Digital broadcasting demonstrations by HD-SAT and dTTb at Montreux ’95

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Two RACE projects on show at Montreux ’95 – HD-SAT and dTTb – gave the first complete integrated demonstration of MPEG-2 digital television broadcasting – terrestrially, by cable and by satellite.

Visitors to the stand were able to watch four widescreen SDTV or one HDTV programme being broadcast in an 8 MHz UHF channel, in a single-frequency network. Another demonstration showed a very high-quality HDTV programme being broadcast via a satellite channel in the 20 GHz band, with a fallback operation which allowed graceful picture degradation if the HDTV signal could not be received satisfactorily due to heavy rainfall.

A third demonstration showed the terrestrial and satellite signals being broadcast, without loss of quality, over the Montreux cable television network.

1. Introduction

Two projects in the EC-sponsored RACE programme – HD-SAT and dTTb – collaborated to give an ambitious demonstration in the Future Technology Hall at the 19th Montreux TV Symposium and Exhibition. The demonstration showed MPEG-2 coded signals – standard definition (SDTV) with stereo sound, and HDTV with surround-sound – transmitted over terrestrial, satellite and cable networks. This is believed to be the first complete integrated demonstration to show the compatibility of MPEG-2 signals with all these broadcast media.

As shown in *Fig. 1*, both these RACE projects include broadcasters, equipment manufacturers and telecomms operators among their partners; the

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HD-SAT Consortium

Alcatel Espace	F	Star Telematics	IRL
Alcatel Italia	I	TDF	F
Alenia Spazio	I	Thomson CSF	F
BBC	UK	University of Salford	UK
CCETT	F		
EBU (sponsoring partner)			
IRT	D		
North West Labs Ltd	IRL		
RAI	I		

Additional sponsorship support to HD-SAT includes : Deutsche Bundespost Telekom (D), The European Space Agency, Telespazio (I) and RTE (IRL).

dTTb Consortium

Barco	B	PESA Electronica	E
BBC	UK	Philips	NL/F/D
CCETT	F	RAI	I
Deutsche Forschunganstalt für Luft und Raumfahrt	D	Retevisión	E
FZ der Deutschen Bundespost Telekom	D	Seleco	I
IRT	D	Telecom Denmark	DK
Italtel	I	Thomson Group	F/D/I
ITC	UK		

Associated partners who support dTTb include France Télécom, TDF and the EBU.

Figure 1
Partners in the RACE projects, HD-SAT and dTTb.

EBU is an Associate Partner in both projects. dTTb is studying all aspects of digital terrestrial broadcasting [1]. HD-SAT is studying the satellite broadcasting of HDTV in the 20-GHz band which was allocated by WARC-92 for digital HDTV broadcasting [2].

A paper published in the Symposium Record [3] gives some of the background to the demonstrations; the present paper aims to document what was actually demonstrated. More technical details of the work of the two projects are given in [4], [5] and [6].

2. The joint HD-SAT / dTTb demonstration

The joint HD-SAT/dTTb demonstration at Montreux consisted of a complete broadcast chain, from the sound and picture sources at the input, through to the television monitors and loudspeakers in the viewing room. The broadcast chain included:

– a satellite link via DFS1 Kopernicus;

– a UHF transmission in Channel 49 from Thollon, on the other side of Lake Geneva;

– a rebroadcast transmission from Clarens, just west of Montreux;

– distribution of the received satellite and terrestrial signals along the Montreux cable network.

2.1. Specification of coding and modulation

An overview of the broadcast chain is shown in *Fig. 2*. It included the following two basic functions:

– picture and sound coding and multiplexing;

– channel coding and modulation for the transmission segment.

The MPEG-2 picture and sound coding / multiplexing (and demultiplexing / decoding) was developed by HD-SAT. This equipment, which was used by both the HD-SAT and dTTb projects, was configured either as one HDTV codec or four SDTV codecs.

For dTTb, the MPEG-2 transport stream can contain four independent SDTV programmes or a single HDTV programme, in both cases at the same net transport stream bit-rate. For HD-SAT, the transport stream contains both an HDTV and an SDTV picture component of the same HDTV programme source; the latter is used to support the graceful degradation feature of the satellite modulation. In all cases the SDTV picture components are associated with MPEG-2 stereo sound, while the HDTV component has an associated MPEG-2 layer II 5-channel surround-sound component.

