DVB-S2 Extension : End-to-End Impact of Sharper Roll-Off Factor Over Satellite Link

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***Abstract*—The world of the geo-synchronous satellite communications is witnessing, for several months now, a strong discussion, if not a dispute, between some systems manufacturers about the opportunity of increasing the efficiency of the coding schemes proposed by the second generation of the Digital Video Broadcasting standard by introducing some extensions. Even if the debate rises the interest of operators and manufacturers, its conclusions are far from being unanimously accepted. This paper concentrates mainly on the sharper low roll-off factor shaping filters proposed among the extensions. Their effects on the satellite channel are presented in a comparative analysis supported by measurements performed on commercial devices. The operational impacts are observed from the point of view of one of the main European satellite operators: Eutelsat.**

Keywords-DVB; satellite transponder; amplifier saturation

I. INTRODUCTION

In 2011, different manufacturers started to release new modulation and coding architectures for satellite communications, claiming to achieve significant performance improvements (higher than 15%) over their competitors and over the existing Second Generation of the Digital Video Broadcasting over Satellite (DVB-S2) standard [1]. The new features encompass, among others, sharp roll-off factors (ROF) for the shaping filters as well as proprietary pre-distortion and equalization techniques mitigating the non-linearity of the active components (mainly high power amplifiers).

These novelties arose the interest of the entire satellite communications world, including standardization committees, such as the current DVB-Technical Module, that are evaluating the insertion of these new features in the DVB-S2 standard [2].

Confronted with this innovation and the increasing requests for high efficiency in the capacity usage, Eutelsat, as one of the leading worldwide satellite operators, has to assume the role of customers guide in order to warrantee a high quality of service by using the very latest standard transmission techniques in the most correct way.

One of the most frequently asked questions concerns the real performance of ROF reduction over a satellite link in particular referring to the existing DVB-S2. The objective of the work presented in this paper is to assess by reliable and reproducible measurements in controlled laboratory environment the pros and cons of reducing the ROF in satellite transmission.

This study is based on measurements obtained with different professional devices and the close collaboration with key manufacturers in satellite communication industry. The devices under test are commercial products; the reported tests are performed over a reference DVB-S2 test bed [3].

The paper is organized as follows: Section II provides some backgrounds including the satellite channel description, the transmission techniques, their extensions and emission constraints. Section III is dedicated to a preliminary analysis of two operational scenarios. The validation equipment and methodology is described in Section IV, whereas the results are discussed in the Section V.

II. BACKGROUND

A. *The Satellite Link*

This paper considers operations over transparent geostationary satellites. To maximize their efficiency, the on-board amplifiers are operated as close as possible to the saturation point. This imposes a trade-off between power efficiency and signal distortion.

Further impairments onto the signal quality come from the Input Multiplexer (IMUX) before, and Output Multiplexer (OMUX) after the satellite Travelling Wave Tube Amplifier (TWTA) [4]. They aim at limiting interferences between adjacent transponders.

On the ground, the uplink earth station high power amplifier (HPA) output is not filtered. So proper back-off setting is of paramount importance to limit in-band and out-of-band distortion.

On the whole, satellite transmission is impacted by amplitude and phase distortions mainly due to amplifiers working in the saturation point, group delay, phase and frequency errors, Additive White Gaussian Noise (AWGN) and phase noise. This paper will consider the effect of amplifiers and AWGN only.

Studies on the non-linear degradation of end-to-end system performance exist in the literature and are here referred. These are simulations [5], extensive testing over emulator or satellite [6] and results obtained by the International Telecommunication Union Radio-communication Sector (ITU-R) [7].

B. Baseline Transmission Standard and Filtering

DVB-S2 [1] specifies the format of the digital signal to be transmitted over a satellite channel. It is used by the manufacturers as a reference document in the implementation of transmitters (or modulators) for broadcasting, interactive services, news gathering, and broadband applications that will be compatible with any receiver. The receiver design is not described in the DVB-S2 standard.

DVB-S2 introduces new modulation and coding (*modcod*) schemes with respect to the previous DVB-S. Three higher order modulation schemes, 8PSK, 16 and 32APSK. In particular, the last two suffer from non-linear distortions and their activation leads to a trade-off between power efficiency and signal degradation.

