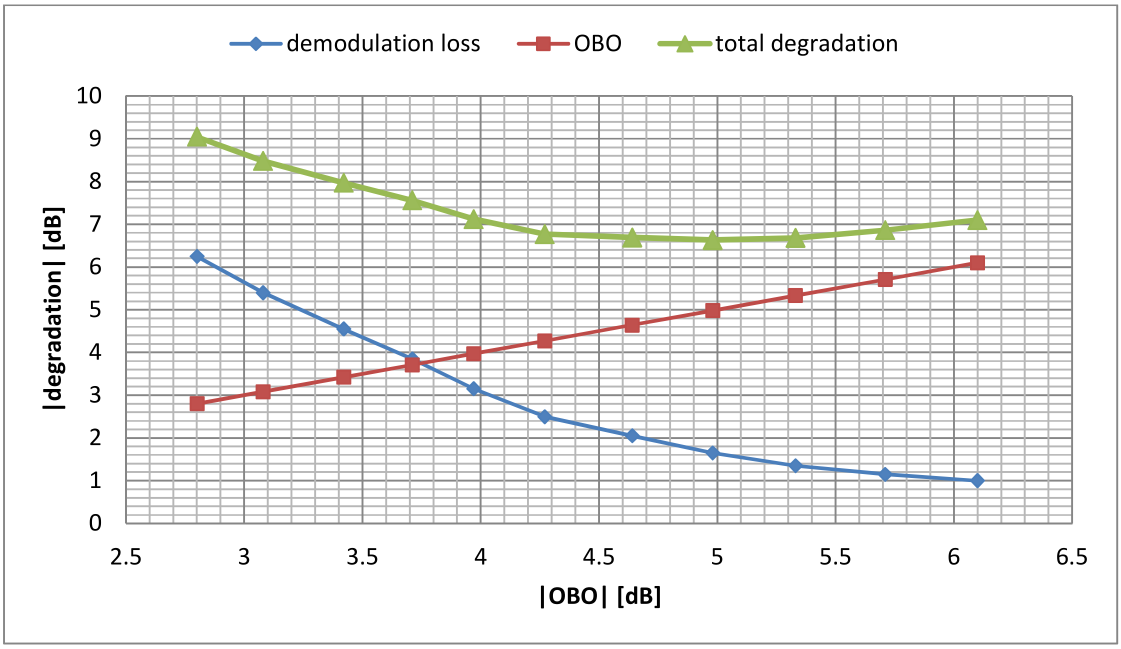


Figure 5-8: Amplifier operating point optimization for 32APSK 8/9

5.4 EXAMPLE OF PERFORMANCE WITH STATIC PREDISTORSION OF POWER AMPLIFIER NON LINEARITY

The objective of this section is:

- to present some additional material about Power Amplifier (PA in the following) operating point optimization when using DVB-S2 High Order Modulations (HOM), in particular through Error Vector Magnitude (EVM [14]) measurements,
- to evaluate the possible improvement when using a very simple symbol Constellation Predistorsion (CP in the following) of the PA non-linearity,
- to evaluate possible constraints on the amplifier operating point related to the Power Spectrum Density (PSD in the following) at the PA output.

5.4.1 METHODOLOGY

The model used is the classical model of non-linearity without memory (already used in section 5.3): the PA is fully characterized by its AM/AM and AM/PM responses. A typical European non-linearized X-band Travelling Wave Tube Amplifier TWTA used for the HDRT of CNES Pleiades satellites is considered, with characteristics shown in Figure 5-9.

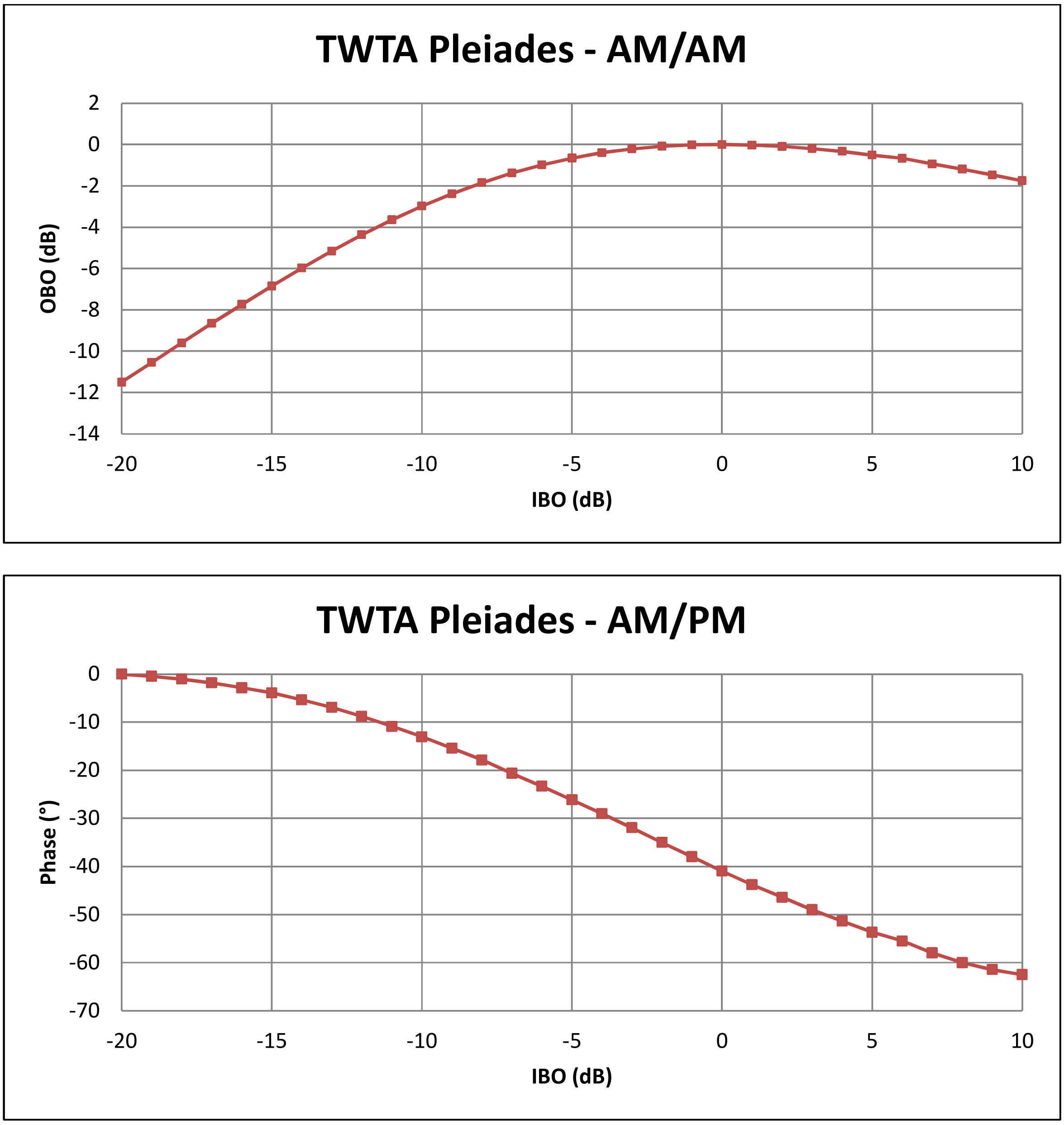


Figure 5-9: AM/AM and AM/PM responses of the 8 GHz TWTA

In the software simulator used, the receiver synchronization is assumed ideal: simple static amplitude and phase shift compensations are applied to the received signal to be able to measure the EVM.

