Consultative Committee on Space Data Systems
Space Link Services
Radio Frequency and Modulation Working Group

DVB-S2 HOMs: EVM and PSD simulations in non-linear channel

SLS-RFM_15-04

J.-P. Millerioux, C. Dudal, P. Lafabrie - CNES

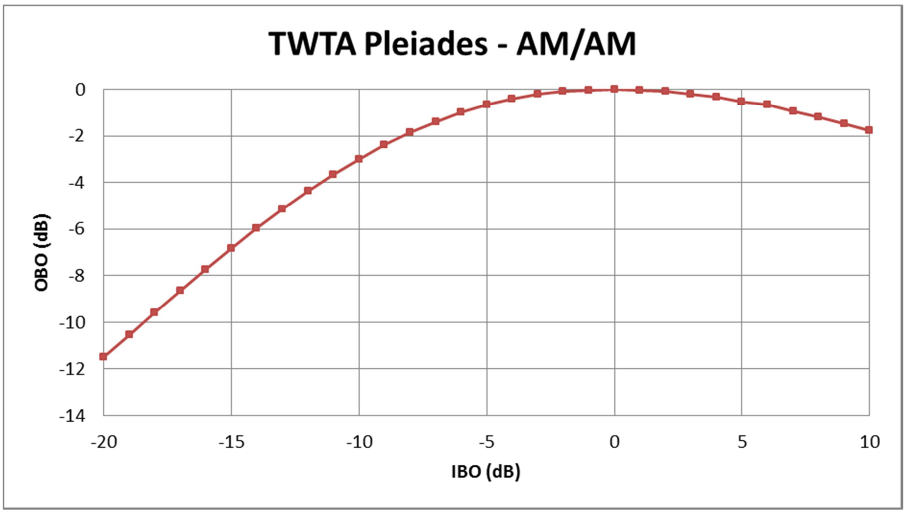
1. Introduction

The objective of this document is:

- to present some material towards a recommandation of an Error Vector Magnitude (EVM [3]) requirement at the on-board High Data Rate Telemetry (HDRT) Power Amplifier (PA) output when using High Order Modulations (HOM) of the DVB-S2 standard [1][2]
- to evaluate the possible improvement when using a very simple channel symbol Constellation Predistorsion (CP) of the PA non-linearity
- to evaluate possible constraints on the amplifier operating point related to the power spectrum density (PSD) at the PA output

2. Methodology

The model used is the classical model of non-linearity without memory: the PA is fully characterized by its AM/AM and AM/PM responses. A typical X-band TWTA (Travelling Wave Tube Amplifier) used for the HDRT of CNES Pleiades satellites is considered, see Figure 1.



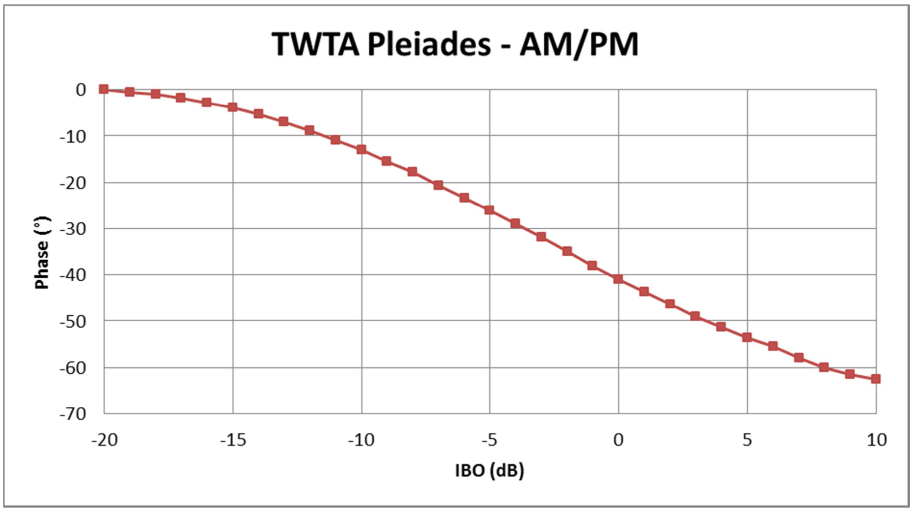


Figure 1: AM/AM and AM/PM responses of the TWTA

In the 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.

