CCSDS TELEMETRY OVER DVB-S2: CHARACTERISTICS, RECEIVER IMPLEMENTATION AND PERFORMANCES

A. Guérin (1), J.-P. Millerioux (1), X. Deplancq (1), G. Lesthievent (1), M. Llauro (2), N. Pasternak (2), S. Baissac (2)

(1) Centre National d'Etudes Spatiales (CNES),
18 Avenue E. Belin, 31401, Toulouse cedex 9, France
Emails: alexandre.guerin@cnes.fr, jean-pierre.millerioux@cnes.fr, xavier.deplancq@cnes.fr, guy.lesthievent@cnes.fr

(2) Zodiac Data Systems, Aerosafety & Technology,
5 Avenue des Andes, 91978 Courtaboeuf cedex, France
Emails: mathieu.llauro@zodiacaerospace.com, nicolas.pasternak@zodiacaerospace.com, sylvain.baissac@zodiacaerospace.com

ABSTRACT

The CNES (French Space Agency) has recently proposed to apply the ETSI DVB-S2 telecom standard onto the CCSDS ones (currently "red book") to cope with the high data rate requirement of Telemetry for Earth Observation Satellites. A very high data rate implementation (up to 400 MBauds) of this recommended standard has been achieved by Zodiac Data Systems onto their Cortex HDR XXL receiver. This paper presents the latest version of that recommended standard as well as results obtained with the Cortex demodulator. A specific focus is done on the extremely low degradation performed at high rate, even with 32APSK modulation.

INTRODUCTION

The constant increase of data generated by Earth Exploration Satellite Systems (EESS) leads to strong requirements on data volumes to be downloaded on Earth ground stations. New innovative modulation and coding schemes are therefore required in order to satisfy this ever-growing throughput and to match the bandwidth and/or power limited conditions of satellite channels. Similarly, in a commercial context, the high demand in TV broadcasting and High capacity Broadband has pushed the DVB and ETSI organizations to define a new satellite communication standard called DVB-S2, well suited to high data rate transmissions with high power and bandwidth efficiencies. The DVB-S2 standard also allows the adaptation of the transmission scheme to the channel conditions thanks to Variable or Adaptive Coding and Modulation (VCM or ACM) offering consequently a better margin management and throughput increase.

Taking these facts into account CNES (French Space Agency) has proposed to use that advanced communication techniques of DVB-S2 for Earth Observation satellites. Synergies between EESS and Telecom domains are hence maximized. One of the huge advantages of the DVB-S2 standard for telemetry is the possibility to use VHDL Intellectual Property (IP) modules from the telecom market for the on-board or ground developments, and even hardware components from the telecom market for ground developments. A standard has thus been proposed as a CCSDS Red Book to define a recommended interface between CCSDS Space Link Protocols and the DVB-S2 telecom standard, which is well-suited to high data rate telemetry applications, such as EESS payload telemetry.

In this context Zodiac Data Systems has developed with CNES a very high data rate DVB-S2 receiver on a Cortex HDR-XXL basis. This new equipment includes also a high data rate DVB-S2 transmitter, which can be connected to the receiver. This modem integrates functioning in CCM and VCM modes with modulation and coding schemes according to the DVB-S2 standard: modulations from QPSK to 32APSK associated to all encodings of the EN302307 norm have been implemented. The equipment is compliant with the new CCSDS proposed standard and can support data rates up to 400 MBauds with limited degradation.

This paper details first the main general characteristics of the DVB-S2. The CCSDS over DVB-S2 red book is then presented in its last version. The implementation of the DVB-S2 on a Cortex HDR-XXL is also described and the obtained performances are finally given.

1. MAIN CHARACTERISTICS OF THE DVB-S2 STANDARD

DVB-S2 is the second-generation specification for satellite broadcasting developed by the DVB (Digital Video Broadcasting) Project of ETSI organization in 2004, with small corrections in 2006 and 2009. The DVB-S2 standard is fully described in [1]. It implements advanced modulations techniques (QPSK, 8PSK, 16APSK and 32 APSK) with low Square Root Raised Cosine (SRRC) roll-off (down to 0.2) and a wide range of coding rates (from 1/4 to 9/10). In the DVB-S2 terminology a combination of a modulation and a coding rate is called a MODCOD. Figure 1 gives the functional block diagram of the DVB-S2 standard for a Generic Continuous Stream transmission [2], with the following main functions:

- Mode and Stream Adaptation
- Forward Error Control (FEC) Encoding
- Physical Layer (PL) Framing and Modulation

The mode and stream adaptation functions achieve buffering, slicing, signaling and scrambling of the input data to generate the protocol data unit called BaseBand Frame (BBFRAME). The signaling corresponds to a header insertion (BBHEADER) so as to notify the receiver of the input stream format and Mode Adaptation type. The scrambling is performed to guaranty independence to the data contents ensuring sufficient bit transitions and bit equiprobability.