In the same way than in section 5.3, the value to be minimized (by modifying the PA operating point or the CP) is the Total Degradation (TD), equal to the sum in dB of the Output Back-Off (OBO) and the Demodulation Loss (DL) implied by the non-linearity:

$$\mathrm{TD(dB)} = \mathrm{OBO(dB)} + \mathrm{DL(dB)}$$

The DL is obtained by the following formula, with natural values:

$$\mathrm{DL} = \frac{\frac{\mathrm{C}}{\mathrm{N}}\,\text{required at demodulation with PA non linearity}}{\frac{\mathrm{C}}{\mathrm{N}}\,\text{ required at demodulation without PA non linearity}}$$

C is the carrier power and N is the additive noise power measured in the equivalent noise bandwith (equal to the symbol rate).

We assume that the constellation distortion induced by the PA non-linearity has the same behavior as AWGN and acts as interference on the link. The C/I induced by the PA non-linearity is then linked to the measured EVM (without AWGN) by the following formula (see [14][30]), in dB:

$$\mathrm{C/I(dB)} = -20\,\log10(\mathrm{EVM}(\%))$$

To make the link possible with the target FER, the received C/(N+I) has to be equal to the required E_s/N_0 at the receiver input. We get, with natural values (see for example [29]):

$$\left(\frac{\mathrm{C}}{\mathrm{N+I}}\right)^{-1} = \left(\frac{\mathrm{C}}{\mathrm{N}}\right)^{-1} + \left(\frac{\mathrm{C}}{\mathrm{I}}\right)^{-1} = \left(\text{required } \frac{\mathrm{E_S}}{\mathrm{N_0}}\right)^{-1}$$

or

$$\frac{\mathrm{C}}{\mathrm{N}} = \left(\left(\text{required } \frac{\mathrm{E_S}}{\mathrm{N_0}}\right)^{-1} - \left(\frac{\mathrm{C}}{\mathrm{I}}\right)^{-1}\right)^{-1}$$

Finally, we obtain in natural values

$$\mathrm{DL} = \frac{\left(\left(\text{required } \frac{\mathrm{E_S}}{\mathrm{N_0}}\right)^{-1} - \left(\frac{\mathrm{C}}{\mathrm{I}}\right)^{-1}\right)^{-1}}{\text{required } \frac{\mathrm{E_S}}{\mathrm{N_0}}}$$

or in dB

$$\mathrm{DL(dB)} = 10\log10\left(1 - 10^{\left(\text{required}\,\frac{\mathrm{E_S}}{\mathrm{N_0}}(\mathrm{dB}) - \frac{\mathrm{C}}{\mathrm{I}}(\mathrm{dB})\right)/10}\right)$$

We consider for the exercise a perfect receiver, using the theoretical E_s/N_0 values taken from the DVB-S2 (see table 13 in [2]). This approximation appears close to reality for modern receivers (see section 5.5) at least up to 16APSK.

It is worth noting that all along in this section 5.4, TD, OBO and DL are expressed with negative values.

It is also interesting to underline that the optimization process considered in this section 5.4 is fully similar to the one considered in section 5.3, the only difference being the computation of the demodulation loss DL using EVM measurements in 5.4 (of interest to reduce simulation time with respect to section 5.3).

5.4.2 QPSK AND 8PSK

The optimization can only be performed on the amplifier operating point (CP is not applicable for constant envelop constellations).

The Peak-to-Average-Power Ratio (PAPR) is the same for QPSK and 8PSK, because of the constant envelope constellation. However, the PAPR increases when the roll-off alpha value decreases. The demodulation loss induced by the PA (in absolute value) varies in the opposite direction of the PAPR.

The operating point optimization leads to a higher TD (in absolute value) for 8PSK than for QPSK, because theoretical required E_s/N_0 are lower for QPSK than for 8PSK.

It can be noted that for both QPSK and 8PSK, whatever the roll-off is, the best operating point is found very close to the saturation. Figure 5-10 shows the TD for different OBO and for the 3 highest coding rates (5/6, 8/9 and 9/10) for 8PSK. The blue lines (marker +) are for α = 0.2, whereas the green lines (marker o) are for α = 0.35.

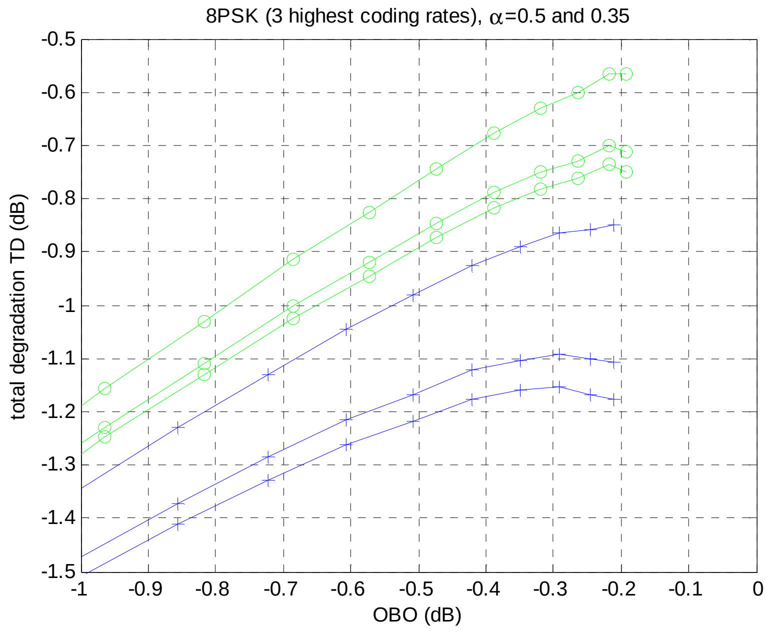


Figure 5-10: TD for 8PSK

5.4.3 16APSK

The optimization is performed on:

- the PA operating point,
- the increase of the radius ratio with respect to the nominal constellation ($\Gamma=\gamma_{CP}/\gamma_{nominal}$),
- the phase shift of the second ring with respect to the nominal constellation ($\Delta\varphi$).

The optimization is performed by the brute force approach. For each IBO, an optimal couple (Γ, $\Delta\varphi$) is found by testing possible values of Γ and $\Delta\varphi$. Figure 5-11 shows the TD (in dB) as a function of Γ and $\Delta\varphi$, for the case of 16APSK 9/10 and with an IBO equal to -3 dB. The optimal couple (Γ, $\Delta\varphi$) is about (1.5, 20°) and leads to a TD equal to -2.8 dB.

