New DVB standard for DSNG
– and contribution satellite links

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In July 1997, the Technical Module of the DVB Project set up an Ad-hoc Group on Digital Satellite News Gathering (DSNG) under the chairmanship of the RAI. Its tasks were: (i) to define the specification of the modulation/channel coding for DSNG and other contribution applications by satellite, (ii) to define the specification for the auxiliary co-ordination channels and (iii) to co-operate with other DVB groups in order to define the user guidelines for source coding, Service Information (SI) and scrambling for Conditional Access (CA).

A flexible DVB-DSNG system [1] has now been defined and is described here. Mainly based on the DVB system for satellite broadcasting (DVB-S), it offers a range of different picture-quality levels at various bit-rates by using the MPEG-2 MP@ML and 422P@ML algorithms. The specification for the auxiliary co-ordination channels [2] was finalized by the group in Autumn 1998 and the approval procedure is still in progress within DVB and ETSI. It is not described in this article for reasons of conciseness.

1. Introduction

Today's broadcasting is dominated by increasing competition and, consequently, the real-time acquisition of news material (e.g. sports events, interviews, concerts, calamities) – in both the domestic and the international environments – is a major factor in the search for audience ratings. In this context, light-weight satellite news-gathering (SNG) transmit terminals – with 90 to 150 cm antennas – offer a cost-effective solution to establishing rapid connections between outside broadcast (OB) vans and TV studios without requiring local access to the fixed telecom network.

In the case of PAL, SECAM and NTSC, *analogue* SNG systems using frequency modulation (FM) are currently operated in both the C and Ku bands. In Europe, the TV satellite contribution

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links are commonly in the Ku band (using the 14 - 14.5 GHz band for the up-link and the 10.71 - 12.75 GHz band for the down-link). Although there have been progressive improvements in antenna and amplifier design, and the original bulky and heavy analogue SNG equipment has been reduced in weight and size, portability is still very much a key issue requiring adequate solutions in the analogue world.

The required EIRP of an up-link of course depends on the footprint of the satellite which will receive its signals. The EIRP of analogue up-links are typically 69 - 75 dBW, depending on the size of the antenna and the high-power amplifier (HPA) in use. Antenna sizes vary from 1.5 to 2.4 m and the HPA powers range from 300 to 600 W.

The commercial introduction of small digital equipment in the domains of video / sound compression, advanced error protection and modulation has recently enabled the development of operational *digital* SNG (DSNG) systems. These new systems have a number of advantages over analogue systems, including:

⇨ *miniaturization* of the up-link terminal;

⇨ lower required EIRPs;

⇨ more efficient use of the frequency spectrum.

Digital SNG systems permit multiple signals to be transmitted simultaneously through the satellite transponders, significantly increasing the flexibility of the transponder access, and reducing the cost per channel. The inherent flexibility of DSNG systems allows us to fulfil the different quality requirements of news, sports events and entertainment by operating the video / audio compression algorithm at the most appropriate bit-rate. Moreover, the ruggedness of a digital system against noise and interference enables constant picture and sound quality to be obtained at the receiving site, down to a certain threshold signal level.

Before the development of the DVB-DSNG standard, digital contribution links by satellite were often based on the ETSI 300 174 standard for video compression [3]. This system, which was designed for *contribution* applications at 34 and 45 Mbit / s, also became available in proprietary scaled versions at 17 Mbit / s and 8.5 Mbit / s which were more suitable for pure DSNG applications. The modulation and channel coding were usually based on the IDR specification, using QPSK modulation and convolutional coding.

In 1993-94, the DVB Project developed the specification of a digital multi-programme television system for satellite broadcasting (DVB-S), under the direct responsibility of the RAI Research Centre [4][5]. With the world-wide success of this system, it became more and more clear that it could be suitable also for DSNG applications, with significant advantages in cost, performance and flexibility over the previous systems [6]. In the summer of 1997, the DVB Project decided to start the development of a new specification for DSNG, based on the DVB-S system [4] but with a number of new features designed to cover the commercial and operational requirements of contribution applications. This project was also the responsibility of the RAI.

The DVB-DSNG system [1] is transparent to any signal in the MPEG-2 Transport Stream format and can transport video signals encoded in either the MP@ML format, or in the 422P@ML format when higher quality and enhanced editing facilities are required. Other MPEG-2 profiles and levels may be transported as well, e.g. 422P@HL which is suitable for HDTV contribution links.

The DVB-DSNG system is based on QPSK modulation and convolutional coding, which were originally developed to provide DTH television services via satellite in the MCPC mode, but which are also suitable for DSNG and contribution applications in the SCPC mode. Nevertheless, two optional transmission modes have been added to the DVB-DSNG system: trellis-coded 8PSK and 16QAM. These offer higher spectrum efficiency in those applications which are less affected by power limitations (e.g. vehicle-based DSNG up-links). The main feature of the DVB-DSNG system is thus the flexibility of its modulation and channel-coding schemes which – on a case by case basis – allow the most appropriate modulation scheme, symbol rate and coding rate to be selected in order to optimize the satellite link performance (i.e. the spectral occupancy within the satellite transponder and the power requirements).

Specific technical solutions have been defined by DVB for the transport of MPEG signals on terrestrial telecom networks such as PDH and SDH, by mapping the Transport Stream packets into ATM cells. These adapters can be used to connect the DSNG receiving stations to the TV studios.

2. Basic user requirements

The technical characteristics of DVB systems are largely market-driven. Based on an analysis of the market needs, the DVB Commercial Module (CM) produces *Commercial Users' Requirements* for input to the DVB Technical Module (TM) which is responsible for developing the required specifications.

In accordance with the ITU, the CM has adopted the following definition of SNG (ITU-R Rec. SNG.770-1): *"Temporary and occasional transmissions with short notice of television or sound for broadcasting purposes, using highly portable or transportable up-link earth stations operating in the framework of the Fixed-Satellite Service (FSS)".*

A DSNG "terminal" or "up-link" is a portable (or transportable) earthstation which can be moved to a remote location in order to transmit back the video programme with its associated sound, or sound-only programme signals, either "off-tape" or "live". It can either be packaged in "fly-away" form (i.e. in flight cases suitable for air transportation) or integrated into a vehicle.

DSNG up-link terminals should be highly reliable and have reduced size and weight, while the receiving station should be dimensioned appropriately to ensure the required link availability. Therefore the transmission format should provide both high ruggedness against noise and interference and the best exploitation of satellite capacity.

High intervention promptness and low set-up complexity are required. In particular, *"the equipment should be capable of being set up and operated by a crew of no more than two people within a reasonably short time (for example, one hour)"*. Interoperability between different pieces of equipment is another key feature of DSNG, especially in an international programme-exchange environment. In particular, the CM has identified within the complex DVB/MPEG SI/PSI tables a possible source of problems for DSNG, affecting equipment interoperability and rapid link set-up.

By nature, DSNG links are contribution links, the quality objectives of which are defined by ITU-R Rec. BT.1121: *"There is no need to define lower quality objectives, if it is understood that, due to circumstances, possible relaxations are to be accepted by the user. For DSNG links, the typical bit-rate used by fly-away and small transportable terminals are about 8 Mbit/s, using MPEG-2 MP@ML. However for transportable stations"*, when higher quality and enhanced editing facilities are required, *"use of MPEG-2 422P@ML should be supported. … In this case, bit-rates should be higher than 8 Mbit/s and lower than 34 Mbit/s"*.

As regards multiplexing, although DSNG transmissions usually transport a single TV programme and its associated sound signals (SCPC), "*advantage should be taken of the flexibility of the MPEG-DVB multiplex*" to convey multiple programmes (MCPC).

The processing delays of digital compression systems may be very high (even exceeding one second), especially with today's sophisticated coding algorithms which allow high bit-rate compression ratios. Short video-coding delays are important characteristics for those applications where the DSNG transmission is mixed together with a live programme, since long delays would prevent dialogues between journalists in the studio and in the field.

Optionally, DSNG equipment should be capable of providing two or more duplex co-ordination (communication) circuits by satellite, whenever possible in the same transponder as the main DSNG signal. These channels should be available prior to, during and after the DSNG transmission in order to connect the DSNG operator, the satellite operator and the broadcaster. This equipment may also provide for data transmission and faxes. The specification [2] was finalized within the DSNG group in Autumn 1998 and the approval procedure by DVB and ETSI is now in progress.