The Forward Error Control encoding provides near Shannon limit error protection. The combined use of Low Density Parity Check Code (LDPCC) as inner code and Bose-Chaudhuri-Hocquenghem (BCH) bloc code as outer code avoids error rate flattening. Bit interleaving is also applied to the FEC coded bits, which results in the so-called FECFRAME. Two sizes of such FECFRAMEs are possible in the DVB-S2 standard: the normal FECFRAME with 64800 coded bits or the short FECFRAME having 16200 coded bits.

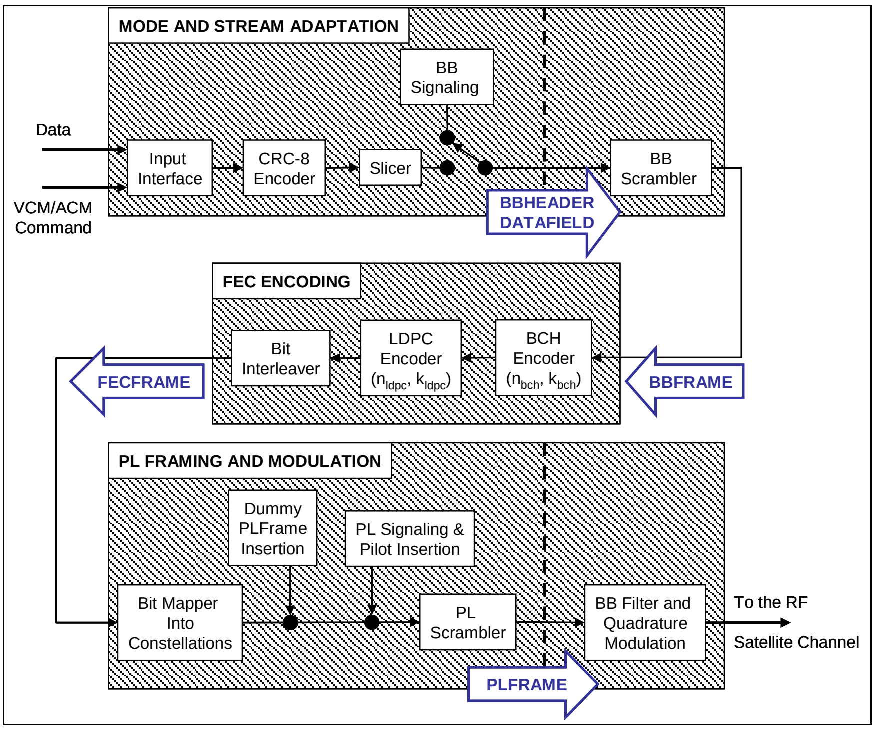

Figure 1: Functional Block Diagram of the DVB-S2 Standard.

The Physical Layer Frame (PLFRAME) is then obtained by mapping the coded bits of the FECFRAME with a specific header (PLHEADER) and optional pilots' symbols distributed along the frame. For robustness purpose, this PLHEADER and those pilot symbols are scrambled and modulated with a very robust scheme in order to help the demodulator in low Signal-to-Noise Ratio (SNR) conditions. The content of the PLHEADER allows identification of the PLFRAME start but also the chosen coding and modulation (defined at the frame level), the length of the frame (normal or short) and the use of pilot symbols or not. Specific dummy frames can also be inserted at this level when no data are present at the interface, so as to continue frame transmission. Those specific dummy frames can easily be identified and suppressed at the receiver side without any ambiguity. Finally, baseband filtering (SRRC) and quadrature modulation are applied to shape the signal spectrum and to generate the satellite RF signal.

The DVB-S2 standard offers thus a very robust and independent Physical Layer that allows the change of modulation and coding without any data loss. It can indeed propose a Variable Coding and Modulation mode (VCM), which adapts the transmission scheme, i.e. the MODCOD, to the channel conditions following a predetermined schedule (for example following a dynamic link budget). When a channel is available to provide feedback (e.g. via a return link in telecom, or a telecommand link for telemetry), the transmission scheme can be dynamically adjusted using the Adaptive Coding and Modulation mode (ACM) in real time. By using VCM/ACM capabilities of DVB-S2 for High Data Rate Payload Telemetry of EO satellites it is possible to keep a global worst case margin as low as possible. Non useful power margin is switched into increased bit rate offering then about 30% of gain in spectral efficiency compared to Constant Coding Modulation (CCM) transmissions (cf. [3]). Taking these advantages into account CNES has proposed to use that advanced communication techniques of DVB-S2 for EO satellites.

