PART I

Project number	AC106
Project title	Verification and Launch of Integrated Digital Advanced Television in Europe (VALIDATE)
Deliverable type	Major deliverable

CEC Deliverable number	AC106/BBC/DR/021/P/a1
Contractual date of delivery to the CEC	June 1998
Actual date of delivery to the CEC	
Title of Deliverable	Project Final Report
Workpackage contributing to the Deliverable	WP6
Nature of the Deliverable	Report
Authors	BBC

Abstract

This Final Report summarises the results of the VALIDATE project which has verified the DVB-T specification for digital terrestrial broadcasting and carried out technical work to speed up the launch of services. The work of the Project has covered modem development and interworking, lab tests, field trials, distribution networks, transmitters and gap-fillers or on-channel repeaters. VALIDATE has also given several influential demonstrations and has published its results in Implementation Guidelines, at conferences, and in contributions to standards bodies.

Keywords list:

digital terrestrial television, DVB, COFDM, broadcasting, standards

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PART II

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Partners in VALIDATE			
BBC (Coordinator)		UK	
Robert Bosch	D	Radio Telefis Éireann	IRL
CCETT	F	RAI	I
Deutsche Telekom Berkom	D	Retevisión	E
Deutsche Thomson Brandt	D	Rohde & Schwarz	D
EBU		TDF	F
IRT	D	Tele Danmark	DK
ITIS	F	Televés	E
Mier Comunicaciones	E	Teracom	S
NOZEMA	NL	Thomcast	F

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1. EXECUTIVE SUMMARY

The European specification for DTTB (Digital Terrestrial Television Broadcasting) is one of four closely related specifications prepared by the DVB project — for satellite (DVB-S), cable (DVB-C), SMATV (DVB-C), and terrestrial (DVB-T) broadcasting. All use MPEG-2 video and sound coding and MPEG-2 multiplexing, but use different forms of channel coding and modulation appropriate to the respective channels.

Because of the complexity of the terrestrial broadcasting channel, which is particularly subject to interference and multipath propagation, the DVB-T specification was the last of the four to be prepared, and is the most difficult to verify.

The VALIDATE project started work in November 1995, when the DVB-T specification was close to being finalised.

VALIDATE was led by the BBC and included several broadcasters and the EBU representing other public service broadcasters in Europe. Other participants included broadcasting research centres, telecom operators (which in some countries are responsible for distribution and emission of broadcast signals) and both professional and domestic equipment manufacturers.

The aims of VALIDATE were to verify in detail the DVB-T specification and carry out technical work that would speed up the start of services.

VALIDATE partners in effect set up a "virtual laboratory", standardising test procedures and exchanging and comparing test results from laboratories all over Europe. The workplan of the project included upgrading existing COFDM modems to conform with the DVB-T specification and conducting laboratory tests and field trials both to verify the Specification and to supply the parameter values needed for service planning. VALIDATE also studied all aspects of transmission and distribution of the signals including primary distribution networks, transmitters, sharing with existing analogue services and re-broadcast transmitters (gap-fillers) — when COFDM is used, domestic gap-fillers become a real possibility that could provide 'portable' reception throughout a house or flat even in areas of low signal strength.

In just under three years VALIDATE has verified the DVB-T specification and has provided test results for reliable service planning and international coordination. Its work has ensured that a range of conformant equipment is available and has helped IC designers to design chips for domestic receivers with confidence. DVB-T services are now ready to start in the UK and Sweden, with long-term trials on air in several more

PROJECT OBJECTIVES

The Project's main objectives were as follows :

Main goal	
To prepare for the introduction of digital terrestrial television in Europe	
Subsidary goal	**Operational goal**
• To verify in detail the DVB-T specification	◦ To contribute to the standardisation of the Specification ◦ To prepare an implementation guide bearing in mind users' needs
• To carry out trials using the DVB-T Specification	◦ To modify existing modems to conform with the Specification ◦ To carry out laboratory and field measurements to test all aspects of the Specification ◦ To develop service planning criteria based on laboratory and field measurements ◦ To verify service planning criteria by comparing predicted and actual coverage
• To study network and transmitter issues relevant to digital terrestrial television broadcasting	◦ To investigate issues of sharing frequency bands between digital and analogue television ◦ To specify transmitter performance achievable in practice ◦ To give guidelines for synchronisation in networks
• To demonstrate active deflectors for improving domestic portable reception	◦ To study feasibility and identify possible techniques ◦ To build and test an active deflector demonstrator
• To publish the results of the Project	◦ To organise a Workshop on Project results

European countries. This success has been achieved thanks to the excellent teamwork of the Partners in exchanging and comparing results from tests and trials carried out all over Europe.

2. RELATIONSHIP TO THE PROGRAMME OBJECTIVES

VALIDATE addressed Task AC117 and also aspects of Tasks AC101 and AC115 of the ACTS Workplan. The description of Task AC117 made it clear that the work should involve broadcasters, programme providers, cable TV companies, telecommunications network operators, consumer electronics manufacturers, and end users. To do this on a European scale requires a large Project with many Partners.

VALIDATE worked on implementing the European specification for digital terrestrial television broadcasting (DTTB) in experimental networks. It used these experimental networks to verify the Specification in detail and to carry out further work needed for the successful launch of digital terrestrial broadcasting services using single frequency networks (SFNs) and interleaved ("taboo") channels.

The DVB specifications conform to the European policy objective of completely digital television systems using common standards. Terrestrial broadcasting is an important part of the whole digital scheme because:

- It offers near universal coverage at low cost;
- It allows regional and local, as well as national, programming;
- It offers a service to portable receivers.

Participation in Domains and Chains

VALIDATE participated in Domain 1, Multimedia Services, Subdomain 2, Interactive Distribution and Transmission. The Project was represented at all Concertation Meetings and made contributions to Workshops on Quality of Service issues and on mobile reception.

The Project followed the work of the SII Chain but found only minor opportunities to contribute.

Links with individual Projects

VALIDATE worked closely with AC108 DV BIRD whose aim was to develop a prototype integrated receiver, which VALIDATE intended to test.

A link to AC056, QUO VADIS, was assured by several common Partners. Rohde & Schwarz (P13) had complementary activities in each project whose results were made available to both Projects.

3. MAIN ACHIEVEMENTS

3.1 DVB-T conformant modems

Modems were essential to all the aims of the Project. At the outset the DVB-T specification was not yet stable and no conformant modems were available. During the Project six equipments have become available to the VALIDATE project:

The BBC modem was already largely designed when the VALIDATE project started. It was the first DVB-T conformant modem to be completed and so provided the first test results that initially verified the Specification. Initially it implemented only the 2K modes of the Specification but has recently been upgraded to implement also the 8K modes. The modulator is being commercialised through a collaboration with the transmitter manufacturer Itelco; know-how from the demodulator has been incorporated in an IC developed in a collaboration between the BBC and LSI Logic. This IC was first demonstrated at the Cable & Satellite Show in London, 18-20 May 1998.

The Sterne modem was completed by CCETT during 1997 and is used for field trials in France. It is being commercialised through a collaboration between CCETT and partner ITIS.

The ITIS modem is available as a commercial product. It includes a DVB-T modulator (V-CAST) supporting SFN operation, a DVB-T test receiver (V-TER) providing complete test facilities, and a flexible SFN adapter (V-SFN) supporting hierarchical operation. It supports most of the features of both DVB-T standard and SFN-DS technical specification.

A complete set of Windows based PC control software has been developed for the receiver. The DVB-T test receiver software provides many error measurement recording possibilities that are required for field tests.

The Bosch modulator is based on the terrestrial modem which was developed in the German $^{H}DTV_{T}$ project. Because of many functional differences between the $^{H}DTV_{T}$ system and the requirements of the DVB-T standard, the developments must result in a completely redesigned version of the $^{H}DTV_{T}$ modulator. The Bosch modulator was used for demonstrations and was shown in different locations e.g. at ITVS in Montreux and IBC in Amsterdam. During the IFA fair in Berlin a transmission link was set-up together with DTAG and used for a demonstration of new services which could be realised using the DVB-T system.

The Bosch modulator has since been used for additional demonstrations, laboratory tests and field trials within the VALIDATE project. It is available as a commercial product.

The Rohde & Schwarz modulator was developed in close collaboration with a sub-contractor who was responsible for the lay-out of the modules providing the functionalities in the digital domain, whereas R&S concentrated on the analogue signal domain and the software related

Pictures of modems made available during lifetime of project.

aspects of the control and the man-machine interface.

An intermediate version of the modulator was made available for field trials during the CEPT conference in Chester, in July 1997. The version that became available in late summer was then integrated into the transmitter exciter stage. For this process software and hardware adaptations had to be carried out which were accomplished in November 1997. This equipment is now used for interoperability tests in close collaboration with other partners.

A companion demodulator has been developed by Rohde & Schwarz as part of the QUO VADIS project; both modulator and demodulator have been available to both Projects. The modulator is available as a commercial product.

The Teracom demodulator is being optimised for mobile reception and is being used for field trials in Sweden. Know-how from this development is being commercialised through a collaboration between Teracom, Nokia, and Siemens to produce an integrated circuit for use in domestic receivers.

In addition**, the dTTb modem**, has been available to VALIDATE. It was designed and constructed within the RACE dTTb project, which gave VALIDATE priority in the use of the modem. It has been used for laboratory tests, field trials, major demonstrations, and checking other modems by many of the VALIDATE partners. The experience gained in this work has been published to DVB TM and has immeasurably strengthened the DVB-T specification.

3.2 Verifying the DVB-T Specification

3.2.1 Comparison of Software Models

To obtain an early verification of the Specification, VALIDATE participants compared simulations of a DVB-T modulator developed independently by different laboratories. Once the simulations had been verified, real DVB-T modulators could be compared with the simulations, giving designers confidence that no errors had crept in during hardware design. Hardware interworking, verifying the Specification completely, could then be expected with some confidence. Five partners (BBC, Bosch, CCETT, Tele Danmark, Teracom) had developed software models of a general DVB-T modulator, including all specified DVB-T modes. Teracom proposed a "Specification of test signals of DVB-T modulator" and conducted a series of comparisons of software-generated DVB-T signals from their own and other Partners' models. All the software models generated identical outputs, showing that all participants had the same understanding of the Specification. This encouraging result was reported to DVB in September 1996.

3.2.2 Hardware Interworking

During 1996 two DVB-T compliant modems were completed by VALIDATE participants. These were the BBC modem and the modem belonging to the RACE dTTb project. The BBC modem then implemented all non-hierarchical 2K modes of the Specification (it has since been upgraded to include 8K modes); the dTTb modem, which was developed by Thomson Multimedia, ITIS, and CCETT, implements eight combinations of code rate, modulation level, and guard interval in both 2K and 8K.

In December 1996 interworking was demonstrated between the BBC modem and the dTTb modem. The test was successful with both senses of interoperability, and for all modes that were tested. (All 2K non-hierarchical modes that the dTTb demonstrator is capable of working with were tested, except one, which was omitted in one direction by an oversight!) MPEG-2 coded video and audio were transmitted successfully in both senses. The test was successful on the first interconnection of the equipment. This was the first demonstration of interoperability between a modulator fully compliant with the DVB-T specification and a compatible demodulator. This success was an important step in the work of VALIDATE.

These interworking tests showed that the DVB-T specification is sound. But they also uncovered some areas where, although the Specification is correct and unambiguous, some clarifications would be helpful to equipment manufacturers in the future.

Interworking tests between the BBC modem and the dTTb-2 modem, Torino, December 1996.

VALIDATE prepared an Informative Annex to the DVB-T specification drawing these points to the attention of all users.

Because of the very powerful error correction coding in the DVB-T specification it is possible for a modulator and demodulator to interwork even though one or both of them may not be totally conformant with the Specification. To demonstrate full conformance it is necessary to demonstrate not just interworking but interworking with the expected level of performance in a difficult channel.

Since the important tests described above, more equipment has become available to VALIDATE: a modulator from Bosch, a modem from CCETT (the Sterne IV modem), a modem from ITIS based on the Sterne IV modem, a modem from Rohde & Schwarz, and a modem from Teracom. Some of these modems are still being optimised, but all were demonstrated to interwork with at least one other modem.