Regarding the equipment cost, the CM pointed out that *"the total cost of the system and its operation should be considered, and not just the receiver cost. A non-negligible part of the overall cost of an SNG transmission lies in the requirements for satellite capacity. Modulation techniques, additional to QPSK, such as 8PSK and 16QAM, should be investigated to optimize the efficient use of satellite capacity"*.

3. Source coding and multiplexing

The success of the DVB standards is also due to the adoption on all media (e.g. satellite, CATV, terrestrial VHF/UHF and MMDS networks) of a "common solution" for video/audio coding and digital multiplexing, making possible the mass production of VLSI chips for consumer IRDs.

3.1. Video coding

The MPEG-2 MP@ML format may be used as the baseline solution for picture coding in DSNG applications. It allows high flexibility, being able to operate with variable bit-rates from 1.5 to 15 Mbit/s.

MPEG-2 codecs are based on Hybrid DPCM/DCT algorithms with motion compensation, operating on I-frames (intra), P-frames (predicted) and B-frames (bi-directional prediction). It should be noted that MP@ML is a 4:2:0 system which was designed for distribution rather than contribution. At bit-rates of 6 Mbit/s and 9 Mbit/s, it allows a subjective quality for current programme material that, respectively, is equivalent to PAL and 4:2:2 pictures. Lower bit-rates may be acceptable for specific applications (e.g. films, news, educational), where power and bandwidth limitations are dominant over the picture quality requirements.

In 1995, MPEG-2 defined a picture coding "profile" called 422P@ML to fulfil the requirements of the production environment. It offers a number of additional features compared with the MP@ML format such as (i) the coding rate can be increased up to 50 Mbit/s and (ii) the chroma components maintain the same 4:2:2 format as the uncompressed studio format. This allows: higher picture quality; better chroma resolution; post-processing after co-decoding; and short GoPs to improve the editability in compressed form and to shorten the coding delay. Subjective quality tests (non-expert viewers, 4H distance) have been carried out by the RAI Research Centre and other organizations [7] on computer-simulated 422P@ML sequences, with single and multiple generations (eight co-decoding processes) and colour matte post-processing.

Different GoP structures have been analyzed:

- a purely intra-frame configuration which allows one-frame editing precision at the expense of low compression efficiency, running at 50 and 30 Mbit/s (indicated as *I@50* and *I@30);*
- one I-frame and one B-frame, which allows a good compromise between editing and compression ratio, running at 30 and 20 Mbit/s (indicated as *IB@30* and *IB@20*);
- the traditional MP@ML GoP, with 15 IBBP frames, running at 20 Mbit/s (indicated as *IBBP@20*).

With reference to the double-stimulus continuous quality 100-grade scale, the following quality levels are arbitrarily defined in MPEG documents:

- *"transparent"* (0 to 12.5);
- *"nearly-transparent"* (12.5 to 20);
- *"good"* (20 to 40).

The subjective test results indicate that after eight co-decoding processes, the *I@50* (including chromakey) and *IB@30* coding structures fulfil the "transparency" ratings and, after a single co-decoding process, chromakey can be performed "transparently" on *I@30* and *IB@20*. In addition, all the coding structures gave ratings which matched well the "nearly transparent" quality, apart from a few tests which moderately exceeded the 20% target.

Summarizing, to fulfil the wide range of picture-quality levels and bit-rates required by DSNG and other contribution applications, MP@ML at bit-rates from 1.5 to 15 Mbit/s can cover the applications where no (or very limited) post-processing is performed in the studio before re-broadcasting. The 422P@ML format at bit-rates from 15 to 30 Mbit/s can, on the other hand, cover high-quality applications where post-production and cascaded co-decoding are required.

In any case, it must be kept in mind that the switching and editing of MPEG-2 transport streams in the studio, without decoding, can be very difficult because of the problems related to clock handling and buffer overflow control. Therefore, in many cases the DSNG contributions (independently of the adopted compression scheme) must be re-converted into 4:2:2 format in the studio, edited and then re-encoded for final broadcasting (in MP@ML format).

3.2. Audio coding

All the DVB systems – in line with the trend toward international standardization – have adopted the MPEG Layer II audio coding method which allows a wide range of bit-rates (e.g. from 64 to 256 kbit/s) in order to satisfy the various service requirements. Bit-rates as low as

64 kbit/s may be applicable for some DSNG applications with mono channels. The optional use of linear (uncompressed) audio coding is also under evaluation by DVB for contribution applications that require maximum audio quality.

4. Transport Multiplexing and Service Information (SI)

The DVB-S system adopts a common framing structure, based on the MPEG-2 transport multiplex, with fixed length packets of 188 bytes, comprising one sync byte, three header bytes and 184 useful bytes. This structure allows easy interworking between broadcast channels and telecom networks using ATM protocols.

The MPEG-2 multiplex is very flexible for merging a variety of video, sound and data services in the transport stream, as well as additional information (e.g. Service Information, Conditional Access). Therefore it allows SCPC as well as MCPC services.

The DVB-MPEG Service Information tables defined for broadcasting applications describe in detail the multiplex configuration and the programme content, and allow the user to access easily a wide programme offer through the Electronic Programme Guide (EPG). Annex D of the DSNG specification deals with a simplified Service Information mechanism based on few fixed tables. It avoids the need to compile SI information in the field, thereby accelerating the link set-up time and simplifying any interoperability problems. Up-link station identification is also provided, for emergency interference situations.

Of the MPEG2-defined SI tables that have been introduced to describe the multiplex configuration and the programme content in broadcasting services, only the Programme Associated Table (PAT), the Programme Map Table (PMT) and the Transport Stream Descriptor Table (TSDT) are kept in the DSNG specification as mandatory. These tables may be fixed for a DSNG station. In the TSDT table, a descriptor indicates that the Transport Stream is for Contribution Applications (not for the general public). Furthermore, for DSNG transmissions, another descriptor is inserted to allow fast identification of the up-link station in cases of transmission problems (e.g. access to the wrong transponder or satellite). These SI structures may prevent compatibility with consumer IRDs and, therefore, if this compatibility is required by the operator, all the SI tables must be compiled according to the DVB-SI specification.

Since no forward error correction (FEC) protects the TS packet headers, a rugged “channel adapter” is required to provide an *error-free* datastream to the demultiplexer input, as described in the following section.

5. Channel coding and modulation

The transmission performance of a typical DSNG system depends on the various components included in the satellite chain:

- ⇨ the transmit earthstation;
- ⇨ the space segment (up-links and down-links);
- ⇨ the satellite transponder (IMUX, OMUX filters, TWTA);

➩ the receive earthstation.

The satellite channel is basically *non-linear, wide-band* and *power limited*. The main signal impairments are introduced by noise, rain attenuation and interference on the space segment, and eventually by incorrect alignment of the transmit and receive stations and equipment. The non-linearity (amplitude and phase distortions) of the on-board TWTA is responsible for impairments to the overall system performance.

In the case of digital DTH services, a single QPSK carrier is transmitted in the transponder and, to achieve the maximum power efficiency, the satellite TWTA is usually operated close to saturation. The effects of TWTA non-linearity are waveform distortion and side-lobe regeneration of the power spectrum. In these applications, due to the reduced dimensions of the receiving antennas, the service availability is mainly limited by the down-link noise.

For DSNG and contribution applications, the usual method of accessing the transponders is FDM where part of the transponder bandwidth (frequency slot) is allocated to each signal, in SCPC mode. In order to reduce the effect of intermodulation noise introduced on adjacent carriers occupying the same transponder, the TWTA must be operated significantly below the saturation point. The linearity requirements are raised also by the fact that the aggregated FDM signal is no longer characterized by a constant envelope, even if each individual signal has a quasi-constant envelope (e.g. QPSK or 8PSK). The higher the spectrum efficiency of the modulation / coding scheme, the more stringent are the linearity requirements, because of the reduction of the system ruggedness against intermodulation interference from the adjacent signals.

In FDM transmissions, the down-link level of any one signal does not noticeably change as a function of the total transponder load, making it straightforward to set and monitor the down-link EIRP. This more linear type of operation also provides more protection against single up-link drive fluctuations.

