

**Consultative Committee on Space Data Systems
Space Link Services
Coding & Synchronization Working Group**

**CNES VCM in lab experiment for DVB-S2 High Data Rate
Telemetry
SLS-CS_13-06**

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Abstract: This article describes a “VCM (Variable Coding and Modulation) experiment” performed in the CNES HDRT laboratory. It consists in simulating an end-to-end transmission of data during a LEO satellite pass.

1. Introduction

The constant increase of data generated by Earth Exploration Satellite Systems (EESS) leads to strong requirements on data volumes to be downloaded to the ground. The CNES strategy for the next generation of High Data Rate Telemetry (HDRT) is to reuse a maximum of current X-band stations, in order to provide a continuity of service at reasonable cost for final users. It is important to carefully optimize the link as the bandwidth allocated to X-band EESS is limited to 375MHz.

The CNES proposes to apply the telecom standard DVB-S2 (Digital Video Broadcast by Satellite, 2nd generation) [1], adopted as a blue book in CCSDS as 131.3 [2], to maximize the HDRT throughput. This standard allows changing the modulation and coding rates during a pass and hence guarantees an optimum useful bit rate for all link budget conditions.

This article describes a “VCM (Variable Coding and Modulation) experiment” performed in the CNES HDRT laboratory. It consists in simulating an end-to-end transmission of data during a LEO satellite pass.

2. Principle and objective of the experimentation

The data is constituted of CCSDS transfer frames. These are read from a mass memory developed by the French company Steel Electronique [4], and fed to a Zodiac Data Systems' transmitter [5] embedded within a High Data Rate demodulator Cortex HDR, DVB-S2 compatible [3]. The coding and modulation changes are scheduled based on a pre-calculated link budget. The signal is then transmitted through a Propagation Channel Emulator to simulate the variation of attenuation and Doppler effect during a pass. The signal is finally demodulated, decoded and recorded by the Cortex HDR DVB-S2. It is then possible to post-process it to detect and visualize errors in CCSDS transfer frames. The objective of this experiment is to verify the feasibility of the data transfer with variable modulation and coding rate, to determine the required margin, and to acquire experience on the implementation.

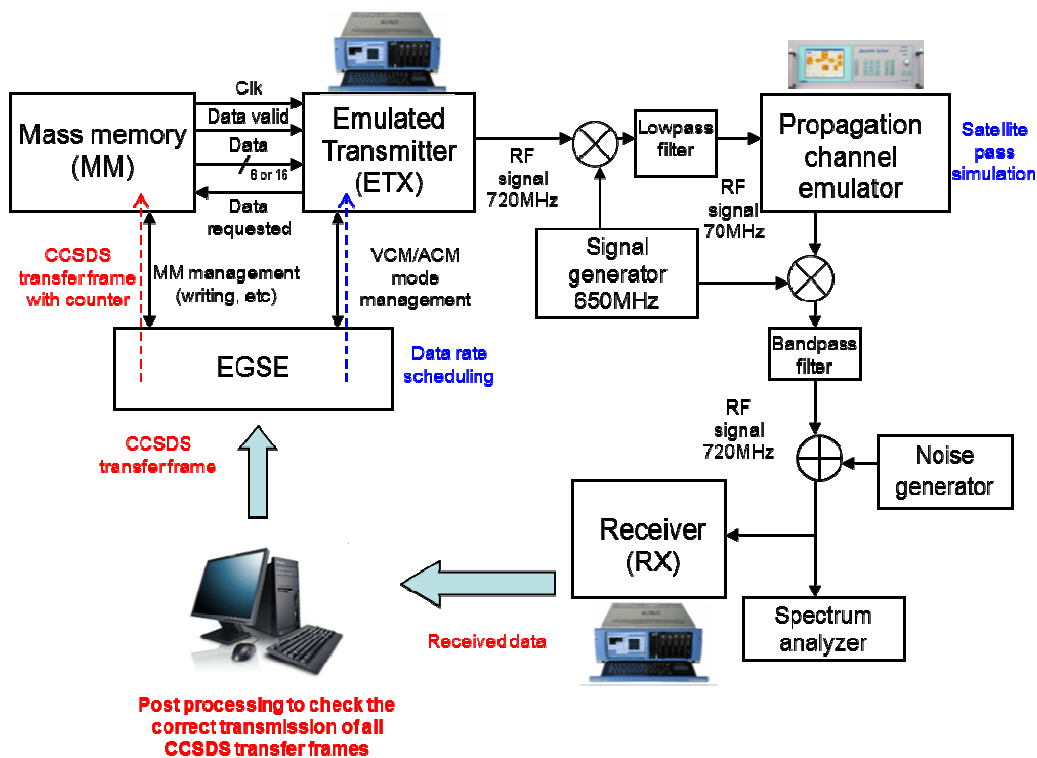


Figure 1: overall view of the experimentation

In order to maximize the throughput in the 375MHz bandwidth allocated to EESS in X-band, the CNES considers as a baseline the use of two carriers, each with a symbol rate of 150MBauds. However in this experiment the symbol rate is 25MBauds in order to fit in the 40MHz bandwidth of the Propagation Channel Emulator.

