# Laboratory evaluation of DVB-S2 state-of-the-art equipment

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**This article describes the results of laboratory tests carried out by RAI-CRIT in June 2006 on DVB-S2 state-of-the-art equipment. AWGN (Additive White Gaussian Noise) performance, non-linear-channel and phase-noise degradation were measured, and the results show that the equipment is in line with the simulation results reported in the DVB-S2 standard.**

**Single-carrier and multi-carrier configurations were implemented and compared to the equivalent DVB-S configurations. The results show that DVB-S2 can offer excellent gains over DVB-S – in terms of not only capacity and/or performance, but also flexibility.**

DVB-S2 [1][2] is the second-generation DVB system for satellite broadband services, designed for various different types of applications, such as:

- Broadcasting of standard-definition (SD) and high-definition (HD) TV;
- Interactive services, including Internet access, for consumer applications running on Integrated Receiver-Decoders (IRDs) and personal computers;
- Professional applications such as Digital TV contribution and newsgathering;
- Data content distribution and Internet trunking.

The DVB-S2 standard has been specified around three key concepts: best transmission performance, total flexibility and reasonable receiver complexity [3][4]. To achieve the best performance-complexity trade-off – quantifiable in a capacity gain of around 30% over DVB-S [7] – DVB-S2 bene-

## Abbreviations

| | |
|---|---|
| **ACM** | Adaptive Coding and Modulation |
| **APSK** | Amplitude Phase Shift Keying |
| **AWGN** | Additive White Gaussian Noise |
| **C/N** | Carrier-to-Noise ratio |
| **CCM** | Constant Coding and Modulation |
| **DVB** | Digital Video Broadcasting http://www.dvb.org/ |
| **DVB-S** | DVB - Satellite |
| **DVB-S2** | DVB - Satellite, version 2 |
| **$E_S/N_O$** | Signal-to-noise ratio |
| **FPGA** | Field-Programmable Gate Array |
| **IBO** | Input Back-Off |
| **ITU** | International Telecommunication Union http://www.itu.int |
| **LDPC** | Low Density Parity Check |
| **MPEG** | Moving Picture Experts Group http://www.chiariglione.org/mpeg/ |
| **MPEG-TS** | MPEG – Transport Stream |
| **OBO** | Output Back-Off |
| **OMUX** | Output Multiplexer |
| **PER** | Packet Error Rate |
| **PSK** | Phase Shift Keying |
| **QPSK** | Quadrature (Quaternary) Phase-Shift Keying |
| **VCM** | Variable Coding and Modulation |

fits from more recent developments in channel coding and modulation. For interactive point-to-point applications, such as IP unicasting, a further increase in the spectrum utilization efficiency of DVB-S2 over DVB-S is possible: the Adaptive Coding & Modulation (ACM) functionality allows optimizing the transmission parameters for each individual user on a frame-by-frame basis, dependent on path conditions, under closed-loop control via a return channel.

In the two years since the system was published as an ETSI standard, a variety of DVB-S2 products have come on the market, and services are being launched by several broadcasters around the world. To verify the status of the DVB-S2 technology, DVB launched a laboratory test campaign, with the task of verifying the compliancy of available equipment to the standard. The results of this activity will allow DVB to support the ITU work to adopt the DVB-S2 standard.

Tests were carried out at the RAI-CRIT laboratories in the second half of June 2006, with DVB-S2 equipment made available by several manufacturers [1], either in the form of off-the-shelf products or laboratory prototypes.

This article summaries the test objectives, the methodology and experimental set-up, and the test results. A complete description can be found in [5].

## Tests objectives and laboratory set-up

The DVB-S2 system encompasses 28 different modulation & coding options, two different frame sizes, optional pilots for receiver synchronization in critical conditions, and many other options to choose from, for maximum flexibility. An in-depth description of the DVB-S2 system is given in [6].

In order to allow for an effective validation of the DVB-S2 system performance, a selection of modes was adopted for the lab tests, with the objective of covering all the application areas and profiles targeted by DVB-S2, and to assess the equipment performance against [1] and [2]. The main attention was devoted to the CCM (Constant Coding & Modulation) configuration, with a constant frame size of 64'800 bits (Normal FECFRAME). The presence/absence of pilot sequences was selected as required by the equipment and measurement configuration. QPSK 1/2, 8-PSK 2/3, 16-APSK 3/4 and 32-APSK 4/5 were selected for an in-depth analysis, even if baseline tests have been carried out for all modulations and coding rates.