In DVB-S2, a conventional square-root raised cosine (RRC) shaping filter is defined at the transmitter. The 35% ROF is inherited from DVB-S whereas new values of 25% and 20% have been added. Today's industry manufacturers aim at extending the portfolio of their products by further deploying new *modcod*s and new ROF.

C. Extension Towards New Features and Sharper Filters

Sharpening the roll-off of the filters changes the characteristics of the modulated signal. The impact onto the entire transmission chain should be identified to derive the new operational parameters to be used, for ground and space segments, from consolidated experience.

The analysis and measurements performed by Eutelsat onto professional equipment is based on the following assumptions. The reference waveform is DVB-S2 with roll-off 35%. Competitive waveforms operate at sharper roll-off of 5% and 10%. The impact of compensation techniques (i.e., pre-distortion and equalization) is assessed but these additional techniques are considered as non-standard [1].

D. Eutelsat's Emission Constraints

Eutelsat aims at maintaining a high level of services and is mainly concerned about the amount of out-of-band emissions and the in-band distortion. That is why the European operator has published a standard, commonly known as EESS 502 [8], giving the basic requirements for the earth stations (E/S) and the spectrum utilization.

At the uplink E/S, the HPA sizing and linear operation has to be verified in order to reduce the risk of interference with other customers using the same Eutelsat satellite as well as with adjacent satellites.

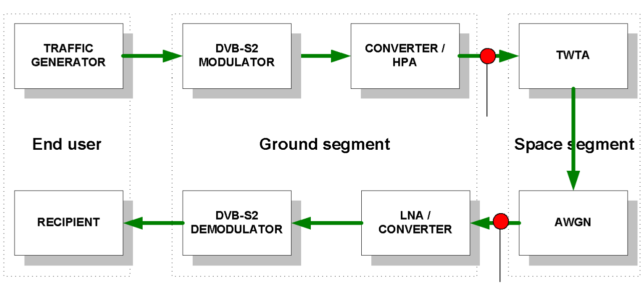

Figure 1. Emulated satellite chain and critical measurement: the IMUX and OMUX effects have not been investigated during the tests

At the receiver, the error performance over a non-linear channel should be known to ensure correct link closure, as well as the robustness against inter-channel interference (ICI). The two measurement points can be found at the HPA output and at the Low Noise Amplifier (LNA) input in Fig. 1.

III. PRELIMINARY ANALYSIS

A. Definitions

This section and the remaining part of the paper, considers the resources of satellite transponders, or capacity, in terms of bandwidth and power. As all natural resources, also the transponder bandwidth and power are limited: Eutelsat's satellites provide transponders with bandwidth of 33, 36, 72, 115 and 237.5 MHz whereas the power received on ground depends on the footprint extension.

In order to dissociate the power and the frequency, the power spectral density (PSD), or power per frequency unit (in dBW/Hz) is introduced. For linear modulation, the PSD is proportional, if not equivalent, to the symbol energy E_S which is representative of the quality of the received signal through the ration E_S/N_0 with N_0 the thermal noise energy.

From these definitions, it follows that a carrier modulated on a bandwidth B has a power C (in dBW) that is the mathematical integral of the signal PSD calculated over the bandwidth B at the receiver. Assuming an AWGN channel the noise power is given by $N = N_0 B$. The ratio C/N is also representative of the received signal quality and we can use the approximation

$$\frac{C}{N} = \frac{C}{N_0 \cdot B} \cong \frac{E_S}{N_0} \quad (1)$$

The expression (1) is already indicative of the fact that if we need to improve the performance of the received signal, the symbol energy must be increased. But, since the available power on board the satellite is limited to *C*, the only way is reducing the bandwidth B and increasing the PSD.

B. Two Reference Scenarios

The DVB-S2 (or related extensions) carriers can be used with two configurations: single and multiple carriers per transponder.