3. Equipment used

- Mass memory (**MM**) and its controller (**EGSE**) :

The mass memory and its controller are an upgrade of a testbench developed to prepare the next generation of CNES microsattellites by the French company STEEL Electronique [4].

The upgrade consists in developing a new output for the memory board to be able to interface it with the Emulated Transmitter (Cortex Test Modulator) for the data flow. The EGSE (Electrical Ground Support Equipment) is modified to integrate the VCM management unit which sends the VCM commands to the modulator.

The memory board provides three signals: clock, data_valid and the data (8 or 16 bits) and it receives the data_requested signal (See Figure 1).

The clock rate is 20MHz, therefore the maximum bitrate with the 8bit output is 160Mbits/s and at slower rates flow control is needed.

The VCM management unit is independent from the memory interface and has its own reference clock. It generates three signals: clock, code_word_load and code_word (1 bit), it receives the acknowledgement signal VCM_change. To program a modcod the controller sends a serialized 7-bit codeword, and an acknowledgement is sent by the modulator.

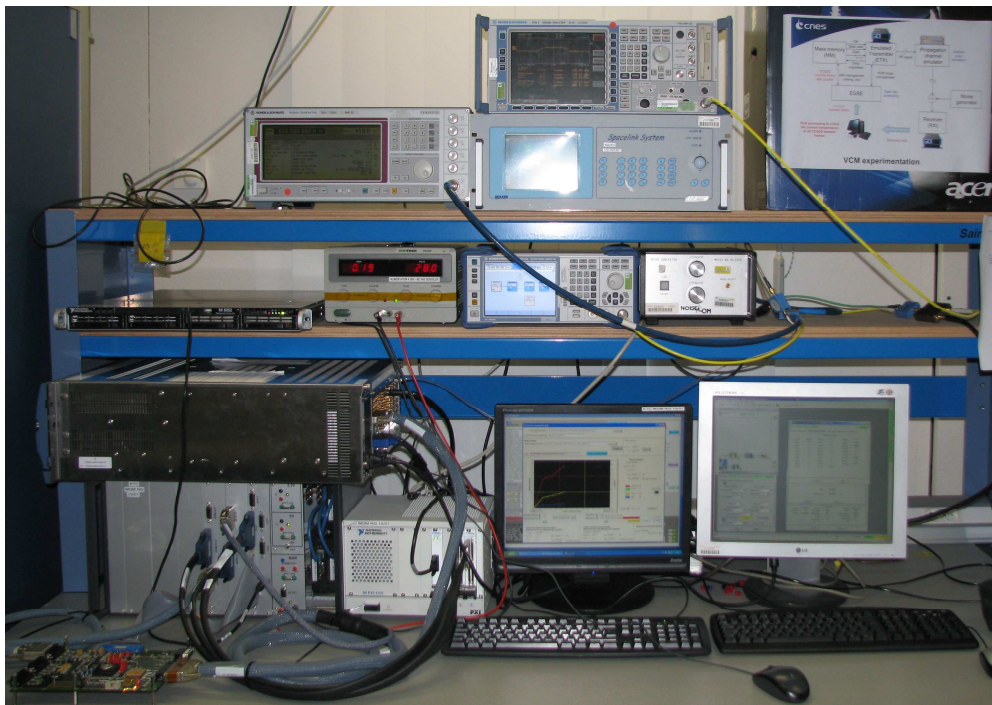


Figure 2: Photograph of the experimentation



Figure 3: VCM controller interface

- DVB-S2 Cortex demodulator by Zodiac Data Systems (**ETX** and **RX**) [5][3]

The equipment used for modulation and demodulation is primarily a demodulator but it also provides a test modulator which is used in this experiment. It has also been modified to provide data flow control and to handle external VCM commands.