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:

$$\mathrm{TD} = \mathrm{OBO} + \mathrm{DL}$$

The DL is obtained by the following formula, still in dB:

$$\mathrm{DL} = \frac{E_S}{N_0}\,\text{required at demodulation with PA} - \frac{E_S}{N_0}\,\text{required at demodulation without non linearity}$$

Now, noting "theoretical E_s/N_0" and "constellation SNR" with natural value (DL still being in dB), we get:

$$\mathrm{DL} = 10\log10\left(\left(\left(\text{theoretical } \frac{E_S}{N_0}\right)^{-1} - (\text{constellation SNR})^{-1}\right)^{-1}\right) - 10\log10\left(\text{theoretical } \frac{E_S}{N_0}\right)$$

$$\mathrm{DL} = 10\log10\left(1 - \left(\text{theoretical } \frac{E_S}{N_0}\right)(\text{constellation SNR})^{-1}\right)$$

with (see [3]):

$$\text{constellation SNR} = -20\log 10(\text{measured EVM})$$

The theoretical E_s/N_0 used are taken from the DVB-S2 ([1] table 13).

It is worth noting that in all the following, TD, OBO and DL are expressed with negative values.

3. 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 decreases. The PA degradation (in absolute value) varies in the opposite way 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.

Anyway, for both QPSK and 8PSK, whatever the roll-off is, the best operating point is found very close to the saturation. Figure 2: TD for 8PSK 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 are for α=0.2, whereas the green lines are for α=0.35.

The highest EVM (corresponding to the optimal operating point for 8PSK 9/10) is 18.5 dB (for an OBO equal to 0.3 dB).

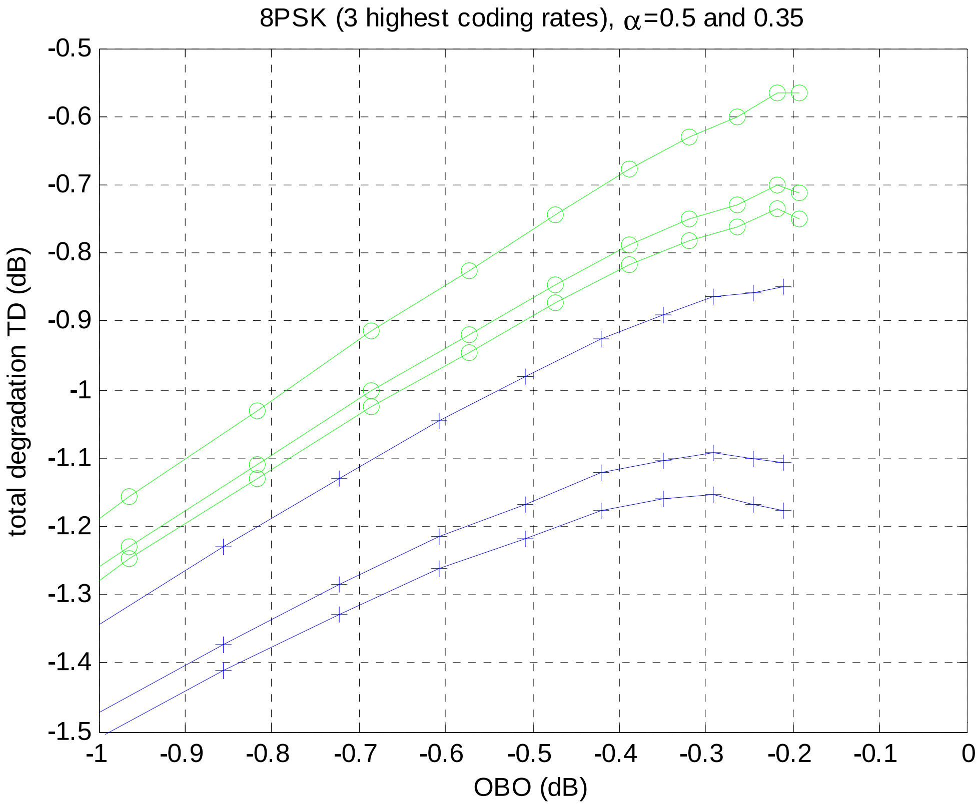


Figure 2: TD for 8PSK

4. 16APSK

The optimization is performed on

- the amplifier operating point
- the increase of the radius ratio wrt the nominal constellation ($\Gamma=\gamma_{CP}/\gamma_{nominal}$)
- the phase shift of the second ring wrt 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, as shown in Figure 3 for the case of 16APSK 9/10. Notice than the OBO slightly depends on the waveform and consequently depends on the CP. The optimal couple (Γ, $\Delta\varphi$) is about (1.5, 20°) and leads to a TD equal to -2.8 dB.

