

FLASH-TV

The flexible bit-rate solution for satellite outside broadcasts of digital HDTV

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1. Introduction

Television outside broadcast transmissions by satellite, generally known as satellite news gathering (SNG), are widely utilised by broadcasters to connect the places where live events occur and the television studios. The up-link to the satellite is achieved by transportable stations installed on vans which can easily reach areas where fixed telecommunication networks may not be available, or may be saturated, and can be set up in a short time-scale.

To be successful, the future introduction of digital high-definition television (HDTV) broadcasting services must be accompanied by a corresponding transportable system for “light” contribution links. The broadcaster requirements for such a system are:

- service availability superior to 99.8% of the worst month;
- video quality approaching that of studio-to-studio contribution links;
- good mobility of the up-link station (e.g. antenna dimensions of no more than 2.4 metres). Less stringent requirements are imposed on antenna diameters at the receiving sites, although they should be less than 6 metres to allow their installation in the vicinity of the HDTV studios.

Satellite transmission has become a regular feature of the outside broadcasting activities of broadcasters. Looking ahead to the era of digital HDTV broadcasting, the FLASH-TV project of the RACE II programme has been developing solutions for satellite outside broadcasting of programme material having source bit-rates of the order of up to 70 Mbit/s.

The proposed system exploits the graceful degradation achieved with modern video coding algorithms to allow a reduction in bit-rate on the satellite link during periods of adverse reception, whilst maintaining acceptable picture quality.

The above requirements cannot be satisfied simultaneously by a traditional fixed bit-rate approach, even with state-of-the-art digital video compression algorithms and modulation and channel coding systems. To overcome this, the three-year FLASH-TV Project was set up in January 1992 as part of the RACE II programme, sponsored by the Commission of the European Communities (CEC). This project is developing a satellite digital HDTV system based on the flexible bit-rate con-



The work described here has been carried out in Work Package 4 "Transmission sub-systems" of the FLASH-TV project. The organizations involved are:

RAI Research Centre Work Package Leader	Italy
Eutelsat	France
Alcatel Telspace	France
Space Engineering	Italy
Arecom Telecom	France
TDF/C2R	France
France Telecom	France

The following partners have contributed to other work in the FLASH-TV project:

Thomson-CSF/LER	France
Heinrich-Hertz Institut	Germany
Robert Bosch GmBh	Germany
INESC	Portugal
Telespazio	Italy
European Broadcasting Union	Switzerland
Retevisión	Spain
Alcatel Espace	France
NTUA	Greece

cept. It is designed to operate at Ku-band frequencies (14 GHz band on the up-link and 11–12 GHz band on the down-link, the frequencies assigned to the FSS Fixed Satellite Service) and is optimised for 36 MHz transponders, the most widely available transponders in Europe.

The project devoted the first year to system design and specification and the second year to the implementation of the sub-systems, while the third year is for assembling, testing and live demonstrations.

This article describes the modulation and channel coding chosen by FLASH-TV and reports the results obtained by computer simulations on an additive white Gaussian noise (AWGN) channel and on a typical Eutelsat channel. Other elements of the complete system, such as the variable bit-rate HDTV codec [1], the rate decision unit, or the terrestrial network interfaces have been specified and developed by the project, but they are not addressed here in detail.

2. Basic considerations on digital HDTV by satellite

To clarify the advantages of a flexible bit-rate system versus a fixed bit-rate system, it is necessary to illustrate the propagation statistics of the satellite channels under consideration, the characteris-

tics of the advanced modulation and channel coding techniques and the relationship between HDTV picture quality and transmitted bit-rate.

2.1. Characteristics of SNG in the Ku band

For SNG applications, the mobility requirements for the transportable up-link stations put a limitation on the antenna dimension (2.4 metres). At the same time, the interference constraints on the up-link limit the maximum transmittable power (about 650 watts at saturation) and require that the high-power amplifier be operated in a quasi-linear condition (output back-off of about 3 dB). Consequently, and assuming reception with a 6-metre antenna on the 44 dBW satellite transmit contour, the up-link is significantly weaker than the down-link and the carrier-to-noise ratio (C/N) available at the receiver is mainly imposed by the up-link.

The C/N ratio changes in time due to weather conditions: taking climatic zone K as typical for Europe, and considering the worst month, the rain attenuation on the up-link at 14 GHz can exceed 1.5 dB for 5% of the time, 3.9 dB for 1% of the time and 9.2 dB for 0.2% of the time [2]. These examples indicate that at 14 GHz the C/N variations are moderate for a very large percentage of time. Nonetheless, if a high service availability is required, the transmission system must be capable of handling large C/N reductions for short periods.