The channel modulation for dTTb is coded orthogonal frequency division multiplex (COFDM) in a standard 8 MHz UHF channel. The COFDM signal can be received off-air at a cable head end and transposed to any convenient channel for distribution over a cable network.

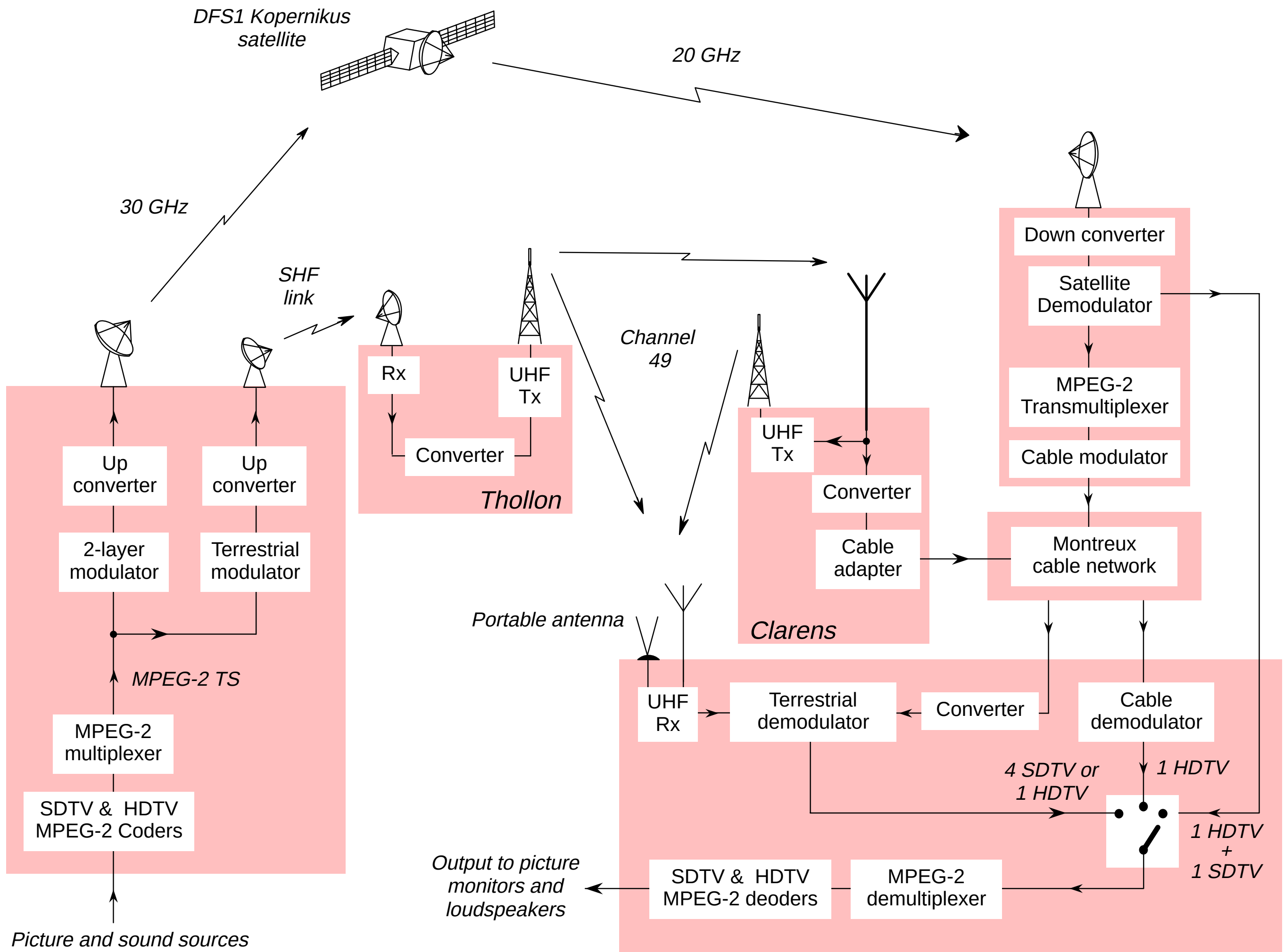
A draft specification for a COFDM system has been prepared by the DVB project. However, the equipment used in the demonstration was designed before the DVB-T specification was available; details of the channel coding and modulation actually used in the dTTb demonstration, and the corresponding parameters of the DVB-T specification are given in *Fig. 3*.