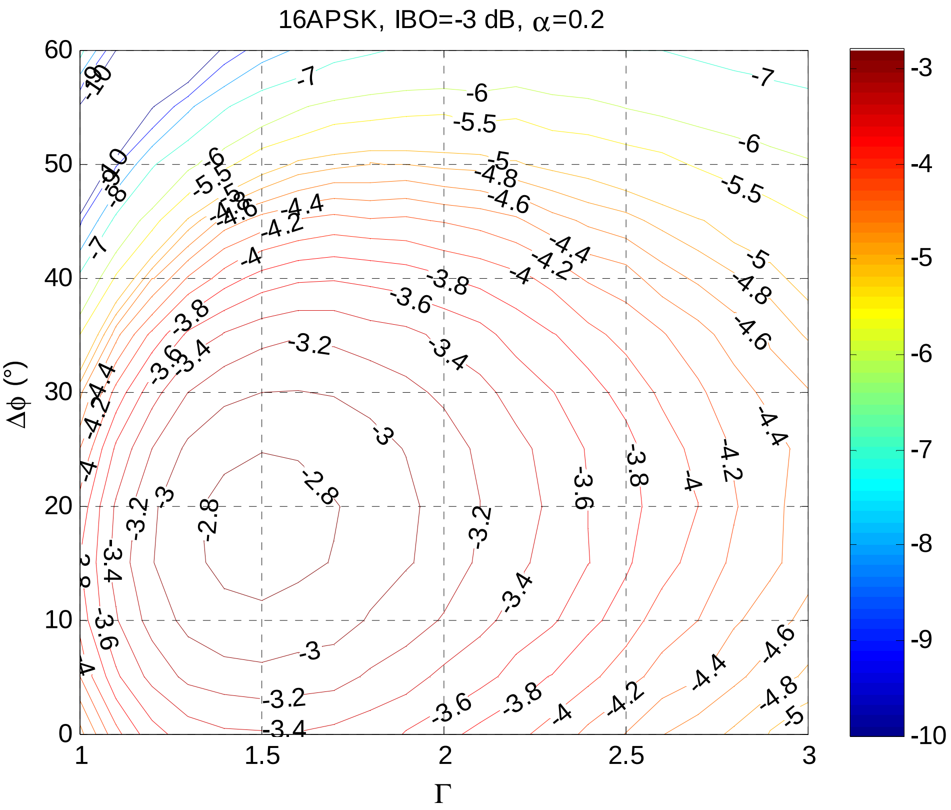


Figure 3: TD (in dB) as a function of Γ and Δφ for a fixed IBO

Figure 4 shows the best TD for different OBO and for the 6 16APSK of the DVB-S2 standard. The blue lines are with CP, whereas the green lines are without CP (PA operating point optimization only).