In June 1998 VALIDATE organised a final interworking demonstration, bringing together a wide range of DVB-T equipment from different manufacturers within and outside the Project:

- seven different modulators including first generation prototypes and industrial products
- nine different receivers including first generation prototypes, commercial professional receivers and consumer chip-sets.

61 different DVB-T modes were tested; these included examples of all the possibilities and options offered by DVB-T specification. Interoperation of hierarchical modes was successfully demonstrated for the first time. Single Frequency Network (SFN) operation was successfully demonstrated using modulators from different manufacturers.

The successful results of all of these tests prove the interoperability of DVB-T equipment from different manufacturers. Network operators can safely mix equipment from different manufacturers in their networks. These results provide a sound basis for the launch of commercial services.

The multidimensional interoperability tests being performed in Rennes, June 1998.

3.3 Laboratory Tests

Detailed laboratory tests were first conducted with the dTTb modem at the RAI laboratories in Turin and with the BBC modem. The first BBC demodulator was optimised for ultimate carrier-to-noise ratio performance in a Gaussian channel, and achieved performance very close to the theoretical figures given in the DVB-T specification — the second aspect of verifying the Specification. However, when the channel equalisation was modified to give improved performance in time-varying channels, the results in a Gaussian channel were degraded by a small amount, accurately predicted by simulations.

Following the improvements to the BBC modem, BBC R&D conducted a number of laboratory tests in 1997 to establish the performance of the upgraded modem. One of the improvements that was made involved reducing the filtering that is used in the channel equaliser. This allows for a much better response in time-varying channels, but inevitably carries with it a noise penalty. It was expected that this penalty would also slightly worsen the protection ratio measurements, but the laboratory tests showed that in practice, other improvements in the modem more than compensated for the expected penalty. Overall, the results still showed that an improvement had been achieved, and that the implementation margin of the modem is now as low as could be expected.

A series of tests was also conducted with domestic tuners. The tests were carried out in cooperation with the tuner manufacturers, allowing them to optimise their designs where appropriate. These tests showed that the adjacent channel protection ratios assumed in the UK frequency planning project can be exceeded by a comfortable margin in practice. The results of this work were reported in a paper presented at IBC'97: "Evaluation of a DVB-T compliant digital terrestrial television modem".

At the RAI Research Centre, a complete DVB-T chain had been set up in the laboratory in 1996, including real time MPEG-2 encoders/decoders (for three programmes), a transport stream multiplexer/demultiplexer, the dTTb

modem, a 50 Watt RF transmitter on UHF channel 28 or 43 and a "quasi-consumer" tuner. A series of tests were carried out using this set up, and performance of the system was assessed by changing the parameters of the channel impairments (noise, interference, multipath echoes, phase noise, frequency offsets, non linearity) and measuring the BER at the receiver side, after Viterbi error correction. The results of these tests, which were very positive, were fed to the Task Force and other Modules as appropriate. These results were presented at a DVB Technical Module meeting and later at Montreux ITS. They were also submitted to CEPT PT FM 24 in preparation of the Chester conference of July 1997.

Most recently, two first-generation DVB-T compliant chip sets that have become available (from Motorola and LSI-Logic) have been tested by the BBC. Both gave accaptable performance, although there remain some worries over co-channel interference from PAL signals. Unfortunately the DV BIRD chipset never became available to VALIDATE, so the results of these tests on Motorola and LSI chips have been submitted as a Deliverable in place of results on the DV BIRD chipset.

3.4 Field Trials

Field trials have been carried out in nine countries to gain an understanding of the DVB-T system in real channels and to allow Partners to gain experience that will be helpful in the introduction of services. A full list of field trial details is given in Annex 5.

Field trials in Germany

First field measurements using an 8K-FFT modem became possible with the completion of the dTTb-2 demonstrator, developed by the European RACE project dTTb. IRT set up a complete DVB-T transmission chain in Munich using this modem. Pseudo random sequences or video sequences or live encoded TV programmes were transmitted using different modes of the dTTb-2 modem (i.e. different data rates and different error protection schemes). The DVB-T signal was radiated from the tower of the Bayerischen Rundfunk next to the IRT with 75 Watt ERP (TV Channel 43) using an antenna with vertical polarisation at about 80 m height.

The system performance and service coverage under real propagation conditions, including multipath propagation and noise, were determined by evaluating the curves of the bit-error ratio in the field and by observing the picture quality to evaluate the onset of impairment and the break-down of the reception in terms of C/N. At every location a directional antenna (10 m height) and an omni-directional antenna (1.5 m height) were used. The propagation conditions were examined by measuring the spectrum and the receiving power. For the evaluation of the ratio C/N the noise figure of the receiver was also measured.

The field trials performed in the area of Munich proved the benefits of digital terrestrial television. The results for stationary and portable reception in the field were as good as expected or even better in terms of C/N. The different modulation modes and channel coding rates tested showed a stable bit-error behaviour. In comparable poor receiving conditions the quality of DVB-T was found to be well superior to the analogue TV reception.

Mobile Reception

P04 Deutsche Telekom investigated the DVB-T standard in terms of mobile reception and SFNs. Laboratory tests have been carried out together with the project partners from the Task Force on Laboratory Tests and Field Trials.

Deutsche Telekom also carried out extensive field trials for DVB-T mobile reception in Cologne and Berlin. The results of these tests were very encouraging. The tests revealed that there is a certain capability within the DVB-T standard to support mobile reception as well as stationary and portable reception. Results were reported to VALIDATE and to DVB-TM. Nevertheless, additional tests should be done if the channel estimation of the DVB-T receiver is optimised for the mobile reception or portable reception in the case of strong echoes. This additional work will be carried out by a new project, MOTIVATE, in which most of the VALIDATE partners participate.

SFNs

A single frequency network was set up in Berlin including a professional co-channel repeater made by P08 Mier to extend the coverage to the town of Potsdam. This test, which was also running during the exhibition IFA'97 showed that it is possible to extend the service area of an MFN transmitter in a very cost efficient manner.

Field trials in Denmark

The system set-up of the field trials were based initially on the dTTb-2 demonstrator and later on the ITIS modem, both with a 1 kW peak sync power analogue transmitter, which was backed off to 300 W and equipped with suitable linearity correction. A COFDM modulated PRBS sequence was radiated from 300 m height at 4.5 kW EIRP for the measurement purpose.

On the receiver side the demodulator was installed in a measurement vehicle together with a PC controlled measurement set-up. This configuration has been decided in order to be capable of performing the measurements automatically which is necessary for recording and later processing of the large amount of data.

Measurements have been performed at a number of positions at different distances form the transmitter. The positions were identical or very close to positions that had previously been measured for analogue reception from the same transmitting site and antenna height. This will allow comparison of coverage for the analogue (600 kW EIRP) and digital signals.

The positions were chosen in different environments representative for the propagation conditions typically experienced in Denmark, for Urban to Rural. The first measurement campaign was carried out during the autumn, i.e. after leaf fall, and the second one was carried out during early summer.

At each position the following signals were recorded for every 0.5 m from 3 to 10 m antenna height:

- Received signal strength, from which the field strength is calculated
- Bit error ratio after Viterbi decoder
- Added AWGN signal to achieve a bit error rate of $2*10^{-4}$
- Environment class and exact position coordinates.

The large amount of data has been processed, and from the results the noise margin at each position and for varying antenna height has been presented.

Field trials in France

Tests in France were conducted in two main sites, one in Metz, and one in St-Pern, near Rennes.

The Metz network is composed of one main transmitter (3.4 kW ERP) 17 km away from Metz and one isofrequency gap-filler (25 W ERP).

The transmission frequency is 626 MHz (channel 40) which is upper adjacent to the TV5 commercial programme. The two programmes share the same antenna and therefore, a high selective RF 8-cavity combiner is used. The digital signal is broadcasted with a power 17 dB lower than the analogue one.

An NICAM analogue transmitter of 1.5 kW (peak sync) has been optimised in order to broadcast 200 W digital signal power with –40 dB out of channel intermodulation products.

The isofrequency gap-filler, specifically designed for TDF is able to cope with the high power of the adjacent analogue channel by using specific selective IF treatments.

A second experimental site was set up at St-Pern, one of the main TDF transmitting sites of Brittany. A contribution was written on the field strength measurement campaign. A second transmitter at CCETT can be used in a single-frequency network with St Pern; this arrangement was used in the interworking tests described above.

Video, NICAM and audio protection ratios between L-SECAM interfered with by DVB-T were measured.

Co-channel, upper and lower adjacent channel configurations were investigated. Several out-of-band intermodulation products of the digital signal were used and their impact on the protection ratios was studied.

Special care was taken concerning DVB-T in the upper adjacent channel which is the most critical case where the SECAM AM audio carrier could be impaired. Effects of using a DVB-T frequency offset in terms of audio protection ratio relaxation were therefore studied.

Field trials in Sweden

Measurements of location variation of the field strength were carried out by P17 Teracom in four different terrain classes. In total 144 sequences (each being 400 m) were measured. There were also measurements of indoor location variation and measurements of building penetration loss for stone and concrete houses. In total 58 rooms in 14 buildings were measured.

Field Trials in Ireland

P19 RTÉ, who joined the Project at the beginning of 1997, designed and built a digital television measurement vehicle and established two test transmitters for use exclusively by the project. Both transmitters are co-channel UHF, one analogue PAL I and the other digital (2K). A third temporary transmitter was set up using the dTTb2 demonstrator. RTÉ carried out co-channel measurements, and interoperability testing of different modems. RTÉ has investigated the unique Irish spectrum planning constraints with digital and analogue transmissions.

P07 ITIS provided an SFN adapter (V-SFN) and two DVB-T modulators (V-CAST) to RTÉ. which allowed the setting up the first DVB-T Single Frequency Network (SFN) using a primary distribution network as described in the SFN-DS specification.

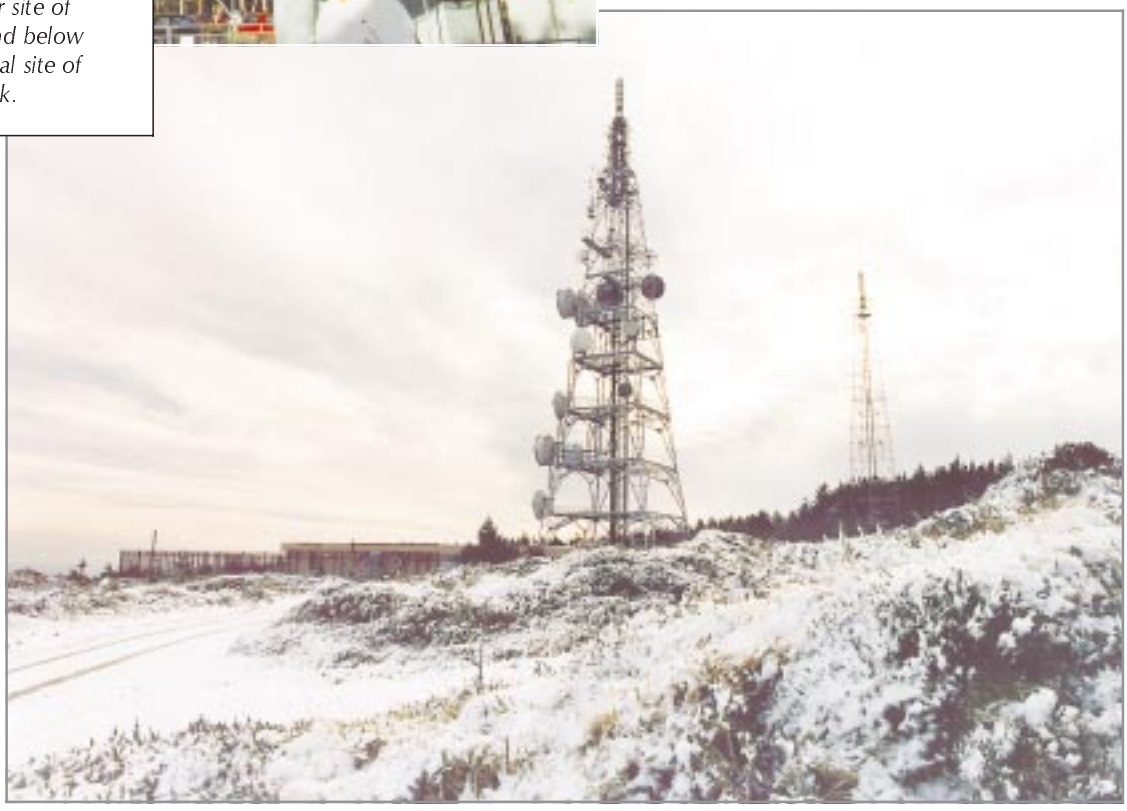
Field trials in the UK

In April 1996, the BBC made the world's first DVB-T compliant transmission from its Crystal Palace transmitter, the main transmitter for the London area. Since then, a signal has been maintained on air from Crystal Palace, which has been used for numerous demonstrations and for an extensive programme of field trials. For some months a regional service was also radiated from the transmitter at Pontop Pike near Newcastle upon Tyne in north-east England. The network was fed from Television Centre in London using single-mode fibre to Crystal Palace and an SDH-based network to Newcastle.