2.2. Characteristics of modulation and channel coding systems for digital television

Uncorrected errors produce annoying artifacts on digital television signals. This problem can be solved by adopting very rugged modulation and channel coding schemes, capable of delivering "quasi error-free" (QEF) performance, i.e. less than one uncorrected error event per hour, corresponding to a bit-error ratio (BER) after correction of about 10^{-10} to 10^{-11} . These advanced modulation and channel coding schemes are characterised by a steep failure characteristic: the transition between QEF operation and service interruption takes place within a C/N reduction of, typically, 1 dB only. Therefore the transmission link must be designed to operate above the service interruption threshold for a very high percentage of time.

Modulation and channel coding systems can be optimised either for high spectrum efficiency, i.e. to transmit a high bit-rate in a small bandwidth, or for high power efficiency, i.e. low C/N require-

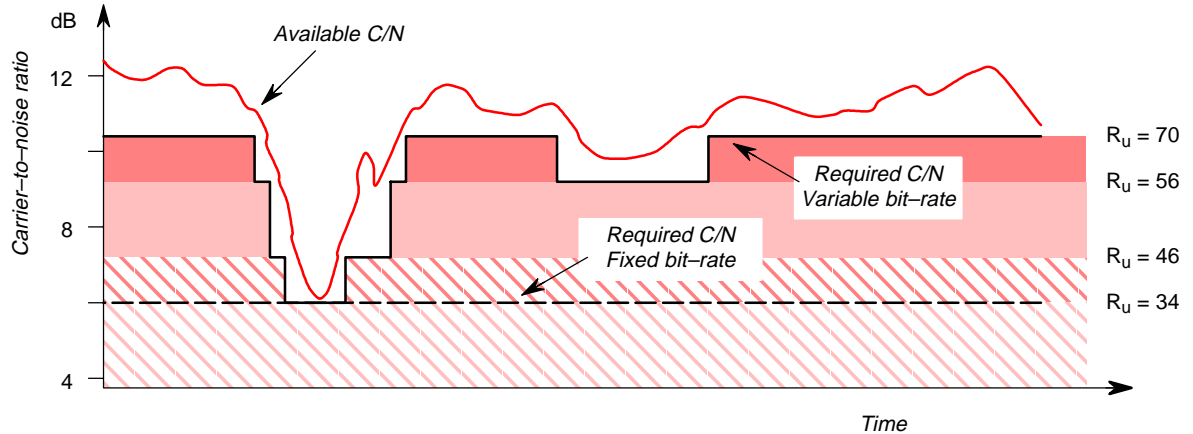


Figure 1 Principles of fixed and variable bit-rate operation.

ments with maximum occupation of bandwidth. In the first case a dense signal constellation is adopted (e.g. 16PSK or 8PSK), together with low redundancy forward error-correcting codes (FECs), while in the second case a sparse constellation is used (e.g. QPSK or 2PSK), together with high-redundancy FECs. Given a set of constraints on available bandwidth and available C/N on the channel, the system designer can establish a trade-off between power efficiency and bandwidth efficiency.

2.3. Characteristics of picture coding algorithms

Under error-free conditions, the intrinsic quality of digitally-coded HDTV signals depends on the efficiency of the source coding algorithms and on the output bit-rate. While it is widely admitted that, with modern DCT-based algorithms using motion compensation, a bit-rate of the order of 70 to 50 Mbit/s can achieve “near studio quality” HDTV for outside broadcasting applications, these bit-rates are still quite demanding in terms of C/N requirements on the satellite link. However, it is a known property of HDTV codecs that, when the bit-rate for picture coding is progressively reduced, the picture quality degrades gracefully without abrupt steps; this characteristic can be exploited by the transmission system, by reducing the useful bit-rate under adverse propagation conditions. For example, at 34 Mbit/s the picture impairment can still be acceptable for short periods [1].

2.4. Fixed bit-rate versus variable bit-rate

The conventional approach to digital transmissions by satellite is based on fixed bit-rate systems. Given a service continuity target (for example 99.8% of the worst month) and defined satellite link characteristics (i.e. EIRPs, rain attenuation

characteristics, antenna gains, front-end noise figures), the minimum operational C/N available at the receiver can be computed by means of link budget evaluations. Based on this minimum C/N, the system designer is able to choose a single modulation and channel coding system to achieve the highest transmitted bit-rate and complying with the transmission quality target (e.g. quasi error-free transmission).

This fixed bit-rate approach wastes a significant part of the channel capacity, since it is derived from the C/N ratio which prevails for a small percentage of the time. As shown in Section 2.1., at 14 GHz this worst case C/N ratio is only relevant to a few hours per year; for the rest of the time the C/N ratio is significantly higher and would allow higher bit-rates. In other words, a fixed bit-rate system requires high power margins to achieve the service continuity targets, and this excess power is not exploited to transmit useful information.

A variable bit-rate system is capable of using a variety of modulation and channel coding schemes with different trade-offs between power and spectrum efficiency and a case-by-case selection of the scheme that allows the highest bit-rate compatible with the actual C/N ratio on the channel (see Fig. 1). Such a system, instead of keeping high power margins, uses all the available power to transmit useful information, while fulfilling the same “quasi error-free” target at the receiver and the same service continuity as that of a fixed-bit-rate system. It will be shown (see Section 5) that a well-designed variable bit-rate system can almost double the total number of bits transmitted over a long period compared to a fixed bit-rate system.