A two-layered satellite modulation scheme is used for HD-SAT [7], in order to support the graceful degradation operation needed to maintain service continuity for broadcasting in the 30/20 GHz satellite frequency band, where signals are occasionally subject to attenuation by heavy rainfall. A time multiplex of a bandwidth-efficient, but less robust modulation (TCM-8PSK, applied to the HDTV components) and a less bandwidth-efficient but very robust modulation (QPSK with Turbo-Code, applied to the SDTV "fallback" components) is implemented. When atmospheric receiving conditions begin to degrade (passage of a rainstorm, for example), the robust modulation layer and the associated SDTV fallback programme can continue to be received after the less robust modulation layer fails. Thus the service degrades gracefully to SDTV during certain periods of bad weather.

The operation of this two-level graceful degradation, as a function of the theoretical received satellite C/N, is illustrated in *Fig. 4*.

HD-SAT also supports delivery of its HDTV service over standard TV cable networks. The modulation at the cable head-end is a three step process. First, the satellite signal is received using a dish larger than would be used for direct-to-home reception, in order to assure service continuity at HDTV quality. The MPEG-2 transmultiplexer removes the fall-back components of the MPEG-2 transport stream which are not needed for the HDTV service in the cable segment, thus creating a new transport stream. This new transport stream is Reed-Solomon encoded and modulated at a bit-

Figure 2
Configuration of the HD-SAT / dTTb joint demonstration.



dTTb characteristics

	Montreux demonstration	DVB-T draft specification
Signal input	MPEG-2 transport stream	MPEG-2 transport stream
Outer coding	R-S (204, 188, t=8), interleaved to depth 12	R-S (204, 188, t=8), interleaved to depth 12
Inner coding	Convolutional turbo-code of rate 2/3 allowing for iterative decoding, time and frequency interleaved	Punctured convolutional code with rates 1/2, 2/3, 3/4, 5/6 and 7/8, frequency interleaved
Modulation	COFDM All carriers are 64-QAM with Gray mapping	COFDM All carriers in one OFDM frame are either QPSK, 16-QAM, 64-QAM, non-uniform 16-QAM or non-uniform 64-QAM with Gray mapping
Demodulation	Pilot driven	Pilot driven
Synchronization	Dedicated symbols	Dedicated symbols
Number of carriers	896	6785
Carrier spacing	7.8 kHz	1.1 kHz
Guard interval	32 µs	224 µs, 112 µs, 28 µs
Total symbol duration	160 µs	1120 µs, 1008 µs, 924 µs
Signal bandwidth	7 000 000 Hz	7 571 428 Hz
Bit-rate (payload)	18.97 Mbit/s	From 4.7 Mbit/s to 32.05 Mbit/s, depending on the modulation options chosen to suit the channel characteristics

Figure 3
Main technical characteristics of the dTTb system used at Montreux, compared with the DVB-T draft specification.

rate of 45 Mbit/s in an 8 MHz cable channel, using a similar 64-QAM as specified for DVB (but the roll-off is sharper when compared with the DVB specification).

The parameters of the HD-SAT prototypes which were demonstrated are summarized in *Fig. 5*.