Efficient and reliable transmission of digital television signals over satellite channels is focused on the design of the “channel adapter”, which performs the adaptation of the multiplexed video / audio / data bitstream to the physical channel, by adopting powerful channel coding and modulation techniques. In the definition of the DSNG system, the design target has been the minimization of the effects of the various channel impairments, such as additive noise, interference from analogue and digital signals, and linear and non-linear distortion. The specified system offers many transmission modes (inner coding and modulations), giving different trade-offs between power and spectrum efficiency. QPSK modulation has been adopted (and optionally the 8PSK and 16QAM modulation schemes) and the concatenation of convolutional and Reed-Solomon codes is introduced.

The QPSK mode is compliant with the DVB-S system defined in [4] while for 8PSK and 16QAM, “pragmatic” trellis coding [8] has been applied, optimizing the error protection of the same convolutional code. The convolutional code is able to be configured flexibly, allowing the optimization of the system performance for a given satellite transponder bandwidth. The QPSK and 8PSK modes, thanks to their quasi-constant envelopes, are suitable for operation with saturated satellite power amplifiers, in a single-carrier-per-transponder configuration. 16QAM (as well as QPSK and 8PSK) is appropriate for operation in quasi-linear satellite channels, in multi-carrier FDM-type applications, where better spectrum efficiency is attained.

Fig. 1 gives a functional block diagram of the DVB-DSNG transmission system. The input stream, organized in 188-byte packets following the MPEG-2 transport multiplexer [9], is randomized bit by bit through a scrambling PRBS, in order to comply with the Radio Regulations interference requirements (the transmitted signal must have a regular spectrum shape), and also to facilitate clock recovery in the receiver. Then the shortened R-S code (204,188, t = 8) – derived from the original R-S (255, 239, t = 8) code – is applied to each randomized transport packet.

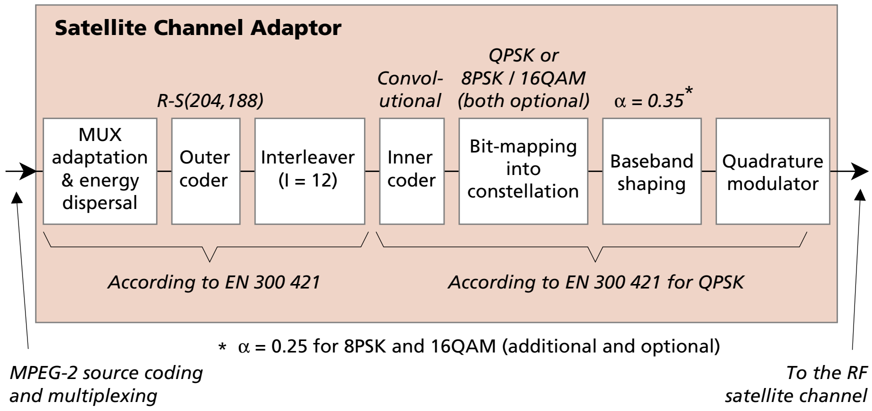

Figure 1
Functional block diagram of the DVB-DSNG system.

Since, on the receiver side, the residual errors at the output of the Viterbi decoder are not statistically independent, but are grouped in a burst which may overload the R-S code correction capability, the error distribution is randomized through a convolutional interleaver with depth I equal to 12 bytes applied to the error-protected packets. The interleaved packets are then passed to the convolutional encoder, which is based on a rate 1/2 mother convolutional code with constraint length equal to 7 (64 trellis states), and which allows the selection of the most appropriate level of error correction for a given service or data-rate.

Punctured convolutional coding is associated with QPSK modulation (according to the DVB-S system specification [4]) with the possibility of operating at five possible rates: 1/2, 2/3, 3/4, 5/6, 7/8. Pragmatic Trellis Coded Modulation (TCM) [8] on the other hand is associated with 8PSK and 16QAM. The operating principle of the pragmatic trellis encoder is shown in *Fig. 2*.

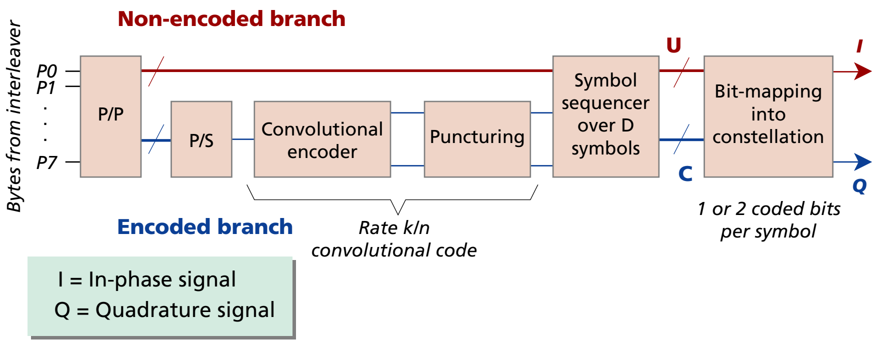

Figure 2
Principle of the inner trellis coder.

The byte-parallel stream at the output of the convolutional interleaver is conveyed to a parallel-to-parallel (P/P) converter which splits the input bits into two branches, depending on the selected modulation / inner coding mode. It has been designed to reduce, on average, the byte error-ratio at the input of the R-S decoder (high concentration of bit-errors in bytes) and, therefore, to reduce the bit error ratio (BER) after the R-S decoder.

In the *non-encoded* branch, the symbol sequencer generates a sequence of signals **U**, each to be transmitted in a modulated symbol. These bits generate parallel transitions in the trellis code, and are only protected by a large Euclidean distance in the signal space. In the *encoded* branch, the signals first pass through a parallel-to-serial (P/S) converter for subsequent processing by the punctured convolutional encoder. These bits generate, through the symbol sequencer, a sequence of signals **C**, each to be transmitted in a modulated symbol.

The 8PSK 5/6 and 8/9 schemes are characterized by one coded bit per symbol (referred to as 1CBPS), while the 8PSK 2/3 and 16QAM 3/4 and 7/8 schemes have two coded bits per symbol (2CBPS). The optimum bit-mapping into constellations are different for 1CBPS and 2CBPS. The selection of the trellis coding schemes, from a number of different proposals, was based on accurate computer simulations carried out by the RAI Research Centre.

The selected schemes were the ones which offer the best performance on a linear channel affected by Additive White Gaussian Noise (AWGN). With comparable performance in mind, the 1CBPS schemes are preferred since they require a lower processing speed in the TCM Viterbi decoder, compared with 2CBPS schemes, and therefore they allow the implementation of higher-speed modems (for high-quality contribution applications or MCPC transmissions).

Finally, baseband shaping and quadrature modulation are applied to the signal. Square-root raised-cosine base-band shaping, with a roll-off factor of $\alpha = 0.35$, is considered for all constellations, as in the DVB-S system [4]. An additional roll-off factor $\alpha = 0.25$ may be used for the 8PSK and 16QAM modulation schemes, in order to increase the spectrum efficiency within the transponder bandwidth. This choice was based on extensive computer simulations, including satellite TWTA effects, carried out by the RAI.

6. Performance on the AWGN channel

Sensitivity to transmission noise is expressed, for the various rates of the convolutional code, by the E_b/N_0 ratio required to achieve a target residual BER. E_b is the energy per useful bit and N_0 is the spectral density of the AWGN. The DVB-DSNG system has been designed to provide a QEF quality target, i.e. approximately less than one incorrect error event per transmission hour at the input of the MPEG-2 demultiplexer. This target, achievable by interleaving and by R-S error correction, corresponds to a BER of about 2×10^{-4} at the output of the TCM Viterbi decoder and to a byte error ratio of between 7×10^{-4} and 2×10^{-3} depending on the coding scheme.

It should be noted that these evaluations take into account stationary noise only, and ideal demodulation. Furthermore, the effects of phase noise and carrier-recovery instabilities might generate bursts of uncorrectable errors, separated by large time intervals. DVB-DSNG coding schemes are not rotationally invariant (i) because, in the majority of cases, pragmatic schemes were not available and (ii) in order to optimize the BER performance. Therefore, care should be taken in the design of the frequency converters and the carrier-recovery systems, in order to avoid “cycle skipping” and “phase snaps” which may produce service interruptions. These goals may be achieved easily in professional front-ends

Table 1 gives the IF loop system performance requirements for the different modes, in terms of the required E_b/N_0 to provide BER = 2×10^{-4} (Quasi Error Free quality target). The figures for E_b/N_0 are with reference to the useful bit-rate R_u (188-byte format, before R-S coding), and take into account the factor $10 \log 188/204 \cong 0.36$ dB due to the R-S outer code and the modem implementation margins. For QPSK, the figures are derived from [4]. For 8PSK and 16QAM, modem implementation margins which increase with the spectrum efficiency are adopted, to cope with the larger sensitivity associated with these schemes.