The BBC has a mobile survey vehicle, equipped of DVB-T work. Detailed surveys have been conducted in London and Newcastle to compare the coverage achieved in practice with the computer predictions. In general, this work showed that the coverage exceeds the predictions. Some areas at the edge of the predicted service area which were predicted to be only marginally served were in fact completely covered.

More recently, a campaign of measurements has been started to determine the extent to which reception will be possible using set-top antennas. Also, as part of this work, some tests have been conducted with the prototype domestic gap-filler developed by P16 Televés.

The transmitter site of Navacerrada, and below the Irish field trial site of Three Rock.



A series of measurements was also made to determine whether there was any disadvantage if a digital transmitter was not co-sited with an analogue transmitter intended to cover a similar area. This work showed that there would be some reduction in coverage by non co-siting, which helped to establish the case for co-siting of all transmitters.

Field trials in Spain

P12 Retevisión has installed an experimental network in the Madrid area. The real transmissions started in May 1997, with an infrastructure composed of the source coding system (four MPEG-2 MP@ML coders and one MPEG-2 TS multiplexer), an optical fiber link between the Retevision Laboratory (Madrid) and a transmitter located in Torrespaña (500 W RMS power, 6 dB back-off), where the dTTb second demonstrator was used to modulate the signal and build a MFN radiating in UHF channel 26.

This DVB-T network was used in May 1997 to carry out the first demonstration of a real DVB-T transmission in

Spain, and in July to check the performance and availability of the domestic gap-filler used to re-radiate DVB-T signals. The second dTTb demonstrator was very important for P12 Retevisión to carry out these tests, since it was the first 8K demodulator available for Retevisión.

This infrastructure has been growing and, currently, the network has been upgraded with a new transmitter, Navacerrada (300 W), located 50 km from Torrespaña, and one 5 W professional gap-filler located in the center of Madrid. The power of the main transmitter (Torrespaña) has been increased up to 900 W and the source coding system is now located in Pozuelo de Alarcón. With this infrastructure, a SFN has been setup, using ITIS modulators and SFN adapter, and preliminary tests have been carried out in order to check that the synchronization scheme is correct and to verify the overall performance of the system. Analog and digital radio links have been used to check the feasibility of different options for the primary distribution network.

This DVB-T network has supported the first public demonstration of a DVB-T SFN in Spain, held in Madrid in June 1998. The performance of fixed and portable reception under a real DVB-T SFN has been shown in this demonstration, even with an adjacent and a co-channel interferer PAL signal.

Field trials in the Netherlands

P20 Nozema installed a experimental transmitter in Lopik at the end of 1997. The output power is 9 kW ERP and is radiated from an antenna at 150 m height. The city of Utrecht is covered by this transmitter. The field trials where carried out in the period January — April 1998. For the field trials a PRBS sequence was transmitted in 16 QAM and 64 QAM 8K mode.

On the receiver site all the measurements were carried out with a omnidirectional antenna at 1.5 m height and a directional antenna at 10 m. Field strength, BER, C/N and received spectra were stored on a computer. Measurements were done at about 100 locations in rural and suburban areas and at 100 locations at difficult locations in urban areas.

The results were compared with the field strength and coverage predictions. The coverage was as good as expected, in rural areas sometimes even better than expected.

For field strength prediction it is important to have up to date clutter information in the database used to make the predictions

The results of the field trials are used as input for the VALIDATE deliverable "Comparison of actual and predicted service areas".

Field trials in Italy

The RAI Research Centre has set up a complete DVB-T experimental transmitting chain in Turin. The transmitter was located in the hills south of Turin and was characterised by a nominal ERP of 290 W with an OFDM power of 40 W, guaranteeing adequate field levels over the entire urban and suburban area, as well as the plain towards the North West (Caselle airport). The OFDM modulator was configured to work in the 2K mode, using 64 QAM modulation rate 2/3 coding and guard interval 1/32. Three TV stereo programmes were transmitted, at 6.8 Mbit/s each.

Field trials have been performed at the RAI Research Centre, which is located approximately 5 km far from the transmitter, and is in sight of it. Measurements of portable reception have been performed in several locations inside the RAI Research Centre, at different floors. The received signal power, bit error rate, picture quality and reception margin have been evaluated at each location.

In a second phase, a Televés gap filler has been installed at the RAI Research Centre, to allow coverage of the areas where portable reception was not possible.

3.5 Preparing for the Launch of Services

3.5.1 Implementation Guidelines

VALIDATE participants have amassed a great deal of experience in all aspects of the implementation of DVB-T services. To make this experience available to broadcasters not involved in the Project they have prepared Implementation Guidelines aimed at the technical staff of other broadcasters. These Guidelines draw attention to the technical questions that need to be answered in setting up a DVB-T network and offer some guidance in finding answers to them. They give an explanation of the DVB-T specification and the basic characteristics of transmission networks; they then cover transmitters and issues of sharing with existing services, distribution networks, SFN operation, and network planning.

The Guidelines were submitted to DVB and to the EBU and were first published on the VALIDATE website (http://www.bbc.co.uk/validate/). They were welcomed by DVB as "a major contribution to the list of deliverables of the [DVB] project [which] will become part of our marketing campaign to the rest of the world". The Guidelines have now been published as an ETSI Technical Report.

3.5.2 Service Planning Parameters

Results of VALIDATE laboratory tests and field trials were reported as they became available to the EBU, ITU-R, and CEPT. In June 1997 a massive document (120 pages) bringing together all the results relevant to service planning was sent to CEPT PT FM24 which was preparing for a conference on coordination procedures for digital terrestrial television held in Chester (UK) in July 1997. Delegations from 37 countries attended this conference; many of them had no direct experience of DTT, but the comprehensive results available, confirmed by

a demonstration of reception in the BBC measuring vehicle, reassured them that the Conference proposals were realistic. All approved the output document which gives details of procedures for international coordination of frequency allocations and transmitter powers and tables of parameters to be used.

3.6 Transmission and Reception

3.6.1 Network Configuration

Two approaches are possible to the planning of DVB-T networks: multi-frequency networks (MFNs) and single frequency networks (SFNs).

MFNs are planned in the same way as analogue networks, using an individual set of radio frequencies for each transmitter. This approach might be considered when an Administration wishes to re-use some or all of the spectrum used for analogue broadcasting.

SFN planning relies on the relative insensitivity of COFDM to delayed signals arriving within the guard interval. It is possible, if a suitable frequency is available and a sufficiently long guard interval is chosen, for all transmitters in a region, or in a country, to use the same frequency.

The Implementation Guidelines give advice on the relative advantages of the two approaches and on the modes of the Specification that might be appropriate for different kinds of networks and modes of reception.

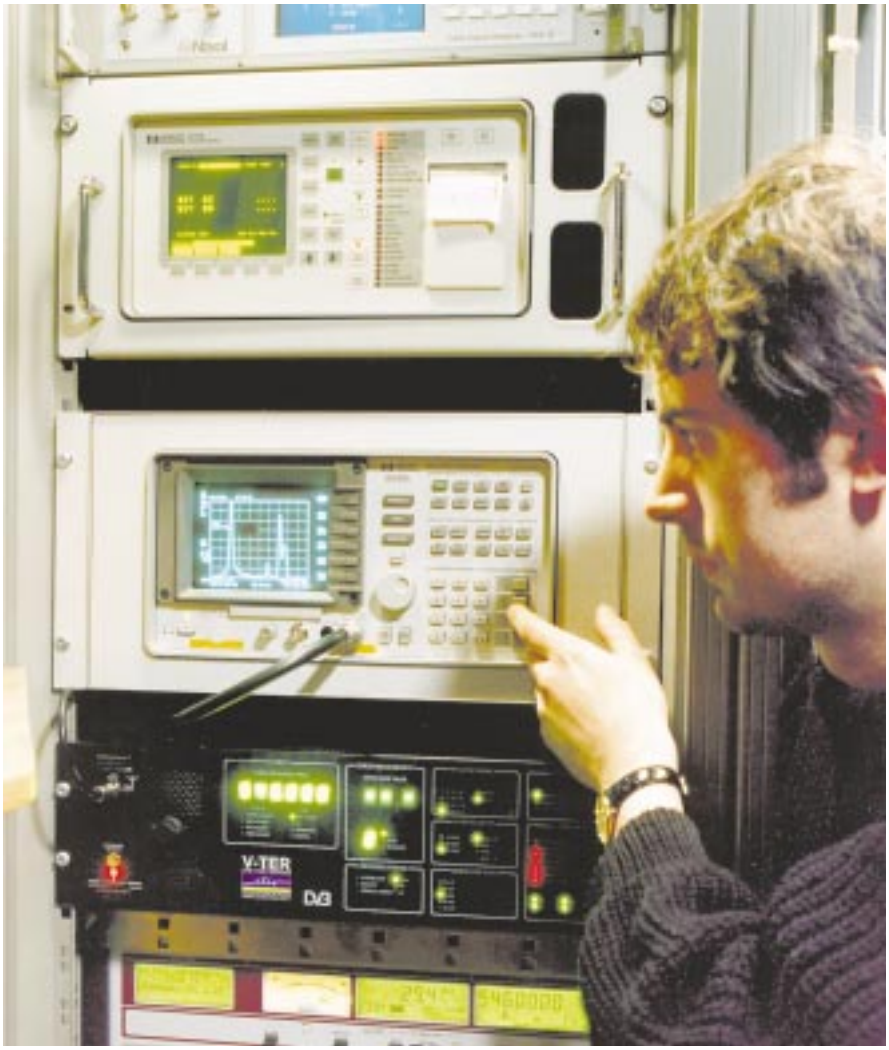
3.6.2 Primary Distribution

A digital primary distribution network will be needed to distribute MPEG-2 transport streams from TV studio centres to remultiplexing sites (if the network has regional variations) and to transmitters. Possible choices are optical fibre, PDH or SDH networks, ATM, and satellite distribution; of course a real network may use a combination of these techniques. The timing of the primary distribution must be controlled to ensure that it does not induce jitter in MPEG-2 decoders and to ensure stable synchronisation of the MPEG-2 multiplexers and the COFDM modulators.

Standards for transporting MPEG-2 signals in PDH, SDH, and ATM networks have been prepared by DVB and early equipment is being tested by VALIDATE participants in their trial networks. In one VALIDATE trial conducted by the BBC an SDH network was cascaded with the *JAMES* international ATM network to feed a satellite uplink station. The signal received from the satellite was then remultiplexed with local programmes, distributed via an optical fibre link, to simulate a regional opt-out. The resulting transport stream was COFDM modulated and perfect reception was demonstrated. This showed that all the challenges of network synchronisation in a mixed primary distribution network can be met.

3.6.3 SFN Synchronisation

All transmitters in an SFN must be synchronised so that their broadcasts are frequency identical and bit identical. VALIDATE partners have devised a method of synchronising all the transmitters in an SFN by defining a megaframe in the MPEG-2 transport stream using a megaframe identification packet (MIP). A group led by Teracom developed a specification which was accepted by DVB and published by ETSI as a Technical Specification. The megaframe length has been chosen to contain an integral number of OFDM frames, of Reed-Solomon packets, and of the



Channel profile in SFN being tested by RTÉ and ITIS in Ireland.

energy dispersal sequences, thus ensuring that it is possible to produce identical waveforms at each transmitter. The MIP contains a timestamp indicating the time at which the megaframe should be broadcast, related to a universal time and frequency reference such as that available from the GPS satellite system. By comparing the timestamp with the universal time reference at the transmitter, all transmissions can be time synchronised.