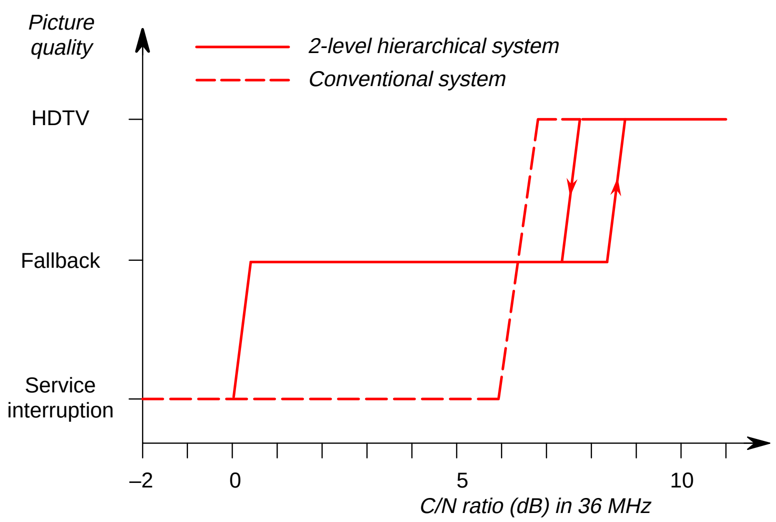


Figure 4
Two-level graceful degradation operation of the HD-SAT system.

2.2. Format of the demonstration

The demonstration was given as a half-hour presentation in a theatre which was behind a stand in the Future Technology Hall, conveniently placed between the DVB stand and the EBU Village. A presentation was given each hour during the five days that the exhibition was open. The theatre seated twenty people, and most sessions were full, so about 800 people saw the demonstration.

The main programme source was a specially-made demonstration production, partly in 625-line widescreen format and partly in HDTV; it used the device of a magician doing conjuring tricks to make some of the points and to link the presentation together. It included a number of HDTV programme extracts from various sources. Several high-quality wide-screen 625-line tapes, and a live wide-screen 625-line camera in the reception area of the stand were also used. The commentary came partly from the demonstration programme and partly from a live presenter. The two projects made presentations which were linked by the common demonstration programme.

Standard definition programme material was displayed on four widescreen monitors, and HDTV programme material was displayed with a projector on a large screen. We had intended to show all

625-line material up-converted on the projector screen as well as on the monitors, but an unexplained fault made it difficult to synchronize the up-converter in some configurations. A caption monitor gave information about what was being displayed; this monitor could also be used to show information about reception conditions from small cameras looking at displays on the measurement equipment.

2.2.1. *dTTb demonstration*

For the dTTb demonstration, the MPEG-2 transport stream was coded and modulated and then transmitted by a microwave link to a transmitter across the lake at Thollon (see the photograph in *Fig. 6)*. From Thollon, the signal was broadcast on UHF channel 49 (698 MHz). The signal from Thollon could be received by a rotatable antenna on the roof of the Centre des Congrès, either directly from Thollon or via a rebroadcast transmitter on the same frequency at Clarens, just west of Montreux. The signal picked up at Clarens was transposed to 369 MHz in order to feed the Montreux cable TV network.

The dTTb demonstration was presented first. It used the demonstration tape to point out the advantages of digital broadcasting – using MPEG-2 to achieve interoperability between different media, with all signals being received via a common decoder, and flexibility for operators to choose between quantity and quality of programmes in a single channel.It described the spectral efficiency achieved with digital terrestrial broadcasting by single-frequency networks, use of interleaved ("taboo") channels, and the transmission of four standard-definition programmes in a single channel. This was demonstrated by displaying the four programmes on the monitors and fading up the sound from each of the four channels in turn.

The concept of a single frequency network was demonstrated by displaying the impulse response of the channel, as derived by the COFDM demodulator, on the caption monitor. When the antenna was pointing directly at Thollon, the impulse response appeared as a single spike. As the antenna was turned towards Clarens, a second spike appeared, 1.5 μs later, growing in amplitude until it was greater than the signal from Thollon (see *Fig. 7)*. Reception could thus be demonstrated with a delayed signal as great as the wanted signal. In a PAL channel simulation, the decoder lost lock when the delayed signal was 8 dB down.

Next, reception via a small gap-filler transmitter (100 mW) in the exhibition building and a non-directional portable antenna was demonstrated. Provided the antenna was not moved too quickly, perfect reception could be obtained in most positions. When the antenna was unplugged, the pictures froze and the sound failed; when it was plugged in again, reception was perfect after a brief resynchronization period.