2. CCSDS SPACE LINK PROTOCOLS OVER ETSI DVB-S2 STANDARD

A CCSDS Red Book standard [4] has been prepared by CNES to define a recommended interface between CCSDS TM and AOS Space Link Protocols, specified in [5] and [6] respectively, and the DVB-S2 telecom standard [1]. This recommended standard [4] is an adaptation profile describing how to use the DVB-S2 standard to transmit CCSDS Transfer Frames for telemetry purpose. It specifies a method to generate a data stream including CCSDS Transfer Frames received from the layer above by embedding each CCSDS Transfer Frames with an Attached Sync Marker (ASM) into a Channel Access Data Unit (CADU). ASM and CADU are defined in [8]. The recommended standard specifies also the DVB-S2 options to transmit CADU streams.

Figure 2 illustrates the frames structures and stream formats at different stages of processing for the sending end. The ASM is introduced before transmission to achieve CCSDS Transfer Frame synchronization at the receiver side. CADU streams are then sliced into DVB-S2 DATAFIELD blocks thanks to the DVB-S2 Mode and Stream Adaptation function that has been introduced in the previous chapter. The Radio-Frequency signal shall finally conform to the DVB-S2 standard [1]. At the receiving end, the DVB-S2 demodulator accepts a Radio-Frequency modulated signal and delivers a CADU stream. The Transfer Frame synchronization with ASM allows then the recovery of the CCSDS Transfer Frames from the CADU stream and allows finally the delivery of these frames to the Data Link Protocol Sublayer.

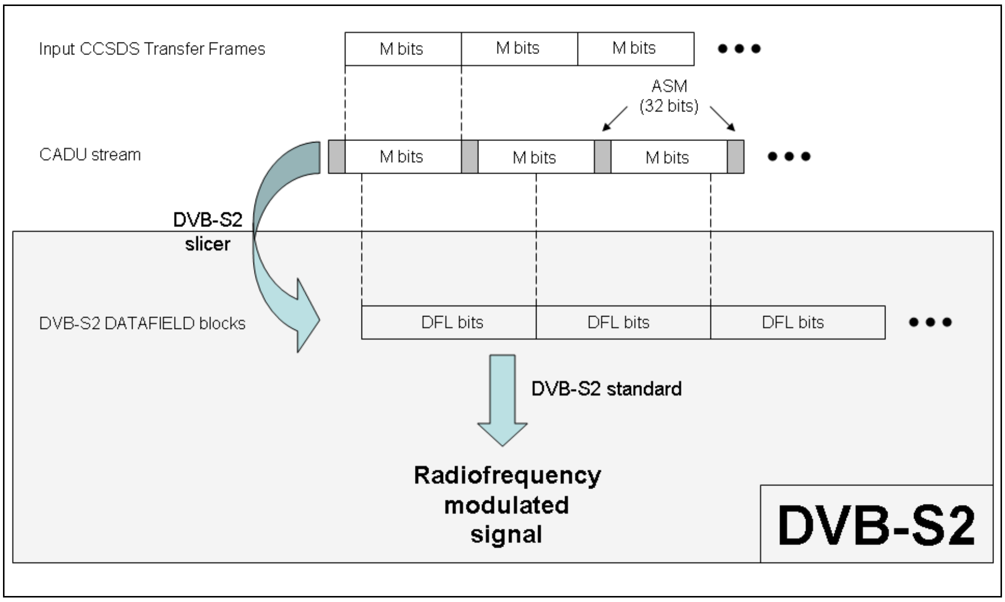

Figure 2: Stream format while transmitting CCSDS Transfer Frames using DVB-S2, cf. [4].

The Input Transfer Frames can either be TM Transfer Frames as specified in [5] or AOS Transfer Frames as specified in [6]. Their length shall thus vary between 223 octets (1784 bits) and 2048 octets (16384 bits). For each Transfer Frame, the system constructs a CADU containing the ASM and the CCSDS Transfer Frame. The CADU stream consists consequently of a stream of fixed length Transfer Frames with each Transfer Frame preceded by an ASM.

The CADU streams are then transmitted with a DVB-S2 process using the single input continuous Generic Stream (GS) mode adaptation format of the DVB-S2 standard (cf. [1] § 5.1). Note that no particular alignment between the Transfer Frames of the CADU stream and the DVB-S2 DATAFIELD is needed. The DVB-S2 slicer of the recommended standard shall however allocate a number of input bits equal to the maximum DVB-S2 DATAFIELD capacity for the current MODCOD. The transmitted BBHEADER within this recommended standard shall conform to the DVB-S2 standard, which allows to guaranty compatibility with DVB-S2 commercial telecom receivers with appropriate options. Concerning the DVB-S2 transmitter, it can be noticed that the BBHEADER does not have to change during a CCM transmission, and the BBHEADER only has to change with the current MODCOD during a VCM/ACM transmission.