To test this synchronisation technique, VALIDATE partners RTÉ and ITIS set up, with the assistance of TDF, a DVB-T Single Frequency Network (SFN) using two transmitters in the Dublin area on 8 November 1997. The transmission mode used for this experiment was 8K, 64QAM, R=2/3, guard interval=1/4. An MPEG-2 Transport Stream generator, an SFN adapter, a DVB-T modulator, and a 1 KW TV transmitter operating at 50 W were set up at the site of Three Rock. A second DVB-T modulator and a 25 W transmitter were set up at the site of Donnybrook. Both transmitters used UHF channel 30. A 34 Mb/s PDH link was established from Three Rock to Donnybrook which fed the second DVB-T modulator with the MPEG2-TS output from the SFN adapter. This complete SFN arrangement was synchronised by using GPS receivers. At a site near Donnybrook where the signals from the two transmitters were at similar levels, the signals was received successfully with a small omni-directional antenna and a professional DVB-T receiver. This field arrangement represents the world's first SFN operation based on a real primary distribution network according to the ETSI specification.

In June 1998, the first public demonstration of a DVB-T SFN in Spain took place in Madrid. The experience was based on the SFN that Retevisión installed and set up for trials and field tests. Currently, this network is made up of two main transmitters: Torrespaña and Navacerrada. They are separated about 50 km distance. The DVB-T equipments in the transmitter sites are from ITIS and different Spanish manufacturers, and has been arranged in the framework of the Spanish VIDITER project. In the receiving side (demonstration room), other equipments from manufacturers of different countries were also presented, including 2K IDTV receivers, domestic gap-fillers, TS analyzers and a video quality measurement instrument. A preliminary software for data insertion and Internet access based on DVB-T channels with an interactive channel on the PSTN was also presented.

The demonstration showed not only fixed reception in DVB-T single frequency networks, but also portable and in-door reception. The SFN was working in channel 26, with mode 8K, 64 QAM, FEC 2/3 and guard interval 1/4. The on-air signal received by MATV was demodulated, decoded and shown in four monitors, since the TS was composed of four live programs. The demodulated TS was also used to feed a new 2K modulator in channel 67 (64 QAM, 2/3, 1/32), which addressed the IDTV receivers by means of a domestic gap-filler located in the same room. The signal taken from the MATV was also re-radiated in channel 26 with another domestic gap-filler. Additionally, a reception set (aerial, demodulator, MPEG-2 decoder and monitor) was installed on a small travelling table, in order to show the performance of DVB-T with portable reception in a slow motion mode.

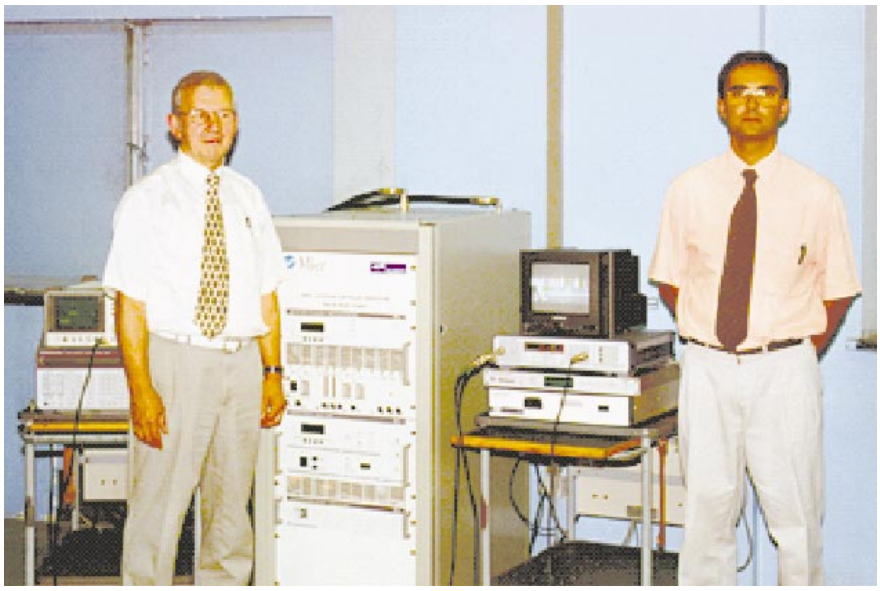
3.6.4 Transmitter Parameters

Setting up digital terrestrial TV broadcasting networks will require agreement between transmitter manufacturers and transmission network operators and between the network operators and the service providers on the specifications for the performance of transmitters, including functional blocks and the interfaces between them. As this is a new technology, there is no existing basis for such specifications. VALIDATE has therefore drawn up a transmitter performance specification and submitted it to DVB. The aim of this document is to suggest the parameters that need to be measured and some realistic values for them as well as to define the minimum interface specifications (not all of which are mandatory).

Transmitter performance is largely based on the idea of Equivalent Noise Degradation (END) as the main (perhaps the only) performance criterion. The degradations in performance produced by different impairments can be expressed in terms of the loss of noise margin that they produce in a Gaussian channel, and these noise equivalents can then be added as noise powers to derive an END figure for the transmitter. The work of VALIDATE has shown that this procedure is valid provided the individual impairments are small (each significantly less than 3 dB loss of noise margin).

An alternative but related method of specifying the overall performance of a transmitter is the Equivalent Noise Floor (ENF). To measure ENF the transmitter is connected to a demodulator and noise is added to achieve quasi-error-free reception (QEF — bit error ratio of 2×10^{-4} before Reed-Solomon correction, corresponding to about one error an hour after correction). The transmitter under test is then replaced by an undistorted laboratory test modulator and noise is added from a second noise generator in parallel with the first to obtain QEF reception again. The level of noise from the second generator then represents the ENF of the transmitter.

It will often be helpful to broadcast DVB-T from the same sites as analogue TV signals, re-using transmission infrastructure and receiving antennas and maximising the number of households able to receive the signals at the start of services. A prototype 8-cavity high power combiner for combining a DVB-T signal with adjacent channel analogue TV signals has been designed and built by Thomcast,



The professional gap-filler developed by Mier, being installed by Deutsche Telekom and Mier, Berlin, summer 1997.

following the TDF specifications, and has been installed at a TDF experimental site at St Pern near Rennes. Much useful information about the issues raised in sharing sites with analogue transmissions is included in the Implementation Guidelines.

3.6.5 Gap-Filler Transmitters

SFN techniques can be used on a smaller scale to improve coverage. VALIDATE partners have studied both professional gap-fillers, installed by the network operator to fill gaps in the coverage of a main transmitter caused by shadowing from terrain or large buildings, and domestic gap-fillers installed within a house to improve portable reception. Obviously, the main technical problem of such gap-fillers is oscillation cause by feedback from the transmitted signal to the receiving antenna.

A professional gap-filler was demonstrated by Mier and DT Berkom in Berlin to provide coverage to the Potsdam area that is shadowed by hills from the main transmitter at Alexanderplatz in the centre of Berlin. With both receiving and transmitting antennas mounted on the same concrete tower an isolation of 105 dB was obtained. The ripple on the output DVB-T signal spectrum was less than 3 dB with an output ERP of 100 W. Field trials in Potsdam showed that portable reception was possible at all locations with a reasonable field strength. One important conclusion is that some trials have shown that no signal degradation has been observed for a ripple amplitude up to 10 dB peak-peak.

For the domestic gap-filler, Televes developed a channel model based on field tests in houses and a device model to study the configuration, the antennas that might be used, and the gain that might be achievable. As a domestic device, the safety of such a gap-filler and its cost have been important considerations. A feasibility study gave encouraging conclusions and several prototypes were built. A comprehensive campaign of field tests using a prototype was conducted by the BBC in the London area during last autumn. Five dwellings (houses and flats of different sizes and different methods of construction) were measured, some of them in areas of poor reception where indoor portable reception would otherwise have been impossible. In all of them, the domestic gap-filler gave sufficient field strenght to provide portable reception in all rooms of the buildings tested with an output power less than 1 mW (less than 100 μW in some cases). There were no problems of stability when the device was fed from a rooftop antenna, but some care was needed in setting up when a receiving antenna within the roof space of the house was used.

Tests have also been carried out by P11 RAI in Torino within the area of the "Centro Ricerche" of this company. A domestic gap-filler transmitting an output power of 10 mW provided portable reception to three floors with a total area of about 800 m2. Isolation between transmitting and receiving antennas did not limit the performance of the system.

Domestic gap-filler prototypes have also been loaned to P17 Teracom, P12 Retevisión and P06 IRT. These companies plan to carry out more field tests within the next months.

Tests to assess the effect of re-radiation of analogue channels adjacent to the wanted digital ones have also been conducted by the BBC and Televés. Although more work is necessary, results obtained up to now show that such an effect is not as important as it might have been expected to be and that, in any case, it would only be noticeable in unlikely scenarios.

The prototype domestic gap-filler developed by Televés.

3.7 Mobile Reception

Mobile reception was not one of the main considerations in establishing the DVB-T specification; it was optimised for fixed and portable reception with mobile only as an interesting possibility. The main limitation to mobile reception is the ability of the receiver to track channel time variation. However, tests by Deutsche Telekom in the area of Cologne showed that, at the speeds normal in urban areas, mobile reception was possible independent of speed with a 16-QAM mode: only the reception power (depending on field strength) was a restriction. Further tests with a fast driving car showed that reception of the QPSK rate 1/2 mode was robust at speeds up to 140 km/h. Mobile reception in Berlin was demonstrated during IFA'97 and tests continue. A new project, AC318 MOTIVATE, will take further the study of mobile reception of DVB-T.

3.8 Trials and Demonstrations

The first broadcast conforming to the DVB-T specification was made on 9 April 1996 by the BBC from the Crystal Palace transmitter in London. It was received at the BBC's west London centre at White City, and at BBC Research and Development at Kingswood Warren, south of London. In June 1996 the BBC started a trial service, broadcasting a multiplex of four TV programmes with sound and data from Crystal Palace and from the Pontop Pike transmitter serving Newcastle-upon-Tyne in north-east England; the broadcasts from Pontop Pike carried BBC North East regional variations, demonstrating one of the important advantages of terrestrial transmission. This trial service was demonstrated to a wide range of broadcasters and the broadcasting industry. The trial broadcasts from Pontop Pike have now ceased; the broadcasts from Crystal Palace will probably continue until replaced by operational services.

The first public demonstration was given at the International Broadcasting Convention in September 1996 when the MPEG-2 transport stream providing the BBC trial service in London was carried to Amsterdam over an international ATM link kindly provided by ACTS project *JAMES* and broadcast by the local broadcaster NOZEMA with the helpful collaboration of several other VALIDATE participants. Because this demonstration showed live transmission of network TV programmes with some high quality widescreen material and a realistic EPG, it was perceived as more than an engineering demonstration: for many delegates it was a first exciting experience of what digital TV broadcasting can offer.

Another major demonstration was led by TDF and CCETT at the Montreux International TV Symposium in June 1997. A multiplex containing four TV programmes was assembled on the TDF stand and COFDM modulated. The COFDM signal was transmitted to Thollon on the other side of Lake Geneva from where it was broadcast in UHF channel 49 (698 MHz). The signal broadcast from Thollon was picked up at Clarens on the Montreux side of the lake and re-broadcast on the same frequency. Reception was demonstrated on the VALIDATE stand in the exhibition with a rotatable antenna. The signal from Clarens arrived about 1.5 μs later than the signal from Thollon. Turning the antenna varied the proportions of main and delayed signal, to demonstrate that DVB-T can be received even with a 0 dB echo.

IBC and Montreux are exhibitions for the broadcasting industry. DVB-T was shown to the general public at the Internationale Funkaustellung (IFA) in Berlin in September 1997 where both Deutsche Telekom and IRT gave demonstrations. Eight TV programmes and a data service were broadcast using three UHF channels, two of which were adjacent to PAL services broadcast from the same mast. Fixed and portable reception were demonstrated at the exhibition site with good reception even indoors. Mobile reception was demonstrated in a car and buses.

The availability of the dTTb modem has allowed several Partners to arrange short field trials, often including demonstrations to influential national or

Testing the link termination and DVB-T transmission equipment for the demonstration at IBC 96.

international groups. Such trials and demonstrations have been held in Turin, Munich, Madrid, Copenhagen, and Dublin and have contributed greatly to the increasing interest in DVB-T.