Reception of the COFDM signal over the Montreux cable network was then demonstrated.

Finally, the MPEG-2 codecs and multiplexer were reconfigured to demonstrate transmission of a single HDTV programme in the terrestrial chan-

Figure 5
Technical characteristics of the HD-SAT system used at Montreux .

HD-SAT characteristics

MPEG-2 source coding

HDTV component:	39 Mbit/s
SDTV component:	3.9 Mbit/s
5-channel level-II audio	384 kbit/s
Stereo MPEG audio	192 kbit/s

Satellite transmission

Ka-band (DFS-1 Kopernikus)	
– Uplink:	29.58 GHz
– Downlink:	19.78 GHz
2-layer time-multiplexed graceful degradation modem	
27 Msymbol/s in 36 MHz bandwidth	
QPSK modulation *(during T/6)*	
– Instantaneous bit-rate:	54 Mbit/s
– Turbo 3 coding with 1/2 rate	
– Useful instantaneous bit-rate before coding:	27 Mbit/s
8 PSK modulation *(during 5T/6)*	
– Instantaneous bit-rate:	81 Mbit/s
– 2/3-rate Trellis coding with concatenated Reed-Solomon	
– Useful instantaneous bit-rate before coding:	54 Mbit/s

Cable transmission

Modulation:	64-QAM
– Channel width	8 MHz
– Roll-off	7.5 %
– Symbol rate of 7.5 Msymbol/s (45 Mbit/s)	
– Convolutional interleaving	
– Reed-Solomon (204,188,8) channel coding	

MPEG-2 transmultiplexer at the cable head-end

Packet filtering: removal of SDTV and stereo audio components

PID (Packet ID) translation

Output bit-rate adaptation

Programme Clock Reference (PCR) jitter management nel, using a short segment of the demonstration programme shot in HDTV.

2.2.2. HD-SAT demonstration

The HD-SAT demonstration showed very high-quality HDTV, transmitted via a satellite channel in the 20-GHz band, and included the graceful degradation described above. The signal was uplinked at 30 GHz from a ground station on the lakeside outside the Centre des Congrès and received by a TV receive-only (TVRO) prototype antenna developed for this demonstration.

The demonstration started with some short extracts to illustrate the very high picture quality and the five-channel surround sound. Then a heavy rainfall event was simulated by adding noise to the received signal, reducing the carrier-to-noise ratio (CNR) from a nominal value of about 15 dB. The CNR and

Figure 6 *(top)*
TDF microwave link from the terrace of the Centre des Congrès, Montreux, to the terrestrial transmitter at Thollon.

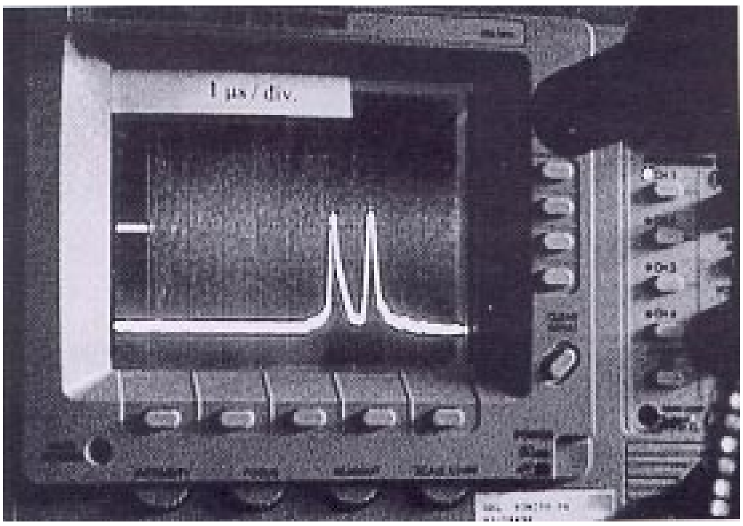


Figure 7 *(bottom)*
Impulse response of the terrestrial channel showing the signals from Thollon (left) and Clarens at equal amplitude.

the constellation diagram (8PSK / QPSK) at the input to the demodulator were shown on the caption monitor. Between a CNR of 12 and 11 dB, HDTV reception failed and the HDTV picture was replaced immediately by an up-converted version of the fallback SDTV signal. The CNR could be further reduced by more than 8 dB before the fallback signal failed. As the CNR was increased again, HDTV reception resumed at a CNR of about 13 dB.