Two possibilities are available to maintain the link continuity if needed. Either the DVB-S2 transmitter can insert Dummy PLFRAME within the PLFRAMING function, or a CCSDS OID Transfer Frame (cf. [5] and [6]) can be inserted at the sending end by the service user. The DVB-S2 receiver shall suppress Dummy PLFRAME whenever present. To finish with link continuity aspects, it should be raised that the channel symbol rate does not change during a transmission [1], even when VCM/ACM is used, resulting in the same transmit spectral occupancy. The required input data rates have just to change whenever the MODCOD changes during a transmission. The required input data rates can be derived from the spectral efficiencies given in Table 1.

To comply with the recommended standard [4], it is currently proposed that the sender and the receiver shall implement specific DVB-S2 configurations, in order to avoid any blocking problem of interoperability while limiting the number of configurations to be implemented for receiving equipments. The sender shall be configurable to transmit a signal with short FECFRAME, pilot symbols insertion and at least one of the following MODCOD (using definitions given in [1] and recalled in Table 1): 4, 6, 7, 8, 9, 10, 13, 14, 15, and 16. The receiver shall accept at least signals with Constant Coding and Modulation (CCM), short FECFRAME, pilot symbols and all the following MODCOD: 4, 6, 7, 8, 9, 10, 13, 14, 15, and 16. It can be noticed that these configurations are likely the more widely implemented in DVB-S2 telecom equipments.

MODCOD	Modulation	LDPC code identifier	**Spectral efficiency [bits/symbol]**				**MODCOD**	Modulation	LDPC code identifier	**Spectral efficiency [bits/symbol]**			
			Short frame with pilots	Short frame without pilots	Normal frame with pilots	Normal frame without pilots				Short frame with pilots	Short frame without pilots	Normal frame with pilots	Normal frame without pilots
1	QPSK	1/4	0,3575	0,3653	0,4786	0,4902	**15**	8PSK	5/6	2,3351	2,3811	2,4223	2,4786
2	QPSK	1/3	0,6155	0,6291	0,6408	0,6564	**16**	8PSK	8/9	2,5280	2,5778	2,5859	2,6460
3	QPSK	2/5	0,7446	0,7609	0,7706	0,7894	**17**	8PSK	9/10	-	-	2,6184	2,6792
4	QPSK	1/2	0,8306	0,8488	0,9653	0,9889	**18**	16APSK	2/3	2,5052	2,5488	2,5746	2,6372
5	QPSK	3/5	1,1317	1,1565	1,1600	1,1883	**19**	16APSK	3/4	2,7616	2,8097	2,8963	2,9667
6	QPSK	2/3	1,2607	1,2884	1,2908	1,3223	**20**	16APSK	4/5	2,9326	2,9836	3,0905	3,1656
7	QPSK	3/4	1,3897	1,4203	1,4521	1,4875	**21**	16APSK	5/6	3,1035	3,1575	3,2219	3,3002
8	QPSK	4/5	1,4757	1,5082	1,5494	1,5872	**22**	16APSK	8/9	3,3599	3,4184	3,4395	3,5231
9	QPSK	5/6	1,5618	1,5961	1,6153	1,6547	**23**	16APSK	9/10	-	-	3,4827	3,5673
10	QPSK	8/9	1,6908	1,7280	1,7244	1,7665	**24**	32APSK	3/4	3,4192	3,4931	3,6233	3,7033
11	QPSK	9/10	-	-	1,7460	1,7886	**25**	32APSK	4/5	3,6308	3,7093	3,8662	3,9516
12	8PSK	3/5	1,6920	1,7253	1,7396	1,7800	**26**	32APSK	5/6	3,8424	3,9255	4,0306	4,1195
13	8PSK	2/3	1,8850	1,9220	1,9357	1,9806	**27**	32APSK	8/9	4,1599	4,2498	4,3029	4,3979
14	8PSK	3/4	2,0779	2,1188	2,1775	2,2281	**28**	32APSK	9/10	-	-	4,3569	4,4530

Table 1: DVB-S2 MODCODs and associated spectral efficiencies, cf. [4].

3. RECEIVER IMPLEMENTATION OF CCSDS OVER DVB-S2

Zodiac Data Systems has developed with CNES a very high data rate DVB-S2 receiver with VCM capabilities on a Cortex HDR-XXL basis. The Cortex HDR-XXL is a COTS very high data rate receiver depicted in **Figure 3**. It can be used for X-band and Ka/Ku-bands applications, with 720MHz and 1.2GHz IF inputs available. It is a versatile multi-mission receiver with a wide range of modulations and coding proposed (Viterbi, TCM, Reed-Solomon, LDPC …). It proposes a wide range of modulations (QPSK, 8PSK, 16APSK and 16QAM) and data rate up to 2 Gbps. It also has advanced capabilities such as blind equalization, cross-polarization cancellation or 32APSK/64APSK modulations support. This platform has a powerful FPGAs based design that provides abilities for advanced resources consuming decoders such as LDPC.

Figure 3: Zodiac Data Systems Cortex HDR-XXL.