It should be noted that this variable bit-rate concept implies a real time adaptation at the transmitting site. A “return link” is therefore required to communicate to the transmitter the information about signal quality at the receiver. This approach cannot be adopted in digital broadcasting to a very



large number of receivers where the downlinks are weaker than the uplink and the reception quality may be different at each receiving site. For these broadcasting applications a different approach is being proposed, known as hierarchical modulation and coding, where the transmitted bit-rate is fixed, but different levels of error protection are assigned to different data streams. At a particular receiving site, the data streams affected by high BERs are discarded, so that the final picture quality depends on the receiving conditions at that site. However, it can be shown that the performance of these schemes, which do not require a “return link” from the receiver to the transmitter, when applied to digital SNG, is significantly worse than that proposed by FLASH-TV.

3. The FLASH-TV solution

The FLASH-TV system makes use of a variable modulation and coding scheme. The useful bit-rate under normal propagation conditions is 69.0 Mbit/s. Three reduced bit-rate steps are available, the lowest being at 34.5 Mbit/s, to cope with rain fades typical of European climates and interference typical of the Fixed Satellite Service environment.

The targets for quality of service are:

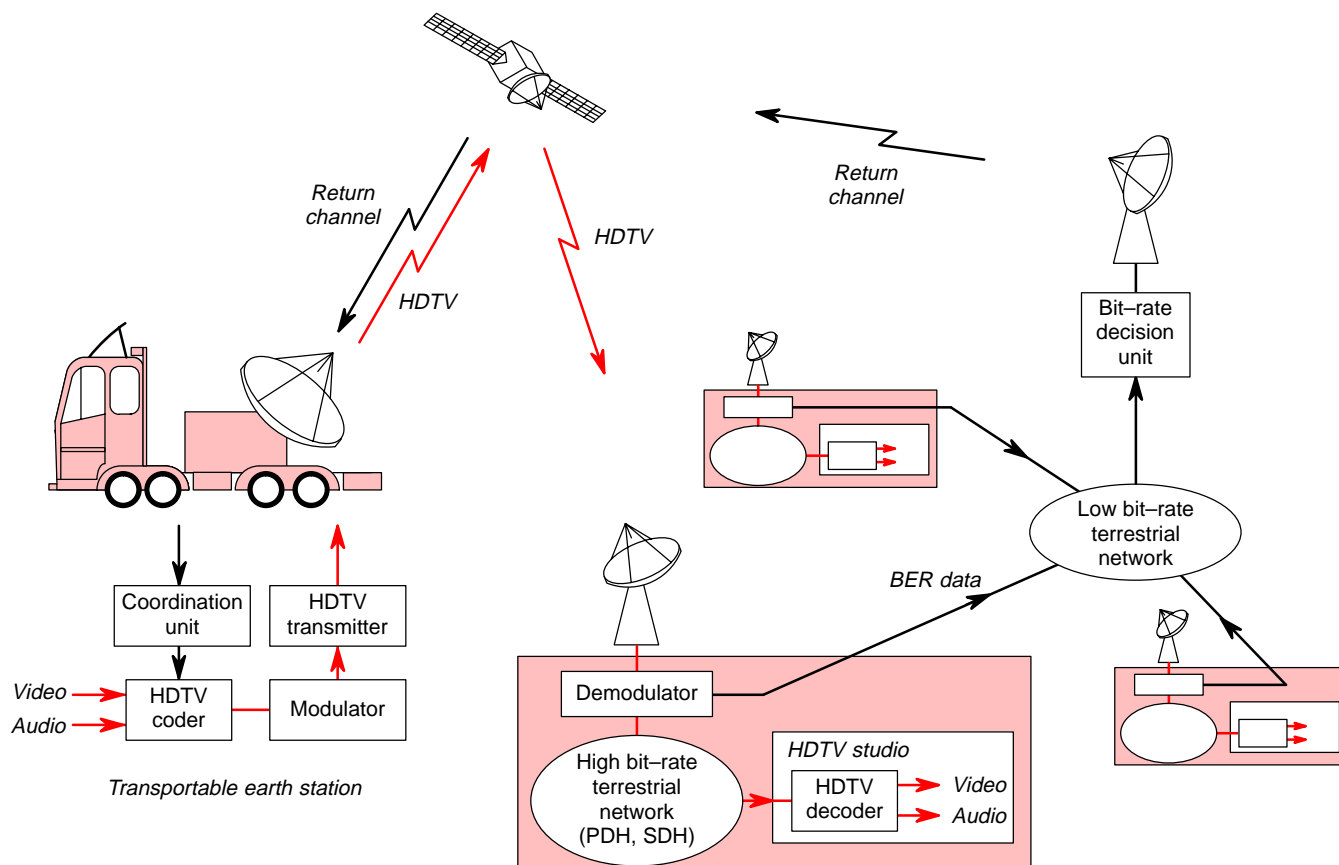
- quasi error-free at 69 Mbit/s for at least 95% of the worst month;
- quasi error-free at 34.5 Mbit/s or above, for at least 99.8% of the worst month.