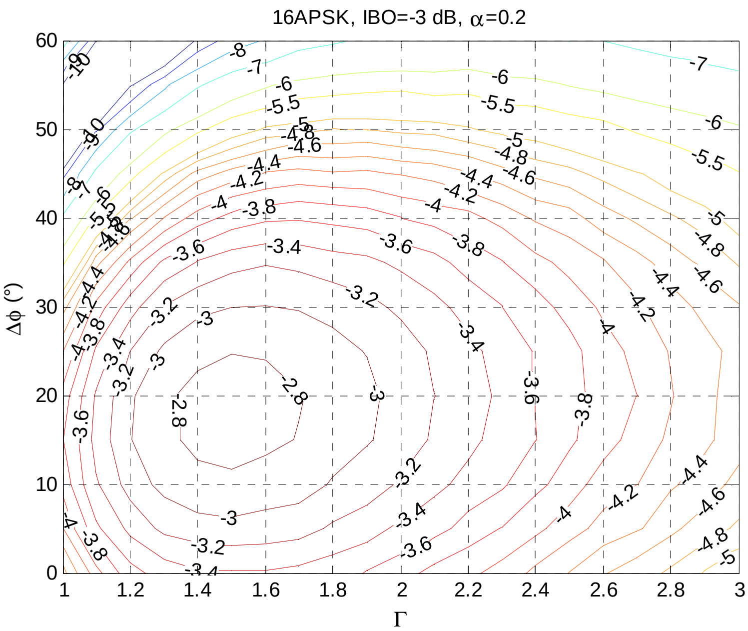


Figure 5-11: TD as a function of Γ and Δφ for a fixed IBO

Notice than the OBO slightly depends on the waveform and consequently depends on the CP.

Figure 5-12 shows the lowest |TD| for different OBO and for the 6 16APSK of the DVB-S2 standard. The blue lines (marker +) are with CP, whereas the green lines (marker o) are without CP (i.e. with nominal DVB-S2 constellations).

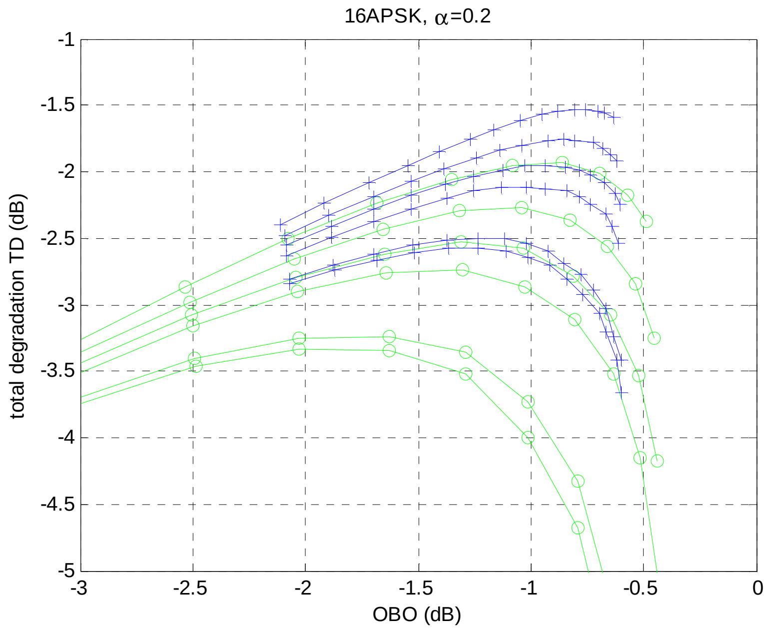


Figure 5-12: Optimal TD for 16APSK

Table 5-1 and Table 5-2 summarize the optimal operating point for roll-off α = 0.2 and α = 0.35. The gain in using CP is found limited: 0.4 to 0.76 dB with α = 0.2, 0.55 dB to 1.1 dB with α = 0.35. Logically, this gain is slightly higher for the highest roll-off value (the PAPR increase induced by the pulse shaping filter is not mitigable by the CP).

	With CP							Without CP					(TD with CP)
constellation	IBO (dB)	OBO (dB)	constellation SNR (dB)	TD (dB)	DL (dB)	Γ	Δφ (°)	IBO (dB)	OBO (dB)	constellation SNR (dB)	TD (dB)	DL (dB)	- (TD without CP) (dB)
16APSK 2/3	-1.5	-0.76	16.9	-1.53	-0.77	1.65	17.5	-3	-0.86	15.6	-1.93	-1.07	0.40
16APSK 3/4	-2.5	-0.85	17.5	-1.76	-0.91	1.5	17.5	-4	-1.04	16.3	-2.27	-1.23	0.51
16APSK 4/5	-3	-0.93	17.8	-1.95	-1.02	1.5	20	-5	-1.31	17.15	-2.53	-1.22	0.58
16APSK 5/6	-3.5	-1.05	18.1	-2.11	-1.06	1.45	17.5	-5	-1.3	17.1	-2.74	-1.44	0.63
16APSK 8/9	-4	-1.12	18.5	-2.5	-1.38	1.4	17.5	-6	-1.63	18	-3.24	-1.61	0.74
16APSK 9/10	-5	-1.36	19.3	-2.57	-1.21	1.3	15	-7	-2.03	19	-3.33	-1.3	0.76

Table 5-1: Optimal operating points, 16APSK, roll-off α = 0.2

	With CP							Without CP					(TD with CP)
constellation	IBO (dB)	OBO (dB)	constellation SNR (dB)	TD (dB)	DL (dB)	Γ	Δφ (°)	IBO (dB)	OBO (dB)	constellation SNR (dB)	TD (dB)	DL (dB)	- (TD without CP) (dB)
16APSK 2/3	-0.5	-0.71	18.3	-1.25	-0.54	1.85	22.5	-3	-0.86	16.1	-1.8	-0.94	0.55
16APSK 3/4	-1.5	-0.77	18.9	-1.4	-0.63	1.75	22.5	-4	-1.04	16.8	-2.1	-1.06	0.70
16APSK 4/5	-2	-0.82	19.2	-1.53	-0.71	1.7	22.5	-5	-1.3	17.7	-2.35	-1.05	0.82
16APSK 5/6	-2	-0.81	19.3	-1.63	-0.82	1.7	22.5	-5	-1.29	17.7	-2.53	-1.24	0.90
16APSK 8/9	-3	-0.95	19.9	-1.9	-0.95	1.6	20	-6	-1.62	18.6	-2.97	-1.35	1.07
16APSK 9/10	-3.5	-1.04	20.3	-1.97	-0.93	1.55	20	-6	-1.61	18.6	-3.05	-1.44	1.08

Table 5-2: Optimal operating points, 16APSK, roll-off α = 0.35

5.4.4 32APSK

The optimization is performed on:

- the PA operating point,
- the increase of the second radius ratio with respect to the nominal constellation ($\Gamma_2=\gamma_{2,CP}/\gamma_{2,nominal}$),
- the phase shift of the third ring with respect to the nominal constellation ($\Delta\varphi_2$).

Thus, the optimization proposed here is suboptimal, because the optimization could also be performed on $\Gamma_1=\gamma_{1,CP}/\gamma_{1,nominal}$ and $\Delta\varphi_1$. However, the third ring of 32APSK is the most subject to PA compression and thus the improvement of a more sophisticated approach can be presumed limited.