4. MAIN CONCLUSIONS

4.1 DVB-T Specification

The DVB-T specification is sound:

The specification is clear and unambiguous: software simulations, laboratory prototype hardware and most recently commercial equipments have been shown to interwork without problems. Network operators can safely mix equipment from different manufacturers in their networks.

The DVB-T system performs as expected in the repeatable conditions of the laboratory. Tests by many Partners using several different sets of equipment have confirmed this. Discussion between Partners has resolved a few apparent problems as they appeared.

The DVB-T system meets the requirements of broadcasters in field trials in many different configurations in eight different countries.

4.2 Preparing for launch of services

Results of VALIDATE tests have been delivered to CEPT and form the basis of the Chester agreement on coordination of digital terrestrial TV transmitter assignments

VALIDATE has studied distribution networks and transmitters for DVB-T services. Its conclusions are embodied in Implementation Guidelines published as an ETSI Technical Report and in a draft transmitter specification submitted to DVB. Other highlights from the original technical work of VALIDATE are:

- A specification for synchronisation of single-frequency networks proposed, verified, and approved by ETSI;
- The concept of 'gap-fillers' or on-channel repeaters has been verified for professional and domestic use.

The work of VALIDATE has shown that mobile reception of DVB-T is feasible. This development will be followed up by a new project MOTIVATE.

4.3 Support to DVB

VALIDATE has given influential demonstrations at important conferences in Europe. These demonstrations have supported the DVB-T specification at the crucial point where it was submitted to the ETSI public enquiry and have raised the profile of DVB-T with potential users in other parts of the world. VALIDATE has subsequently supported DVB's marketing efforts, contributing to the success in Australia.

4.4 Working together

The success of VALIDATE has been achieved thanks to the excellent collaboration between all its participants. A collaborative project of this kind involving broadcasters, network operators, and equipment manufacturers is an excellent vehicle for verifying standards and to ensure a common basis for the early start of services.

5. Input to standards and ACTS Guidelines

5.1 Input to standards

The DVB-T specification was approved by ETSI as ETS 300 744 in February 1997, less than one year after the completion of the draft Specification. The rapid approval of this very flexible specification is largely due to the work of VALIDATE during 1996 reported to DVB in September 1996 and January 1997. The Specification is included in an ITU-R recommendation which was finally approved by ITU October 1997.

The result of the ITU-R TG 11-3 meeting November 1996 was an important achievement for VALIDATE. This meeting was the final meeting of TG 11-3 with the aim to produce the final recommendations on digital terrestrial television. The recommendations now include the DVB specifications. In particular the recommendation on channel coding and modulation for multicarrier systems (COFDM) is the DVB-T specification, including scaling to 6, 7 and 8 MHz. A draft new Report: "Digital terrestrial television broadcasting service coverage studies and field trials" was updated with a large number of results from VALIDATE partners.

A Progress report: "Planning factors and implementation strategy for digital terrestrial television broadcasting" was also updated with results and information, based on inputs from VALIDATE partners.

A part of the work of participants from VALIDATE partners at the meeting was devoted to responding to two contributions from the American administration. Although these contributions were not directly addressing recommendations they gave a totally wrong impression of the performance of COFDM. The response resulted in the contributions being withdrawn.

The successful outcome of this meeting was due to coordinated European contributions and participation in drafting groups, mainly from VALIDATE partners.

The Implementation Guidelines for DVB-T were welcomed by the DVB Steering Board as "a major contribution to the list of deliverables of the [DVB] Project [which] will become part of our marketing campaign in the rest of the world". This document tries to draw attention to the technical questions that need to be answered in setting up a DVB-T network and offers

some guidance in finding answers to them. It is aimed at the Technical Departments of broadcasting organisations that are considering implementing digital terrestrial TV. The Guidelines were available for some time on the VALIDATE website and have attracted many approving comments and some helpful suggestions. The Guidelines are available as an ETSI Technical Report.

The Chester 1997 Multilateral Coordination Agreement was based on the results contributed to CEPT in Deliverable D09. More recent results were contributed to CEPT at the end of the Project.

A VALIDATE contribution on mobile reception of DVB-T formed the basis of a report by DVB-TM to the Steering Board. This document has been used as a benchmark by EBU and other organisations.

The 1997 Technical Audit asked the Project to produce a specification for a reference receiver for service planning purposes. A suitable specification was submitted for comment to DVB-TM in January 1998, and revised at the end of the Project.

The conclusions of Module 5 on gap-filler transmitters were submitted to DVB-TM and will be incorporated into the Implementation Guidelines.

The results of the multidimensional interworking tests were contributed to DVB-TM which welcomed them as an impressive report, exactly the kind of message the DVB Project needed to convey to the whole rest of the world.

5.2 Input to ACTS guidelines

As described above, VALIDATE prepared its own Guideline, an Implementation Guide requested by the DVB project.

VALIDATE made comments on SII Guideline 8, User Aspects of Mobility pointing out the need to consider interactive broadcast services as well as traditional terminal-to-terminal services like GSM, and has made available initial test results.

VALIDATE also added details of the standards it uses to SII Guideline 1, Relevant Standards in the SII Chain.

6. Overall Impact, Exploitation and Dissemination of Results

6.1 Verification of the DVB-T Specification

Verification of the DVB-T specification was achieved in three stages: specification, performance, and suitability.

Specification: Early in the Project, Partner Teracom compared five software simulations of a DVB-T modulator produced independently by different Partners. After some minor problems of file formats had been resolved, all five simulations gave identical results. This gave confidence that the Specification was unambiguous. It also allowed Partners who were designing hardware modems to check the performance of their hardware by comparing the hardware with verified simulations. Interworking of modems checked in this way could be expected with some confidence. Hardware interworking of modems designed and built by separate laboratories was first demonstrated on 6 December 1996 when the BBC modem and the dTTb modem were shown to work together in both directions and all modes common to both modems.

Performance: The BBC's tests on its modem and tests by partner RAI on the dTTb modem showed that their performance in the repeatable conditions of the laboratory was very close to that predicted by the experts who wrote the Specification, verifying the assumptions embodied in it. Again, the verification by independent laboratories using different modems gave complete certainty to the results.

Suitability: A number of VALIDATE partners have used the DVB-T specification in demonstrations and field trials of real broadcasting scenarios. These tests have shown that the Specification meets the needs of broadcasters.

VALIDATE's results verifying the Specification have been reported to DVB-TM and have ensured the rapid acceptance of this flexible system: the DVB-T specification was approved without dissent by ETSI members less than one year after the completion of the Specification. Broadcasters around the world adopting the DVB-T system can do so in the knowledge that it has been rigorously tested, and equipment manufacturers can check the conformance of production equipment against verified prototypes.

6.2 Implementation Guidelines

VALIDATE's Implementation Guidelines were delivered early in 1997. Subsequent versions were produced as further results from the Project became available, and the document has been available publicly from the Project's WWW page (http://www.bbc.co.uk/validate) since April 1997. The document has been widely circulated within the EBU, whose members have made a number of helpful comments. Tele Danmark has presented the Implementation Guidelines to DVB DTTV-SA and TM.

The Guidelines were updated after the results of the CEPT conference in July 1997 were known in order to include the agreed values for co-channel and adjacent channel interference. The DVB TM meeting in October approved the updated version for forwarding to ETSI. The Implementation Guidelines have now been published as ETSI TR 101 190.

The Implementation Guidelines were welcomed by the DVB Steering Board as "a major contribution to the list of deliverables of the [DVB] Project [which] will become part of our

marketing campaign in the rest of the world".

6.3 Test results

6.3.1 Results for Service Planning

VALIDATE partners have carried out a wide range of tests in standardised conditions in the laboratory and extensive field trials in about a dozen areas in seven different countries. A substantial Deliverable (about 120 pages) bringing together all the Project's results relevant to service planning was submitted to CEPT PT FM 24 as part of the preparation of the Chester conference on coordination of digital terrestrial television transmitter assignments. The availability of these results was a critical factor in achieving agreement at the Conference. The Conference output document lists parameters to be used for international coordination that are based on the VALIDATE results.

This work has ensured that coordination of transmitter frequency assignments is based on sound results that are internationally acceptable because they come from a large collaborative project.

6.4 Mobile results

The DVB-T specification was based on considerations from the DVB Terrestrial Commercial Module. The requirements were for stationary fixed and portable reception; mobile reception was not a major determinant of the Specification. Since then, however, mobility has become more important for some broadcasters, and DVB asked for a report on the prospects for mobile reception.

VALIDATE partners have carried out a number of tests of mobile reception, most notably in Germany. A VALIDATE contribution on mobile reception of DVB-T formed the basis of a report by DVB-TM to the Steering Board. This document has been used as a benchmark by the EBU and other organisations.

The work of VALIDATE on mobile reception will be carried on by a new project, MOTIVATE, to be led by Deutsche Telekom Berkom, with many of the VALIDATE partners. It is hoped that the work of MOTIVATE will lead to new multimedia services in mobile applications.

6.5 Transmission matters

The free exchange of ideas and the reporting of experience within VALIDATE have led quickly to a better understanding of all aspects of transmission of DVB-T signals. Issues such as setting up transmitter networks, sharing with existing services, and options for primary distribution of signals from studios to transmitters have been discussed and tested within the Project, and results are given in the Implementation Guidelines described above. In many cases this work has involved the design and construction of special hardware, such as a high-power combiner.

Transmitter specification

VALIDATE has drawn up a transmitter performance specification and submitted it to DVB. The aim of this document is to suggest the parameters that need to be measured and some realistic values for them as well as to define the minimum interface specifications (not all of which are mandatory).

Transmitter performance is largely based on the idea of Equivalent Noise Degradation (END) as the main (perhaps the only) performance criterion. The degradations in performance produced by different impairments can be expressed in terms of the loss of noise margin that they produce in a Gaussian channel, and these noise equivalents can then be added as noise powers to derive an END figure for the transmitter. The work of VALIDATE has shown that this procedure is valid provided the individual impairments are small (each significantly less than 3 dB loss of noise margin).

This specification will help transmitter manufacturers and transmission network operators and network operators and service providers to agree on the specifications for the performance of transmitters, including functional blocks and the interfaces between them.

SFN synchronisation

All transmitters in a single-frequency network (SFN) must be synchronised so that their broadcasts are frequency identical and bit identical. VALIDATE partners have devised a method of synchronising all the transmitters in an SFN by identifying a megaframe in the MPEG-2 transport stream using a megaframe identification packet (MIP). A group led by Teracom developed a specification which was accepted by DVB and published by ETSI as a Technical Specification. The megaframe length has been chosen to contain an integral number of OFDM frames, of Reed-Solomon packets, and of the energy dispersal sequences, thus ensuring that it is possible to produce identical waveforms at each transmitter. The MIP contains a timestamp indicating the time at which the megaframe should be broadcast, related to a universal time and frequency reference such as that available from the GPS satellite system. By comparing the timestamp with the universal time reference at the transmitter, all transmissions can be time synchronised. The verification of this specification is described in Section 3.6.3.

Several Partners will market SFN adapters based on this specification, which will make large-area SFNs for digital terrestrial TV a reality for exploitation by network operators, saving on use of the spectrum.

6.6 Gap-fillers

SFN techniques can be used on a smaller scale to improve coverage. VALIDATE partners have studied both professional gap-fillers, installed by the network operator to fill gaps in the coverage of a main transmitter caused

by shadowing from terrain or large buildings, and domestic gap-fillers installed within a house to improve portable reception. Obviously, the main technical problem of such gap-fillers is oscillation cause by feedback from the transmitted signal to the receiving antenna.

A professional gap-filler was demonstrated by Mier and DT Berkom in Berlin to provide coverage to the Potsdam area that is shadowed by hills from the main transmitter at Alexanderplatz in the centre of Berlin. With both receiving and transmitting antennas mounted on the same concrete tower an isolation of 105 dB was obtained. The ripple on the output DVB-T signal spectrum was less than 3 dB with an output ERP of 100 W. Field trials in Potsdam showed that portable reception was possible at all locations with a reasonable field strength. One important conclusion is that some trials have shown that no signal degradation has been observed for a ripple amplitude up to 10 dB peak-peak.

For the domestic gap-filler, a feasibility study including safety and cost gave encouraging conclusions and several prototypes were built.