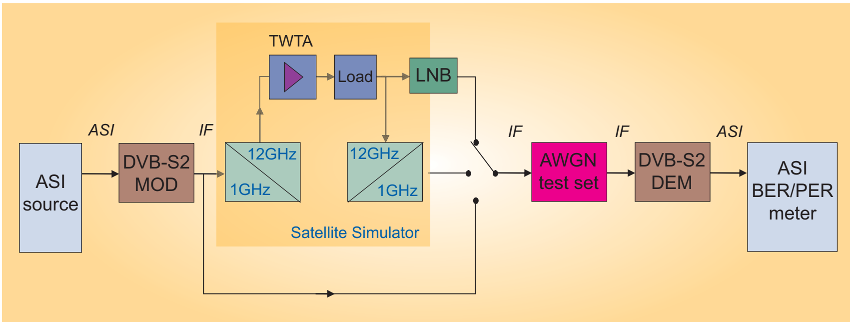


**Figure 1**
**Block diagram of the RAI laboratory set-up**

MPEG-TS Packet Error Rate (PER) was measured versus the signal-to-noise ratio $E_S/N_0$, in the presence of the following channel impairments:

- Additive White Gaussian Noise (AWGN);
- AWGN and satellite channel non-linearity;
- AWGN and phase noise.

*Fig. 1* shows a simplified scheme of the RAI laboratory set-up, simulating the channel impairments.

Furthermore, some VCM (Variable Coding & Modulation) and ACM configurations were tested with the objective of verifying, respectively, the receiver capability to adapt its operations to changes in

1. Advantech AMT [8], Comtech EF Data [9], Efficient Channel Coding [10], Newtec [11], Scopus [12], Space Engineering [13], Tandberg [14].

the modulation and coding format of the transmitted signal, and the system adaptability to channel variations, the target being interactive point-to-point applications.

## Test results

The following diagrams illustrate the average behaviour of the equipment under test in the selected test scenarios: the curves report for each configuration the results for the equipment with an intermediate performance.

### *AWGN channel*

*Figs 2 to 5* show the system performance in the AWGN channel, respectively, for QPSK, 8-PSK, 16-APSK and 32-APSK in the normal FECFRAME configuration. The symbol rate is 27.5 Mbaud,