The bit-rate switching is automatic, is signalled “in-band” and is executed “on-line”, without service interruption or synchronization loss in the demodulators and the video decoders.

A fixed transmission symbol rate is used for the various bit-rate steps and this parameter was chosen to be optimal for 36-MHz transponders on existing communication satellites.

Fig. 2 shows a simplified block diagram of the FLASH-TV network configuration. The transportable up-link station feeds the satellite with the HDTV signal which is received by one or by several receiving stations. From these receiving stations, the demodulated digital signal is sent to the studios via a high bit-rate digital terrestrial network (if required). The receivers monitor the signal quality (i.e., the BER before and after Viterbi decoding), and periodically send this information to the “decision unit”, via a low bit-rate terrestrial network (X25). The decision unit derives the switching commands and communicates these

Figure 2
Network configuration
of the FLASH-TV
system.





commands to the HDTV encoder by means of a return link. The return link is a low data-rate (9600 kbit/s) link which can be set up either via satellite (possibly in frequency-division multiple access, sharing the same satellite transponder as the HDTV signal) or via a suitable terrestrial network.

4. Modulation and channel coding system

The flexible bit-rate FLASH-TV modem is based on 8PSK and QPSK modulations and on a concatenated coding scheme consisting of convolutional/trellis-code modulation inner codes and a Reed-Solomon (RS) outer code. The main characteristics of the modem are listed in Table 1.

The inner code and outer code combinations at the four bit-rate steps are summarised in Table 2.

4.1. 8PSK modes

The inner codes follow the “pragmatic” approach for implementing trellis codes as originally proposed in [3]. The first advantage of this approach is that it provides a wide range of coding rates based on the same rate 1/2 coder-decoder. A se-

cond advantage is that the convolutional code operates on only part of the useful bits and therefore allows the use of a decoder chip with a speed rating lower than the overall useful bit-rate.

Fig. 3 describes the absolute mapping of the 2/3 TC-8PSK scheme for the 55.2 Mbit/s mode. The user bit b_2 is protected by the convolutional code and its generated channel bits, c_2 and c_3 , together define one of the four axes connecting antipodal points of the constellation. The uncoded user bit $b_1 = c_1$ determines the choice of a specific constellation point from these two antipodal possibilities. This bit is only protected by the large Euclidean distance of 2PSK (it defines the “parallel transitions” in the trellis). In this way, the required speed of the convolutional decoder is only half of the useful bit-rate. The 5/6 TC-8PSK scheme for the 69.0 Mbit/s mode is similar to the previous one, but a rate 3/4 punctured coder replaces the rate 1/2 coder.

For both the TC-8PSK schemes, error-correction is performed in two steps: first, the c_2 and c_3 bits are decoded using the Viterbi algorithm and then the c_1 bit is recovered by a “hard-decision”, taking advantage of the knowledge of c_2 and c_3 (i.e., of the axis on which the transmitted point is located).

Table 1
Main characteristics of the FLASH-TV modem.

<i>Modulations</i>	switchable 8PSK and QPSK
<i>Modulation speed</i>	fixed symbol rate of 29.776 Mbaud
<i>Spectrum shape</i>	raised-cosine, roll-off 40%, equally split between modulator and demodulator
<i>Inner codes</i>	four switchable codes derived from the basic rate 1/2 optimum code of constraint length 7 (generators $G_1=133$; $G_2=171$; octal notation), which is a de-facto industry standard; single chip Viterbi decoder with 45 Mbit/s maximum speed (now available on the market) for all the bit-rate steps
<i>Outer code</i>	fixed RS (246,230) shortened from the basic RS (255, 239) code
<i>Interleaver for mitigating error bursts</i>	block interleaving with depth $l = 5$
<i>Synchronization</i>	by means of a unique word, placed at the beginning of the preamble of each 4 ms transmission frame; all demodulator functions are synchronized (including phase ambiguity removal in the demodulator)
<i>Scrambling for energy dispersal</i>	synchronous, without error propagation

Table 2
Characteristics of the modulation and channel coding system.