The demodulator and test modulator can operate at 720MHz or 1200MHz with a symbol rate as high as 200MBauds in 32APSK and 400 Mbauds in QPSK. In this experimentation however, it is used at 25MBauds to fit in the 40MHz bandwidth of the Propagation Channel Emulator.

- Propagation Channel Emulator (ECP)

This equipment developed by ELTA [6] simulates the attenuation and Doppler effect during a satellite pass. It operates at 70MHz with a maximum bandwidth of 40MHz. In this simulation the attenuation varies from -12.7 to -1.4dB with 0.1dB step and 0.01s time resolution.

4. Process and results

4.1. Satellite pass profile

This profile corresponds to a Pleiades-1A satellite pass over Toulouse with maximum elevation. The transmission takes place for an elevation of 5° or higher: here it starts at 74 seconds (1.23minutes) and ends at 751.2s (12.52 min).

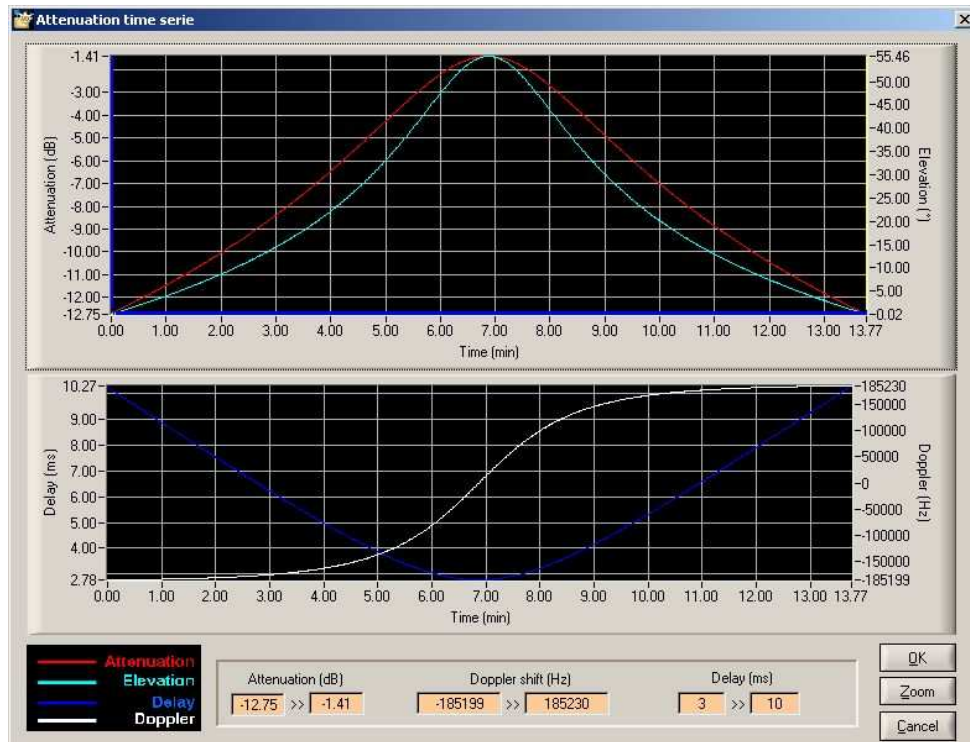


Figure 4: Pleiades-1A pass profile

4.2. Required E_s/N_0 for the Modcod used

MODCOD	MODCOD	E_s/N_0
14	8PSK 3/4	8.3
15	8PSK 5/6	9.9
19	16APSK 3/4	10.9
20	16APSK 4/5	11.6
21	16APSK 5/6	12.1
22	16APSK 8/9	13.4
26	32APSK 5/6	15.2
28	32APSK 9/10	16.9

The MODCOD whose required E_s/N_0 measured at a Frame Error Rate (FER) equal to 10^{-3} are worse than those with higher throughput are taken out as well as the ones whose required E_s/N_0 are too close to another.

4.3. Post treatment of the recorded data

After demodulation and decoding, the data is recorded in files by the Cortex, these files containing the CCSDS transfer frames first transmitted by the mass memory card are treated for error detection. The CCSDS transfer frames used include a 32-bit frame counter which enables to track missing and erroneous frames. Additionally, knowing precisely the modcod change times and the modcod bit rates, it is possible to calculate the number of frames transferred since the beginning of the scenario and therefore date all the received frames.