The first configuration is typical of consumer services like TV broadcasting and the forward channel in interactive networks (as it is described in the DVB-RCS standard [9]:

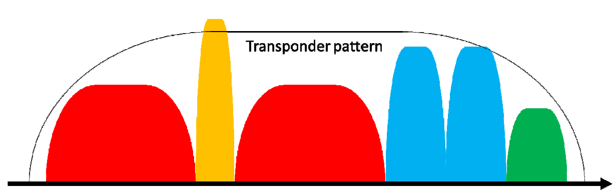

Figure 2. Multi-carriers per transponder configuration

one carrier exploits all the power available in a single transponder, also working close to the saturation point of the TWTA on board, and the signal coming from the satellite can be easily received also by small and cheap end user antennas.

With the same issue of exploiting the resources of a transponder, the configuration with only one carrier per transponder is used for the implementation of wideband data links, in which case the ground segment is represented by very large satellite dishes (typically over 3.2 m antennas). The entire transponder's power is required in order to reach the highest throughput by introducing high efficiency *modcod*s.

The second configuration, i.e., multiple carriers per transponder (see Fig. 2) is typical for the single channel per carrier (SCPC) adopted for relatively small data links based on Very Small Aperture Terminals (VSATs), video contributions and all inbound carriers of interactive systems.

The usage of the extended DVB-S2 features would bring important advantages to both these scenarios, but from the point of view of an operator there are also some counterparts to be taken into account.

C. *Sharpening the Shaping Filters: Spectrum Analysis*

First immediate advantage would come from reducing the ROF down to very low values. In a configuration with single carrier per transponder, this would permit to reduce the bandwidth occupied by the signal and increase the symbol rate and therefore the overall throughput.

For example, in a 36 MHz transponder, the maximum symbol rate reachable with a 20% ROF is $R_S = B/(1+ROF)$ = 30 Msym/s, whereas with 5% ROF it would be 34.3 Msym/s. But also we have to maintain a constant value of the signal power because of the transponder limitation: decreasing the ROF means that the PSD must be reduced of the ratio $(1+20\%)/(1+5\%)$ =1.14=0.6 dB. The link budget would suffer from 0.6 dB reduction and, depending on the link margin assumed, this could impose to choose a less efficient *modcod* and the expected gain of 4.3 Msym/s would be hardly applicable to real cases. Certainly, this scenario would benefit from the introduction of new *modcod*s but only satellite links with large link margin would take a real advantage by the small ROF. In any case, this analysis does not take into account the distortion induced by the filters on both sides of the transponder: measurements are a helpful tool to study these effects, which could require a fine-tuning of the satellite link.

A similar analysis can be performed in the case of multi carriers per transponder where the impairment due to the ICI must be considered. As better shown in the following of this paper, the TWTA saturation generates a spectrum regrowth at the frequencies adjacent the signal band. Such a regrowth is more pronounced for small ROFs (see in particular Fig. 5) leading to increased ICI in a multi-carriers configuration. So, on one hand a small ROF would allow the reduction of the distance between the carriers, or carriers spacing, on the other hand this would also drive the transponders close to saturation, which would increase the interference.

Measurement results reported below in this paper will clarify this point and will permit to add further conclusions.

D. *Low ROF Effects on the Constellations*

One of the effects of sharpening the shaping filters appears in the plot of the transitions from one symbol to another within a constellation. These transitions generate a signal envelope variation over the maximum symbol energy which extent depends on the ROF: as smaller the ROF is as important is this envelope variation.

Fig. 3 shows the envelope variation at ROF 35% (black lines) and 5% (red) for two QPSK signals measured at the output of a modulator.

This behaviour has an immediate impact on the distortion and the Inter Symbol Interference (ISI) when the amplifiers are driven close to the saturation: as indicated in [5] pre-distortion techniques can be applied in order to mitigate this effect, even if they are less effective for high order constellations (APSK) than for QPSK and 8PSK. Small ROF would further reduce the pre-distortion performances. Also,