User bit-rate (Mbit/s)	Modulation	Inner code	Outer code rate	Bandwidth efficiency (bit/s/Hz)
69.0	8PSK	rate 5/6, pragmatic TCM	230/246	2.337
55.2	8PSK	rate 2/3, pragmatic TCM	230/246	1.870
46.0	QPSK	rate 5/6, TCM	230/246	1.558
34.5	QPSK	rate 5/8, punctured convolutional	230/246	1.169

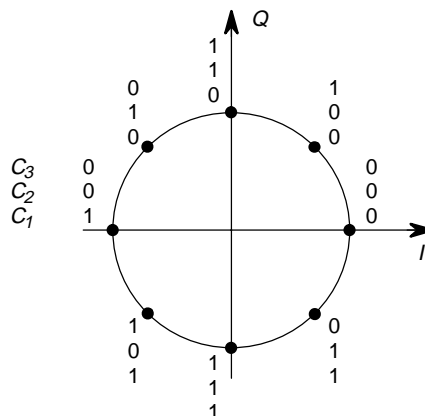
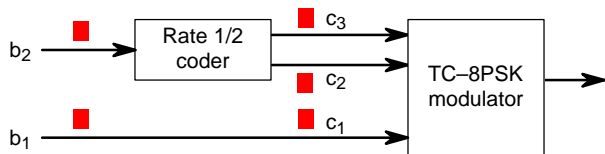


Figure 3
Basis of the
rate 2/3 8PSK
TCM scheme.

Fig. 4 shows a block diagram of the inner decoder for TC-8PSK rate 2/3. The metrics processor block is fed by the demodulated quadrature signals i and q and generates the inputs x and y to the Viterbi decoder. The delay block compensates, for the uncoded bit c_1 , the delay affecting the corresponding c_2 and c_3 bits in the Viterbi decoder. For rate 5/6, the decoding scheme is similar to that of Fig. 4, with the addition of a rate 3/4 “de-puncturing” device before the Viterbi decoder.

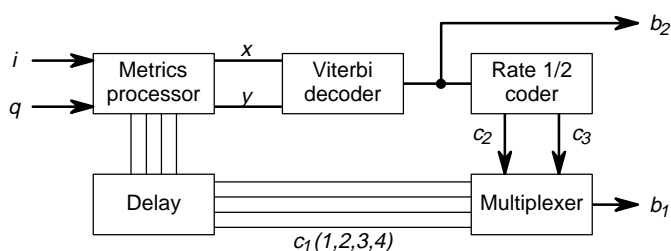


Figure 4
Inner decoder
for TC-8PSK,
rate 2/3.

4.2. QPSK mode

The rate 5/6 TC-QPSK coding scheme for the 46.0 Mbit/s mode, described in Fig. 5, is based on the TC-8PSK scheme by taking the subset of the 8PSK constellation situated on the I and Q axes. The bit c_1 is uncoded and it is protected by the Euclidean distance, while c_2 is the result of a serial punctured rate 2/3 convolutional coding, derived from the rate 1/2 code. The decoding scheme is similar to that of Fig. 4, with the addition of a rate 2/3 “de-puncturing” device before the Viterbi decoder.

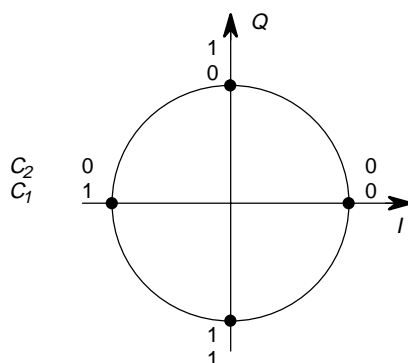
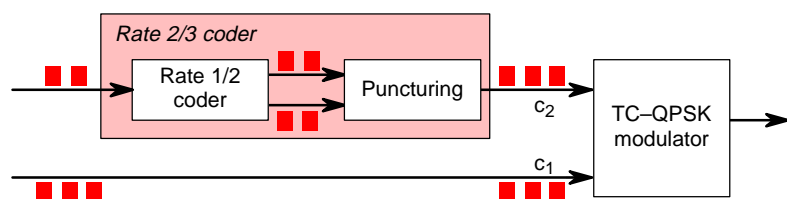
This scheme offers a C/N performance comparable with the conventional 5/6 punctured code, but it has the advantage of being compatible, at the bit-rate step of 46 Mbit/s, with the 45 MHz Viterbi de-

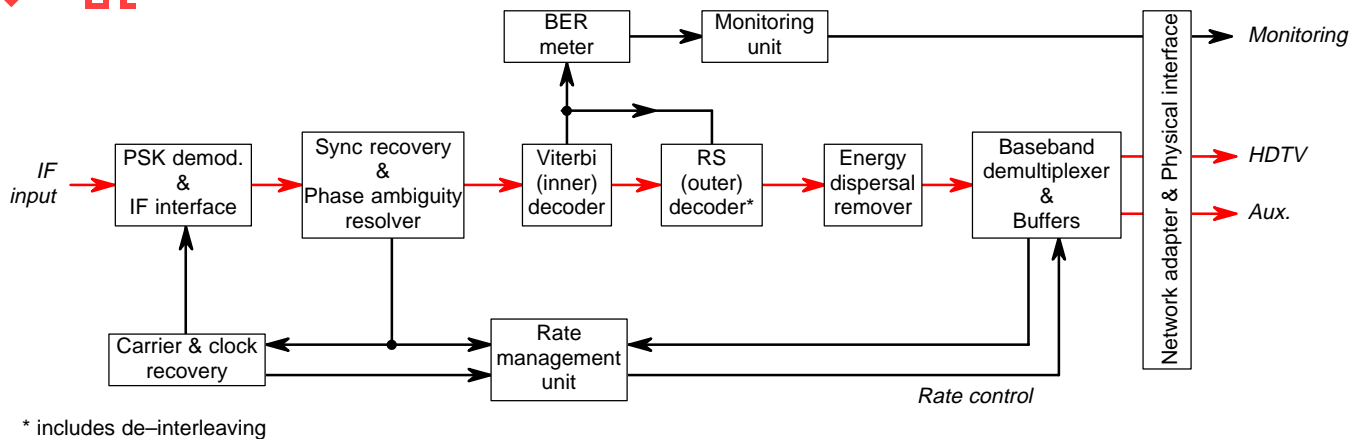
coders available on the market, while the conventional scheme requires a 50 MHz decoder.