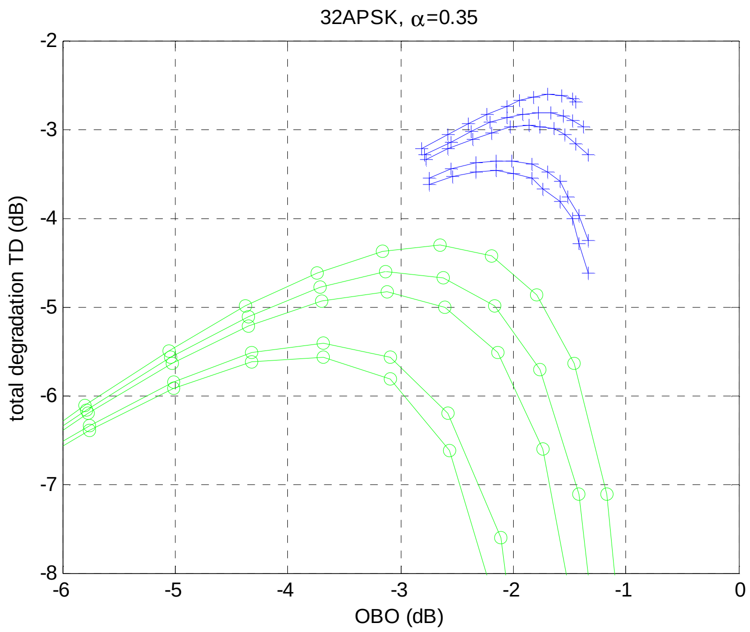


Figure 5-13: Optimal TD for 32APSK

	With CP							Without CP					(TD with CP) - (TD without CP) (dB)
constellation	IBO (dB)	OBO (dB)	constellation SNR (dB)	TD (dB)	DL (dB)	Γ	Δφ (°)	IBO (dB)	OBO (dB)	constellation SNR (dB)	TD (dB)	DL (dB)	
32APSK 3/4	-5.5	-1.85	18.7	-3.11	-1.26	1.35	15	-8	-2.65	17.6	-4.36	-1.71	1.25
32APSK 4/5	-6	-2	19.2	-3.39	-1.39	1.35	12.5	-9	-3.14	18.8	-4.72	-1.58	1.33
32APSK 5/6	-6.5	-2.14	19.7	-3.6	-1.46	1.3	12.5	-9	-3.13	18.9	-4.98	-1.85	1.38
32APSK 8/9	-8	-2.71	21.2	-4.13	-1.42	1.2	10	-10	-3.69	20.2	-5.56	-1.87	1.43
32APSK 9/10	-8	-2.71	21.2	-4.3	-1.59	1.2	10	-10	-3.69	20.2	-5.76	-2.07	1.46

Table 5-3: Optimal operating points, 32APSK, roll-off α = 0.2

	With CP							Without CP					(TD with CP)
constellation	IBO (dB)	OBO (dB)	constellation SNR (dB)	TD (dB)	DL (dB)	Γ	Δφ (°)	IBO (dB)	OBO (dB)	constellation SNR (dB)	TD (dB)	DL (dB)	- (TD without CP) (dB)
32APSK 3/4	-4.5	-1.7	19.9	-2.61	-0.91	1.55	17.5	-8	-2.65	17.7	-4.3	-1.65	1.69
32APSK 4/5	-5	-1.78	20.4	-2.81	-1.03	1.5	17.5	-9	-3.14	19	-4.61	-1.47	1.80
32APSK 5/6	-5.5	-1.86	20.8	-2.96	-1.1	1.4	15	-9	-3.12	19.1	-4.84	-1.72	1.88
32APSK 8/9	-6.5	-2.15	21.8	-3.36	-1.21	1.35	12.5	-10	-3.68	20.5	-5.41	-1.73	2.05
32APSK 9/10	-6.5	-2.15	21.9	-3.47	-1.32	1.35	15	-10	-3.68	20.6	-5.58	-1.9	2.11

Table 5-4: Optimal operating points, 32APSK, roll-off α = 0.35

Table 5-3 and Table 5-4 summarize the optimal operating point for roll-off α = 0.2 and α = 0.35. The gain in using CP is found between 1.25 and 1.46 dB with α = 0.2, and between 1.69 and 2.11 dB with α = 0.35. In the same way than for 16APSK, this gain is slightly higher for the highest roll-off value.

5.4.5 PSD AND ACPR

PSD (Power Spectrum Density) presented here are **PSD at the PA output, whereas SFCG mask is applicable at the satellite output** (in particular possibly after a highly selective RF output filter). PSD is here normalized at the carrier center. SFCG PSD mask is computed depending on the constellation as in SFCG recommendation 21-2R3 in [15].

The spectra are identical for QPSK and 8PSK. Moreover, the spectrum is not significantly dependent on the constellation (possibly with TD) for the different 16APSK or for the different 32APSK. Consequently, results are only presented for 8PSK, 16APSK 5/6 and 32APSK 5/6 in Figure 5-15. It appears quite achievable to respect the SFCG mask with the considered PA.

ACPR (Adjacent Channel Power Ratio) refers here to the ratio in natural value between the PSD at the carrier center and the maximum PSD above a given frequency offset from the carrier center, as shown in Figure 5-14. **This ACPR is computed at the PA output (and not at the satellite output)**. A possible use of the ACPR results shown in Figure 5-16, for a user knowing some mission requirements (carrier frequency, symbol rate noted R_S in Figure 5-16, EIRP, altitude), is to deduce the specification of a RF output filter to avoid coordination with the DSN.