Thanks to this development, the Cortex HDR-XXL implements all DVB-S2 standard [1] Physical Layer processing options. All modulations (QPSK, 8PSK, 16APSK and 32APSK), all frame sizes (short and normal), all coding schemes (1/4 to 9/10) and optional pilots fields are available. The receiver is designed for the highest data rate with a maximum modulation speed of 400 MBauds that means 1.6GBps coded data with a 16APSK modulation. The Cortex Receiver works both in CCM and VCM modes. In VCM configurations, the following parameters: modulation, coding ratio and pilots fields can be changed for each frame. For testing purposes a very high data rate transmitter with the same capabilities as the receiver has also been implemented.

Table 2 summarizes the available MODCOD configurations on HDR-XXL platform. All frame size and coding schemes are available for QPSK, 8PSK and 16APSK modulations. Optional advanced 32APSK configurations are also available.

MODCOD		Short frame	Normal frame	MODCOD		Short frame	Normal frame	MODCOD		Short frame	Normal frame
1	QPSK 1/4	B	B	**11**	QPSK 9/10	-	B	**21**	16APSK 5/6	B	B
2	QPSK 1/3	B	B	**12**	8PSK 3/5	B	B	**22**	16APSK 8/9	B	B
3	QPSK 2/5	B	B	**13**	8PSK 2/3	B	B	**23**	16APSK 9/10	-	B
4	QPSK 1/2	B	B	**14**	8PSK 3/4	B	B	**24**	32APSK 3/4	O	O
5	QPSK 3/5	B	B	**15**	8PSK 5/6	B	B	**25**	32APSK 4/5	O	O
6	QPSK 2/3	B	B	**16**	8PSK 8/9	B	B	**26**	32APSK 5/6	O	O
7	QPSK 3/4	B	B	**17**	8PSK 9/10	-	B	**27**	32APSK 8/9	O	O
8	QPSK 4/5	B	B	**18**	16APSK 2/3	B	B	**28**	32APSK 9/10	-	O
9	QPSK 5/6	B	B	**19**	16APSK 3/4	B	B	**29**	Dummy	B	
10	QPSK 8/9	B	B	**20**	16APSK 4/5	B	B				

Table 2: available configurations (B=Baseline, O=Optional).

The Cortex HDR XXL interfaces the DVB-S2 transmission protocol with the CCSDS transmission protocol (CADU stream). The implemented PLFRAME processor respects the DVB-S2 standard option “single continuous generic stream” and is compliant with the proposed CCSDS recommended standard [4]. The CCSDS CADU layer is linked with the DVB-S2 at BBFRAME layer level as described on **Figure 4**.

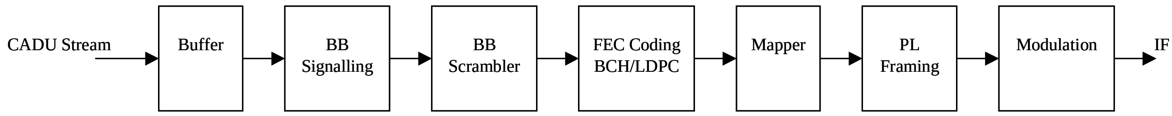

Figure 4: Implemented DVB-S2 functions on HDR-XXL

Figure 5 shows a block diagram of the DVB-S2 receiver that has to deal with two challenges: VCM switches without any synchronization loss and operating points at extremely low SNR. It can be noticed that the receiver is compliant with data rate adaptation using PL Layer Dummy frames. Dummy PLFRAME are thus identified and suppressed if necessary.

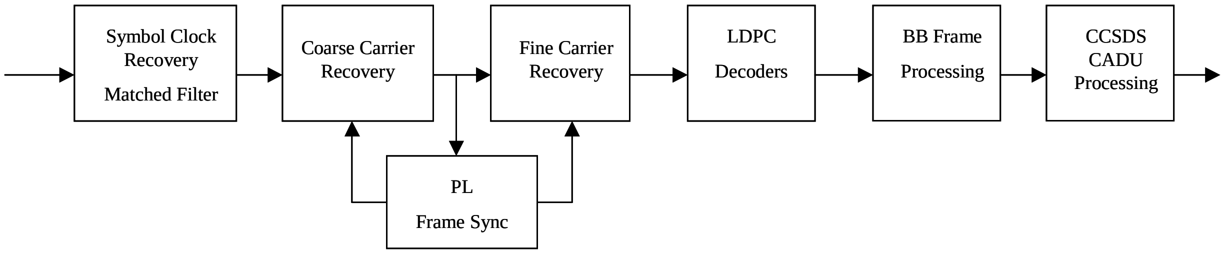

Figure 5: Block diagram of the HDR XXL DVB-S2 receiver.