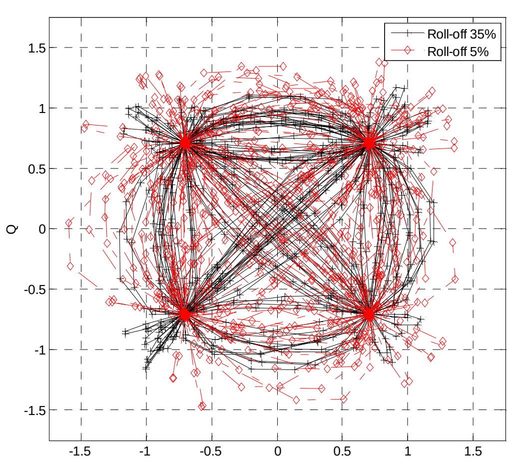

Figure 3. Plots of the QPSK constellation and transition between two symbols

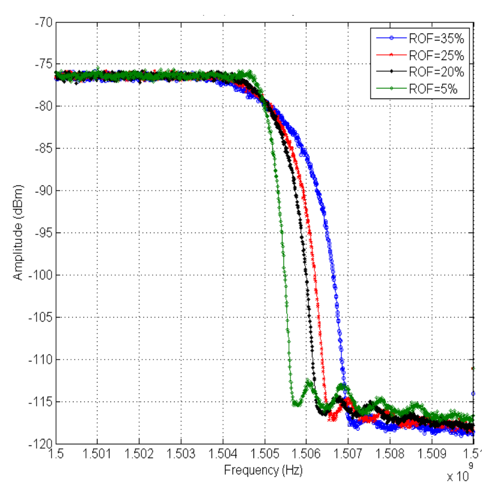

Figure 4. Sharper roll-off signal characterization: frequency response

this argumentation has been subject of some measurements described here below.

IV. THE MEASUREMENTS: THE TESTBED DESCRIPTION

A. The Channel Emulator

Eutelsat's validation equipment mainly consists of a reference satellite channel emulator [3] and state-of-the-art professional DVB-S2 transmitter and receiver. The entire DVB-S2 testbed also includes traffic generators and recipients, spectrum analyzers, a control unit, as well as additional DVB-S2 devices for a multi-carrier per transponder configuration.

The non-linear TWTA profile, defined in the DVB-S2 standard [1], Fig. H.12, is emulated in order to test the spectrum regrowth and the end-to-end performance over a non-linear channel in single carrier per transponder configuration. It is worth mentioning that the adopted profile is pessimistic compared with the modern TWTA characteristics. Anyway, the choice of this profile becomes mandatory in the case the studies done in the literature are taken as reference.

B. Test Conditions

A linear channel, i.e., a link with only the presence of AWGN, is often considered as a reference scenario to verify the performance of the channel decoder. Such a performance should be specified also in terms of difference between the minimum E_S/N_0 allowing a demodulator to lock a received signal (i.e., the lock threshold) and the E_S/N_0 at which the same device already locked to the signal passes to the unlock status (i.e., the unlock threshold).

For the emulation of a single carrier saturating a transponder, a memory-less non-linearity impairment on top of AWGN is added. A phase noise impairment is then introduced to represent the receive chain down-conversion characteristics (in the spacecraft, low-noise block down-converter, and tuner oscillators). At high R_S/B_T ratio (with R_S symbol rate, and B_T the satellite transponder bandwidth), a major impact is due to IMUX and OMUX filtering. In fact, since the signal works close to the transponder boundaries defined by these filters, a severe group delay affects the carrier: this aspect is not investigated hereafter.

Multiple carriers per transponder configuration consist in setting several carriers side by side, and insuring a limited adjacent channel interference of one to the other.

V. RESULTS

A. Transmitter End

Measurements at the modulator output and the HPA output have been performed in order to characterize the signal. At the modulator output the roll-off reduction causes sharper fall of the transmit filter frequency response (Fig. 4). The corresponding impulse response presents oscillations which amplitude decreases in time slowly than for high ROF filters. This behavior has its counterpart in the IQ signal diagram as already presented in Fig. 3.

At the output of the uplink high-power amplifier, the spectrum regrowth is given for Input Back-Off (IBO) values ranging from 0dB (saturation) to 18dB (linear region). Moving from 35% (Fig. 5-a) to 5% (Fig. 5–b) increases the out-of-band spectral regrowth by 1 to 2dB (depending on the IBO) as well as a change of the spectrum shape.

Therefore, whereas a sharper roll-off is activated with the aim of increasing the symbol rate (see the discussion above) a higher power is required to keep the E_S/N_0 ratio constant. Therefore, the uplink HPA could require a re-sizing in order to grant a level of unwanted out-of-band emissions compliant with the Eutelsat EESS 502 standard [8].