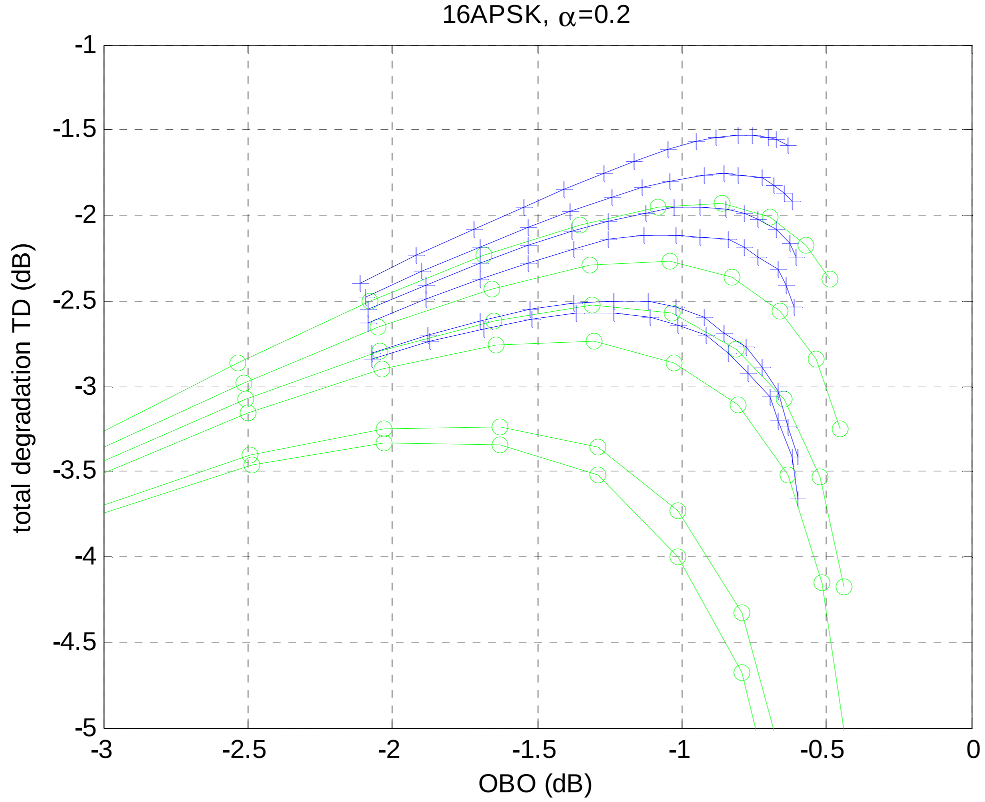


Figure 4: Optimal TD for 16APSK

Tables hereunder summarize the optimal operating point for roll-oll 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 (the PAPR increase induced by the pulse shaping filter is not mitigable by the CP).

	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)	
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

	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)	
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

5. 32APSK

The optimization is performed on

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

Hence, 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 improvements of a more sophisticated approach can be presumed limited.

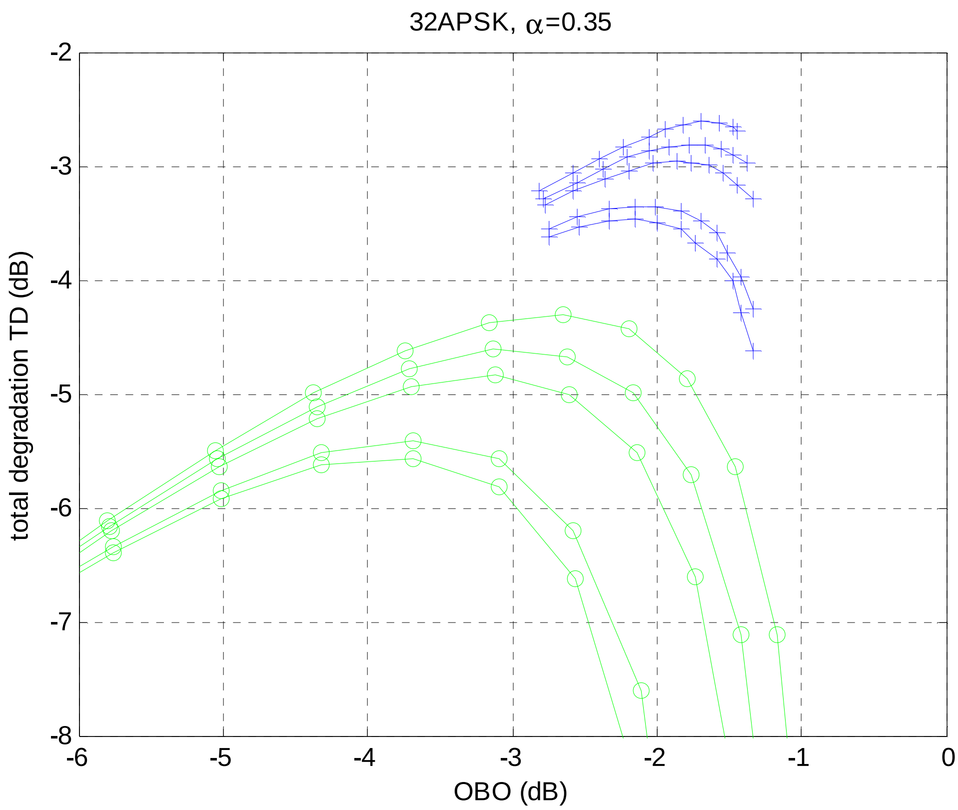


Figure 5: optimal TD for 32APSK

Tables hereunder summarize the optimal operating point for roll-oll 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.