Carrier recovery takes advantage of the static elements of the frame: headers and pilots. Since they are π/2-BPSK modulated, they allow synchronization at very low SNR (near -2 dB). In addition, they are the only invariant elements of the frame during the VCM switches. The use of pilots is strongly recommended to preserve good performances in all transmission conditions. Symbol clock recovery remains processed over data symbols since the modulation switches has no significant impact on it. That design preserves the receiver synchronization over the whole DVB-S2 operating range even if the SNR is below the MODCOD operating point.

To reach the highest data rate, several LDPC processors are used. The HDR-XXL platform provides the huge amount of FPGA resources requested by LDPC family decoders. These decoders have dynamic code switch abilities to operate in VCM environment.

4. CCSDS OVER DVB-S2 RECEIVER PERFORMANCES

Some measurements have been done with this new very high data rate DVB-S2 receiver to assess its performances. Figure 6, Figure 7, Figure 8 and Figure 9 show those performances in terms of Bit Error Rate (BER) obtained at 150 MBauds for respectively the DVB-S2 QPSK, 8PSK, 16APSK and 32APSK configurations. The abscissa is the constellation symbol energy to noise power spectral density ratio (Es/No), in dB. For each available MODCOD, the theoretical performances (dotted lines) are associated to the measured ones (continuous lines). These results have been obtained with normal frames, pilots’ insertion and with an SRRC roll-off of 0.35.

Figure 6 presents the limited degradation of all the DVB-S2 QPSK schemes. Except for the QPSK 1/4, which has a degradation of about 1.4 dB (impact of very low SNR receiving conditions), all the other coding schemes have degradations below 1dB. This degradation is even limited to 0.5 dB for the highest coding rates.

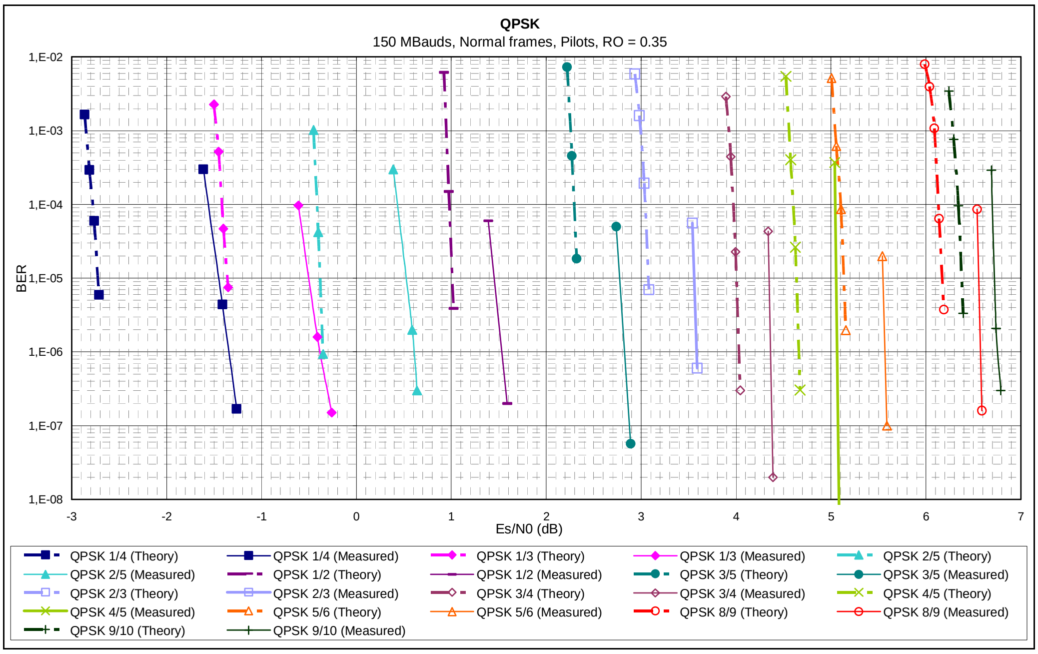

Figure 6: DVB-S2 QPSK performances at 150 MBauds with 0.35 Roll-Off.

The performances of the receiver at high data rate are also excellent in 8PSK. Figure 7 depicts that the degradation variations from 0.5 dB to 0.9 dB depending on the considered coding rate.