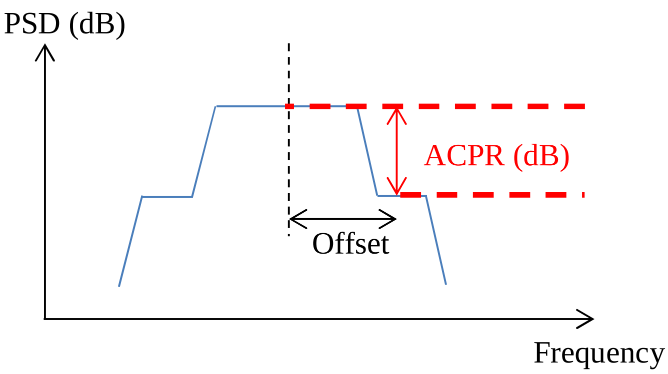
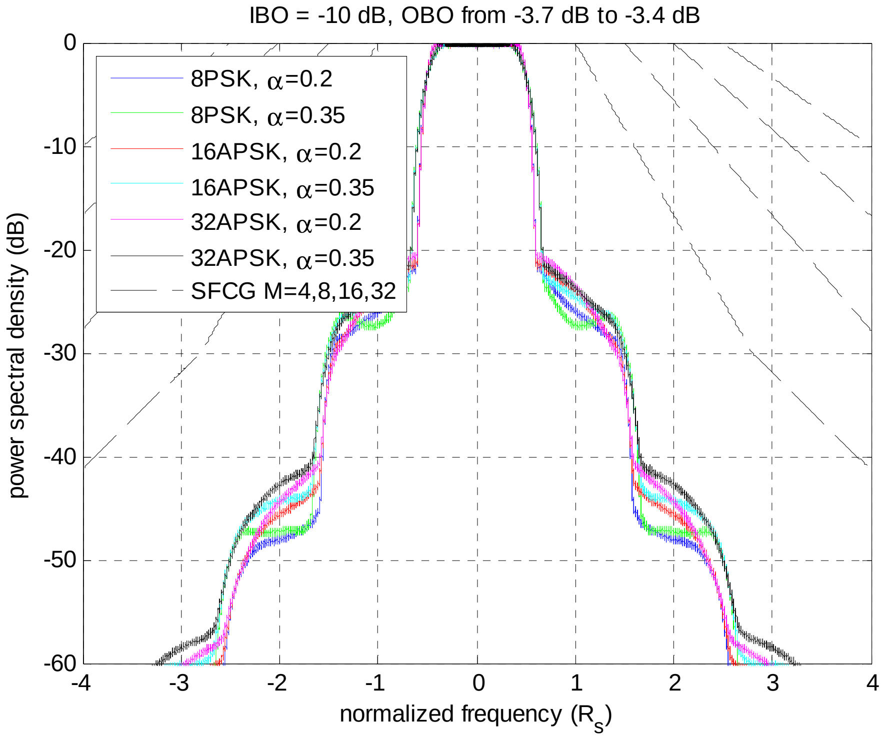
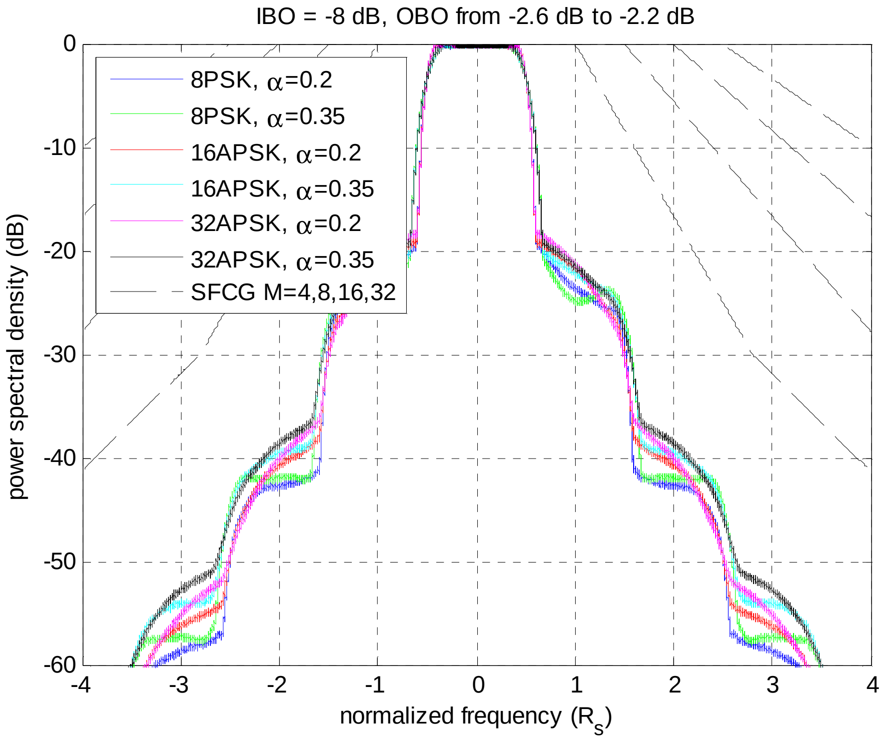


Figure 5-14: Illustration of ACPR measurement


IBO = -10 dB, OBO from -3.7 dB to -3.4 dB
power spectral density (dB)
normalized frequency (R_s)
8PSK, α=0.2
8PSK, α=0.35
16APSK, α=0.2
16APSK, α=0.35
32APSK, α=0.2
32APSK, α=0.35
SFCG M=4,8,16,32
0
-10
-20
-30
-40
-50
-60
-4
-3
-2
-1
0
1
2
3
4


IBO = -8 dB, OBO from -2.6 dB to -2.2 dB
power spectral density (dB)
normalized frequency (R_s)
8PSK, α=0.2
8PSK, α=0.35
16APSK, α=0.2
16APSK, α=0.35
32APSK, α=0.2
32APSK, α=0.35
SFCG M=4,8,16,32
0
-10
-20
-30
-40
-50
-60
-4
-3
-2
-1
0
1
2
3
4