4.4. Transmission scenarios

We consider two main scenarios (depending on the assumed satellite EIRP):

1: start of transmission in 8PSK $\frac{3}{4}$ use of 16APSK and up to 32APSK 9/10

2: start of transmission in 16APSK $\frac{3}{4}$ up to 32APSK 9/10

When no errors are generated by a scenario, there is nothing to visualize. Therefore for the legibility of the results we will use scenarios with small or negative margins or a time offset between the attenuation and the VCM change commands. The reference level is the Signal to Noise Ratio at the start of the satellite pass: for an attenuation of 12.7dB.

- a. Scenario 2: transmission opened in 16APSK $\frac{3}{4}$, margin = -0.2dB, reference level = 9.3dB
- b. Scenario 1: transmission opened in 8PSK $\frac{3}{4}$, margin = 0.0dB, reference level = 6.9dB
- c. Scenario 2: transmission opened in 16APSK $\frac{3}{4}$, margin = 0.2dB, reference level = 9.6dB, delay = -6s
- d. Scenario 2: transmission opened in 16APSK $\frac{3}{4}$, margin = 0.2dB, reference level = 9.6dB, no delay (the goal is to find the minimum margin necessary to be error-free.)

4.4.1. Scenario 2: starting in 16APSK $\frac{3}{4}$, margin=-0.2dB

Here we can notice that there are errors at every modcod change. The errors are symmetrical which means that the VCM change commands are well synchronized with the attenuation in the propagation channel emulator.

There are a few errors in the middle of the pass unrelated to a modcod change. These are due to the Doppler effect, the Doppler rate being maximal at that time. When using another satellite pass profile with fewer Doppler: which matches the actual Doppler effect that would be felt at 150Mbauds -the expected rate in real conditions- instead of the experimentation rate of 25Mbauds, no errors are detected. (The Doppler effect influence is linked to the $\Delta f/R_s$, and is

more important at lower transmission rates). Solutions to improve the receiver behaviour at low data rates with the highest order modulations and high Doppler profiles are currently processed.