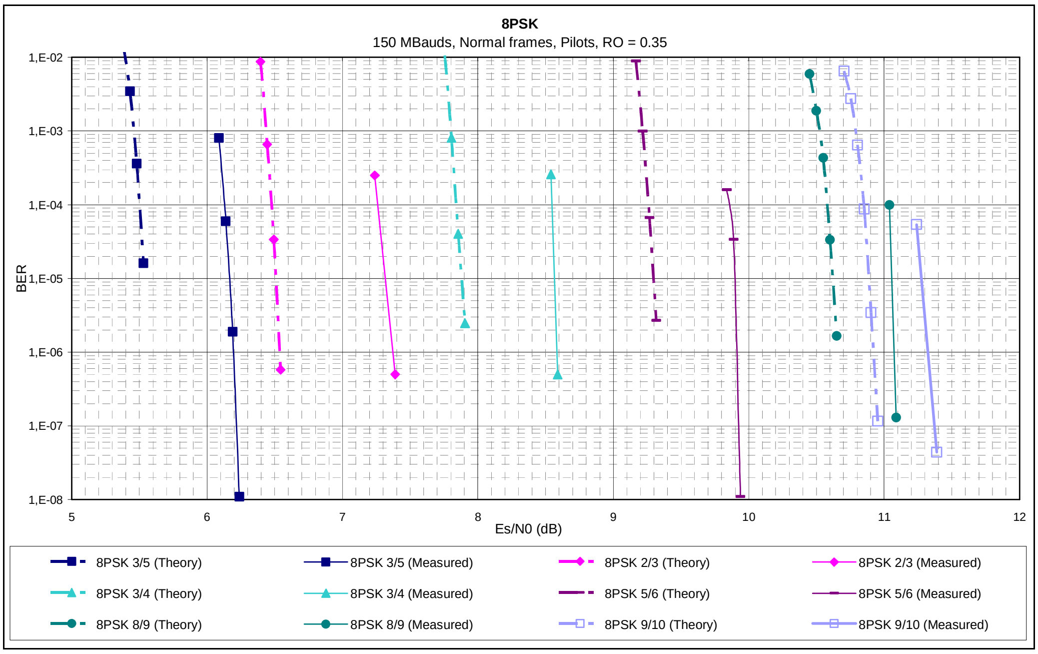

Figure 7: DVB-S2 8PSK performances at 150 MBauds with 0.35 Roll-Off.

As illustrated on Figure 8 the receiver degradation losses are very low even for 16APSK configurations having such high data rates (522 Mbps with the 9/10 coding rate). They are indeed lower than 0.7 dB, which is remarkable taking into account the highness of the symbol rate.

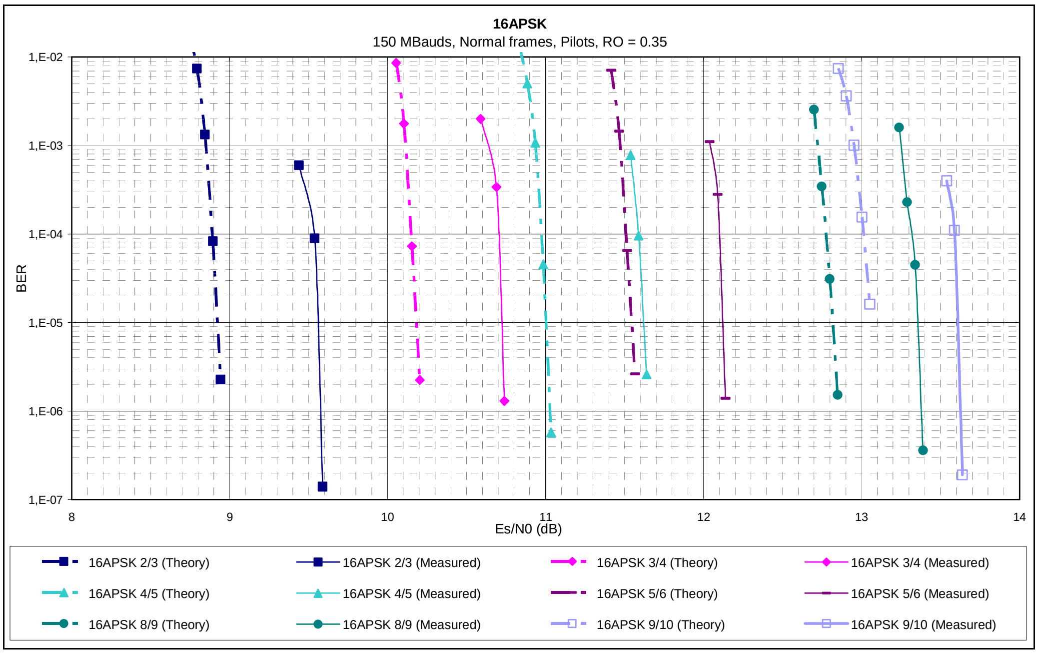

Figure 8: DVB-S2 16APSK performances at 150 MBauds with 0.35 Roll-Off.

For 32APSK, Figure 9 shows that the degradations are naturally increased to about 1.6 dB at 150 MBauds. These values are however very low for that kind of modulations at such high data rates, especially for a quite “classical” transmitter with no specific distortions compensation.