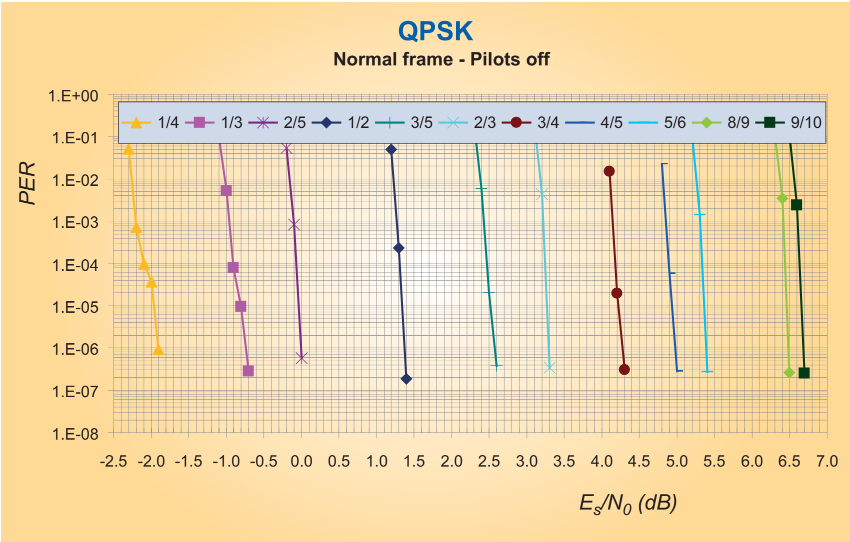


**Figure 2**
**QPSK performance on the AWGN channel (IF loop): normal frame size and no pilots**

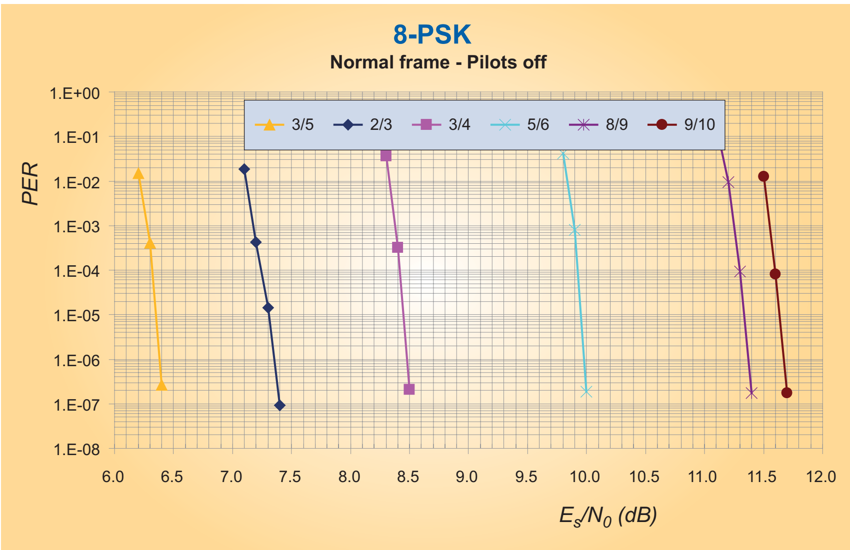


**Figure 3**
**8-PSK performance on the AWGN channel (IF loop): normal frame size and pilots**

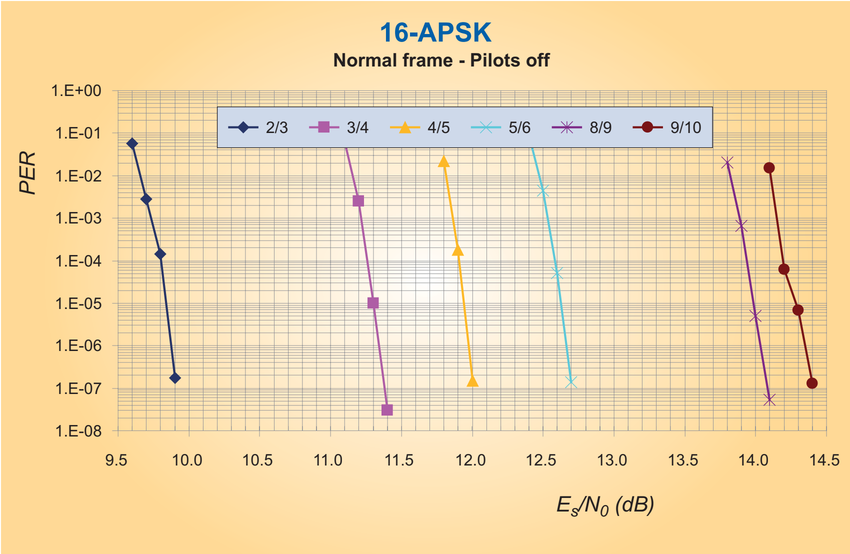


**Figure 4**
**16-APSK performance on the AWGN channel (IF loop): normal frame size and pilots**

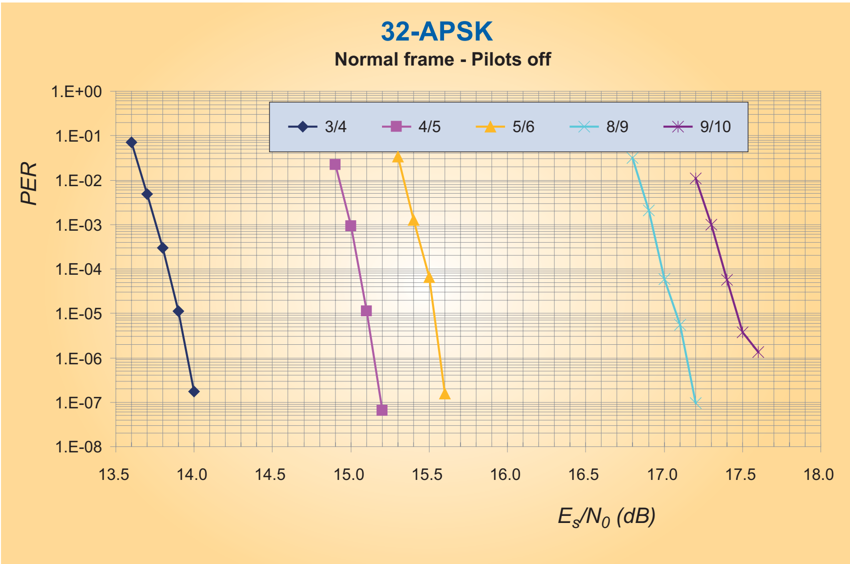


**Figure 5**
**32-APSK performance on the AWGN channel (IF loop): normal frame size and pilots**

except for 32-APSK where it is 20 Mbaud [2], and the roll-off is 35%. The implementation loss $\Delta E_S/N_0$, with respect to the simulation results indicated in Table 13 of [1], for a PER value of $10^{-7}$, are in the range 0.2 to 0.6 dB for QPSK, 0.2 to 0.9 dB for 8-PSK, 0.3 to 1.3 dB for 16-APSK and 1.3 to 1.7 dB for 32-APSK.

Tests carried out using the Short Frame mode, in an AWGN channel and for the same symbol rate, indicate comparable values of the implementation loss to those obtained for the Normal Frame case.