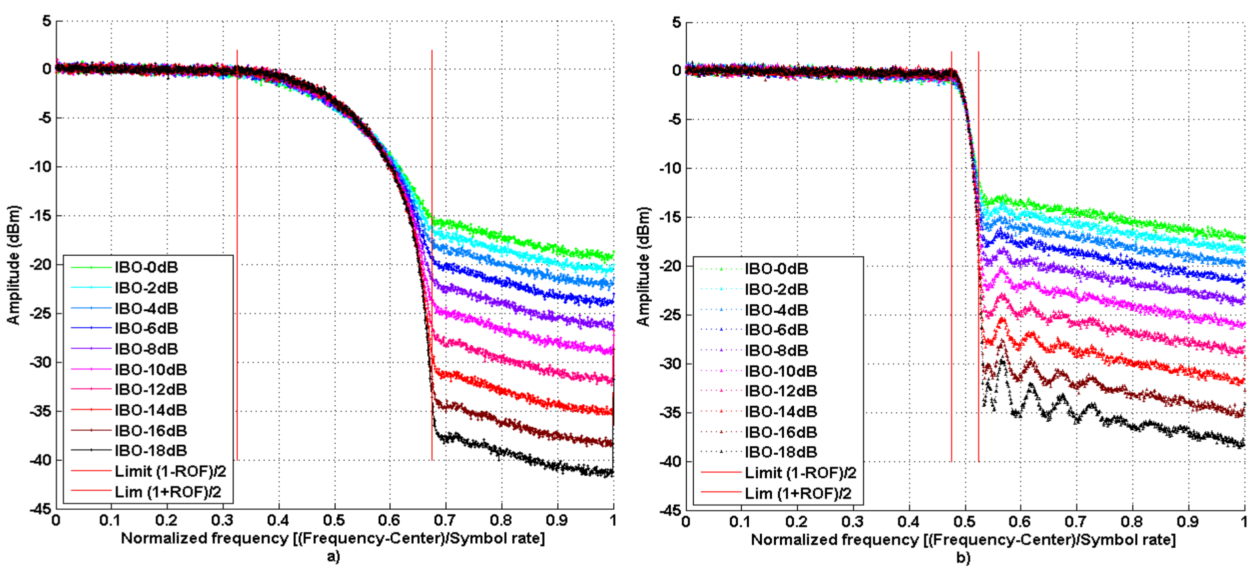

Figure 5. Spectrum regrowth versus IBO for roll-off 35% (a), and 5% (b)