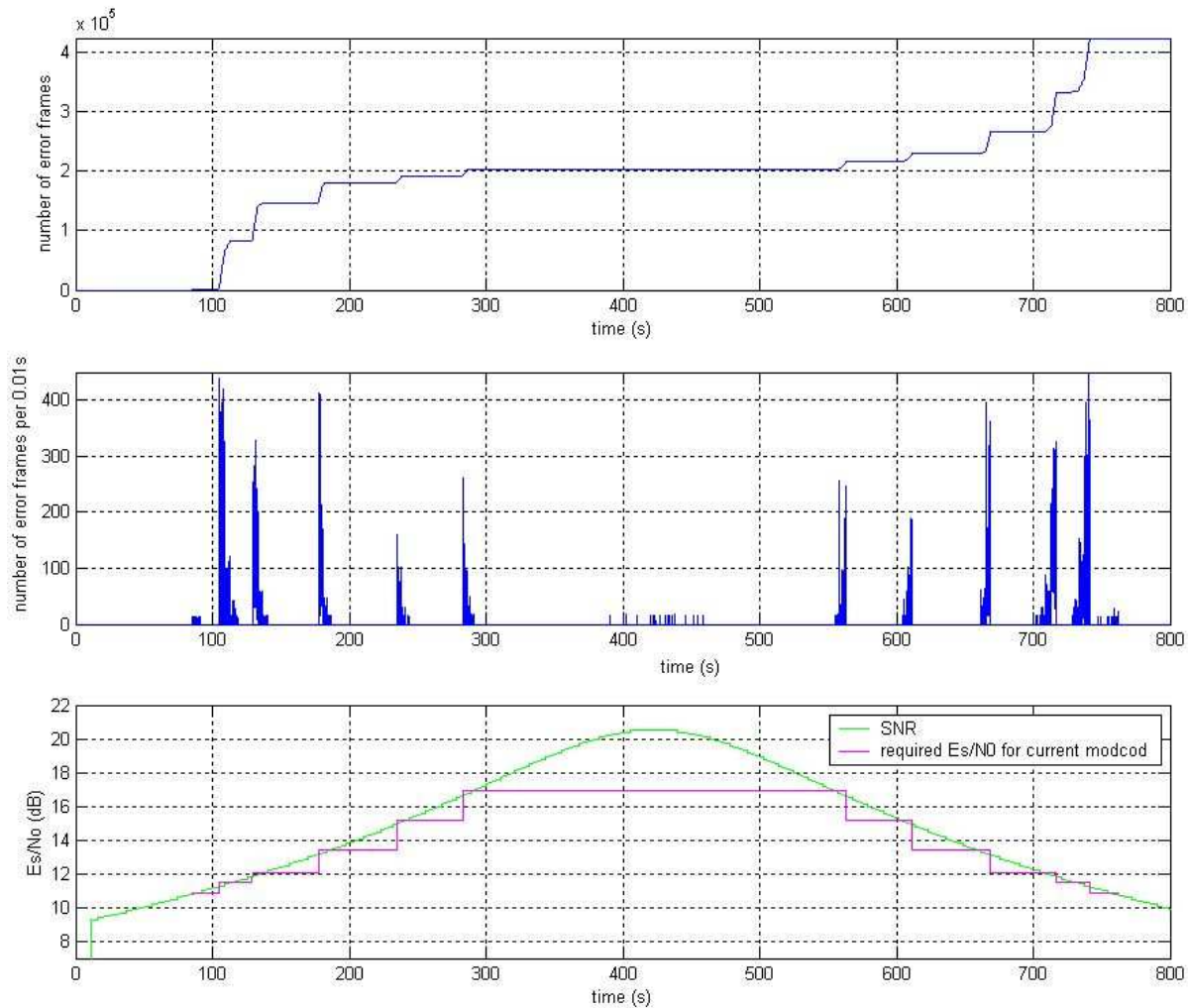


Figure 5: margin = -0.2dB, modcod used: 19, 20, 21, 26, 28

We can see here that the errors appear at the modcod change and that their number decreases as the SNR rises. The SNR rises as the attenuation simulated by the Propagation Emulator decreases, with a 0.1dB step. This explains why the SNR and the error rate do not vary smoothly.