2. Maximum symbol rate available for the 32-APSK configuration. Above 20 Mbaud, the equipment performance is not guaranteed for the time being, since the clock speed and/or the FPGA density do not allow the required number of LDPC decoder iterations to be performed. It can be expected, in the near future, that improvements in FPGA technology could allow full performance to be achieved at extreme baud rates.

## *Satellite channel*

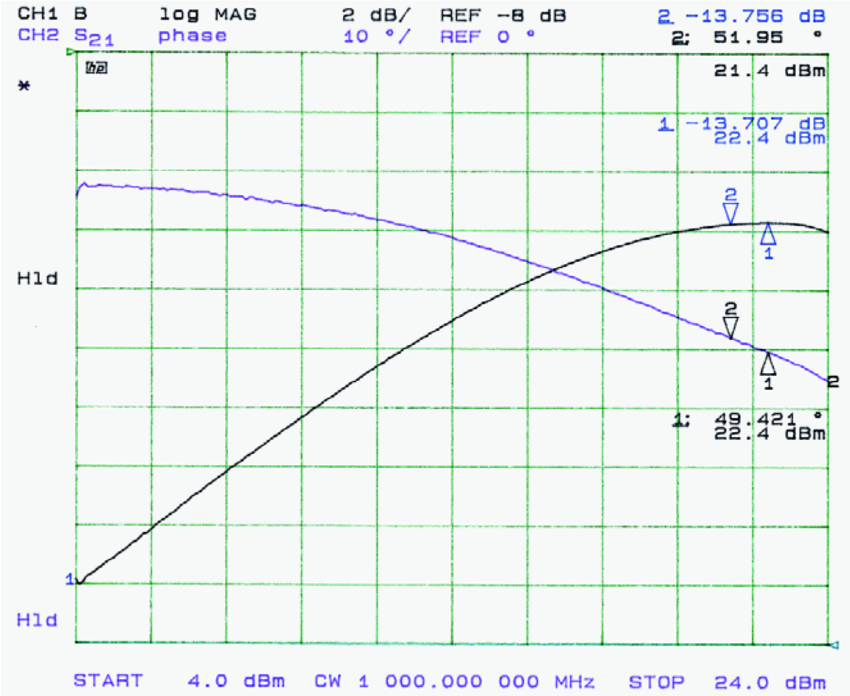


**Figure 6**
**AM/AM and AM/PM curves of the satellite simulator**

*Figs 7 to 10* show the DVB-S2 system performance over the satellite transponder with the non-linear characteristics of *Fig. 6* for the four selected configurations. The measured symbol rate $R_s$ is 27.5 Mbaud, except for 32-APSK where it is 20 Mbaud, the roll-off is 35% and $E_{sSAT}$ refers to an un-modulated carrier at saturation. The figures report the measured results for the system configurations without pilots in QSPK, 8-PSK and 16-APSK, and with pilots for 32-ASPK.