Field tests have been conducted mainly by the BBC and also by the RAI. More tests will be carried out within the following months by Retevisión, Teracom and IRT.

A transmitted output power less than 1 mW has found to be enough to provide portable reception to two storey buildings (100 m2 each floor) whilst 100 μW should allow it in a flat of similar area (100 m2).

Isolation between transmitting and receiving antenna did not limit the performance of the system except in one of the dwellings tested (in which the receiving antenna was located within the roof space of the house). However, installing the gap-filler (mainly setting its gain) may become a difficult task, which makes it advisable that such devices be made available through trained installers who could deal with their installation.

The result of the work carried out on domestic gap-fillers by several VALIDATE partners has been reported to DVB.

It has been demonstrated that the concept of the domestic gap-filler is feasible. However, the use of such devices would need to be legalized if they are to be made available to consumers. The work carried out within VALIDATE project could be an useful input for the appropiate authorities in charge of licensing issues. The fact that these devices could re-radiate analogue signals should also be considered when dealing with these aspects.

The work of VALIDATE has showed that gap-fillers are feasible and useful for both professional and domestic applications. Several project partners would expect to develop equipment for the appropriate market.

6.7 Demonstrations

VALIDATE partners have organised a number of major demonstrations of digital terrestrial broadcasting at high-profile events like the International Broadcasting Convention (IBC), the Montreux International TV Symposium (ITS), and the International Funkaustellung (IFA). The details of the demonstrations are given in Annex 3.

These demonstrations have had an important impact on opinion in Europe and worldwide, demonstrating both the feasibility of digital terrestrial TV broadcasting and the technical features of the DVB-T specification during critical years when decisions were being made about standards.

6.8 Support to DVB

VALIDATE has not only reported its results to DVB: it has also supported DVB initiatives around the world, in addition to the demonstrations described in Section 6.7.

In the ITU VALIDATE has provided results and Project representatives to attend international meetings in support of the DVB-T specification, which has ensured the inclusion of DVB-T as an ITU standard. In TG 11/3 the efforts of VALIDATE representatives forced the withdrawal of a tendentious document erroneously denigrating the DVB-T system and ensured a fair description of contending systems in the draft Recommendation.

VALIDATE representatives have participated enthusiastically in DVB delegations aimed at marketing the DVB-T system to countries outside Europe. This has included presentations in Argentina and Beijing. Demonstrations and presentations were also given at Broadcast Asia in Singapore.

In June 1998, a committee set up to advise the Australian government on the choice of a digital terrestrial TV standard reported in favour of DVB-T. The work of VALIDATE, reported through DVB as well as through personal contacts with leading figures in Australian broadcasting, has been an important factor in the Australian choice.

VALIDATE has supplied over a thousand copies of its publication containing papers presented at the Montreux ITS to DVB for distribution at conferences and events outside Europe. The Project has also tried to refute mistaken statements published by proponents of single-carrier systems — for example in the Australian journal BEN.

7. SELF ASSESSMENT

The work of the VALIDATE project has verified the DVB-T specification, which contains a large number of options so that it can meet the varying requirements of different countries.

VALIDATE has technically proved the excellent behaviour of DVB-T in critical broadcasting situations including co- and adjacent-channel interference and portable reception. This work has ensured its unanimous acceptance by ETSI members less than one year after the completion of the Specification. This success has been achieved thanks to the excellent teamwork of the Partners in exchanging and comparing test results from laboratories all over Europe.

VALIDATE partners have developed a range of prototype equipment and have contributed to open standards. The commercialisation of VALIDATE prototypes will ensure that a wide choice of equipment is available to support the launch of digital terrestrial TV.

VALIDATE has studied all technical aspects of the implementation of DVB-T networks and services. It has reported its work to the DVB project and has made its experience available to other broadcasters in the form of Implementation Guidelines. In particular it has pioneered the mobile reception of DVB-T signals, paving the way for the new project MOTIVATE, and has developed the concept of the 'gap-filler' transmitter for DVB-T.

A collaborative project of this kind involving broadcasters, network operators, and equipment manufacturers is an excellent vehicle for verifying standards and to ensure a common basis for the early start of services.

The wide range of excellent work described in this Report is the result of an exceptional level of commitment of all the current Partners in VALIDATE. A number of valuable bilateral collaborations have also developed within the Project

It is clear that VALIDATE has been the most influential project in the framework of DVB-T in Europe. The information flow from the project into the other bodies (DVB, EBU, CEPT, and ETSI) was constant and very valuable. Due to the work carried out in this project and demonstrated at many high-profile events, network operators gained at a very early stage the confidence that the DVB-T system is working and that the industry will master the development process for the equipment needed to set up networks.

This has led to major investment in this area in many countries in Europe, and has made it possible to maintain the leading position of the European industry in this field.

ANNEXES

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ANNEX 1

List of Deliverables

Deliverable Code	WP Code	Deliverable title	Date	Deliverable Nature[1]	Security Class[2]
01	WP1	Requirements for verification of specification	Feb 96	R	I
02	WP1	Verification report to DVB	Sep 96	R	P
03	WP1	Guidelines on DVB-T implementation	Jan 97	R	P
04	WP2A	Report on equipment available	Jan 96	R	I
05	WP2B	Modified equipment for lab tests and field trials	Nov 96	P	I
06	WP2A	Definition of test programme	Mar 96	R	I
07	WP2B	Results of tests, M2	Oct 96	R	I
08	WP2A	Report on tests on receivers	Jun 98	R	L
09	WP3A	Results of tests, M3	May 97	R	P
10	WP3B	Service planning criteria	Jan 97	S	L
11	WP3B	Comparison of actual and predicted service areas	Jun 98	R	L
12	WP4A	Report on sharing issues	Oct 96	R	I
13	WP4A	Prototype combiner for adjacent channels	Nov 97	P	I
14	WP4B	Transmitter performance specification	Nov 97	S	P
15	WP4C	Specification of a Megaframe for SFN Synchronisation	Jan 97	S	P
16	WP5	Feasibility study on domestic gap-filler	Jul 96	R	P
17	WP5	Prototype domestic gap-filler	Jul 97	P	I
18	WP5	Final report on gap-filler transmitters	Jun 98	R	I
19	WP6C	Workshop on DTTB	Jun 97	O	P
20	WP6A	Report on Project Linkages	Nov 95	R	R
21	WP6C	Project final report	Jun 98	R	P
22	WP4C	Report on tests on SFNs	May 98	P	R

[1] R=Report, S=Specification, P=Prototype

[2] I=Internal, R=Restricted, P=Public

ANNEX 2

List of Published Papers

Author	Title of Paper	Name of Journal/Conference, etc	Vol / Page	Date
A. Oliphant	BBC R&D leads Project developing the technology for digital terrestrial TV broadcasting	http://www.bbc.co.uk/projects/validate		24/01/96
R. Schramm	Building Penetration Loss; Measurements in the VHF and UHF Frequency Bands	IRT Technical Report	No.B 153/96	05/09/96
A. Oliphant	*La télévision numérique hertzienne, la validation de la norme, la mise en place des services*	"*Audiovisuel et Autoroutes*", Journées de Rennes	REE magazine Feb 1997	14/06/96
A. Oliphant	The design of a network for digital terrestrial TV trials	International Broadcasting Convention (IBC 96)	IEE Conference Publication 428 pp. 242-247	12–16/09/96
J. Stott	The DVB terrestrial (DVB-T) specification and its implementation in a practical modem	International Broadcasting Convention (IBC 96)	IEE Conference Publication 428 pp. 255-260	12–16/09/96
P. Cañizares J.L. Torres	*Primera red española de TV Digital Terrenal*	Instelec, October 1996	pp. 46-54	Oct. 1996
P. Cañizares J.L. Torres	The first Spanish experience on digital terrestrial TV broadcasting	International Broadcasting Convention (IBC 96)	IEE Conference Publication 428 pp. 196-199	12–16/09/96
M. Kühn (P04 DTAG)	*Das terrestrische Fernsehen ist tot — es lebe das terrestrische Fernsehen*	Lecture and Proceedings, Euroforum: Digitales Fernsehen		27/11/96
C. Weck	Coverage aspects of digital terrestrial television broadcasting	EBU Technical Review, Winter 1996	No. 270	Winter 1996
S. O'Leary	Hierarchical transmission and COFDM systems	IEEE Transactions on Broadcasting	Vol. 43, No. 2 p. 166	June 1997
P. Cañizares J.L. Torres J.A. Martínez	Viditer: a Spanish experience on DTT	20th International TV Symposium, Montreux	Cable/Satellite/ Terrestrial pp. 219-24	12–17/06/97
L.G. Møller	COFDM and the choice of parameters for the DVB-T system	20th International TV Symposium, Montreux	Cable/Satellite/ Terrestrial pp. 270-280	12–17/06/97
A. Oliphant	VALIDATE: Verifying the European specification for digital terrestrial TV and preparing for the launch of services	20th International TV Symposium, Montreux	Cable/Satellite/ Terrestrial pp. 319-327	12–17/06/97
G. Faria	Single Frequency Network (SFN) for DVB-T and DAB-T	20th International TV Symposium, Montreux	Cable/Satellite/ Terrestrial pp. 654-671	12–17/06/97
C. Weck R. Schramm	Receiving DVB-T: Results of field trials and coverage considerations	20th International TV Symposium, Montreux	Cable/Satellite/ Terrestrial pp. 351-360	12–17/06/97
A. Morello *et al*	Performance assessment of a DVB-T television system	20th International TV Symposium, Montreux	Cable/Satellite/ Terrestrial pp. 298-310	12–17/06/97

Author	Title of Paper	Name of Journal/Conference, etc	Vol / Page	Date
J. Stott	Explaining some of the magic of COFDM	20th International TV Symposium, Montreux	Cable/Satellite/ Terrestrial pp. 341-350	12–17/06/97
C. Nokes I. Pullen J.Salter	Evaluation of a DVB-T compliant digital terrestrial television system	International Broadcasting Convention (IBC 97)	IEE Conference Publication 447 pp. 331-36	Sept. 1997
V. Mignone A. Morello M. Visintin	An advanced algorithm for improving DVB-T coverage in SFN	International Broadcasting Convention (IBC 97)		Sept. 1997
P. Cañizares J.L. Torres	*VIDITER, primera red española de TV digtial terrenal*	NODOS, Philips Telecomunicaciones	No. 21 p. 6	Sept. 1997
R. Burow M. Kühn P. Pogrzeba	*Erfahrungen mit dem terrestrischen DVB-Standard*	7 Dortmunder Fernsehseminar		29/09/97
M. Kühn	*Erfahrungen mit DVB-T*	2 EUROFORUM-Jahrestagung *Fernsehmärkte der Zukunft*		04/12/97
B. Sueur	DVB-T for terrestrial TV broadcasting	Beijing Television Seminar		Dec. 1997
C. Weck	VALIDATE Field Trials of digital terrestrial Television (DVB-T)	NAB 98		April 1998
R. Burow P. Pogrzeba H. Kußman *et al*	On the performance of DVB-T system in mobile environments	ECMAST 98	Lecture notes in Computer Science 1425. Springer. pp. 467-480	May 1998
A. Oliphant	VALIDATE — a virtual laboratory to accelerate the launch of digital terrestrial television	ECMAST 98	Lecture notes in Computer Science 1425. Springer. pp. 481-492	May 1998
R. Burow P. Pogrzeba	*Mobiler Empfang mit DVB-T*	18 Jahrestagung der FKTG (Fernseh und Kinotechnische Gesellschaft), Erfurt		11–14/05/98
C. Weck	*DVB-T-Feldversuche im Europäischen ACTS-Projekts VALIDATE*	18 Jahrestagung der FKTG (Fernseh und Kinotechnische Gesellschaft), Erfurt		11–14/05/98
M. Kühn	From Stationary up to Mobile — Experiences with the European DVB-T system	Broadcast Asia 98		June 1998
E. Stare	Mobile reception of 2K and 8K DVB-T signals	International Broadcasting Convention (IBC 98)	pp. 473-478	Sept. 1998
J.M.Fernández *et al*	Testing and Implementing DVB-T Services in Spain	International Broadcasting Convention (IBC 98)	pp. 284-288	Sept. 1998
J.L. Pavy	Optimised second generation COFDM DVB-T demodulator	International Broadcasting Convention (IBC 98)	pp. 235-240	Sept. 1998
C.R. Nokes	Results of tests with domestic receiver IC's for DVB-T	International Broadcasting Convention (IBC 98)	pp.294-299	Sept. 1998
B. Sueur *et al*	A DVB-T compliant Integrated Receiver for professional use and early digital television experiments	International Broadcasting Convention (IBC 98)	pp.289-293	Sept. 1998
A. Oliphant P. Christ	VALIDATE and MOTIVATE: Collaborative R&D to speed up the launch of digital terrestrial TV	International Broadcasting Convention (IBC 98)	pp.467-472	Sept. 1998