The rate 5/8 QPSK scheme for the 34.5 Mbit/s mode is a conventional rate 1/2 punctured code [4]. Gray bit-mapping is used for the QPSK constellation.

Fig. 6 shows the demodulator block diagram. The intermediate-frequency (IF) signal is first demodulated and filtered, and the “unique word” and preamble are decoded to recover frame synchronization and modulation/coding information. Then the inner and outer codes are decoded and the energy dispersal sequence is removed. The signal quality is monitored in real time by measuring the BER before and after Viterbi decoding (information provided by the Viterbi decoder).

Figure 5
Basis of the
rate 5/6 QPSK
TCM scheme.





* includes de-interleaving

Figure 6
Block diagram of the flexible bit-rate demodulator.

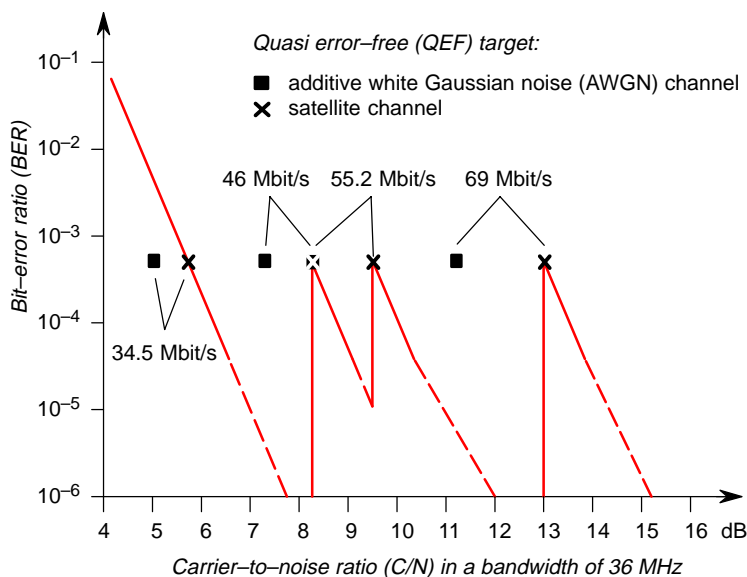
5. Predicted system gains from simulations

The FLASH-TV modulation and channel coding system has been simulated over an additive white Gaussian noise (AWGN) channel, and over a typical satellite channel.

The QEF target for FLASH-TV is that there should be less than a single error event per transmission hour. An error event takes place when an RS code block is affected by more than 8 symbol errors (1 symbol = 8 bits). Assuming ideal symbol interleaving between the inner and the outer decoders (i.e. statistically-independent symbol errors), the QEF target is achieved for a BER of about 6×10^{-4} after Viterbi decoding. Ideal filtering, coherent carrier/clock recovery and large symbol interleaving between the inner and the outer codes are assumed in the receiver.

Figure 7
Carrier-to-noise (C/N) ratio performance on a 36-MHz satellite transponder.

Under the above conditions, the results of simulations on the AWGN channel have been found to be



in agreement with the theoretical figures given in references [3] and [4].

The simulated satellite chain included the up-link station high-power amplifier (HPA), the satellite input and output multiplex filters (IMUX and OMUX) and the satellite travelling-wave tube amplifier (TWTA). The up-link station HPA operating point was set for 3 dB of output back-off (OBO), as required in real operation to avoid the generation of harmful interference to the adjacent channels. The satellite TWTA was set for 2 dB of input back-off (IBO). In the 36-MHz bandwidth, the satellite IMUX and OMUX filters have approximately a 0.5 dB peak-to-peak amplitude ripple and maximum group delays of 27 and 15 ns, respectively. Their group delay in a 30-MHz bandwidth is lower than 8 ns. These characteristics are representative of the EUTELSAT-II 36-MHz transponders.

The added down-link noise power N is relative to the power C of an unmodulated carrier with TWTA at saturation. Therefore the results can be directly compared with the C/N figures achieved by the link budget evaluations. The results do not take into account the modem implementation margins.