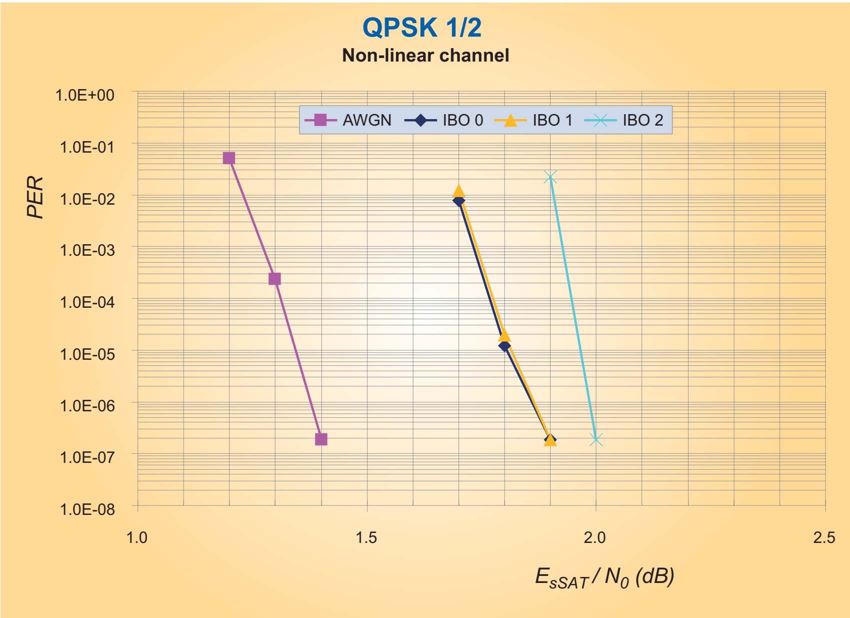


**Figure 7**
**QPSK rate 1/2 performance on the satellite channel for different values of the input back-off: normal frame size without pilots**

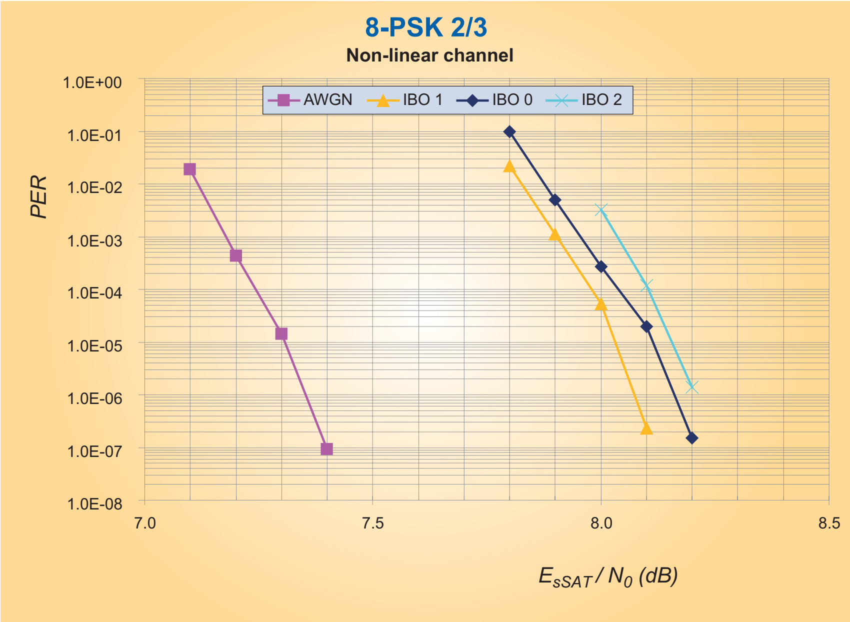


**Figure 8**
**8-PSK rate 2/3 performance on the satellite channel for different values of the input back-off: normal frame size without pilots**