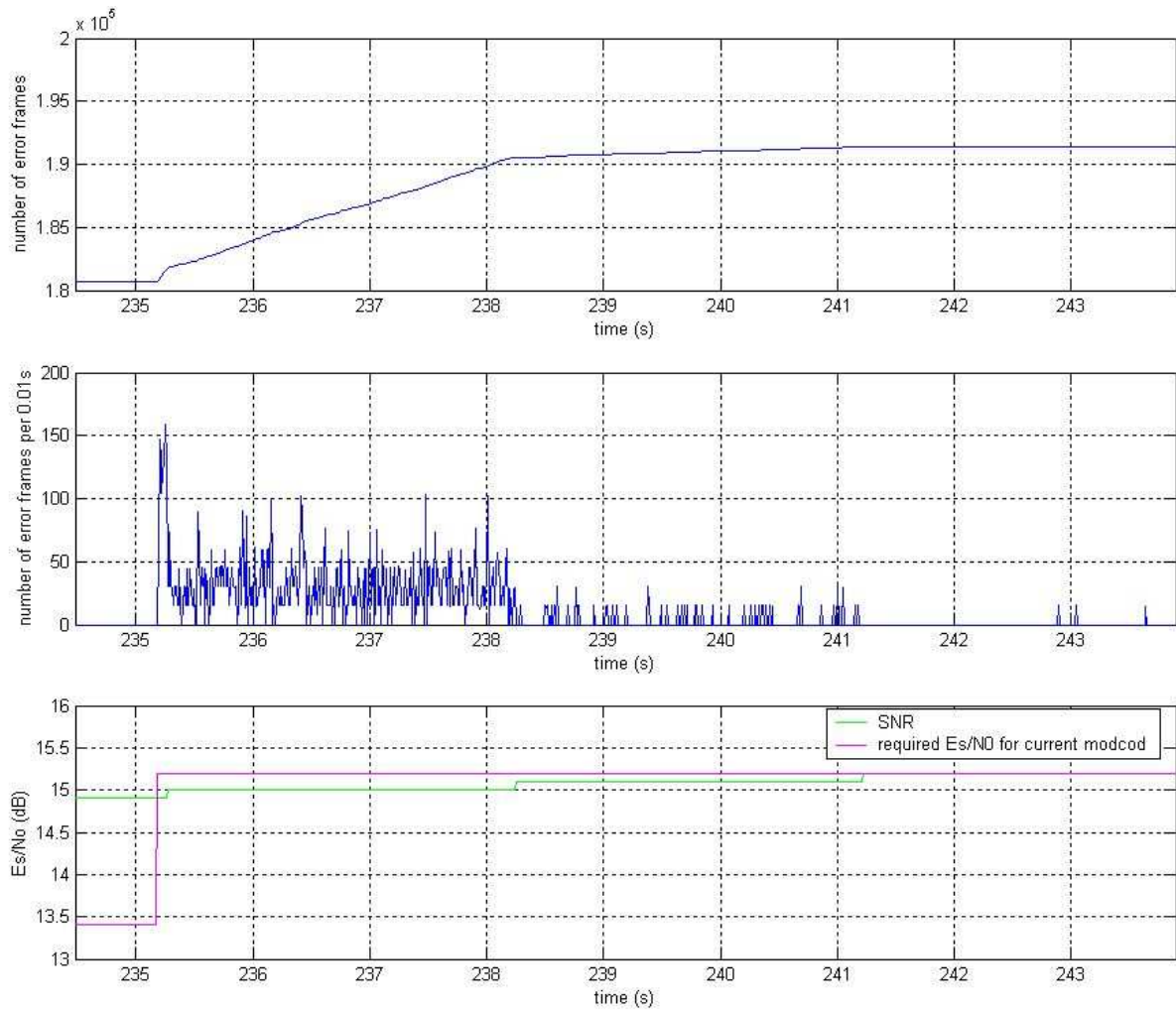


Figure 6: Zoom on a modcod change

4.4.2. Scenario 1: starting in 8PSK 3/4, margin=0.0dB

This simulation is carried out with the low-Doppler profile generated to match at a 25MBauds rate the influence that the actual Doppler effect would have at 150Mbauds (the expected rate in real conditions).

Here as well we can notice that there are errors at every modcod change. There are slightly more errors when the satellite (or signal level) is going down than up. This can be due to a small offset between the modcod commands and the attenuation or to a small signal level change during the simulation, likely coming from the noise generator. There are less errors than in the previous simulation since the margin is higher.