Fig. 7 shows the simulation results on the satellite chain, in terms of BER (after Viterbi decoding) versus C/N (in a reference 36-MHz bandwidth). The outer code efficiency loss, represented as $10 \lg [230/246]$ is also included in this C/N computation. The square dots refer to the results on the AWGN channel at BER = 6×10^{-4} (QEF target for infinite interleaving). The saw-tooth shape of the curve is due to the bit-rate switching which keeps the error rate after the outer decoder below the QEF threshold.

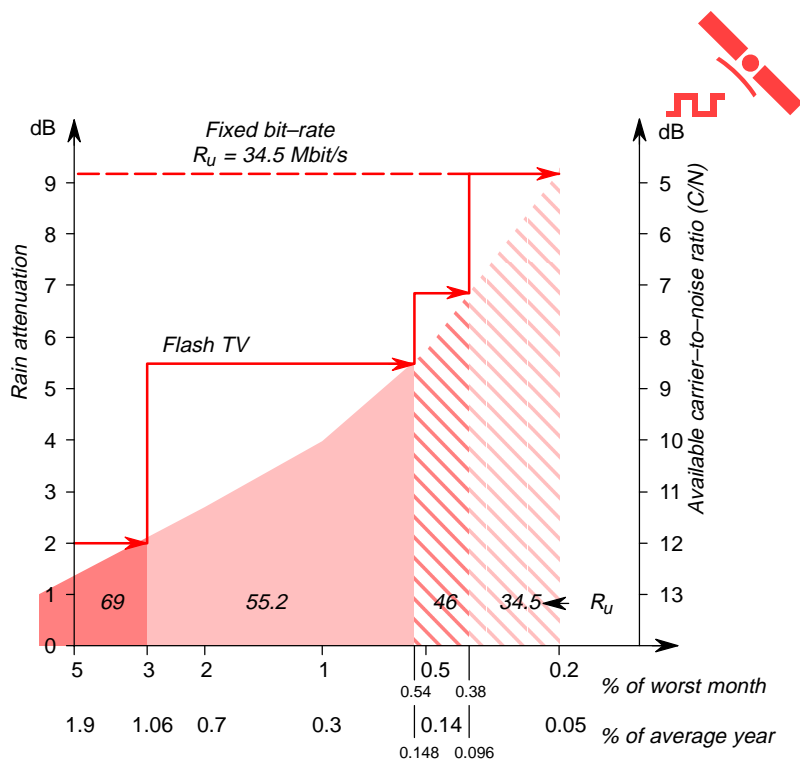
Table 3 summarises the required C/N for QEF HDTV transmission, with ideal interleaving. It may be noted that the satellite degradation is high-

er with 8PSK than with QPSK, especially at 69 Mbit/s. This table shows that the FLASH-TV flexible bit-rate modem has an operative C/N range (difference between the C/N ratio required for 69 Mbit/s and that for 34.5 Mbit/s) of better than 6 dB on the AWGN channel and better than 7 dB on the satellite chain. This range is sufficient to cope with the expected rain attenuations in the Ku band and SNG environment.

Fig. 8 gives an example of the available C/N ratio on the up-link at 14 GHz, as a function of the percentage of time (worst month and average year), and compares the transmission capacity of a fixed-bit-rate system with that of FLASH-TV. The values shown are based on the assumption that the total C/N ratio depends on the up-link only, that the bit-rate commutations take place at the C/N thresholds given in Table 2, and that the link budget is optimised to achieve a service availability of 99.8% of the worst month at 34 Mbit/s. By integration of the functions of Fig. 9, the average number of transmitted bits N in a year is evaluated for the two systems. This calculation shows that $N_{FLASH}/N_{fixed} = 1.9955$. Therefore the transmission capacity of the FLASH-TV system is nearly double that of a fixed-bit-rate system, while maintaining the same service availability at 34.5 Mbit/s, as anticipated in Section 2.4.

Additional simulations have been carried out to define the optimum interleaving depth for the outer code. The considered BER after Reed-Solomon decoding, equal to 10^{-8} , is higher than the QEF point because of limitations in the computer time resources for the simulations. The results, summarised in Fig. 9, indicate that the minimum symbol interleaving depth is between 2 and 4 bytes, but some additional C/N gain can be achieved with $I \geq 7$ for TC-8PSK rate 5/6. In order to allocate an integer number of interleaved matrices in a fixed 4 ms transmission framing structure, in all the coding schemes, a common interleaving depth $I = 5$ was chosen. Under this condition, an additional C/N degradation of about 0.2 to 0.5 dB should be added to the values of Table 2.