ANNEX 3

List of public demonstrations

Date	Event or Exhibition	Nature of Demonstration	Target Audience and Reaction
Sept. 1996	International Broadcasting Convention (IBC 96)	Demonstration of BBC experimental pilot service via ATM link from London and local transmission.	Other broadcasters, worldwide. Demonstrated the feasibility of the DVB-T Specification and the possibilities of digital television.
Sept. 1996	Dutch Broadcasting Convention	Demonstration of two channels DVB-T with simple portable antennas.	
Jan. 1997	EBU Management Broadcasting Research and Development Seminar, Munich	DVB-T portable reception of three programmes (first public 8K FFT demonstration): An MPEG-2 multiplex of 18.1 Mbit/s comprising three live encoded programmes was transmitted via the dTTb-2 modem using 64 QAM and an 8K FFT. The signal was radiated from the tower next to the IRT with 75 Watt ERP (TV channel 43), but the receiving equipment was located in the back of the radiation diagram.	Managers in the broadcast research domain from Europe (including a lot of Eastern European countries) and from some Non-European countries. The visitors appreciated the high reception quality of DVB-T indoors using a small stick antenna.
Jan. 1997	CEPT PT24 meeting, Berlin	Portable indoor reception of a multiplex of four DVB programmes.	Members of the CEPT from several European countries.
Mar. 1997	Munich	Four programmes were transmitted in channel 43 (650 MHz) using a 64-QAM with code rate 2/3 and a guard interval of 1/32. Two programmes were played from a digital video server and two were MPEG encoded in real time. All four received programmes were simultaneously displayed on four monitors or a large split screen projector, respectively. For comparison, an analogue PAL reception was demonstrated too.	The workshop was organised by IRT for key people of the public broadcasters of Germany, Austria and Switzerland. The gain in quality and in number of programmes compared to analogue television convinced the participants of the good performance of DVB-T.
May 1997	4th Retevisión seminar on advanced TV, Madrid	Four programmes in a 22 Mbit/s MPEG-2 TS, OFDM modulated (8K FFT, 64-QAM, R 2/3, GI 1/8) and radiated with 1 kW digital power.	The audience (200 people from specialised press and professional viewers) were convinced about the suitability of terrestrial means to distribute digital TV and other new services. The Spanish administration is aware of the need to create the regulatory context to facilitate the introduction of digital terrestrial TV. As a consequence of the Retevisión work in all topics related with DTT, the Spanish Administration announced the release of a regulatory text before the end of 1997.
June 1997	Montreux 20th International TV Symposium	A multiplex containing four TV programmes was assembled on the TDF stand and COFDM modulated. The COFDM signal was transmitted to Thollon on the other side of Lake Geneva from where it was broadcast in UHF channel 49 (698 MHz). The signal broadcast from Thollon was picked up at Clarens on the Montreux side of the lake and rebroadcast on the same frequency. On the VALIDATE stand in the exhibition (part of the EBU Village), project representatives demonstrated reception with a rotatable antenna.	Broadcasters, particularly from outside Europe. Demonstration gave practical support to a number of papers in Symposium sessions and also to the DigiTAG stand. An important part of the marketing effort of DVB against ATSC. Reports from a number of influential delegates show that the demonstration and papers had a very worthwhile effect.

Date	Event or Exhibition	Nature of Demonstration	Target Audience and Reaction
June 1997	Medientage Köln	Presentation of a statistical multiplexing of four TV programmes where portable indoor reception was used. Presentation of mobile reception in a tram.	Members of the Deutsche TV-Plattform and public visitors.
Aug. – Sept. 1997	IFA 97	Four DVB-T services in UHF channels 37, 43, 46 and 59. Transmission of nine programmes and one DVB-data channel. Portable and stationary reception was demonstrated at different booths. Mobile reception was presented on request in a car and two larger public demonstrations were given using a double-decker bus. Portable and mobile reception was reported on the public television channel ARD.	General public.
Sept. 1997	International Broadcasting Convention (IBC 97)	DVB-T transmission and reception of two different multiplexes. Reception on the DigiTAG stand and the NDS stand.	Impressed by the simple receiving antenna requirements.
Sept. – Oct. 1997	Visits at DTAG	Mobile reception of QPSK and/or 16 QAM in different UHF channels, up to a distance of 15 km from the transmitter. Two taboo channels were used.	Visitors from China, Israel, Singapore and German broadcasters.
26 – 28 May 1998	ECMAST Conference	Stationary Reception of HDTV (22 Mbit/s) by using an in-house antenna and a HDTV decoding chip. Mobile reception of DVB-T with QPSK and 16-QAM in a demonstration bus. Portable reception of four TV Programs by using a 16-QAM mode.	Specialists of multimedia and broadcasting, participants of the ECMAST conference.
June 1998	Fifth Retevisión seminar on advanced TV, Madrid	DVB-T fixed and portable reception using an SFN. 4 programmes in the same TS, OFDM modulated (64-QAM, R 2/3, GI 1/4), radiated from two transmitters and re-radiated from a domestic gap-filler.	The audience was composed , among others, of important personalities in the broadcasting world. Broadcasters from South America could verify in site the good performance of DVB-T. The Spanish Administration has shown its interest and has informed that the draft of the regulatory framework is now being updated.
June 1998	Broadcast Asia, Singapore	Public bus with stick antenna and DVB-T receiver. 24 km demonstration route.	About 80 prominent local decision-makers and conference delegates. Part of competitive trials of ATSC, DVB-T and the proposed Japanese system.

ANNEX 4

List of patents and other IPR

Holder of Patent (Organisation)	Partner Code	Title of Patent	Country (Countries)	Date(s) of Issue	Patent Number(s)
BBC	P01	Apparatus and method for testing digital modulation systems	UK	April 1998	98 04248.4

ANNEX 5

List of VALIDATE field trials

DVB-T Test sites

Country and Area		Transmitter Location	Operating Date/Time	Operator	Details (Channel, Transmission Power, H/V, ...)
United Kingdom	London	London	06/96–08/98	BBC	CH 28, 10 kW ERP.
	North of England	Pontop Pike	06/96–01/97	BBC	CH 59, 5 kW ERP.
Germany	Munich	BR-Freimann	01/97–03/98	IRT	CH 43, ca. 100 W EIRP.
		Ismaning	04/98–	BR/IRT	CH 43, ca. 500 W ERP.
France	Metz	17 km away from Metz		TDF	CH 40, upper adjacent to the TV5 commercial programme main transmission, 3.4 kW ERP, digital signal 17 dB lower than analogue one.
		Metz		TDF	CH 40, iso frequency gap-filler, 25 W ERP.
France	Rennes	Cesson Sévigné		CCETT	CH 61, DVB-T at 19 dB lower than analogue adjacent channel in CH 62.
			02/98–	CCETT	SFN transmitter.
Italy	Torino	Torino Eremo	01/98	RAI	CH 28, 290 W ERP, Vertical polarisation.
Netherlands	Utrecht	Lopik	01/98–	Nozema	CH 57, 9 kW ERP Vertical polarisation. Antenna height 148 m above ground level.
	Hilversum	Hilversum	05/98–	Nozema	First CH 34, ca. 150 W ERP vertical polarization. Antenna height ca. 150m above ground level. Later CH 57 in a SFN with Lopik transmission.
Spain	Madrid	Torrespaña	MFN 03/97– SFN 03/98–	Retevisión	CH 26, 500 W DVB-T power Torrespaña, Navacerrada: both transmission separated 50 Km.
		Navacerrada	03/98	Retevisión	300 W DVB-T power in adjacent CH 27.
Sweden	Stockholm	Nacka	09/96	Teracom	CH 67 (from 06/98 CH 64), 35 kW ERP, Hor.
	Uppsala	Vedyxa	01/98	Teracom	CH 64, 20 kW ERP, Hor.
		Rickomberga	11/97	Teracom	CH 64, 2 kW ERP, Hor.
Ireland	Dublin	Three Rock Donnybrook	11/97–	RTÉ	50 W 25 W } SFN CH30

Propagation Measurements				
Propagation Measurements	**Time and Location**	**Key Parameters**	**Details / Assumptions**	**Results / Conclusions**
Outdoor propagation measurements	*Sept.. 1995* BBC, CCETT, London	1 k test signal, not DVB-T compliant	Location variations measured in rural and urban areas.	Standard deviation measured in 1 km × 1 km squares. 4 dB urban areas, 2.5 dB rural areas
Single transmitter	*Feb. – April 1997* BBC, London and North of England	DVB-T, 2K FFT, 64 QAM, R 2/3, GI 1/32	Derived from about 400 measurements.	Standard deviation 5.8 dB (London) 5.0 dB (North)
	Summer 1996 DTAG, Berlin Germany	OFDM test signal, 6 MHz bandwidth	Channel response analysis, comparison of SFN and MFN, 420 km test route, Ch 59.	SFN gain up to 6 dB.
		SFN/Single transmission	Location variation.	E.g. 77 % of the locations have a standard deviation lower than 4 dB in an MFN compared to 92 % in SFN.
			Delay Spread of the transmitting channel.	MFN: 1 µs , SFN 11 µs.
			Time variance for the stationary reception.	Not significant for the set-up used.
	Nov. 1996 CCETT, Rennes, France	OFDM, 1 k FFT	103000 points 120 test routes standard deviation, margin from 50% to 99%.	Standard deviation for rural 2.4 dB, urban 3.7 dB, margin from 50 % to 99 % rural 9.2 dB, urban 10.4 dB.
	Summer 1997 BBC, London, England	DVB-T, 2K FFT	Local differences in signal levels between co-sited transmissions.	Increased likelihood of differences greater than protection ratio for non co-sited transmissions.
	August 1997 TERACOM, Stockholm	DVB-T, 8K FFT at 842 MHz	Location variation of the field strength in four different terrain classes, total 144 sequences each 400 m.	Standard deviation of fast, slow and combined fading: open field: 1.7, 2.7, 3.3 forest: 2.6, 3.3, 4.4 suburban: 2.3, 3.2, 4.1 urban: 2.2, 2.5, 3.3
	Autumn 1997 Tele Danmark Copenhagen area	4.5 kW EIRP Single transmitter	Data collected in measurement vehicle. Measurements with antenna heights from 3 m to 10 m in steps of 0.5 m. Measurements performed in rural and sub-urban areas.	Smooth increase in field strength for increase in antenna height in rural area. Uneven progress in field strength for increase in antenna height in sub-urban areas.
	Nov. 1997 CCETT, Rennes, France	DVB/T channel adjacent to analogue channel	Differential measurements between digital and analogue terrestrial signal propagation.	Difference margin in rural: 2 dB.
Professional gap-filler	*July – Sept. 1997* Mier and DTAG, Berlin, Germany	DVB-T, 2K FFT 16 QAM, R=2/3	Coverage of a shadowed area in an SFN.	High antenna isolation (up to 105 dB) i.e. 200 W ERP for gap-filler possible.