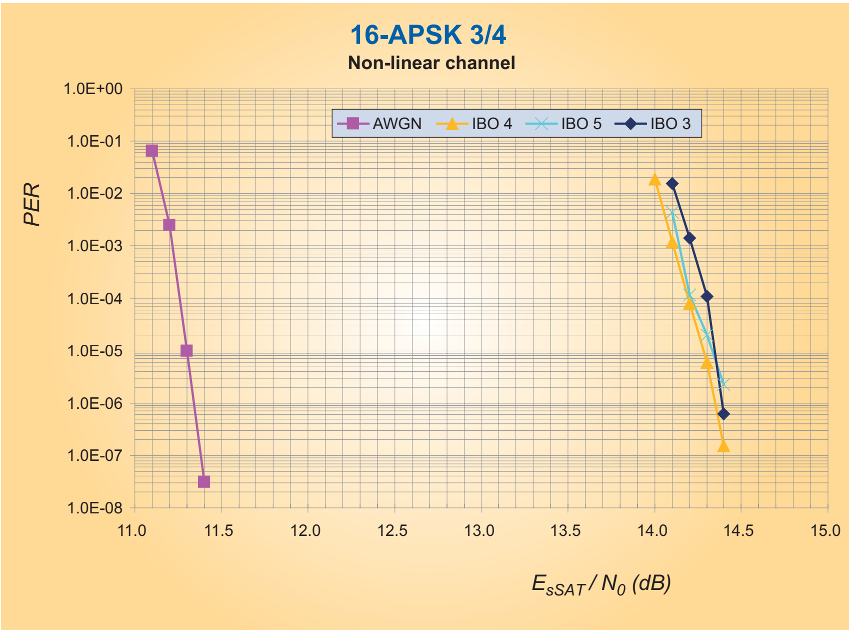


**Figure 9**
**16-APSK rate 3/4 performance on the satellite channel for different values of the input back-off: normal frame size without pilots**

The lab test results confirm the simulation results as reported in Table H.1 of [1]. The optimum operating point is 0 dB IBO (Input Back-Off) for QPSK1/2, corresponding to an OBO (Output Back-Off) of 0.3 dB, and giving a performance degradation of about 0.5 dB with respect to the AWGN channel. For 8-PSK the optimum operating point is 1 dB IBO, corresponding to an OBO of 0.4 dB, and giving a performance degradation of about 0.6 dB. For 16-APSK, the optimum operating point is 4 dB IBO, corresponding to an OBO of 1.6 dB, and giving a performance degradation of about 3.0 dB. For 32-APSK, the optimum operating point is 7 dB IBO, corresponding to an OBO of 3.2 dB, and giving a performance degradation of about 5.4 dB. If pilots are inserted in the transmitted signal, the performance improves by about 0.3 dB for 8-PSK and 1.0 dB for 16-APSK.

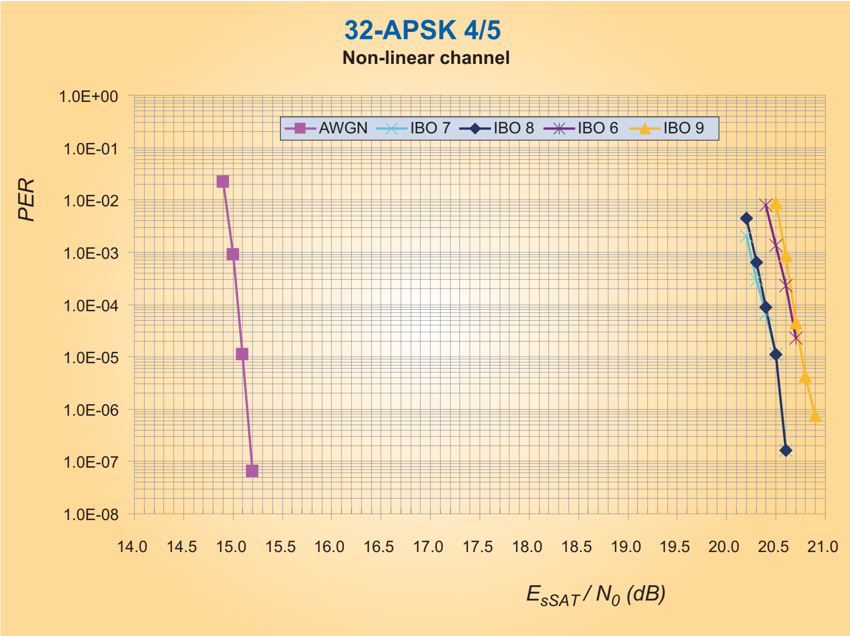


**Figure 10**
**32APSK rate 4/5 performance on the satellite channel for different values of the input back-off: normal frame size without pilots**

Additional tests have been carried out using signal pre-correction in the modulator to reduce the non-linear effects on the demodulated signal and to allow the system to work closer to the saturation point, also for higher order modulations. For 16-APSK, the use of pre-correction in the modulator allows the system to operate optimally at saturation (IBO = 0 dB), with a decrease in the satellite OBO of about 1.3 dB and a performance loss with respect to the AWGN channel of about 1.5 dB, i.e. allowing a gain in performance of about 1.5 dB with respect to the non-pre-corrected signal.