	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

	With CP							Without CP					(TD with CP)
constellation	IBO (dB)	OBO (dB)	constellation SNR (dB)	TD (dB)	DL (dB)	Γ	$\Delta\varphi$ (°)	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

6. ACPR

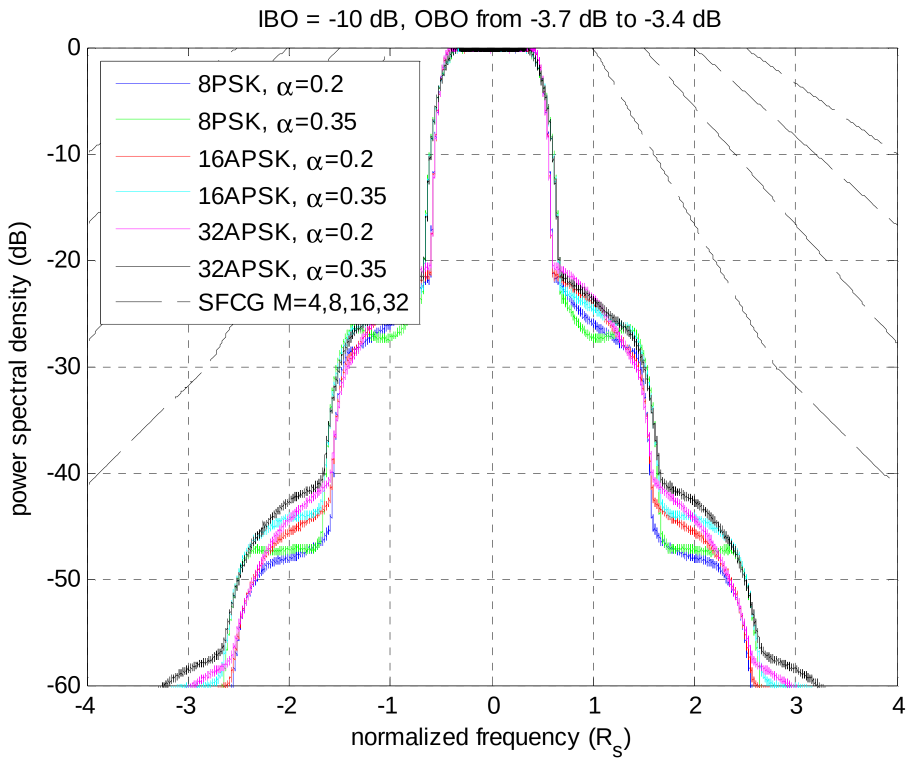
PSD (Power Spectrum Density) presented here are PSD at the PA output, whereas SFCG mask is applicable at the satellite output (in particular possibly after a RF output filter). PSD is normalized at the carrier center.

ACPR (Adjacent Channel Power Ratio) designs here 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.SFCG PSD mask is computed depending on the constellation as in [4].

The spectrums 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 6.

It seems quite achievable to respect the SFCG mask with the considered PA.

It is also of interest to look at the ACPR in the nearest adjacent band (in particular for carriers close to 8.4 GHz, taking into account the maximum pfd requirement on the DSN-band to avoid coordinations). Figure 7 proposes some results.