Table 1
IF-Loop performance of the DVB-DSNG system.

Modulation	Inner code rate	Spectral efficiency (bits/symbol)	Modem implementation margin [dB]	Required E_b/N_0 [dB] for BER = $2x10^{-4}$ before R-S
QPSK	1/2	0.92	0.8	4.5
	2/3	1.23	0.8	5.0
	3/4	1.38	0.8	5.5
	5/6	1.53	0.8	6.0
	7/8	1.61	0.8	6.4
8PSK (optional)	2/3	1.84	1.0	6.9
	5/6	2.30	1.4	8.9
	8/9	2.46	1.5	9.4
16QAM (optional)	3/4	2.76	1.5	9.0
	7/8	3.22	2.1	10.7

The ruggedness against noise of digital TV (QPSK-3/4) and analogue PAL/FM on a satellite channel are shown in *Fig. 3*. The quality impairment is expressed in terms of the C/N ratio, assuming as reference an analogue receiver bandwidth B_{RX} of 36 MHz, which is typical of satellite FM/TV transmissions with 25 MHz/V frequency deviation. To perform a fair comparison, the digital system is operated in single-signal-per-transponder configuration, and the C/N ratio is measured in the same bandwidth B_{RX} of 36 MHz as the analogue signal (about 1 dB additional degradation on the transponder should be considered):

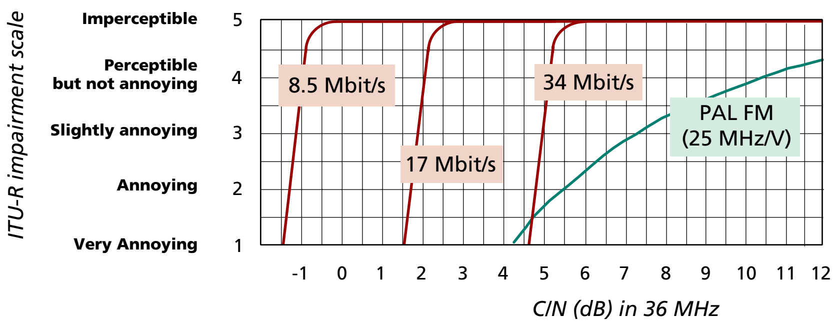

Figure 3
Picture impairment vs. C/N: digital TV (QPSK-3/4) and analogue FM/TV on a satellite channel.

$$C/N\ (dB) = E_b/N_0\ (dB) + 10\ Log\ (R_u/\ B_{RX})$$

From *Fig. 3*, it can be seen that a DSNG signal at 17 Mbit/s, providing near-contribution quality, would require about 3 dB C/N (in 36 MHz) to operate quasi-error-free compared with the 12 - 13 dB required by analogue FM/PAL for an acceptable picture quality. If the transmission rate is reduced to 8.5 Mbit/s, which is suitable for DSNG applications with PAL quality, the required C/N ratio would approach 0 dB.

Thanks to this remarkable performance, the digital solution is capable of delivering the picture and sound quality of the "compressed" source, provided that adequate margin against rain attenuation is allowed for in the link budget design to ensure that the system operates above the service continuity threshold.

7. Examples of the system in use

One of the main features of the DVB-DSNG system is its flexibility. It allows, on a case-by-case basis, the selection of the modulation scheme, the symbol rate and the coding rate in order to optimize the satellite link performance (i.e. the spectral occupancy of the satellite transponder and the power requirements). On the other hand, in order to achieve rapid interoperability and link set-up in emergency situations, the DSNG specification mandates that at least one "user-definable" set-up is available in DSNG equipment. This set-up includes the video/audio coding parameters, the modulation scheme and the symbol rate.

Although DSNG applications usually exploit the satellite bandwidth in the FDM configuration, the DSNG system is suitable also for single-carrier-per-transponder transmissions. In this type of configuration, the transmission symbol rate R_S can be matched to the given transponder bandwidth BW (at –3 dB), to achieve the maximum transmission capacity compatible with the acceptable signal degradation due to transponder bandwidth limitations. To take into account possible thermal and ageing instabilities, reference can be made to the frequency response mask of the transponder.

In multi-carrier FDM configurations, R_S can be matched to the frequency slot BS allocated to the service by the frequency plan, in order to optimize the transmission capacity while keeping the mutual interference between adjacent carriers at an acceptable level.

Fig. 4 gives examples of the maximum useful bit-rate capacity R_u achievable by the system, versus the allocated bandwidths BW or BS. R_u is the useful bit-rate (188-byte format) after MPEG-2 MUX while R_S (symbol rate) corresponds to the –3 dB bandwidth of the modulated signal. $R_S(1 + \alpha)$ corresponds to the theoretical total signal bandwidth after the modulator. The figures for very low and very high bit-rates may be irrelevant for specific applications. In these examples the adopted BW/R_S or BS/R_S ratios are $\eta = 1 + \alpha = 1.35$, where α is the roll-off factor of the modulation. This choice allows us to obtain a negligible E_b/N_0 degradation due to transponder bandwidth limitations and adjacent channel interference on a linear channel. Higher bit-rates can be achieved with the narrow roll-off factor $\alpha = 0.25$ (optional for 8PSK and 16QAM) and BW/R_S or BS/R_S equal to:

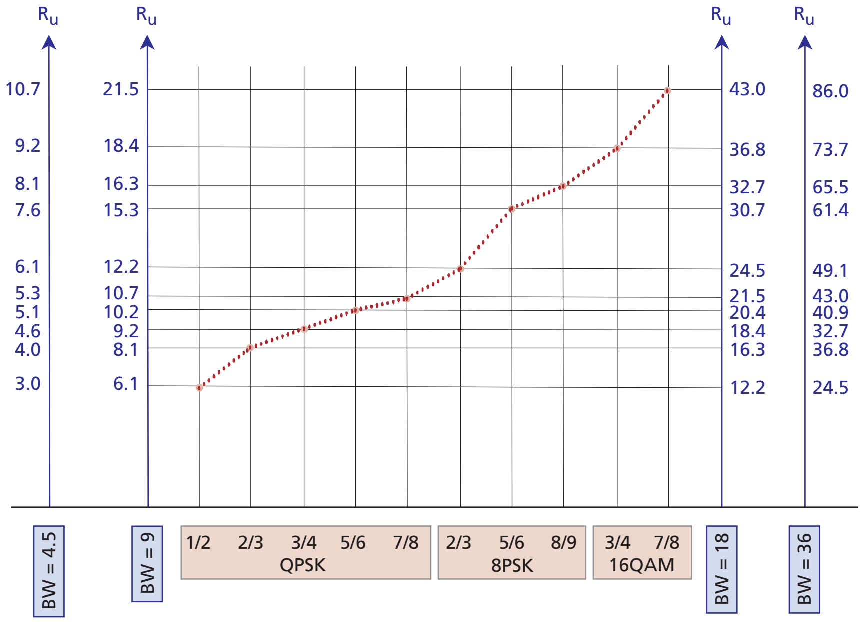

Figure 4
Bit-rate capacity vs. available bandwidth.

$$\eta = 1 + \alpha = 1.25$$

BW/R_S or BS/R_S ratios which are different from $1 + \alpha$ may be adopted for different service requirements. The adoption of figures significantly lower than $1 + \alpha$ (e.g. $\eta = 1.21$ associated with $\alpha = 0.35$), in order to improve the spectrum exploitation, should be carefully studied on a case-by-case basis, since severe performance degradations may arise due to bandwidth limitations and / or adjacent channel interference, especially with 8PSK and 16QAM modulations and high coding rates (e.g. 5 / 6 or 7 / 8).

Table 2 considers possible examples of the system used in the single-carrier-per-transponder configuration. Different modulation and inner code rates are given with the relevant bit-rates. According to typical practical applications, a BW / R_S ratio equal to 1.31 is considered, offering a slightly better spectrum efficiency than the examples of *Fig. 4* for the same modulation / coding schemes. The 36 MHz transponder bandwidth considered here is wide enough to allow high-quality 422P@ML SCPC transmissions, as well as MP@ML and 422P@ML MCPC transmissions.

Table 2
Examples of System configurations by satellite: single-carrier-per-transponder.