*Table 1* compares DVB-S and DVB-S2 in a broadcast scenario: the satellite channel includes the TWTA with the input-output characteristics shown in *Fig. 6* and a laboratory filter with 36 MHz -3dB bandwidth to simulate the satellite OMUX filter. *Table 1* indicates the C/N required by the systems under test to achieve the target PER of $10^{-7}$ in a 27.5 MHz bandwidth. The results in *Table 1* indicate that, at the expense of a marginal increase of the C/N requirements (0 to 0.2 dB), the DVB-S2 system allows us to increase the transmitted capacity, depending on the mode, up to and beyond 30%.

**Table 1**
**Comparative DVB-S / DVB-S2 scenarios for broadcast applications**

| System | DVB-S | DVB-S2 | DVB-S | DVB-S2 |
|---|---|---|---|---|
| Channel bandwidth BW [MHz] | 36 | 36 | 36 | 36 |
| Modulation & coding | QPSK 2/3 | QPSK 3/4 | QPSK 7/8 | 8-PSK 2/3 |
| Roll-off $\alpha$ | 0.35 | 0.20 | 0.35 | 0.25 |
| Symbol-rate (Mbaud) = 1,03*BW/(1+$\alpha$) | 27.5 ($\alpha$=0.35) | 30.9 ($\alpha$=0.20) | 27.5 ($\alpha$=0.35) | 29.7 ($\alpha$=0.25) |
| Useful bitrate (Mbit/s) | 33.8 | 46 (gain=34%) | 44.4 | 58.8 (gain=32%) |
| C/N (in 27.5 MHz) (dB) @PER=$10^{-7}$ | 4.7 | 4.9 | 7.6 | 7.6 |

Multiple-carrier-per-transponder configurations have also been tested with three carriers at 10 Mbaud on a quasi-linear transponder (total IBO=17 dB, OBO=10.5 dB), in the Normal Frame configuration with pilots using modes QPSK rate 1/2, 8-PSK 2/3, 16-APSK 3/4 and 32 APSK 4/5. The results indicate that, for a ratio $D_f/R_S$ (Channel spacing / symbol rate) larger that about 1.1, the performance loss due to the adjacent signal interference is around 0.2 dB for QPSK and 8-PSK, 0.5 dB for 16-APSK and 0.8 dB for 32-APSK. If $D_f/Rs=1$, than the degradation increases to 0.5 dB for QPSK, 1 dB for 8-PSK and 3.5 dB for 16-APSK.

## Phase noise test

Two different configurations were considered for the phase noise tests:

- A professional scenario, with a transmitted symbol rate of 5 MBaud and the satellite amplifier operating in the quasi-linear zone. In this case, the SMW WDL digital type B LNB was inserted in the test chain, with phase noise characteristics as shown in *Table 2*.
- A consumer scenario, with a transmitted symbol rate of 27.5 MBaud and the satellite amplifier operating at the optimum back-off. In this case, the Norsat 1000 PLL LNB was inserted in the test chain, with phase noise characteristics as shown in *Table 2*.

**Table 2**
**Aggregate Satellite Simulator and receiver LNB phase noise masks**

| Frequency | SMW WDL digital type B (professional) | Norsat 1000PLL (consumer) |
|---|---|---|
| **1 kHz** | -75 dBc/Hz | -65 dBc/Hz |
| **10 kHz** | -95 dBc/Hz | -75 dBc/Hz |
| **100 kHz** | -110 dBc/Hz | -85 dBc/Hz |

Results obtained for the professional scenario indicate that the degradation introduced by the LNB phase noise is in the order of 0.3 dB for QPSK and 8-PSK, and 1.2 dB for 16-APSK and 32-APSK. Furthermore, pilots are not required for QPSK, while they start to be beneficial for 8-PSK. Both 16-APSK and 32-APSK need pilots to give good results.