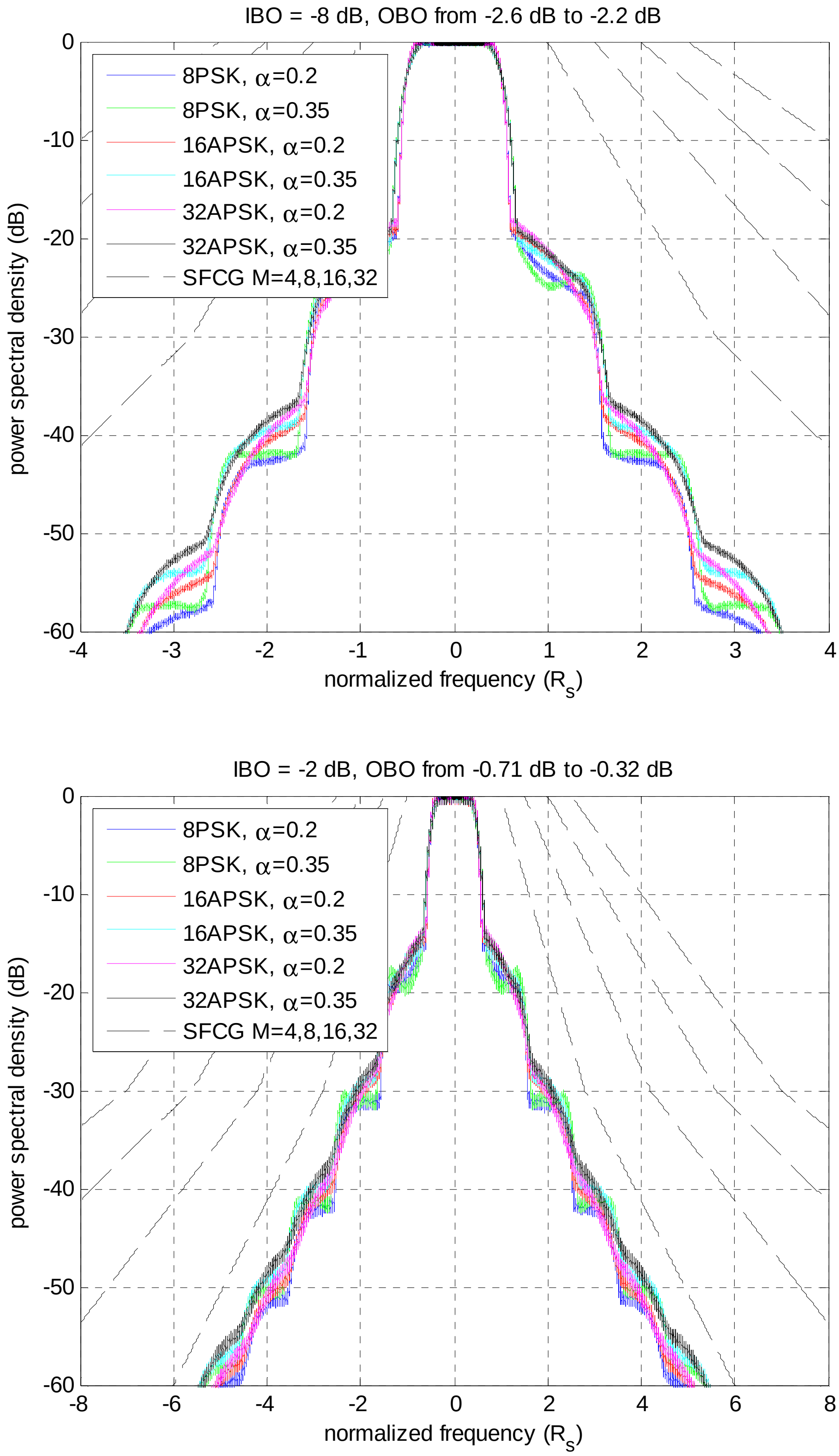
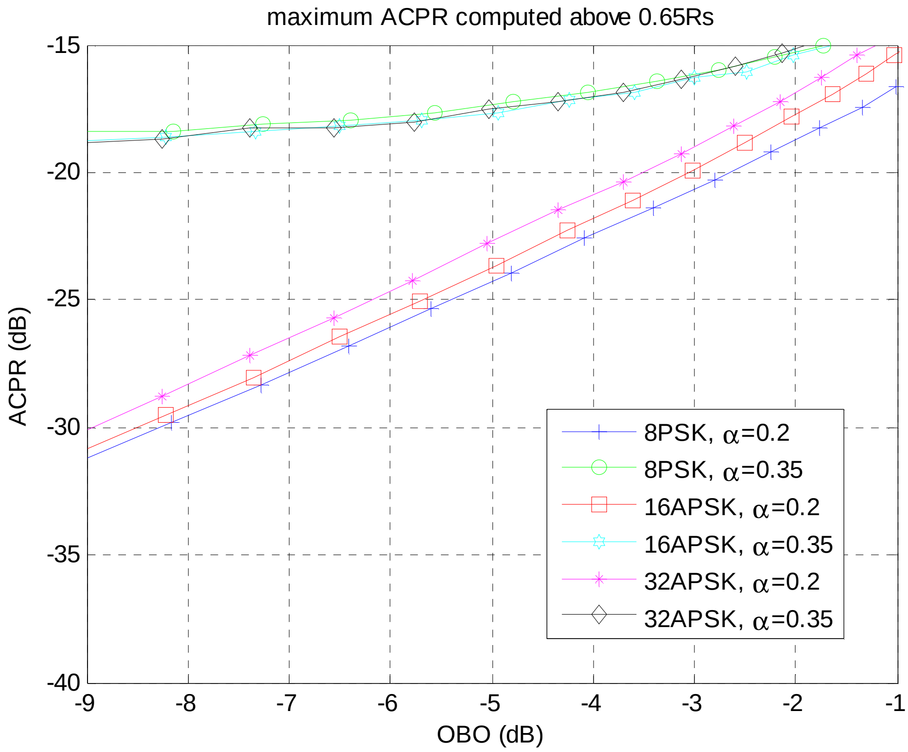