During one of the demonstrations, a real heavy rainfall event occurred and caused graceful degradation to occur. However, this created a certain amount of confusion, as the presenter was not aware of the reason for the loss of the HDTV component!

The SD fallback component is not needed when the service is relayed on a cable TV system, so it is removed in a transmultiplexing operation as described above. The full high quality of the satellite HDTV signal is then available to cable subscribers. To demonstrate this process, the satellite HDTV signal was displayed on the projector with the SD fallback signal on a 625-line widescreen monitor. When reception was switched to the cable demodulator, the SD component froze, indicating that it was no longer being received, and the constellation diagram of the 64-QAM cable modem was displayed. This configuration was used while the demonstration concluded with the magician on the tape sawing his assistant in half (shown on two TV monitors side by side), and a finale from the opening of the Lillehammer Winter Olympics.

3. Conclusions

Unlike the magician on the tape, the engineers who gave the demonstration were not playing tricks. The whole demonstration was given live, including reconfigurations of the MPEG-2 codecs, multiplexers and transmission chains.

During the week preceding the exhibition, the on-site integration of the prototype equipments into the source-to-display transmission chains was not without its difficulties (the hardware included 15 equipment racks, over 20 monitors, five digital tape recorders, 5 km of video cable ...). Of course, there were the inevitable occasional failures during some of the presentations, particularly on the first day. However, the equipment worked well, and all the presentations were convincing. In showing (i) four SDTV programmes or one HDTV programme, MPEG-2-coded in a terrestrial channel, (ii) a very high quality MPEG-2 HDTV programme in a satellite channel in the 20 GHz band and (iii) both terrestrial and satellite signals relayed over the Montreux cable system, we believe we have shown the future of television broadcasting in Europe.

Acknowledgements

The planning, setting up, and presentation of these demonstrations involved a team of about fifty engineers from about a dozen organizations around Europe, including the EBU which took charge of the building of the stand and all relations with the Montreux Symposium organization. In addition, several organizations kindly loaned equipment for the demonstrations. We are grateful to all of them: without their efforts and assistance, these demonstrations would have been impossible.

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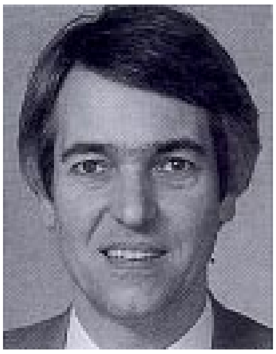

*After studying at Cambridge University, **Andrew Oliphant** joined BBC Research Department in 1972 and first worked on the transmission and reception of teletext. Later, he worked on the digital processing of video signals in telecine systems, and on improvements to PAL which led to work on enhanced video coding systems and on the multiplexing of digital and analogue signals for satellite broadcasting.*

From 1987 to 1984, Mr Oliphant worked on optical routeing of television signals, and was manager of two RACE projects that developed a wavelength- and time-multiplexed routeing system. He then moved to dTTb to lead the demonstration module.

Andrew Oliphant represented the BBC on EBU Specialist Group V1-VID, the group that carried out the preliminary work which led to ITU-R Recommendation BT.601. He also worked within EBU groups V1-EVSS, V4 and T3, and within the CMTT (now ITU SG9).

***Laurent Combarel** received his Engineering Diploma in 1985 and started his career with Telesystems. In this company, he worked under contract to France Telecom on the telecommunication infrastructure needed for computer data exchange.*

Since joining Alcatel Espace, Mr Combarel has been involved in defining the telecommunication networks needed for the Hermès spacecraft, and in the implementation of telemetry/telecommand systems for the ground stations in the satellite networks of the Centre national d'études spatiales (CNES).

At present, Laurent Combarel is working in Alcatel's department for new telecommunication services via satellite. In particular, he is leading the HD-SAT Project.