Satellite BW (at –3 dB)	System mode	Symbol Rate R_S [Mbaud]	Bit-rate R_u (after MUX) [Mbit/s]	E_b/N_0 (specification) [dB]
36	QPSK 3/4	27.500	38.015	5.5
36	8PSK 2/3	27.500	50.686	6.9

Quasi-constant envelope modulations, such as QPSK and 8PSK, are power efficient in a single-carrier-per-transponder configuration, since they can operate on transponders driven near to saturation. Conversely, 16QAM is not power efficient since it can only operate on quasi-linear transponders, i.e. with large OBOs. (In the Appendix to this article, *Fig. A7* shows the E_b / N_0 degradation versus the transponder input back-off for three modulation and channel coding schemes in a single-carrier-per-transponder configuration.) The use of the narrow roll-off $\alpha = 0.25$ with 8PSK can produce a larger non-linear degradation in a satellite system.

Analogously, *Table 3* considers possible examples of the system used in the multi-carrier FDM configuration and in SCPC mode. Different modulation / coding modes are given with the relevant bit-rates. The E_b / N_0 figures refer to the IF loop specification for QEF operation. The overall linear, non-linear and interference degradations of the satellite should be evaluated on a case-by-case basis; typical figures are of the order of 0.5 to 1.5 dB.

Table 3
Examples of system configurations by satellite: multi-carrier FDM transmissions, SCPC mode.

Satellite BW [MHz]	Slot BS [MHz]	Number of Slots in BW	Video Coding	System mode	Symbol Rate [Mbaud]	BS/R_S [Hz/Baud]	Bit-rate R_u [Mbit/s]	E_b/N_0 [dB] (specification)
36	9	4	MP@ML	QPSK 3/4	6.1113	1.47	8.4480	5.5
36	18	2	422P@ML	QPSK 7/8	13.3332	1.35	21.5030	6.4
36	12	3	422P@ML	8PSK 5/6	9.3332	1.28	21.5030	8.9
36	9	4	422P@ML	16QAM 7/8	6.6666	1.35	21.5030	10.7

Link budget evaluations have been carried out to estimate the earthstation characteristics required to achieve a suitable service continuity target (i.e. 99.9% or 99.6% of the average year) in Italy, on a typical Ku-band satellite with Europe-wide up-link and down-link coverage. Two Italian *up-link* locations were chosen to represent (i) a typical case (Palermo, ITU climatic zone K) and (ii) a worst case (Turin, ITU climatic zone L); the chosen reception location was Rome (climatic zone K).

To allow a fair comparison of the results, the link budgets were optimized at each location, although it is clear that operation in Italy would require the adoption of a uniform set of transmission parameters, such as the satellite transponder gain setting. For DSNG applications, the up-link antenna diameters were minimized, while neglecting the possibility of receiving the transmitted TV signal by the DSNG terminal. For contribution links connecting fixed stations, the same antenna diameters were adopted at the transmitting and receiving sites, in order to allow a bi-directional exchange of programme material.

The following link characteristics were adopted:

Up-link Terminals

See *Table 4*.

Table 4
Characteristics of the up-link terminal.

Parameter	Value
Locations	Turin (zone L) Palermo (zone K)
Frequency (GHz)	14.29
Antenna efficiency (%)	60
Coupling loss (dB)	0.3
Pointing loss (dB)	0.3
OBO (dB): – QPSK / 8PSK – 16QAM	 2 6

Up-link propagation

The atmospheric loss and rain attenuation were:

- ⇨ 0.2 + 5.6 dB (Turin) and 0.1 + 3.9 dB (Palermo) for 99.9% of an average year (ay)
- ⇨ 0.2 + 2.9 dB (Turin) and 0.1 + 2.0 dB (Palermo) for 99.6% ay.

Satellite

The G / T (dB / °K) were:

- ⇨ 4.3 (Turin);
- ⇨ 3.6 (Palermo).

The IPFD for saturation (from the –0.5 dB / °K contour) was:

- ⇨ variable (–80 dBW / m^2 nominal gain setting).

The transmitted EIRP at saturation was:

- ⇨ 46.5 dBW (to Rome);

Down-link propagation

The atmospheric loss and rain attenuation at the Rome site were:

- ➯ 0.1 + 2.4 dB for 99.9% ay;
- ➯ 0.1 + 1.2 dB for 99.6% ay.

Receiving Station

See *Table 5*.

Table 5
Characteristics of the receiving station.

Parameter	Value
Location	Rome (zone K)
Frequency (GHz)	11.99
Antenna efficiency (%)	60
Coupling loss (dB)	0.5
Pointing loss (dB)	0.5
LNB noise figure (dB)	1.1

The link analysis method was based on the figures of *Table 1* (IF loop performance) and on computer simulations to estimate the noise margin losses due to the non-linearity, the input/output signal power levels and the intermodulation interference (C/I) between the signals, following the simplified analysis method described in the Appendix [10][11]. An additional link margin of 1 dB was introduced, in order to cope with possible inaccuracies in the simplified analysis method. The link budgets were balanced to achieve the target service continuity (99.9% or 99.6% of the average year) under up-link fading; subsequently the availability of positive margins were verified under down-link fading (for the same service continuity target).

Table 6 shows the results of this analysis for a 36 MHz transponder.

From the examples of *Table 6*, the following considerations may be drawn. For DSNG applications, four QPSK-3/4 signals at 8 Mbit/s may be placed in a 36 MHz transponder (9 MHz frequency slots, see the first row in *Table 4*). In this configuration, very small *fly-away* up-link terminals may be used, with EIRPs in the range 56 - 59 dBW, and 3 m receiving antennas. When higher picture quality is needed (e.g. when using 422P@ML at bit-rates of 21.5 Mbit/s) while at the same time keeping the DSNG up-link antenna small (1.5 m), the satellite bandwidth exploitation has to be reduced from four to two FDM signals (see row 2 in *Table 6*). This configuration requires a larger receiving antenna (4 m). Using 8PSK 5/6 signals (see rows 3 and 4 in *Table 6*), three to four carriers may share the satellite transponder, offering bit-rates of about 20 Mbit/s and 15 Mbit/s, respectively. These configurations require large vehicle-mounted DSNG up-link stations (2.4 m antennas) and large receiving antennas (6 m). Significantly better results, in terms of the requested antenna diameters, may be obtained using satellites with smaller up-link coverage (e.g. national instead of pan-European), since the higher G/T of these satellites directly improves the up-link performance.

Table 6
Example use of the system for DSNG and fixed contribution applications: N digital signals in FDMA in a 36 MHz transponder.

	Signals			Up-link terminal						Satellite			Rx station
	Useful bit-rate (Mbit/s)	Modul. & coding	N	Target service availa-bility [a] (%)	Type	ITU clim. zone	HPA power [b] (W)	Anten. diame-ter (m)	EIRP [c] dBW	IPFD [d] (dBW/m2)	IBO [e] per carrier (dB)	OBO [5] total (dB)	Antenna diameter (m)
1	8.448	QPSK 3/4	4	99.9	DSNG flya-way	L K	110 70	0.9	58.5 56.5	-84 -87	15.7 15.2	4.2 3.9	3
2	21.50	QPSK 7/8	2	99.9	DSNG vehicle	L K	100 70	1.5	62.5 61.0	-82 -86	13.7 11.8	3.7 2.7	4
3	20.48	8PSK 5/6	3	99.9	DSNG vehicle	L K	230 90	2.4	70.2 66.1	-70 -74	18.0 18.6	6.6 7.1	6
4	15.357	8PSK 5/6	4	99.9	DSNG vehicle	L K	300 75	2.4	71.4 65.3	-68 -74	18.9 19.4	6.8 7.2	6
5	18.43	16QAM 3/4	4	99.9	Fixed con-trib.	L K	250 60	7 6	75.9 68.3	-62 -71	20.4 19.4	8.0 7.3	7 6
6	21.50	16QAM 7/8	4	99.6	Fixed con-trib.	L K	60 70	8 7	70.8 70.3	-67 -68	20.4 20.4	8.1 8.1	8 7

a. Percentage of average year; up-link fading.

b. At saturation.

c. At OBO = 2 dB (QPSK and 8PSK), OBO = 6 dB (16QAM).

d. IPFD at saturation for up-links on the –0.5 dB/°K contour (the nominal gain setting is –80 dBW/m^2).

e. Nominal in clear sky.