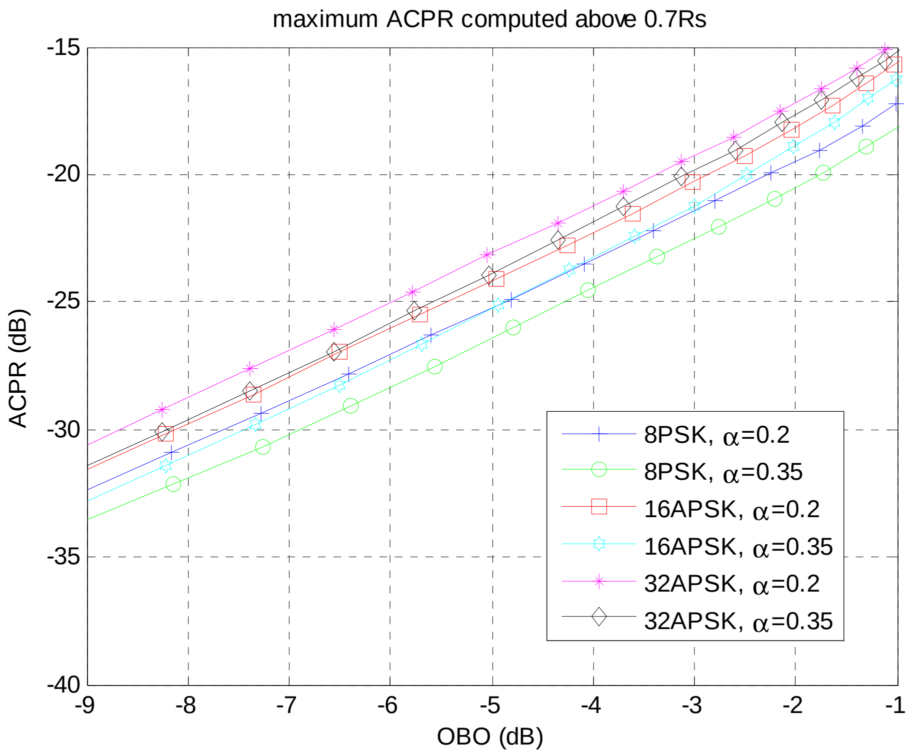