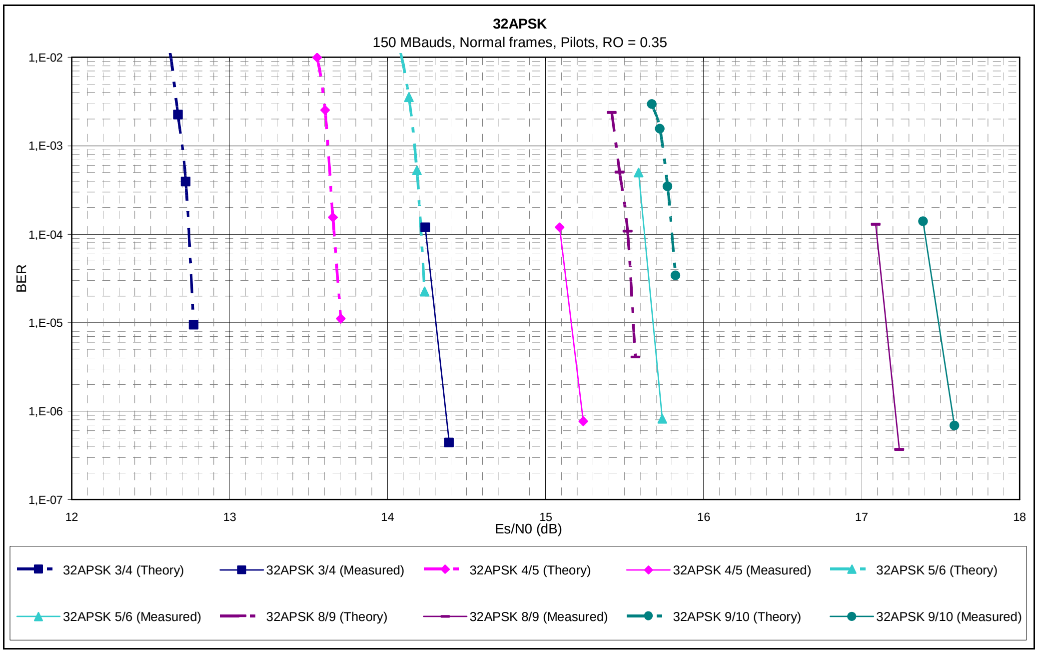

Figure 9: DVB-S2 32APSK performances at 150 MBauds with 0.35 Roll-Off.

It can be noticed that when performing extended measurements at higher data rates than 150 MBauds the additional degradation is also very low (<0.2 dB). Similar degradations have also been found with short DVB-S2 frames (normal behavior due to shorter LDPC codes).

CONCLUSION

DVB-S2 is well suited to high and very high data rate transmissions with high power and bandwidth efficiencies. CNES has thus proposed to use the advanced communication techniques of DVB-S2 for Earth Observation satellite. A CCSDS Red Book standard has consequently been proposed to link the CCSDS world to the DVB world, accessing then with limited investments to a new and performing LEO to Earth Very High Data Rate Telemetry link generation.

A very high data rate DVB-S2 receiver has also been developed by Zodiac Data Systems with CNES support. This receiver has been designed for the highest data rates with a maximum symbol rate of 400 MBauds and for modulations from QPSK to 32APSK associated to all possible encodings of the DVB-S2 standard. Excellent performances resulting in very limited degradations have finally been demonstrated.

REFERENCES

[1] ETSI, "Digital Video Broadcasting (DVB); Second Generation Framing Structure, Channel Coding and Modulation Systems for Broadcasting, Interactive Services, News Gathering and other Broadband Satellite Applications", ETSI EN 302 307 V1.2.1 (2009-08), France, Sophia-Antipolis, 2009.

[2] Lesthievent Guy, Deplancq Xavier, "Use of DVB-S2 standard for High and Very High rate TM links", Proceedings of Toulouse Space Show 2010, France, Toulouse, April 2010.

[3] Guérin Alexandre, Lesthievent Guy, Issler Jean-Luc, "Telemetry Architectures for future earth observation missions: Over 1 Gbit/s In X-band", Proceedings of ITC 2010, USA, San Diego, October 2010.

[4] CCSDS, "CCSDS Space Link Protocols Over ETSI DVB-S2 Standard", Recommendation for Space Data System Standards, CCSDS 131.3-R-20120502, Red Book, Issue 1, USA, Washington, April 2012.

[5] CCSDS, "TM Space Data Link Protocol", Recommendation for Space Data System Standards, CCSDS 132.0-B-1, Blue Book, Issue 1, USA, Washington, September 2003.

[6] CCSDS, "AOS Space Data Link Protocol", Recommendation for Space Data System Standards, CCSDS 732.0-B-2, Blue Book, Issue 2, USA, Washington, July 2006.

[7] ISO, "Information Technology - Open Systems Interconnection - Basic Reference Model: The Basic Model", International Standard, ISO/IEC 7498-1:1994, 2nd ed., Switzerland, Geneva, 1994.

[8] CCSDS, "TM Synchronization and Channel Coding", Recommendation for Space Data System Standards, CCSDS 131.0-B-1. Blue Book, Issue 2, USA, Washington, August 2011.