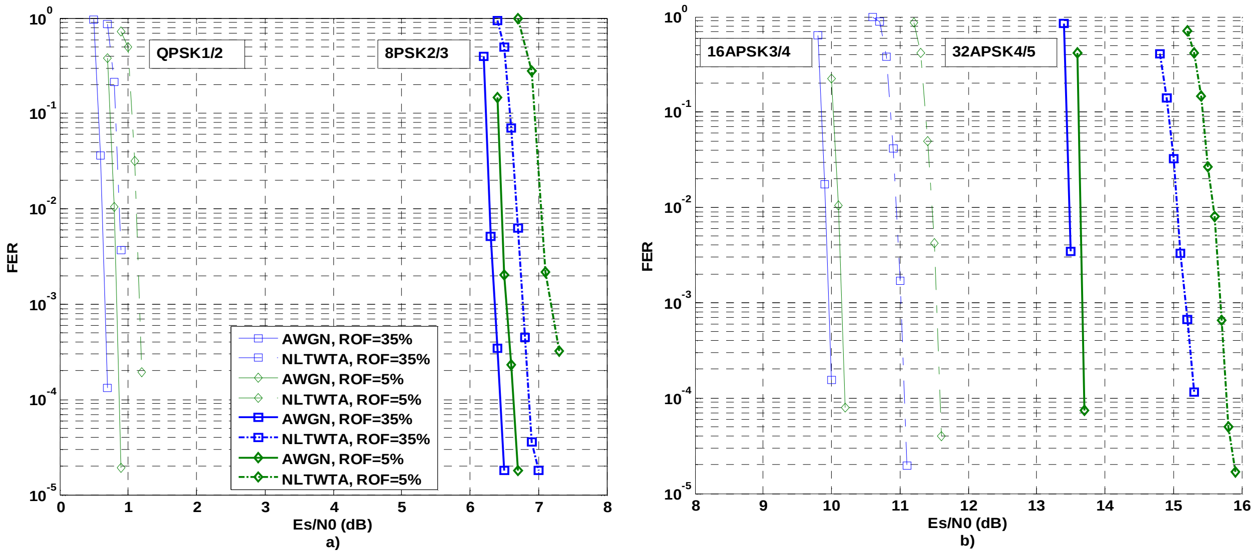

Figure 6. Impact of ROF reduction over linear and non-linear channel

In order to enable smaller ROF, E/S operators shall demonstrate that their out-of-band emissions are compliant with the Eutelsat's requirements. The same amount of spectrum regrowth is also present after on-board satellite TWTA, but will be partly rejected by the satellite OMUX filter.

B. *Receiver End: One Carrier per Transponder*

The error performance curves for *modcod*s QPSK 1/2 and 8PSK 2/3 are given in Fig. 6-a; those for 16APSK3/4 and 32APSK4/5 in Fig. 6-b. For every *modcod*, two channels are investigated (AWGN plain lines, and non-linearized TWTA dashed lines). For each channel the performance for ROF 35% (blue squares) and ROF 5% (green triangles) are presented.

In a linear channel, the most recent DVB-S2 demodulators overcome the first generation DVB-S2 chipsets by about 0.7dB to 1.7dB (from QPSK to 32APSK, see [7]). The use of ROF 5% always requires a E_S/N_0 ratio about 0.3dB higher to lock, but the steep waterfall behavior is unchanged. Over a non-linear channel at optimal IBO (given in [1], Table H.1) conventional ROF 35% suffers from low degradation compared to the reference figures. 5% ROF suffers from additional non-linear distortions of about 0.5dB.

For all *modcod*s, the expected frame error rate (*FER*) versus E_S/N_0 waterfall curves are shifted to a higher E_S/N_0 region when decreasing the ROF from 35% to 5% at the transmitter.

Reference simulations results presented in [5], indicate that the impact on the synchronization of the carrier of ROF 20%, 25% with reference to 35% is negligible. Our measurements onto professional equipment state that ROF 5% slightly degrades the error performance over linear and non-linear channels.

Another way to look at the non-linear channel is to search for the optimum back-off. The total degradation (D_{TOT}), as defined in [5] and reported in (2), is minimized when the sum of the non-linear distortions suffered by modulated signal and the power loss due to the operation of the amplifier at a given back-off is minimized.

$$D_{TOT} = \left[\frac{E_s}{N_0}\right]_{NL} - \left[\frac{E_s}{N_0}\right]_{AWGN} + OBO \qquad (2)$$

The optimum back-off values for ROF 35% and 5% are given in Fig. 7. ROF reduction to 5% does not change the output bock-off (OBO). The optimum IBO is larger, so is the total degradation.

So, when the ROF decreases, the loss over a nonlinear channel due to the distortion becomes stronger. To support the use of sharper roll-off, mitigation algorithms have been introduced. Some results of non-linear compensation techniques are presented in Fig. 7-b: even if the pre-distortion seems achieving better performance than equalization, it also suffers from several known limitations. First, TWTA characteristics must be known by the modulator in order to calculate the pre-distortion coefficients. Second, the pre-distortion algorithm minimizes the non-linear distortion at a given back-off. Consequently, at higher OBO the pre-compensation of the signal increases the degradation: in extreme conditions the usage of pre-distortion in linear region causes a huge penalty.