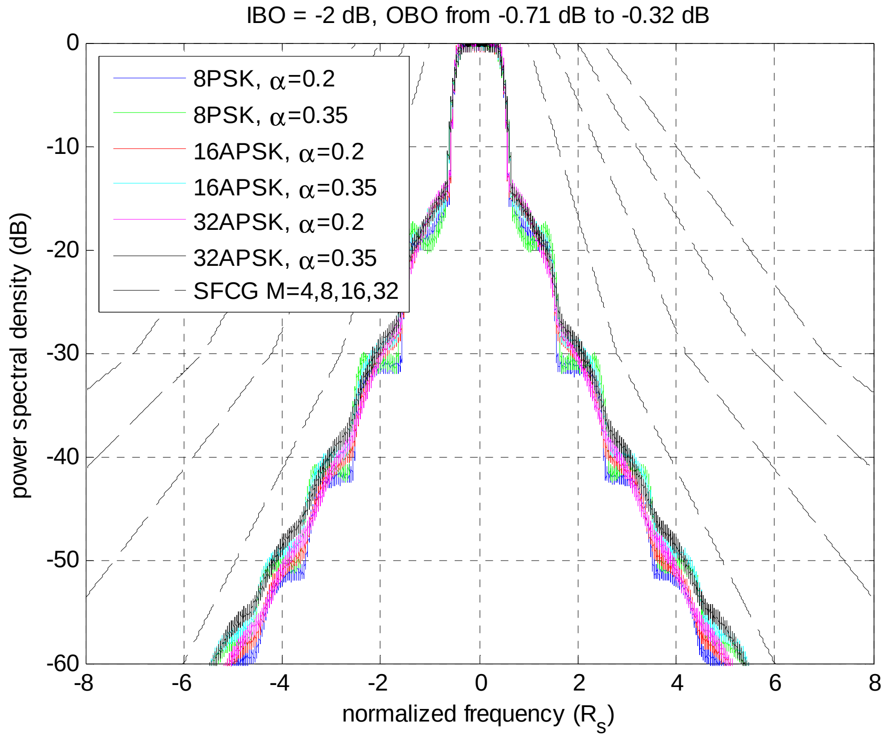
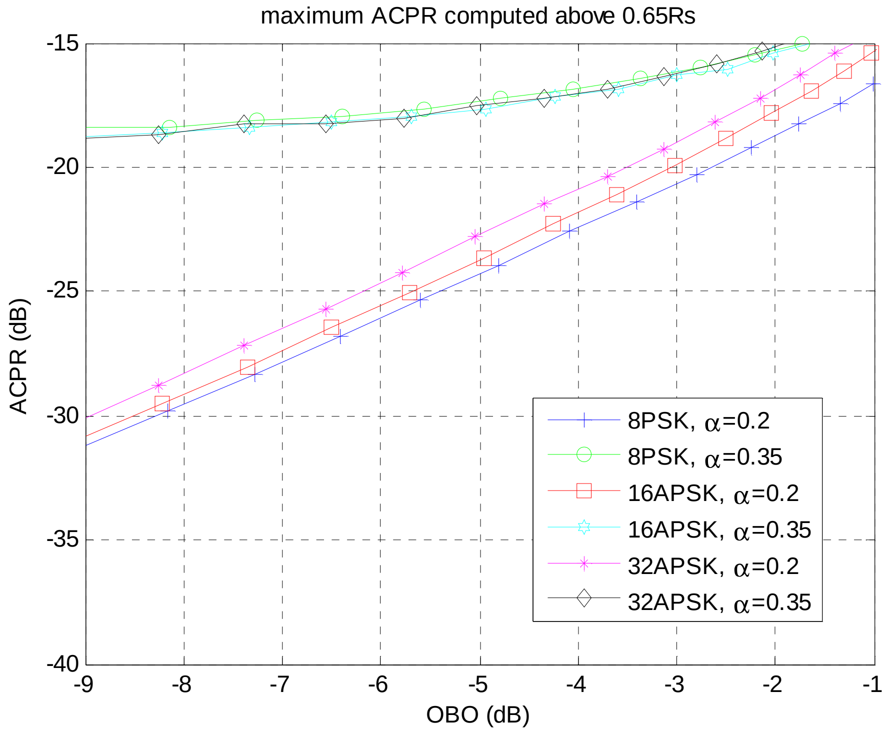
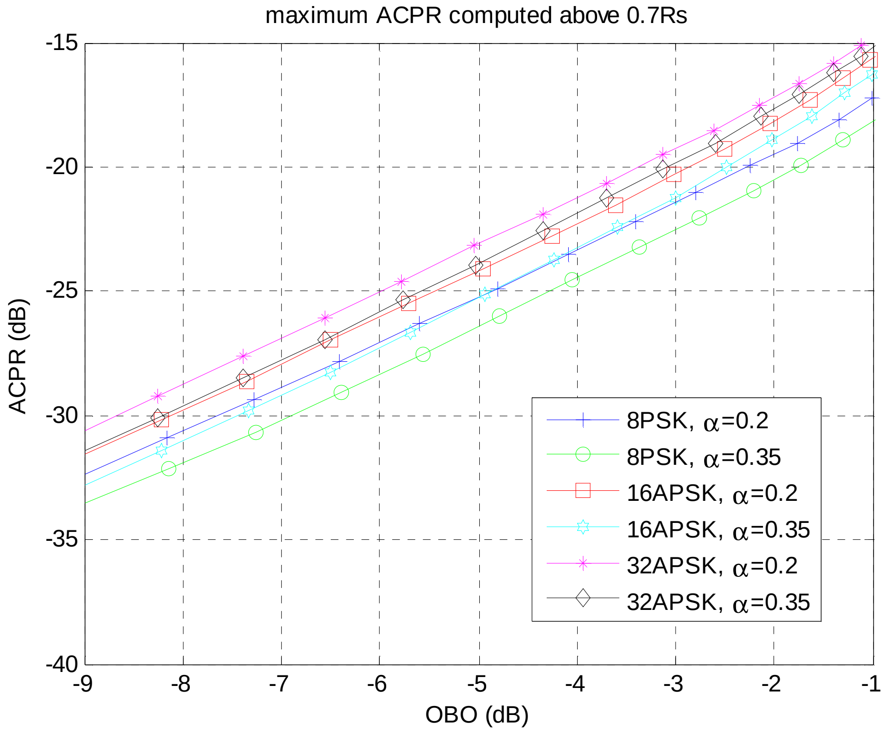
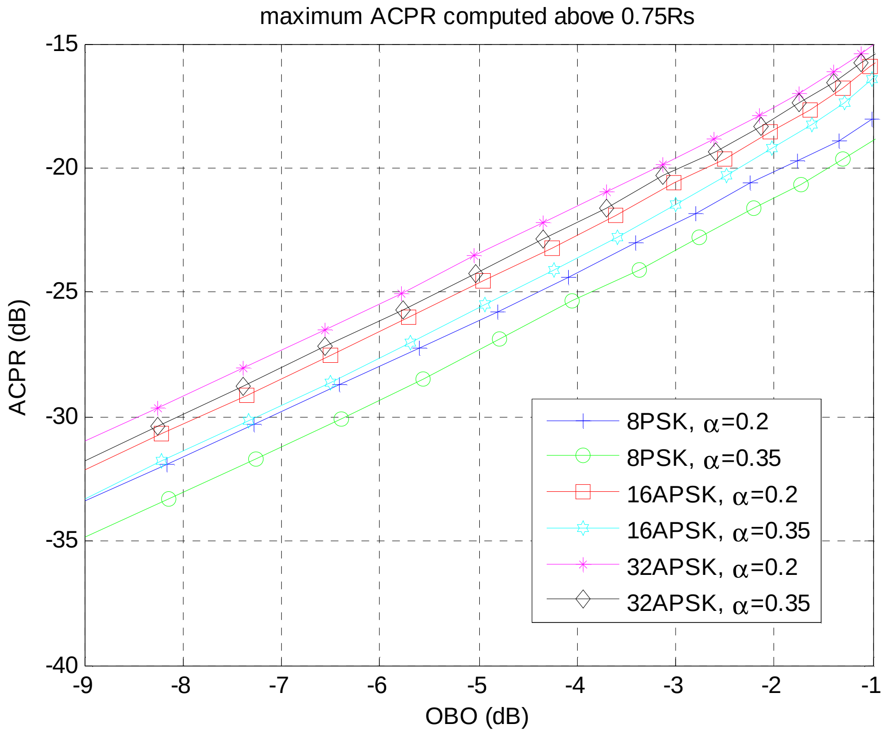


Figure 5-15: PSD at the PA output for various IBO




maximum ACPR computed above 0.7Rs
ACPR (dB)
OBO (dB)
-15
-20
-25
-30
-35
-40
-9
-8
-7
-6
-5
-4
-3
-2
-1
8PSK, α=0.2
8PSK, α=0.35
16APSK, α=0.2
16APSK, α=0.35
32APSK, α=0.2
32APSK, α=0.35


maximum ACPR computed above 0.75Rs
ACPR (dB)
OBO (dB)
-15
-20
-25
-30
-35
-40
-9
-8
-7
-6
-5
-4
-3
-2
-1
8PSK, α=0.2
8PSK, α=0.35
16APSK, α=0.2
16APSK, α=0.35
32APSK, α=0.2
32APSK, α=0.35

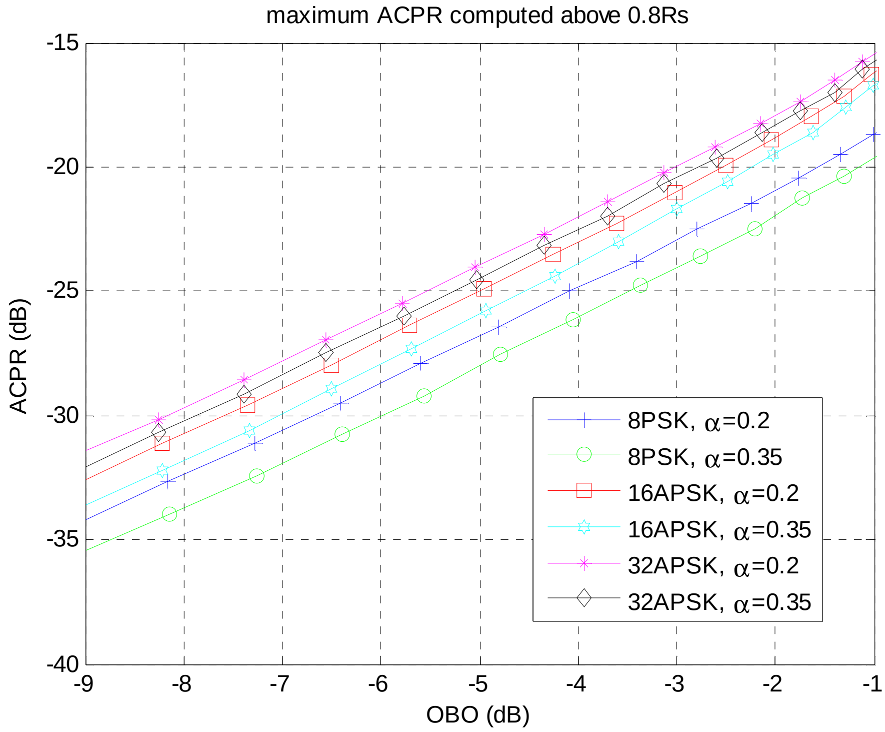


Figure 5-16: ACPR at the PA output

5.5 EXAMPLE OF DEMODULATION LOSS MEASURED ON A HDRT RECEIVER

This section provides an example of demodulation loss for a modern apparatus including a high data rate receiver and a test transmitter. No channel impairment except AWGN is considered for the measurement. The roll-off value 0.35, normal FECFRAME is used, and pilot symbols are inserted.