Propagation Measurements				
Propagation Measurements	**Time and Location**	**Key Parameters**	**Details / Assumptions**	**Results / Conclusions**
Single Frequency Networks	*Summer 1996* DTAG, Berlin, Germany	OFDM test signal 6 MHz bandwidth SFN/Single T	See Section: Single transmitter measurements.	
	Winter 1997 RTE,Dublin, Ireland	MPEG-2 distributed SFN Co-channel PAL I/DVB-T	SFN performance, 2K coverage. Co-channel interference. Modem interoperability. Testing in Dublin.	MPEG-2 distribution of SFN giving network gain. Adjacent PAL I interference noted to low power DVB-T signals.
Single Frequency Networks	CCETT	DVB-T, 8K FFT	SFN demo at TFLFT meeting.	Successful demo with various echo delays.
Indoor propagation measurements	*June 1996* BBC, London, England	DVB-T, 2K FFT, 16-QAM, R = 3/4, GI 1/32	Location variation (indoor).	Location variation. 2–4 dB in one room.
	Summer 1996 BBC, North UK	DVB-T, 2K FFT, 16-QAM, R = 3/4, GI 1/32	Time variance of the channel (indoor).	In agreement with those of TDF/CCETT (1 dB measured in 40 secs).
	July 1996 CCETT and TDF, Rennes		Statistical analysis standard deviation for location variation and time variation.	Standard deviation: local variation 2 dB time variation 1 dB.
	May 1997 TERACOM, Stockholm	Test signal 7.61 MHz bandwidth at 842 MHz	Location variation (indoor).	The field strength was found to be log-normally distributed with a standard deviation of 3.2 dB.
Domestic gap-filler measurements	*July 1997* Televés, Retevisión Madrid	DVB-T, 8K FFT, 64-QAM, R 2/3, GI 1/8	Real off-air signals received via MATV system and rebroadcast on the same frequency in a very hostile laboratory environment.	Results validate the concept of the domestic gap-filler as a device to rebroadcast the DVB-T signal on the same frequency in a house.
	Oct. 1997 – Feb. 1998 BBC, Televés, London	DVB-T, 2K FFT, 64-QAM, rate 2/3, GI 1/32	Real off-air signals received via 10 m log-periodic antenna and rebroadcast on the same frequency in a domestic house.	An output of less 1 mW from the gap-filler could provide good set-top coverage in every room of the house. However, in most houses 100 µW would be sufficient. The main limitation was feedback between transmitting and receiving antennas.
Domestic gap-filler measurements	*April 1998* Retevisión, Televés, Madrid	DVB-T, 8K FFT, 64-QAM, R 2/3, GI 1/8	Real off-air signals received from SFN via MATV system and rebroadcast on the same frequency in a very hostile laboratory environment.	Validation of the concept of the domestic gap-filler as a device to rebroadcast the DVB-T signal on the same frequency in a house.

Propagation Measurements				
Propagation Measurements	**Time and Location**	**Key Parameters**	**Details / Assumptions**	**Results / Conclusions**
Overall building loss (reference rooftop)	*June 1996* BBC, London, England	DVB-T, 2K FFT, 16-QAM, R 3/4, GI 1/32	Measurement of building loss and minimum field strength.	Building loss (incl. height loss) 22 dB upstairs, 29 dB downstairs. 70 dB µV/m at 10 m gives good coverage upstairs. About 80 dB µV/m required at 10 m to cover downstairs.
	July 1996 CCETT and TDF, Rennes, France	COFDM, 7.61 MHz	Measurement of building loss and received signal variations	Standard deviation of 4 dB for variations over one flat and Standard deviation of 2 dB for variations over one square meter Building loss between 7 and 17 dB.
Building penetration loss (reference outdoor)	*Sept. 1996* IRT, Munich	VHF and UHF	Test signal with 120 kHz and 1.5 MHz bandwidth.	Average penetration loss: 8.8 dB to 14 dB in VHF 7.8 dB to 17 dB in UHF.
	May 1997 TERACOM, Stockholm	Test signal 7.61 MHz bandwidth at 842 MHz	BPL was measured for stone and concrete houses, in total 58 rooms in 14 buildings.	Mean BPL was found to be 6.4 dB, the standard deviation of the BPL was 3.6 dB.

Service Coverage Measurements				
Measurements	**Time and Location**	**Key Parameters**	**Details / Assumptions**	**Results / Conclusions**
Coverage measurements and service prediction	*Feb. – April 1997* BBC, London and North England	DVB-T, 2K FFT, 64-QAM, rate 2/3, GI 1/32	Comparison with service prediction for stationary reception.	Coverage rather better than predicted.
	Spring 1997 IRT, Munich	DVB-T, 8K FFT	Comparison with service prediction, only few measurements, mainly Rice channel.	Good accordance with prediction
	March 1997 DTAG, Cologne	DVB-T, 2K FFT	See section: System performance	
	Jan. – April 1998 Nozema	8K FFT, 16 QAM rate 1/2, 64 QAM rate 1/2, 64 QAM rate 2/3	Single transmitter. Receiving antenna at 10 m and 1.5 m height. Measurements of field strength, BER and C/N.	
System performance	*Summer 1996* BBC, London and North of England	DVB-T, 2K FFT, 16-QAM, Rate3/4, GI 1/32	Measurements in channel 28 at Crystal Palace (London) and Channel 59 (upper adjacent to PAL) at Pontop Pike (North England).	Minimum C/N for stationary reception average 17.8 dB (London) 16.7 dB (north).
	Winter 1996 – 1997 RAI, Torino	DVB-T, 2K/8K FFT, various modes	Detailed system performance measurements in laboratory.	See VALIDATE laboratory test results.
	Spring 1997 IRT, Munich	DVB-T, 8K FFT	Curves of BER versus received power and C/N; comparison with simulated values. Minimum C/N and field strength required for stationary reception and for indoor reception.	Good performance, implementation loss lower than expected, receiver noise figure: 8 dB, noise floor: –97 dBm.
	March 1997 DTAG, Cologne	DVB-T, 2K FFT	Stationary and portable reception, various modes.	Up to 5 dB C/N loss with respect to a gaussian channel, validation of the DVB-T specification.
	Autumn 1997 Tele Danmark Copenhagen area	Single transmitter DVB-T, 2K-FFT 64 QAM, R 2/3GI 1/32.	Data collected in measurement vehicle.Measurements of C/N @BER≈$2{\cdot}10^{-4}$ in rural and sub-urban areas with antenna heights from 3 m to 10 m.	Scattering of 3-4 dB in required C/N @BER≈$2{\cdot}10^{-4}$ in different propagation environments with different antenna heights.
Performance for mobile reception	*March 1997* DTAG, Berlin, Cologne	DVB-T, 2K FFT	Modes tested: QPSK, R=1/2, Ch 40, QPSK, R 2/3, Ch 59, 16 QAM, R 1/2, Ch 40	speed successfully tested: up to 170 km/h 100 km/h 60 km/h
	Sept. 1997 DTAG, Cologne	DVB-T, 2K FFT QPSK, R=1/2	Modes to be tested broadcasting on UHF taboo channels to mainstations.	
Performance for mobile transmission	*Spring 1998*	DVB-T 2K FFT QPSK		

Distribution and Transmitter Issues				
Distribution and Transmitter Issues	**Time and Location**	**Key Parameters**	**Details / Assumptions**	**Results / Conclusions**
Power amplifier trials	*Summer 1996* CCETT/ Thomson	COFDM, 1 k FFT	Test of different Thomson tubes and Siemens tubes, test of output back-off and intermodulation level.	Tube power amplifier can be used for DVB-T at reasonable back-off by using linearisers.
Transmitter trials	*March 1998* Retevisión, Madrid	DVB-T, 8K FFT, 64 QAM	Non-linearities effects on implementation losses.	Implementation losses depend strongly on output back-off and phase noise of the oscillators.
Professional gap-filler	*July 1997* Mier, Barcelona	DVB-T, 2K FFT 16 QAM, R=2/3	Gap-filler antenna coupling effects.	DVB-T signal stands a high gap-filler feedback value.
	Jan. 1998 Retevisión, Madrid	DVB-T, 8K FFT, 64 QAM	Gap-filler antenna coupling effects in SFN.	DVB-T signal stands a high gap-filler feedback value.
Combiner	*1996 – 1997* BBC, Pontop Pike, North England	DVB-T, 2K FFT, 16 QAM, Rate 3/4, GI 1/32	Signals transmitted using same antenna as that used for co-sited adjacent channel PAL-I via high power combiner.	C/N requirement for stationary reception not impaired by combiner.
	Nov. 1997 TDF and Thomcast Paris , France	Eight cavity combiner designed for adjacent channels high power type.	Measurement of RF parameters.	Suitability of combining one DVB-T channel and two analogue adjacent channels (standard L).
	Feb. 1998 TDF and CCETT Rennes , France	Eight cavity combiner designed for adjacent channels high power type.	Measurement of END.	C/N not impaired by combiner.
Distribution Network	*1996 – 1997* London , North UK, Amsterdam, Betzdorf		Synchronous distribution by dark fibre, SDH, ATM and satellite, synchronised by GPS.	DVB-T signals carrying multiplex from London successfully carried throughout distribution network.
	May 1997 – June 1998 Retevisión, Madrid	DVB-T 8K FFT, 22.12 Mbits MPEG-2 TS.	Primary distribution of the 8K DVB-T signal (via analogue radio links, satellite links) or MPEG-2 TS (by optical fibre, digital radio link, PDH Retevisión network, satellite) to different transmitter centres of the DTT experimental network installed in Madrid.	Suitability of different transmission means to distribute primarily the signal to all transmitting points in the network.
Co-channel Transmissions	*Spring 1998* RTE	DVB-T 2K FFT	Interference to DVB-T off-air reception from co-channel PAL I Transmitter on UHF channel 30, and from co-channel DVB-T source.	To be reported.
Transmitter Trials	*1996 – 1997* BBC, North England	2K and 8K signals	Effect on PAL relay transmission of DVB-T signals.	Levels of spurious radiation from PAL-I relays.

ANNEX 6

Acknowledgements

We would like to thank all the people who have contributed to making this project a success.

P01 **British Broadcasting Corporation (BBC)**

Stephen Anderson
Andy Ball
John Barrett
Hélène Bernaërt
Alastair Bruce
Paul Burfield
Chris Clarke
Kevin Claydon
Neale Davison
Gerry Englefield
Chris Jenkins
John Green
Keren Greene
Oliver Haffenden
Pam Hart
Mark Lee
Phil Leveridge
Richard Marsden
Charles Martin
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Justin Mitchell
John Moore
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Andrew Oliphant
(Project Manager)
Helen Pedro
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P03 **Centre Commun d'Etudes de Télédiffusion et Télécommunications (CCETT)**

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Benoît De La Filolie
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Jean-François Hélard
René Le Dain
Bernard Le Floch
Yvon Le Goff
Jean-Claude Lesaffre
Pierrick Louin
Philippe Piole
Joël Richard
Marc Rivière
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P04 **Deutsche Telekom Berkom**

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Heinrich Offermann
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P05 **Deutsche Thomson Brandt GmbH (DTB)**

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P06 **Institut für Rundfunktechnik (IRT)**

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Dietmar Heinzig
Michael Kreipl
Gerd Petke
Claus Pfaffinger
Günter Schneeberger
Raul Schramm
Emil Sipek
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P07 **Innovations Télécommunications Image Son (ITIS)**

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Gérard Faria
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Pascal Olivier
Jean Luc Pavy
Eric Pinson
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P08 **Mier Comunicaciones**

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Manel Beltrán
Juan Egea
Josep Fanés
Carles Gaig
Domènec Iborra
Josep Jordana
Jorge Luna
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P09 **NW Labs**

Kieran Cleary
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P10 **Nederlandse Philips Bedrijven (Philips)**

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P11 **RAI Radiotelevisione Italiana**

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B.Sacco
M.Tabone
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P12 **Retevisión S.A.**

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P13 **Rohde & Schwarz GmbH & Co KG**

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Jürgen Lauterjung
Thomas Loichinger
Johann Mieslinger
Peter Mühlbacher
Friedrich Rottensteiner
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Knud K.Jensen	Lars Prip	
P16		**Televés SA**
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Modesto Gómez	Alberto Prieto	
Ramón Lois	Justo Rodal	
P17		**P17 Teracom AB**
Magnus Ahxner	Staffan Nyström	
Staffan Bergsmark	Erik Stare	
Mats Ek	Björn Wergeland	
Magnus Nilsson		
P18		**Thomcast**
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Denis Bonaglia	Michel Najman	Pierre Vasseur
Gérard Cotelle	Jean-Luc Paquier	
François Larbey	Bernard Pastre	
P19		**Radio Telefís Éireann (RTÉ)**
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Red Coady	Keith McInerney	Peter Rogers
Brendan Crinion	Paul Myhal	Fintan Ryan
Malachy Donohue	Seamus O' Leary	David Sherwood
P18		**Nederlandsche Omroep Zendermaatschappij (NOZEMA)**
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