The consumer type scenario, with a larger symbol rate, is instead much less critical with respect to phase noise: the degradation introduced by the LNB phase noise is negligible for QPSK, even without pilots, in the order of 0.1 dB for 8-PSK and 0.3 dB for 16-APSK with the use of pilots.

## VCM and ACM tests

VCM tests were carried out, demonstrating the receiver's capability to adapt to changes in the transmission configuration. A sequence of DVB-S2 frames were generated and stored on an Arbitrary Waveform Generator. Noise was then inserted to give different values of signal-to-noise ratio. Provided that the signal-to-noise ratio was larger than the minimum requested by a specific modulation & coding, the receiver was able to decode the corresponding DVB-S2 frame.

Finally, ACM functionality was tested, to investigate the receiver's capability to estimate the signal-to-noise ratio experienced, and the corresponding flexibility of the modulator to change the modulation and coding. The results show that, in a point-to-point connection, the equipment is able to track the signal-to-noise ratio variations and to adapt correspondingly.

# Conclusions

This article has reported on the laboratory results obtained by RAI-CRIT when testing several DVB-S2 equipments. The tests investigated the ruggedness of the system in the presence of a variety of typical channel distortions, such as Gaussian, nonlinearity, receiver phase noise. Furthermore, the VCM/ACM capability has been verified on specific equipment.

The test results are largely in line with the performance predicted by computer simulations, and allow us to gain an important insight into the characteristics of the sophisticated modulation, channel coding, framing and synchronization techniques of the DVB-S2 system. The equipment under test represented a first generation of equipment and, consequently, some improvements to the receiver algorithms can certainly be expected (especially in the less conventional modes for broadcasting, i.e. 16-APSK, 32-APSK) which will offer further enhancements to performance in the future. In spite of this, the results indicate that DVB-S2 is an excellent system, not only on paper, but also in terms of real hardware.

Furthermore, comparison with the performance of DVB-S, in operational configurations, indicate that DVB-S2 offers the promised gain of about 30% in capacity in CCM configurations both in single-carrier and in multiple-carrier-per-transponder configurations.

Finally, tests have been carried out by coupling modulators and demodulators from different manufacturers, proving that the available equipment shows excellent interoperability.

**Andrea Bertella** was born in 1970 and received the *Laurea in Ingegneria Elettronica* degree from *Politecnico di Torino*, Turin, Italy in 1995. Since 1997, he has been with the RAI Research and Technologic Innovation Centre. He is involved in laboratory test, field trials, integration of experimental system and interworking tests between different equipments in digital terrestrial television (DVB-T and DVB-H), satellite television (DVB-S) and the second generation of satellite transmission (DVB-S2). He is author of several technical and scientific papers. He was a member of the European groups MOTIVATE (covering DVB-T mobile reception) and INSTINCT (laboratory tests on DVB-H terminals).

**Vittoria Mignone** received the *Laurea in Ingegneria Elettronica* degree from Turin Polytechnic in 1990. In 1991, in co-operation with the Electronics Department of Turin Polytechnic, she was engaged in studies on satellite broadcasting, on behalf of the National Research Council. Since 1992, she has been with the RAI Research and Technical Innovation Centre in Turin, involved in studies to define the ETSI Standards for digital television broadcasting via satellite, cable and terrestrial channels. Her current activities are in the field of advanced digital modulation and channel coding techniques for satellite and terrestrial transmissions. She is the author of various technical papers.

**Bruno Sacco** was born in 1962 and received a degree in Electronic Engineering from the *Politecnico di Torino*, Turin, Italy in 1988. He first joined Alenia (Italian aerospace company) where he was involved in the design of radar and antenna measurement systems. He then moved to the RAI Research Centre, becoming involved in RF design, antenna design, laboratory tests and the development of advanced digital transmission system prototypes for satellite and terrestrial transmission, including digital modems and multicarrier systems (COFDM). He is also involved in the biological effects of electromagnetic fields. He is the author of various technical papers.

**Mirto Tabone** is involved in laboratory tests covering performance assessments and validation of digital transmission systems, also within the framework of European project activities. He is also involved in the integration of experimental digital transmission systems and pre-operative field trials.

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