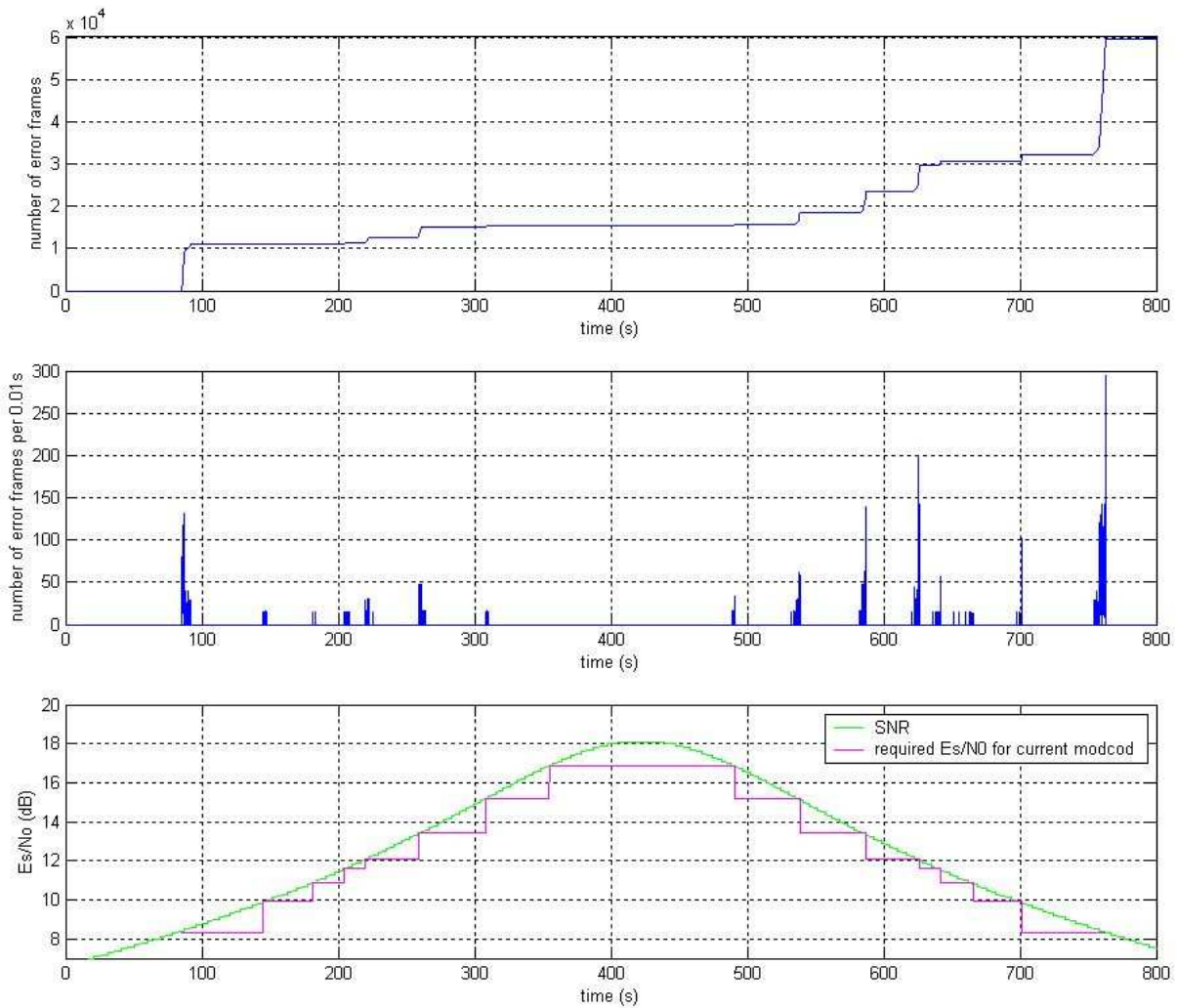


Figure 7: margin = 0dB, modcod used :14, 15, 19, 20, 21, 22, 26, 28

4.4.3. Scenario 2: starting in 16APSK 3/4, margin = 0.2dB, delay=-6s

The commands are sent 6 seconds ahead of time, therefore there are errors when the satellite is going up: the modcod is changed too early thus the attenuation is still too important. On the other hand when the satellite is going down when the modcod is changed the attenuation is still at higher level than needed, therefore there are no errors.

We notice errors due to the Doppler effect again since the profile used is the high-Doppler one. Beside this the behaviour is exactly as expected with errors at modcod changes when the satellite is rising.

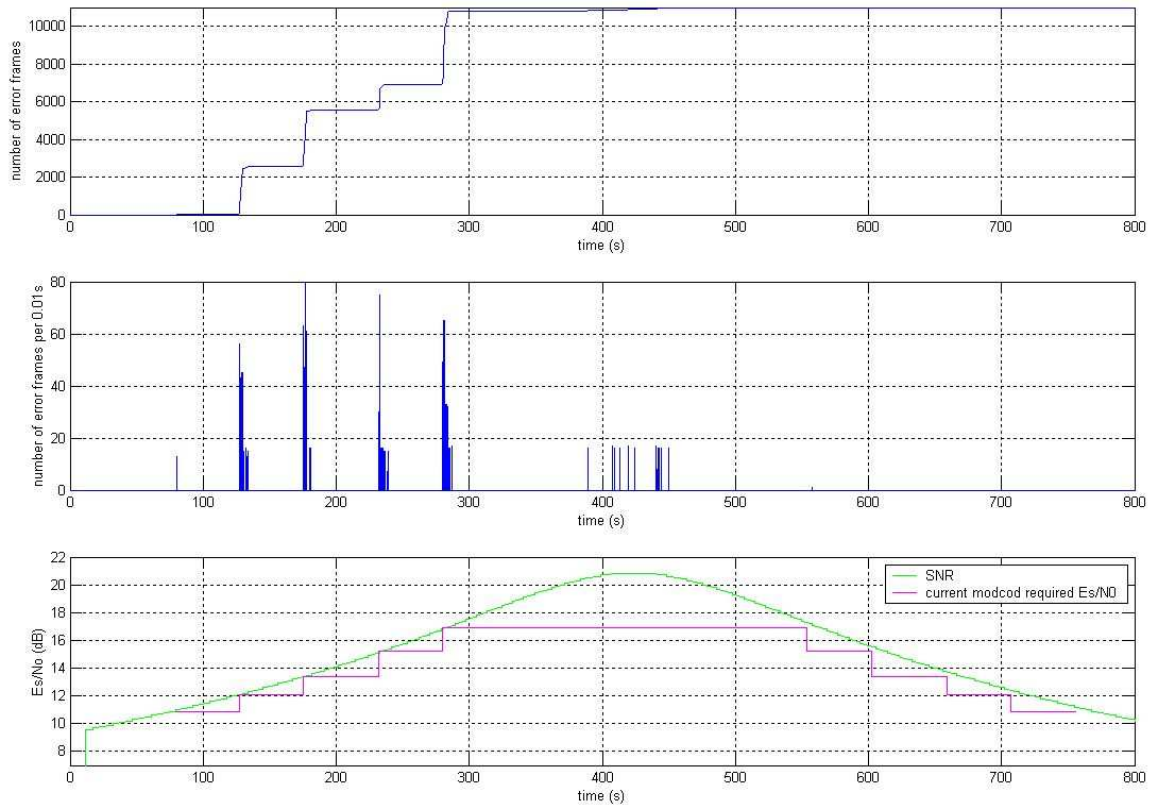


Figure 8: margin = 0.2dB, 6 second offset, modcod used: 19, 20, 21, 26, 28

4.4.4. Scenario 2: starting in 16APSK 3/4, margin = 0.2dB, no delay

In this configuration, with the low-Doppler profile the transmission is completely error-free.