C. *Receiver End: Multiple Carriers per Transponder*

The measurements performed with ROF down to 5% highlight the risks for ICI due to the sharpening of the shaping filters. Fig. 8 is comparable to the Fig. 30 in [10] and shows that the degradation increases with the reduction of the carrier spacing (*CS)* much rapidly for very small ROF. The consequence is that, in particular for small carriers, the transmission is easily exposed to frequency errors that add heavy impairments due to ICI. In other words, very low tolerance is allowed to the central frequency for low ROF

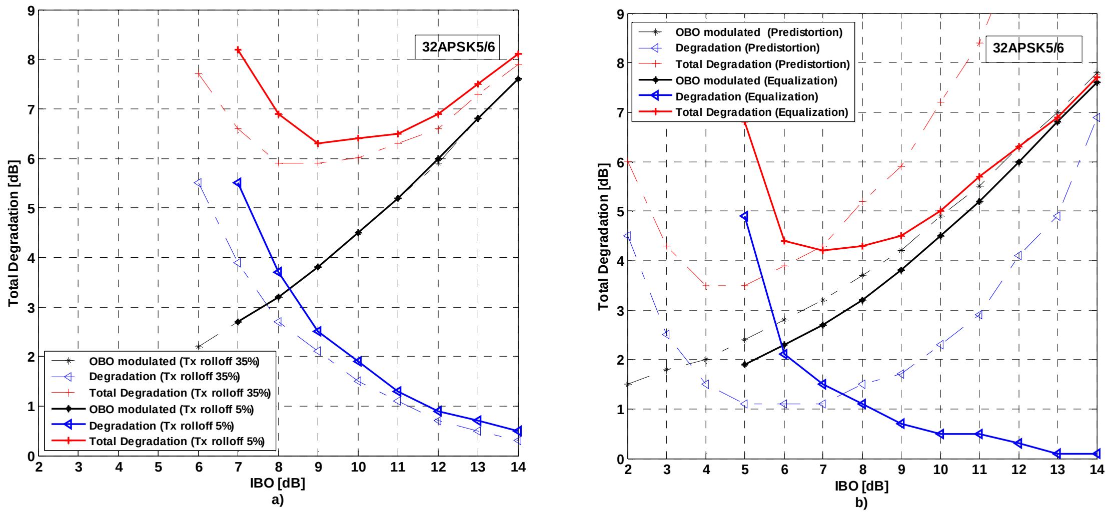

Figure 7. Signal degradation vs. IBO with ROF 35% and 5% a) and with pre-/post-compensation techniques b)

modulations. In the figure, the carrier spacing is normalized to the symbol rate R_S .

Another source of degradation of the end-to-end link appears when the receiver filter does not match the transmit filter. The dashed lines Fig. 8, labelled as "unknown" are an example of receivers using ROF higher - even if not explicitly indicated by the manufacturer - than the transmit filters. Obviously the ICI impact on the degradation is not negligible.

VI. CONCLUSIONS

This paper reports on the test results obtained by Eutelsat with professional DVB-S2 equipment featuring small ROF. Error performance in single and multiple carriers per transponder configurations have been assessed. The outcome unveils several issues as seen from a system operator perspective. At the receiver, the end-to-end link degradation is amplified. At the transmitter as well as on board satellite, non-linearity is increased. In multicarrier per transponder configuration, the old DVB-S2 only receivers suffer from additional losses.

In case of adoption of sharper roll-off factors, important changes must be planned at the transmitter and receiver. At the uplink station, more powerful high power amplifiers are required to limit out-of-band emissions.

At the modulator and demodulator ends, proprietary pre-and/or post-compensation techniques are available to mitigate the non-linear distortions. Their advantages and weaknesses have been highlighted, but since they are not part of a standard no commitment onto the interoperability and achievable performance among chipset manufacturers can be assured.

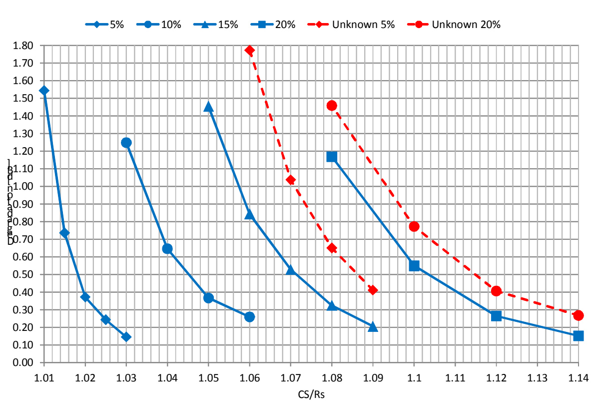

Figure 8. Degradation versus carrier spacing

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