For fixed contribution links, high bit-rates (422P@ML video) and high spectrum efficiencies are often required. In the examples of *Table 6* (rows 5 and 6), four 16QAM signals at 18.4 or at 21.5 Mbit/s are allocated in 9 MHz frequency slots, using large transmitting and receiving stations (6 to 8 m antennas). At 21.5 Mbit/s, due to the high C/N+I requirements of 16QAM-7/8, a slightly reduced service availability is accepted in order to keep the antenna diameters at a reasonable level.

It should be noted that in typical operational environments, the optimization of the transponder gain setting (see “IPFD at saturation” in *Table 6*) is limited to about ±3 dB with respect to the *nominal* gain setting, in order to keep the up-link power levels balanced in cross-polar transponders and to avoid severe interference problems on the up-link. Nevertheless, in the given examples, a significantly wider adaptation has been allowed (in the range +7 to –18 dB), requiring careful interference handling by the satellite operator. This is necessary with high-level modulations, demanding both high C/N+I ratios on the up-link and good transponder linearity.

8. Conclusions

The DVB-DSNG system described here offers significant advantages in terms of picture quality (MPEG-2 coding with 4:2:0 and 4:2:2 image formats), modulation / coding flexibility and rapid link set-up for DSNG applications.

Thanks to its flexibility, it allows the required trade-offs between ruggedness against noise / interference and spectrum efficiency to be achieved. For example, on a typical Pan-European satellite, one to four digital TV signals may be allocated within a 36 MHz transponder, in frequency division multiplex (FDM) format. The resulting link budgets indicate that, when using QPSK modulation, DSNG services at 8 Mbit / s may be established with small "fly-away" terminals using 0.9 m antennas.

When higher picture quality is required (e.g. from 15 to 21 Mbit / s), DSNG services may be established by vehicle-mounted terminals (1.5 - 2.4 m antennas) if QPSK or 8PSK modulation is used. In the case of fixed-contribution links at high bit-rates (e.g. 18 to 21 Mbit / s), 16QAM modulation may be chosen to increase the space segment exploitation, but with a requirement for larger transmitting / receiving antennas (e.g. from 6 to 8 m).

The new DVB-DSNG standard represents a significant step forward in Digital Satellite News Gathering and for fixed contribution links by satellite.

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Abbreviations

422P@ML	(MPEG-2) 4:2:2 Profile at Main Level
8PSK	Eight-phase-shift keying
16-QAM	16-state quadrature amplitude modulation
64-QAM	64-state quadrature amplitude modulation
ATM	Asynchronous transfer mode
AWGN	Additive white Gaussian noise
BER	Bit error rate
C/I	Carrier-to-interference ratio
C/N	Carrier-to-noise ratio
CA	Conditional access
CATV	Community antenna television
CBPS	Coded bit per symbol
CM	(DVB) Commercial Module
DCT	Discrete cosine transform
DPCM	Differential pulse code modulation
DSNG	Digital satellite news gathering
DTH	Direct-to-home
DVB	Digital Video Broadcasting
DVB-S	DVB - Satellite
E_b/N_o	Ratio between energy-per-useful-bit and the spectral density of the noise
EIRP	Effective isotropic radiated power
EPG	Electronic programme guide
ETSI	European Telecommunication Standards Institute
FDM	Frequency division multiplex
FDMA	Frequency division multiple access
FEC	Forward error correction
G/T	Gain/temperature ratio
GoP	Group of pictures
HPA	High power amplifier
IBO	Input back-off
IDR	Intermediate data-rate
IEC	International Electrotechnical Commission
IMUX	Input multiplexer
IPFD	Isotropic power flux density
IRD	Integrated receiver/decoder
ISI	Inter-symbol interference
ISO	International Organization for Standardization
ITU	International Telecommunication Union
ITU-R	International Telecommunication Union, Radiocommunication Sector
LNB	Low-noise block
MCPC	Multiple channels per carrier
MMDS	Multipoint microwave distribution system
MP@ML	(MPEG-2) Main Profile at Main Level
MPEG	(ISO/IEC) Moving Picture Experts Group
OBO	Output back-off
OMUX	Output multiplexer
PAT	(MPEG) Programme Associated Table
PDH	Plesiochronous digital hierarchy
PMT	(MPEG) Programme Map Table
PRBS	Pseudo-random binary sequence
PSI	(DVB) Programme Service Information
QEF	Quasi-error-free
QPSK	Quadrature (quaternary) phase-shift keying
R-S	Reed-Solomon
RAI	*Radiotelevisione Italiana*
SCPC	Single channel per carrier
SDH	Synchronous digital hierarchy
SI	(DVB) Service Information
SNG	Satellite news gathering
TCM	Trellis-coded modulation
TSDT	(MPEG) Transport Stream Descriptor Table
TS	(MPEG) Transport Stream
TWTA	Travelling-wave-tube amplifier
VLSI	Very large-scale integration
XPD	Cross-polar antenna discrimination

Appendix: Simplified analysis method

A simplified analysis method has been developed [10] in order to allow a first estimation of the system performance under different operating conditions (e.g. up-link EIRP, nominal TWTA input back-off, noise power density levels etc.), without the need to perform complete computer simulations. A nominal channel spacing respectively of 18 MHz in the case of two carriers per transponder, 12 MHz for three carriers and 9 MHz for four carriers is adopted. The analysis method is focused on signal *b* (see *Fig. A1*), which means the central signal in the three-carriers-per-transponder configuration, and the second signal *b* in the two- and four-carriers-per-transponder configuration.

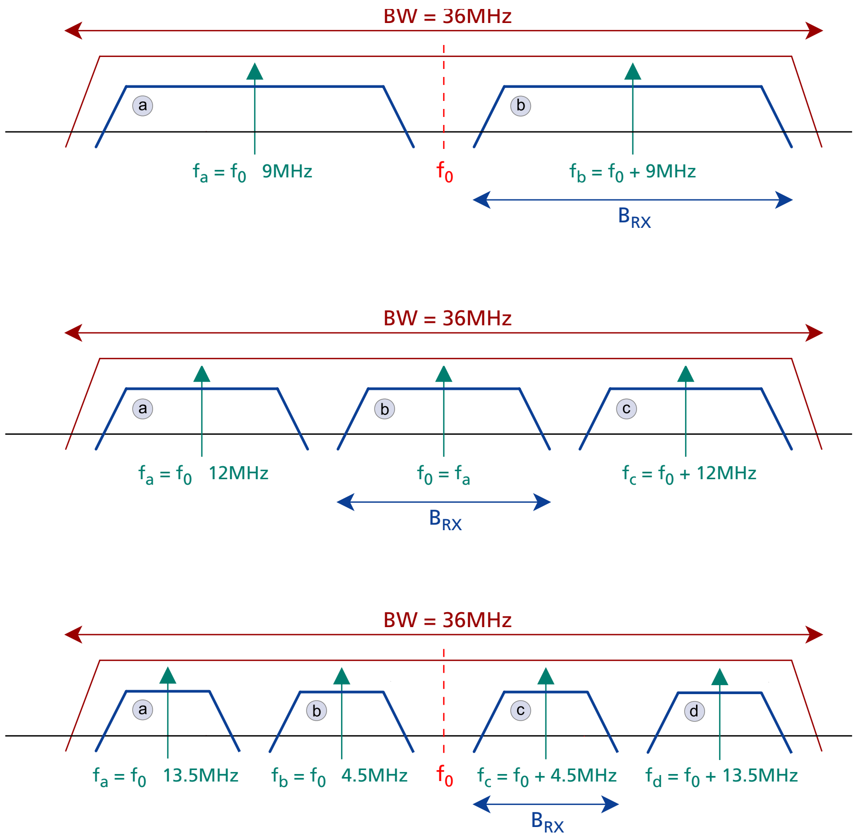

Figure A1
FDM configurations in a 36MHz transponder in the case of two, three and four carriers.

Fig. A2 gives the AM / AM and AM / PM characteristics of the TWTA, while *Fig. A3* shows the frequency responses of the input multiplexer (IMUX) and the output multiplexer (OMUX) which were adopted in the simulations. The total usable transponder bandwidth was of the order of 36 MHz (at the –3 dB points) and the total group delay at the edge of this band was around 50 - 60 ns.