4.4.5. Comparison between the theoretical and the actual number of DVB-S2 frames received

During simulation we can record the number of DVBS2 frames received per modcod as shown on the Cortex interface (ACM standing for modcod).

Here we use the results of Scenario c: starting in 16APSK3/4 and with a -6s delay. The theoretical number is obtained by dividing the time between two VCM commands by the duration of a DVB-S2 frame. This duration depends on the modulation: 6.6744e-4s in 16APSK, and 5.3352e-4s in 32APSK at 25Mbauds.

The highest difference between the theoretical and actual number of frames is 14 frames which shows that the modcod change time is highly reliable from one change to another.

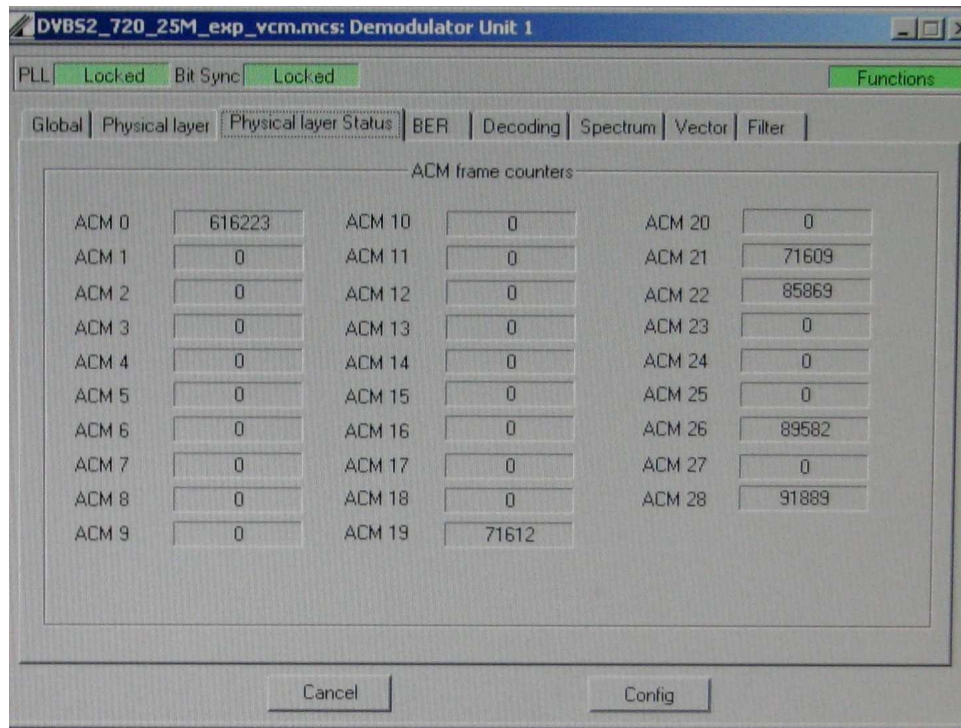


Figure 9: Cortex HDR Demodulator interface

MODCOD	Time spent on the modcod (according to the VCM controller) (seconds)	Theoretical number of frames	Number of frame received (according to the demodulator)
16 APSK	47.8	71617	71612
16 APSK	47.8	71617	71609
16 APSK	57.31	85865	85869
32 APSK	47.8	89593	89582
32 APSK	273.73	513064	513078
32 APSK	48.3	90531	90523
16 APSK	57.31	85865	85871
16 APSK	47.8	71617	716609
16 APSK	49.3	73864	73860

5. Conclusion

This experiment proves the feasibility of a data transfer with variable coding and modulation. It further shows that no additional margins are needed compared to a transfer using constant coding and modulation (CCM).

6. Reference

- [1] Digital Video Broadcasting (DVB); Second Generation Framing Structure, Channel Coding
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- [2] CCSDS space link protocols over ETSI DVB-S2 standard, CCSDS 131.3-B-1.
- [3] “CCSDS telemetry Over DVB-S2: Characteristics, Receiver implementation and
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- [5] <http://www.zds-fr.com/en/>.
- [6] http://www.elta.fr/uk_index.php.