The results are shown in Table 5-5.

It is worth noting that:

- These results were obtained without dynamic equalization (hence slightly better results seem achievable),
- The demodulation loss includes degradation from the test transmitter and from the receiver.

	MODCOD	Demodulation loss 100 MBauds (dB)	Demodulation loss 300 MBauds (dB)	Demodulation loss 500 MBauds (dB)	Demodulation loss 600 Mbauds (dB)
QPSK	1	1.6	1.3	1.3	1.2
	2	1.5	1.4	1.1	1.4
	3	1.5	1.1	1.0	1.1
	4	1.1	0.7	0.7	0.9
	5	0.9	0.7	0.7	0.8
	6	0.7	0.5	0.5	0.6
	7	0.7	0.5	0.5	0.7
	8	0.6	0.4	0.5	0.6
	9	0.6	0.4	0.5	0.6
	10	0.6	0.4	0.6	0.6
	11	0.7	0.4	0.6	0.6
8PSK	12	1.5	1.3	1.2	1.5
	13	1.2	1.0	1.0	1.1
	14	1.1	0.9	0.9	1.0
	15	0.9	1.0	0.8	1.0
	16	0.7	0.6	0.7	0.8
	17	0.7	0.5	0.7	0.8
16APSK	18	1.0	0.9	1.0	0.9
	19	0.9	0.8	1.0	0.9
	20	0.9	0.7	0.9	0.9
	21	0.7	0.6	0.9	0.8
	22	0.7	0.6	0.8	0.8
	23	0.7	0.7	0.9	0.9
32APSK	24	1.2	1.2	1.7	1.5
	25	1.2	1.3	1.6	1.5
	26	1.1	1.1	1.5	1.4
	27	1.1	1.3	1.6	1.5
	28	0.9	1.4	1.7	1.6

Table 5-5: Example of demodulation loss measured on a modern receiver

For the lowest coding rates of a given modulation, the demodulation loss is higher than for other coding rates because of the higher noise level in the carrier tracking loop.

For the highest coding rates of a given modulation, the demodulation loss can be slightly higher than for the medium coding rates because of the higher sensitivity to frequency selectivity from the transmitter and the receiver (due to the higher required E_s/N_0).

ANNEX A

ACRONYMS AND TERMS

16APSK	16-ary Amplitude and Phase Shift Keying
32APSK	32-ary Amplitude and Phase Shift Keying
8PSK	8-ary Phase Shift Keying
ACM	Adaptive Coding and Modulation
ACPR	Adjacent Channel Power Ratio
AOS	Advanced Orbiting Systems
ASIC	Application Specific Integrated Circuit
ASM	Attached Synchronization Marker
BB	BaseBand
BBFRAME	BaseBand Frame in the DVB-S2 standard
BBHEADER	Header of BBFRAME in the DVB-S2 standard
BCH	Bose-Chaudhuri-Hocquenghem
BPSK	Binary Phase Shift Keying
CADU	Channel Access Data Unit
CCM	Constant Coding and Modulation
CCSDS	Consultative Committee for Space Data Systems
CP	Constellation Predistorsion
CRC	Cyclic Redundancy Check
DFL	Data Field Length in the DVB-S2 standard
DL	Demodulation Loss
DVB	Digital Video Broadcasting project
DVB-S2	DVB System of second generation for satellite broadcasting
Eb/No	bit Energy and Noise power spectral density No ratio
EESS	Earth Exploration Satellites Systems
EIRP	Equivalent Isotropic Radiated Power
Es/No	channel symbol Energy and Noise power spectral density No ratio
ETSI	European Telecommunications Standards Institute
FEC	Forward Error Correction
FECFRAME	Forward Error Correction FRAME in the DVB-S2 standard
FER	FECFRAME Error Rate
GS	Generic Stream
HDRT	High Data Rate Telemetry
IBO	Input Back-Off
ITU	International Telecommunications Union
LDPC	Low Density Parity Check
LLR	Log-Likelyhood Ratio
LVDS	Low Voltage Differential Signalling
MODCOD	Modulation and Coding identifier of the DVB-S2 standard
MPEG	Moving Pictures Experts Group
MSB	Most Significant Bit
NA	Not Applicable

OBO	Output Back-Off
OID	Only Idle Data in its Data Field
OSI	Open Systems Interconnection
PA	Powre Amplifier
PFD	Power Flux Density
PSD	Power Spectral Density
PLFRAME	Physical Layer Frame in the DVB-S2 standard
PLHEADER	Header of the PLFRAME in the DVB-S2 standard
QPSK	Quaternary Phase Shift Keying
RF	Radio Frequency
SFCG	Space Frequency Coordination Group
SNR	Signal power to Noise power Ratio
SOF	Start Of Frame
SRC	Square root Raised Cosine shaping
SYNC	SYNChronization byte
TD	Total Degradation
TM	TeleMetry
TWTA	Travelling Wave Tube Amplifier
VCM	Variable Coding and Modulation
VHDL	VHSIC (Very High Scale Integrated Circuits) Hardware Description Language

ANNEX B

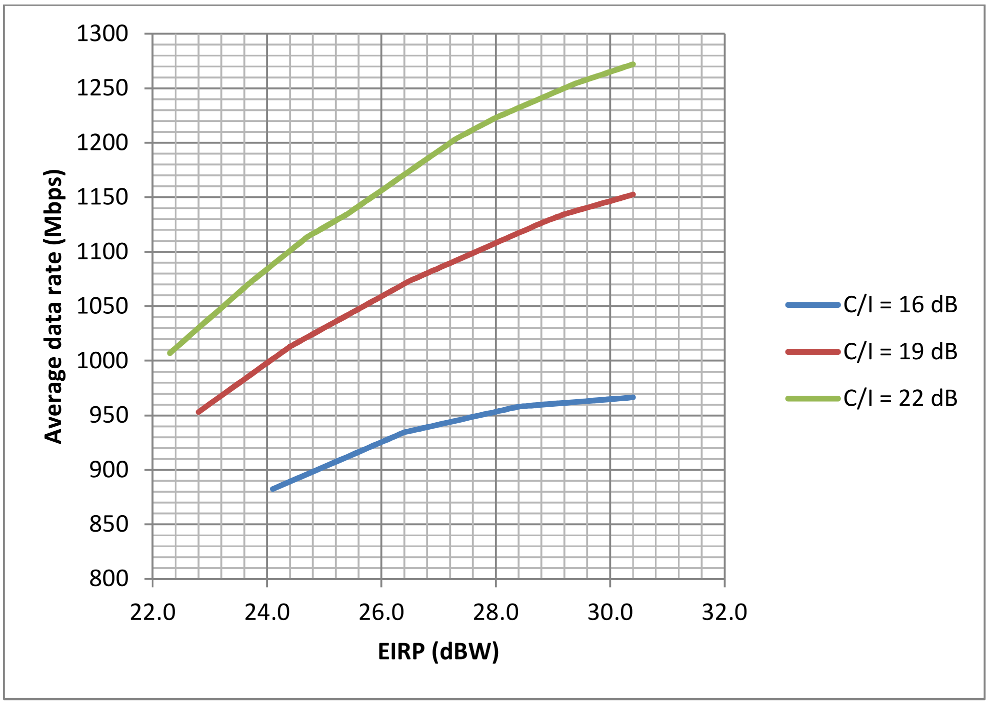
EXAMPLE OF SYSTEM PERFORMANCE WHEN USING DVB-S2 VCM AND ACM

Example 1

Hypotheses:

- X-band EESS with VCM
- DVB-S2 with normal FECFRAME, pilots, all MODCODs
- Heliosynchronous satellite at 700 km height
- Earth station in Toulouse (France) with clear sky G/T = 30.5 dBK^{-1} at 5° elevation
- 1 HDRT channel at 300 Msps
- Pointed antenna
- Average data rate computed on all satellite passes with elevation > 5°
- C/I = overall interference on the link (transmitter own degradation, power amplifier non-linearity, intersymbol interference, potential cross-polarization interference)
- Unavailibility for tropospheric propagation equal to 1%
- ITU recommendations for tropospheric propagation
- System margin 3 dB

Results:

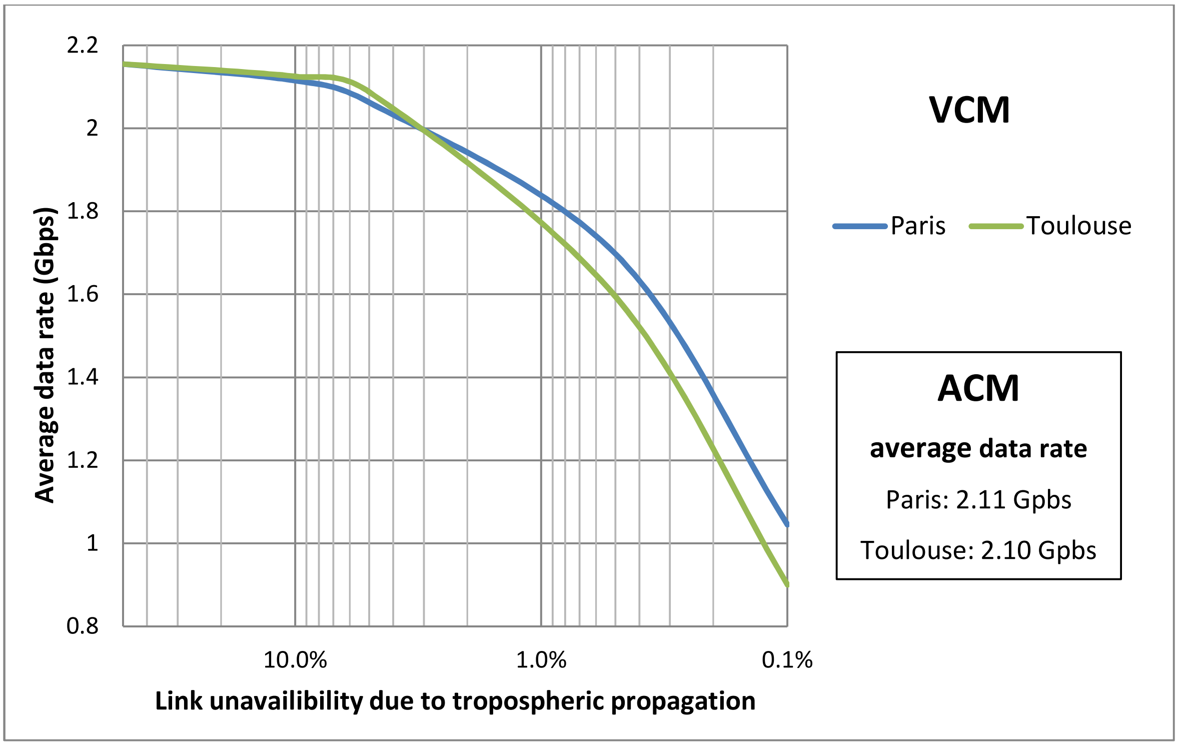


Remark: it appears possible to consider 2 channels at 300 Msps (1 channel per polarization)

Example 2

Hypotheses:

- Ka-band EESS with VCM or ACM
- DVB-S2 with normal FECFRAME, pilots, all MODCODs
- Heliosynchronous satellite at 600 km height
- Earth station in Toulouse (France) or Paris (France) with clear sky G/T = 36 dBK^{-1} at 5° elevation
- 1 HDRT channel at 500 Msps
- Pointed antenna with EIRP 38.4 dBW
- Average data rate computed on all satellite passes with elevation > 5°
- C/I = overall interference on the link (transmitter own degradation, power amplifier non-linearity, intersymbol interference, potential cross-polarization interference) = 19 dB
- ITU recommendations for tropospheric propagation
- System margin 3 dB



Remark: it appears possible to consider 4 channels at 500 Msps (2 channels per polarization)

ANNEX C

POINTERS TO ETSI DVB-S2 USER GUIDELINES [3] SECTIONS OF INTEREST FOR TELEMETRY APPLICATIONS, AND TO OTHER TECHNICAL REPORTS OF INTEREST FOR RECEIVER IMPLEMENTATION

<u>ETSI DVB-S2 User Guidelines [3]</u>

Section 4.3.2.1 (p. 19): single carrier per transponder configuration

4.3.2.1.1: sensitivity to satellite power amplifier characteristics

4.3.2.1.2: sensitivity to roll-off

Annex A (p. 63): Low Density Parity Check Codes

A.1: Structure of Parity Check Matrices of Standardized LDPC Codes

A.2: Description of Standardized LDPC Codes

A.3: Performance Results

Annex B (p. 69): DVB-S2 Physical Layer Frame and pilot structure

B.1: Structured PLS code Frame Synchronization

B.2: Pilot Structure

Annex C (p. 73): Modem algorithms design and performance over typical satellite channels

C.1: Modulator with predostorsion

C.2: Clock recovery

C.3: Physical Layer Frame Synchronization

C.3.1: An algorithm for Frame Synchronization

C.3.2: An Alternative Frame Synchronization Algorithm

C.3.2.1: Acquisition procedure description

C.3.2.2: Performance Analysis

C.3.2.3: Acquisition parameters optimization

C.4: Carrier Frequency Recovery

C.5: Automatic Gain Control

C.6: Carrier Phase Recovery

C.6.1: Pilot-Aided Linear Interpolation

C.6.2: Fine Phase Recovery for High Order Modulations

C.7: Performance Results

Annex E.1 (p. 95): Channel estimator

<u>Other technical reports</u>

Frame synchronization: [26]

SNR estimation: [20][21]

LLR computation: [23][24][25]

LDPC decoding: [22][27][28]