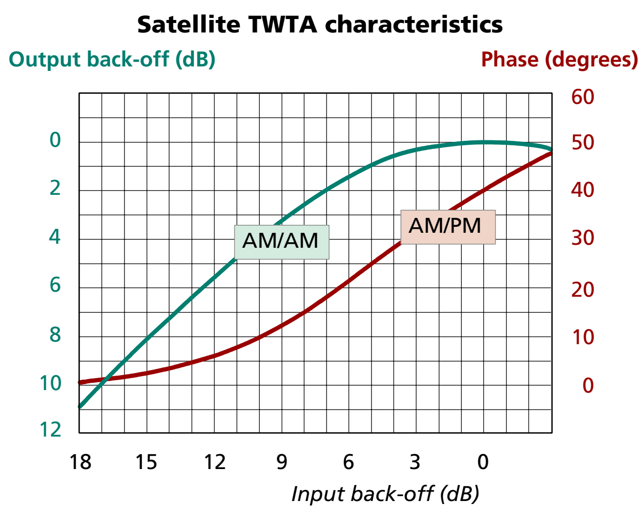

Figure A2
Simulated TWTA AM/AM and AM/PM characteristics.

When multiple signals are transmitted in an FDM within a single transponder, the generated TWTA output power is split between the signals according to (i) their input level and (ii) the TWTA AM / AM non-linear characteristic.

Fig. A4 gives OBO_b (the output back-off of signal *b* with respect to the transponder output saturation power) as a function of IBO_b (the input back-off of signal *b* with respect to the transponder input saturation power), for different values of the input back-off of the interfering signals $IBO_{a,c,d}$. The results, obtained by computer simulations, refer to a configuration with four signals in the transponder, where interfering signals were modulated using QPSK, but signal *b* was unmodulated (*Fig. A5*). The power of signal *b* was measured after a narrow-band filter (200 kHz) which suppressed the interference from the other signals. In a first approximation, the cases where N = 2 and N = 3 signals per transponder can be derived from *Fig. A4* through the formula:

$$OBO_b(N) = OBO_b(4) + 10\ \log_{10}(N/4)$$

8PSK and 16QAM modulations give approximately the same results and thus *Fig. A4* may be used also for these modulations.

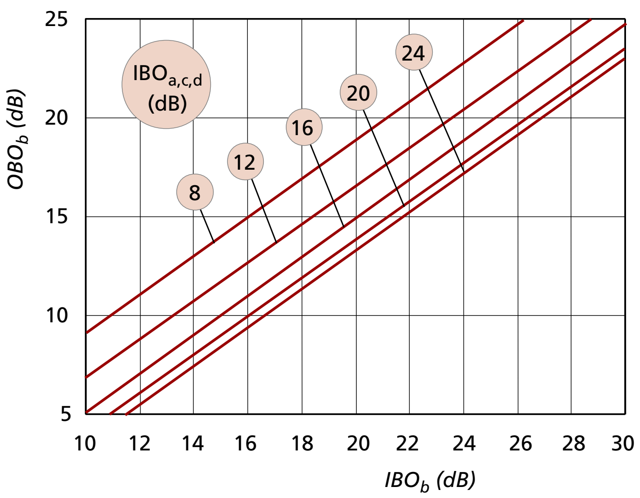

Figure A4
OBO_b vs. IBO_b for different values of $IBO_{a,c,d}$ in the case of four signals per transponder (simulation results).

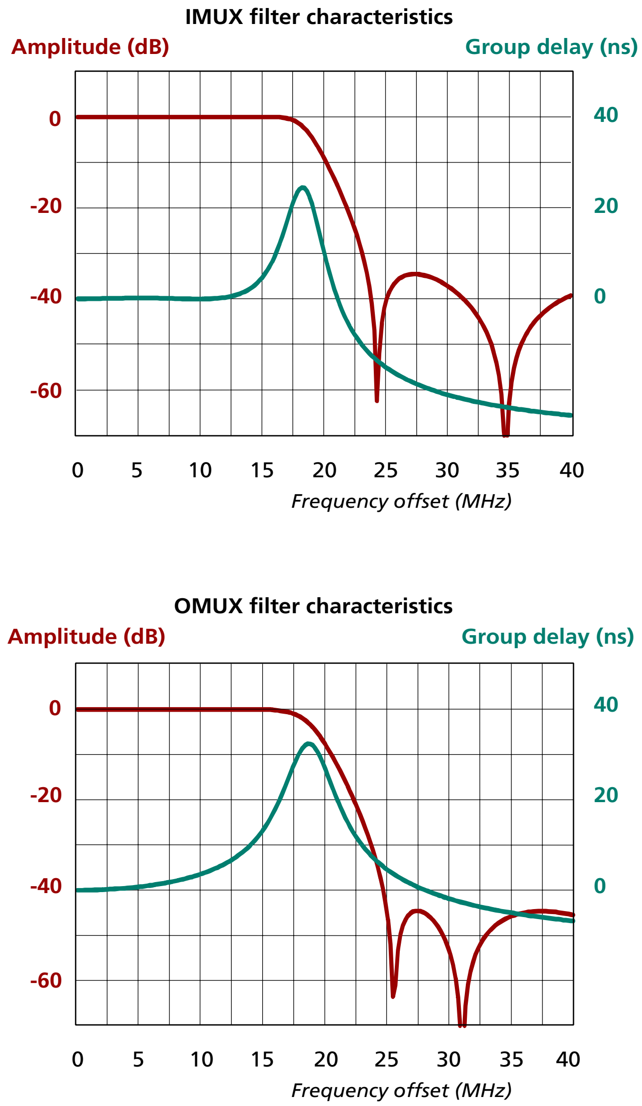

Figure A3
Simulated IMUX and OMUX amplitude and group delay characteristics.

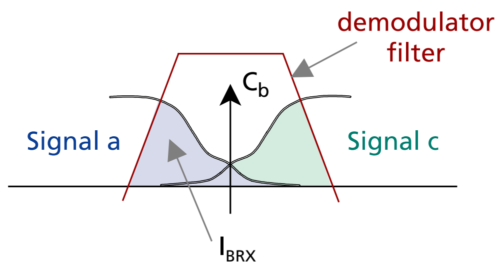

Figure A5
Measurement of the interfering power I_{BRX} in the demodulator filter.

In the simplified analysis method, the following sources of degradation are considered:

a) *Gaussian noise:*

Neglecting the noise compression on the satellite TWTA, the assumption is made that up-link and down-link noise of equal power have the same effect on the system BER, and their powers can be freely added.

b) *Interference (intermodulation) from adjacent signals in FDM:*

Assuming that the channel spacing is larger than the total signal bandwidth including the roll-off, the mutual interference between the signals on a quasi-linear up-link is negligible.

On the down-link, the equivalence and additivity of noise and interference is assumed. In other words an interfering signal of power I_{BRX} (in the receiver bandwidth) is assumed to produce the same BER as a Gaussian noise of equal power (i.e. $N_{BRX} = I_{BRX}$).

This approximation neglects the fact that the envelope of the intermodulation signals is not Gaussian and that it is correlated with the signal itself. It should be noted that the noise and interference contributions must be evaluated and added after the demodulator receiving filter (with noise bandwidth B_{RX} equal to the symbol rate R_s). A practical problem is how to measure the interference power (I_{BRX}) in the demodulator filter without removing the useful signal or modifying the TWTA working point.