Figure 6: PSD at the PA output


maximum ACPR computed above 0.65Rs
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 0.7Rs
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

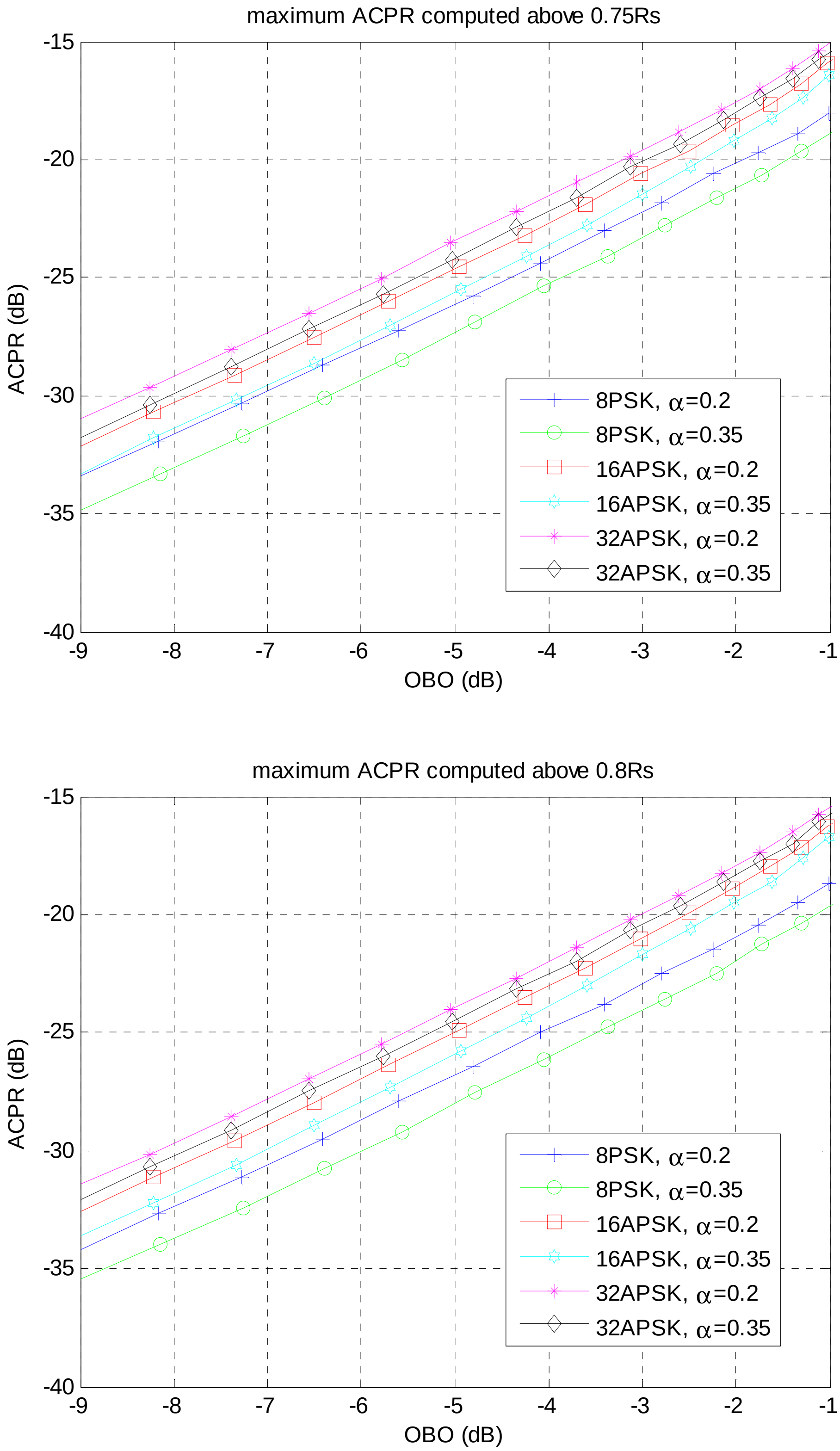


Figure 7: ACPR at the PA output

7. Conclusion

The optimal operating point in the PA amplifier leads to the following constellation SNR values for the highest coding rate

- 8PSK : ~20.4 dB
- 16APSK : ~20.3 dB
- 32APSK : ~21.9 dB

8. References

[1] Digital Video Broadcasting (DVB); Second generation framing structure, channel coding and modulation systems for Broadcasting, Interactive Services, News Gathering and other broadband satellite applications (DVB-S2), ETSI EN 302 307, V1.2.1, April 2009.

[2] CCSDS space link protocols over ETSI DVB-S2 standard, CCSDS 131.3-B-1.

[3] http://cp.literature.agilent.com/litweb/pdf/5989-3144EN.pdf

[4] SF34-13/D, Boulder, CO (USA), June 2014.