The modulation and code-switching process has been simulated, making use of a single Viterbi decoder, without resetting the decoder path memory during switching. The system can switch the modulation and coding scheme only during a fixed preamble, which separates different 4-ms transmission frames. At the end of each frame, a null byte is always loaded into the convolutional coder, in order to force it into a known "0 state" (transmission of the phase 0). This technique is sufficient to



User bit-rate (Mbit/s)	C/N ratio with $I = \infty$	
	AWGN	Satellite
69.0	10.3	12.0
55.2	7.3	8.5
46.0	6.3	7.3
34.5	4.0	4.8

Figure 8
Example of transmission capacity with fixed and variable bit-rate systems.

avoid discontinuities in the Viterbi decoding process and to obtain error-free switching in the absence of noise. Further simulations, taking into account noise, showed that in the transition region the error-rate smoothly connects the stationary BER levels of the two coding schemes. An additional BER improvement in the vicinity of the switching point can be achieved by loading the in-

Table 3
Carrier-to-noise ratio (C/N) required, in a bandwidth of 36 MHz, to achieve quasi error-free (QEF) reception.

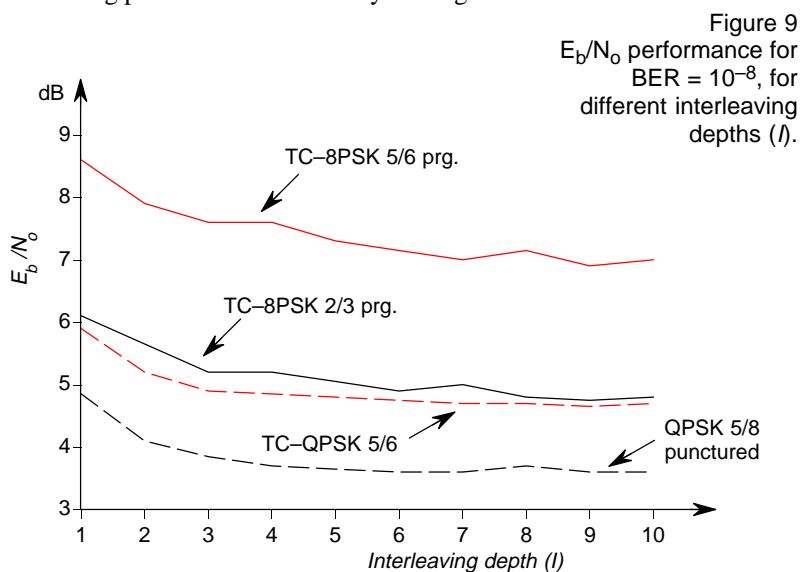


Figure 9
 E_b/N_0 performance for $BER = 10^{-8}$, for different interleaving depths (I).



ner decoder with “clean phase 0” inputs (i.e., without noise) during the preamble period.

6. Conclusions

The three-year RACE II FLASH-TV Project, set up in January 1992, has developed a solution for satellite outside broadcast of digital HDTV. This application will be an essential element for attractive HDTV programme production and for the introduction of HDTV broadcasting.

The main features of the specified modulation and channel coding system are:

- operation on Ku band communication transponders, with 36 MHz bandwidth;
- quasi error-free HDTV transmission (i.e., less than one error event per hour);
- four user bit-rates: 69.0, 55.2, 46.0 and 34.5 Mbit/s;
- switchable user bit-rate, under real-time control of an external rate decision unit;
- flexible modulation and channel coding schemes, with different bandwidth efficiency and ruggedness levels;
- switchable inner codes based on the rate 1/2, constraint length 7, using a single-chip Viterbi decoder working at a maximum clock speed of 45 MHz;
- single-chip RS(246,230) shortened outer code, with a correction capability of 8 symbols;
- automatic, on-line bit-rate switching, without service disturbances;

- state-of-the-art BER versus C/N performance;
- accurate receive BER monitoring to drive the rate decision unit;
- direct interfacing with PDH terrestrial networks, and future adaptation to ATM networks.

It may be noted that the FLASH-TV principle could be adopted to double the transmission capacity of other point-to-point telecommunication systems, simply by replacing the modem and the interfaces and by installing return link facilities.

A complete hardware demonstrator of the FLASH-TV chain is under development and its first public demonstration is planned for the International Broadcasting Convention, IBC' 94, in Amsterdam. Commercial products based on the project specifications are expected to be on the market in 1995.

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Dr. Alberto Morello graduated in electronic engineering at Turin Polytechnic in 1982 and took his doctorate degree in 1987. He joined the Research Centre of RAI-Radiotelevisione Italiana in 1984 and is now in charge of the Digital Communications Laboratory. He is engaged in research on digital modulation and coding techniques for audio, data and television, and high-definition television transmission and broadcasting via satellite and terrestrial channels.

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Mr. Nghia Pham received in 1981 his Diplôme d'Ingénieur des Télécommunications, option Systèmes Aérospatiaux from the Ecole Nationale des Télécommunications de Bretagne, France. After two years with Thomson-CSF, he joined the Eutelsat organization in

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Mr. Pham has represented Eutelsat in many standardization bodies and European projects, including the ITU, ETSI, Eureka 95, ISO-MPEG and DVB. He initiated the RACE FLASH-TV project in 1991.