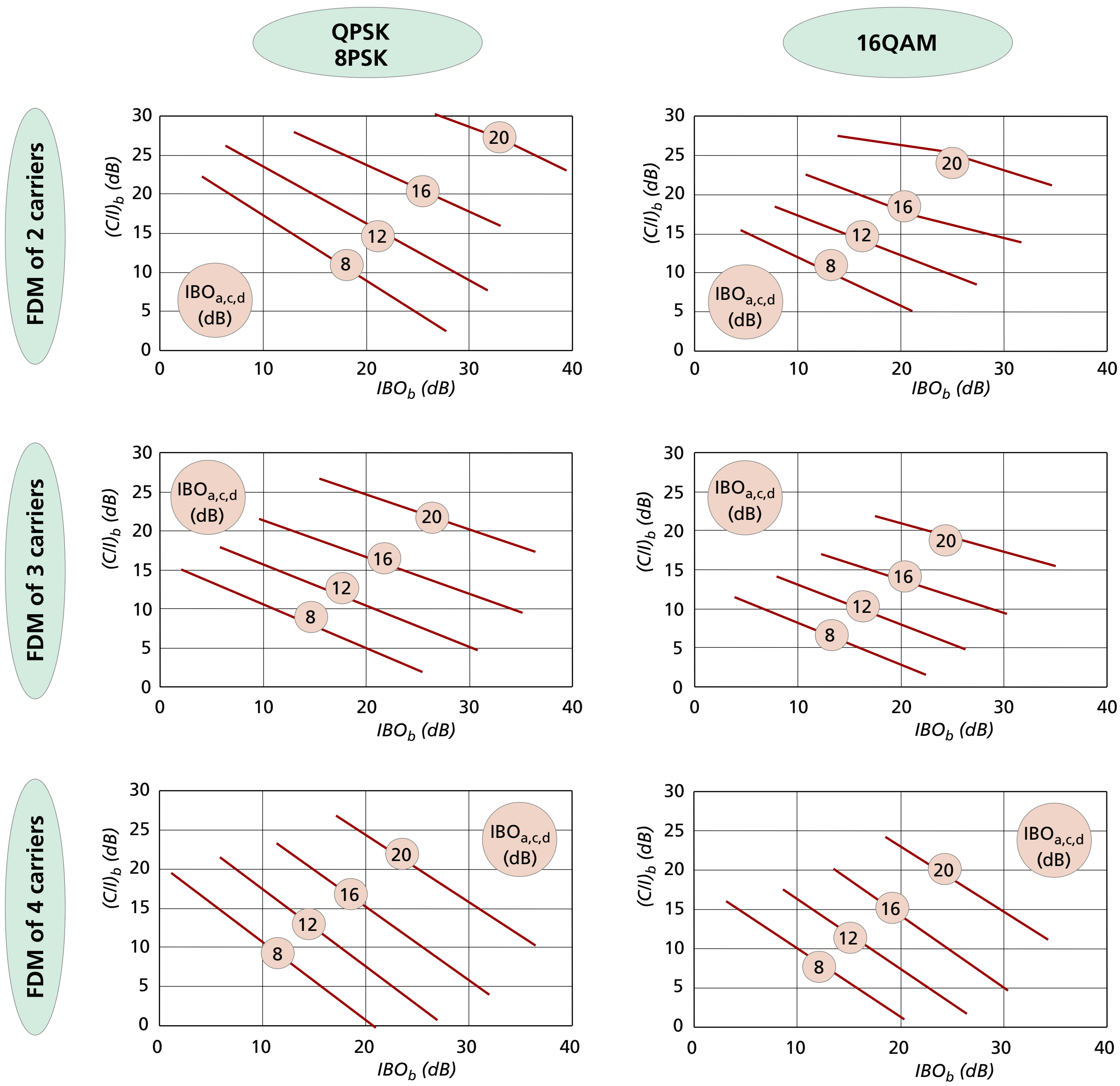

Figure A6
$(C/I)_b$ curves vs. IBO_b for different values of $IBO_{a,c,d}$ (simulation results).

In the computer simulations, while the interfering signals were modulated, the wanted signal was un-modulated (see *Fig. A5*). The interference power I_{BRX} has been measured by filtering the received signal through a notch filter, centred at the frequency of the unmodulated useful signal, with rejection bandwidth 200 kHz. The parameter C_b corresponds to the TWTA saturation power attenuated by OBO_b. *Fig. A6*, obtained by computer simulations, shows – for the different FDM configurations and modulation schemes – the $(C/I)_b$ curves for the wanted signal *b* versus IBO_b, for different values of $IBO_{a,c,d}$ of the other signals.

c) *Inter-symbol interference:*

The inter-symbol interference (ISI) produced by the TWTA non-linearity depends on the working point (IBO) which, in turn, is determined not only by the signal itself, but also by the other signals that are multiplexed in the transponder. In the simplified analysis described here, it is assumed that the ISI degradation in the FDM configuration is the same as for the single-signal configuration for the same total IBO (the power sum of the input signals). For a single carrier, the noise margin loss Δ_{ISI} with respect to the AWGN channel tends to 0 dB for high back-offs (quasi-linear TWTA) while, approaching the TWTA saturation, the values depend on the modulation and coding rate.

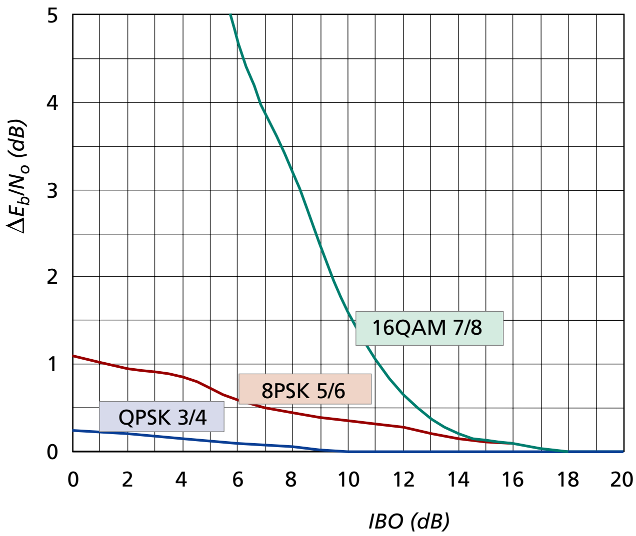

Figure A7
Noise margin loss $\Delta E_b/N_0$ vs. TWTA IBO.

In *Fig. A7* the noise margin loss is given with respect to the performance on an AWGN channel for the three different modulation schemes of the DVB-DSNG system, for one representative coding rate. In link-budget computations, since the variation of Δ_{ISI} with the coding rate is very low (about 0.1 dB at the typical quasi-linear TWTA operating points in FDM configurations), the curves of *Fig. A7* have been adopted for any coding rate.

d) *Cross-polar co-channel digital interference:*

It is assumed that cross-polar co-channel digital interference has similar effects on the system BER as Gaussian noise with equal power in the receiving filter. When the cross-polar transponder carries the same signal configuration as the wanted transponder, the interference power (I) is equal to the wanted power (C) attenuated by the cross-polar antenna discrimination (XPD): i.e. C / I = XPD.

The simplified analysis method described in this Appendix adds all the interference, intermodulation and noise power contributions (measured within the receiver filter bandwidth) in order to evaluate the *available* C / (N+I) ratio on the satellite links, and compares it with the C / (N+I) ratio *required* by the modulation system to deliver a target BER of 2×10^{-4}. The service continuity and quality is assured when C / (N+I) (available) > C / (N+I) (required). The detailed computation procedure is summarized in *Table A1*.

Table A1
Simpified analysis method.

Step	What to evaluate:	Formulae, constants & figures to use
Evaluation of the required C/(N + I) in the noise bandwidth B_{RX}		
1	Required E_b/N_0 on AWGN at BER = 2×10^{-4}	From *Table 1* (IF loop) + 1 dB margin, to allow for possible inaccurancies of the simplified analysis method
2	IBO_{tot}	Add TWTA input powers, normalized with respect to the saturation point
3	ISI noise margin loss on TWTA at IBO_{tot}	from *Fig. A7*
4	Required E_b/N_0 by satellite at IBO_{tot}	Combine the results from 1 and 3
5	Required C/(N + I) by satellite in B_{RX}	C/(N + I) (required) = $E_b/N_0 + 10\ \mathrm{Log}(R_u/B_{RX})$
Evaluation of the available C/(N + I) in the noise bandwidth B_{RX}		
6	OBO_b versus IBO_b , $IBO_{a,c,d}$	from *Fig. A4*
7	Available C/N_u and C/N_d in B_{RX}, at IBO_b and OBO_b	$E_b/N_{0,u} = EIRP_u - A_u - L_u - PL_u - AL_u + G/T_s - k - R_u$ $E_b/N_{0,d} = EIRP_{sat} - OBO_b - A_d - L_d - PL_d - AL_d + G/T_{RX} - k - R_u$ $C/N_u = E_b/N_{0,u} + 10\ \mathrm{Log}(R_u/B_{RX})$ $C/N_d = E_b/N_{0,d} + 10\ \mathrm{Log}(R_u/B_{RX})$ where: k = Boltzmann constant A = rain attenuation L = free space loss PL = pointing loss AL = atmospheric loss The sub-script "u" refers to the up-link and "d" to the down-link
8	$C/I_d(b)$ (intermodulation) in B_{RX} at $IBO_{a,b,c}$	from *Fig. A6*
9	Available $C/(N_u + N_d + I_u + I_d)$	Combine results from 7 and 8
The service quality is guaranteed if C/(N+I) (available) > C/(N+I) (required)		